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POWER TRANSFORMERS QUALITY ASSURANCE

INDRAJIT DASGUPTA

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Dedicated
to

my wife Jaya

my daughter Debolina

my son Debodatta

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Preface

Indian Industry is being challenged in today's competitive market on multiple counts: Inferior quality of products, inefficiencies, indifferent and ill-trained workforces, short-sighted policies of managements.

These turbulent environment have created much anxiety in the management circles of Indian industries which face new realities, challenges and uncertainties. The stakes are very high for Indian industries. If we don't control and set the direction and pace right now, we may as well not participate in the race.

We have no other choice, but to look for survival. The need of the hour is to pick-up some lessons from the fast developing countries in the world and catch-up with them. Cross culture comparison of Indian quality management practices with those of industrialised nations will help in identification of the organisational weaknesses and correct themselves according to the need of the hour.

There is paucity of literature on 'QUALITY ASSURANCE' from the stand point of empirical analysis, more so from Indian aspect. Most of the literature is mainly anecdotal, though refreshing but, in the absence of practical data, is of limited value.

Top management is responsible for establishing quality performance. Leadership is shown through management actions, example: vision, mission, policy and approach. Top management needs to involve in the improvement of process and should drive organisation's efforts towards excellence in quality. Higher priorities should be given to the quality than cost and scheduling objectives. A culture of trust is necessary to establish through open and frequent communications. Quality is an integral part of strategic plan. Management should involve in approach, development and results of the business process strategy. Dr. Deming's PDCA (Plan-Do-Check-Act) cycle of continuous improvement strategy should be employed in all processes. Informations and knowledge should be shared with all employees. It is necessary to see that the available sources are successfully provided to carry desired changes.

Middle management has to play the pivotal interactive role between management and employees, besides managing empowerment and fostering team work in the transformation process. The task of middle management in quality transformation will require a basic change in habits, beliefs, attitudes and assumptions. Traditionally, the top management has very little direct contact with employees and the middle management has been serving as conduit.

Certification under ISO-9000 (or it's equivalent) is a building block of quality. Quality is implemented through the introduction of disciplined systems, process and documentations.

The system of quality is prevention and not detection. We vaccinate our children in order to prevent them from contracting specific disease. We plan our expenditures in a way that does not cause us to spend more money than available. We look both ways before attempting to cross the street. We have learnt these things through experience.

Today's slogan for the management:

"We shall deliver defect free products and services to our customers and co-workers on time and every time at agreed cost."

I have been working in the transformer industries for more than 35 years. I have the privilege to handle small, medium and large size power transformers. I thought to share some of my knowledge and experiences with the engineers, students and especially those who have just started their profession in the transformer industries. The power utilities, who often buy transformers can also take reference of this book for installation, erection, commissioning, maintenance etc., as well as the procedure of testing of transformers.

As the materials play a vital role towards the ultimate quality of the finished products, I thought it appropriate to share some of my experiences with the material processors and suppliers on a few vital raw materials and components.

Apart from the material processing, the book has dealt with the requirements of ISO-9000 for the quality system implementation in the manufacturing technique up to testing of finished products, inspection and servicing. The chapter describing non-conforming products, condition monitoring, training, statistical technique etc. may look to be useful to the manufacturers.

The chapter "Failure Analysis of Transformers During Short Circuit Test — A Case Study" may attract the users as well as manufacturers, especially the paragraph "Nature of Failure of Transformers Under Short Circuit Tests" at CPRI and probable remedial measures.

I would like to add here that the quality of any product not only depends on good design, but also on the successful implementation of the 7 'M' which the Japanese called as:

1. Men : Skilled workforce
2. Machine : Machine being used for manufacturing transformers
3. Material : Quality materials
4. Method : Good process
5. Motivation : Eager to reach the target
6. Media : Advertisement
7. Money : Resources

Skilled workmen, healthy machines, and quality materials can easily be organised by following the quality path of ISO-9000. I strongly recommended the entrepreneurs to go for the quality system implementation as described in ISO-9000 procedures.

I wish to conclude the paragraph with a quote from the great quality Guru Philip B Crosby that 'Quality is Free'.

It reduces the cost of products by way of less wastage, less rework, and timely delivery.

Sharing informations, training and education increase the quality awareness. The purpose of writing this book is to stimulate thinking in the quality direction, promote product excellence, and help 'Made in India' products known worldwide for their excellence in quality.

Indrajit Dasgupta

Acknowledgement

- Few extracts from the Indian Standards have been reproduced in this book; references have been given at various places in the book.
- References have been drawn from the product catalogue of Nippon Steel Corporation, Japan for **“CRGO** Processing and Slitting Operation”.
- References have been drawn from the various product catalogue and test certificates of Raman Boards Ltd. and Senapathy Whiteley Ltd., Bangalore for processing of insulating pressboards.
- References have been drawn from the magazine ‘Power Line’, July 1997 issue on ‘Power Theft’.
- References have been drawn from the Times of India, June 7, 2000 New Delhi issue on “Ageing equipment contributes to power breakdowns”.
- Thanks to J.B. Conductors and Cables, Nalagarh, Himachal Pradesh for providing a write-up on “Processing of wires and strips”.
- Thanks to Nu-cork product, Gurgaon for providing a write-up on “quality of gasket”.
- Thanks to my colleague, Mr. Anil Aggarwal, Managing Director, P.M. Electronics Limited to encourage me to write the book.

Author

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Abbreviations

Φ	Diameter, Flux
Ω	Ohm (Unit of Resistance)
°C	Degree Centigrade
°F	Degree Fahrenheit
23 ZDMH	Grade of CRGO Steel—ZDMH, Thickness 0.23 mm
27 M4	Grade of CRGO Steel—M4, Thickness 0.27 mm
A	Ampere (Unit of Current)
A/sq. mm	Ampere per Square Millimetre
AC	Alternating Current
ACB	Air Circuit Breaker
ACSR	Aluminium Conductor Steel Reinforced
AD	Annodomini
A_g	Gross Core Area
A_n	Net Core Area
AMDT	Amorphous Metal Distribution Temperature
APPO.	Approved
ASTM	American Society for Testing and Material
AT	Ampere Turn
AV	Average
BDV	Breake Down Value
BEST	Bombay Electricity and State Transport
BHP	British Horse Power
BIL	Basic Insulation Level
BIS	Bureau of Indian Standards
BM	Bench Marking
BS	British Standard
BSEB	Bihar State Electricity Board
C/d	Current Density
C/L	Limb Centre
CBIP	Central Board of Irrigation and Power
CC	Cubic Centimeter
CEO	Chief Executive Officer
CESC	Calcutta Electricity Supply Corporation

CESI	Centro Elettrotecnico Sperimentale Italiano
CHP	Customer Hold Point
CKD.	Checked
cm	Centimeter (1 cm = 10 mm)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CNC	Computerized Numeric Control
CPRI	Central Power Research Institute
C & R	Capacitance & Resistance
CRCA	Cold Rolled Continuously Annealed
CRGO	Cold Rolled Grain Oriented
CT	Current Transformer
dB	deci-bel (Unit of Sound)
DC	Direct Current
dia.	Diameter
DPC	Double Paper Covering
DRG.	Drawing
DRN.	Drawn
DVB	Delhi Vidyut Board
DVDF	Double Voltage Double Frequency
Dyn-11	D-delta, y-Star, n-Neutral, 11-phase displacement
E	Earth
EGIP	Electrical Grade Insulating Paper
EMF/emf	Electromotive Force
EOT	Electrically Operated
ERDA	Electrical Research and Development Association
ERW	Electric Resistance Welding
E_t	Voltage per Turn
f	Frequency
GI	Galvanised Iron
gr	Gram (Unit of Weight)
gr/cc	Gram/Cubic Centimetre
GTP	Guaranteed Technical Particulars
HI-B	High Saturation Flux (Brand Name of CRGO Steel)
HP	Horse power
HPSEB	Himachal Pradesh State Electricity Board
HRC	High Rupturing Capacity
HRD	Human Resource Development
Hrs.	Hours
HSEB	Haryana State Electricity Board
HT	High Tension
HV	High Voltage
Hz	Hertz (Unit of Frequency)

$I^2 R$	(Current I)^2 × Resistance R
I/R	Insulation Resistance
ID	Inside Diametre
IEC	International Electrotechnical Commission
IER	Indian Electricity Rule
IFT	Inter Facial Tension
I_m	Magnetising Current
I_o	No-load Current
I_p	Phase Current
IR	Current (I)′ Voltage (V)
IR	Insulation Resistance
IR-drop	Current (I)′ Voltage (V) Drop
IS	Indian Standard
I_s	Rated Current
ISI	Indian Standard Institute
ISO	International Organization for Standardization
ISS	Indian Standard Specification
$I_{(h+e)}$	Hysteresis and Eddy Current
kA	Kilo Ampere
Kg	Kilogram (1 kg = 1000 g) (Unit of Weight)
Km	Kilometre (1 km = 1000 m)
KOH	Potassium Hydroxide
kV	kilovolt
kVA	Kilovolt Ampere
kVP	Kilovolt Peak
kW	Kilo Watt
Lit	Litre
LT	Low Tension
LV	Low Voltage
m	Metre (1 m = 100 cm)
M/C	Machine
mA	Milliampere
MB	Macholling Box
Max.	Maximum
MCB	Miniature Circuit Breaker
MCCB	Moulded Case Circuit Breaker
Mil	Unit of Thickness of Paper
Min.	Minimum
MLT	Mean Length Turn
mm	Millimetre (Unit of Length)
MOG	Magnetic Oil Gauge
MPC	Multiple Paper Covering
MPEB	Madhya Pradesh Electricity Board

MRS	Material Return Slip
MS	Mild Steel
MSL	Mean Sea Level
MT	Metric Ton
MV	Medium Voltage
mV	Milli Volt
MVA	Mega Volt Ampere
MW	Mega Watt
NC	Nonconformance
No.	Number
NTH	National Testing House
OCB	Oil Circuit Breaker
OD	Outside Diameter
OGA	Outline General Arrangement
OLTC	On Load Tap Changer
ONAN	Oil Natural Air Natural
O-Ring-1	Endless Ring
OTI	Oil Temperature Indicator
PCB	Chlorinated Biphenyl
PDCA	Plan-Do-Check Act
PF	Power Factor
PPM	Parts Per Million
PSC	Power Short Circuit
PSEB	Punjab State Electricity Board
PSR	Pressed Steel Radiator
PT	Potential Transformer
PVC	Polyvinyl Chloride
Q	kVA
QA	Quality Assurance
QAE	Quality Assurance Engineer
QAP	Quality Assurance Plan
QPC	Quadruplicate Paper Covering
QS	Quality System
R	Resistance
R/S	Ratio Switch
REC	Rural Electrification Corporation
RMS	Root Mean Square
RPM	Revolution Per Minute
RSEB	Rajasthan State Electricity Board
SC	Short Circuit
SEB	State Electricity Board
SK Value	Property of Insulating Oil
sq cm	Square Centimetre

sq m	Square Metre
sq mm	Square Millimetre
SRBP	Synthetic Resin Bonded Paper
SSI	Small Scale Industry
T and D	Transmission and Distribution
T	Turn
Tesla	Unit of Flux Density
TNEB	Tamil Nadu Electricity Board
TOBS	Transformer Oil Base Stock
TOFS	Transformer Oil Feed Stock
TPC	Tripple Paper Covering
TQM	Total Quality Management
UHBVNL	Uttar Haryana Bijli Vitaran Nigam Limited
UPF	Unity Power Factor
UPPCL	Uttar Pradesh Power Corporation Limited
UPSEB	Uttar Pradesh State Electricity Board
V	Volt (Unit of Voltage)
V/N	Voltage Divided by Turns
VA	Volt Ampere
V_p	Phase Voltage
VPI	Vacuum Pressure Impregnated
V_s	Rated Voltage
W	Watt (Unit of Wattage)
W/H	Window Height
W/kg	Watt per kg
WBSEB	West Bengal State Electricity Board
WTI	Winding Temperature Indicator
X	Reactance
Z	Impedance
ZDMH 23	Brand Name of CRGO Steel with 0.23 mm Thickness

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PROCESS CONTROL

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SECTION I

Elementary Transformer Engineering

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Section I

CHAPTER 1

Working Principles of Transformers

FOOD FOR THOUGHT

Life is too short to be wasted. A pill for success has not been invented as yet. Success is like a good timber, which does not grow with ease. The stronger the wind, the stronger will be the tree. It is the same with human life. There are plenty of opportunities all around us. What we need most of the time is perseverance. It is a virtue by which even mediocrity can achieve glorious success.

We can do almost anything if we work and keep on working; if we try and keep on trying. Nothing in this world can replace persistence. Calvin Coolidge says: ''Talent will not; nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education will not; the world is full of educated derelicts. Persistence and determination alone are omnipotent.''

If we want to have more than what we have got, we have to become more than what we are. This is possible only if we do our best every day. We should always be willing to stretch beyond our limits, willing to renew our commitment to happiness, to becoming the best we can do. Too often we give up too soon. Sometimes, we don't even bother to try because we are convinced that we will be unsuccessful. It would be interesting to examine why this is so. Is it because we are letting our past experiences dictate our present ? Whatever beliefs we are holding about happiness or failure, be willing to get rid of these self-limiting beliefs. We must break through our own self-imposed boundaries. Incontrovertible and undeniable victories come as a result of hard labour. No real victory comes cheap and none will in the future. Luck is not merely being in the right place at the right time. In fact, it is an energetic and dynamic process of creating the life we want. Do not just sit back and hope that good things will happen. Be courageous and go all out after what you want. Commit yourself to your good and visualise your success daily. Luck will then ''happen'' to you. It will come to you when you do what you are meant to do in order to make your dream come true. Do not fall into the category of people who are always talking about the trouble they once had, or the trouble they now have, or they expect to have. Instead, believe that yesterday got over last night and today, there is a chance to begin a new. Put the past behind you and move on.

True wisdom lies in knowing when and what to overlook and ignore. Do not trap yourselves in the past, including past regrets and past hurts. Start opening doors to your happiness by opening yourself to its possibility. Henry David, an Amrecian thinker has said: ‘‘What a man thinks of himself, that is what determines, or rather indicates, his fate.

AT A GLANCE

The basic function of transformer, in particular, is to transform electric power at one voltage to some other voltage without effecting much on electric power for which it is intended. Core is made-up of thin insulated laminations of electrical steel sheet carries two windings, which are insulated from each other. If one of the windings is supplied with an alternating voltage, a magnetic flux will produce in the core linking both the windings. According to law of electromagnetic induction the varying magnetic flux will induce emf in both the windings. The magnitude of emfs depend on the number of turns and the magnetic flux produced in the core.

A very important characteristic of the transformer is the transformation ratio which is the ratio of the emfs induced in the windings. Under no-load condition it may safely be assumed that the emfs induced in the transformer windings are equal to the voltage across the windings. Further, the induced emfs are proportional to the number of turns of the respective windings.

The chapter has briefly touch the open-circuit and short-circuit characteristics of transformer.

1.1 INTRODUCTION

Before we commence discussion on the subjected topic of the book *i.e.*, ‘‘TRANSFORMER: QUALITY ASSURANCE’’, it is essential to understand the definitions of a few basic parameters relating to the application and operation of transformer in service.

Power stations, either fuel fired (thermal) or hydroelectric, are installed at a point of location generally hundreds and thousands kilometres away from the consumers, hence a vast transmission lines between generating point and consumer load centre is needed. It has been seen in practice that generation voltages at the power stations are in the range of 10 to 15 kV. It is a known fact that when a power is transmitted through a overhead line, some of the power it carries is dissipated in the line conductor as I^2R in the form of heat, where ‘I’ is the current drawn by the line conductor and ‘R’ is the line resistance. It is not economical to try to reduce the losses by solely decreasing the conductor resistance, because this would require a substantial increase in the cross-sectional area of conductor, resulting a huge expenses of copper conductor beyond means.

It is preciously to reduce the power loss and the cost of line conductor, transformers are used. The transformer while leaving the transmitted power unchanged, decreases the current by increasing the voltage and the loss which is proportional to the square of the current (I^2) is thus sharply reduced. For example, a ten-fold increase in supply voltage reduces the power by a factor of one hundred.

1.2 APPLICATIONS OF TRANSFORMER

At the beginning of the power transmission line near the generating station, the line voltage is raised by a step-up transformer and at the end of the line the voltage is lowered by series of step-down transformers to a value convenient for the consumers (400 V or nearer).

The prime role in the present day power station is played by power transformers. The transformer is used to raise or lower the voltage in the supply network of the power system which serve to transmit electric power over great distance and distribute it among consumers.

Power transformers are notable for their high power capacities and operating voltages.

Since electricity has to transmit over thousands of kilometres to the integrated power grid, the load centre and directly to numerous minor consumers, the system voltage has to be transformed four to five times, hence the need to installed a large number of step-up and step-down transformers. Also, it should be noted that each transformation stage operating at progressly lower voltage the total capacity of power transformers is usually greater than that at the preceding stage. Therefore in any power station the installed capacity of transformer is six or seven times the installed generating capacity. As an example, Fig. 1.1 shows the layout of a transmission and distribution network.

Supply network operating at voltage more than 220 kV sometimes make wide use of auto-transformers. Such transformers have generally windings conductively connected so that there is some portion of the winding common to both primary and secondary circuit.

Besides power transformers, distribution and auto-transformers, there are a great variety of special transformers including electric furnace, rectifier, welding, regulating, testing, traction, marine, mining and instrument transformers.

Numerous types of transformers find application in communication equipments, automation and telecontrol systems, domestic appliances and so on. Today there is hardly a single electrical installation operating without transformer. The capacities and voltages of existing transformers vary over a very wide range—from a few fractions of a kilovolt ampere to hundreds or thousands of kilovolt ampere and from a few fractions of a volt to hundreds of kilovolts.

1.3 PRINCIPLES OF OPERATION

Transformer is an electromagnetic apparatus consisting of two or more independent electric circuits (windings) linked by electromagnetic induction, converts one or more alternating current systems to one or more alternating current system without the use of rotating parts. The basic function of transformer, in particular, is to transform electric power at one voltage to some other voltage without effecting much on electric power for which it is intended. For its operation the transformer depends on the phenomenon of electromagnetic induction which generates electromotive force (emf) in a closed conductive circuit by a change in magnetic flux linking that circuit.

Fig. 1.2 shows a schematic diagram of a single-phase transformer. Core (3) is made-up of thin insulated laminations of electrical steel sheet carries two windings (1) and (2) which are insulated from each other. If one of the windings, say winding (1) is supplied with an alternating voltage (V_1), current

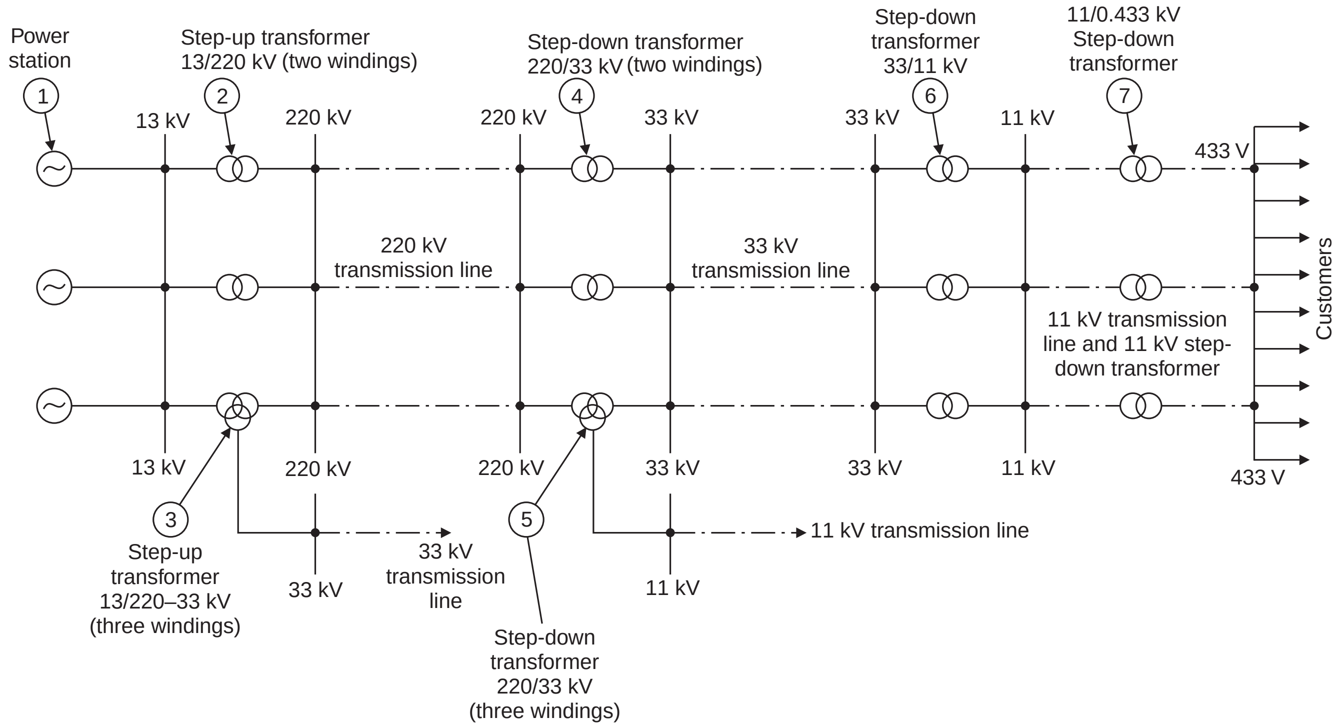


Fig. 1.1. Single line diagram of a transmission and distribution network

(I_1) will flow in it, producing magnetic flux (ϕ), which varies at the same frequency as voltage V_1 does. Since the permeability of steel is 800 to 1000 times that of air, a major part of the magnetic flux ϕ (which is called main flux) has its path through the core. The other parts of the flux (referred to as the leakage flux ϕ_L), much smaller in magnitude than the main flux, does not link magnetically with winding (2) and has its path through air. The leakage flux takes no part in voltage transformation.

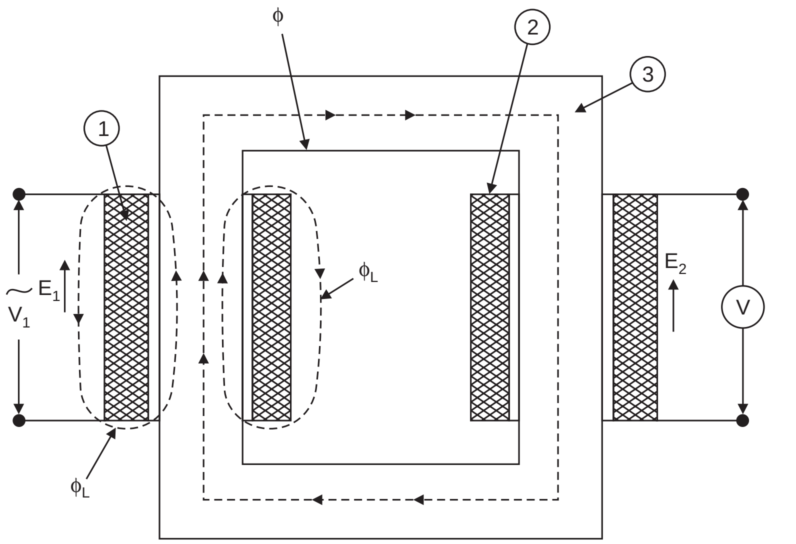


Fig. 1.2. Simple single phase transformer
1. Primary winding; 2. Secondary winding
3. Core; ϕ = Direction of main flux
ϕ_L = Direction of leakage flux

According to the law of electromagnetic induction, the periodically varying main flux (ϕ) linking both windings (1) and (2) induces an emf in each winding. Let us designate the emfs as E_1 and E_2. Electromotive force E_2 can be measured with a voltmeter connected across winding 2. If winding 2 is connected across some load, this will give rise to a flow of current through the load and this current will cause an increase in the current flowing in winding 1.

Thus principally, the electric energy supplied to winding 1 is first transformed to electromagnetic energy and then becomes electrical energy again consumed by the load circuit connected across winding 2.

The transformer winding to which the A.C. power being fed is referred to as primary winding, which the other from which the transformed A.C. power is drawn is called secondary winding.

1.4 ELECTROMOTIVE FORCE

The magnitudes of emfs E_1 and E_2 induced in the primary and secondary windings are measured in volt and may be calculated by the formula

$$E_1 = 4.44\, f\, n_1\, \phi \quad \text{volt}$$

$$E_2 = 4.44\, f\, n_2\, \phi \quad \text{volt}$$

where f = Frequency of the alternating current in Hz

n_1 and n_2 = No. of turns in primary and secondary windings

ϕ = Magnetic flux in Weber

Electromagnetic force E_1 induced in the primary winding is practically equals to the applied voltage. The magnitude of the secondary emf E_2 depends on the number of turns on the secondary winding. An increase in the number of turns on the secondary side causes an increase in the secondary emf and vice versa. In practice, to calculate emf induced in the transformer winding, use is made of a formula in which frequency is taken as 50 Hz.

Then
$$E = 4.44 \times 50 \times n \times A_i \times B_m \times 10^{-4}$$
$$= 2.22 \times 10^2 \times n \times A_i \times B_m \times 10^{-4}$$
$$= 222 \times n \times A_i \times B_m \times 10^{-4}$$

where n = Number of turns

A_i = Net cross sectional area of the core limb in sq mm

B_m = Magnetic induction (flux density) in tesla

In this equation, flux (ϕ) is replaced by $A_i \times B_m$

The net cross sectional area (A_i) is the area of the core sheet minus (–) the lamination insulation which is taken by a factor 0.97 for all practical purposes.

Therefore
$$A_i = A_g \times 0.97$$

where A_g = Gross cross sectional area of core limb in sq mm

The emf expression may be re-written as

$$E_t = \text{Voltage per turn} = E/n$$

and
$$E/n = 222 \times A_g \times 0.97 \times B_m \times 10^{-4}$$

The voltage induced per turn (E_t) is the same for both the primary and secondary windings, since they are linked by the one and the same flux. This is a very important characteristic of transformer which is widely used in calculation.

1.5 TRANSFORMATION RATIO

A very important characteristic of transformer is the transformation ratio which is the ratio of the emfs induced in the high voltage (HV) winding to the low voltage (LV) winding and so it is always greater than unity. Under no-load condition, it may be safely assumed that the emfs induced in the transformer windings are equal to the voltage across the windings,

i.e.
$$E_1 = V_1 \quad \text{and} \quad E_2 = V_2$$

Hence, if the primary and secondary windings have n_1 and n_2 turns respectively, we may write

$$E_1/E_2 = V_1/V_2 = n_1/n_2 = \text{constant, } k$$

Therefore
$$V_1 = k\,V_2$$
$$n_1 = k\,n_2$$

Thus knowing the transformation ratio and voltage on the secondary side of a transformer, we can easily find out the voltage of the primary side and vice versa. This equally applies to the number of turns in the windings.

1.6 DEFINITION OF A FEW BASIC PARAMETERS OF TRANSFORMER

According to the operating voltage, the transformers are categorized into different classes. The transformer winding of higher voltage class is referred to as 'high voltage winding', and that of lower voltage class as 'low voltage winding'. The winding of a voltage class intermediate between those of the HV and LV windings is called the medium voltage winding.

A transformer whose core carries two independent windings is called two winding transformer, while that of with three independent windings on its core is referred to as three winding transformer. A transformer with single winding is called auto-transformer. High capacity power transformers have three windings—HV, MV and LV. One of these is called primary and two others are secondaries.

A transformer with a single-phase magnetic field produced in its magnetic circuit (core) is referred to as single-phase transformer, while the three-phase transformer is the one in whose magnetic circuit produces a three-phase magnetic field.

To improve the electrical insulation of the current carrying components of a transformer and its cooling conditions, the transformer windings, together with the core are placed in a tank filled with transformer oil. Such transformers are called oil-immersed or oil cooled. Some special transformers use a non-combusible synthetic liquid 'askeral' instead of conventional oil. Transformers operating in air (not immersed in oil) are called 'Dry type' or 'air cooled' transformer.

The rated capacity of a transformer is usually expressed as its apparent power in kilovolt ampere (the kVA rating). The transformers are built for certain standard capacities and voltages. The rated primary voltage is the one for which the primary winding of the transformer is designed. The rated secondary voltage is the voltage developing across the secondary winding when the primary of the transformer is supplied with the rated voltage under no-load condition. The rated currents are determined by the corresponding rated voltages and the kVA rating of the transformer. In India, the rated frequency for supply input is 50 Hz.

1.7 PERFORMANCE PARAMETERS

Performance parameters are those which declare the status of quality of a transformer. We shall discuss, in brief, a few of the vital performance parameters.

No-Load (Open-Circuit) Characteristic

If rated alternating voltage V_1 is impressed on transformer windings, say the primary winding ($P_1 - P_2$) having n_1 turns (Fig. 1.3) when the secondary winding is open-circuited, the transformer is said to be operating under no-load condition. The current I_o flowing in the primary winding of the transformer on no-load is known as no-load current. Its magnitude is small in comparison to the rated primary current and generally in the order of 2 to 4% in low capacity distribution transformers and 0.5 to 1% in medium and high capacity transformers.

The reactive component of the no-load current produces the main magnetic flux ϕ in the core and a weak leakage flux ϕ_L which causes an inductive reactance to come into play in the primary circuit.

The resistive component has a negligible effect on the later and causes a resistive drop across the primary winding. The no-load current is commonly called the exciting current.

The transformer under no-load transfer no-electrical energy, since the secondary winding having n_2 turns is open-circuited. The active power consumed by the transformer is dissipated as heat in the core steel and particularly in the windings. These power losses as a whole are referred to as the no-load losses of the transformer and designated as (P_{no}).

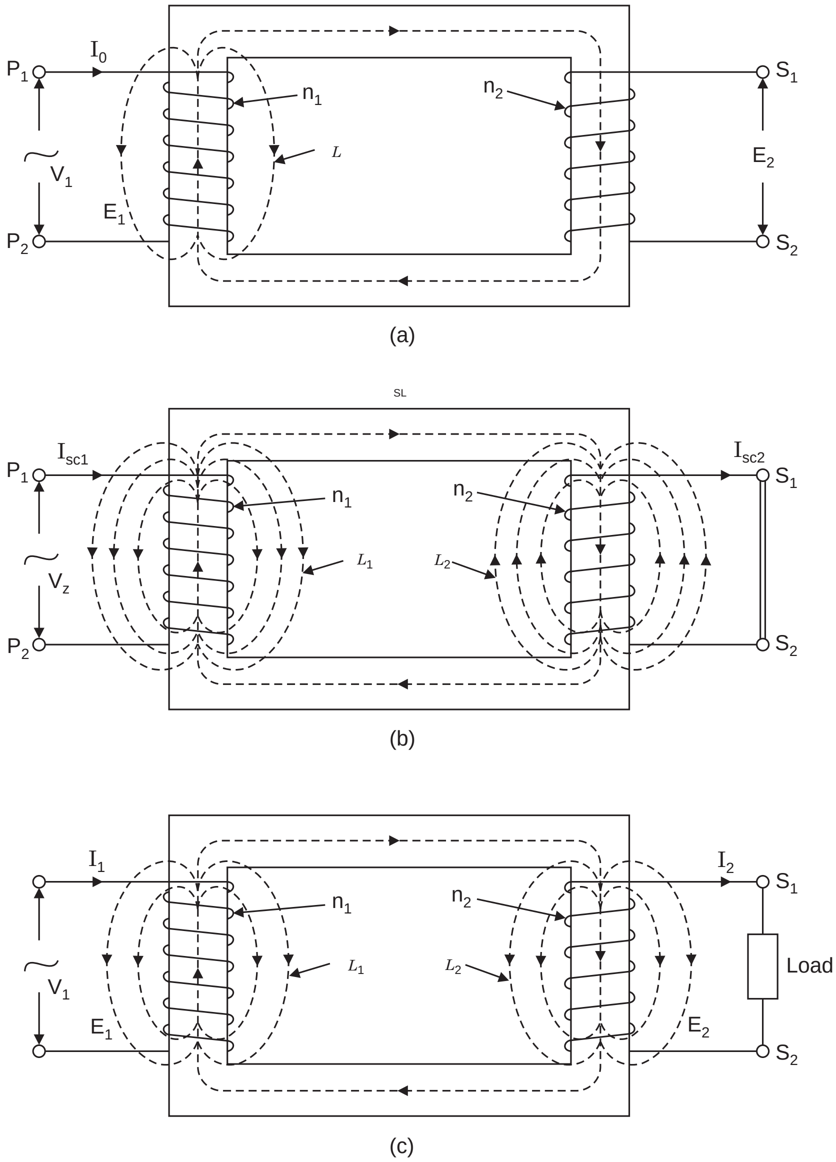


Fig. 1.3. Illustrating power transformer performance
(*a*) No-load condition; (*b*) Short-circuit test; (*c*) On-load condition

The I^2R loss (copper loss or winding loss) is the primary winding due to no-load current is low, because the current is small, therefore this loss is disregarded and the active power consumed by the transformer under no-load condition is considered to be dissipated only as loss in the core steel.

The power losses in the core steel are caused by its cyclic magnetization (reversed magnetic field sense at twice the supply frequency) and by eddy currents. The reversal of magnetization is accompanied by the generation of heat in the core and requires power expenditure, as in any other type of work. This loss of power in the transformer core due to cyclic magnetization of core steel is called 'hysteresis loss'.

The Transformer core is made of steel and operates in an alternating magnetic field. According to the law of electromagnetic induction this induces a current in it. These currents flow in plain, perpendicular to the direction of magnetic flux and are referred to as 'eddy current'. The thicker the core laminations and lower their resistivity, the greater the magnitude of these currents. Eddy currents are also called parasitic. When the path is completed through the core steel, it forms a current, causing some wastage of energy.

If the core steel were made solid, eddy current would grow enormous and causes prohibitive heating of the core. To reduce the eddy current loss, transformer cores are made up of 0.23 mm to 0.35 mm thick laminations (also called stampings) insulated one from other. The insulating film prevents the flow of current from lamination to laminations.

In practice, the hysteresis and eddy current losses are not taken separately, and one simple consideration what is called core loss (or iron`loss), bearing in mind that this is the sum of hysteresis and eddy current losses. It is customary to estimate the core loss in terms of specific loss *i.e.*, the loss of power per kilogram of the core steel. This loss per kilogram of a given grade of core steel depends on the permeability, resistivity and lamination thickness, as also frequency of the current and magnetic induction.

During normal operation, the no-load loss of a transformer comes only to 0.25% to 0.5% of its rated kVA. Nevertheless no effort is spared to minimize these losses. While operation of a transformer in service, the induction in the core and consequently the core loss remain constant, whatever the operative condition prevail on the transformer (*i.e.* no-load, under-load, full-load or over-load) and as a result the total annual loss of power amounts to a substantial figure. For core-steel of grade M4 of thickness 0.27 mm, the specific loss at 50 Hz standard frequency and an induction of 1.6 tesla amounts to be 1.0 W/kg.

The no-load loss`crow materially as the induction in the core is increased. This may occurs due to inadequate stacking of core (reduced number of laminations), or fault in the windings (reduced number of turns) during manufacturing. The ageing of the core laminations and the mechanical damaging of the core laminations and their insulation contribute to an increase in the core loss. Electrical steel sheet partially looses its valuable magnetic properties when subjected sharp blows and bending. All these causes a wastefull increase in the no-load current and power drawn by the primary winding of the transformer from the current source.

Short-Circuit Characteristic

One of the transformer windings is short-circuited and a voltage is applied to the others, the transformer is said to be operating under short-circuit. If such a short-circuit occurs during operation of the transformer at rated voltage, the short-circuit current arising in the winding exceeds the rated current by 20 to 25 times or more. Under such conditions heavy mechanical stresses develop in the windings and the temperature of the later rises. The operation of the transformer on a short-circuit [Fig. 1.3(*b*)] is very harmful and a special protection device is required, which must switch-off the transformer in a fraction of a second.

Short-Circuit Impedance Voltage and Losses

Let us consider the case of short-circuit test which helps to determine one of the basic characteristic of the transformer. As has been shown in Fig. 1.3(*b*). The secondary is short-circuited while a reduced voltage is fed to the primary windings. This reduced voltage is gradually increased to a certain value (V_z) which made to circulate rated short-circuit current I_{sc1} and I_{sc2} in the primary and secondary windings respectively. V_z is called the short-circuit voltage or impedance voltage of the transformer.

The short-circuit voltage V_z is usually expressed as percentage of the rated primary voltage.

$$V_z\ (\%) = \frac{V_z \times 100}{\text{Rated primary voltage}}$$

where V_z (%) = Short-circuit impedance voltage expressed in percentage.

V_z = Short-circuit impedance voltage measured across primary winding

The short-circuit voltage is a very important operating characteristic. The quality of the short-circuit voltage of transformer is one of the conditions requisite for their possible paralled operation. V_z (%) is indicated on the name plate of each transformer.

Its value, depending upon the type and capacity of transformer, is specified by the pertinent standard and ranges from 4 to 6% for low and medium capacity distribution transformers and 6 to 17% or more for high capacity transformers.

During short-circuit test, the applied short-circuit voltage of low magnitude produces a weak flux ϕ_{SL} in the transformer core. Besides the rated current flowing in the primary and secondary windings, it produces leakage flux ϕ_{L1} and ϕ_{L2} whose paths are partly in air and partly in the metal components of the transformer. The leakage fluxes produced in the transformer operating on a short-circuit gives rise to a substantial inductive reactance, thereby limiting the short-circuit currents in the windings and protecting them against excessive heating and mechanical damages. It is mainly the reactive voltage drop across the windings that determines the magnitude of short-circuit voltage. The higher the short-circuit voltage, the less the danger that the windings will be damaged by mechanical forces developing under short-circuit emergency condition.

However the short-circuit voltage should not exceed a certain value, otherwise an inadmissibly high reactance voltage drop across the secondary winding due to the high inductive reactance caused by the leakage fluxes will reduce secondary voltage V_2 and consequently the useful power available to the consumers. In addition, the leakage fluxes having their paths partly in the metal components of the transformer cause extra eddy current and hysteresis losses (also known as stray losses) which reduce the efficiency of the transformer.

When designing a transformer, the magnitude of impedance voltage V_z is selected so to make the transformer strong mechanically and thermally as possible on one hand and have the maximum possible efficiency on the other hand *i.e.*, to strike a balance between these two conflicting requirements.

Voltage V_z fed to the transformer during short-circuit test is by a factor 5 to 25 lower than the rated voltage depending upon the type of transformers, therefore, the exciting flux ϕ_{sh} which takes its path in the core amounts to not more than 5 per cent of the main flux. For this reason the core loss during short-circuit test is disregarded and the power P_{sc} consumed by the transformer under such condition is considered to be dissipated completely as the copper loss in the primary and secondary windings and stray hysteresis and eddy current losses due to leakage fluxes in the steel structural components (like tank walls, yoke clamps etc.). Since these losses have the same magnitude as in the case of the transformer operation under full load, they are frequently referred to as the load loss.

1.8 CONCLUSION

Before we go into in-depth study of various aspects of 'Quality Assurance', it is appropriate to highlight in brief the application, classification, operation and basic parameters of transformer.

The transformer is an electromagnetic apparator, consisting of two or more independent electric circuits, linked by electromagnetic induction. It serves the purpose of transforming power to one voltage to some other voltage without effecting much on electric power for which it is intended. Operation of transformer in terms of emf generation, open-circuit, short-circuit etc. have been discussed.

Every common man in an electrified city/town/village is familiar with the name 'transformer'. The main reason for this familiarity with transformer is the fact that it is subject to a very high rate of failure in service. Each case of failure is followed by days or even week of life without electricity and even water.

Transformer is a static machine having no moving or wearing part. If transformers are properly manufactured and maintained, they should operate with a failure rate of negligible percentage. The quality of materials—their selection and checks etc. also increase the life of a transformer.

A good design is necessary to produce a quality product. But all good design may not yield always good products. Good design need to be supplemented by good materials, good machines (healthy machines) and good (skilled) manpower. Right kind of machines, materials and manpower together with good design can definitely produce good transformers.

The following chapters will cover the method of selecting materials and their checks, controlling manufacturing processes and preventive maintenance of transformer in service (Chapter 3 to 41).

Section I

CHAPTER 2

Elementary Engineering of Transformer Operation

2.1 INTRODUCTION

Electricity is generated through Generator (commonly known as Alternator). Bulk of the generation is done either by Thermal Power Plant or by Hydro Power Plant or in the Nuclear Power Plant. Wind Power Energy, Bio Gas Energy, Power generated by Natural Gas, Energy developed from waste etc. are some other forms of source of energy whose contribution to the total generation is limited to less than one per cent in India. The thermal plants are generally constructed by the National Thermal Power Corporation (NTPC), Hydel plants are mostly constructed by the National Hydro-electricity Power Corporation (NHPC) and Nuclear Power Plant is constructed by the Nuclear Power Corporation (NPC). Generally thermal and nuclear power plants are set up far away from the localities to keep the air pollution in control. Hydro Plant by its character, need to be set-up in such areas where we get a natural height of water falling from some appreciable altitude and is generally available in hill areas. Since the point of generation is far away from the distribution network, it is always a difficult task for the power engineers to transfer bulk power from the generating station up to the point of utilization *i.e.,* customers.

The main hurdle to transfer power from one point to other is the loss of energy. Transformer is a static equipment which helps in transmitting power without affecting much of energy loss. The function of step-up transformer is to raise the voltage at the generating station and the increase is in the range of 132 kV, 220 kV, 400 kV, 800 kV, 1050 kV and so on. The increase of voltage is done without affecting the frequency and not much of loss of energy (neglecting the transformer inherent losses which are less than one per cent). The generated power at extra high voltage is then transmitted miles away from the generating station to some distribution locality. Power is thus available at the distribution system (commonly known as Sub-Station, S/S) at a very high voltage. It is now required to reduce the voltage to an appreciable low value, suitable to the industrial load and home appliances. The reduction of voltage is done through step-down transformers. The reduction of voltage to the tune of 415 V is done in two to three stages (*i.e.,* 220 kV to 33 kV, then 33 kV to 11 kV and finally 11 kV to 415 V).

The chapter covers in brief the elementary engineering of transformer application in terms of construction, working methodology, vector diagram of currents and voltages and calculation of equipment resistance and reactance.

2.2 PRINCIPLES OF OPERATION

According to Faraday's Laws of Electromagnetic Induction, if an alternating voltage is applied to one winding placed in a closed magnetic circuit, an alternating flux will generate in the magnetic loop, the direction of which is indicated in Fig. 2.1.

If the magnetic circuit has more than one windings, each winding will link the flux (*i.e.*, cut the flux) and will generate an Electro Motive Force (E.M.F.). The magnitude of E.M.F. depends upon the number of turns in each winding and amount of flux generated in the magnetic circuit.

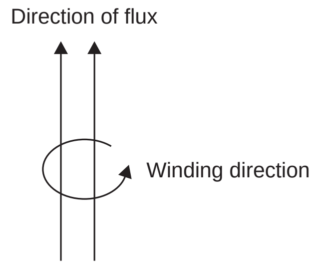


Fig. 2.1. Elementary diagram of flux and winding

Operation of transformer, its step-up and step-down configuration are based upon Faraday's principal.

Only rotating component in transformer operation is flux, which moves electromagnetically (not physically), rest everything is stationary and hence transformer is a static electrical equipment.

A schematic view of closed magnetic circuit with two sets of coils is shown in Fig. 2.2. The same figure may further be modified with a block diagram as shown in Fig. 2.3.

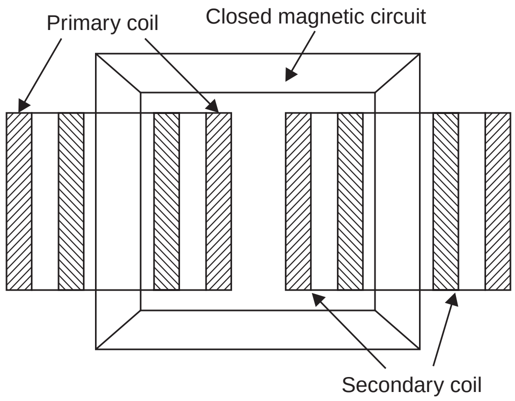


Fig. 2.2. Primary and secondary coils placed in a closed magnetic circuit

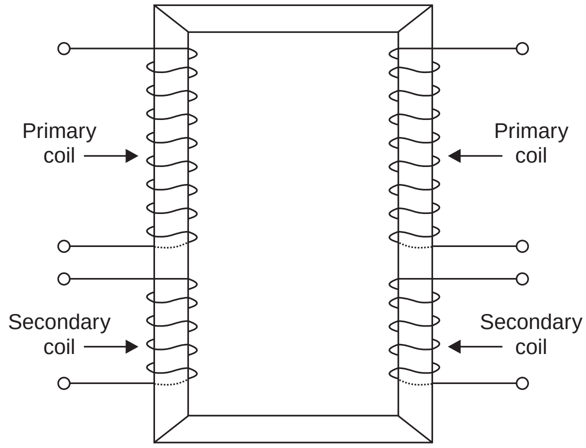


Fig. 2.3. Block diagram of elementary transformer

The induced emf depends upon the number of turns each of primary and secondary coil. Since the flux around the windings are same and the only variable is the number of turns in the windings, the induced emf in the windings are directly proportional to their turns. In case of step-up transformer, the secondary turns are more than the primary turns

$$i.e., \qquad \frac{\text{Primary Turns}}{\text{Secondary Turns}} < 1$$

Alternatively, secondary turns is less than primary turns in case of step-down transformer

$$i.e., \qquad \frac{\text{Primary Turns}}{\text{Secondary Turns}} > 1$$

In a transformer action if the power is kept same, the primary and secondary voltages and currents are inversely proportional. In other words, in the process of transformation, a voltage is decreased or increased with proportional increase and decrease of current respectively.

We have so far seen that a transformer will function only when two winding are placed in a closed magnetic circuit, with one of the windings is energized with an alternating supply, an alternating emf is produced on the other winding. The magnitude of voltage depends upon the number of turns provided in the coil. The ratio indicates whether the transformer is step-up or step-down type. Step-up transformer will have a ratio less than one and vice-versa.

The coil which receive voltage from source is called primary coil and the other coil which is magnetically induced to generate emf is called secondary coil. If the secondary coil is electrically closed through a load (as shown in Fig. 2.4), a current will flow throught it. The magnitude of current depends upon the voltage available across the secondary terminals and the characteristics of the load. Here the transformation of energy from one winding to the other is completed through electromagnetically. It is needless to say that the frequency of the alternating voltage remain unaffected.

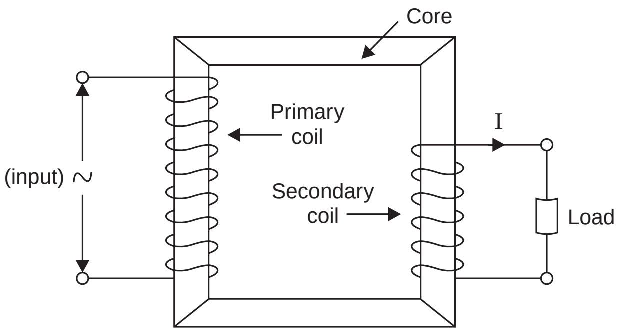


Fig. 2.4. Primary coil is energized and secondary coil is loaded

2.3 PRINCIPLES OF CONSTRUCTION

So far we have learnt that a transformer necessarily have a closed magnetic circuit and atleast two sets of coils, known as primary and secondary. The construction of core in the form of mitredjoints has been shown in Fig. 2.5.

Principally the magnetic circuit *i.e.* core should remain at earth potential and coils are charged to their respective voltages. Apart from core and coils, a transformer needs the followings:

- Core insulating materials
- Coil insulating materials
- Insulating cylinder between primary and secondary coils
- Steel frame to hold the core
- Core clamping screws to apply mechanical rigidity to core assembly
- Connection materials

- Tap changing switch, if provided
- Steel container (M.S. Tank) to house the core-coil assembly
- Suitable insulating terminals
- Insulating and cooling material (Transformer Oil)
- Radiators to enhance cooling surface

Whether it is a step-up or step-down transformer, the low voltage winding is generally placed nearer to the core. High voltage winding remains away from the core and is placed over LT coil in co-axial fashion. Right kind of insulation is needed to insulate the core from the secondary coil. Similarly insulating cylinder and oil ducts are used in between coils. Vertical supports of coils are done through insulating rings and blocks.

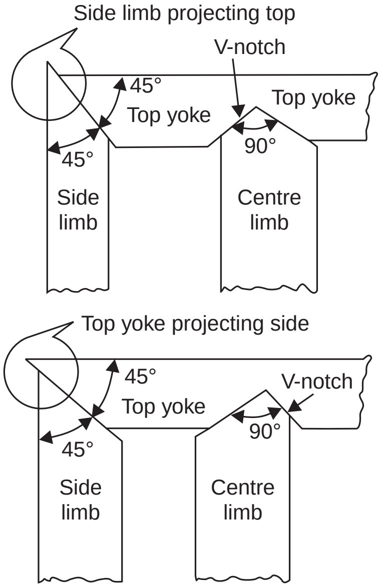


Fig. 2.5. Mitred core construction

Windings are made either from aluminium or copper, in the shape of wires (for small current) or rectangular strip (for high current). For oil cooled transformer, winding wires are either enamel coated or paper covered. Strips are usually paper covered. Electrical Grade Insulating Paper (EGIP) of very thin thickness (in the order of 1.5 to 2 mil) are used for covering the wires and strips. Paper cylinders, rings and blocks are made from insulating pressboard. Papers and pressboards used for making transformers are made from wood pulp.

Steel frame either in the shape of rolled angle or channel or formed channel from mild steel sheet are used to hold the core assembly. To apply rigidity, the core assembly is further tightened with horizontal and vertical screws.

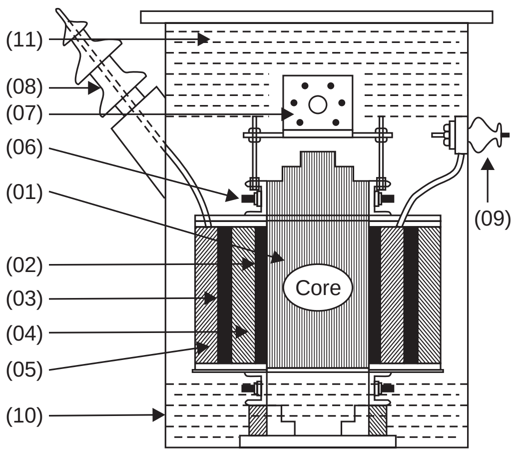


Fig. 2.6. Core-coil assembly placed inside a steel enclosure

Let us relate a few of the above in Fig. 2.6.

(01) —Core assembly side view
(02) —Insulating cylinder between core and secondary coil
(03) —Insulating cylinder between secondary and primary coil.
(04) —Sectional view of secondary coil
(05) —Sectional view of primary coil
(06) —Horizontal core binding screw
(07) —Tap switch
(08) —Primary termination (porcelain bushing)
(09) —Secondary termination (procelain bushing)
(10) —Steel enclosure
(11) —Insulating liquid

In the previous paragraph, we have mentioned that the connection materials are one of the components in transformer construction. This is nothing but thickly insulated copper wire having higher cross section than winding materials.

These insulated leads are either brazed or crimped to the winding ends for terminating to the tap switch (no. 7) or to the incoming and outgoing terminals (no. 8 and no. 9). For three phase transformer, the connections between phases are also made by the insulated leads to form star and delta (as represented in Fig. 2.7)

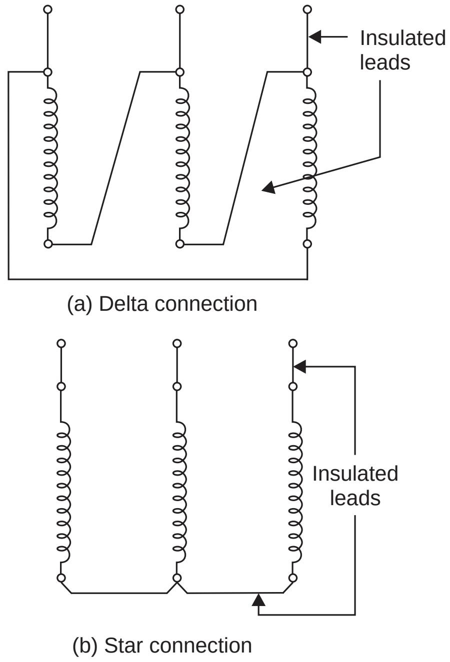


Fig. 2.7. Phase connection

Tap Switch

Use of tap changing switch for small transformers is an optional choice to the buyers. The switch is used to control the secondary voltage in cases where the primary voltage is either high or low. We must bear in mind that tap switch is provided on the high voltage side of the transformer where the current is comparatively low. Voltage available near the substation is always high with respect to rated voltage and the same is comparatively low in remote area. That is why the high voltage winding is designed to operate both plus and minus tappings. A few steps are provided between plus and minus tappings. In India, the widely used tapping voltage is ± 2.5% and ± 5% for HV variations. The tap switch may be off-circuit or on-load with push button control.

Fig. 2.8 represents a schematic view of taps provided on HV winding to maintain constant LV voltage. The HV winding shown in Fig. 2.8 has a break between tap no. 5 and 6. Taps no. 3 and 4 and 7 and 8 are taken out from the bottom and upper halves of HV winding respectively. The tap switch has a roller contact which connect one end of the upper and lower taps.

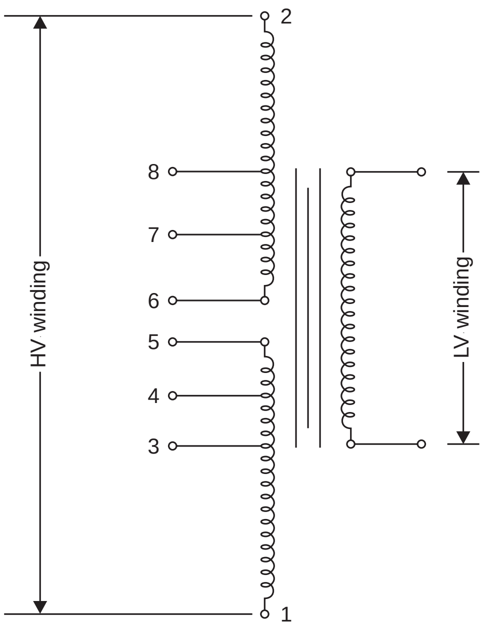


Fig. 2.8. Schematic view of taps on HV winding

The following table indicates the function of tap switch for a 11/0.433 KV transformer with ± 2.5% and ± 5% tappings on HV side.

Tap position	*% HV Variation*	*Short*	*Primary voltage*	*Secondary voltage*
1.	+5%	5–6	11550 V	433 V
2.	+2.5%	6–4	11275 V	433 V
3.	Normal	4–7	11000 V	433 V
4.	–2.5%	7–3	10725 V	433 V
5.	–5%	3–8	10450 V	433 V

From the above we can safely conclude that the operation of tap switch can maintain the secondary voltage (*i.e.*, load voltage) fairly constant even if the primary voltage varies within a reasonable percentage of ± 5%.

Use of Insulating Oil as Cooling Medium

While in operation, the transformer *i.e.*, core and winding emits heat which is detrimental to the insulating materials being used for transformer construction. It is customary to keep the temper ature under control. Mineral oil, available from fractional distillation of crude petroleum liquid has a unique property to cool the transformer as well as acts as an insulating material. The oil is used in medium and high voltage transformers. The active part of the transformer *i.e.*, core-coil assembly is placed inside a leak proof steel enclosure (no. 10) and is filled with insulating oil. The oil acts as a media to carry heat from the windings up to the tank surface. The tank then dissipate the heat to the atmosphere by radiation. In the process of transferring heat from winding to tank, the winding and oil retain certain amount of heat. If the rise in temperature of winding and oil exceeds pre-determined values of 50°C rise for winding and 40°C rise for oil, the electrical properties of both oil and insulating materials start deteriorating. To limit the rise in temperature of winding and oil, the tank surface area needs to be increased. It is customary to use radiators in such cases. Radiators are made from steel pipe, either in the shape of round or elliptical tubes or in the form of fins (discussed separately in section-II). It has an inlet, an outlet and is fixed in the tank wall. Hot oil circulates through such radiators and gets cooled by convection process. This aspect has been discussed at length in the later part of the book.

All openings and joints like tank cover, terminal holes, inspection pocket, tap switch handle, air release plug etc. are sealed with respective components and sealing gaskets. Connection to the bushing terminals are made. Oil is added to the required level. Now the transformer is complete and is ready for floor testing. High voltage test is recommended to carry out atleast 24 hours after the oil being filled, as the paper insulation used inside the transformer needs time to absorbs oil and to offer higher electrical strength to the windings.

2.4 CONSTRUCTION OF CORE

The basic core material is electrical steel and is available in the form of thin laminated sheet, commercially knowL as **Cold Rolled Grain Oriented (CRGO) Silicon Steel.** It is an alloy steel which contain certain percentage of silicon. This material has excellent magnetic property of high permeability and low hysteresis loss at reasonable operating flux density, which is 1.6 Tesla. When a coil is placed in a closed magnetic circuit and is energized with an alternating voltage, a magnetic loss occurs in the core material which is commercially known as **'Core Loss'**. Core loss has two components : HYSTERESIS LOSS AND EDDY CURRENT LOSS. Hysteresis Loss depends upon the quality of magnetic material at the operating flux density, frequency of the system and weight of core material. Eddy current loss is inversely proportional to the thickness of the laminated sheet and that is why we have seen a mark improvement of the availability of thinner sheet, in the range of 0.18 mm, 0.23 mm, 0.27 mm, 0.30 mm, 0.35 mm. Each laminated sheet is insulated on either side by a thin oxide film, commonly known as **'Carlite film'**. The laminations available from mills are in the form of roles. After the steel is produced in the mill, it is annealed at a temperature of 800 to 900°C. This is done to get the magnetic grain uniform towards the rolling direction. The roled laminations are sheared to various shape and designed dimensions as indicated in Fig. 2.9.

Fig. 2.9 represents a view of assembled core of a 3-phase, 3 limb transformer. Two side limbs are identified as '*A*' and are identical in shape. The ends are sheared at 45°. The centre limb is identified as '*B*' and the ends are cut at 90°. The top and bottom limbs are identified as '*C*' and are identical in shape. The ends of '*C*' laminations are cut at 45°C and have a '*V*' notch at the centre to match '*A*' and '*B*'. All these laminations are sheared in such a configuration so as to enable them match the assembly without leaving air gap between them.

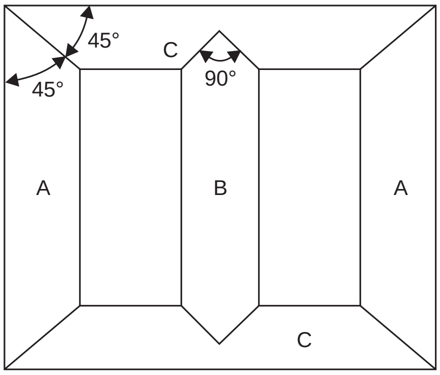


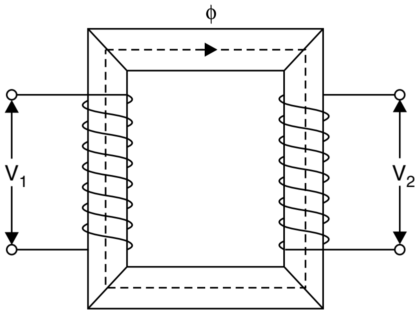
Fig. 2.9. View of an assembled core indicating three steps of lamination

To minimize the eddy current loss, the core laminations are made thin. In order to build a stack core, it is assembled layer by layer in staggered way. During the process of assembly one has to take utmost care towards joints and ensure that the joints between lamination are free from air gap. Further the laminations need a few millimeter overlap to build a firm assembly. Usually for small transformers up to 100 kVA, an overlap of 5 mm is kept in each joint. Overlap and assembly of alternate layers have been shown in Fig. 2.5.

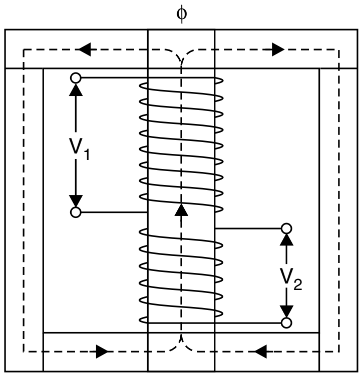
Classification of Construction

Construction of core is classified by the placement of its primary and secondary coils in the core and how the core is being constructed. Two type of core constructions are familiar. They are: (*a*) **Core Type and** (*b*) **Shell Type.**

Fig. 2.10 represents a schematic view of core-type and shell type transformers. In core type transformer, the windings are placed on either limb of the core, whereas in shell type transformer, the windings are placed in the centre limb only. The side limbs are left open. In other words we can simply say that in core type transformer the windings surround a considerable part of the core, whereas in shell type transformer the core surrounds a considerable part of the windings. Electrically shell type transformer performs better than core type transformer as the flux generated in the magnetic circuit remain concealed in the core and the loss of flux in air is minimized. However in core type transformer, a good amount of flux is lost in the air. This loss of flux is called leakage flux. Generally core type transformer is cheaper and hence is widely used in industries.



(a) Core type transformer



(b) Shell type transformer

Fig. 2.10. Single-phase core type and shell type transformers

To simplify the view and to make the construction easily understandable, the primary and secondary coils have been shown separately wound on either side of the core (Fig. 2.10, *a*) or placed one above the other (Fig. 2.10, *b*). Practically this is not correct. The coils are usually wound co-axially as shown in Fig. 2.6 earlier. Co-axial coils have better linkage of flux in the windings and also it reduces the leakage flux.

2.5 VECTOR DIAGRAM

The angular positions of voltages induced e.m.f. and currents are called vector diagram. When a transformer operates under no-load, the vector diagram is quite simple, representing only the primary and secondary voltages and the exciting current drawn by the core material. Vector diagram becomes complicated when the transformer is loaded, as it starts drawing a load current which creates a dropping of voltage due to inherent resistance and reactance of the transformer windings.

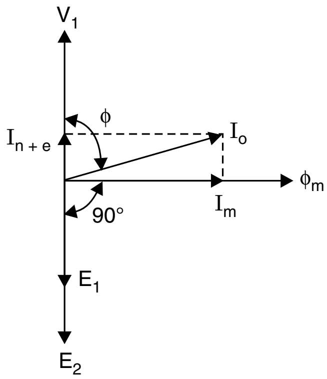


Fig. 2.11. Vector diagram at no-load

We shall discuss each of the above operating conditions separately.

(*a*) Vector diagram of a transformer under no-load (off-load)

Fig. 2.11 represents the following parameters:

V_1 = Input voltage to the primary winding

E_1 = Back emf induced in the primary winding

E_2 = Induced emf on the secondary winding

ϕ_m = Direction of magnetic flux

I_{h+e} = Hysteresis and eddy current

I_m = Magnetising current

I_0 = No-load primary current

To understand the composition of no-load primary current (I_0), it has two components—hysteresis and eddy current which is in-phase with V_1 and the other is magnetizing current which is perpendicular to V_1.

I_{h+e} is known as active component of no-load current and I_m is known as reactive component of no-load current. ϕ is the power factor angled between V_1 and I_0.

The components of no-load current may be written as

$$I_{h+e} = I_0 \cos \phi$$

$$I_m = I_0 \sin \phi$$

$$I_0 = \sqrt{(I_{h+e})^2 + (I_m)^2}$$

When a transformer operates under no-load condition, it has to account for iron loss of the magnetic circuit which is mainly due to the hysteresis and eddy current loss. Magnetizing component of no-load current do not add to any loss as it is at right angle to V_1 and cos 90° is zero.

Power loss at no-load condition is $V_1 I_0 \cos \phi$

In the above discussion we have eliminated the effect of copper loss in the primary winding due to the no-load current. Since the magnitude of no-load current is very small and to the extent of one to two per cent of full load current, the copper loss generated in the primary winding during the no-load condition is negligible and hence neglected in the aforesaid discussions. Hence we conclude that the power loss at no-load is practically equal to iron loss in the transformer.

(*b*) Vector diagram of a transformer under no-load

Fig. 2.12 (*a*) shows a simple schematic diagram of a single phase transformer on no-load condition

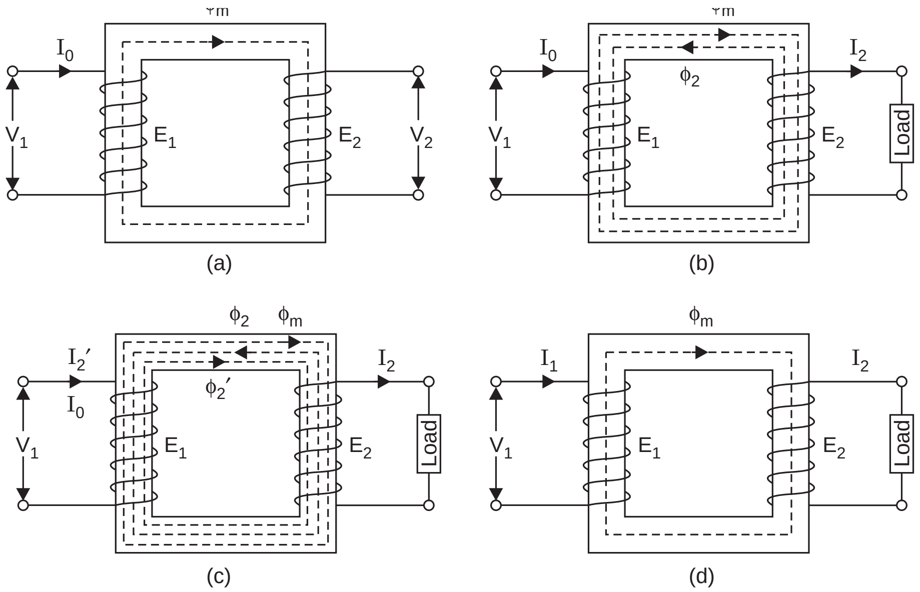


Fig. 2.12. Transformer at load

An input voltage of V_1 is applied to the primary winding which generates a no-load current (I_0) and a flux (ϕ) rotating in the magnetic circuit in an assumed direction. Secondary open circuit voltage is (V_2), and remains off-load.

Fig. 2.12 (*b*) shows a simple schematic diagram of a single phase transformer whose secondary is loaded with a resistive load. Loaded secondary will set up a current I_2 whose magnitude depends on the characteristics of the load and the secondary voltage. Current I_2 is in phase with V_2 if the load is resistive. It lags if the load is inductive [Fig. 2.12 (*c*)] and it leads if the load is capacitive [Fig. 2.12 (*d*)].

Fig. 2.13 (*a*) shows a simple vector diagram when the secondary is loaded with a resistive load. Current I_2 is in phase with E_2.

Current I_2 will lag E_2 by an angle ϕ_3 in case of inductive load. The same will lead in case of capacitive load (not shown in Fig. 2.13)

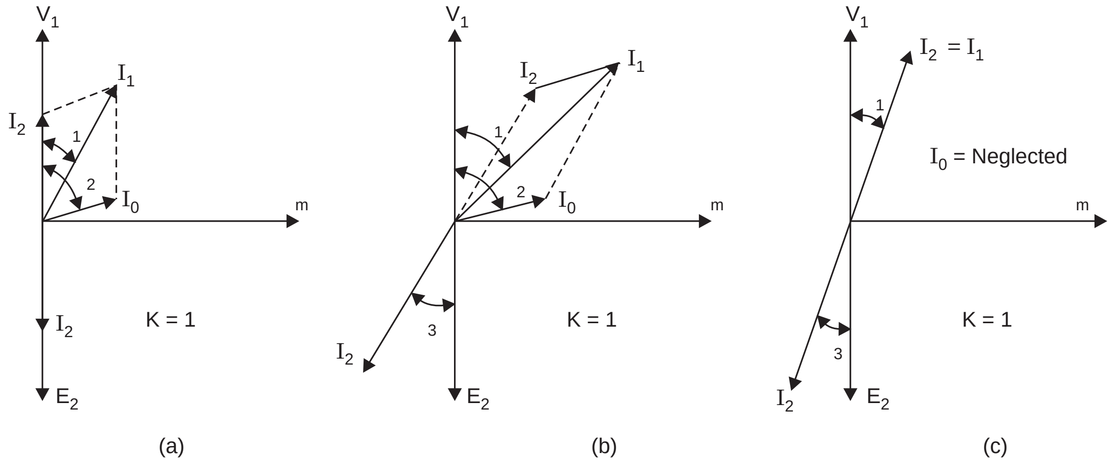


Fig. 2.13. Vector diagram on load

The secondary current will establish its own magnatomotive force (which is proportional to N_2I_2) and generate a momentary flux ϕ_2 which is in opposition of main flux ϕ as indicated in Fig. 2.12 (*b*). The two fluxes are rotating on the same closed magnetic circuit, but in opposite direction. This weaken the main flux momentarily and hence the secondary opposing flux is called de-magnetizing amp-turns. This causes a slight momentary gain of V_1 over E_1 and thus more current flows in the primary windings.

Fig. 2.12 (*c*) shows this primary current I_2', flows in the primary winding alongwith the primary no-load current (I_0) both being in the same direction. I_2' is antiphase with respect to I_2 as shown in Fig. 2.12 (*c*). The additional primary current I_2' will create a momentary mmf $N_1I'_2$ which sets up a flux ϕ'_2 [Fig. 2.12 (*c*)]. This momentary flux ϕ'_2 is in opposition to ϕ_2, but in the same direction of main flux ϕ_m. Since the magnitude of ϕ_2 and ϕ'_2 are same, they cancel each other and the main flux ϕ_m remains only in existence. This is represented in Fig. 2.12 (*d*).

We now come to an understanding that the momentary flux ϕ_2 generated by the secondary and the antiflux ϕ'_2 generated by the primary current cancel each other leaving the main flux ϕ_m in existence which is same when the transform was at no-load. This could be an important conclusion that the magnetic loss (or core loss) is a constant loss which remains practically constant at all loading conditions.

Flux is the product of number of turns and current generated in the magnetic circuit.

From the above we conclude the following:

$$\phi_2 = \phi'_2$$

i.e., $$N_2 I_2 = N_1 I_2'$$

or $$I'_2 = \frac{N_2}{N_1} I_2$$

Primary will have two currents at load—one is I_0 and other is I'_2 which is anti-phase with I_2 and 'K' times in magnitude. The total primary current is the vectorial sum of I_0 and I_2'.

Fig. 2.14 (*a*) and (*b*) represent the vector diagrams of a transformer when the load is non-inductive as well as inductive load respectively. Voltage transformation ratio is assumed unity to make primary and secondary voltage vector equal. As indicated in Fig. 2.14(*a*), in a non-inductive load (*i.e*., resistive load), the secondary current I_2 is in phase with E_2 and causes a primary current I'_2 which is anti-phase and equal to its magnitude (as $K = 1$). The resultant primary current I_1 is the vectorial sum of I_0 and I'_2 and lags behind V_1 by an angle ϕ_1.

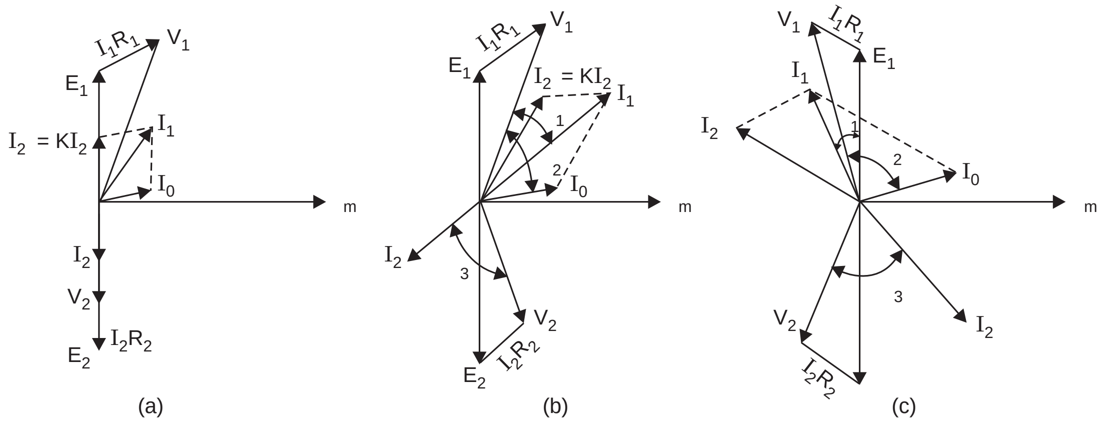


Fig. 2.14. Vector diagram with the presence of winding resistance

A close look to the vector diagrams shows that ϕ_1 is slightly greater than ϕ_3 because of the existence of I_0. Since I_0 is very small as compared to I_2 its presence may be neglected while drawing vector diagram. This aspect has been shown in Fig. 2.13 (*c*), where ϕ_1 is equal to ϕ_3.

2.6 EFFECT OF WINDING RESISTANCE IN VECTOR DIAGRAM

So far we have discussed the vector diagram for transformer having no inherent resistance which is not correct. Practically the primary and secondary resistance do have some resistances and when there is a current flows through the winding, it create a voltage drop (IR) across the winding.

To make the statement more simple, let us categorise the following:

(*a*) The secondary terminal voltage V_2 is vectorially less than the secondary induced emf E_2 by an amount I_2R_2, when R_2 is the secondary winding resistance (Fig. 2.14). In other words V_2 is equal to the vector difference of E_2 and resistive voltage drop I_2R_2

i.e., $$\overline{V_2} = \overline{E_2} + \overline{I_2 R_2}$$

(*b*) The winding resistance of primary creats a voltage drop $I_1 R_1$. The primary induced emf E_1 is equal to vector difference of V_1 and $I_1 R_1$,

i.e., $$\overline{E_1} = \overline{V_2} - \overline{I_2 R_1}$$

(*c*) The vector diagrams of non-inductive, inductive and capacitive loads have been shown in Fig. 2.14 (*a*), (*b*) and (*c*) respectively

2.7 EQUIVALENT RESISTANCE

The winding resistances of primary and secondary are denoted as R_1 and R_2 respectively and have been shown externally in Fig. 2.15 (*a*). For simplicity in calculation, the resistances can be transferred to one side, *i.e.* either both the resistances on primary side (Fig. 2.15, *b*) or both the resistances on secondary side [Fig. 2.15 (*c*)]. We must take into account the transformation ratio (K) while transferring resistances to other side. It can be seen below that the secondary resistances R_2 becomes R_2/K^2 when it is transferred to primary side.

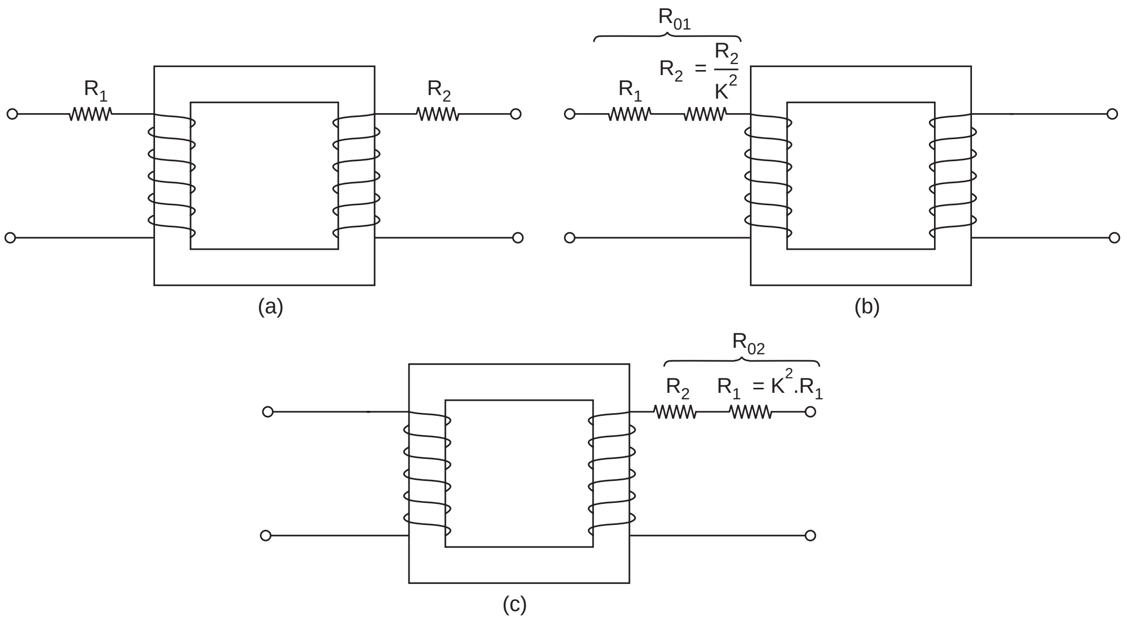


Fig. 2.15. Schematic diagram of windings with inherent resistance and reactance shown outside

Thus the equivalent secondary resistance as referred to primary $= R'_2 = \dfrac{R_2}{K^2}$

Further, the copper loss in secondary is $I_2 R_2$

This loss is supplied by primary which takes a current I_1

Hence if R_2 is the equivalent resistance in primary which would have caused the same loss as R_2 in secondary, Then $$I_2R_2' = I_2R_2$$

or $$R'_2 = \left[\frac{I_2}{I^2}\right] \times R_2$$

 Now, neglecting the effect of no-load current I_O.

Then, $$\frac{I_2}{I_1} = \frac{I}{K}$$

Hence, $$R'_2 = \frac{R_2}{K^2}$$

Similarly the equivalent primary resistance as referred to secondary is

$$R_1' = K^2R_1$$

Fig. 2.15 (*b*) represents equivalent resistance (R_{01}) of the transformer as referred to primary

$$R_{01} = R_1 + R'_2 = R_1 + \frac{R_2}{K^2}$$

Similarly the equivalent resistance of transformer as referred to secondary (R_{02}) is

$$R_{02} = R_2 + R_1'$$
$$= R_2 + K^2R_1 \text{ (Fig. 2.15, } c\text{)}$$

2.8 EFFECT OF REACTANCE ON VECTOR DIAGRAM

It was assumed in our previous discussion that all the flux generated in the primary winding also links the secondary winding. But it is practically not correct. A part of the magnetic flux (ϕ_{L1}) in the primary winding complete is circuit through air rather than around the core as shown in Fig. 2.16. This leakage flux is produced when the mmf due to primary amp-turns, existing between point 'a' and 'b', acts along the leakage paths. Hence the flux is known as primary leakage flux and is proportional to the primary amp-turns alone, as the secondary turns do not link the magnetic circuit of ϕ_{L1}. The flux ϕ_{L1} is in time phase with I_1. It induces an emf eL_1 in the primary, but not in secondary.

Similarly secondary amp-turns (or mmf) acting across point '*c*' and '*d*' set up leakage flux ϕL_2 which is linked with secondary winding alone. This flux ϕL_2 is in time phase with I_2 and produce a self induced emf eL_2 in the secondary winding.

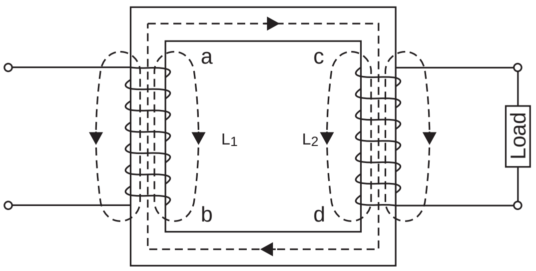


Fig. 2.16. Distribution of leakage, flux in the windings

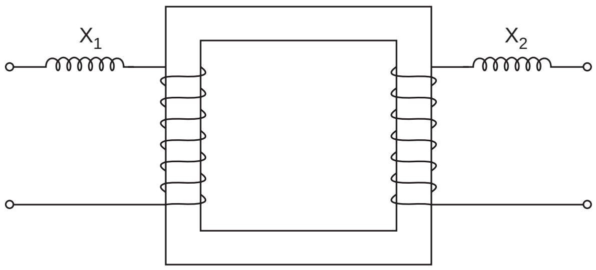


Fig. 2.17. Reactance of the windings shown Z_2 separately

At no-load and light load, the primary and secondary amp-turns are small and hence leakage fluxes are negligible. But with increased load, both primary and secondary windings carry huge current. Hence large mmfs are set up which while acting on leakage paths, increase the leakage flux.

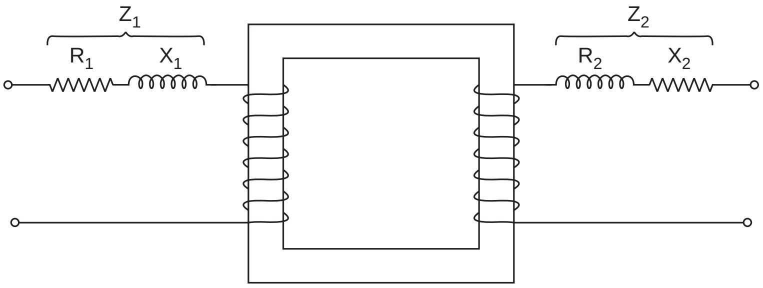


Fig. 2.18. Reactanes and resistances of the windings shown separately

The leakage flux linking with each winding produces a self induced emf in that winding. Hence in effect, it is equivalent to a small choke or inductive coil in series with each winding such that voltage drop in each series coil is equal to that produced by leakage flux. In other words, a transformer with magnetic leakage is equivalent to an ideal transformer with inductive coils connected in both primary and secondary circuit as shown in Fig. 2.16 such that the internal emf in each inductive coil is equal to that due to the corresponding leakage flux in the actual transformer.

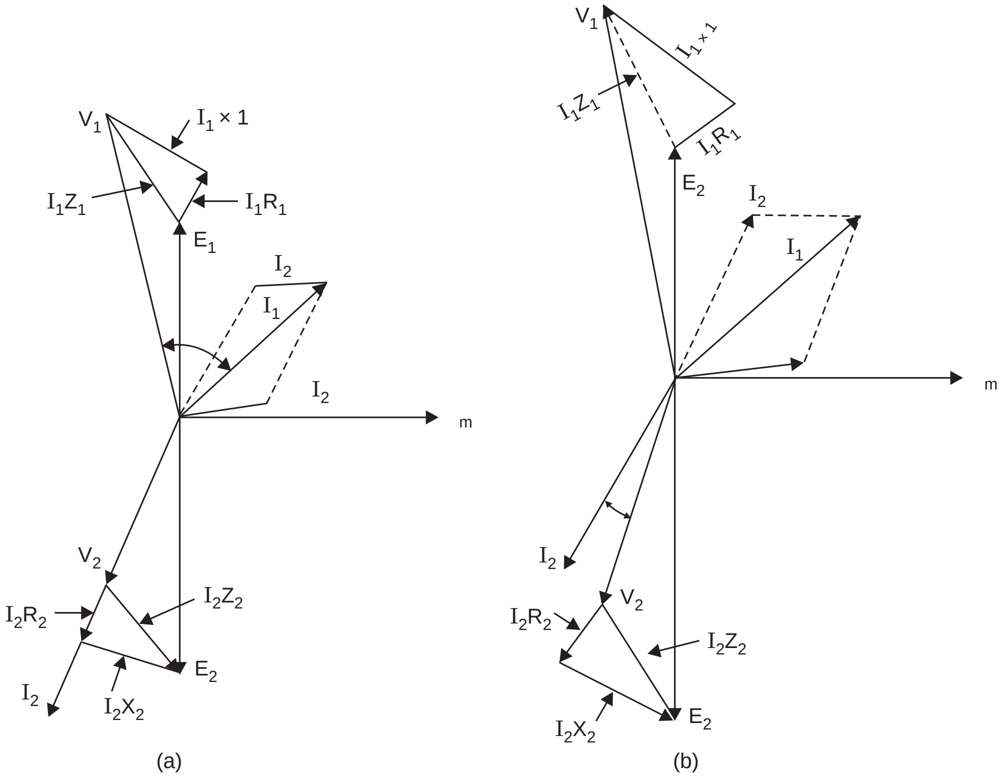


Fig. 2.19. Vector diagram showing resistive and inductive drop

$$X_1 = \frac{eL_1}{I_1}$$

and $$X_2 = \frac{eL_2}{I_2}$$

The terms X_1 and X_2 are known as primary and secondary leakage reactance respectively.

Let us conclude the following:

(*a*) The leakage flux links one or the other winding, but not both, hence it in no way contributes to transfer of energy from primary to secondary winding

(*b*) The primary voltage V_1 will have to supply reactive drop I_1X_1 in addition I_1R_1. Similarly E_2 will have to supply I_2X_2 and I_2R_2.

2.9 COMBINED EFFECT OF RESISTANCE AND LEAKAGE REACTANCE ON VECTOR DIAGRAM

Fig. 2.20 represents a block diagram where both the resistance and the reactance have been shown series with the winding. Impedance is the vectorial sum of resistance and reactance.

The primary impedance $Z_1 = \sqrt{R_1^2 + X_1^2}$

The secondary impedance $Z_2 = \sqrt{R_2^2 + X_2^2}$

The resistance and reactance of each winding create some voltage drop, Mathematically, we can write

$$V_1 = E_1 + I_1 \; (R_1 + J\,X_1) = E_1 + I_1Z_1$$

and
$$E_2 = V_2 + I_2\,(R_2 + JX_2)$$
$$= V_2 + I_2Z_2$$

The vector diagram of such a transformer with various kind of load is shown in Fig. 2.19 (*a*) and (*b*).

Similar to transfer to resistance, the leakage reactance can also be transferred from one winding to the other in the same way

$$X'_2 = \frac{X_2}{K^2}$$

and $$X'_1 = K^2X_1$$

Therefore, $$X_{01} = X_1 + X'_2$$
$$= X_1 + \frac{X_2}{K^2}$$

and $$X_{02} = X_2 + X'_1$$
$$= X_2 + K^2 \,.\, X_1$$
$$Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$$

$$Z_{02} = \sqrt{R_{02}^{\ 2} + X_{02}^{\ 2}}$$

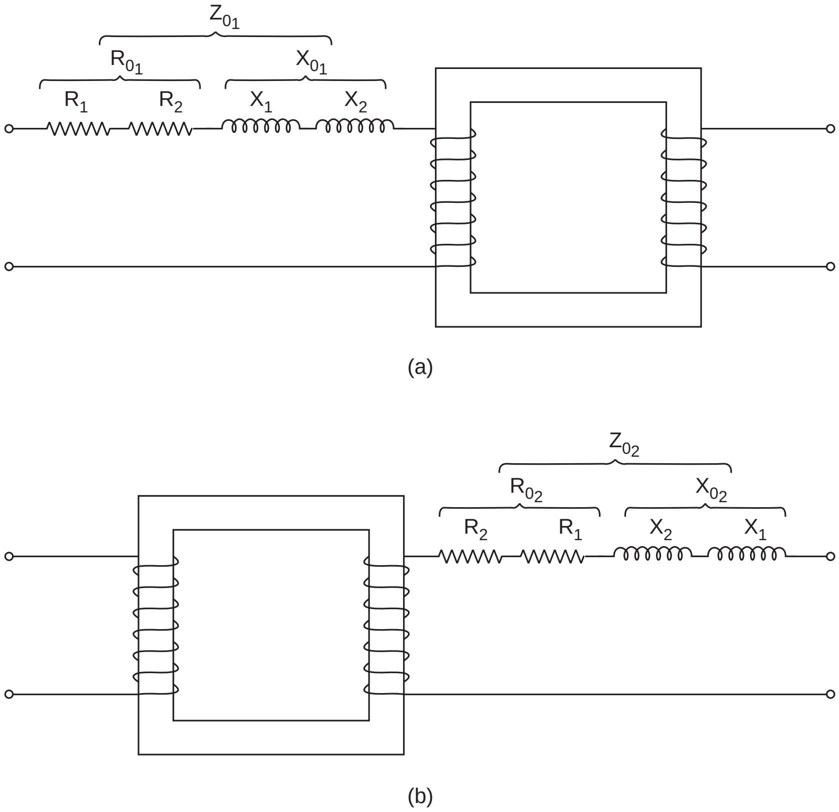


Fig. 2.20. Equivalent resistance and reactance of transformer windings

2.10 CONCLUSION

Let us conclude here the discussion on elementary engineering and working methodology of transformer. We have so far seen that the transformer has mainly two sets of windings, designed to operate at two different voltages and are linked electro-magnetically (not electrically). Each winding has its own inherent resistance and reactance which are vectorially added to form impedance. The relation of voltage, emf, current and drop due to impedance have been shown in the form of vector diagrams.

With fair amount of knowledge on the basic engineering of transformer, we shall now step into the discussion on the choice of raw materials and see how quality materials affect the performance of transformer.

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SECTION II

Selection of Raw Materials and Their Quality Check

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Section II

CHAPTER 3

Classification of Materials

FOOD FOR THOUGHT

Many people feel that they are condemned to mediocrity and will not amount to anything in life. There are some who question why others have got that they have not. It is important to remember that geniuses seldom distinguish themselves early in their lives. Many have been labelled difficult, slow or even stupid. Thomas Edison, whose record 1093 patents outstripped every inventor in history and transformed human life, was not a good student in school. ''My father thought I was stupid.'' Edison later recalled, ''and I almost decided I must be a dunce.''

As a child, Albert Einstein, too seemed not good enough to his elders. He had difficulty in both speaking and reading. His poor language skill provoked his Greek teacher to tell him, ''You will never amount to anything.'' Only his mother encouraged him and told him that he would be a great man one day. Einstein was expelled from his school. He also failed in his college entrance examination. After finally completing his bachelor's degree, he failed to obtain either an academic appointment or a recommendation from his professors. He was literally forced to accept a lowly job in a Swiss patent office. In his mid-twenties, Einestein seemed fated for a life of mediocrity. But in his twenty-sixth year, he published his Special Theory of Relativity—which contained his famous formula ($E = mc^2$) in the summer of 1905. Sixteen years later, he won the Nobel Prize and became an international celebrity.

It was same with Dr. Hargobind Khurana, who failed to get job as a Professor in Punjab University, Chandigarh. After migrating to the USA, he won the Nobel Prize.

The present President of India, Dr. APJ Abdul Kalam, failed to get an assignment in the Indian Institue of Bangalore as a Professor. Later he was awarded the Bharat Ratan, and found eminently suitable and acceptable as the First Citizen of the country.

These are the inspiring examples, which show that man can achieve what they strive for.

AT A GLANCE

It is an introductory chapter on raw materials and components. Here we have identified a few basic materials which constitute almost 95 per cent of the materials required for manufacturing transformers.

Few paragraphs have been added on the utility of transformer in power system network and present Indian power scenario.

3.1 INTRODUCTION

The alternating current system of transmission and distribution has come into universal use largely because the transformer makes it possible to connect the different parts of the system at their most suitable voltages. It would not be an exaggeration to say that without the simplicity, reliability and high efficiency of the transformer, the enormous growth of electric transmission and distribution system in the country would have been possible. Moreover, the best of the generation technology, transmission technology, and the distribution technology have been linked together by the transformers.

In a transformer, inductive action is used whereby electromagnetic energy is transferred from a primary to secondary conductive circuit. In order to link the two current carrying circuits, both circuits comprise coils mounted on a ferro-magnetic core. The quality of a transformer can only be assured if right kind of materials are used in right manner to ensure reliable performance.

In Section II, we shall examine the features on which the reliability of transformer depends. Then we shall discuss the state of art of the available materials. Lastly we shall discuss the properties of the materials and how they influence the performance of a transformer.

3.2 INDIAN POWER SCENARIO

Power sector has grown immensely from the time of independence. Against an installed capacity of 1713 MW at 1950, the installed capacity today (upto 2006) is more than 1,20,000 MW. The per capita consumption has increased from 15.6 kWh in 1950 to more than 600 kWh at present. However the level of satisfaction is more or less is same, if not worse. The number of outages per day is tremendously high, atleast 4 to 5 times.

The sharply increasing cost of electrical energy are forcing electricity supply authority to recognize the critical importance of the cost of electrical losses. Electricity utilities are increasingly required to operate their network more efficiently and to reduce the total real running cost of the equipments and assets. The transformer, after the transmission lines, are the largest loss-making components in the electricity network. There are about 2526517 nos. of transformers with a total installed capacity of 759239 MVA (as on 31.3.2006) in the power system. It is estimated that about 35 billion kWh of energy is lost in transformation every year. The total losses due to transformer in the electricity network in our country exceed 6% of the total energy generated, equivalent to about 8–10% of the total loss from the system.

Although power transformers are generally purchased after considering losses over life cycle of the transformer, distribution transformers are generally purchased on the least cost basis. Distribution transformers form 98.5% of the total installed transformers, however, this enormous stock of transformers is often overlooked as a source of cost savings. In fact avoidable losses from the distribution transformers currently in service would mean release of about 650 MW of generating capacity, which could intend be used to serve customer needs. Furthermore, buying efficient transformers would save literally hundreds of thousands of rupees in operating losses over the installed life for transformers in a typical facility.

Losses in Distribution Transformers Only

There are about 2.4 million distribution transformers with 206668 MVA installed capacity in the country and they account for about 17 billion kWh of distribution system losses and even this may be an underestimation. Electronic equipments and other non-linear loads now make up most of the loads on transformers in many facilities. Even in the daily office use many individuals plug in computers, printers, scanners and other electronic gazates to 240 V system. When feeding the increasingly electronic nature of connected equipments, distortion of the voltage wave form can reduce the operating reliability of both the electrical system and the connected equipments. The load profit of the electronic equipments—from the computer in the office to the variable speed drive in the factory—drives both additional losses and unwanted distortion. Loads such as variable speed drives, computers and uninterruptible power supply draw non-linear currents from the supply, resulting in substantial current at harmonic frequencies. Harmonic currents have a significant effect on transformer losses. About 5% of the total losses is due to eddy current in the windings and these losses are proportional to the square of the frequency. As a result the losses arising from a current at the 3rd harmonic is nine times that due to a fundamental of the same magnitude. Since transformer manufactures test only under ideal (linear) conditions, as called for in present construction standard, a substantial gap exists between published loss and actual loss incurred after installation.

3.3 VARIOUS RAW MATERIALS

The transformer was first developed on 16th September, 1884 in Budapest, Hungary in the form of a tiny unit of 1.4 kVA, with voltage ratio of 120/72 V. Undoubtedly operating principle was based on Faraday's experiments and Maxwell's theory of electromagnetic fields. Today it has grown into an awesome size touching 2000 MVA and nearing 1500 kV voltage class. The dominating factors for the sharp rise in the improvement of transformer technology was due to the availability of transformer-friendly raw materials, which are broadly classified as under:

(*i*) **Development of core material:** As a matter of fact, this one aspect is mainly responsible for the development of high efficiency, low loss and compact sized super large rating transformers. Graduating from the hot rolled laminations used in the beginning, invension of CRGO Silicon Steel in the early fifties made all the differences. The process and R and D has been continuous. Various steel gients, like Arm-Core, USA and Nippon Steel Corporation. Japan have been at it relentlessly. The result has been the availability of low loss, Hi-B core. Recent development of Laser irradiated (domain refined) Hi-B core is a dream come true for many designers. With this wonder material, the core loss and magnetizing currents have been reduced drastically. Further, the problems such as noise due to 'Magnetostriction', 'Harmonic components' and phenomenon of 'Magnetic Inrush Currents' etc. are also reduced to great extent.

Amorphous metal core is even a step further in this particular area of transformer technology. No-load loss can be reduced by about 70 to 80% by using Amorphous metal core with respect to conventional silicon steel of 'M4' grade.

(*ii*) **The winding conductor:** Wile the basic conductor material used for winding has remained the same, which is EC grade copper, aluminium was also added to this in the early 70's for small size distribution transformers up to 250 kVA ratings. However, improvement in the quality of conductor insulation has made it possible to reduce the overall size of windings and achieving higher temperature class of operation. Foil-wound LV coil reduces the eddy current loss in the winding and hence minimize load loss.

(*iii*) **Solid insulating materials:** The improvements in solid insulating materials, method of impregnation, design structures and shielding also resulted in the vast increase in the operating voltage of transformers with the availability of various grades of calender pressboards, Type-C, Type-D, Precompressed boards etc., manufacturers have the scope to choose from a wide range of variety.

(*iv*) **Transformer oil:** Use of oil as an insulating and cooling medium has greatly helped in the rise of transformer rating and the voltage class. Improvement in the desired parameters are continuously going on. Further, to meet specific requirements of very low ambient temperature or to reduce fire hazards, other insulating liquids were also developed, such as 'Chlorinated biphenyl', 'Silicon liquid' etc.

3.4 CONTENTS OF SECTION TWO

Fundamental requirements in our effort to achieve excellency in transformer technology are:

(*i*) Quality and Optimization of design with particular reference to energy efficient transformer.
(*ii*) Use of high quality raw materials.
(*iii*) High quality manufacturing processes for producing reliable transformers.

Pursuit for excellence in transformer technology is meaningful only with reference to quality. Quality of a transformer can be improved by taking effective steps in the origin stage itself which are 'use of high quality raw materials' and improved manufacturing processes' (apart from design which has been taken up in Section III of this book).

It is needless to mention that the performance of a transformer largely depends on the excellence of design. However all good designs may not yield good end products unless they are well supported by good materials, good and healthy machines and skilled workmen (operators). In Section Two, we shall discuss the availability of various raw materials and components and how they influence the performance of a transformer. The effect of machines and manpower is discussed in Section III.

Major materials and components which constitute 90% of transformer manufacturing have been covered in Section II. They are:

(*i*) CRGO steel and Amorphous metal core — Chapter 4
(*ii*) Winding wires and strips — Chapter 5
(*iii*) Insulating pressboards — Chapter 6
(*iv*) Insulating oil — Chapter 7
(*v*) Transformer tanks and radiators — Chapter 8
(*vi*) Porcelain bushings and fittings, Off-circuit ratio switch and sealing gaskets — Chapter 9

3.5 CONCLUSION

Though other miscellaneous materials like insulating tapes, sleevings, hardwares, paints etc. also influence the performance of transformers, we shall not cover the details of such items in this book.

The reason of discussing raw materials is to impress the readers how the quality of raw materials influence the performance of a transformer. We have briefly discussed the procedures of selection of materials, their processing and use.

Section II

CHAPTER 4

CRGO Silicon Steel

4.1 INTRODUCTION

Cold Rolled Grain Oriented (CRGO) silicon steel is used as core material in transformers. In recent years, importance is being laid on conservation of energy and manufacturers of transformers are encouraged to minimise losses in transmission and distribution of power. During the period 1987 to 1998, the demand for electricity in India has increased and the generation of power has almost doubled. The demand is expected to grow and perhaps double in coming years, and hence minimising the losses in transmission and distribution of power is important.

Earlier, transformer manufacturers used grade M4 0.27 mm of CRGO steel, as the availability of other grades was restricted. Over time and with advanced technology, super fine grades of CRGO steel, commonly known as HI-B and lazer grade, are available and use of these grades helps in reducing losses.

4.2 GRADES OF CRGO STEEL

In India, distribution transformers are manufactured using 0.27 M4 CRGO steel. The following changes in grades are suggested in order to minimise losses.

(*a*) CRGO-0.27 M4 replaced by HI-B-0.27 MOH (effecting a reduction of losses by 16 per cent)

(*b*) HI-B-0.27 MOH replaced by HI-B-0.23 MOH (effecting a reduction of losses by 8 per cent)

(*c*) HI-B-0.23 MOH replaced by lazer grade-0.23 ZDMH (effecting a reduction of losses by 8 per cent)

(*d*) Lazer grade-0.23 ZDMH replaced by amorphous metal core (effecting a reduction of losses by 42 per cent etc.).

From the above points it can be seen that by using better grades of steel, the losses can be reduced by (16 + 8 + 8 + 42 =)74 per cent from that of the conventional core transformers designed with 0.27 M4 grade CRGO steel.

Reduction of losses not only minimises the running cost, but also helps to reduce the core frame size (except amorphous metal core transformer), thereby reducing the cost of windings as well as the cost of oil.

4.3 CORE SLITTING

Slitting operation is done to slit the mother coil into narrow hoops. In the case of electrical steel, slitting operation causes deterioration of magnetic properties of the mother coil.

In order to achieve good slitting without much deterioration of magnetic properties, the cutting tools of the slitter lines need to be properly adjusted. In case the cutting blades are not sharpened or the blades are not properly aligned, considerable amount of burrs may result in the cut edges. Moreover, sometimes, the insulation coating along the cut edges may also get scratched because of the mismatch of the cutting blades. The blades are to be refixed depending on lamination thickness.

The acceptable maximum burr on the cut edge is 40 microns. In case the burrs are more than 40 microns, the cause of such extra burrs should be identified and eliminatied before further processing of CRGO steel.

4.4 CORE PROCESSING

After slitting, the next operation is CRGO processing. This operation involves mitring and notching. The two side limbs are cut at an angle of 45°, The top and bottom laminations are cut as 'V' at the centre thereby creating a notch to receive the centre leg laminations. A representative view is shown in Fig. 4.1.

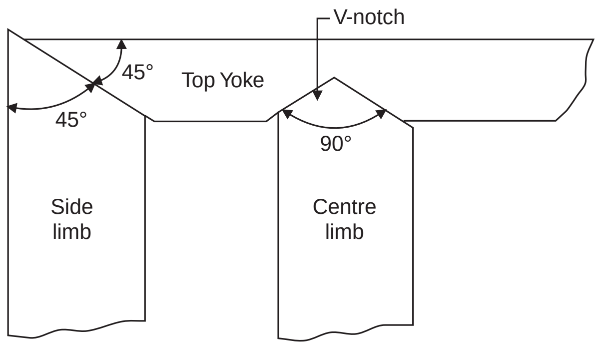


Fig. 4.1. Cutting angle of mitred-cut laminations

Since it is a continuous operation of cutting steel sheet while processing CRGO laminations, the sharpeness of the cutting tools is very important. If the tool is not sharp it will produce lot of burrs on the cut edges. The acceptable limit of burr is 30 to 40 microns. More burrs will cause more air gaps in the core assembly which will result in high no-load loss and current, even though good quality of CRGO steel is used.

4.5 ANNEALING

During slitting, mitring and notching operations, the laminations lose some of its magnetic properties. It is further annealed to achieve the following:

(*a*) Reduce the mechanical stress in the lamination and yield optimum magnetic properties

(*b*) Prevent contamination of steel with oxygen and/or carbon

(*c*) Retain or enhance the insulation quality of lamination coating.

Annealing is done at a temperature of 1400 to 1500°F (760 to 845°C), preferably in a protective atmosphere. The protective atmosphere is pure nitrogen, which protects the steel from oxidation.

Two types of furnaces are generally employed:

(*a*) Batch furnace

(*b*) Continuous roller hearth furnace

The batch furnace is advantageous when core sizes vary considerably and when production is intermittent. The continuous roller furnace is generally used for annealing CRGO lamination of reasonably uniform sizes.

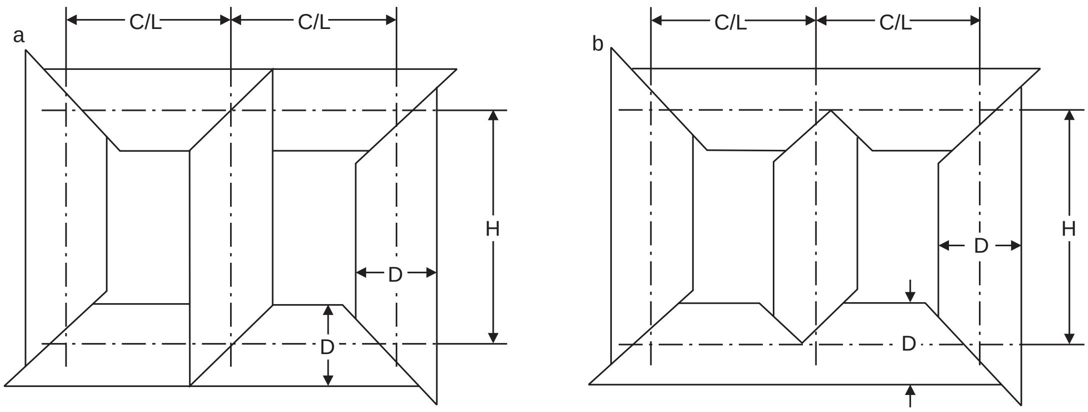
4.6 CORE BUILDING

Various types of core stackings are adopted for three phase transformers during manufacture. Some of the core building schemes are shown in Fig. 4.2 which are only representative.

Each scheme has its own advantages and disadvantages. The manufacturers should look into the applicability of each of these schemes before deciding on the final design of core building.

The scheme and style of assemblies shown in Fig. 4.2 (*a*) and (*b*) are exactly the same, except for the configuration of yoke laminations, which are of two pieces in the case of Fig. 4.2 (*a*) and of single piece in the case of Fig. 4.2 (*b*). Two side limbs in both the assemblies are identical, but the shape of centre lamination is different. The number of joints in Fig. 4.2 (*a*) are eight, whereas they are six in the case of Fig. 4.2 (*b*). Because of more number of joints, Fig. 4.2 (*a*) yields more losses than Fig. 4.2 (*b*) for the same core area and flux density.

Similarly Fig. 4.2 (*c*) and (*d*) and Fig. 4.2 (*e*) and (*f*) are same, except for the yoke configurations as described above.



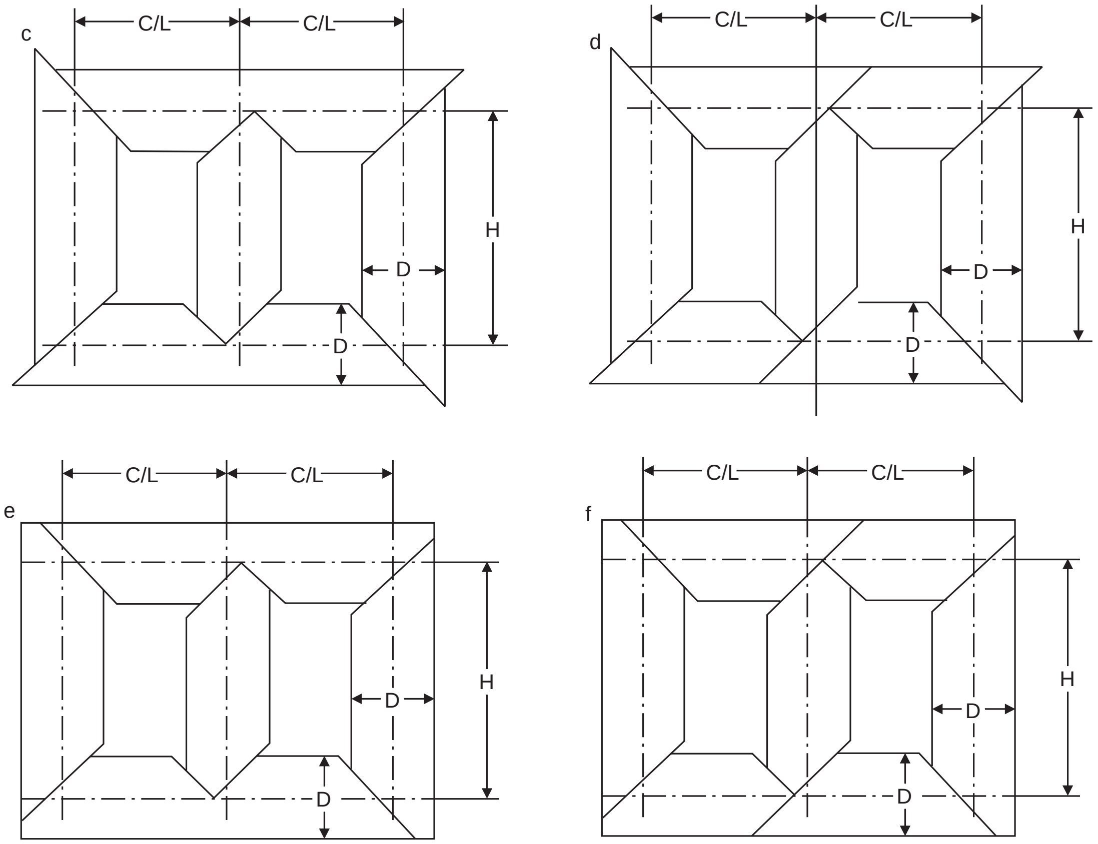


Fig. 4.2. Types of core stackings for three phase transformers

4.7 STEP-LAP CONSTRUCTION

Apart from the models of core building shown in Fig. 4.2, there are some more schemes, commonly known as 'step-lap' constructions as indicated in Fig. 4.3 and Fig. 4.4.

The construction of step-lap may be 'cross-step' or 'longitudinal-step'. These types of core building schemes have some specific advantages over other schemes, especially in no-load loss and current.

'Step-lap' core assembly has less no-load loss than conventional stacked assembly. But in India 'step-lap' construction is not very popular, since the cost of processing equipments is huge and are beyond the reach of small manufacturing units. The processing equipment is known as 'Automatic Cut to Length, CNC Control'.

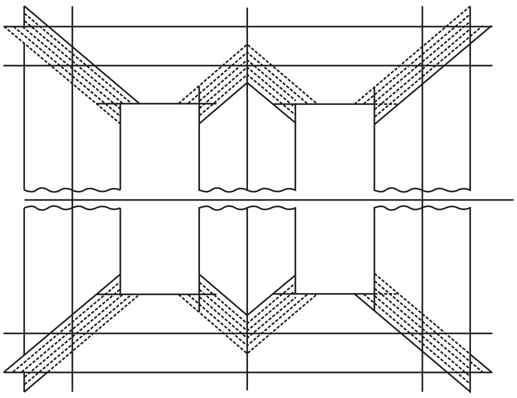


Fig. 4.3. Cross-step step-lap construction

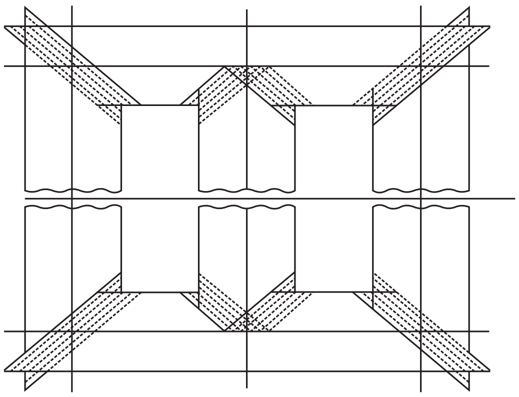


Fig. 4.4. Longitudinal-step step-lap construction

4.8 AMORPHOUS METAL CORE TRANSFORMER

The national average of T and D losses in India is bout 23 per cent of the generated power. Eighty per cent of these losses are attributed to the distribution network. Losses in the distribution network are mainly due to lengthy feeders, low power factor in the system and transformers. One of the steps for energy conservation, therefore, could be the efforts to reduce transformer losses. Losses in a transformer consist of no-load loss and load loss. No-load loss (or core-loss) is fixed loss irrespective of loading of the transformer. This loss is more significant, particularly in rural areas where the transformers are lightly loaded for most of the time. It is estimated that about 5 per cent of the energy consumed in rural areas is wasted due to no-load losses. Therefore, efforts to reduce these losses will be a step towards energy conservation. In India, where the gap between the supply and demand is increasing day by day, reduction in transformer loss will go a long way in reducing the gap and in increasing overall efficiency of the distribution network.

Amorphous alloy: There has been constant search for transformer core material with minimum loss. Iron-Boron-Silicon amorphous alloy has evolved as the low loss material for distribution transformers. Molten metal when cooled to solid state at a very high rapid rate, retain a random atomic structure which is not crystalline. This metal is called ‘amorphous’. This resembles glass and is also referred to as ‘glass metal’. The need to achieve the required cooling rate restricts the thickness of the metal to about 0.025 mm, *i.e.*, almost 1/10th of the thickness of the conventional CRGO steel.

Due to its small thickness and low saturation factor, larger core and consequently larger coils and tank size are required as compared to CRGO core transformer. The problem of small thickness is overcome to some extent with the development of amorphous metal strips. This is achieved by compacting a number of thin laminations into comparatively thick ribbons. These strips commonly known as ‘power core’, have been developed upto a thickness 0.25 mm. Amorphous strips are four times harder than CRGO steel. Hardness along with reduced thickness makes slitting and shearing difficult.

Due to these and other limitations, the amorphous core technology has been limited at present only to distribution transformers in India. Amorphous metal core has some merits. The non-crystal-line structure and random arrangement of atoms give low field magnetisation and high electrical resistivity. Due to low field magnetisation, hysteresis loss is low and due to high electrical resistivity, eddy currents are suppressed. As such, the core losses in amorphous metal alloys are reduced by almost 74 per cent as compared to conventional stacked core.

4.9 PROPERTIES OF AMORPHOUS METAL ALLOY

The important properties of the amorphous magnetic alloy along with those of the conventional CRGO silicon steel are given in Table 4.1.

Table 4.1

Sl. No	*Properties*	*Amorphous alloy*	*CRGO silicon steel 27–M4 grade*
1.	Saturation flux density at: 25°C 100°C	 1.55 tesla 1.49 tesla	 2.03 tesla 2.09 tesla
2.	Core loss (watts/kg)	0.21 at 1.4 tesla	1.02 at 1.6 tesla
3.	Excitation power (VA/kg)	0.37 at 1.4 tesla	1.4 at 1.6 tesla
4.	Specific resistance Ohm-mm^2/m	130	45
5.	Hardness	DPH 10.3	RB 76
6.	Thickness in micron	25–30	275
7.	Space factor in per cent	78–82	95–97.5
8.	Sensitivity to pressure	Appreciable	Negligible
9.	Magnetostriction	Higher	Lower
10.	Brittleness	Higher	Lower
11.	Available form	Ribbons/Foils	Sheets/Rolls

The most attractive characteristics of amorphous alloy are obviously its extremely low core loss—a reduction of almost 74 per cent—and low magnetising current—a reduction of almost 78 per cent. Except these two properties, practically all other properties of amorphous alloy are inferior to those of CRGO steel. It is a challenge to engineers to overcome the inferior properties so that the low loss property is exploited in the most cost effective way.

4.10 COST OF AMORPHOUS CORE TRANSFORMERS

The amorphous metal saturates almost at 1.55 tesla whereas CRGO steel saturates at around 2.03 tesla. Hence amorphous metal core transformers require increased core size, larger conductor, larger tank and more insulating oil. Thus overall cost of amorphous core transformer is approximately 40 per cent higher than that of conventional core transformer.

4.11 DEMERITS OF AMORPHOUS CORE TRANSFORMERS

Though amorphous core transformer has excellent magnetic properties such as low no-load loss and current, it is not popular in the Indian market because of its high initial cost. Moreover, considering the high rate of failure of distribution transformers, REC has recommended the use of suitable protective devices (MCCB with matching characteristics) on LT side of the transformer to protect it from faults and shortcircuits which occur frequently on LT lines. With such recommendation, the amorphous core transformers become costlier and remain beyond reach to most of the SEBs.

Further, most of the SEBs are not able to undertake repair of failed amorphous transformers as they do not have sufficient knowhow as well as infrastructure to handle such repair work.

It is suggested that the SEBs buy a limited quantity of amorphous transformers for monitoring their performances in the distribution network, as well as to acquaint themselves in maintenance and repair of such transformers.

4.12 CONSTRUCTION OF AMORPHOUS CORE TRANSFORMERS

Figures 4.15 to 4.26 provided at the end of this chapter may be referred for the construction of amorphous core transformers.

Figure 4.5 shows the construction of AMDT core in both closed and open conditions. It is available in the market (on order) duly formed according to the specific size and design of the customer.

Figure 4.6 shows the assembly of 4 sets of such AMDT core duly clamped together at the bottom with steel frame. The top laminations are un-bladed and made straight-up. This will facilitate to insert the pre-fabricated coils around the core limbs.

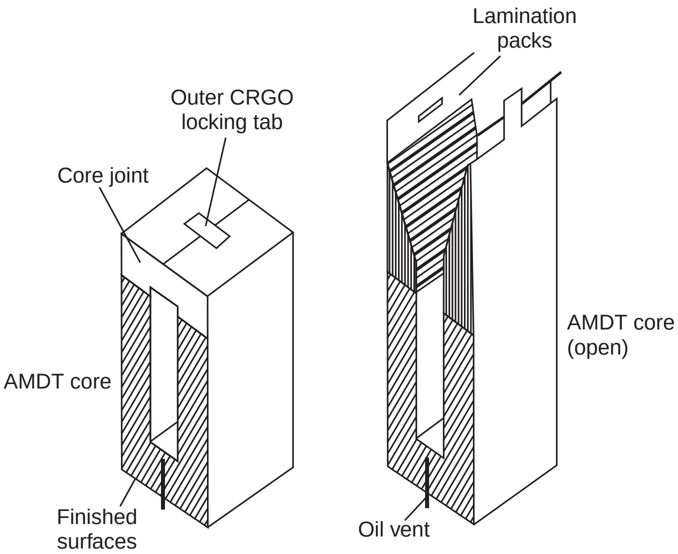


Fig. 4.5. AMDT core

The location of pressboard insulating paper, winding, spacer block, core framing channel, mounting bracket etc. are shown.

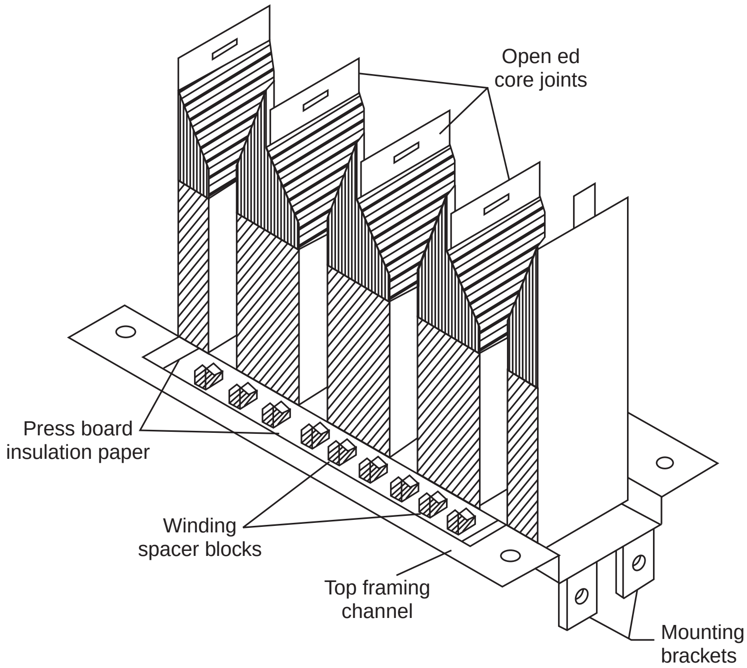


Fig. 4.6. AMDT core/coil assembly (core joints open, ready for coil installation)

The next operation is to insert LV/HV coils from the top as shown in Fig. 4.7. The coils must rest at the bottom support as indicated. The winding leads are shown coming out through the holes of the channel.

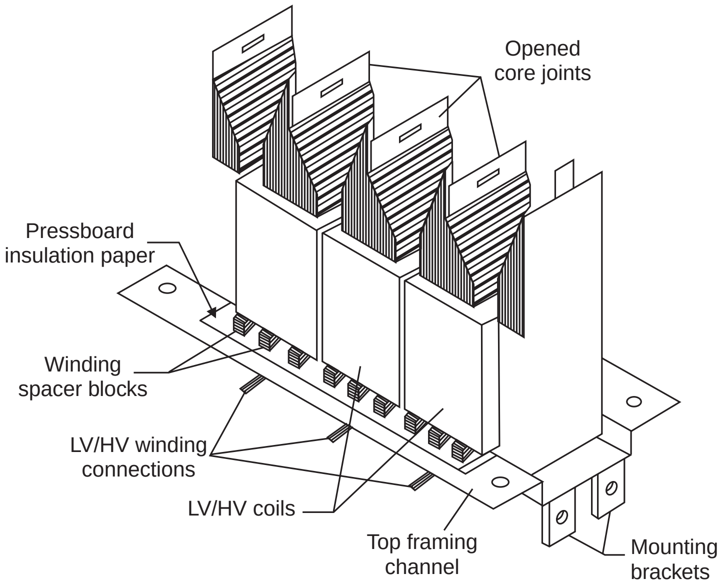


Fig. 4.7. AMDT core/coil assembly (core joints open, LV/HV coils installed)

Figure 4.8 indicates the re-blading of top laminations to their original settings. Pressboard insulations as per design requirements are placed at the top.

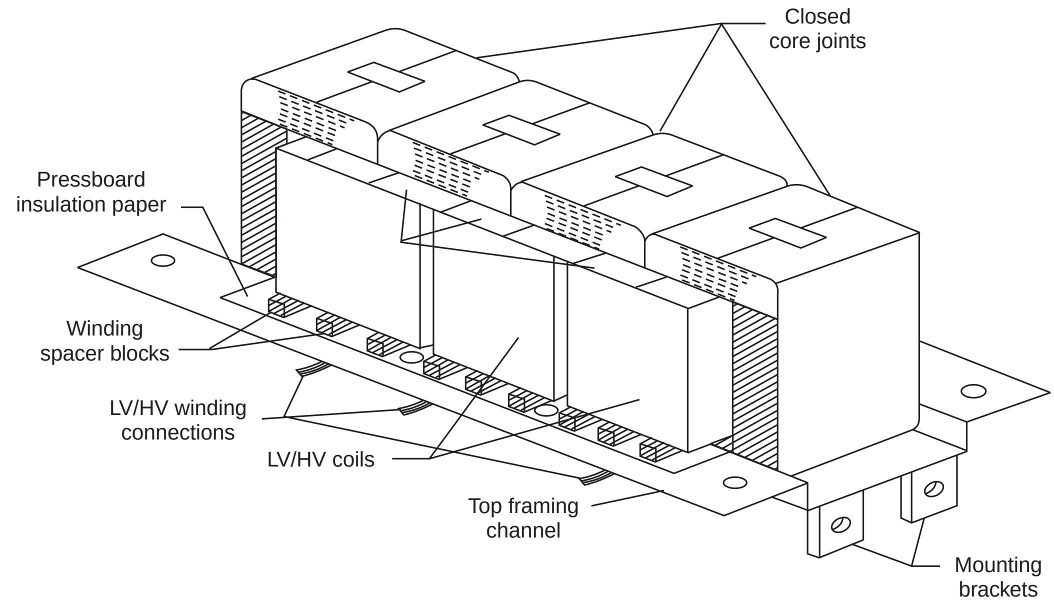


Fig. 4.8. AMDT core/coil assembly (core joints closed, LV/HV coils installed)

The placement of winding spacer blocks and framing channel insulation are shown in Fig. 4.9.

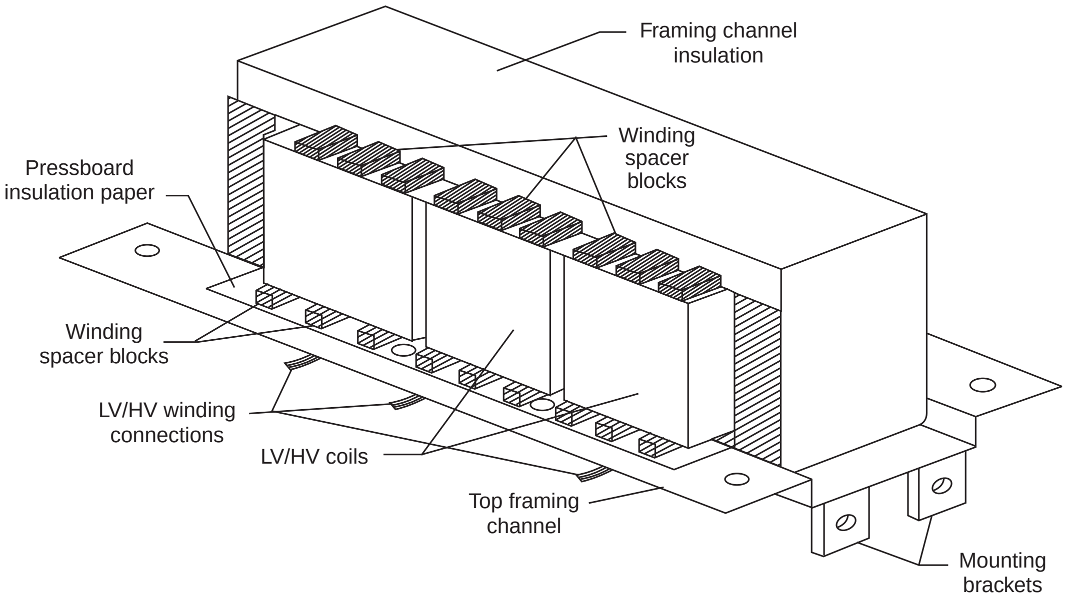


Fig. 4.9. AMDT core/coil assembly (core/coil assembled—final framing)

AMDT core-coil assembly is usually made in up-side down, *i.e*. inverted condition. Fig. 4.10 shows the arrangement of bottom framing channel with the tie rods in position.

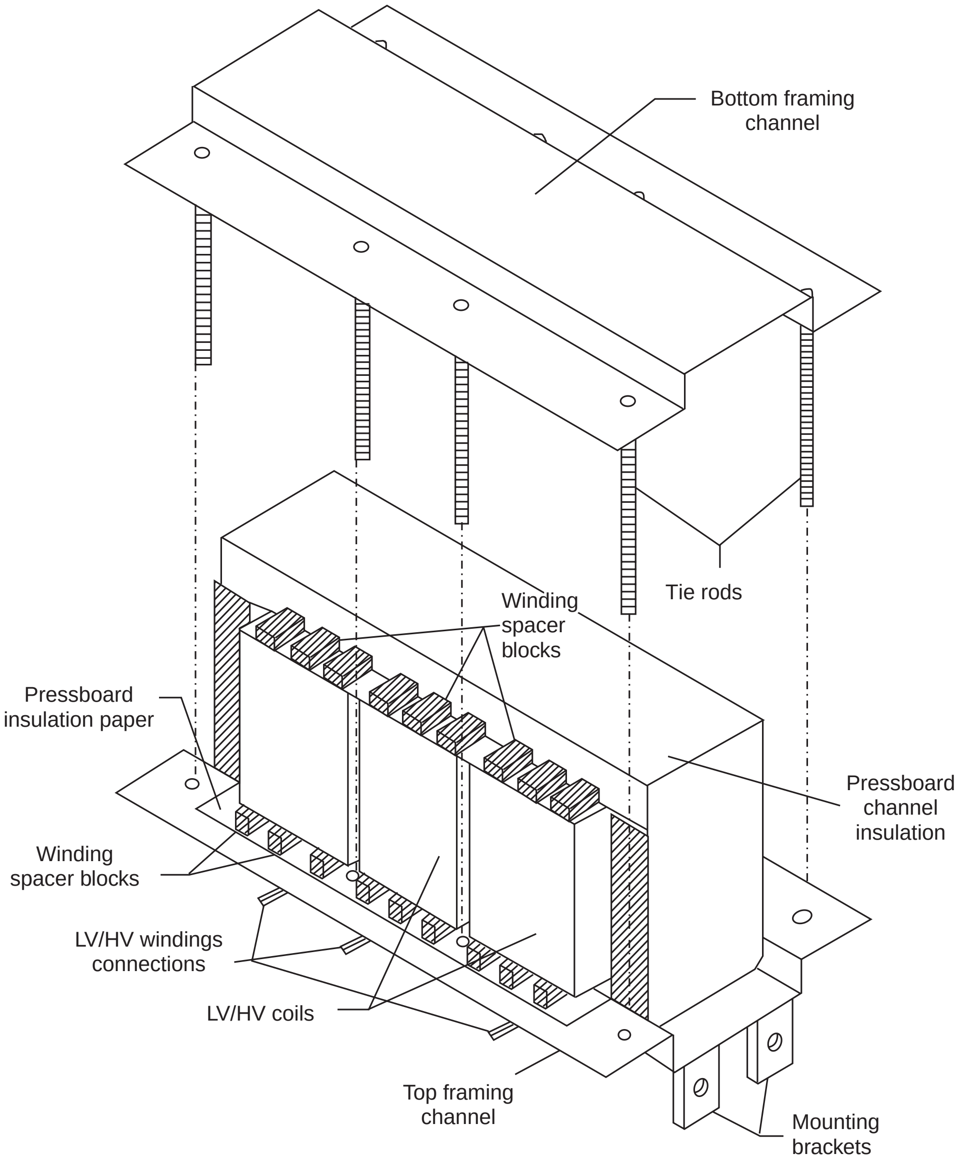


Fig. 4.10. AMDT core/coil assembly (final framing fixture)

Figure 4.11 shows the clamped core-coil assembly with tie rods holding both bottom and top framing channels.

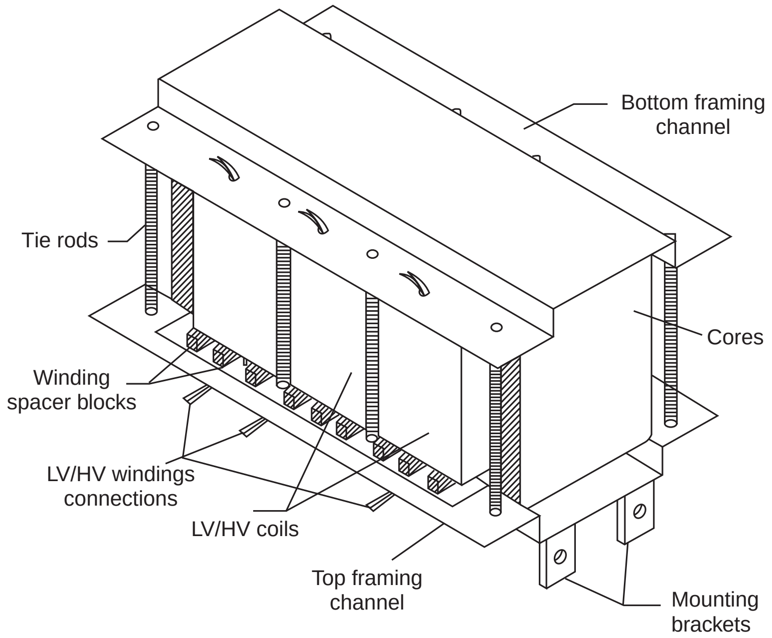


Fig. 4.11. AMDT core/coil assembly (core joint on top)

As described above, the usual practice is to assemble the AMDT coil in bottom-up/top-down condition. Now it is the time to invert the assembly, *i.e.* top-up/bottom-down as indicated in Fig. 4.12.

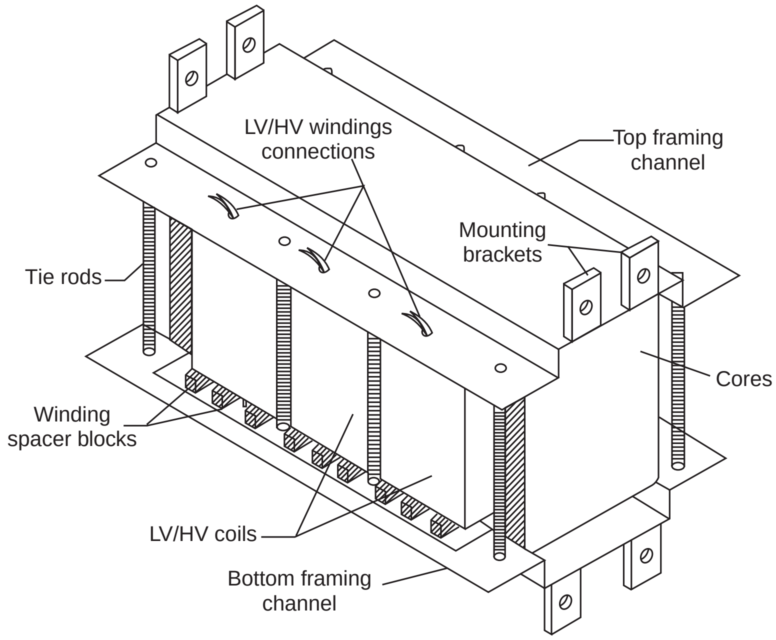


Fig. 4.12. AMDT core/coil final assembly position (core joint on bottom)

Figure 4.13 shows all the manufacturing stages right from AMDT core upto the final core assembly in sequential order.

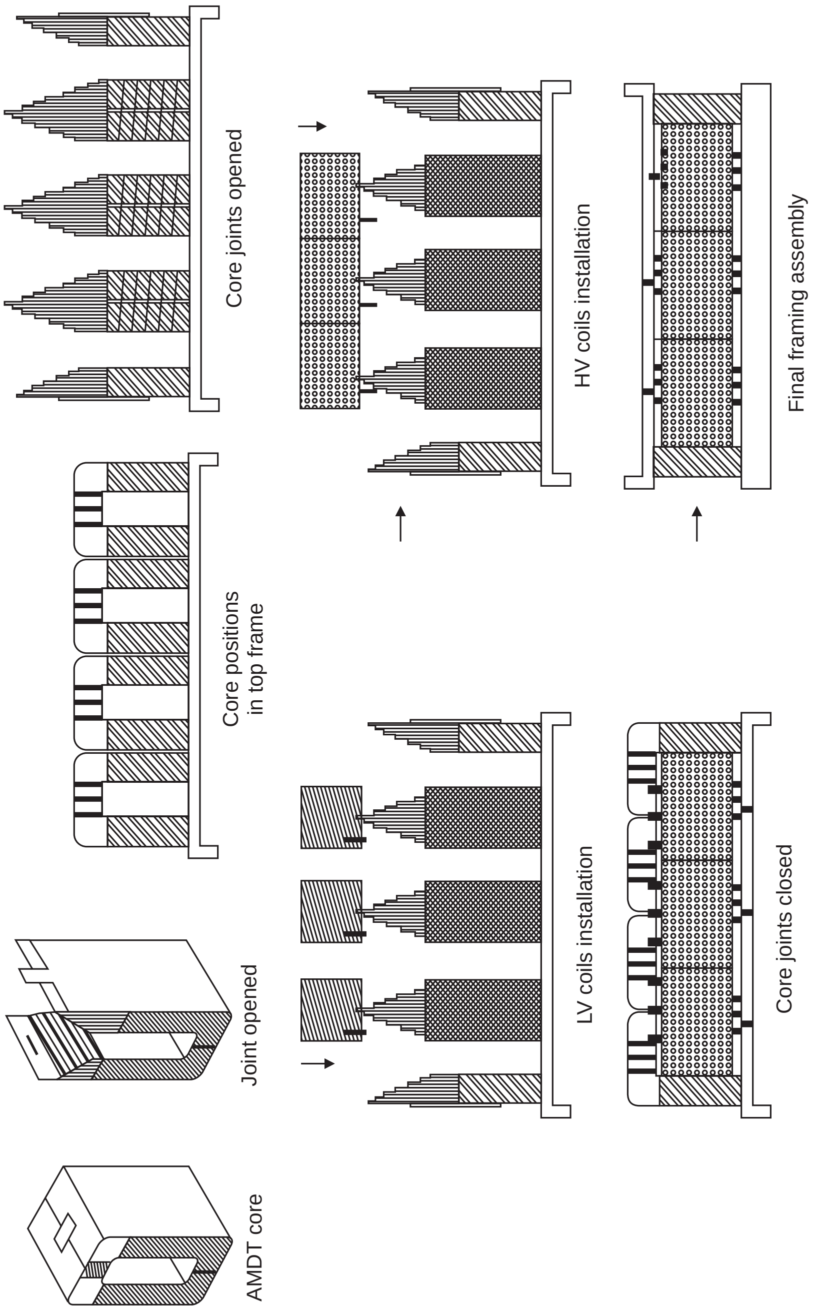


Fig. 4.13. 5 Leg-AMDT core and coil assembly

4.13 QUALITY CHECKS OF CRGO LAMINATIONS

So far we discussed the selection of grades of CRGO material, their processing, cutting, mitring notching and other constructional features. We shall now discuss in brief the systematic approach to quality checks on processed laminations.

4.13.1 Surface Conditions

The laminations should be reasonably free from surface defects such as holes, scabs, blisters, silver spots, dents, rust and other harmful defects. The coating should be smooth and uniform, and free from dust. It should be sufficiently adherent during processing and should be compatible with hot transformer oil.

4.13.2 Finish, Workmanship and Appearance

Sharp and short waves and buckles are extremely detrimental to the effective use of grain oriented electrical steel. Burrs on the cut and slit edges should be limited to 40 microns. Camber should be as minimum as possible.

4.13.3 Tolerance on Dimensions

(*i*) **Thickness:** Though ISS has recommended an acceptable tolerance on thickness as ±0.025 mm, for all practical purposes the tolerance should be ±0.025 mm to have effective control on the uniformity of the overall core stack/diameter.

(*ii*) **Width:** The width of materials supplied either as slit rolls or cut lengths shall be as close as possible to the ordered width, and in no case should the maximum deviation from the specified width exceed the values given in IS-3024 (Table 6) which is reproduced in Table 4.2.

Table 4.2

Specified width		*Width tolerance*	
Over	*Up to and including*	*Over (+)*	*Under (–)*
–	100 mm	(+) 0.15 mm	(–) 0.15 mm
100 mm	230 mm	(+) 0.2 mm	(–) 0.2 mm
230 mm	380 mm	(+) 0.25 mm	(–) 0.25 mm
380 mm	580 mm	(+) 0.4 mm	(–) 0.4 mm
580 mm	–	(+) 0.5 mm	(–) 0.5 mm

The CRGO steel processors should be aware of the above tolerance limits to enable them to keep rigid checks while slitting the mother coils to baby hoops. Width beyond tolerance will create unwanted air gaps during assembly, resulting in high no-load loss and current. Further, both the processors and the users should have requisite calibrated gauges (like vernier, micrometer, scale etc.) of adequate sizes to make them able to measure the width within tolerance limits.

(*iii*) **Length:** ISS is silent over tolerance on length below 500 mm. For all practical purposes, the length should be as close as possible to the ordered length, but in no case should the maximum deviation from the specified length exceed the values as given in Table 4.3.

Table 4.3

Specified length		*Length tolerance*	
Over	***Upto and including***	***Over (+)***	***Under (–)***
–	300 mm	(+) 0.5 mm	(–) 0.5 mm
300 mm	700 mm	(+) 0.75 mm	(–) 0.75 mm
700 mm	1100 mm	(+) 1.0 mm	(–) 1.0 mm
1100 mm	1500 mm	(+) 1.25 mm	(–) 1.25 mm

(*iv*) **Cutting angle:** Tolerance on cutting angle shall be limited to ± 0.5°. Necessary protractor should be made available for measuring such cutting angles with tolerance.

(*v*) **Out of square (cut length):** The deviation of an edge from a straight line placed at right angle to the side touching one corner and extending to the other side, shall not exceed 2 mm over 150 mm width or fraction thereof.

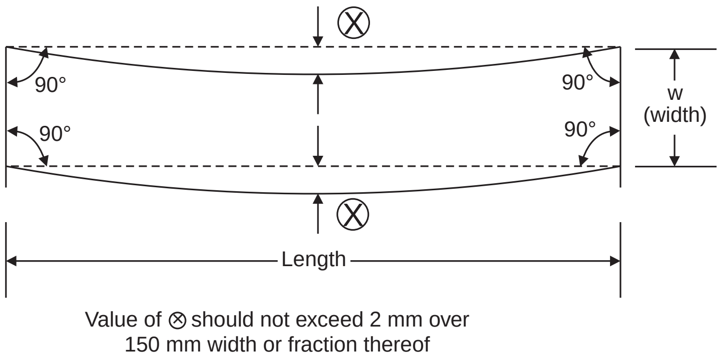


Fig. 4.14. Out of square

4.14 CHECKS ON SPECIFIC LOSS (watt/kg)

Specific loss, *i.e.*, loss per kg of the mother coil, is generally known from the test certificates provided by the mills. But the transformer manufacturers are keen to know the watt loss per kg at the designed flux density on the processed laminations, since this would give the correct value of ‘handling factor’ which includes all the deteriorations the laminations had suffered during slitting, shearing, notching as well as due to human errors and workmanship.

To measure such losses, ISS has recommeded to check through Epstein Test Frame. It need not be elaborated further here, since IS-649 gives all the related informations with constructional details of such test frames.

Refer Figs. 4.15 to 4.26 for the relationship between core loss and induction for various grades of laminations.

4.15 SELECTION OF SPECIFIC GRADE OF CRGO LAMINATION

As stated earlier, various grades of CRGO steel laminations with different thicknesses are available in the market and some of the widely available grades are given in Table 4.4.

Table 4.4

Conventional grade	*HI-B grade*	*Lazer grade*
M6—0.35 mm	MOH—0.27mm	ZDMH-95—0.27 mm
M5—0.30 mm	MOH—0.23 mm	ZDMH-90—0.27 mm
M4—0.27 mm		ZDMH-90—0.23 mm
M3—0.23 mm		ZDMH-85—0.23 mm

Various other grades of CRGO laminations are also available which have not been mentioned here. CRGO steel is basically an imported material and is not produced in India in large scale. We therefore need to ascertain the availability of the particular grade of material in the market before selecting it for use.

For acceptable performance figures of no-load loss, no-load current, working flux density etc. the designer should select a suitable grade of CRGO lamination from the grades readily available in the market. The word 'readily available' has great importance, since we must ensure the timely availability of the materials on demand. These days 'timely delivery' is also considered to be a part of quality assurance. Quality products with delayed delivery is not appreciated by any customer.

4.16 CONCLUSION

To conclude the discussion on CRGO laminations, a brief table is given below for ready reference on few aspects of quality assurance.

Table 4.5

Particulars	***Quality checks***
Surface conditions	Free from surface defects, hole, scab, blister, silver spot, dent, rust and other harmful defects such as non-uniform insulating surface coating on either side of the lamination.
Finished workmanship and appearance	Free from sharp and short waves, buckles etc. with minimum burrs in the slit and cut edges. Camber should be appreciably low.
Thickness tolerance	(+) or (–) 0.0125 mm over guaranteed value.
Tolerance on width	< 100 mm ± 0.15 mm > 100 mm < 230 mm ± 0.2 mm > 230 mm < 380 mm ± 0.25 mm > 380 mm < 580 mm ± 0.4 mm > 580 mm ± 0.5 mm
Tolerance on length	< 300 mm ± 0.5 mm > 300 mm < 700 mm ± 0.75 mm > 700 mm <1100 mm ± 1.0 mm > 1100 mm < 1500 mm ± 1.5 mm
Tolerance on cutting angle	Should be limited to ± 0.5° on the declared angle.
Out of square (cut length)	2 mm over 150 mm width or fraction thereof.
Checks on specific loss *i.e.* watts/kg	Recommended to check through epstein test frame and the values should match the mills certificates.
Selection of specific grade of CRGO	To select on the basis of no-load loss, no load current and permissible maximum flux density. Market availability on demand should also be considered while selecting a specific grade of material.

The discussion above provides a general guideline to the CRGO processors and transformer manufacturers to produce a better product. In case the materials beyond tolerance limits are used, the performance of the transformer will be adversly affected.

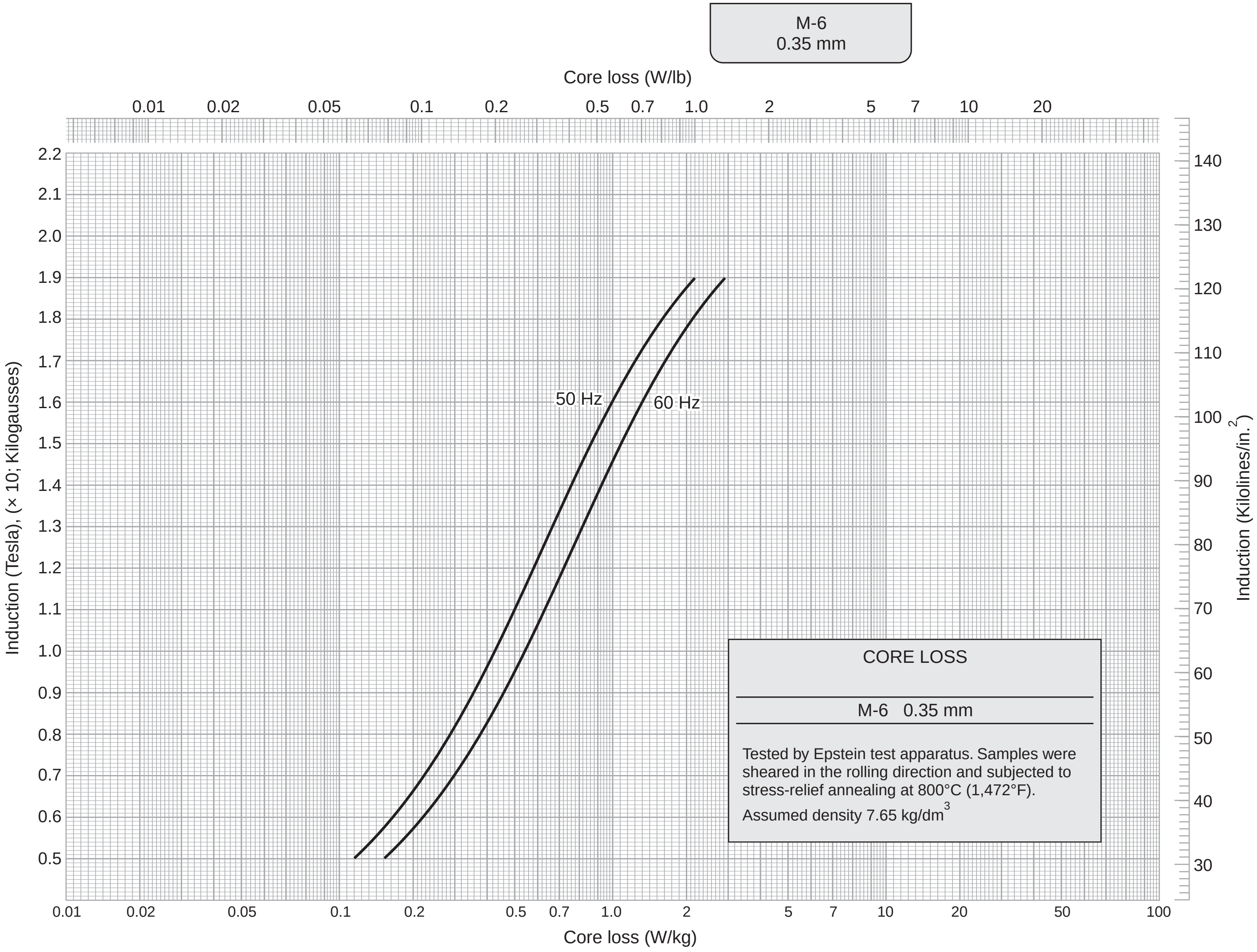

M-6
0.35 mm
Core loss (W/lb)
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20
Induction (Tesla), (× 10; Kilogausses)
2.2 2.1 2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5
Induction (Kilolines/in.²)
140 130 120 110 100 90 80 70 60 50 40 30
50 Hz
60 Hz
CORE LOSS
M-6 0.35 mm
Tested by Epstein test apparatus. Samples were sheared in the rolling direction and subjected to stress-relief annealing at 800°C (1,472°F).
Assumed density 7.65 kg/dm³
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20 50 100
Core loss (W/kg)

Fig. 4.15

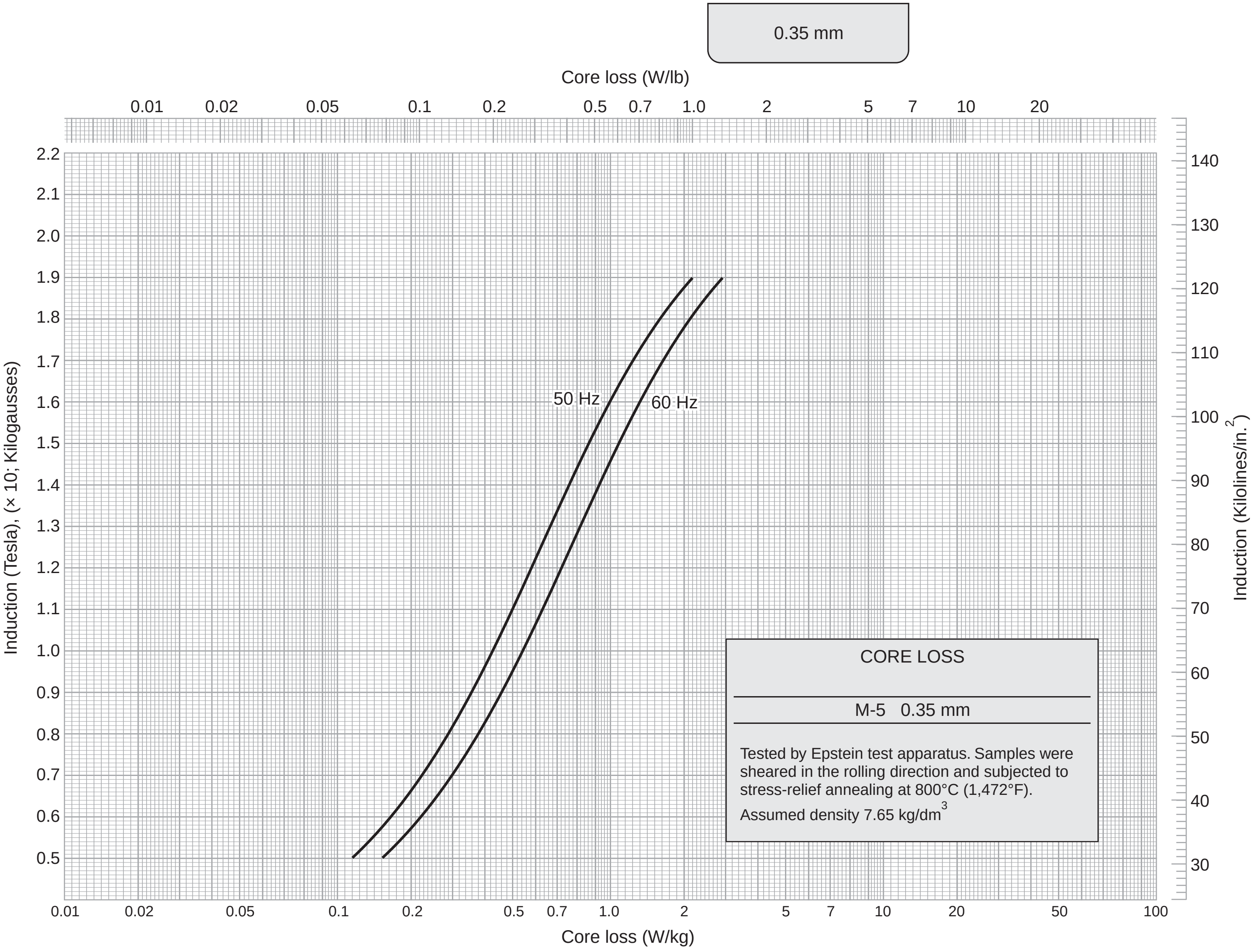

0.35 mm
Core loss (W/lb)
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20
Induction (Tesla), (× 10; Kilogausses)
2.2 2.1 2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5
Induction (Kilolines/in.²)
140 130 120 110 100 90 80 70 60 50 40 30
50 Hz
60 Hz
CORE LOSS
M-5 0.35 mm
Tested by Epstein test apparatus. Samples were sheared in the rolling direction and subjected to stress-relief annealing at 800°C (1,472°F).
Assumed density 7.65 kg/dm³
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20 50 100
Core loss (W/kg)

Fig. 4.16

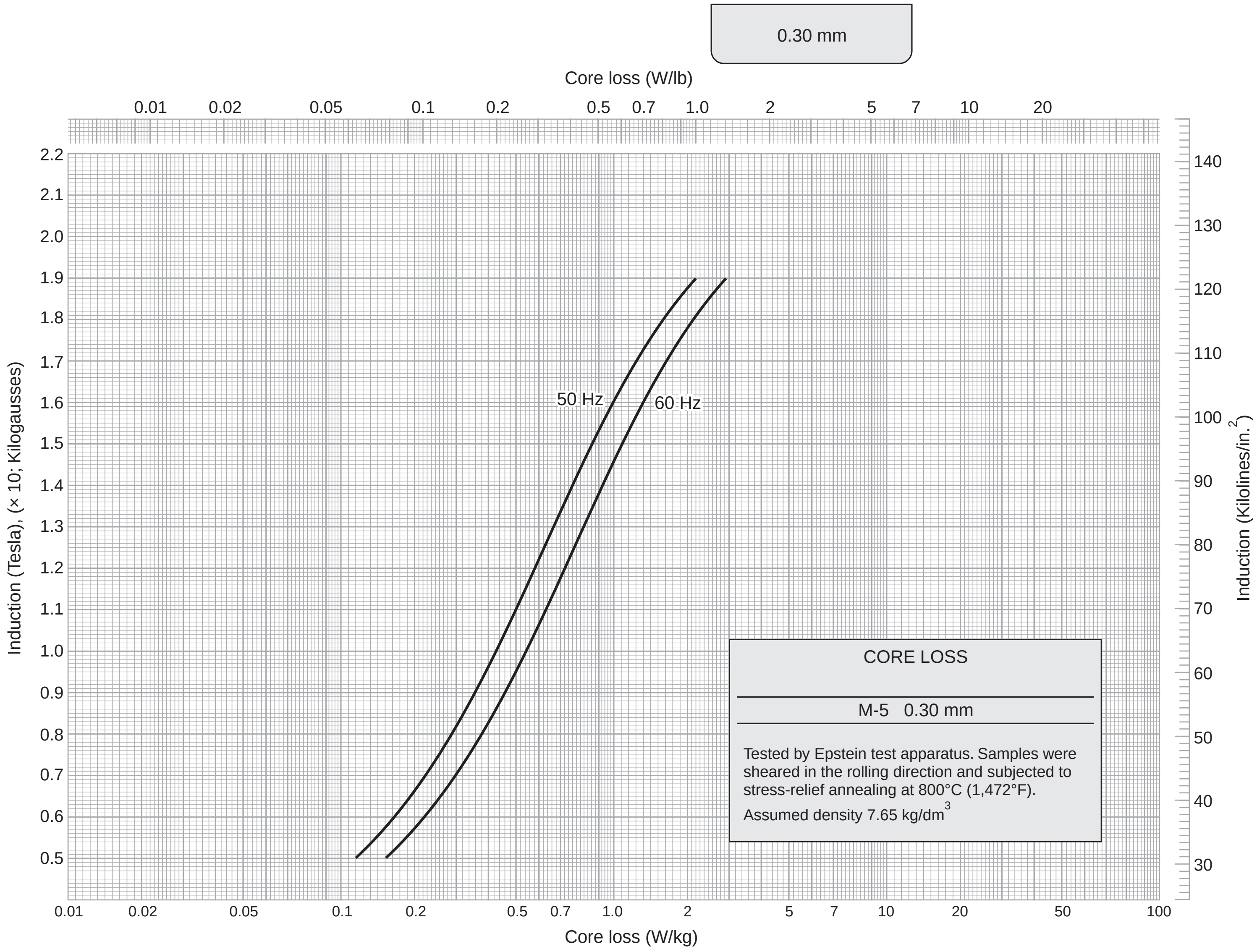

0.30 mm
Core loss (W/lb)
Induction (Tesla), (× 10; Kilogausses)
Induction (Kilolines/in.^{2})
50 Hz
60 Hz
CORE LOSS
M-5 0.30 mm
Tested by Epstein test apparatus. Samples were sheared in the rolling direction and subjected to stress-relief annealing at 800°C (1,472°F).
Assumed density 7.65 kg/dm^3
Core loss (W/kg)

Fig. 4.17

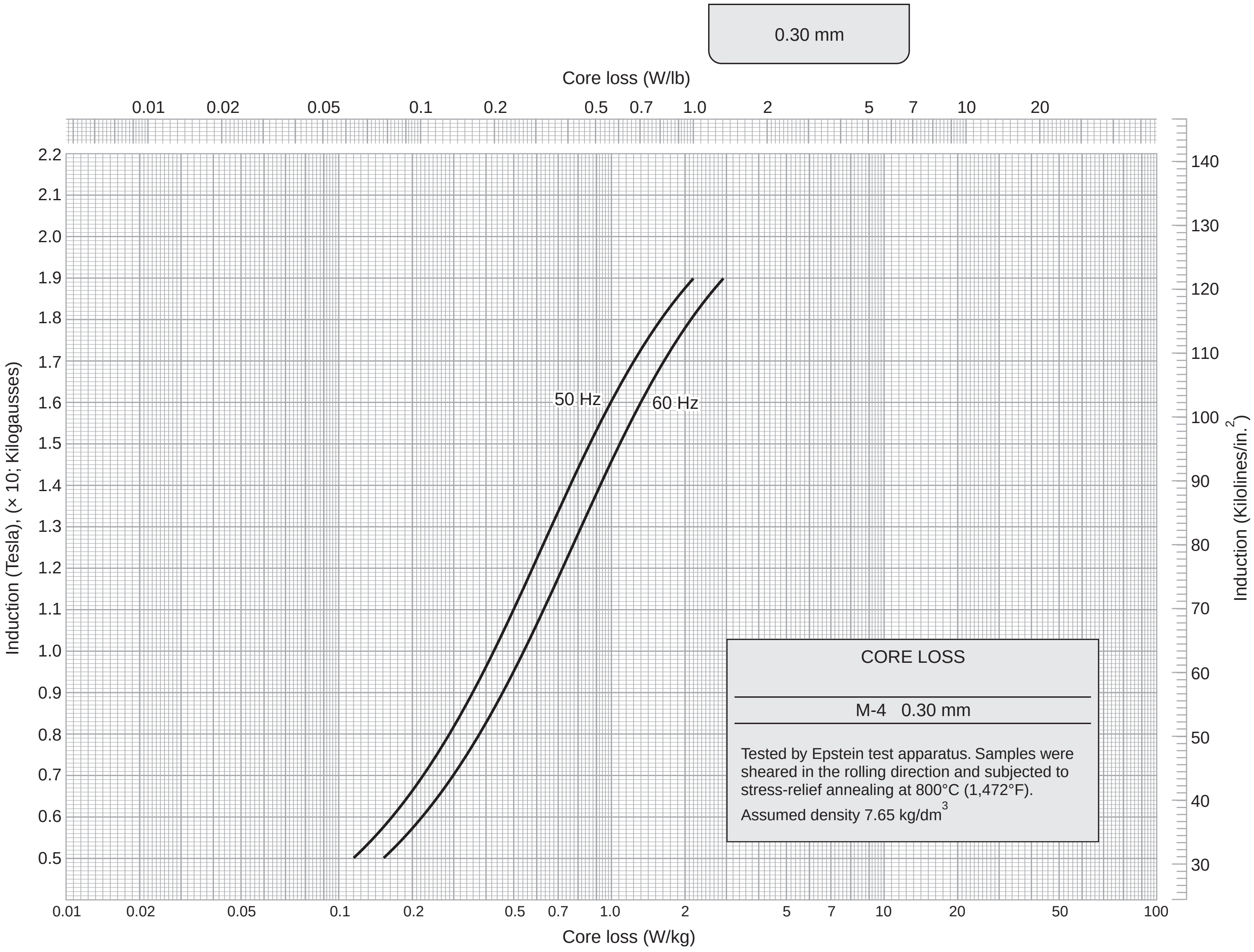

0.30 mm
Core loss (W/lb)
0.01
0.02
0.05
0.1
0.2
0.5
0.7
1.0
2
5
7
10
20
Induction (Tesla), (× 10; Kilogausses)
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
50 Hz
60 Hz
CORE LOSS
M-4 0.30 mm
Tested by Epstein test apparatus. Samples were sheared in the rolling direction and subjected to stress-relief annealing at 800°C (1,472°F).
Assumed density 7.65 kg/dm3
140
130
120
110
100
90
80
70
60
50
40
30
Induction (Kilolines/in.2)
0.01
0.02
0.05
0.1
0.2
0.5
0.7
1.0
2
5
7
10
20
50
100
Core loss (W/kg)

Fig. 4.18

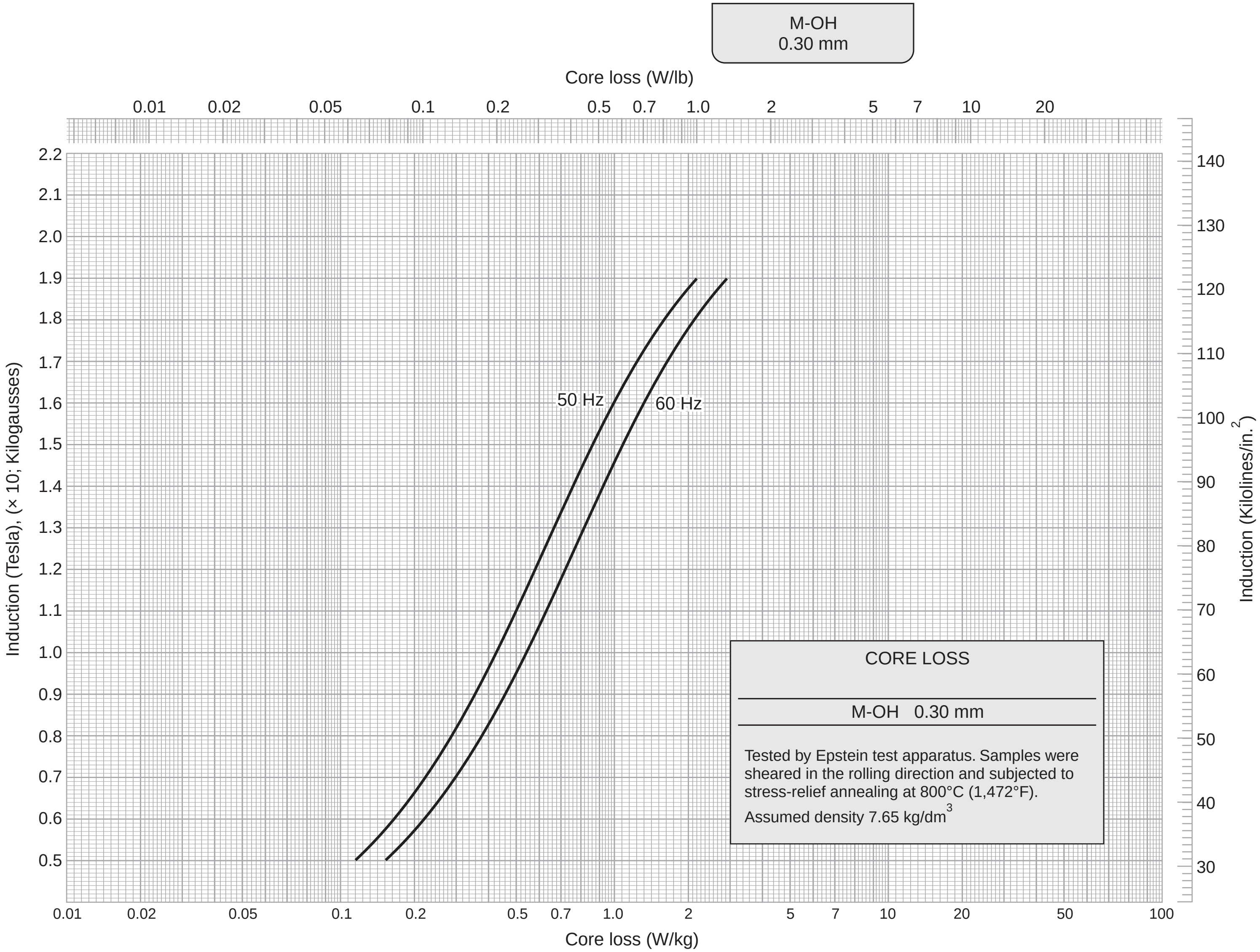

M-OH
0.30 mm
Core loss (W/lb)
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20
Induction (Tesla), (× 10; Kilogausses)
2.2 2.1 2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5
Induction (Kilolines/in.^{2})
140 130 120 110 100 90 80 70 60 50 40 30
50 Hz
60 Hz
CORE LOSS
M-OH 0.30 mm
Tested by Epstein test apparatus. Samples were sheared in the rolling direction and subjected to stress-relief annealing at 800°C (1,472°F).
Assumed density 7.65 kg/dm^3
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20 50 100
Core loss (W/kg)

Fig. 4.19

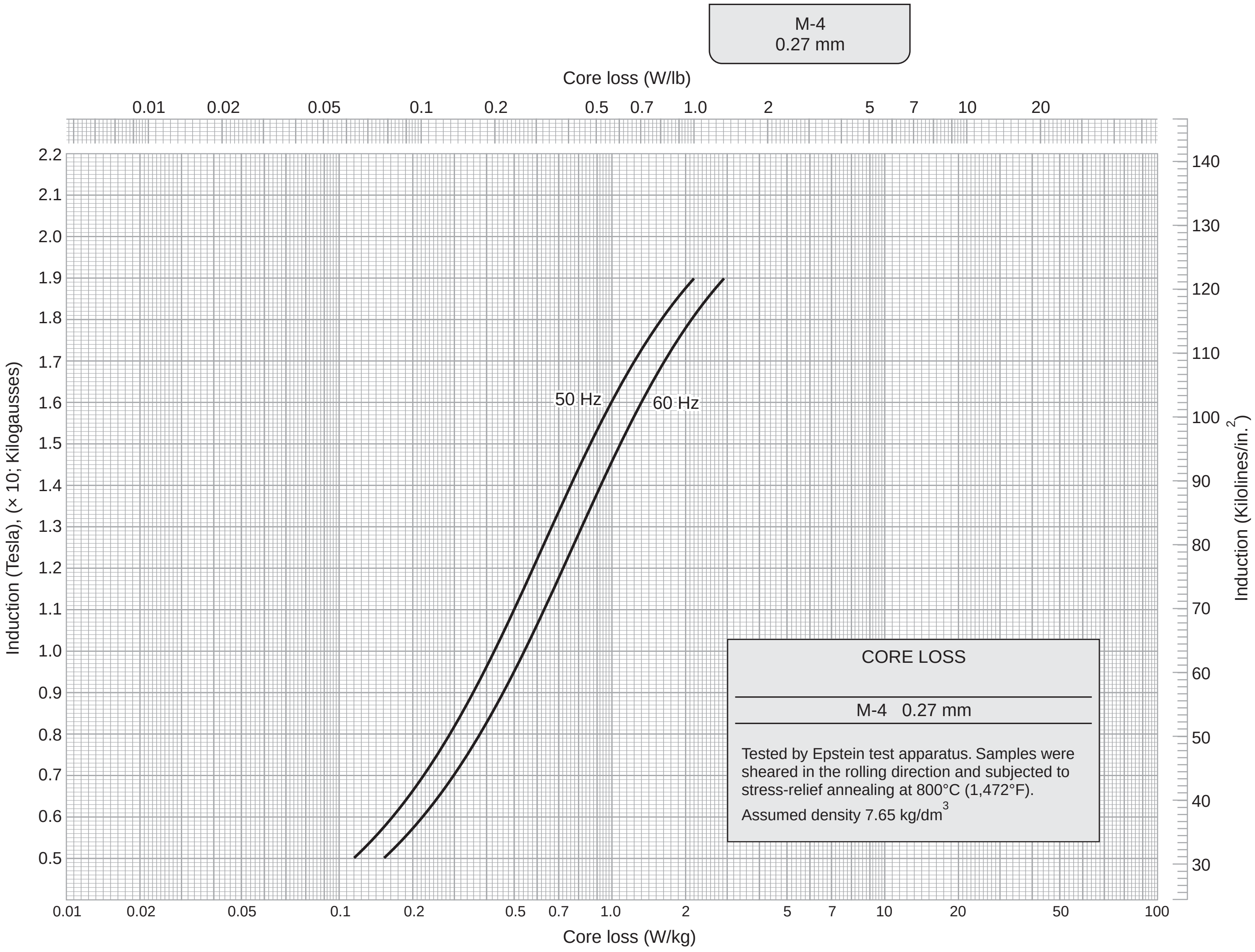

M-4
0.27 mm
Core loss (W/lb)
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20
Induction (Tesla), (× 10; Kilogausses)
2.2 2.1 2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5
Induction (Kilolines/in.²)
140 130 120 110 100 90 80 70 60 50 40 30
50 Hz
60 Hz
CORE LOSS
M-4 0.27 mm
Tested by Epstein test apparatus. Samples were sheared in the rolling direction and subjected to stress-relief annealing at 800°C (1,472°F).
Assumed density 7.65 kg/dm³
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20 50 100
Core loss (W/kg)

Fig. 4.20

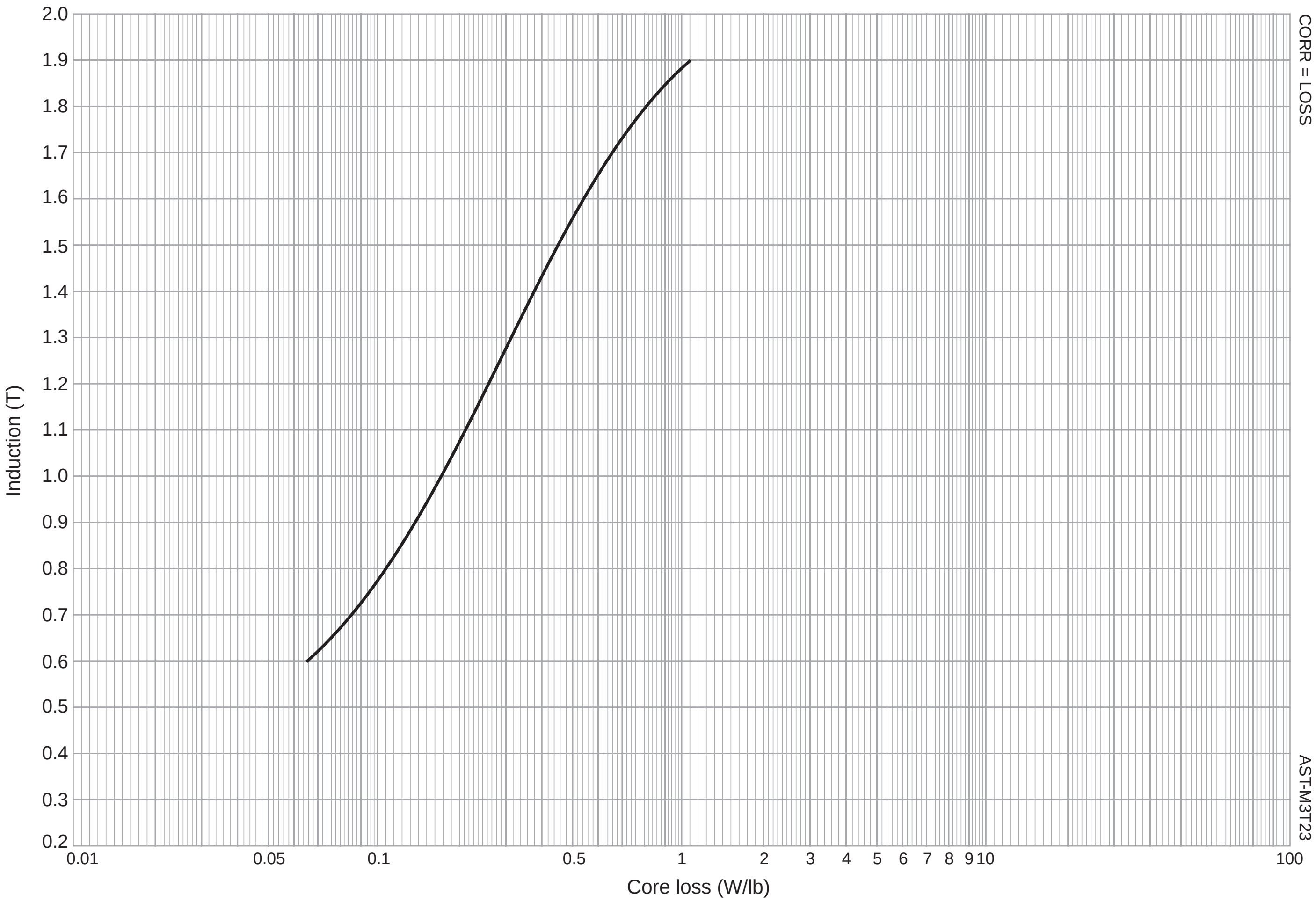

Induction (T)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.01
0.05
0.1
0.5
1
2
3
4
5
6
7
8
9
10
100
Core loss (W/lb)
CORR = LOSS
AST-M3T23

Fig. 4.21

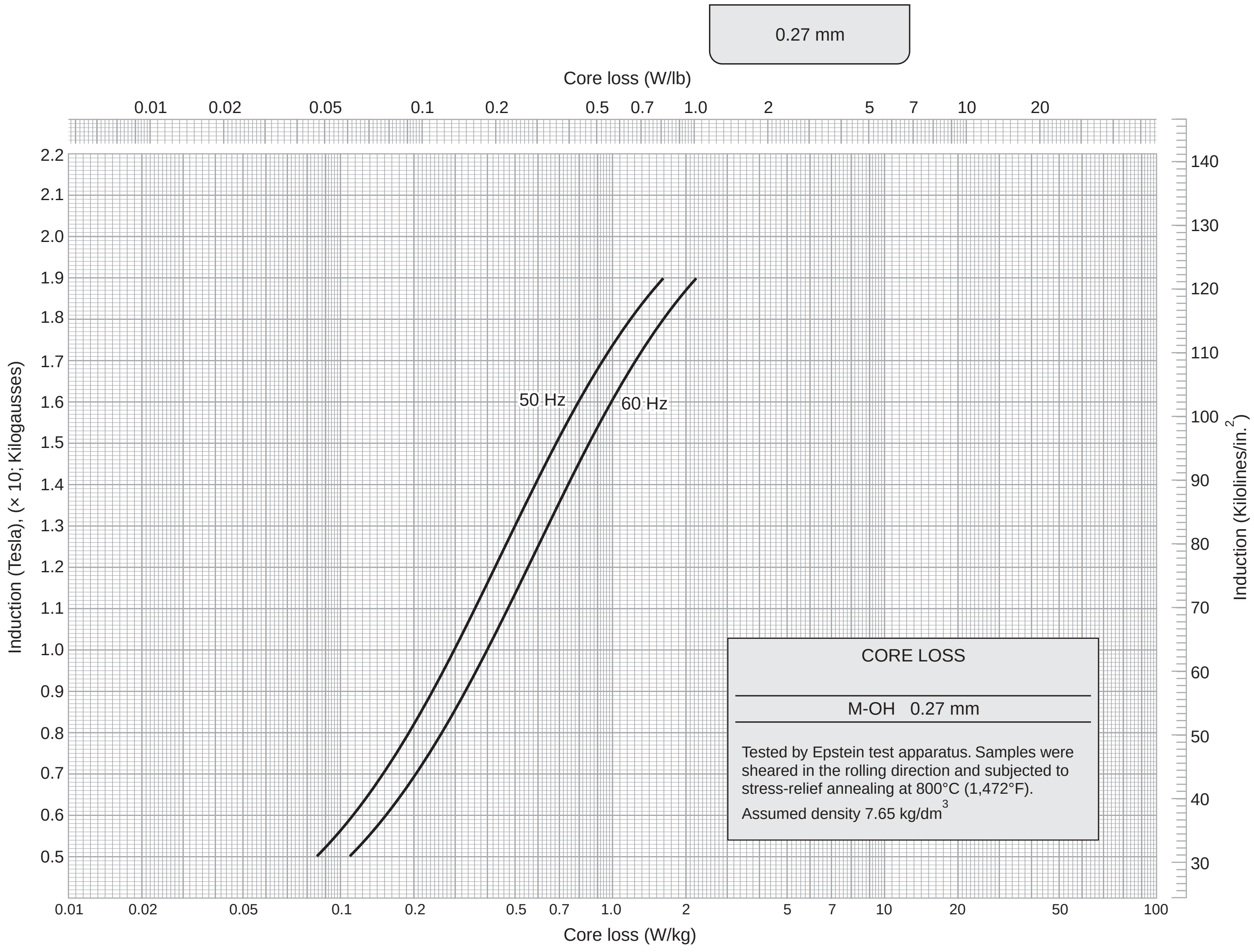

0.27 mm
Core loss (W/lb)
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20
Induction (Tesla), (× 10; Kilogausses)
2.2 2.1 2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5
Induction (Kilolines/in.²)
140 130 120 110 100 90 80 70 60 50 40 30
50 Hz
60 Hz
CORE LOSS
M-OH 0.27 mm
Tested by Epstein test apparatus. Samples were sheared in the rolling direction and subjected to stress-relief annealing at 800°C (1,472°F).
Assumed density 7.65 kg/dm³
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20 50 100
Core loss (W/kg)

Fig. 4.22

M-OH
0.23 mm

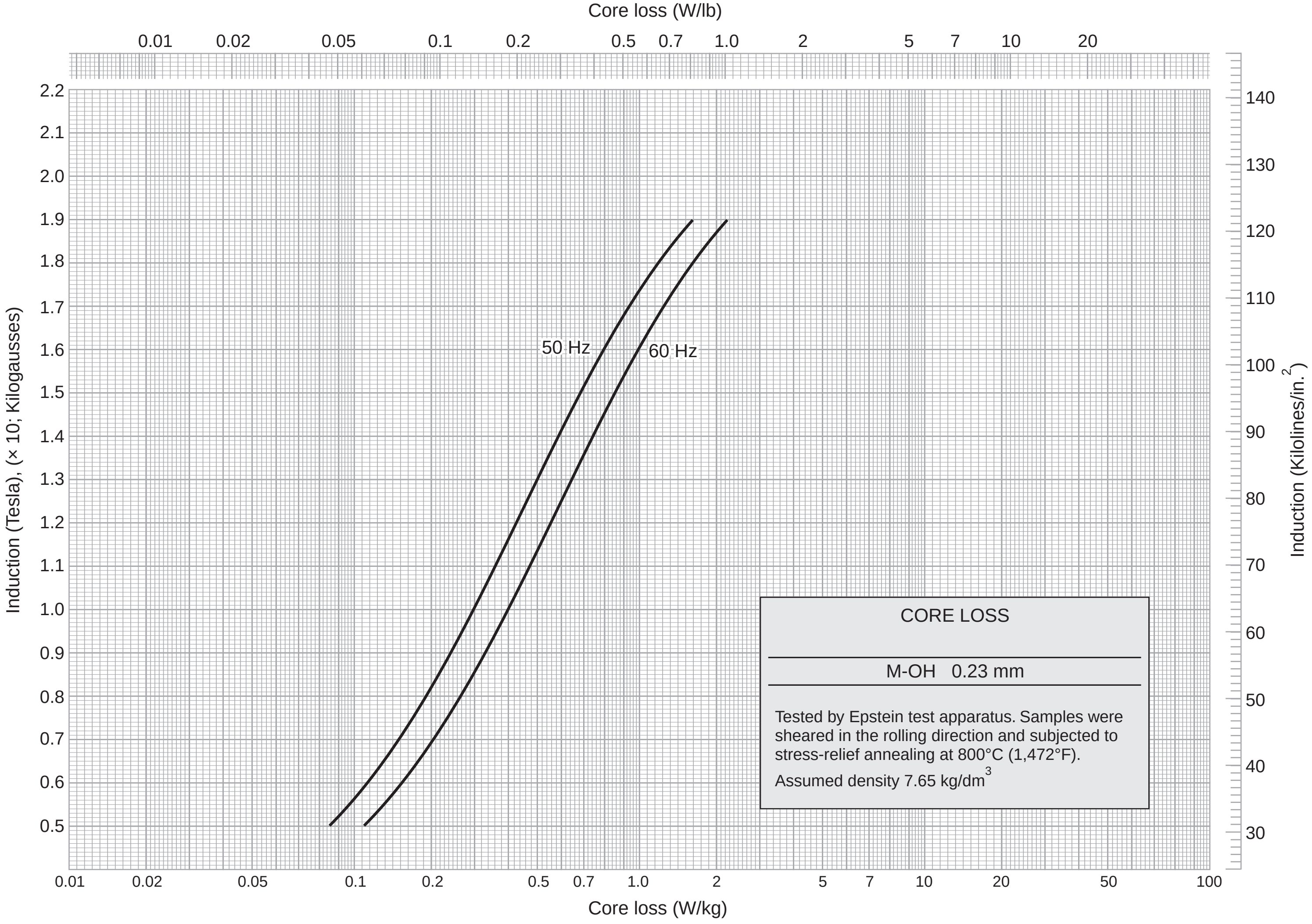


Fig. 4.23

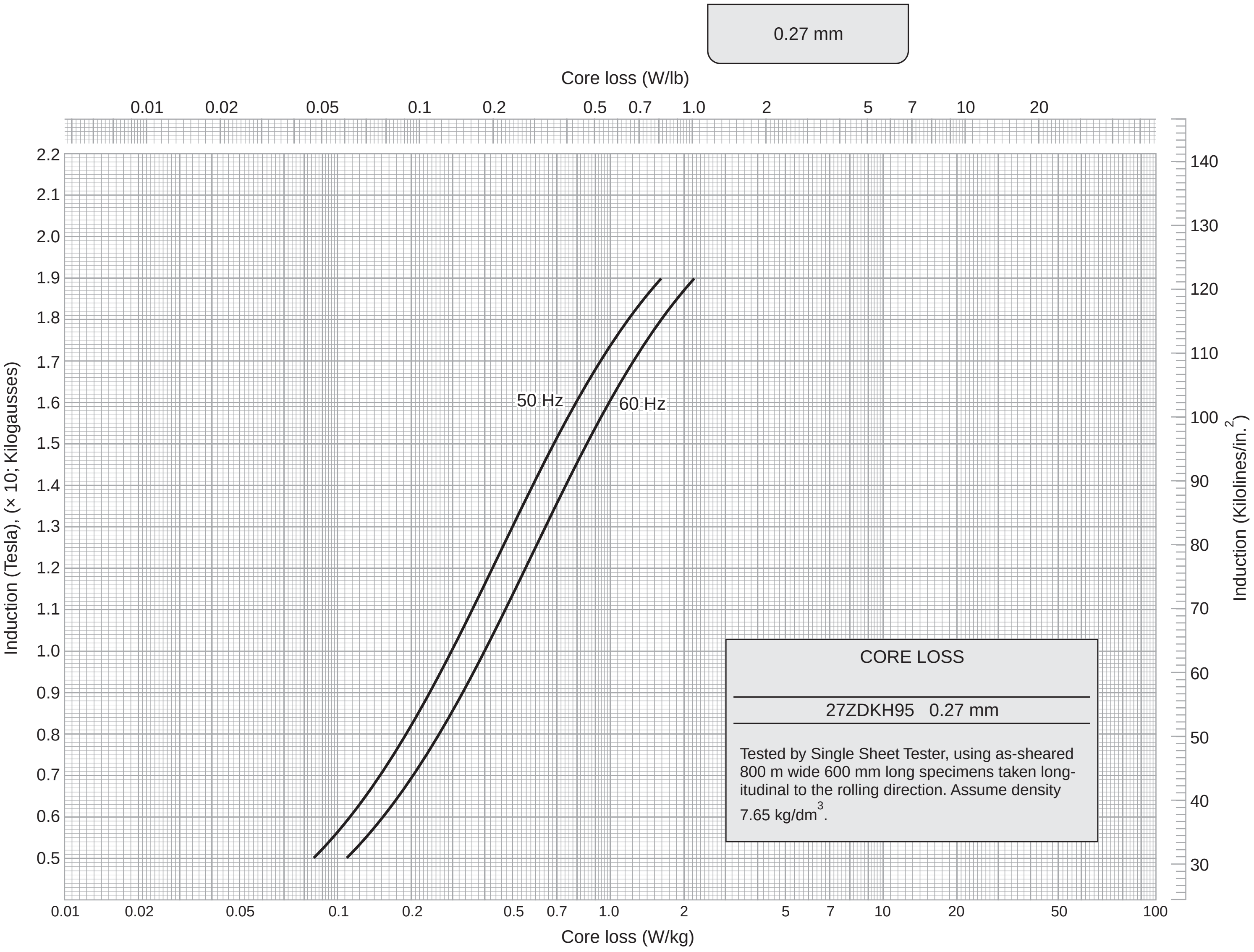

0.27 mm
Core loss (W/lb)
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20
Induction (Tesla), (× 10; Kilogausses)
2.2 2.1 2.0 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5
Induction (Kilolines/in.²)
140 130 120 110 100 90 80 70 60 50 40 30
50 Hz
60 Hz
CORE LOSS
27ZDKH95 0.27 mm
Tested by Single Sheet Tester, using as-sheared 800 m wide 600 mm long specimens taken long-itudinal to the rolling direction. Assume density 7.65 kg/dm³.
0.01 0.02 0.05 0.1 0.2 0.5 0.7 1.0 2 5 7 10 20 50 100
Core loss (W/kg)

Fig. 4.24

0.23 mm

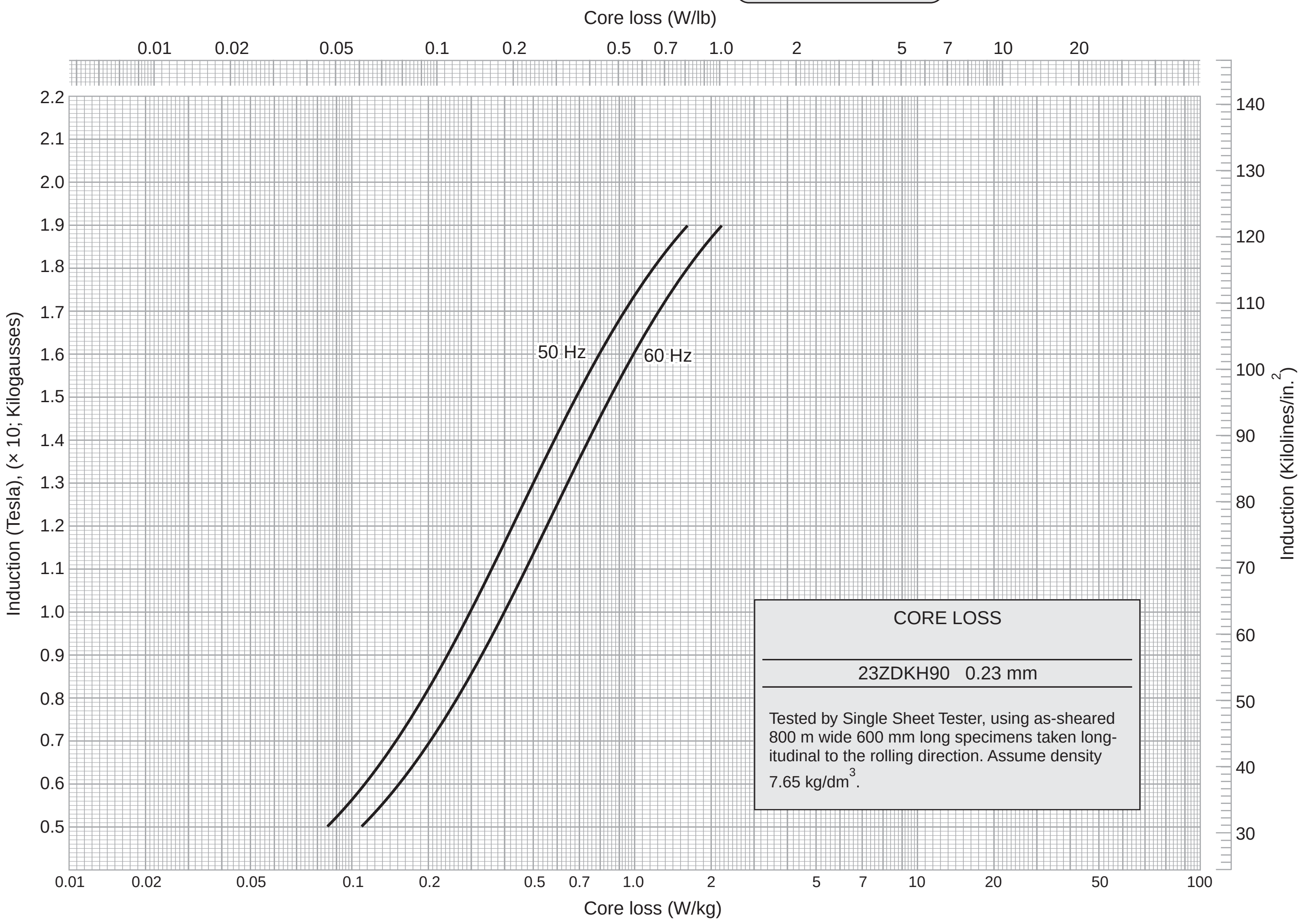
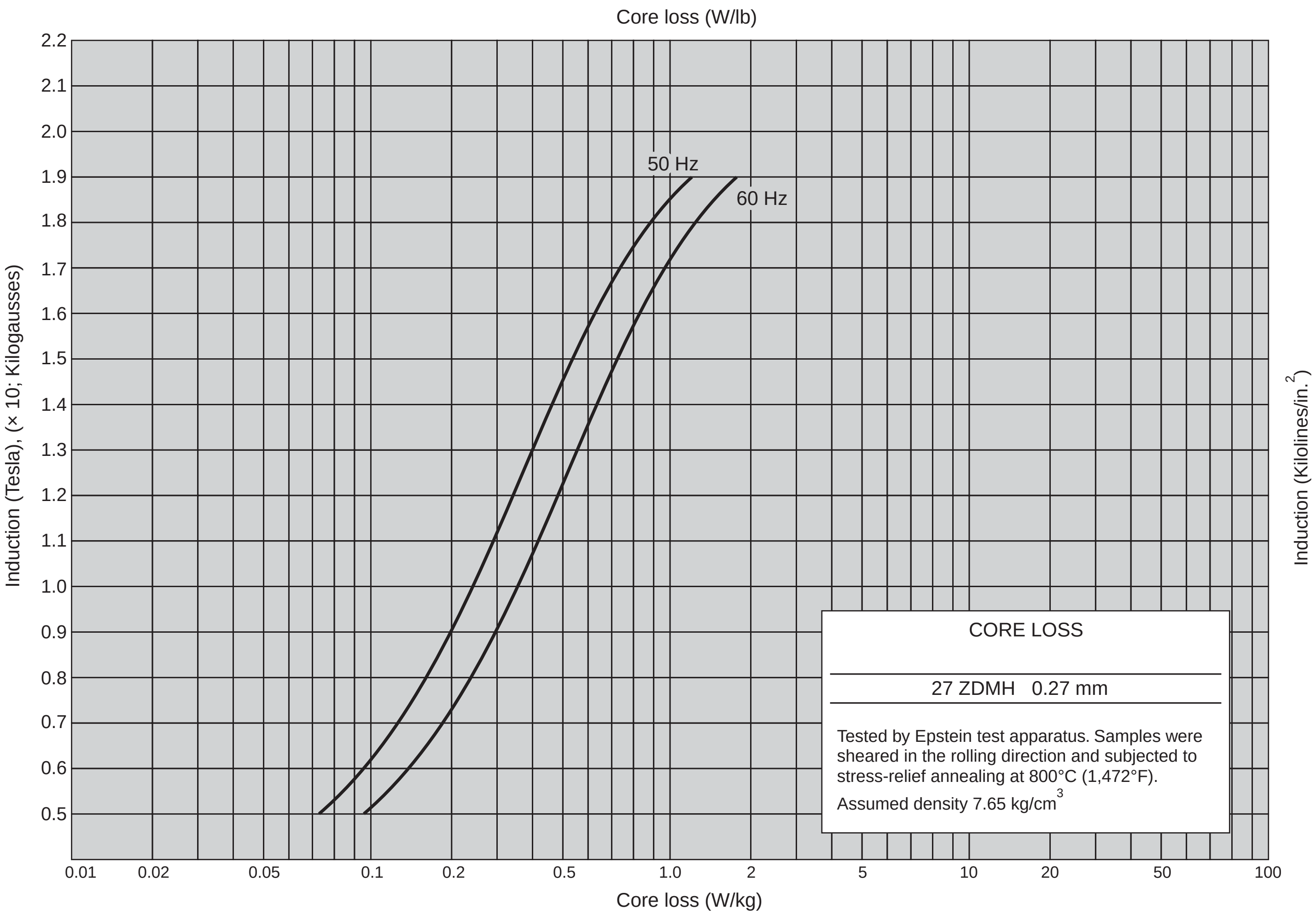


Fig. 4.25



Core loss (W/lb)
Induction (Tesla), (× 10; Kilogausses)
Induction (Kilolines/in.²)
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
50 Hz
60 Hz
0.01
0.02
0.05
0.1
0.2
0.5
1.0
2
5
10
20
50
100
Core loss (W/kg)
CORE LOSS
27 ZDMH 0.27 mm
Tested by Epstein test apparatus. Samples were sheared in the rolling direction and subjected to stress-relief annealing at 800°C (1,472°F).
Assumed density 7.65 kg/cm³

Fig. 4.26

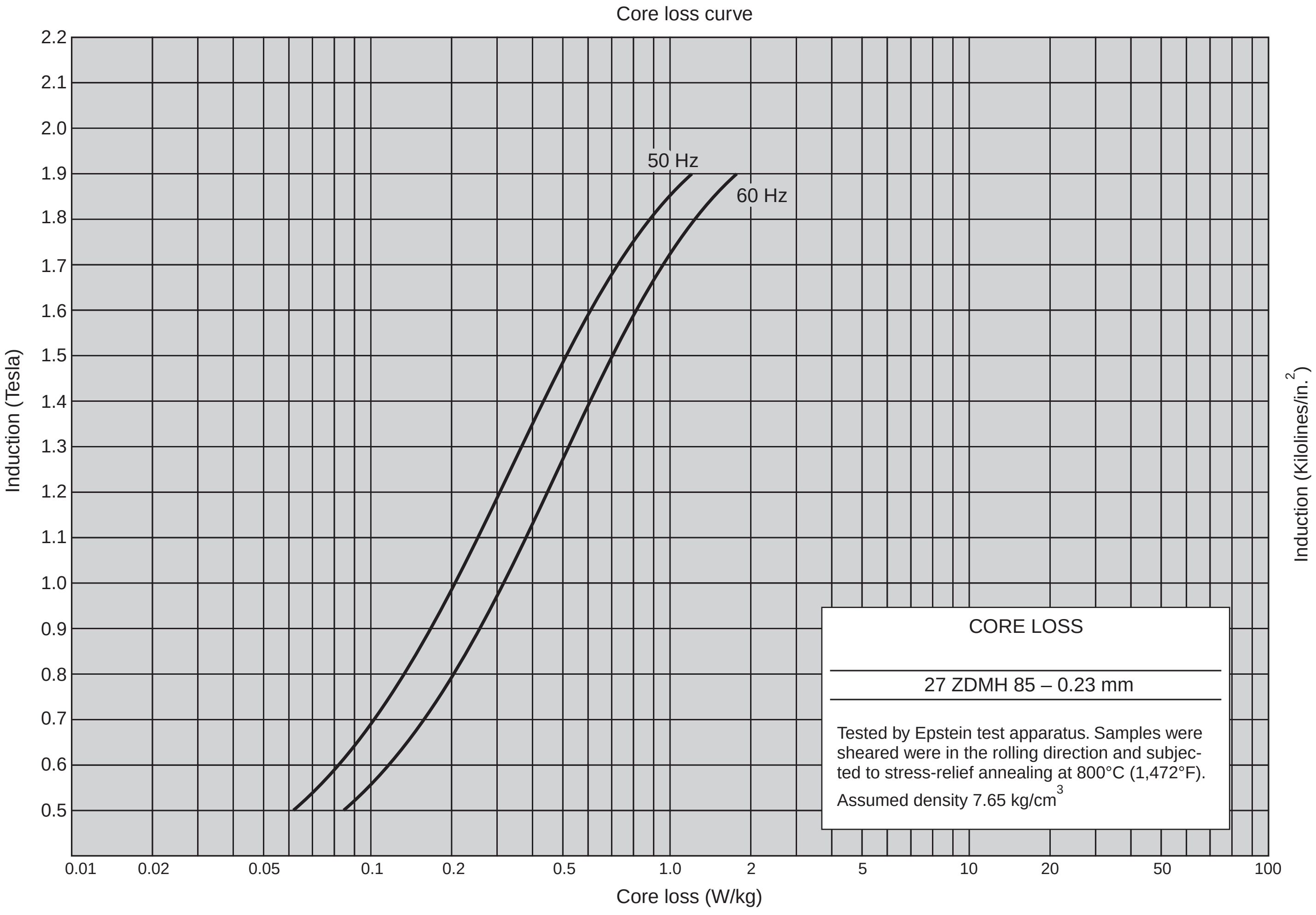

Core loss curve
Induction (Tesla)
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
50 Hz
60 Hz
0.01
0.02
0.05
0.1
0.2
0.5
1.0
2
5
10
20
50
100
Core loss (W/kg)
Induction (Kilolines/in.^{2})
CORE LOSS
27 ZDMH 85 – 0.23 mm
Tested by Epstein test apparatus. Samples were sheared were in the rolling direction and subjected to stress-relief annealing at 800°C (1,472°F).
Assumed density 7.65 kg/cm^3

Fig. 4.27

Section II
CHAPTER 5

Winding Wires and Strips

FOOD FOR THOUGHT

The concept of quality assurance in engineering has changed vastly over the last few decades. From simple quality control it has changed to quality in system engineering. Quality control activities were predominant in 1940s, 50s and 60s. The 1970s was an era of quality engineering; the 1990s showed quality system as an emerging field. Quality system requires global thinking in many facets of design, production and service.

In the past, people in the quality assurance field needed to be proficient in statistics, statistical control charts, regression analysis, sampling plan and other techniques. Over the years, many software packages have been developed and the quality assurance professionals can use these as aids in making intelligent decisions. ISO element 4.20 requires the use of statistical techniques to establish control and verify process capability and product characteristics (Section-II, Chapter-14).

Quality assurance came into prominence with an increase in global competition. Awareness of quality system was created in all levels of employees and officers.

The role of professionals in the twenty first century is quite different from the role played in the twentieth. He is expected to think in terms of total system quality and have a strategic approach and be a team player rather than an individual contributor. Working smarter rather than working harder is the norm. Knowledge of human psychology, software applications and teamwork concepts is an asset; besides statistical knowledge.

It will not be an easy path for quality professional. There will be a constant fight for survival. The demanding and challenging future will not accept a bureaucratic approach. A flexiable approach based on sound judgement and ethical principles will be accepted whole-heartedly. An efficient and effective approach will be required in all action under-taking.

5.1 INTRODUCTION

Like CRGO steel, winding wires and strips are also vital raw materials used in the transformer. The basic material available in the market is in the form of wire rods with diameters varying from 8 mm to

16 mm. The wire rod is then drawn to the required size and insulated with paper or other insulating materials. Annealing or heat treatment is done on drawn materials for softening and stress relieving.

5.2 WIRE DRAWING

The process consists of extruding the rod through a die thereby causing reduction in cross sectional area of the wire rod. The wire is drawn by pulling the rod in bull-block machine through several dies of decreasing diameter in order to obtain a thin wire. The drawing processes of aluminium and copper are almost same; but the drawing oils are different for the two materials. The drawing oil is used as lubricant and also as cooling agent for the die. It also helps to provide a bright finish.

In wire drawing, there are two types of processes; single draft drawing and continuous drawing. In single draft drawing method, the drawing operation is started by making the end of the rod pointed and pushing it through a tapered hole in the die. The pointed end is pulled by 'pull-in-dog' which is further attached to a power operated reel.

The reel is rotated at a calculated speed and the wire is drawn through a die at the desired speed. The wire is drawn through several dies of reducing sizes till the necessary reduction is obtained. The area of contact between the wire and the die is continuously lubricated to minimise friction.

In continuous drawing operation, the wire is drawn continuously through several dies and the drawing blocks are arranged in 'service'. The number of dies in service depends upon the reduction required and the kind of materials being processed. The speed of drawing is carefully monitored so that the length of wire between the blocks remain constant.

The dies generally used are of tungsten carbide. The final size is obtained using a diamond die.

5.3 STRIP DRAWING

The strip is formed from the round wire obtained at bull-block machine using a flattening mill. Cold rolling process is used. By continuously passing the material through the machine 2 to 4 times, the desired cross section of the strip is achieved. The final size is obtained either with the help of edger roll unit forming a part of the machine or by using tungsten carbide rectangular strip die.

The edger roll has grooves of various sizes which are adjustable to control the width and the corner radius of the strip. Final size of the strip can be obtained after passing the rolled strips through the tungsten carbide drawing die which is nonadjustable and is made to draw specific size of strip.

5.4 ANNEALING OF WIRE AND STRIP

The objective of annealing is to soften the metal from the stresses developed during the cold drawing process.

Annealing helps to:

(*a*) improve machinability

(*b*) obtain grain size and product uniformity

(*c*) increase activity of the metal

(*d*) modify and improve electric and magnetic properties (*e*) relieve internal stresses

(*f*) produce definite micro structure.

Annealing of Copper

The wires and strips after drawing/rolling are full of stresses and are hard in nature. To relieve the material of stresses, it is annealed under vacuum in the electrically heated annealing plant. The process requires a temperature of 400–500°C. The 'vacuum-sealed pot' when pulled out from the furnace remains at high temperature and is allowed to cool down to the ambient temperature. After about 48 hours when the pot attains ambient temperature, the vacuum is released and the material inside the pot is transferred to insulation section. Monitoring the vacuum during these 48 hours is very important, since any leakage of air (which essentially contains oxygen) will result in its reaction with copper affecting the surface finish.

Annealing of Aluminium

Since aluminium does not react with oxygen normally, the annealing process is carried out in open furnace.

5.5 INSULATING PAPER

Electrical Grade Insulating Paper (EGIP) is generally used for covering the bare conductor. EGIP has certain properties which makes it a superior material to use as insulation in electrical equipments.

These are:

(*a*) Flexibility

(*b*) Easy to use

(*c*) Higher insulation with lesser thickness

(*d*) Higher resistance to oil

(*e*) Reasonable heat resistance while in contact with oil

(*f*) Good compatibility with transformer oil

(*g*) Low chloride content.

Because of the above properties, EGIP finds a wide range of usage in insulated wires and strips for oil immersed transformers and in certain other electrical equipments.

EGIP is available in various widths in the form of rolls. The jumbo roll is slit to various sizes in the shape of small discs. The paper is slit into different widths depending upon the number of coverings required on the conductor (*e.g*. DPC/TPC/QPC/MPC etc.). The width of the slit also depends on the factor of overlapping.

In the case of double paper covered conductor, two slit papers are used which are wrapped in opposite directions. However in the case of triple or more paper covering all the papers shall be overlapped in the same direction, unless otherwise specified/agreed upon.

5.6 ISS FOR WINDING WIRE AND STRIP

The following ISS may be referred:

IS-6162 (Part-I)	:	Paper covered conductors (round conductor)
IS-6160	:	Rectangular conductors for electrical machines

IS-6162(Part-II)	:	Paper covered aluminium conductor (rectangular conductor)
IS-7404(Part-I)	:	Paper covered copper conductor (round conductor)
IS-7404(Part-II)	:	Paper covered copper conductor (rectangular conductor)
IS-10452(Part-I)	:	Test methods.

5.7 WINDING MATERIAL

The material of winding wire or strip could be copper or aluminium. The choice depends upon the end users. Most of the Indian power utilities prefer transformers upto 250 kVA/11 kV with aluminium windings, because of its wide availability and lower cost. But owing to some limitations in its inherent properties, higher rated transformers are made with copper windings. Distribution transformers of 22 kV and 33 kV with smaller ratings are also preferred with copper windings.

Because of its low conductivity and high resistivity, aluminium conductor occupies almost double the volume of a copper conductor and hence aluminium-wound transformer looks always bigger than copper-wound transformers of same kVA rating.

Aluminium-wound transformer was inducted into service in early seventies after REC has formulated the revised specification for transformers upto and including 100 kVA rating at 11 kV voltage class. Even after about 30 years of use, the superiority of copper-wound transformers over aluminium-wound transformers is yet to be established.

In fact, a well designed and good quality aluminium-wound transformer will provide equal, if not better, service to that of a copper-wound transformer.

5.8 SELECTION OF WINDING WIRES AND STRIPS

Winding wires and strips are designed based on the current they have to carry. The size of the conductor depends on the material used as well as current density. For preliminary design, current densities of 1.5 A/sq.mm (max.) and 3A/sq.mm (max.) may be used for aluminium and copper windings, respectively.

The choice of current density is sometimes restricted by the buyers. For instance, in the case of aluminium-wound transformers, PSEB, UPPCL, HPSEB etc. have restricted the current density to 1.5 A/sq. mm. Similarly, for copper-wound transformers DVB has restricted it to 2.5 A/sq. mm, UPPCL to 2.8 A/sq. mm and so on.

The rated current for which the conductor is to be designed may be calculated on the basis of kVA, no. of phase and rated voltage.

$$\text{kVA} = \sqrt{3} \times V \times I \text{ (for 3 phase transformer)}$$

or

$$I = \frac{\text{kVA}}{\sqrt{3} \times V}$$

For 100 kVA 3 phase transformer having voltage ratio 11/0.433 kV with Delta/Star connected windings,

the secondary current per phase (star connected) = $\dfrac{100}{\sqrt{3} \times 0.433}$ = 133.34 A

Similarly, the primary line current = $\dfrac{100}{\sqrt{3} \times 11}$ = 5.25 A

Since the primary winding is delta connected,

The primary current per phase = $\dfrac{5.25}{\sqrt{3}}$ = 3.03 A.

Once the currents are known, the conductor area may be calculated on the basis of the assumed current density as follows:

$$\text{Conductor area} = \frac{\text{current per phase}}{\text{current density}}.$$

5.9 HV CONDUCTOR

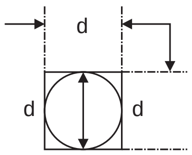
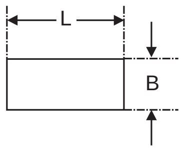
For distribution transformers of medium capacity, the conductor chosen for primary windings are mostly round in shape and the diameter of the round conductor may be calculated from the available conductor area.

$$\text{Conductor area} = \frac{\pi \times d^2}{4} \quad \text{or} \quad d = \sqrt{\frac{(\text{conductor area} \times 4)}{\pi}}$$

where '*d*' is the diameter of bare HV conductor.

The diameter of the winding wire as calculated above may further be revised from the standard table available in IS-6162. In case the diameter of the conductor is more than 3.5 mm, a suitable rectangular strip of equivalent sectional area may be selected instead of a round conductor. An equivalent rectangular strip will yield a better result compared to a thick round conductor. While selecting the conductor, one has to take care of the available conductor surface area as well as space factor. Thick round conductor has a poor surface area as well as space factor. This can very well be illustrated by a simple example.

Table 5.1

Particulars	***Round conductor of diameter 3.6 mm***	***Equivalent strip size 6 × 1.7 mm***
Cross sectional area	$\dfrac{\pi d^2}{4} = \pi \times \dfrac{3.6^2}{4}$ = 10.18 sq. mm	6 × 1.7 = 10.2 sq. mm
Surface length	$\pi\, d = \pi \times 3.6$ = 11.3 mm	$2 \times (L + B) = 2 \times (6 + 1.7)$ = 15.4 mm
Area of space occupied	 $d^2 = 3.6 \times 3.6$ = 12.96 sq. mm	 $L \times B = 6 \times 1.7$ =10.2 sq. mm
Space factor $= \dfrac{\text{Area of space occupied}}{\text{Cross sectional area}}$	$\dfrac{12.96}{10.18}$ = 1.27	$\dfrac{10.2}{10.2}$ = 1.0

From the above it may easily be concluded that the equivalent rectangular strip has a better surface length and has 27 per cent better space factor than that of round conductor.

5.10 LV CONDUCTOR

In the case of LV conductor where the current is generally high, rectangular conductor is commonly used. Multiple strips in parallel are also used for higher rated transformers. Selection of size of LV strip plays a significant role on the performance of a transformer.

The advantage of using two parallel strips over a single thick strip is illustrated in the following example.

Current has a tendency to flow through the surface of a conductor which is commonly known as ‘skin effect’.

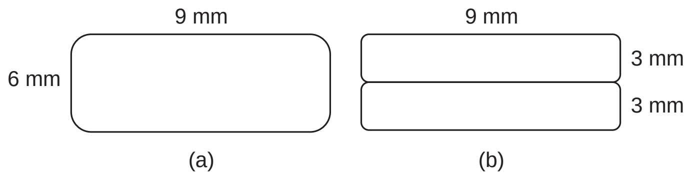


Fig. 5.1. Two parallel strips instead of a thick single strip

Suppose the requirement is for a strip having cross sectional area 54 sq. mm. The strip shown in Fig. 5.1 (*a*) has an area of 9 × 6 mm = 54 sq. mm. The total surface length of the strip is 2 × (9 + 6) = 30 mm. Consider the two parallel strips each having a size of 9 × 3 mm shown in Fig. 5.1 (*b*). The equivalent cross sectional area of this alternative conductor is 2 × (9 × 3) = 54 sq. mm, which is the same as that of the single thick strip. The surface length of the alternative strip is 2 (9 + 3) × 2 = 48 mm; which is about 1.6 times more than the first one. This is one reason for using more number of strips in parallel instead of selecting a thick single strip, where higher rating is required.

Refer Table 5.2 for the comparison between the single thick strip and the alternative strip with two strips in parallel.

Table 5.2

Particulars	***Strip size 9×6 mm***	***Alternative strip size (9×3 mm) × 2 nos. in parallel***	***Remarks***
Cross sectional area	54 sq. mm	54 sq. mm	Both are equal
Surface length	30 mm	48 mm	Alternative strip has a better surface length
Ratio of surface length	–	48/30 = 1.6 times	Skin effect on alternative strip is better. Thus there is less stray loss

Maximum Depth of Strip

In general, the depth of a strip should not be more than half of the strip width, which means if the width of a strip is 9 mm, the depth should not be more than 4.5 mm in any case.

i.e., $$\frac{\text{width}}{\text{depth}} \geq 2$$

Minimum Depth of Strip

ISS has recommended the minimum depth as 1/6 of the width of the strip,

i.e., $$\frac{\text{width}}{\text{depth}} \leq 6$$

But considering the practical difficulties, it is suggested that the ratio be restricted to ≤ 4, which means the minimum depth of a strip having 9 mm width should not be below 9/4 = 2.25 mm.

This restriction is due to the limitation in the plant for drawing the strip as well as for insulation covering.

It is seen in many occasions that some of the manufacturers prefer to use single thick strip instead of sectionalising it to multiple thinner strips to avoid transposition.

5.11 TRANSPOSITION

In case a coil is designed with more than one strip and if the strips are placed one above the other, then transposition is a must.

In the case of a non-transposed coil, the strip placed below [strip no. 2 of Fig. 5.2 (*a*)] will have comparatively lower length than that of the upper strip [strip no. 1 of Fig 5.2 (*a*)]. In such cases since the length of the two strips are different, the resistances will obviously be different. When two such strips of unequal lengths and resistances are used, the strip placed below will carry more current because of its low resistance, while the strip placed above will carry less current because of its high resistance.

The purpose of transposing the strips is to make the length of the strips almost equal, thereby making the resistances also equal as shown in Fig. 5.2 (*b*).

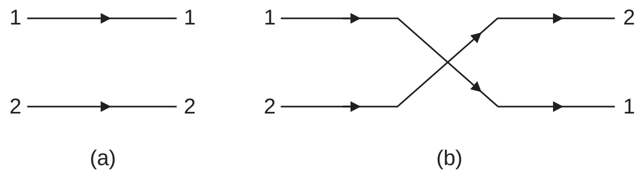


Fig. 5.2. Elementary method of transposition

Distribution of current among the parallel strips for a transposed coil will be almost equal, which is an advantage over non-transposed coil.

The distribution of current in a non-transposed coil having two strips placed one above the other may be explained with some numerical values.

Example: Let us consider a coil which has been designed with two strips suitable to carry a total current of 150 A.

In a non-transposed coil of unequal lengths and resistances, the bottom strip will draw more current (say 80 A) because of its low resistance, whereas the upper strip will draw less current (say 70 A) because of its high resistance. The unequal distribution of currents among the two strips will affect the performance of the transformer, especially load loss and reactance. Non-transposed coil will always yield higher load loss arid reactance than the calculated value. This aspect must be considered while making coils with multiple strips and care must be taken to provide proper transposition.

In the foregoing paragraphs it was explained how the quality of a transformer is affected by the processing of wires and strips. Selection of correct sizes, their placement and transposition also play a vital role in its performance. We shall now discuss the systematic approach to quality checks on winding wires and strips.

5.12 QUALITY CHECKS

(*a*) Checks on Basic Raw Materials

Basic materials are available in the form of rods. Before taking the materials to a drawing plant, the test certificate available from the mills must be reviewed for quality assurance. Chemical composition and physical properties should be checked in line with the requirements of ISS. The relevant quality standards, IS-12444 and IS-5484 may be consulted for copper and aluminium rods respectively.

(*b*) Some Basic Properties of Metal

(i) ***Density:*** The density at 20°C is 8.89 g/cm^3 and 2.703 g/cm^3 for copper and aluminium respectively.

(ii) ***Resistance:*** The resistances at 20°C of conductors of annealed copper and aluminium of one metre length and of uniform cross-sectional area of one sq. mm are 0.017241 ohm and 0.028 ohm respectively (unit is ohm-mm^2/m).

(iii) ***Coefficient of linear expansion:*** Coefficient of linear expansion of annealed copper over a temperature of 0 to 150°C is 0.000017 mm/°C. The same for annealed aluminium is 0.000023 mm/°C.

(iv) ***Purity:*** Purity should be 99.9 per cent (minimum).

(*c*) Preferred Sizes of Wires and Strips

(i) ***Wires:*** Table 1 of standard IS-6162 (Part-I) for aluminium and IS-7404 (Part-I) for copper can be referred to for the sizes of bare wires.

(ii) ***Strips:*** For sizes of the bare strips, both copper and aluminium, no reference is presently available as BIS has withdrawn the relevant ISS-6160. It is recommended that the guidelines given in Section 2.10 (LV conductor) be followed while selecting strip sizes.

(iii) ***Corner radius of strip:*** The rectangular strips are made round at all the four corners for easy drawing. Corner radius with reduction of effective area is shown in Table 5.3.

Table 5.3

Strip depth	*Corner radius*	*Reduction in effective area*
Upto 1.6 mm	0.5 mm	0.2147 sq. mm
Above 1.6 mm upto 2.24 mm	0.65 mm	0.3629 sq. mm
Above 2.24 mm upto 3.55 mm	0.8 mm	0.54976 sq. mm
Above 3.55 mm	1.0 mm	0.859 sq. mm

(*d*) Tolerance on Bare Wire Size (Both Copper and Aluminium)

Table 5.4

Nominal conductor diameter (mm)	*Tolerance (±) as recommended by IS-6162/7404 (mm)*
0.25	0.004
0.29	0.004
0.315	0.004
0.355	0.004
0.40	0.005
0.45	0.005
0.50	0.005
0.56	0.006
0.63	0.006
0.71	0.007

Nominal conductor diameter (mm)	*Tolerance (±) as recommended by IS-6162/7404 (mm)*
0.71	0.007
0.75	0.008
0.80	0.008
0.85	0.009
0.90	0.009
0.95	0.01
1.00	0.01
1.06	0.011
1.12	0.011
1.18	0.012
1.25	0.013
1.32	0.013

Contd.

Nominal conductor diameter (mm)	*Tolerance (±) as recommended by IS-6162/7404 (mm)*
1.4	0.014
1.5	0.015
1.6	0.016
1.7	0.017
1.8	0.018
1.9	0.019
2.0	0.020
2.12	0.021
2.24	0.022
2.36	0.024
2.50	0.025
2.65	0.027
2.80	0.028
3.00	0.030
3.15	0.032
3.35	0.034
3.55	0.036
3.75	0.038
4.0	0.040
4.25	0.043
4.5	0.045
4.75	0.048
5.0	0.050

(*e*) Tolerance on Bare Strip Size

Table 5.5

Dimensions-width or depth (bare strip)		*Recommended tolerance*
Over	*Up to and including*	
–	3.15 mm	± 0.03 mm
3.15 mm	6.30 mm	± 0.05 mm
6.30 mm	12.5 mm	± 0.07 mm
12.5 mm	16.0 mm	± 0.10 mm

(*f*) Width of Paper

(i) ***Wires:*** Unless agreed to between the manufacturer and the user, the width of the paper used for wrapping should not exceed three times the diameter of the conductor with a maximum of 12 mm and a minimum of 3 mm.

(ii) ***Strips:*** Unless agreed to between the manufacturer and the user, the width of the paper for overlapping should not exceed 1.5 times the sum of the width and the thickness of the conductor; subject to a maximum of 25 mm.

(*g*) Arrangement of Layers

(*i*) ***Double wrapping (DPC):*** When there are two layers of paper covering, both of them shall be overlap-wound in the opposite directions.

(*ii*) For more than two layers (TPC, QPC or MPC), all layers shall be overlap-wound in the same direction.

However, overlapping arrangement differing from the above may also be adopted by arrangement between the manufacturer and the user provided that the insulated conductor satisfactorily meets all other requirements.

(*h*) Tolerance on Covering for both Wires and Strips

Table 5.6

Increase in diameter due to covering	***Tolerance in percentage***
0.25 mm to 0.5 mm	(±) 10
Over 0.25 mm up to 1.3 mm	(±) 7.5
Over 1.3 mm	(±) 5.0

The discussions on winding wires and strips are concluded here with a table below for ready reference on quality checks.

Table 5.7

Particulars	***Quality checks***
Basic materials	Mills' test certificate for physical composition and chemical properties shall be checked in accordance with IS-12444 for copper rod and IS-5484 for aluminium rod.
Density	(*a*) *For copper:* 8.89 g/cm^3 (*b*) *For aluminium:* 2.703 g/cm^3 A certificate of density may be obtained from the supplier of copper/aluminium rod for review before accepting the materials for processing.
Specific resistance or resistivity	(*a*) *For copper:* 0.017241 ohm-mm^2/m at 20°C (*b*) *For aluminium:* 0.028 ohm-mm^2/m at 20°C A certificate for the above figures may be procured from the supplier before the materials are released for production.

Contd.

Particulars	*Quality checks*
Coefficient of linear expansion	(*a*) For copper: 0.000017 mm/°C. (*b*) For Aluminium: 0.000023 mm/°C. Though the coefficient of linear expansion has very little effect on the performance of transformer, a certificate for the above figures may be procured from the supplier along with each supply.
Purity	The purity of metal should be above 99.9 per cent. A certificate for the above figure may be procured from the supplier along with each supply.
Size and area of strip	Size of bare strip for both copper and aluminium shall be chosen from Table 5.5. While calculating the effective cross sectional area of strips, reduction of area due to corner radius shall be as below: Up to a depth of 1.6 mm: Reduction of 0.2147 sq. mm Above 1.6 mm up to 2.24 mm: Reduction of 0.3629 sq. mm Above 2.24 mm up to 3.55 mm: Reduction of 0.54976 sq. mm Above 3.55 mm: Reduction of 0.859 sq. mm
Size of wire	Sizes of bare wires are given in the standards IS-6162 (Part-I) for aluminium and IS-7404 (Part-I) for copper.
Tolerance on dimensions for bare strips	Over 3.12 mm ± 0.03 mm Above 3.15 mm up to 6.3 mm ± 0.05 mm Above 6.3 mm up to 12.5 mm ± 0.07 mm Above 12.5 mm up to 16 mm ± 0.10 mm
Tolerance on dimensions for wires	As mentioned earlier under Heading 2.12 (*d*)
Tolerance on dimensions for covering thickness for both wires and strips	Increase in overall dimension due to covering: From 0.25 mm to 0.5 mm: Tolerance ± 10% Over 0.5 mm up to 1.3 mm: Tolerance ± 7.5% Above 1.3 mm: Tolerance ± 5%
Width of paper for covering	(*a*) *For wires:* Width of paper should not exceed three times the diameter of the conductor, subject to 12 mm maximum and 3 mm minimum. (*b*) *For strips:* Width of paper should not exceed 1.5 times the sum of width and a thickness of the conductor, subject to a maximum of 25 mm.

Section II

CHAPTER 6

Insulating Pressboard

FOOD FOR THOUGHT

Generally, in a closed loop sysem the input equals the output. ‘Garbage-in-garbage out’ is true in the industrial world today. Parts suppliers (defined as vendors providing materials, components, sub-assemblies or other services) must play an important role if a company is to compete effectively in the market place. To have a ‘win-win situation’, it is necessary to understand the supplier’s role. Technological change, mass-production techniques, time factor, and a high quality awareness have forced a change in our thinking. Programme for improving the quality of incoming materials often do not accomplish their full potential because of a one-sided 'dictatorial' approach to suppliers. A friendly attitude will certainly create a hassle-free relationship. A healthy relationship with the suppliers helps the business to compete effectively.

6.1 INTRODUCTION

After CRGO steel and winding wires and strips, the next important material which affect the quality of a transformer is the insulating pressboard.

There are only two indigenous manufacturers in India, viz. M/s Senapathy Whiteley Limited and M/s Raman Boards Limited, who manufacture quality insulating pressboards of various grades. It is just a coincidence that both of them are within an arms reach in the state of Karnataka. M/s Senapathy Whiteley started production of insulating pressboards around four decades ago in collaboration with the world famous Whiteley group, whereas M/s Raman Boards started production around two decades ago under the technical collaboration of M/s Rogers Corporation of USA. Both these manufacturers are reputed for their quality products so that minimum quality checks would suffice at the workshop. However considering the availability of various grades of pressboards, the right kind of materials should be chosen with care. The grades available are commonly known as Type-C, Type-D and pre-compressed. The boards are available in various thicknesses of 1 mm, 2 mm, 3 mm etc.

The following paragraphs deal with the composition, manufacturing processes, and electrical and mechanical properties of insulating pressboards.

A pressboard can be considered as nothing but a thick insulating paper of the highest quality. Paper as well as pressboards are manufactured from unbleached sulfate cellulose. The Scandinavian and Canadian conifers contain cells that grow especially slow and dense. Cellulose products made from these raw materials are especially suited for insulating pressboards subjected to mechanical loading. The discussion here will be restricted to materials which are made out of wood pulp only.

6.2 COMPOSITION—CELLULOSE

Cellulose is the chief constituent of plant life. It does not exist in nature in its pure form, but is obtained in the form of a mixture with a variety of organic substances, the presence of which pose a difficult problem in the manufacture of electrical insulation. The most unwanted organic materials present with cellulose are pentosans and lignin. Quantum of pentosans and lignin present depends on the source of cellulose fibre. The removal of these unwanted constituents without affecting the cellulose itself is the major problem in the manufacturing of insulating pressboard.

6.3 MANUFACTURING PROCESS

Pure virgin sulfate cellulose sheet (wood pulp) is the basic raw material for insulating pressboards and presently it is being imported.

In addition to 40 to 60 per cent fibre, wood pulp contains other substances including pentosans and lignin. These substances and other impurities must be separated from the individual fibres and washed by means of different chemical processes. However, all of these processes must be carried out in such a manner that the cellulose itself is not attacked.

The cellulose is then dispersed in fresh water and temporarily stored in pulp chest. The individual fibres are crushed in order to expose additional surface area. Paper or pressboard strength is primarily determined by the bonding forces between the fibres, whereas the fibres themselves are stressed far below the breaking point. The bonding forces are influenced primarily by the type and degree of refining.

Fibres separated in this manner are mixed with water in mixing chest and are again subjected to intensive cleaning. In this process even pure sulphate cellulose fibres, which do not comply with high quality standards for single fibres, are extracted since they get interwined and form small knots rather than float in the water as individual fibres. The cellulose-water mixture is routed through a wide rotating cylindrical screen. While the water flows through the cylindrical screen, the cellulose fibres are filtered out on the screen surface and form a paper cylinder.

The higher the paper grade, the thinner the paper web and greater the number of layers. There are approximately 35 layers (each having a thickness of 30 microns) per millimetre thickness of insulating pressboards. The wet lamination of many thin layers without bonding agent will form the required thickness of board. This is done on the board making machine by continuous winding of the paper layer onto the forming roll.

Manufacturing of the wet sheet is done as described above. Then dehydration, compression and drying are performed in special hot process. This pressboard is designated as pre-compressed transformer board. The density of such material is approximately 1.25 g/cm^3. The wet sheets which contain approximately 70 per cent water are dried and compressed in one operation between two heated plates.

They are exposed temporarily to alternating temperature and pressure. They are completely dry when they leave the press and are ready for further processing.

The hot moist fibres assume a plastic behaviour and become cross-linked and much stronger than in the case of conventional, elementary pressure application. This yields a material resistant to bending with rigid tensile and pressure behaviour. The sheets leave the hot press in a completely stressfree status and remain flat and dry. The sheets retain their shape in hot oil even after decades of operation.

We have discussed the manufacturing process of electrical grade pressboards from soft wood sulfate pulp. There are various forms of raw materials used for manufacturing pressboards. Some of them are mentioned below:

(*a*) Unbleached soft wood sulfate pulp for electrical grade (discussed above)
(*b*) Unbleached soft wood sulfate pulp combined with used cotton fibres
(*c*) Virgin or used cotton fibres
(*d*) Pressboards made of used cellulose fibres (waste paper)
(*e*) Pressboards produced from chemically thermo-stabilized cellulose
(*f*) Pressboards manufactured from synthetic fibres (applicable for air cooled transformers)

6.4 DRYING AND OIL IMPREGNATION

Papers and pressboards act as good insulating materials only when they are impregnated with dry insulating oil. Papers and pressboards are very hygroscopic in nature and retain between 6 to 12 per cent water by weight at a relative humidity of 50 to 70 per cent. It is therefore very important to dry the papers before impregnating with oil. The presence of moisture in the pressboards will affect the electrical values adversely. The major reasons for this are given below:

(*a*) Reduction of electrical strength when the moisture content is high
(*b*) Accelerated ageing in the presence of moisture
(*c*) Breakdown due to disturbance of the moisture equilibrium
(*d*) Low partial discharge inception voltage and high partial discharge intensity in the presence of moisture.

Impulse withstand property is further dependent on the moisture content of the pressboards.

The decrease in electrical strength is quite evident when moisture content of the paper is greater than 0.1 per cent. Not only the electrical values are influenced by the presence of moisture, but moist papers and pressboards also age faster. Review reports of various laboratories have shown that a paper with one per cent moisture content ages ten times faster than one with 0.1 per cent. Several operational malfunctions can result from too high a humidity factor when the moisture equilibrium is disturbed.

6.5 ELECTRICAL AND MECHANICAL PROPERTIES

A comparative chart representing the electrical and mechanical properties of various grades of pressboards, commonly used by the transformer industry is shown in Table 6.1.

Table 6.1

Properties	*Type-C*	*Type-D*	*Pre-compressed*
Density (g/cm^3)	0.9–1.10	1.1–1.27	1.15–1.3
Composition	Mixture of cotton and other fibres	Kraft wood pulp	Kraft wood pulp
Compressibility (%) (*a*) In air (*b*) In oil	 5.5–8.44 8.54–16.63	 3.53–6.32 6.04–11.60	 2.73-3.58 4.0-4.87
Shrinkage in air (%) (*a*) Machine Direction (MD) (*b*) Cross Machine Direction (CMD) (*c*) I r	 0.39–0.78 0.66–1.31 1.97–3.20	 0.53–0.88 0.78–1.47 3.6–4.8	 0.31–0.39 0.52-0.65 3.36–4.44
pH value	7.2–8.4	7.2–8.4	6–8.4
Conductivity of aqueous extract mS/m	45–85	36–70	40–112
Mineral ash (%)	0.6–1.4	0.45–1.0	0.37–0.55
Tolerance (%)	+ 0 to –10	+ 0 to –10	± 5
Electric strength in oil (kV/mm)	9–12	8–12	10–15
Oil absorption (%)	20	15	10
Moisture content (%) (maximum)	8	8	8

6.6 STORAGE OF INSULATING PAPERS AND PRESSBOARDS

Papers and pressboards made out of cellulose are highly hygroscopic. Hence, right kind of storage plays a major role in its quality and reliability. Any damage causing seepage, absorption of water or any other liquid may seriously affect the properties of the material. The materials should be kept away from dust, metal filings etc. during processing in the shop floor.

6.7 COMPRESSIBILITY OF INSULATING PRESSBOARD

It is necessary to evaluate the compressibility of the pressboards in air as well as in oil. Compressibility property indicates that the thickness of the pressboard reduces under compression. Compression is more when it is impregnated with oil (refer Table 6.1). To overcome such problems, it is suggested to pre-heat the core-coil assembly for atleast 24 hours under required pressure. The compression is for created by clamping the coils and insulating blocks with the help of tie rods and clamping channels.

This is done without refilling of top yoke. This will help in reducing inbuilt voids in the pressboards. Since the change in thickness due to compression is less in case of pre-compressed boards, it is suggested to use spacer blocks and rings made out of pre-compressed board only. Moreover spacer blocks in the dovetailed shape should be used to reduce the probability of displacement during short-circuit forces.

6.8 CONCLUSION

A summary of the discussions on the insulating pressboards is given below:

(*a*) In case, the transformer manufacturers want to use indigenous material, it should be sourced from M/s Senapathy Whiteley or M/s Raman Boards, since their products are guaranteed for quality and as on today, there are no other manufacturers who can match their quality.

(*b*) Since the pressboard is highly hygroscopic in nature, right kind of storage increases the reliability of the material.

(*c*) Hygienic environment in the shop floor also has a great bearing on quality, since dust, metal fillings etc. can cause havoc on electric strength.

(*d*) Selection of grade and thickness is one of the major criteria which affect the quality of the ultimate product.

(*e*) To counter the hygroscopic property of insulating pressboard, we must ensure proper drying before impregnating with dry insulating oil.

(*f*) The materials should be accepted on the basis of mills test certificates and must be reviewed by the quality assurance engineer.

The right choice of material along with environmental checks offer a longer life to the transformer while improper selection or incorrect processing of materials may adversely affect its performance.

Section II
CHAPTER 7

Insulating Oil

FOOD FOR THOUGHT

A business is not merely an organization chart; it is a network of people, materials, methods, equipment—all working in support of each other for the common aim of improving quality and productivity. Corporate culture is the basic pattern of shared beliefs, behaviours, and assumptions acquired over time by members of an organization. It reflects attitudes and practices related to quality system applications. Vision, mission, values, goals and strategy are important factors for the success of an organization. Strategy ties down with vision, mission, values and goals to make an organization work. Quality is a complex multifaceted concept and it means prevention, customer satisfaction, productivity, flexibility, efficiency, meeting a schedule, investment, etc. Quality is a systematic approach to the search for excellence. Quality system is a series of functions or activities within an organization that work together to achieve the aim of the organization. A quality system includes the processes in an organization intended to yield consistency or improvement in the working of the enterprise. Total Quality Management (TQM) approach is a cost effective system, integrating the continuous quality improvement of people at all levels in an organization, to deliver products and services which ensure customer satisfaction. In essence, quality management means elimination of drain on resources and generation of profits by preventing mistake, misjudgement, and miscommunication in all phases of a business.

Quality management is available in companies that manages quality as a strategic business issue and constantly review and renew quality management.

7.1 INTRODUCTION

After CRGO steel, conductor and insulating pressboard, insulating oil is considered to be the most vital raw material which affect widely the performance of a transformer. The oil used in the transformer is a product of petroleum. The oil acts in two ways, (*i*) as insulating medium and (*ii*) as heat transfer medium. Though it is a petroleum product, it has a very high flash point (about 140°C) which permits its use in transformer.

The ever growing needs of electricity consumption and the open door policy of the Government to private as well as foreign participants in power sector necessitated to add huge additional power generation capacity. The demand for power and distribution transformers closely follow the establishment of additional generation capacity.

To ensure long uninterrupted service life of a transformer, most important step is to select an oil that has the properties required for the equipment in question. The essential properties of liquid dielectric required for successful operation of transformer are listed below:

(*a*) Chemical stability—stability in oxidation, thermal degradation and hydrolysis

(*b*) Thermal characteristic—good thermal conductivity and high specific resistance

(*c*) Non toxic and compatibility with transformer construction materials

(*d*) Mutual compatibility with other transformer fluid

(*e*) High di-electric strength, low loss tangent and high resistivity

(*f*) Easy for reconditioning and reclamation.

Mineral oil as transformer oil fulfils a number of important functions in an insulating system as di-electric, heat transfer agent, arc quencher etc. The reliable performance of mineral insulating oil depends upon basic oil characteristics, its oxidation stability, stability in electric field and its compatibility with other insulating materials in the system. It is very important to understand the different oil parameters when selecting oil for electrical equipment, especially transformer of very high quality.

7.2 CHEMISTRY OF TRANSFORMER OIL

Transformer oil is manufactured by refining the petroleum oil feed stock. Transformer Oil Feed Stock (TOFS) is obtained as first distillate under vacuum distillation of crude oil after taking out lighter cuts like gasoline, kerosene, and middle distillate (diesel) at atmospheric pressure. Characteristic properties of TOFS are dependent on the origin of crude oil, *i.e.* on its hydrocarbon composition. These petroleum products are classified into aromatic, naphthanic and paraffinic; containing small amounts of polar compounds.

7.3 REFINING OF TOFS

Various commercial and conventional methods of refining TOFS are shown in Fig. 7.1.

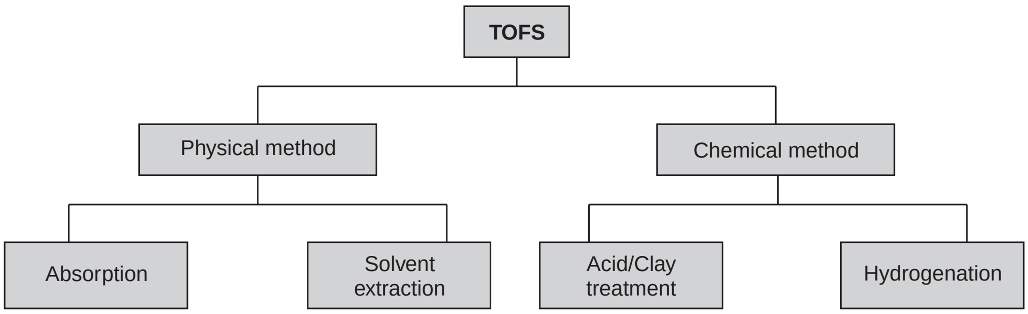


Fig. 7.1. Method of refining TOFS

The physical methods are expensive and of historical importance, whereas chemical treatment method of hydrogenation (hydrofinishing and hydrotreatment) makes it possible to produce oil with high solvating power and low level of polycyclic aromatics. In hydrogenation process, aromatics are converted to naphthanic hydrocarbons and hetrocyclics containing sulphur, nitrogen etc. are eliminated as hydrogen sulphide, ammonia and water. The process requires high safety precautions as high pressure hydrogen is involved. Moreover, the process is highly capital intensive and is economically viable only at plant capacities more than 50,000 MT/year.

The other chemical treatment method using sulphuric acid is the most conventional and widely used in India. In this process, the unsaturated hydrocarbons and aromatics are sulphonated to sulphuric acid. While polycyclic and polyphenyl alkalines are easily sulphonated, monocyclic aromatic heterocarbon compounds are either oxidized or polymerized forming acid sludge. The unwanted impurities are further removed by neutralization, solvent wash and clay treatment and finished oil is obtained. Typical flow diagram is illustrated in Fig. 7.2.

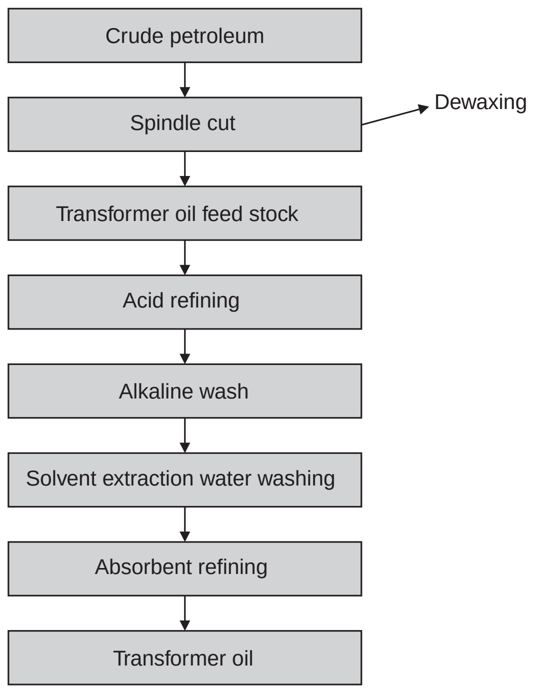


Fig 7.2. Flow diagram for manufacturing transformer oil

7.4 CHARACTERISTIC PROPERTIES AND SPECIFICATION

To satisfy the function of di-electric and coolant media in transformer, oil has certain specific properties.

The specifications laid down by Bureau of Indian Standards (former ISS) for transformer oil are among the most stringent quality requirements. These properties can be classified into three categories:

physical, chemical and electrical. Various properties covered under IS-335 are listed later in Table 7.1. Comparative specifications of transformer oils used worldwide are also given in the same table.

While characteristic properties of interfacial tension, resistivity, ageing and oxidation stability are not covered in the specifications of many European countries, IS-335 has retained these in their specifications. The pour point requirement is relaxed to (–) 6°C as the tropical conditions prevailing in India, barring Himalayan region, allow free flow of oil during the initial fill.

As many as sixteen characteristics have been specified to evaluate the quality of transformer oil. Out of these, electrical properties and stability characteristics are important, whereas other properties like flash point, interfacial tension and S.K. value do signify the condition of oil. A brief description of the tests and the important performance characteristics are given below.

7.5 PHYSICAL PROPERTIES

(*a*) **Appearance:** The oil should be clear, transparent, and free from suspended matter or sediments. Oil of pale yellow colour is considered to be good. Any other colour such as yellow, amber, brown etc. indicates the presence of contaminants.

(*b*) **Density:** Recommended maximum density at 29.5°C is 0.89 g/cc. But the oils which are available from the Indian refineries have varying densities of 0.85 to 0.87 g/cc at ambient temperature.

(*c*) **Viscosity:** Viscosity is the controlling factor in the dissipation of heat. Ageing and oxidation of the oil tend to increase viscosity.

(*d*) **Flash point:** The temperature at which the oil gives-off so much of vapour, that this vapour when mixed with oil forms an ignitable mixture and gives a momentary flash on application of a small pilot flame under prescribed conditions of test is known as the flash point.

A low flash point is an indication of presence of volatile combustible products in the oil. Prolonged exposure of the oil to a very high temperature under fault conditions may produce sufficient quantities of low molecular weight hydrocarbons to cause a lowering of the flash point of the oil.

(*e*) **Pour point:** Pour point is the lowest temperature expressed as multiple of 3°C at which the oil is observed to flow when cooled and examined under prescribed conditions.

Pour point is the measure of the ability of the oil to flow at low temperature. There is no evidence to suggest that the property is affected by oil deterioration. Change in pour point may normally be interpreted as the result of topping up with a different grade of oil.

(*f*) **Interfacial tension:** It is the force necessary to detach a planar ring of platinum wire from the surface of the liquid of higher surface tension that is upward from the water-oil surface. It is expressed in N/m.

The interfacial tension between oil and water provides a means of detecting soluble polar contaminants and products of deterioration. This characteristic change is fairly rapid during the initial stages of ageing, but level off when the deterioration is still moderate. For this reason results are rather difficult to interpret in terms of oil maintenance. However, oil with minimum limiting interfacial value should be further investigated.

(*g*) **Neutralization value:** It is the measure of free organic and inorganic acids present together and is expressed as milligram of potassium hydroxide required to neutralize the total acids in one gram of oil and is expressed in mg KOH/g. The permissible maximum value as recommended by BIS is 0.03 mg KOH/g.

7.6 STABILITY CHARACTERISTICS

In view of the longer time required to assess the behaviour of insulating fluids in actual system, various types of accelerated tests have been developed. The accelerating factors in all these types of tests are, in general, higher temperature, higher availability of air/oxygen and presence of copper catalysts. Even though the direct bearing of these tests on actual system could not be demonstrated due to various complexities of the process, two such accelerated tests which have been adopted currently in power sector industries are given below.

(*a*) **Accelerated ageing test:** A known amount of oil (300 ml) is taken in a beaker with a copper catalyst in the form of wire/strip with 15 cm^2 of clear surface available for exposure to the oil and aged at 115°C for 96 hours. After the stipulated period the samples are tested for electrical properties such as resistivity, dissipation factor, acidity and quantity of sludge. Originally this test was devised for assessing the ageing resistance of cable oil as per ASTM-D-1934. Since this was the only ageing test which assess the deterioration of electrical properties, such as resistivity and dissipation factor, it has been adopted for transformer oil also as recommended by Indian Standard.

The limits for various characteristics after ageing have been fixed upon the customer's requirement.

(*b*) **Oxidation stability test:** Hydrocarbons easily undergo oxidation resulting in the formation of polar compounds such as aldehydes, ketones, acid and peroxide. Apart from the external impurities, oxidation products are the main cause of deterioration in the quality of oil. In several cases, the oil-insoluble sludges are formed due to oxidation and are deposited on the core and winding, which impairs the heat transfer characteristics.

These conditions result in severe damage of the equipment. Hence the oxidation stability test is very important. It is carried out by oxidizing a known quantity of oil (25 g) at 100°C with a continuous oxygen flow at the rate of 1 litre per hour in the presence of copper catalyst in the ratio of 0.39 sq. cm/g for 164 hours. The oxidized product is quantitatively analysed for the acid and sludge formed. The oil possessing inferior stability characteristics are found to yield higher acidity and sludges.

(*c*) **SK value:** SK value is defined as the increase in volume of concentrated sulphuric acid on adding a given test sample. It signifies the degree of refinement of oil. This test is still under consideration in IS-335.

The effect of SK value on other characteristic properties like resistivity, dissipation factor, and stability—like accelerated ageing and oxidation stability—have been studied in various oil refineries (namely Apar India Limited). While there exists no correlation between increase in SK values with resistivity, dissipation factor increases with SK value, but still within IS specification. Similar effect of SK value on stability characteristics do not specify any correlating trend. These results have been collected by research laboratories, like CPRI and EDRA for further study.

The present trend for the manufacture of transformer oil is based on achieving the best performance and stability characteristics specified above. The indigenous TOFS available are paraffinic in nature and require more refining. This results in eliminating some natural oxidants in oil rendering it to be less stable. However, naphthanic oil shows good trend in resistivity and temperature characteristics and being a low viscosity oil shows good heat transfer characteristics.

7.7 ELECTRICAL PROPERTIES

(*a*) **Electrical strength [breakdown value (BDV)]:** Electrical strength is the minimum electrical stress in kV that would cause a breakdown in the insulating ability of the medium when tested in the specified conditions. It is determined by applying a constantly increasing voltage at a rate of approximately 2 kV per second to the spherical or mushroom electrodes immersed in the fluid and separated by a gap of 2.5 mm. It is very sensitive to the external impurities, particularly to the presence of moisture, metallic particles, fibres etc. and are found to affect the electric strength drastically.

The measurement of breakdown voltage, therefore serves primarily to indicate the presence of contaminants such as water or conducting particles, one or more of which can be present when low breakdown voltage values are found by test. However a high breakdown voltage does not necessarily indicate the absence of contaminants.

(*b*) **Specific resistance:** It is the ratio of DC potential gradient in volts per centimetre paralleling the current flow within the specimen to the current density in ampere per square centimetre at a given instant of time and under prescribed conditions. This is numerically equal to the resistance between opposite faces of a centimetre cube of the liquid. It is expressed in ohm-centimetre. This is measured between the opposite faces of an oil sample filled in the annular gap of a three terminal test cell using a million meg-ohm-meter (ohm $\times 10^{12}$). It is sensitive to the presence of conductive impurities. When such impurities which include conductive metallic particles, ion-forming particles and free ions, are low, the oil will have a higher specific resistance. Also the presence of moisture in any of the form, such as free water and dissolved water etc. are very much prone to affect this property.

(*c*) **Di-electric dissipation factor:** Power factor is the ratio of power loss in di-electric media to the apparent power. Dissipation factor is the tangent of the angle (delta) by which the phase difference between applied voltage and resulting current deviates from $\pi/2$ radian, when the di-electric of a capacitor consists exclusively of the insulating oil.

When the angle of deviation is low, the power factor becomes the dissipation factor. The dissipation factor is a measure of power loss through the di-electric media as a result of the presence of polar molecules.

7.8 STORAGE, HANDLING AND TRANSPORT OF TRANSFORMER OIL

After the transformer oil has been produced meeting the specifications, the next decisive step is to store and deliver the product without affecting the properties. A number of crucial properties may influence the performance of oil during storage, handling and despatch. All these require a high level of expertise.

(*a*) **Storage in tank (at oil refinery):** Storage tanks used for transformer oil are similar to the tanks for other oils or chemicals, made of mild steel or stainless steel. Mild steel coated with oil resistant paints like epoxy resins are commonly used.

Water content in the transformer oil affects the insulating properties to a great extent. Exposure to humid air in storage tanks must be avoided by equipping the storage tanks with silica gel breather for extraction of moisture or by connecting a nitrogen / dry air source to the tank via pressurized valve. The loading line should be equipped with a particular filter that has nominal hole size of less than 5 microns.

(*b*) **Handling operation:** Handling operations include in-plant storage and receipt of supplies at site. It is vital to keep the tank completely separate with dedicated piping. If not possible to keep separate dedicated lines/ tank, thorough cleaning must be carried out to a degree and technique dictated by the character of the previous products. Special care has to be taken for engine oil, thermic fluid, used oils, halogenated hydrocarbon solvent etc.

Transport in tanker/drums: Tankers and drums are the most common means of transportation. Special care has to be taken about cleanliness. Tankers ideally dedicated for transformer oil are thoroughly cleaned by flushing with transformer oil. Suitability of tanker is assessed by checking the properties of the flushing oil sample. In addition to this, visual inspection of tanks and lines are done to check for cleanliness. Quality of the sample oil is checked from each compartment of the tanker. The samples from the bottom of the compartment is checked for contamination using dedicated amber coloured sample bottles.

Drums of 208 litres capacity made of mild steel having two openings, sealed with screw caps of tri-sure type are used. Empty drums are randomly checked by visual inspection for cleanliness. Each drum is flushed with transformer oil by pressurized spray cleaning system. Drums are filled, sampled and sealed. Precautions are taken by checking the seals to tighten the screw caps and keeping the drums horizontal to avoid any ingress of moisture or water.

However the oil is filled into transformer after passing through de-gassing filter as recommended by BIS.

7.9 COMPATIBILITY AND CONTAMINANTS

Transformer oil is compatible with insulating materials used in transformer and care should be taken about its compatibility with materials used in storage tank and line materials, *i.e.* rubber gaskets etc. as solubility of these will greatly affect the properties of transformer oil. When used for topping-up, the characteristic properties of the blend should be tested for interfacial tension, di-electric dissipation factor and most importantly oxidation stability. The blend must meet the specification.

Transformer oil properties may deteriorate due to contamination; occurring during handling, transportation and storage. Major contaminants could be water particles and chemical base oils/ solvents. Possible corrective action to remove these contaminants is discussed below.

(*a*) **Water:** Water is the most common contaminant in transformer oil during storage, handling and transport, especially in humid climates. Moreover, it is used as universal solvent for cleaning transport vehicles and handling equipments. Free water can be drained-off from the bottom of the tank/ container. Dissolved water can be removed by bubbling dry air/ nitrogen at slightly elevated temperatures. The most suitable and recommended method is degassing by vacuum filtration. Here the oil is heated upto 65 to 70°C, vacuum treated and filtered through particle filter.

Though this requires lot of electricity, it is by and large the most effective method.

(*b*) **Particles:** Suspended particles together with water lower the break down voltage. Particles are likely to be accumulated during storage and transportation. These particles can simultaneously be removed by grading through particle filters. A five micron filter should be used.

(*c*) **Chemical contamination:** Chemical contaminants can be either the product filled previously in the tankers used for transportation or the detergents used for equipment cleaning etc. The nature of contamination depends on the characteristics of the product. Activated clay treatment is an effective method for purification of chemical contaminant. However information on specific contaminant is required before adopting the treatment method.

Table 7.1 Comparison of characteristic requirements of transformer oil of different specifications

Sl. no.	*Characteristic property*	*IS -335*	*IEC-296 Class-I*	*IEC-296 Class-II*	*BS-148 Class-I*
1.	Appearance	The oil should be clear, transparent, free from suspended matters or sediments.			
2.	Density (max.)	0.89 g/cc at 29.5°C	0.89 g/cc at 20°C	0.89 g/cc at 20°C	0.89 g/cc at 20°C
3.	Kinematic viscosity	27 cst at 27°C	16.5 cst at 40°C and 800 cst at (–)15°C	11 cst at 40°C	16.5 cst at 40°C and 800 cst at (–) 15°C
4.	Interfacial tension (min)	35 N/m (recommended)	Not specified	Not specified	Not specified
5.	Flash point (min.)	140°C	140°C	130°C	140°C
6.	Pour point (min.)	(–) 6°C	(–) 30°C	(–) 45°C	(–) 30°C
7.	Electric strength BDV (*a*) New unfiltered oil (*b*) After filtration (min.)	 40 kV (recommended) 60 kV	 30 kV 50 kV	 30 kV 50 kV	 30 kV (as delivered)
8.	Di-electric dissipation factor at 90°C (max.)	0.0015 (recommended)	0.005	0.005	0.005
9.	Resistivity at (*i*) 90°C (*ii*) 27°C (min.)	 6×10^{12} ohms. cm 1500×10^{12} ohms. cm	Not specified	Not specified	Not specified
10	Oxidation stability (*i*) Neutralization value (*ii*) Sludge content percentage by weight (max.)	 0.4 mg KOH/g 0.1 mg KOH/g	Not specified	Not specified	Not specified
11	Neutralization value (*i*) Total acidity (*ii*) Inorganic acidity (max.)	 0.03 mg KOH/g NIL	Not specified	Not specified	Not specified
12.	Corrosive sulphur	Non corrosive	Not specified	Not specified	Not specified
13.	Oxidation inhibitor	0.05 per cent	Not detectable	Not detectable	Not detectable
14.	Water content	20 ppm (recommended)	40 ppm	40 ppm	40 ppm
15.	SK value	Under consideration	Not specified	Not specified	Not specified

Contd.

Sl. no.	Characteristic property	IS -335	IEC-296 Class-I	IEC-296 Class-II	BS -148 Class-I
16.	Accelerated ageing test (open beaker method with copper catalyst)				
	Resistivity at 27°C (min.)	2.5×10^{12} ohms-cm	Not specified	Not specified	Not specified
	Resisitivity at 90°C (min)	0.2×10^{12} ohms-cm	-do-	-do-	-do-
	Tan-delta at 90°C (max.)	0.2	-do-	-do-	-do-
	Total acidity (max.)	0.05 mg KOH/g	-do-	-do-	-do-
	Total sludge (max.)	0.5 per cent by weight	-do-	-do-	-do-

7.10 CONCLUSION

The discussion on insulating oil is concluded herewith a note below on the selection and the procedure of quality checks of unused oil before accepting a tanker for off-loading at the factory premises:

(*a*) The oil should be purchased only from the reputed manufacturers who have all the testing facilities as recommended in IS-335.

(*b*) Before accepting an oil tanker, the manufacturer's original seals at the top inlet as well as on the bottom drain valve should be checked. It should be ensured that the seals are not tampered with. If the seals are not found in good condition the tanker should not be off-loaded and the matter should be brought to the notice of the oil supplier immediately.

(*c*) Manufacturer's test certificates for oil must accompany each supply.

(*d*) In case the oil tanker has more than one compartment, the following checks on oil samples drawns from each of the compartment should invariably be done.

(*i*) The colour of the oil should be checked which should necessarily be transparent (pale yellow).

(*ii*) The smell of the oil should be natural. In case it smells like diesel or kerosene, the matter should be investigated further.

(*iii*) Di-electric breakdown value should be checked as per recommendation of IS-335 and the average breakdown value of six readings should be more than 30 kV (40 kV being recommended by ISS)

(*iv*) Off-loading of oil from the tanker should not be done during rain to eliminate the probability of contamination of water in the oil.

(*v*) Quantity verification should be done by total weight minus truck weight. The weight available after such measurement should be within a tolerance of ±1 per cent of the invoice quantity.

(*vi*) In case the requisite facilities are available with the firm; the resistivity, tan-delta, acidity etc. should also be checked for verification of the values available in the test certificates.

Section II
CHAPTER 8

Transformer Tank Body and Radiators

FOOD FOR THOUGHT

Technological advances will make many products obsolete. New processes, materials and product applications will require new skills. Companies have to be prepared to train and educate workers.

Technical vitality should be maintained to get the job done with expertise, motivation, creativity, drive, knowledge, practice and awareness. Challenges should be responded to with innovation and vitality. Partnerships with suppliers should be stressed, as an organization may not have all the required expertise and skills. An idea-friendly environment, free from perceived set of rules and regulations, will propagate creativity and teamwork.

Success depends on communication from top to bottom and vice-versa. Two-way communication must be maintained all the time. Workers have to be given tools to do the job correctly. Work-stations within the reach of those needing to use them will be required all the time. Information should be used as the basis of problem-solving, decision-making, and continuous-improvement. Data and information should be used actively for planning, day to day management and evaluation of quality and customer satisfaction. Care should be taken to assure that this information is reliable, timely, accurate and accessible to all levels of the organization.

8.1 INTRODUCTION

So far we have discussed the quality aspects of four major raw materials, viz. CRGO steel, winding wires and strips, insulating pressboards and insulating oil. We shall now take up for discussion some of the quality aspects of raw materials related to transformer tank body and radiators.

Transformer tank body acts as a liquid filled enclosure of the active part, *i.e.*, core-coil assembly. Terminations of high voltage and low voltage windings are done through porcelain bushings. Since the tank is filled with oil, it is necessary to ensure that there is no seepage or leakage of oil from any of the joints of the tank. In case the tanks are fabricated out side the factory premises or supplied by a sub-vendor, inprocess stage inspection is recommended during manufacturing. Here we shall restrict our discussion to the quality checks and limit of tolerances on the basic input materials. Procedure of quality checks on finished tanks are discussed in Section-2.

8.2 SHEET THICKNESS AND TOLERANCE

IS-1852 has recommended the following tolerances (Table 8.1) on thickness of MS sheets produced by hand mills.

Table 8.1

Thickness in mm	*Tolerance (±) in mm*
2.0	0.18
2.24	0.19
2.50	0.20
2.8	0.21
3.15	0.22
3.55	0.24
4.0	0.25
4.3	0.25
4.67	0.27

In the case of sheets of intermediate size, the tolerance for immediate lower thickness is made applicable. For example, if we are looking for thickness tolerance of 3 mm sheet, it would be the same as that applicable for 2.8 mm, *i.e.*, ±0.21 mm.

ISS has recommended different tolerance limits for sheets produced by rolled in continuous hot strip mill which are reproduced in Table 8.2.

Table 8.2

Width of sheet	*Tolerance on thickness (±) in mm*				
	1.6 to 2 mm	*Over 2 mm and up to 3 mm*	*Over 3 mm and up to 5 mm*	*Over 5 mm and up to 8 mm*	*Over 8 mm and up to 10 mm*
500 mm up to 1250 mm	0.18	0.20	0.25	0.30	0.35
Over 1250 mm up to 1550 mm	0.20	0.25	0.30	0.35	0.40
Over 1550 mm up to 1850 mm	0.22	0.28	0.35	0.40	0.40
Over 1850 mm	–	0.28	0.35	0.40	0.40

Tolerance on thickness exceeding 10 mm shall be agreed to between the purchaser and the supplier.

Since the tolerance limit available for hand drawn mill and hot rolled mill are different, the users may get confused on the correct applicability of tolerance limit. It is suggested that the tolerances as prescribed for hot rolled sheets may be considered since the availability of such sheets in the market are more.

Moreover, the thickness shall be measured at different points on the sheet as follows:

(*a*) One at each corner of the sheet

(*b*) One in the middle of the sheet

(*c*) One in the middle of the length.

These measurements shall be 25 mm away from the edge at points randomly chosen. The thickness measured at each of these points should satisfy the tolerances specified above.

8.3 ROLLING TOLERANCES ON FLATS

(*a*) Tolerance on Width of Flat

Table 8.3

Width measurement in mm	*Tolerance (±) in mm*
Upto 50 mm width	1.0
Over 50 mm and up to 75 mm	1.5
Over 75 mm and up to 100 mm	2.0
Over 100 mm	2 per cent subject to maximum of 6 mm

(*b*) Tolerance on Thickness of Flat

Table 8.4

Thickness measurement in mm	*Tolerance (±) in mm*
Upto and including 12 mm thickness	0.5
Over 12 mm	4 per cent subject to maximum of 1.5 mm

8.4 ROLLING TOLERANCE ON ROUND RODS

Table 8.5

Diameter of rod in mm	*Tolerance (±) in mm*
Up to 25 mm dia rod	0.5
Over 25 mm and up to 35 mm	0.6
Over 35 mm and up to 50 mm	0.8
Over 50 mm and up to 80 mm	1.0
Over 80 mm and up to 100 mm	1.3
Over l00 mm	1.6 per cent of diameter

8.5 TOLERANCE ON EQUAL LEG ANGLES

Table 8.6

Leg length in mm	*Tolerance (±) in mm*
Up to 45 mm	1.5
Over 45 mm and up to 100 mm	2.0
Over 100 mm	2 per cent of leg length

ISS is silent over tolerance on thickness of angle. For general guidance, the tolerance for thickness of angle may be referred to tolerances on flats as stated under Section 8.3(*b*), Table 8.4.

8.6 TOLERANCE ON CHANNELS

(*a*) Depth

Table 8.7

Depth of channel in mm	*Tolerance (±) in mm*
Up to 200 mm	2.5
Over 200 mm and up to 400 mm	3.0

(*b*) Width

Table 8.8

Width of flange in mm	*Tolerance (±) in mm*
Up to and including 100 mm	2.0

(*c*) Out of Parallel

In the case of a channel, the width of the flanges should remain almost parallel. Tolerance on out of parallel should be within 1 mm in 60 mm width or proportional thereof (refer. Fig. 8.1).

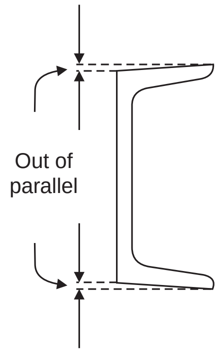


Fig. 8.1. Out of parallel on channel

(*d*) Flatness

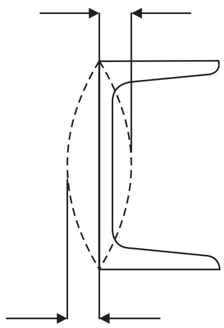


Fig. 8.2. Tolerance on flatness of channel

The tolerance on flatness on outer faces of web shall be as follows:

Convexity: Not permitted.

Concavity: 15 per cent of nominal thickness of web.

(*e*) Camber or Sweep

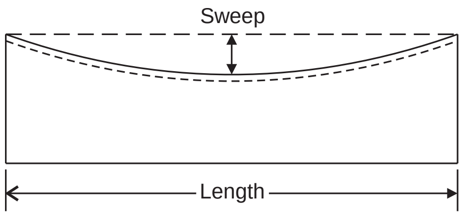


Fig. 8.3. Tolerance on camber or sweep of channel

The maximum permissible camber or sweep shall be 0.2 per cent of length

8.7 RADIATORS

The function of radiator is to dissipate heat generated in a transformer by way of radiation and/or convection. During service, the tank body can dissipate a loss equivalent to 500 watts/sq. m of the tank surface area for a maximum top oil temperature rise of 40°C. In case the total loss (*i.e.*, no load + load loss at 75°C) is more than the loss dissipated by the tank surface, the loss in excess is required to be dissipated with the help of radiators.

Types of Radiators

Radiators commonly used are of three different types. They are:

(*a*) Conventional round/elliptical tube radiator

(*b*) Pressed steel radiator

(*c*) Corrugated wall panel.

Round tube radiators are almost obsolete since its efficiency with respect to elliptical tube is poor. Moreover, round tube contains more of oil. As such we shall restrict our discussion to elliptical tube radiators only.

Elliptical tube radiators and pressed steel radiators which operate on convection process of cooling, whereas corrugated wall panel perform cooling by radiation only.

Corrugated wall panel radiators are commonly used for sealed type transformers and also in places where there are restrictions on overall dimensions. These radiators are widely used for transformers built for export, as corrugated wall panel transformers occupy less space and can accommodate more number of transformers in one container during transportation.

The design approach of each of the above radiators are different and we shall discuss them in brief in the following paragraphs.

(*a*) **Conventional elliptical tube radiators:** The standard length of elliptical tube available in the market is 6.1 m. It is cut into a number of pieces and welded together to form a radiator bank. Each radiator bank has an inlet and outlet for free flow of oil.

When a transformer is in service, losses occur which gets transformed into heat energy. As we know, liquid when heated up becomes lighter since it looses its density and results in increase in volume. The same phenomenon is applicable for transformer oil also, The heated oil becomes lighter and rises up by displacing the heavier oil on the top. The heated oil, in the process of displacement, has no other alternative but to push through the outlet (top) of the header pipe. When the oil gets into the header pipe, due to gravity the oil falls down through the pipe and reaches at the inlet pipe, Thus the sequence of oil flow by natural convection is established. The circulation of oil is represented by a flow diagram in Fig. 8.4.

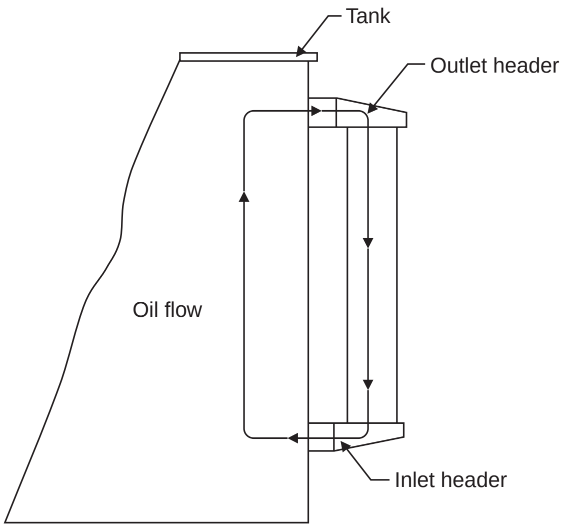


Fig. 8.4. Elliptical tube radiator and flow of oil

(*b*) **Pressed steel radiators:** Pressed steel radiators are produced from 1.0 to 1.2 mm CRCA sheet of width varying between 230 mm, 300 mm and 520 mm. The centre height of radiators are from 400 mm to 3200 mm in multiples of 100 mm. Number of fins per radiator is calculated on the basis of guaranteed losses and dissipation chart. For reference the dissipation per fin for various length and width of radiators is shown in Tables 8.9 to 8.12.

(*i*) ***Vertical distance between transformer core and radiator centre line*:** The difference between the core centre line and radiator centre line is shown in Fig. 8.5. The correction factor corresponding to the value of *'x'* is derived from Table 8.10.

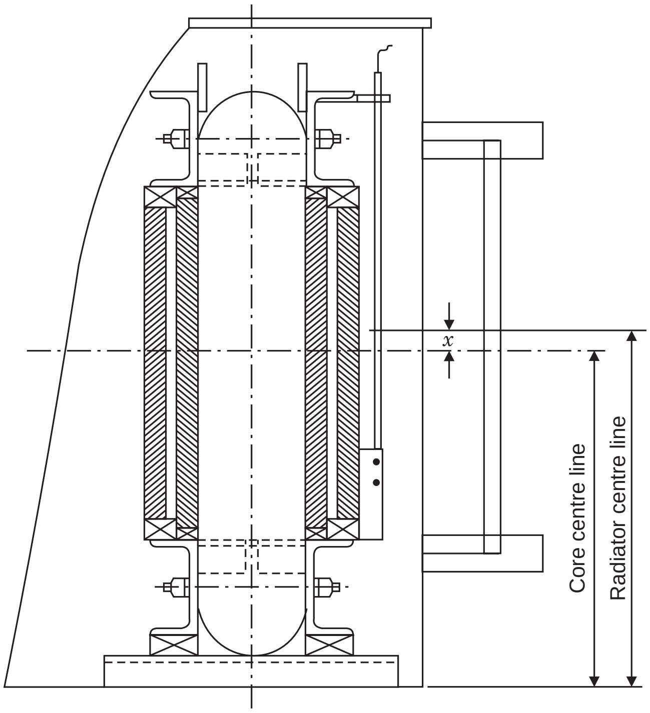


Fig. 8.5. Correction factor for vertical distance between transformer core and radiator centre lines

(*ii*) ***Horizontal distance between two consecutive radiators:*** Figure 8.6 shows four radiators fixed on the longer side of the tank with the distance between two consecutive radiators as '*c*'. The correction factor corresponding to the value of *'c'* is derived from Table 8.10.

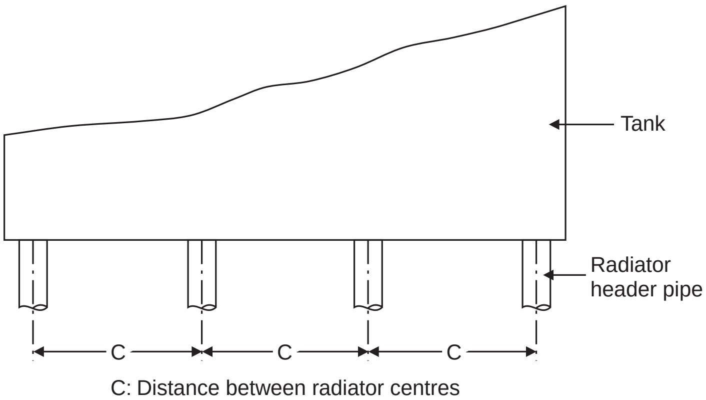


Fig. 8.6. Horizontal distance between consecutive radiators

Table 8.9 Heat Transmission Table for 'on' Cooling Section width—226 mm (3 Channels))
Heat Dissipated for Oil Excess Temperature of

CC (mm)	*Cooling area (m^2)*	*35°C watts per*		*40°C watts per*		*45°C watts per*		*50°C watts per*		*55°C watts per*		*60°C watts per*		** Oil content per section (I)*	*** Weight per section (kg)*
		see	*m^2*	*see*	*m^2*	*see*	*m^2*	*see*	*m^2*	*see*	*m^2*	*see*	*m^2*		
600	0.280	72	290	81	331	92	337	105	423	120	472	130	527	0.9	2.66
700	0.343	98	285	112	326	127	370	143	416	160	465	178	519	0.97	3.56
800	0.390	109	280	125	321	142	363	160	409	179	458	119	511	1.12	4.01
900	0.437	120	275	138	316	156	357	176	402	197	451	219	502	1.27	4.46
1000	0.484	131	270	151	311	170	351	191	395	215	444	239	494	1.42	4.91
1100	0.531	141	266	162	306	184	346	207	389	232	437	258	486	1.57	5.36
1200	0.578	151	261	175	302	197	340	221	382	249	431	276	478	1.72	5.81
1300	0.625	161	257	186	297	209	335	235	376	265	424	294	470	1.87	6.26
1400	0.672	170	253	196	292	222	330	248	369	280	417	310	462	2.02	6.71
1500	0.719	179	249	207	288	234	325	261	363	295	410	326	454	2.17	7.16
1600	0.766	188	245	218	284	245	320	274	358	309	404	342	446	2.32	7.61
1700	0.813	197	242	228	280	256	315	286	352	324	398	357	439	2.47	8.06
1800	0.860	206	239	237	276	267	311	298	347	336	391	372	432	2.62	8.51
1900	0.907	213	235	248	273	278	306	310	342	349	385	386	426	2.77	8.96
2000	0.954	222	233	257	269	288	302	322	338	363	380	400	419	2.92	9.41
2100	1.001	230	230	266	266	298	298	333	333	375	375	413	413	3.07	9.86
2200	1.048	238	227	276	263	309	295	345	329	388	370	427	407	3.22	10.31
2300	1.095	246	225	284	259	319	291	356	325	400	365	440	402	3.37	10.76
2400	1.142	255	223	292	256	329	288	368	322	411	360	452	396	3.52	11.21
2500	1.189	262	220	301	253	339	285	379	319	422	355	465	391	3.67	11.66
2600	1.236	269	218	309	250	349	282	389	315	434	351	477	386	3.82	12.11
2700	1.283	277	216	318	248	358	279	399	311	445	347	490	382	3.97	12.56
2800	1.330	285	214	326	245	367	276	410	308	456	343	504	379	4.12	13.01
2900	1.377	293	213	335	243	376	273	421	306	467	339	516	375	4.27	13.46
3000	1.424	300	211	343	241	386	271	431	303	478	336	528	371	4.42	13.91

* Add 0.60 litre per section to include oil in header pipes.

** For the weight of the radiator, multiply by number of sections, and add the weight of flanges, straps, sockets, plugs etc. (totalling to 6 kg approx.)

Table 8.10 Heat Transmission Table for 'on' Cooling Section width—226 mm (3 Channels))
Heat Dissipated for Oil Excess Temperature of

CC (mm)	*Cooling area (m^2)*	*35°C watts per*		*40°C watts per*		*45°C watts per*		*50°C watts per*		*55°C watts per*		*60°C watts per*		** Oil content per section (litres)*	*** Weight per section (kg)*
		sec	*m^2*	*sec*	*m^2*	*sec*	*m^2*	*sec*	*m^2*	*sec*	*m^2*	*sec*	*m^2*		
700	0.447	125	280	143	320	163	365	179	400	206	460	230	514	1.46	4.57
800	0.510	140	275	161	316	183	358	205	403	231	453	258	505	1.66	5.17
900	0.573	155	270	178	311	202	352	227	396	256	446	284	496	1.86	5.77
1000	0.636	169	265	194	305	220	346	248	390	279	439	310	488	2.06	6.37
1100	0.699	182	260	210	300	238	340	268	383	302	432	336	480	2.26	6.97
1200	0.762	194	255	226	296	255	334	287	377	325	426	360	472	2.46	7.57
1300	0.825	207	251	240	291	271	329	305	370	346	419	384	465	2.66	8.17
1400	0.888	219	247	254	286	288	324	322	363	366	412	405	456	2.86	8.77
1500	0.951	231	243	268	282	304	320	340	357	385	405	427	449	3.06	9.37
1600	1.014	242	239	282	278	319	315	357	352	404	398	446	440	3.26	9.97
1700	1.077	255	237	295	274	334	310	373	346	422	392	466	433	3.46	10.57
1800	1.140	266	233	310	272	348	305	390	342	440	386	486	426	3.66	11.17
1900	1.203	277	230	322	268	361	300	404	336	457	380	505	420	3.86	11.77
2000	1.266	289	228	333	263	376	297	420	332	474	375	523	413	4.06	12.37
2100	1.329	299	225	346	260	389	293	436	328	492	370	542	408	4.26	12.97
2200	1.392	309	222	358	257	404	290	448	322	508	365	560	402	4.46	13.57
2300	1.455	320	220	367	252	415	285	466	320	524	360	576	396	4.66	14.17
2400	1.518	331	218	380	250	428	282	480	316	539	355	594	391	4.86	14.77
2500	1.581	340	215	391	247	441	279	495	313	553	350	610	385	5.06	15.37
2600	1.644	350	213	401	244	455	277	510	310	569	346	625	380	5.26	15.97
2700	1.707	360	211	413	242	466	273	521	305	584	342	642	376	5.46	16.57
2800	1.770	368	208	425	240	480	271	536	303	597	337	660	373	5.66	17.17
2900	1.833	379	207	434	237	491	268	550	300	610	333	678	370	5.86	17.77
3000	1.896	389	205	446	235	502	265	563	297	626	330	694	366	6.06	18.37

* Add 0.60 litre per section to include oil in header pipes.

** For the weight of the radiator, multiply by number of sections, and add the weight of flanges, straps, sockets, plugs, etc. (totalling to 6 kg approx.)

Table 8.11 Heat Transmission Table for 'on' Cooling Section width—520 mm (7 Channels)
Heat Dissipated for Oil Excess Temperature of

CC (mm)	*Cooling area (m^2)*	*35°C watts per*		*40°C watts per*		*45°C watts per*		*50°C watts per*		*55°C watts per*		*60°C watts per*		** Oil content per section (Litres)*	*** Weight per section (kg)*
		see	*m^2*	*see*	*m^2*	*sec*	*m^2*	*sec*	*m^2*	*sec*	*m^2*	*sec*	*m^2*		
700	0.756	197	261	229	303	258	341	290	383	326	431	363	480	2.61	7.48
800	0.864	223	258	259	300	292	338	327	379	269	427	410	435	2.96	8.52
900	0.972	248	255	289	297	326	335	365	375	410	422	457	470	3.31	9.57
1000	1.080	272	252	318	294	359	332	401	371	449	416	501	464	3.66	10.61
1100	1.188	297	250	345	290	390	328	436	367	488	411	545	459	4.01	11.66
1200	1.296	319	246	371	286	420	324	469	362	525	405	586	452	4.36	12.70
1300	1.404	341	243	396	282	449	320	501	357	560	399	626	446	4.71	13.74
1400	1.512	361	239	420	278	476	315	531	351	594	393	665	440	5.06	14.79
1500	1.620	382	236	444	274	502	310	561	346	627	387	706	436	5.41	15.83
1600	1.723	401	232	467	270	527	305	589	341	658	381	736	426	5.76	16.88
1700	1.836	419	228	488	266	551	300	615	335	687	374	771	420	6.11	17.92
1800	1.944	437	225	507	261	575	296	642	330	717	369	803	413	6.46	18.96
1900	2.052	456	222	527	257	597	291	667	325	743	362	835	407	6.81	20.01
2000	2.160	471	218	549	254	618	286	691	320	771	357	864	400	7.16	21.05
2100	2.268	490	216	567	250	640	282	714	315	796	351	894	394	7.51	22.10
2200	2.376	504	212	587	247	661	278	737	310	822	346	920	387	7.86	23.14
2300	2.484	519	209	604	243	681	274	758	305	847	341	946	381	8.21	24.18
2400	2.592	534	206	622	240	700	270	778	300	871	336	975	376	8.56	25.23
2500	2.700	548	203	640	237	721	267	799	296	894	331	999	370	8.91	26.27
2600	2.808	564	201	654	233	741	264	820	292	918	327	1025	365	9.26	27.32
2700	2.916	577	198	671	230	758	260	843	289	942	323	1050	360	9.61	28.36
2800	3.024	590	195	686	227	777	?57	862	285	965	319	1074	355	9.96	29.40
2900	3.132	604	193	702	224	796	254	883	282	990	316	1096	350	10.31	30.45
3000	3.240	616	190	716	221	813	251	904	279	1011	312	1121	346	10.66	31.49

* Add 0.60 litre per section to include oil in header pipes.

** For the weight of the radiator, multiply by number of sections, and add the weight of flanges, straps, sockets, plugs etc. (totalling to 6 kg approx.)

Table 8.12 Correction Factors for Heat Transmission Data

The best transmission depends on the actual disposition of the radiators. The following correction factors will apply for different dispositions										
1.	Vertical distance between transformer core (mm) centre line and radiator centre line.	0	100	200	300	400	500	600	800	1000
	Correction factor	0.80	0.85	0.89	0.93	0.95	0.98	1.00	105	1.10
2.	(*a*) Horizontal distance between 226 mm (mm) (3 channel radiators)	280	300	325	360	400	450	600		
	Correction factor	0.76	0.82	0.86	0.91	0.95	0.99	1.00		
	(*b*) Horizontal distance between 300 mm (mm) (4 channel radiators)	350	375	400	425	450	500	550		
	Correction factor	0.75	0.82	0.87	0.90	0.93	0.97	1.00		
	(*c*) Horizontal distance between 520 mm (mm) (7 channel radiators)	550	575	600	625	650	700	750		
	Correction factor	0.80	0.89	0.92	0.93	0.95	0.98	1.00		
3.	No. of sections per radiator	3	4–5	6–8	9–11	12–14	15–17	18–20	21–24	
	Correction factor	1.10	1.06	1.02	1.00	0.99	0.98	0.97	0.96	

(*c*) **Corrugated wall panel:** In recent times, in response to the increase in cost of materials and labour, a new concept in heat exchange, by the use of built in corrugations on transformer tank wall, has virtually eliminated the concept of radiator practically for distribution transformers; in all advanced countries.

The corrugated wall panels are fabricated from CRCA steel sheet of thickness ranging from 0.75 mm to 1.2 mm, using special purpose machines. The plain side wall, top cover and bottom of the tank are constructed in the conventional manner using regular mild steel materials. Structural steel items, like angles, channels etc. are used wherever required for strength and support.

Apart from the benefit of compactness, elegant appearance and saving in steel, oil freight cost and space are the major advantages with such constructions that lends itself ideal for making hermetically sealed transformers. Bellows action of the corrugation itself will accommodate the expansion and contraction of the transformer oil. Thus with the elimination of contact of oil with the outside atmosphere, the whole arrangement becomes maintenance free.

Exotherm Pvt. Ltd., Mahadevpur, Bangalore and Kotson, Agra are equipped with such special purpose machines and are in a position to supply either complete tank or just corrugated wall panels as per customer's specification.

A complete view of a corrugated wall tank is shown in Fig. 8.7.

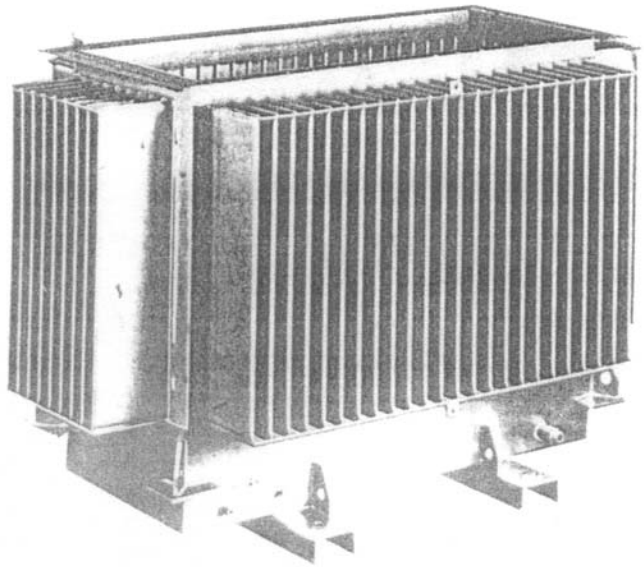


Fig. 8.7. Photograph of corrugated wall tank for distribution transformer

8.8. CONCLUSION

The discussion on transformer tank body and radiators is concluded highlighting few points on the basic checks of steel materials and radiators:

(*a*) The surface of the MS plates and sheets for fabricating the tank body should be smooth. The sheet/plate with pitted surface and/or wavy surface should not be used.

(*b*) Channel should be checked for out of square, camber, convexity, concavity etc. before processing.

(*c*) Flat, angle, channel, rod etc. should be checked to verify their dimensions with respect to the tolerance limits available in IS-852.

(*d*) Sheet thickness should be checked to verify the conformity with the specified limit.

(*e*) Wall thickness of elliptical tube having section 75 × 15 mm is 18 swg (1.2 mm) and weight per metre is approximately 1.5 kg. Material—CRCA sheet.

(*f*) In case of pressed steel radiators, the fins connected between the pipes at top and bottom should remain parallel. The seam welding, joining the two sheets of a fin, should be uniform. If the number of fins in a radiator is more than 5, then all the fins should be tied with a thin flat as stiffener. The stiffener can be either at the centre of the fin or at top and bottom as per requirement.

(*g*) Header pipe of pressed steel radiator should be made from a seamless pipe and not from a pipe made out of sheet. The wall thickness of such pipes should be around 3 mm.

(*h*) In case of detachable radiator, air release plug at top and drain-out socket at the bottom should invariably be provided in each radiator.

(*i*) Inside of both elliptical tube radiators and pressed steel radiators should be coated with hot oil proof varnish or zinc chromate base paint.

(*j*) Since welding electrodes are considered to be one of the basic inputs for the tank fabrication, the quality of the same should be monitored. Generally, electrodes are available from the quality suppliers, *viz.* Indian oxygen, Advani or likon, Modi group etc. However, incase a new vendor is to be introduced, samples of each gauge of electrode should be used on trial before approving for regular use. It has been seen on a few occasions that these new vendors while seeking approval for their products use the electrodes of the reputed firms as samples, packed in their own branded cartons. This is how they try to make fool of the users. Consistency in the quality of the electrodes also should be checked with new suppliers.

Section II

CHAPTER 9

Porcelain Bushing and Fitting, Off-Circuit Ratio Switch and Gaskets

FOOD FOR THOUGHT

The cost of quality should be tracked, *i.e.* the costs of prevention, appraisal, internal failure and external failure etc. should be visible to all. Scrap, re-work, large inventory of raw materials and finished goods and warranty costs should be reduced. Just-In-Time (JIT) and continuous flow manufacturing should be part of the planning process. Scrap and re-work eat away profit. Scrap and re-work are related to poor processes, inadequate tools and a lack of training. They should be completely eliminated with properly designed processes, adequate tools and training.

Profitability can be increased by using TQM along with bench-marking principles. Continually improving and evaluating processes will help an organization to respond better to market needs. All stakeholders should be involved in the planning stages. A strategic direction and long-term planning are essential for future growth.

Quality gurus Deming, Juran, and Crosby have preached that top management involvement is essential for quality efforts to succeed. Managers should act as change agents. Processes should be reviewed periodically to incorporate new changes and delete old ways of doing business. Resistance to change should be avoided by clear communication of the benefits of the changes. Change should not be forced, but should be implemented smoothly. Obstacles to change can be overcome with better understanding and a team approach.

Managers today should learn to delegate responsibility and authority by using participative management principles. Manager must not abuse the system. Employee empowerment and teamwork are essential for success. Manager needs to learn the importance of controlling the process and not the product or end result. Management determines the climate and frame-work of operations. A reactive and crisis-oriented management style focusing on short-term goals must give way to a system that is constantly focused on customers and their needs and expectations. Top management should be personally committed, visible and involved in development, and should maintain a focus on customer satisfaction and service quality. Measurement analysis and continuous improvement should be the foundation of the strategy. Effective leadership will manage boundaries and core competencies by keeping an eye on mission, vision, values and principles.

Deming's PDCA (Plan-Do-Check-Act) cycle is a useful management tool. Success requires personal integrity, ethical conduct and team work.

9.1 CLASSIFICATION OF BUSHINGS AND FITTINGS

Bushings are used for terminating windings on the tank body. It is made out of porcelain and generally brown glazed in colour. The ISS references for different classes of bushings are shown in Table 9.1.

Table 9.1

Particulars	*Dimensions of porcelain bushing-ISS reference*	*Dimensions of metal parts and gasket—ISS reference*
Upto and including 1 kV bushing	IS-3347 (Part-I/Sec-1)	IS-3347 (Part-I/Sec-2)
3.6 kV bushing	IS-3347 (Part-II/Sec-1)	IS-3347 (Part-II/Sec-2)
12 and 17.5 kV bushing	IS-3347 (Part-III/Sec-1)	IS-3347 (Part-III/Sec-2)
24 kV bushing	IS-3347 (Part-IV/Sec-1)	IS-3347 (Part-IV /Sec-2)
36 kV bushing	IS-3347 (Part-V/Sec-1)	IS-3347 (Part-V/Sec-2)

For 6.6 kV class transformer with system high voltage of 7.2 kV it is recommended to use 12 kV bushing.

The minimum creepage distance recommended by IS-3347 for lightly polluted atmosphere is 16 mm/kV. The numerical values would be 280 mm for 17.5 kV, 384 mm for 24 kV and 576 mm for 36 kV bushings.

The physical parameters and the dimensions of porcelain bushings for lightly polluted atmosphere are covered under IS-3347.

In the case of bushings for heavily polluted atmosphere, the minimum total creepage distance shall be 25 mm/kV for highest system voltage. The numerical values would be 438 mm for 17.5 kV, 600 mm for 24 kV and 900 mm for 36 kV systems. Dimensions of porcelain bushings used for heavily polluted atmospheres are covered under:

IS-8603 (Part-I) : For 17.5 kV bushing

IS-8603 (Part-II) : For 24 kV bushing

IS-8603 (Part-III) : For 36 kV bushing.

9.2 SELECTION OF BUSHING

Bushings are selected on the basis of highest system voltage as well as continuous rated current equivalent to its rated kVA and is designated as kV/A.

For a 100 kVA, 11/0.433 kV transformer, the highest system voltage for HV is 12 kV and rated current is 5.25 A. It is recommended to use HV bushings for normal polluted atmosphere in accordance with IS-3347, Part-III/Sec-l and is designated as 12 kV/250 A.

Similarly, the highest system voltage for LV is 1 kV and rated LV current is 133.33 A. It is recommended to use LV bushings in accordance with IS-3347, Part-I/Sec-l and is designated as 1 kV/250A.

9.3 QUALITY CHECKS ON PORCELAIN BUSHINGS

Physical Appearance

The external surface of the bushing should be uniform without any blister or surface crack.

Entire external surface except the recommended portions shall be of brown glazed. Recommended portions as suggested in ISS shall remain absolute flat/unglazed to ensure proper sealing, particularly the bushing areas which come in contact with the tank surface as well as metal fittings and gaskets. These surfaces should critically be attended to for flatness.

Dimension Check

Unless otherwise specified, the tolerance on dimension of porcelain bushing shall be $\pm (0.03d + 0.3)$ mm, where d is the dimension in millimetre.

For example, the total length of 12 kV/250 A bushing as per IS-3347 (Part-III/Sec-1) is 295 mm.

Tolerance allowed = $\pm (0.03 \times 295 + 0.3)$

= $\pm$ 9.15 mm (which is roughly 3.1 per cent of the declared length)

Similarly the diameter of the bottom portion of the bushing which goes into the tank is 70 mm.

Tolerance allowed = $\pm (0.03 \times 70 + 0.3)$

= $\pm$ 2.4 mm (which is roughly 3.4 per cent of the declared diameter)

Check on Under Fire or Porosity

It is suggested to locate a portion of a cracked bushing where the white portion is visible. Add one drop of concentrate fountain pen ink and let it remain for an hour. In case the firing of the porcelain is satisfactory and the porosity is satisfactory, the ink drop will not spread appreciably, or else, you will notice that the ink has spread over a considerable area indicating unsatisfactory firing and porosity. This is a typical method of checking porosity on porcelain products at site where no appropriate equipment to assess porosity is available.

Check on Electrical Parameters

Since bushing is one of the sensitive components which affect the performance of a transformer, we must ensure its quality to satisfy the electrical parameters before accepting it for use. ISS has recommended a couple of routine tests. Vendor approval should be done only after assessment of the availability of testing facilities. It is recommended to accept bushings only on the basis of manufacturer’s test certificates. In case the test certificate is not available along with the supply, the bushing should not be approved for use. Upon receipt of test certificate, the same should be reviewed by the quality assurance engineer.

Moreover, during physical verification, it is to be ensured that the manufacturer's name and month/year of manufacture are visible on the bushing surface. This will help the user to keep a check on the traceability.

9.4 QUALITY CHECKS ON BUSHING FITTINGS

Dimension

Unless otherwise specified the allowable tolerance on dimensions of any machined metal part and / or forged or cast metal part shall be in accordance with IS-2102 (with medium class for machined components and coarse class for forged or cast components).

However the tolerance may be restricted to ±1 per cent of the declared dimensions.

Weight of Complete Bushing Fittings

Though ISS is silent on this requirement, it is suggested to make a proto-type assembly as sample with all standard components as per recommendation of ISS. The weight of such sample assembly may be kept as reference for random checking and verification. In case the weight of such assemblies during the incoming material inspection is found to be less than 5 per cent with respect to the standard as stated above, such fittings may not be accepted and the cause of such under weight may be investigated. This is a unique routine practice for PSEB while carrying out inspection in the manufacture's premises.

Check on Proper Threading

Since fittings are used to conduct current from the transformer to the distribution system, it is recommended to check the main stud for proper threading. In case the grip between the nut and the stud is found too loose, *i.e.* if the nut plays loose between the threads of the stud, the material may not be accepted since such assemblies may cause unnecessary arcing and sparks during service.

Check on Thickness of Nuts

It is often seen that the fittings are supplied with nuts having lesser thickness than that specified in ISS. Users should make a note of it while carrying out incoming material inspection. Number of nuts per fitting should also be checked with respect to the requirement of ISS. All nuts should be of uniform thickness since provision of lock nut is not there in IS-3347 and the same may be checked before using the material.

9.5 OFF-CIRCUIT RATIO SWITCH

Use of ratio switch in a transformer is to adjust the number of HV turns with respect to the incoming supply, in order to maintain a constant secondary voltage. It is a three phase gang-operated switch generally placed over the core-coil assembly of the transformer in oil. The switch has an operating shaft which is coupled mechanically with the handle fixed on the side wall of the tank. The tap contacts are mounted on an insulated bakelite plate over the periphery of a circle. A gun metal spring loaded ring touches two of the contacts over a snap action. Construction of an off-circuit switch with operating handle is shown in Figs. 9.1 and 9.2 respectively.

Since the ratio switch is used on HV side of the transformer, it is designed to withstand the BIL of the HV winding, both for separate source as well as impulse voltage requirement. Moreover, the switch contacts should also be quite rigid to eliminate the probability of getting loose contact during service.

The following points may also be kept in mind while carrying out incoming material inspection:

(*a*) Manufacturing drawing showing various dimensions of the switch and the operating handle is made available at the time of incoming material inspection.

(*b*) Grade of bakelite sheet used for the contact plates should be mentioned in the drawing. Hylum make of electrical grade (P-120 or P-116) is preferred.

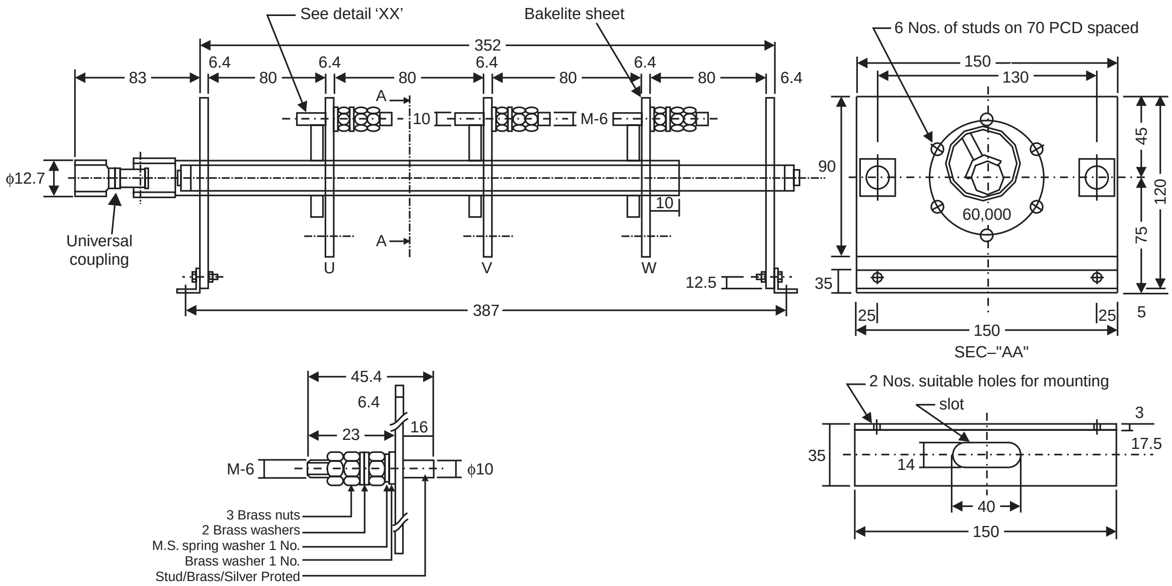
(*c*) Contact pins should be made out of extruded copper or brass rod as per design requirement. Cast rod should be avoided.

(*d*) Tie rods used for clamping the bakelite plates should be of glass-fibre material.

(*e*) Spring tension of the roller contact should be such that the contact resistance is minimum.

(*f*) It is preferred to provide universal coupling instead of rigid coupling between the operating shaft of the switch and switch handle.

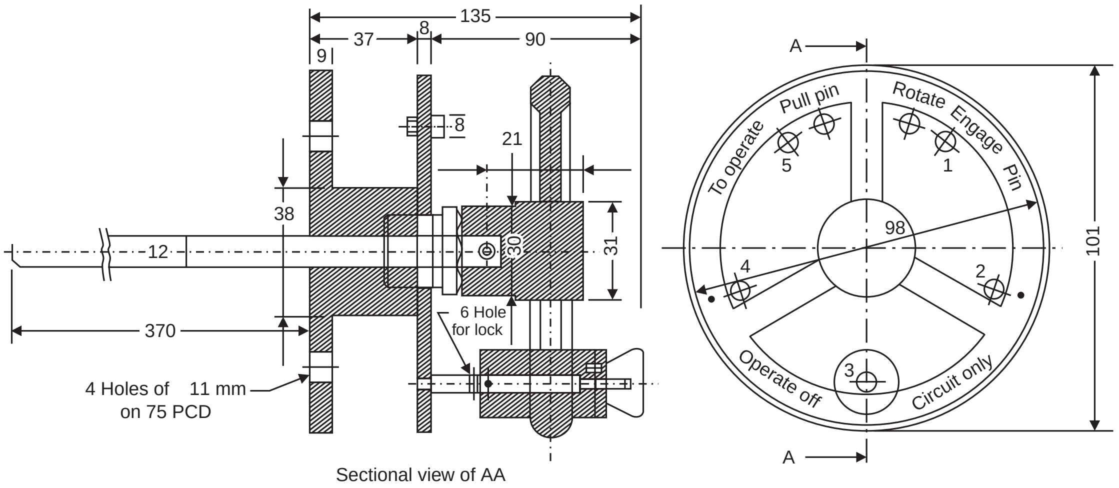
(*g*) Suitable provision of locking the handle at a particular tap position should be made.



Notes: Details of 'XX'

1. End TIE rods to be covered by SRBP tubes
2. Fibreglass operating shaft up to 'W' phase only
3. All dimensions are in mm unless otherwise specified

Fig. 9.1. Off-circuit tapping switch, 5 position, 11 kV, 30 A



Notes:
1. All Dimensions are in mm
2. ±10% Tolerance on dimension

Fig. 9.2. Tap changer handle

9.6 GASKET

Gasket is used between the joint of two metal surfaces. It is made out of synthetic rubber and cork. Synthetic rubber bonded cork sheet is the mixture of Nitrile Butadine Neoprene rubber and cork with certain amount of chemicals.

Cork and rubber is taken approximately in equal ratio by weight and is reinforced with filler not more than 10 per cent.

Following chemicals are added:

(*a*) Accelerator : Varies from 1.5 to 2 per cent

(*b*) Steric acid : 2 per cent (max.)

(*c*) Zinc oxide : 5 per cent (max.)

(*d*) Plasticizer : for easy processing and longer shelf life

(*e*) Suitable anti-oxidant, anti-fungus and ozone resistance chemical.

The brand name of acceptable quality of gasket material is RC-70 and is covered under IS-4352 (Part-II).

It is very difficult to ascertain the quality of gasket material by visual inspection. It is therefore recommended to procure the gaskets from the reputed manufacturers only. It is often seen that some gasket manufacturers adulterate the product with natural rubber instead of synthetic rubber. To keep a check on such products, it is suggested to do the following factory checks:

A small piece of gasket material is kept in a closed glass jar filled with petrol for 24 hours. In case the sample is made out of a combination of synthetic rubber and cork, the shape and size of the sample will remain unchanged. However for a combination of natural rubber and cork, the volumetric expansion of the sample will be abnormal and roughly it will be double compared to the original size.

The results of such checks may also be demonstrated to the gasket manufacturers for their knowledge as well as for improvement in the subsequent lot.

9.7 OTHER MATERIALS

So far, we have covered in brief, discussions on the following raw materials and components:

- CRGO silicon steel
- Winding wires and strips
- Insulating pressboards
- Insulating oil
- Transformer tank body and radiators
- Porcelain bushing and fitting
- Off-circuit ratio switch
- Gasket.

There are various other materials which also influence the quality of the ultimate product. But it is not in the scope of this book to discuss those materials/components. However the ISS to be referred for adopting necessary quality assurance procedures are given here.

IS-5	Colours for ready mix paints and enamels.
IS-335	New insulating oil.
IS-649	Methods of testing steel sheets for magnetic circuits of power electrical apparatus.
IS-1180	Outdoor transformers up to 100 kVA, 11 kV.
IS-1852	Specification for rolling and cutting tolerances for hot rolled steel products, (which covers MS sheet, angle, channel etc.).
IS-1866	Code of practice for maintenance and supervision of mineral insulating oil in equipment.
IS-2026	Specification for power transformers.
IS-3024	Grain oriented electrical steel sheets and strips.
IS-3070	Specification of lightning surge arrestors.
IS-3347	Dimensions for porcelain transformer bushings.
IS-3637	Specification for Gas operated relays.
IS-3639	Specification for fittings and accessories for power transformers.
IS-4257	Dimension for clamping arrangement for porcelain transformer bushings.
IS-5484	EC grade aluminium rod produced by continuous casting and rolling.
IS-6160	Rectangular conductors for electrical machines (withdrawn).
IS-6162	Paper covered aluminium conductors (round and rectangular).
IS-6792	Method for determination of electric strength of insulating oils.
IS-7404	Paper covered copper conductor (round and rectangular).
IS-8570	Specification for press paper for electrical purposes.
IS-8603	Dimensions of porcelain transformer bushings for use in heavily polluted atmospheres.
IS-9147	Specification for cable sealing boxes upto 36 kV.
IS-9335	Specification for cellulose papers for electrical purposes.

IS-10028	Code of practice for selection, installation and maintenance of transformer.
IS-10711	Sizes of drawing sheets.
IS-11171	Specification for dry type transformers.
IS-12444	Continuously cast and rolled electrolytic copper wire rods for electrical conductors.
REC-2/1971	Outdoor type three phase transformers upto 100 kVA.
IEEMA-14: 1992	IEEMA standard for buchholz relay for transformers.
IEC-76	Specification for power transformers (International standard).
BS-171	Specification for power transformers (British standard).
IEC-296	Specification for unused mineral insulating oils for transformer and switchgears (International standard).
IEC-148	Unused mineral insulating oil for transformers and switchgears (British standard).

9.8 NON-CONFORMANCE

It is recommended to document first the quality requirements of all major materials and components and subject them to checks during incoming materials inspection as per procedure. In case, the facilities for carrying out the electrical and mechanical checks on incoming materials/components are not available, the materials may be accepted on the basis of manufacturer's test certificates. However the results of such tests should be reviewed with respect to the requirements of ISS before acceptance.

The materials/components which do not conform to the requirements of relevant ISS and/or the specifications assigned by the design department, are generally called ‘non-conforming materials’. The non-conforming materials are stored in an identified area (commonly known as quarantine area). It is to be ensured that the non-conforming materials are not used for normal production. The non-conformance should be recorded in a register for analysing its causes. Such review reports should be sent to the respective vendors for taking necessary corrective measures for improvement of quality in subsequent supplies.

Recording of non-conformance is done under the following four categories:

(*a*) Nature of non-conformance

(*b*) Analysis of non-conformance

(*c*) Corrective action proposed

(*d*) Disposition.

Example:

Let us sight a specific example of recording a non-conformance on winding wires supplied by the X-Party.

As per the requirement of the purchase order, the sizes of the bare and the covered wires were specified as 1.4 mm and 1.65 mm respectively.

However, the material supplied by the vendor was checked during incoming inspection and was recorded as

Bare size : 1.38 mm

Covered size : 1.62 mm

Therefore the size of the bare wire was less by (1.4 – 1.3 8) = 0.02 mm(–)

Since the reduction in diameter was 0.02 mm as against the tolerance allowed on 1.4 mm dia. wire of ± 0.014 mm, the material was declared non-conforming and was not taken to use.

9.9 PROCEDURE OF RECORDING NON-CONFORMANCE

(*a*) **Nature of non-conformance:** Winding wires supplied by X-Party against P.O.No..........under Invoice No..........Dated ....was found to be of dia. 1.38 mm as against a requirement of 1.4 mm.

(*b*) **Analysis of non-conformance:** Tolerance allowed on 1.4 mm dia. wire is ± 0.014 mm. Since the size of the bare wire supplied by X- Party is less by (–) 0.02 mm, the material is beyond tolerance limit.

(*c*) **Corrective action proposed:** Under-sized conductor may cause over heating and may result in the failure of transformer and hence the material should not be accepted for use.

(*d*) **Disposition:** The material is recommended for rejection.

Report reviewed by:

(*i*) ***Q.A. Engineer :*** ....

(*ii*) ***Authority :*** ....

It is clear from the above recording that the material was rejected because of poor quality. Purchase department should communicate the cause of rejection to the supplier with a note to improve upon the quality in future lot.

9.10 CONCLUSION

The discussion on raw materials can be concluded with a specific mention that quality of materials/ components is the main pillar upon which the success of the finished product depends. The working engineers should be encouraged to make it a routine practice to check the incoming materials before accepting them for use. In the case of non-conforming materials, the same should be recorded in the register as highlighted above. By this process, the suppliers will also get tuned to produce quality materials. If a particular supplier fails to cope with the quality requirements, he may be disqualified from doing further business.

In the transformer industry, very few materials and components are kept in stores. Major materials like CRGO steel, MS sheet, angle, channel, tank, oil drum etc. are stored either in the workshop or in the open yards. The raw materials and components, either kept in stores or in the workshop or in the open yards, should be stacked properly so that the physical value of the materials are not abused. In ISO-9000, this aspect is known as condition monitoring which is discussed in Section-II of this book. The procedures of storing some of the vital raw materials are discussed there.

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SECTION III

Process Control

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Section III

CHAPTER 10

Process Control—A Part of Quality Assurance

FOOD FOR THOUGHT

One of the core elements of TQM is process orientation. It requires one to be oriented towards process rather than results. It shows firm belief in the theory that if a process is good, the results are bound to be favourable. One aims at better results through more capable processes. Quality gurus have long been saying that 85 per cent of quality problems are system related and are under management control and only 15 per cent are people (employee) related.

A process is defined as a series of activities or tasks performed to produce a desired results. The process, by a series of operation converts available inputs into desired output. All work one does is a process. While most people can relate to processes in manufacturing, they do not see work in offices or in administrative function as processes. The essential features of a process are inputs of various types used to produce an output or outputs by a series of value adding activities. The inputs are provided by suppliers and the output goes to customers. There has to be an agreement between the processor and his suppliers about the requirements that the inputs must meet.

Every company, however small it may be, carries a large number of processes. These processes are connected to one another by linkage between internal customers and internal suppliers. The output of one process becomes the input of the next process.

AT A GLANCE

With a view to attain higher reliability and economy in the power system operation, the QUALITY ASSURANCE in the field of power and distribution transformers has claimed growing attention. Besides new developments in the material technology and manufacturing processes of transformers, regular diagnostic testing and maintenance can help to achieve higher reliability. The quality performance of any engineering product may be ascertained by ensuring (*i*) correct selection of materials and their quality checks, (*ii*) application of correct manufacturing processes, and (*iii*) the user's awareness towards preventive maintenance of transformers on service. The successful performance of the product can only be assured once these three independent functioning authorities (vendors, manufacturers and utilities) join hands together for the common cause, *i.e.*, 'QUALITY ASSURANCE'. Without this tie-up, we can not expect uniform quality product with satisfactory life span.

Keeping the above in mind and to identify the responsibility of each individual, the content of the chapter is framed.

10.1 INTRODUCTION

Process is a sequence of steps and operation which blend the inputs to produce required outputs that satisfy the customers who receive them. Quality assurance is a set of well integrated and planned activities which gives confidence to the management that the requirements of the customers will be met. ISO : 9000 standards describe one such widely used system for quality management. World-wide, over 40,000 companies have been certified. India is also fast catching up the race.

10.2 DEFINATION—PROCESS CONTROL

When we talk about 'Process', there are two fundamental issues, best defined by Dr. Deming—(*i*) the process must be capable of delivering the desired output, (*ii*) and then it must be consistent in doing so. The statisticans use the term 'Process Capability' and 'Process Stability'. We need to review technical and business processes from the perspective to understand the impact of quality system, in particular, and process management, in general. Quality culture according to Dr. Deming is based on the pride of workmanship. Yet there is an increasing trend to move away from people towards process automation and technology sophistication that minimize the people interface.

A product is made through various processes. Some of the processes are machine operated and some are human oriented. However it is the responsibility of the manufacturers to keep checks on the processes so that the products are made to the requirements and performance satisfy the quality criteria.

10.3 PROCESS CONTROL v/s PRODUCT CONTROL

What is more important 'Process control' or 'Product control' ? There are as many answer as there are individuals with different perception and need. A controled process should produce a product that meets the requirements. Process control is the prevention, whereas product control is the after effect. Process in control may always produce a product that meets all the requirements unless process capability studies have proven that the product will meet the requirements. And further, based on feed-back, adjustments have to be made from time to time to comply with the requirements.

It is true that what gets measured gets managed. All activities of process control should come under measurements, and once we are able to measure the output of a process, we shall be able to improve the quality of the product by removing the cause of weaknesses during future production.

Many companies require regular progress reports, but no action is taken to bring about improvements as a results of these reports. A heavy focus is placed on the measuring systems and methods instead of the results and possible improvements. Company's walls are decorated with colourful charts, but no action is taken to find out the root cause of the problems. Instead, the charts are used to hide imperfection of the walls or to satisfy the requirements of the standards.

The measurement of the current performance is essential for continuous quality improvements. What can not be measured can not be improved. There is no end to quality improvement processes when results are continuously monitored.

10.4 PROCESS CONTROL AND MANUFACTURING ACTIVITIES

The word 'Process Control' has been derived from the ISO : 9000 dictionary. Very few machines are required for manufacturing a transformer. Approx. 70 to 80% of the manufacturing activities are manual, thereby chances of committing human mistakes are more. That is why knowledge of process control become so important for a transformer manufacturing unit.

Each activity of the process control should be well defined. The activities of each process should be identified in such a way that there is no super-imposition of inter-departmental activities. Each process should have its own quality procedure supported by the work instructions. Few processes which directly implant quality to the products are identified as 'Special Processes'. In transformer manufacturing unit, 'welding', 'brazing', 'oil filtration', 'operation of oven for de-moisturization', 'sand blasting' etc. are known as special processes. We must identify certified skilled operators having sufficient working knowledge to handle such processes independently.

10.5 SHEARING RESPONSIBILITY

Allotment of human responsibility for achieving the quality output of a particular process should be identified. One person may be alloted to fulfil many responsibilities. Care must be taken while alloting the responsibilities in such a way that no two persons are alloted a single responsibility. In such cases for non-achievement of quality in a particular product, it is very difficult to reason out the cause for it. It is, therefore defined as:

- One person ⟶ with many responsibilities ⟶ O.K.
- Many persons ⟶ with single responsibilities ⟶ Not correct

Human mistakes are bound to occur in manufacturing organizations, especially in transformer industries, where 70 to 80% of the processes are manual. Responsibility structures should be made in such a way that it is easy to identify the person involves for a particular process. Proper analysis of non-compliance can be made easily with a view to prevent such occurrences in future activities.

10.6 '8-M' PHILOSOPY

It is understood and well accepted that a good design is essential to produce a good transformer. But all good design may not be enough to yield good transformers, for which we need the following eight good '*M*'s:

First '*M*' ⟶ Good Materials (Inputs)
Second '*M*' ⟶ Good Machines (Infrastructures)
Third '*M*' ⟶ Good Manpower (Skilled)

Fourth '*M*' ⟶ Good Methods (Processes)
Fifth '*M*' ⟶ Good Motivation (Dedication)
Sixth '*M*' ⟶ Preventive Maintenance (Maintenance)
Seventh '*M*' ⟶ Media (Advertisement)
Eighth '*M*' ⟶ Enough Money (Funds)

Combination of the above '*M*'s along with a good design can definitely produce efficient and quality transformers.

We have already discussed the quality requirements and the availability of first '*M*' *i.e.*, Materials in Section-II. Now we shall proceed for manufacturing the transformer (*i.e.,* Process Engineering) with the available quality materials lying in out stock. Section-III will cover mostly the discussion Second, Third, Forth and Fifth '*M*', *i.e.*, Machine, Manpower, Method (Process) and Motivation. Sixth '*M*' *i.e.,* Maintenance has been covered in Section-IV. However Seventh and Eighth '*M*' *i.e.,* Money and Media have not covered in the book as these are commercial in nature.

Section-III *i.e.,* Process Control has identified 18 different topics as a part of process engineering. They are:

1. Role of machine – Chapter 11
2. Purchase procedure and checks on inputs – Chapter 12
3. Various manufacturing processes – Chapter 13
4. Special process – Chapter 14
5. Design Process – Chapter 15
6. Inprocess inspection and quality checks – Chapter 16
7. Allowable working tolerances – Chapter 17
8. Test and inspection on finished products – Chapter 18
9. Control of non-conforming products, their review and disposal – Chapter 19
10. Jop progress card – Chapter 20
11. Condition monitoring – Chapter 21
12. Calibration status – Chapter 22
13. Customer complaints and feed-back – Chapter 23
14. Validation of reference standards – Chapter 24
15. Training – Chapter 25
16. Statistical techniques – Chapter 26
17. Basic concept of ISO : 9000 – Chapter 27
18. Benchmarking and process improvement – Chapter 28

We shall discuss, in brief, each of the above topics separately with a view to emphasis how the application of correct processes add to the quality of finished products.

Section III
CHAPTER 11

Role of Machine

FOOD FOR THOUGHT

Process is a sequence of operations which blend the inputs to produce required outputs that satisfy the customers. Quality assurance is a set of well integrated and planned activity which gives confidence to the management that the requirements of the customer will be met. ISO-9000 standards is one such widely used system for quality management. World-wide, over 40,000 companies have been certified. India is also fast catching up in this race.

When we talk about process, there are two fundamental issues, best described by late Dr. Deming. One, the process must be capable of delivering the desired output, and then it must be consistent in doing so; statisticians use the terms ‘Process Capability’ and ‘Process Stability’ for these. We need to review technical and business processes from the perspective to understand process management in general and the impact of quality system in particular.

Quality culture according to late Dr. Deming is based on the pride of workmanship. Yet there is an increasing trend to move away from people towards process automation and technology sophistication that minimize the people interface.

What is more important, process control or product control? There are as many answers as there are individuals with different perceptions and needs. A controlled process should produce a product that meets the requirements. Process control is the prevention, whereas product control is the after effect. But again, process in ‘Control’ may not always produce a product that meets all the requirements unless process capability studies prove that the product will meet requirements. And further, based on feedback, adjustments have to be made from time to time to comply with the requirements.

It is true that what gets measured gets managed. All activities of process control should come under measurements and once we are able to measure the output of a process, we will be able to improve the quality of the product by removing the cause of weaknesses in the process during future production.

Many companies obtain regular reports, but take no action to bring about improvements as a result of those reports. A heavy focus is placed on the measuring system and methods instead of the results and possible improvements. Company's walls are decorated with colourful charts, but no action is taken to find the root cause of problems. Instead, the charts are used to hide imperfection in the wall or to satisfy the requirements of standard.

The measurement of current performance is essential for continuous quality improvement. What can not be measured, can not be improved. There is no end to quality improvement processes when results are continually monitored.

11.1 INTRODUCTION

Section-I has mainly covered the availability of various raw materials and components, their quality aspects, and quality guidelines. Now we shall discuss the process of manufacture of a transformer with materials already in stock. In line with the recommendation of ISO-9000, purchase process and incoming material checks come under process control.

The word 'process control' is taken from the ISO-9000 dictionary. Very few machines are required for manufacturing a transformer. Approximately 70 to 80 per cent of the manufacturing activities are manual. Hence chances of human mistakes are more. That is why, knowledge of process control is important for a transformer manufacturing unit.

Each activity of the process should be well defined. The activities and duties of the individuals of each process should be identified in such a way that there is no super-imposition of responsibility of the inter departmental activities. Each process should have its own quality procedure supported by work instructions. A few processes which are directly linked with quality are identified as 'special processes'. In transformer manufacturing welding, brazing, oil filtration, operation of oven for de-moisturisation of core-coil assembly etc. are special processes. Skilled operators having sufficient job knowledge should handle such processes.

Allotment of responsibility to people for achieving the quality output of a particular process should be made. One person may be allotted to fulfill two responsibilities. Care must be taken during allotment of responsibilities in such a way that no two persons are allotted a single responsibility. In such cases, for non-achievement of the quality in a particular product, it is very difficult to reason out the cause for it. It is defined as:

- One person $\rightarrow$ With many responsibilities $\rightarrow$ OK
- Many persons $\rightarrow$ With single responsibility $\rightarrow$ Not correct

Human mistakes are bound to occur in a manufacturing organisation, especially in transformer industries, where 70 to 80 per cent of the processes are manual. Responsibility structure should be made in such a way that it is easy to identify the people involved in a particular process. Proper analysis of non-compliance should be made with a view to prevent such occurrences in future activities.

We shall review and discuss the following activities as a part of process control:

(*a*) Role of machine
(*b*) Purchase procedure and checks on incoming materials for quality assurance
(*c*) Various manufacturing processes
(*d*) Special process
(*e*) Inprocess inspection and quality checks
(*f*) Allowable working tolerances
(*g*) Test and inspection on finished products
(*h*) Non-conforming products and their review
(*i*) Job card
(*j*) Condition monitoring
(*k*) Calibration status
(*l*) Customer complaint and feedback
(*m*) Training
(*n*) Statistical technique
(*o*) Basic concept of ISO-9000
(*p*) Use of reference standards.

11.2 ROLE OF MACHINE

Machine plays a vital role in a process industry. Various types of mechines *viz.* mechanical, electrical, gas operated etc. are employed in manufacturing a transformer. It is of utmost important to ensure that the machines employed are adequate in number and amply rated for the job being handled and are well maintained. Right kind of maintenance at proper time reduces the chance of breakdown while in operation. Breakdown of machine increases the wastage as well as reduces the productivity, effecting delay in delivery. The chapter discusses in brief, a few aspects of maintenance schedule, recording of non-conformance (if an uncalled breakdown occurs during operation) and types of low voltage earthing necessary in industrial application to protect human life.

Before starting production, the requirement of machines necessary to manufacture transformers should be studied and they should be made available. The machines should include all the test and measuring instruments also. A list of machines should be readily available for verification.

It should be ensured that adequate number of machines of the right capacity to deliver targeted output in scheduled time are available.

The suitability of the machines for the particular operation should be certified by a competent authority.

Each machine should have a history card, an example of which is shown in Table 11.1.

Table 11.1. History card of machine

Sl. No	*Item*	*History*
(1)	Name of the machine, its make and serial no.	Name : HV winding machine Make : P. C. Ghosh, Calcutta Sl. No. : 122354 Year of mfg. : 1989
(2)	Location	Winding department
(3)	Brief specification	Front tension, suitable for cross-over coil, upto a wire diameter of 3 mm, driven by one HP, 3 phase, 1440 rpm, 440 volts motor Counter : Kaycee make
(4)	Code no.	Firm should provide a code no. of its own which should appear on the body of the machine for easy identification. (For example: 001)
(5)	Preventive maintenance done on	2nd January, 2000
(6)	Spare parts used, if any	Nil
(7)	Due date of next preventive maintenance	2nd April, 2000
(8)	Maintenance done by	Name of the maintenance staff should appear here (For example: Pankaj Kumar)
(9)	Date of last breakdown	August 19, 1998
(10)	Nature of breakdown	Machine revolving counter was not working properly
(11)	Cause of breakdown	Due to prolonged use
(12)	Part replaced during	Counter was replaced by a new one of kaycee make breakdown
(13)	Recommended spare for stock	• Ball bearing having code no .... • V-belt with size .... • Counter, make .... • Motor with starter ....
	Remarks, if any	Any critical observation which is helpful to increase the life of the machine may be made.

11.3 MAINTENANCE OF MACHINE

All machines need two types of maintenance:

(*a*) Preventive maintenance

(*b*) Breakdown maintenance

Preventive Maintenance

Preventive maintenance is essential to reduce the recurrence of breakdown of the machine in service. Depending upon the type of machine and its nature of use, the frequency of maintenance is fixed. Rotary machines like motor, generator, EOT crane etc. require frequent attention. Maintenance mechanic should have enough skill to judge the requirement of preventive maintenance.

Method of inspection may be classified broadly as:

(*i*) External

(*ii*) Internal

External inspection is done to find out corrosion, crack, change of colour due to heat or any other apparent external defect. Certain conditions, like abnormal sound, vibration etc. are also to be noted during external inspection.

Internal inspection is carried out while the machine is under shut-down. Wear and tear of the moving parts, internal cracks, if any, condition of ball bearing etc. are checked.

Based on the experience and judgement, and detailed study of the equipment, essential spares which are needed for frequent replacement should be listed out in advance and the availability of such spares should be monitored.

Maintenance plan: Schedule of preventive maintenance is done on annual basis. The master plan containing the entire plant and machineries should indicate the proposed date of preventive maintenance. Date of last maintenance, whether preventive or breakdown, should also appear in the master plan. Maintenance schedule is done in such a way that the productivity of that particular machine is not disturbed. Maintenance is done either on weekly-off day or after working hours.

In the case of machines, scheduled for continuous operation round the clock (like electric oven), maintenance schedule should be done judiciously to ensure minimum loss of production. If a spare capacity of such machines is made available, the loss of production can be minimised.

Breakdown Maintenance

We cannot overrule the possibility of breakdown maintenance, even if preventive maintenance is done meticulously. In case the breakdown occurs during the operation of a machine, it should be attended to by the skilled mechanic on priority. Cause of such breakdown along with the spare parts replaced should be recorded in the history card.

On the whole, we must ensure that the machines are in good working condition before operating them. The operators should also be trained to handle routine maintenance in case of emergency.

11.4 SYSTEM OF MAINTAINING NON-CONFORMING RECORDS

If a particular machine could not be attended to for preventive maintenance as per the master maintenance plan, then, it is a case of non-conformance and the same should be recorded in a register. The reasons of non-adherence to the maintenance schedule should be recorded in addition to the details of machine, code number etc. A sample of such recording is shown below:

Record of Non-Conformance

Nature of non-conformance: EOT crane, code no. 133 was scheduled for routine preventive maintenance on 16.12.99 and the same was not done.

Analysis of non-conformance: It was a case of human mistake. Maintenance supervisor was busy attending to a breakdown maintenance of 400 kVA diesel generator and forgot to attend to the maintenance of EOT crane.

Corrective action proposed: Maintenance of the EOT crane should be done on priority in such a way that the normal production is not affected. It is suggested that the maintenance work be taken up after duty hours.

Disposition: The preventive maintenance was done successfully on 20.12.99 after duty hours. Maintenance supervisior was advised to monitor such activities in a systematic manner.

A warning letter was issued to the concerned supervisor for not honouring his allotted responsibility on time.

Signature: Q.A. Engineer Signature: Authority

11.5 SYSTEM EARTHING

Though the system earthing does not come under the quality assurance of transformers, a few lines on this aspect may be added here.

Statutory Provision for Earthing

Earthing is generally carried out in accordance with the requirement of Indian Electricity Rules–1956, as amended from time to time and the relevant regulations of the Electricity Supply Authority concerned.

All medium voltage equipments should be earthed by two separate and distinct connections.

As far as possible all earth connections should be visible for inspection.

All connections should be carefully made—poor or inadequate installation may lead to loss of life or serious personal injury.

All materials, fittings etc. used in earthing should conform to the Indian Standards Specification.

Typical method of using pipe earth electrode and plate earth electrode as per recommendation of IS-3043 are shown in Figs. 11.1 and 11.2 respectively. Different ways of making earth connections are shown in Figs. 11.3 to 11.6.

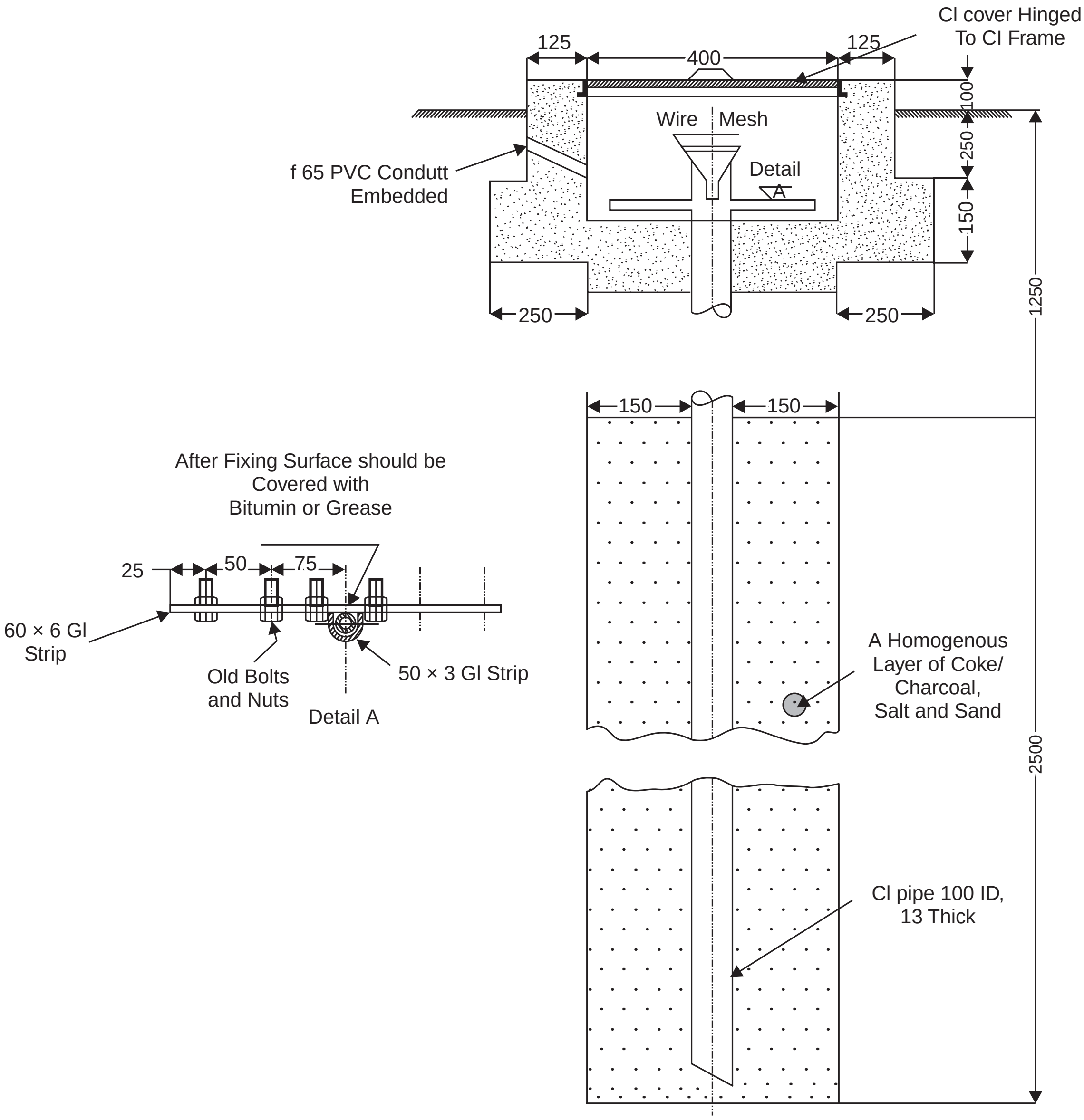


Fig. 11.1. Typical arrangement of pipe electrode

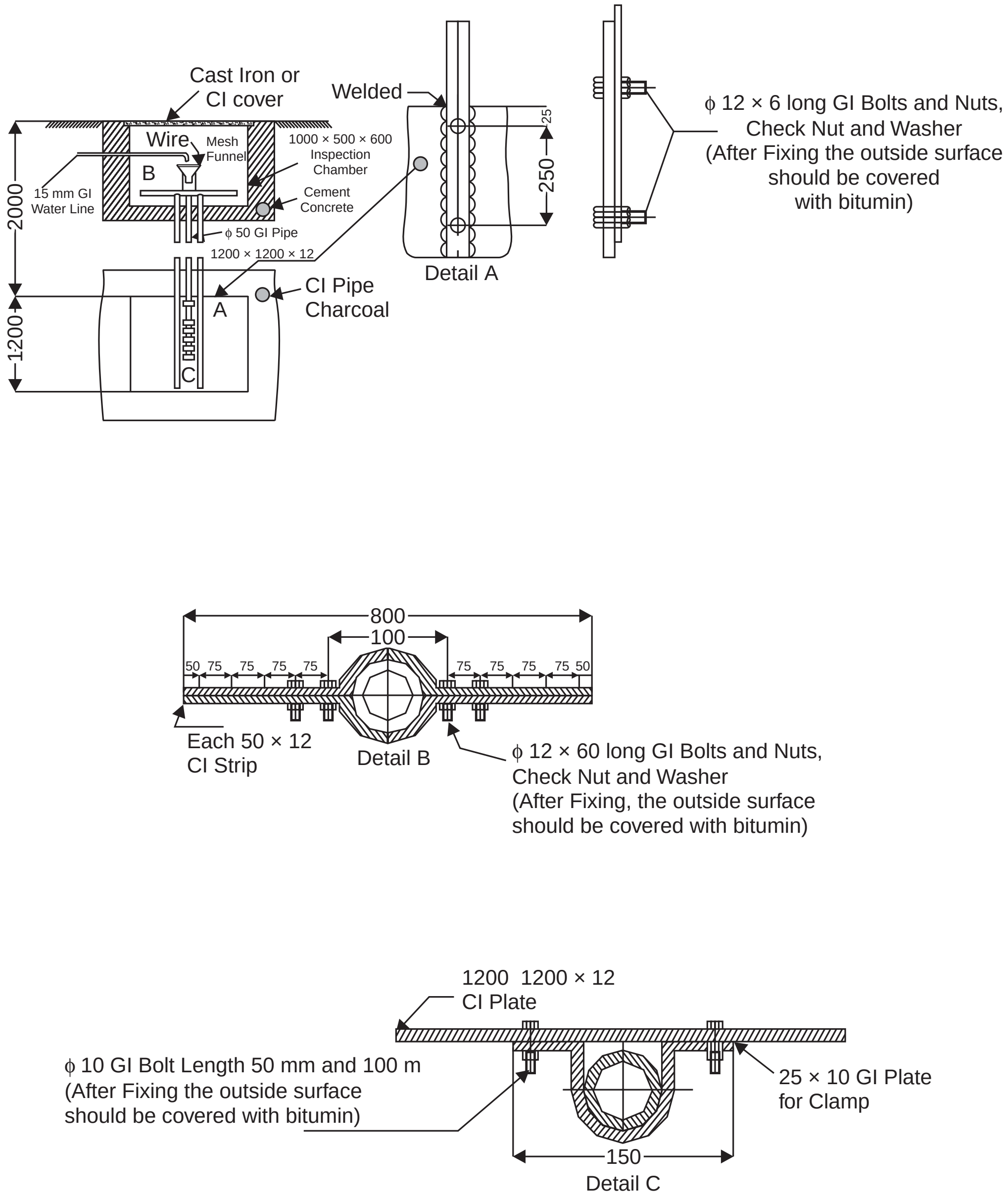


Fig. 11.2. Typical arrangement of plate electrode

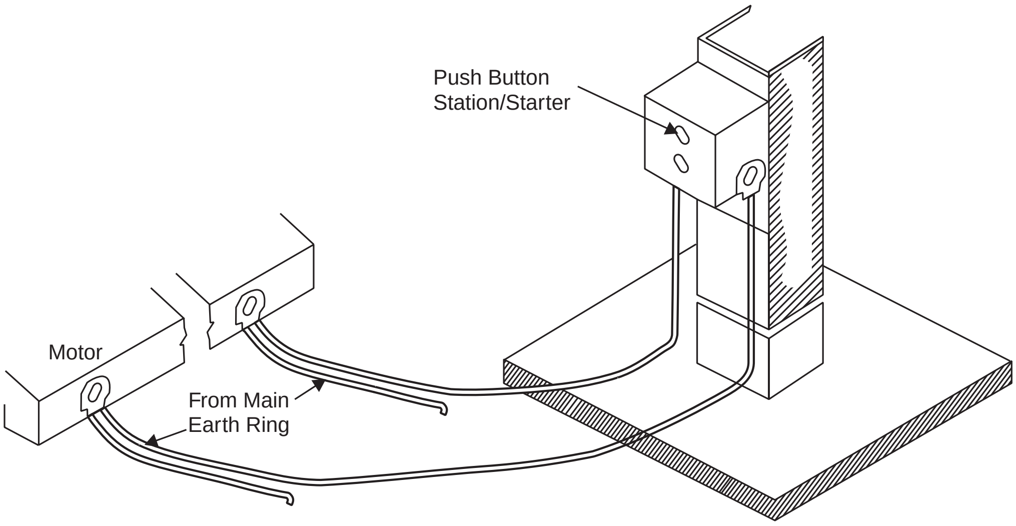


Fig. 11.3. Earthing arrangement for motor with push button station/starter; earth connection to starter looped form earth connections of motor

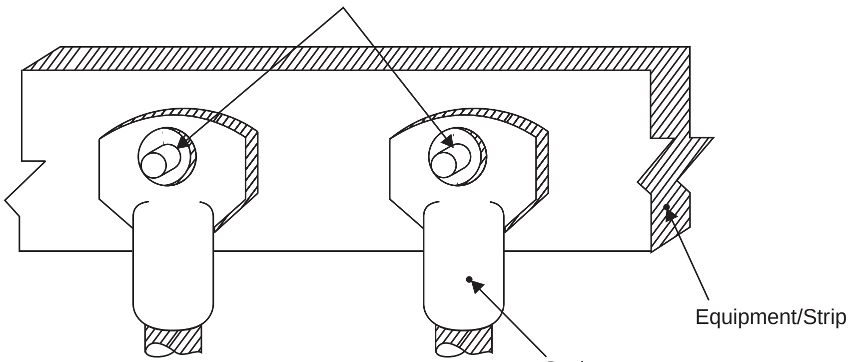


Fig. 11.4. Arrangement of double earth connection to equipments (Strip to conductor connection)

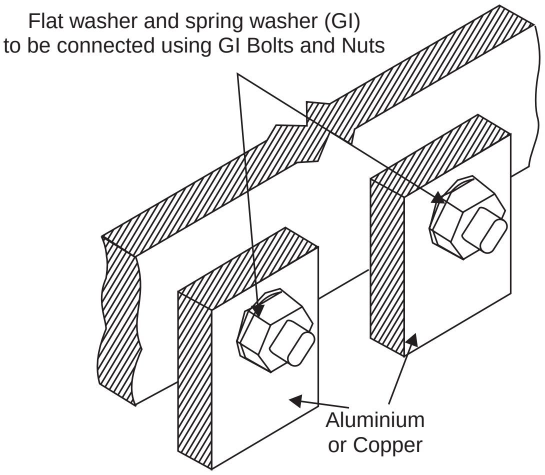


Fig. 11.5. Arrangement of strip to strip and strip to equipment connection

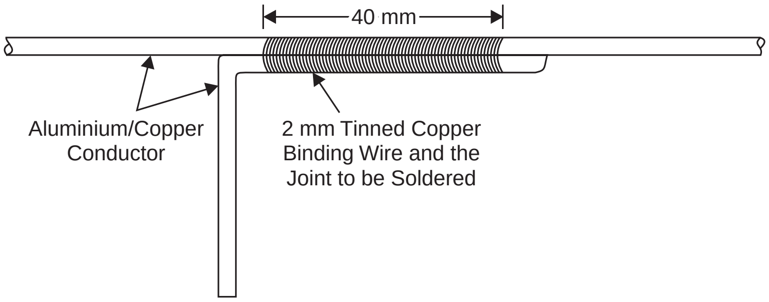


Fig. 11.6. Conductor to conductor joint (round conductor)

Section III

CHAPTER 12

Purchase Procedure and Checks on Incoming Materials for Quality Assurance

FOOD FOR THOUGHT

'Time and tide wait for none.' Science and engineering have removed many obstacles, but no one has ever conquered time. With technological advances it appears that tasks are becoming more complex, leaving less time for other activities. With the introduction of electronic gadgets, life should have been easier to manage. But that is not happening.

It is becoming impossible to strike a balance between work, personal life and social events. When time is taken from one for the other, it just makes matter worse. People get the feeling that they are not in control of their lives. Work, personal life and other activities take up the available time. Procrastination and time robbers don't leave any time to think. Not having enough time for desired activities creates frustration. Burning the midnight oil becomes common when planning is not done appropriately.

The answer to these questions lies in setting priorities and goals, and planning, in addition to working harder and smarter. We can help others save time by directing information to the right person, reading thoroughly before asking questions, filling out information on a form neatly and legibly, and doing it right the first time and every time. Time can be effectively utilized by following a systematic plan. More will be gained from a flexible plan than with a rigid bureaucratic plan. The challenge lies in getting rid of the time-wasters and avoiding getting into the trap of doing unnecessary things. Gaining control will steer us in the right direction. But our choices of action will not guarantee the success of those choices.

12.1 INTRODUCTION

Quality of the finished products depends a great deal on the quality of the basic inputs. As such we must ensure the availability of quality materials at the right time. It is strongly recommended that the incoming materials be inspected for quality assurance before they are regulated for production.

The design department should prepare the technical specifications for all basic input materials with working tolerances as recommended by ISS and/or customer specifications and also based on experience. Standard formats for material inspection reports of all major raw materials should be prepared in advance. On receipt of materials at stores, they should be inspected in accordance with the requirements and recorded. The quality assurance engineer should review the outcome of such inspections before the materials are released for production.

12.2 PURCHASE CONTROL

As said earlier, the quality of the finished product depends on the quality of input materials and components purchased from various sources. This chapter highlights the procedures to be adopted to ensure the quality of purchased raw materials and components. The following are few of the activities the purchaser should do:

(*a*) Selection of suppliers
(*b*) Incorporation of all quality requirements in the purchase order
(*c*) Analysis of quotations with quality in perspective
(*d*) Surveillance quality audit at the supplier's works
(*e*) Inspection and verification of incoming materials and components
(*f*) Reporting defects and settlement of disputes with the suppliers
(*g*) Assistance to subcontractors or vendors by way of training, technical advice etc.
(*h*) Review and rating of suppliers from the point of view of product quality and adherence to delivery schedule.

12.3 ASSESSMENT OF THE SUBCONTRACTOR OR VENDOR

This is one of the crucial controls on the purchase activities, as the quality of the purchased products depends mainly on the suppliers. An institutionalized procedure for assessing the strength of the suppliers is essential. They should be evaluated on the basis of the following:

(*a*) Their ability to meet the quality requirements of the products or services
(*b*) Availability of machinery, tools and manpower at the required technical levels
(*c*) Their commercial and financial viability
(*d*) Their production capacity and ability to maintain specified delivery schedule
(*e*) The effectiveness of their quality assurance system.

There are a number of ways to assess prospective suppliers. Previous performance in supplying the same or similar kind of products is an useful indicator. For this it is essential that a detailed record of incoming supplies and their quality status is maintained. The records in question should contain details of quantity supplied, quantity rejected, adherence to delivery schedules and share in total supplies to the company over the period being reviewed.

For one-time purchase or when the quantity involved is very small, the buyer should carry out detailed inspection and testing of the product before granting approval for its use.

12.4 METHODOLOGY OF CAPACITY VERIFICATION

Since the capacity verification is a purchase function, overall responsibility of this activity is that of the purchase department. Normally, it involves visits by company's experts to the subcontractor's or vendor's works. Before organising such a visit, the subcontractors or vendors should be asked to furnish data on its production facilities, organization, personnel and finance along with data on its ability to supply the product at the requisite quality level.

Since the assessment of a supplier requires expertise in different areas, such as process engineering, quality control and finance, some of which may not be available in the purchase department, a committee is usually appointed for this task. The committee comprises experts from different functional groups. However, overall co-ordination is provided by the purchasing department. The committee examines data submitted by the prospective suppliers.

A team of experts should visit the workplaces of suppliers who look promising to carryout a physical verification of their facilities, infrastructure and quality assurance system. While it is necessary for the assessment team to obtain the data it needs, it should not assume the role of inspectors. No criticism of the supplier and its facilities should be made. The assessment team should confine itself to areas directly affecting the supplier's ability to execute the order in question. Generally, the use of standard questionnaire is advisable. Important aspects to be covered during assessment are listed below:

(*a*) Can the subcontractor's or vendor's plant and machinery produce at the required rate?

(*b*) Are all the machines capable of maintaining quality parameters within acceptable limits.

(*c*) Does the firm have a well-staffed quality organization and a functional quality control programme?

(*d*) Does the firm use a considerable number of components obtained from the trade or from subcontractors? If so, how does it control the quality of these components?

(*e*) What are the firm's sources of raw materials? Does it maintain adequate reserve stocks to safeguard itself from interruptions in the supply of materials? How is the supply of raw materials ensured?

(*f*) Does the firm have complete testing facilities for the product in question?

(*g*) Has the firm executed an order for a product similar to the one being considered? If so, details of the order should be obtained.

(*h*) What is the financial standing of the firm?

(*i*) What is the general attitude of the firm's management towards quality assurance?

The purchase department takes one or the other of the following actions on the basis of the findings of the assessment committee:

(*a*) If the firm in question is found to have a sound quality assurance system, its name is included in the list of registered suppliers.

(*b*) If the firm has minor deficiencies, it is advised to take remedial actions and it is registered after further verification.

(*c*) If the company has any significant defect, it is informed that it cannot for the moment be registered as a supplier.

Subcontractors or vendors should be registered for specific products and for limited period, *e.g*. two years. In addition to monitoring the products they supply, the company should periodically check that the subcontractors or vendors in its register maintain performance standards as laid down by the company. A group should be formed in the purchase department for this periodic monitoring of subcontractors or vendors.

All findings should be properly recorded and the data is used for updating the register of approved subcontractors or vendors. Suitable guidelines and criteria should also be laid down for the addition or deletion of registered names.

12.5 PURCHASING DATA

Successful procurement begins with a clear definition of requirements. Usually requirements are contained in the contract specifications, drawings and purchase orders provided to the subcontractors or vendors.

Appropriate methods should be developed to ensure that the requirements are clearly defined, communicated and most importantly understood clearly by the subcontractors or vendors. These methods may include written procedures for the preparation of specifications, drawings and purchase orders, meetings between the suppliers and the company prior to release of purchase orders.

Purchase documents should contain data clearly describing the product or service ordered. Important elements are listed below:

(*a*) Precise identification of product and grade

(*b*) Inspection instructions

(*c*) Quality standard to be applied etc.

All inspection/test methods and technical requirements should refer to the appropriate national and international standards. The status of all documents mentioned in the purchase order should be clearly indicated. When technical requirements, drawings and inspection procedures are cited, it is essential that they are identified by their document numbers in order to remove any source of confusion. Detailed quality requirements should be stated in the purchase order; any intermediate inspection requirements should be shown as ‘hold point’ in the purchase order. ‘Hold point’ is a point in the manufacturing process beyond which the subcontractors or vendors will not proceed without the buyer’s explicit permission/clearance.

12.6 CONTROL OF ADEQUACY AND CORRECTNESS OF PURCHASE DATA

A company should have specific procedures for verifying a purchase order before it is released. Possible methods are listed below:

(*a*) All specifications (*e.g*. technical, metallurgical, mechanical and other quality requirements) are clearly stated in the drawings so that these can be reproduced in the purchase order.

(*b*) A reference number is given to the drawing and the subcontractors or vendors are asked to refer to the drawing for all specifications.

(*c*) The quality assurance department is required to verify the purchase order for completeness and accuracy of all specifications.

(*d*) The requirements are discussed with the design and quality assurance departments before being reproduced in the purchase order.

The other procedures to be followed should also be made clear in the purchase order. For example, the buyer may expect the approval of a proto-type sample before undertaking batch production. The subcontractors or vendors may not have this in mind at all. Such procedural details should carefully be spelt out in the purchase order.

12.7 CHECKS ON INCOMING MATERIALS

So far we have discussed some of the procedures for the purchase of raw materials and components conforming to required quality. On receipt of materials at stores, they should be subjected to various checks as per pre-determined quality guidelines. The Quality Assurance Engineer (QAE) should review the outcome of such inspections before the materials are released for production.

Formats for such quality checks of some of the major raw materials and components are shown in the following pages. In case, the complete tank body is fabricated outside through sub-vendors, then it is considered to be a component and should be subjected to quality checks. Report No. 7 gives details of such checks.

12.8 INSPECTION REPORT OF WINDING WIRES AND STRIPS USED IN WINDING DEPARTMENT

Report No. : One Date : ....

Table 12.1

Spool/bobbin	*Specification assigned by the designer*		*Verified as under*		*Remark (acceptable or not)*
	Bare size	*Covered size*	*Bare size*	*Covered size*	

Remark: 5 per cent spools of winding wires and 100 per cent bobbins of strips shall be checked.
Note: The report should be reviewed and certified by the quality assurance engineer.

12.9 INSPECTION REPORT OF CRGO LAMINATIONS USED IN ASSEMBLY DEPARTMENT

Report No. : Two Date : ....

Name of the supplier : ....

Customer : ....

No. of set : ....

Core drawing No. : ....

kVA/kV : ....

Grade of lamination : ....

Weight per set : ....

Table 12.2

Sl. No.	*Particulars*	*Specification of material*	*Verified as under*	*Remark (acceptable or not)*
1.	Thickness of lamination	0.27 mm		
2.	Colour of lamination	Grey		
3.	Cutting edges	Minimum		
4.	Finish	Smooth		
5.	Verification of dimensions	As per drg. no		

Remark: Quantity of materials for inspection should be selected in such a way that it gives a complete picture of the entire lot.

Note: The report should be reviewed and certified by the quality assurance engineer.

12.10 INSPECTION REPORT OF MATERIALS BEING USED IN COIL ASSEMBLY DEPARTMENT

Report No. : Three Date : ....

The following materials are covered under coil assembly department:

(*a*) Insulating materials like press boards, kraft paper, crape paper, epoxy dotted paper etc.

(*b*) SRBP tube, cotton tape, sleeving

(*c*) Bakelite sheet

(*d*) Copper flat and flexible

(*e*) Core bolt and tie rod

(*f*) Other related materials.

Table 12.3

Material	*Make/supplier*	*Qty.*	*Specification*	*Verified as under*	*Remark (acceptable or not)*

Remark: Quantity of materials for inspection should be selected in such a way that it gives a complete picture of the entire lot.

Note: The report should be reviewed and certified by the quality assurance engineer.

12.11 INSPECTION REPORT OF THE OFF-CIRCUIT RATIO SWITCH

Report No. : Four Date : ....

Name of the supplier : ....

kVA/kV/customer : ....

No. of switch : ....

Drg. No. : ....

No. of position/
Current rating : ....

Table 12.4

Particulars	*Requirement as per drawing*	*Verified as under*	*Remark (acceptable or not)*
No. of tap position	5 positions		
Distance between bakelite plates	80 mm		
Centre height of the operating shaft from the base	75 mm		
Diameter of the contact pin	6/10 mm		
Material of the operating shaft	Glass fibre		
Material of the tie rod connecting the plates	Glass fibre		
Type of joint used for coupling the handle with the switch	Universal coupling		

Remarks: 100 per cent of the switches should be checked.
Note: The report should be reviewed and certified by the quality assurance engineer.

12.12 INSPECTION REPORT OF BREAKDOWN VALUE OF INSULATION OIL

Report No. : Five Date : ....

Name of the supplier : APAR (INDIA) LTD.

Specification : IS-335 or IEC-296 or BS-148

Colour of oil : Transparent/pale yellow

Manufacturer's test certificate : Available or not

Test sequence : (*a*) ☐ Before accepting an oil tanker

: (*b*) ☐ Before filling oil in the transformer

✓ Whichever is applicable

Table 12.5

Sl. No.	***Before accepting an oil tanker and without filtration***		***After filtration but before filling in the transformer***		***Remark (acceptable or not)***
	Breakdown value (kV)	***Average breakdown value (kV)***	***Breakdown value (kV)***	***Average breakdown value (kV)***	
1.					
2.					
3.					
4.					
5.					
6.					

Remarks:

(*a*) Ensure that all the compartments of the oil tanker, both top and bottom, are sealed before accepting an oil tanker.

(*b*) Oil should be subjected to test within 24 hours from the time of arrival of tanker.

(*c*) In case the oil tanker has multiple compartments, the oil from each compartment should be checked before accepting an oil tanker.

Notes:

(*a*) The report should finally be certified by the quality assurance engineer.

(*b*) Manufacturer's test certificate must be reviewed with respect to the requirements of the relevant specifications including parameters like acidity, tan-delta, resistivity etc.

12.13 INSPECTION REPORT OF MATERIALS USED FOR TANK FABRICATION

Report No. : Six Date : ....

The following major materials are used in the tank fabrication department:

(*a*) MS sheet and plate

(*b*) Flat, angle and channel

(*c*) Round and elliptical tube

(*d*) Corrugated wall panel and pressed steel radiator

(*e*) Cap, plug, roller and other related components

(*f*) Welding electrodes.

Parameters which affect the quality of the above materials were discussed in the previous section of this book. In case, the format is not sufficient to cover the quality aspects of some of the materials, separate format as deemed fit may be generated.

Table 12.6

Materials	*Supplier*	*Qty.*	*Specification*	*Verified as under*	*Remark (acceptable or not)*

Remark: Quantity of materials for inspection should be selected in such a way that it gives a complete picture of the entire lot.

Note: The report should be reviewed and certified by the quality assurance engineer.

12.14 INSPECTION REPORT OF COMPLETE FABRICATED TANK

Report No. : Seven Date : ....

Name of the supplier : ....

kVA/kV/customer : ....

Reference drawing No. : ....

Quantity received : ....

Table 12.7

Sl. No.	*Particular*	*Recommended in the drawing*	*Verified as under*	*Remark (acceptable or not)*
1.	Tank dimensions (L × B × HT)			
2.	Sheet thickness (side × top × bottom)			
3.	Radiator details			
4.	Mounting hole details			
5.	Conservator dimensions			
6.	Locking height			
7.	Ratio switch centre			
8.	Availability of all fittings as per drawing			

Remark: All tanks should be subjected to the above checks.
Note: The report should be reviewed and certified by the quality assurance engineer.

12.15 INSPECTION REPORT OF MATERIALS USED IN BOX-UP DEPARTMENT

Report No. : Eight Date : ....

Following major materials are used in the box-up department:

(*a*) Bushings and bushing fittings

(*b*) Gaskets

(*c*) Valves and gauges like buchholz relay, OTI, WTI, MOG etc.

(*d*) Hardware

(*e*) Other related components.

Parameters which affect the quality of bushing, bushing fitting, gasket etc. were discussed in the previous section of this book. In case, the format is not suitable to cover the quality aspects of some of the materials, separate format as deemed fit may be generated.

Alarm and trip contacts for buchholz relay, OTI, WTI and MOG should also be checked for quality assurance.

Table 12.8

Quantity received	***Specification assigned by the design dept.***	***Verified as under***	***Remark (acceptable or not)***

Remark: Quantity of materials for inspection should be selected in such a way that it gives a complete picture of the entire lot.

Note: The report should be reviewed and certified by the quality assurance engineer.

12.16 INSPECTION REPORT OF MATERIALS USED IN PAINTING AND FINISHING DEPARTMENT

Report No. : Nine Date : ....

The following major materials are used in the painting and finishing department:

(*a*) Ready mix paint and other intermediate paint – Colour shade and date of expiry
(*b*) Bi-metallic connectors and brass lugs – Major dimension as per drawing
(*c*) Silicagel breather – Content of silicagel
(*d*) Dial type thermometer – Calibration
(*e*) Name, rating and diagram plate – Verification with respect to the drawing and data sheet
(*f*) Cable gland – Major dimensions
(*g*) Other related components – If any

Table 12.9

Material	***Make/ supplier***	***Qty.***	***Specification***	***Verified as under***	***Remark (acceptable or not)***

Remark: Quantity of materials for inspection should be selected in such a way that it gives a complete picture of the entire lot.

Note: The report should be reviewed and certified by the quality assurance engineer.

12.17 CONCLUSION

This chapter mainly dealt with the purchase procedures and quality checks on some of the basic raw materials and components. Once the requirement of quality is understood, it is very easy for the working engineers to maintain it. The main responsibility lies with the design department where the specifications of raw materials and the components are prepared. Once the specifications are available, they should be circulated to the respective vendors to enable them to check the materials for compliance before despatch. With the process of quality checks at the incoming stages, it is possible to reduce the rejection/failure of the finished products. Moreover with such activities, overall quality of the equipment including longer operational life may also be expected.

The power utilities, while carrying out the inspection of the finished products at the manufacturer's premises, may desire to review the inspection reports on the raw materials and components. The utilities should demand these reports to encourage the manufacturers to maintain them for verification and review. The improvement on the quality of the finished transformer is achievable only when the buyer and the manufacturer join hands for the common cause, *i.e.* quality assurance.

Section III

CHAPTER 13

Various Manufacturing Processes

FOOD FOR THOUGHT

Process capability studies are performed prior to new product introduction in the production line. Statistical Process Control (SPC) techniques are applied at the critical process steps. Processes are documented in the form of flow charts which are easy to understand. Error prevention techniques are used in the production processes. 'Best of the best' process techniques are applied. Variances are reduced through the implementation of quality engineering techniques and tools, such as design of experiments, sampling plan etc. Optimization of seven M's (Man, Material, Method, Machine, Media, Motivation and Money) is achieved. Process design used five W's (What, When, Who, Where and Why) and one H (How) principle. Process ownership at each process step is established in the beginning itself.

Supplier partnership approach is practiced in the organization. Supplier selection is based on the performance rather than price. Suppliers are given technical assistance whenever feasible and required. Long term relationships with the suppliers is emphasized and is characterized by mutual confidence and trust. Supplier response is appreciated. Suppliers are involved in problem solving and continuous improvement efforts.

Quality informations, such as quality cost, rework, scrap, yield and customer complaints are systematically and regularly collected, analyzed and acted on. Quality information is used wisely in decision making, planning, control and improvement opportunities. Five R's (Reject, Report, Represent, React and Recall) principle is used in the information system. The continuous improvement process relies on obtaining, communicating and analyzing valid data.

The application of above mentioned practices will yield lower rework level, lower finished product defect rate, lower scrap level, higher through put and productivity, high employee morale and satisfaction, lower employee turnover, lower absenteeism level, lower product cost, higher quality level and performance, on time delivery and service, higher profit, higher market share and overall higher customer satisfaction. Zero-defect and continuous improvement goals are accomplished with these practices. The best quality management system is an error prevention system.

13.1 INTRODUCTION

This chapter covers the various processes of manufacturing a transformer. Most of the processes are manual oriented. Very few machines are used in the process of manufacturing a transformer. It is therefore essential for the working engineers to establish documented procedures for each of the processes. Each procedure should be well defined and supported by the work instructions, process flow charts, illustrative photographs, drawings etc. This will help the workmen to understand better the requirement of manufacturing specifications and to produce uniform quality transformers.

Manufacturing of transformer broadly covers the following processes:

(*a*) Coil winding
(*b*) Core assembly
(*c*) Core-coil assembly
(*d*) Tank fabrication
(*e*) Tank painting
(*f*) Box-up or tanking
(*g*) Final testing
(*h*) Finishing and despatch.

The process flow chart has been shown in Fig. 13.1.

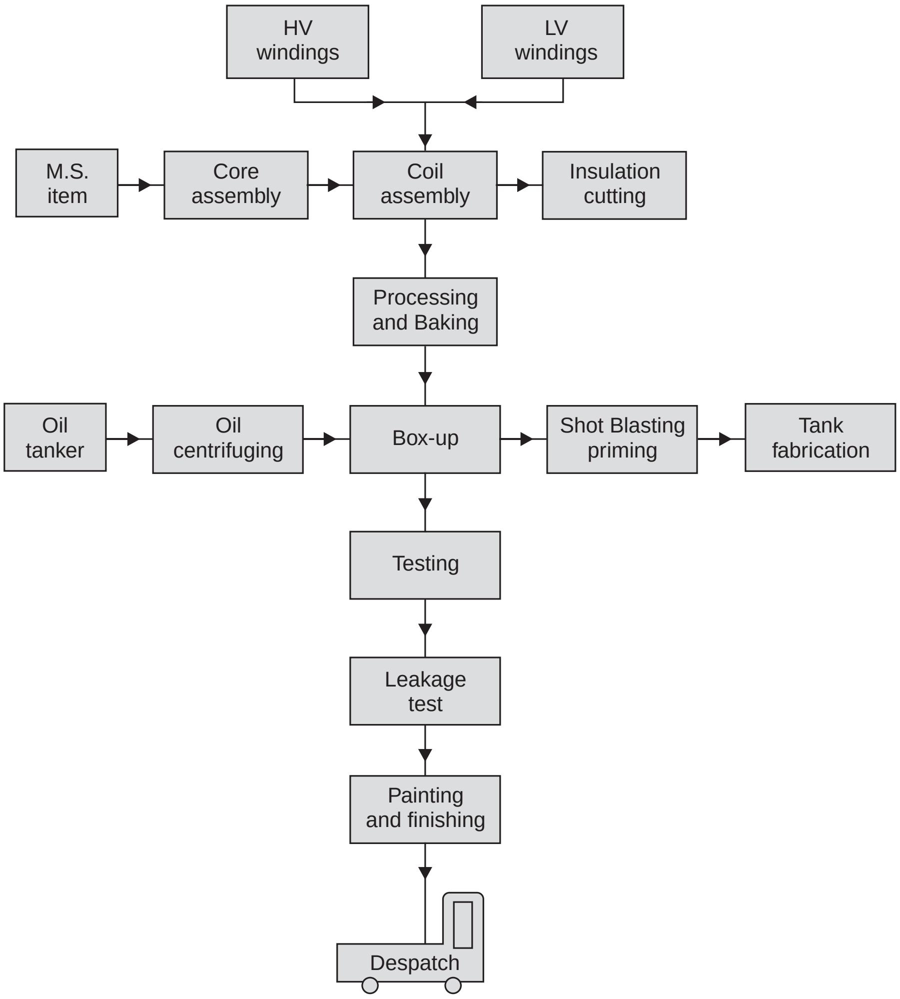


Fig. 13.1 Process flow chart

13.2 COIL WINDING

High Voltage Coil

High voltage coil is a component of finished transformer. In the case of distribution transformers, high voltage coils are made on automatic layer-setting coil winding machines. A solid cylindrical former of pre-determined diameter and length is used as base, over which the coil is made. Generally round insulated wire, either copper or aluminium, is used as basic raw material. The coils are made in multiple layers. Insulated kraft paper or epoxy dotted paper of specified thickness is used between the two consecutive layers as inter-layer insulation. The starting and finishing leads of the coil are generally terminated on either side of the coil. These leads are properly sleeved and locked at a number of positions. If the transformer has tappings to accomodate various voltages, the same are provided on high voltage coils. While taking out tappings, it is to be ensured that they are properly placed and are clearly numbered. Fig. 13.2 shows a photograph of high voltage cross-over coil of a 500 kVA transformer.

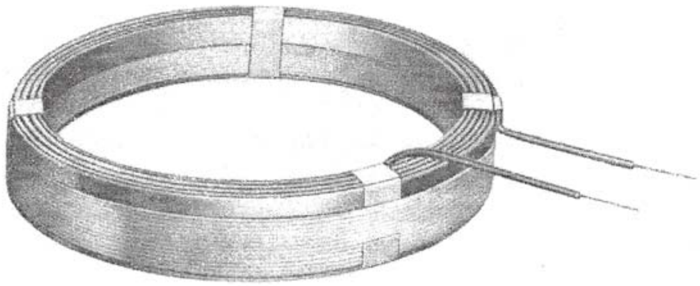


Fig. 13.2. Photograph of high voltage cross-over coil

Low Voltage Coil

Low voltage coil is another component of the finished transformer. The procedure of making low voltage coil is generally the same as described above, except that the basic raw material is a rectangular strip and the starting and finishing leads are mostly terminated on the same side. Because of the thick rectangular conductor and less number of turns, low speed winding machine is employed. In medium sized distribution transformers, more than one strip runs parallel. In that case it is required to transpose the strips to ensure uniform distribution of current among them. Fig. 13.3 shows a photograph of low voltage spiral coil of a 500 kVA transformer.

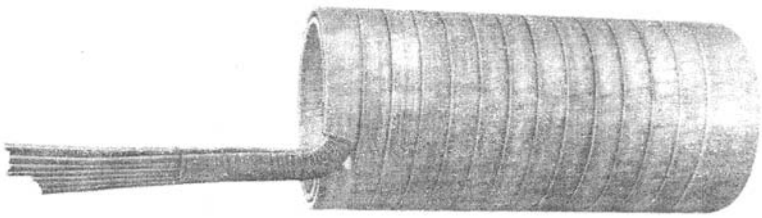


Fig. 13.3. Photograph of low voltage spiral coil

13.3 CORE ASSEMBLY

Core assembly is also one of the components of the finished transformer. Core assembly is done manually. The basic raw material is cold rolled grain oriented silicon steel and is in the form of thin sheet cut to size as per design. Rectangular-cut core is almost obsolete these days since it increases the no-load loss and current with respect to mitred cut configuration.

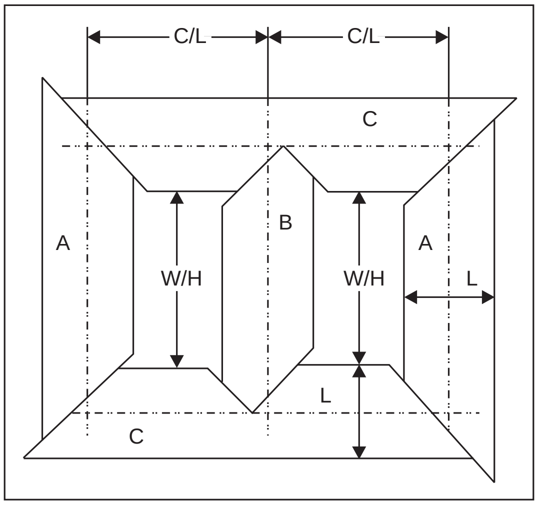


Fig. 13.4. Core assembly details

In the case of full mitred cut core, three different shapes of core laminations are generally employed in one core assembly. They are centre limb (*B*), side limbs (*A*) and top and bottom yokes (*C*) as shown in Fig. 13.4.

The laminations are assembled in such a way as to ensure no appreciable air gap between the joints of two laminations.

The entire assembly is done on a frame commonly known as core channel. These frames are used as a holding support for the core assembly. Hooks are provided on the core frame for easy lifting.

13.4 CORE-COIL ASSEMBLY

The components produced in the coil winding and core assembly departments are used for core-coil assembly by further processing. The procedure of core-coil assembly includes the following:

(*a*) The core assembly is vertically placed with the foot plate touching the ground. The top yoke of the core is unbladed and is kept in a safe place. The limbs of the core are tightly wrapped with cotton tape.

(*b*) Cylinder made out of insulating pressboard is wrapped around the limbs. Low voltage coil, one per limb, is placed on the insulated limb. Insulating blocks of specified thickness and number are placed at the bottom of LV coil.

(*c*) Cylinder made out of corrugated paper or plain cylinder with oil ducts are provided over LV coil. HV coils are placed over the insulated cylinder. Gaps between each section of HV coil including top and bottom clearances are maintained as per design specification.

(*d*) Top yoke laminations are refilled. Top core frame including core bolts and tie rods are fixed in position.

(*e*) Primary and secondary windings are connected as per the requirement of vector group. Phase barriers are placed between HV limbs. Tap switch, if provided, are connected to provide suitable voltage variation. Figs. 13.5 and 13.6 show the constructional details of core-coil assembly and Fig. 13.7 shows a fully assembled transformer viewed from low voltage side.

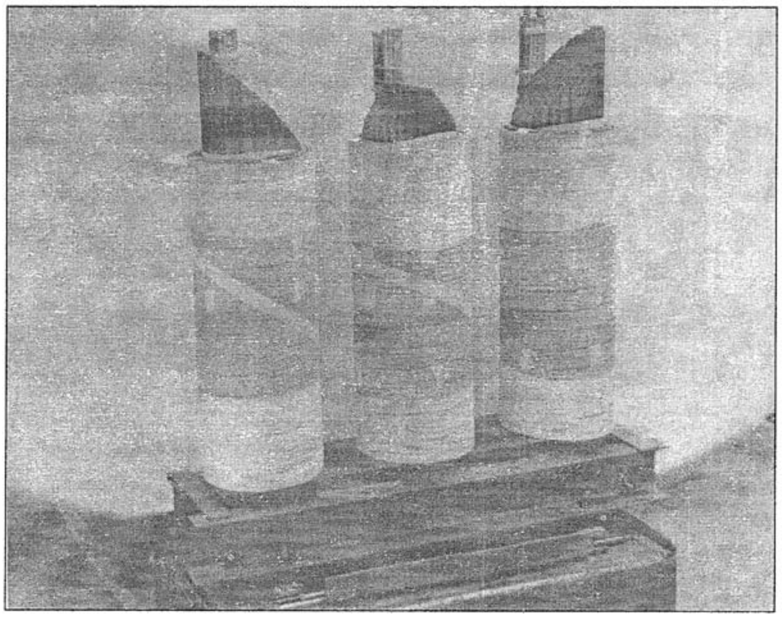


Fig. 13.5. Photograph of 3-phase mitred, taped core, LV spiral coil in position

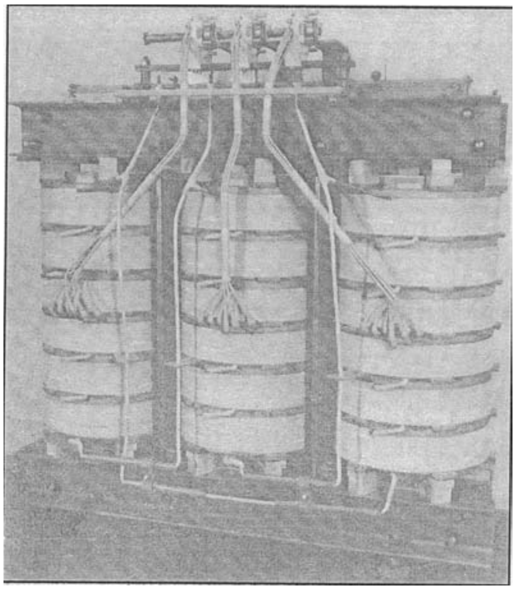


Fig. 13.6. Photograph of cross-over HV coils fitted with tappings brought up to an externally operated tap switch

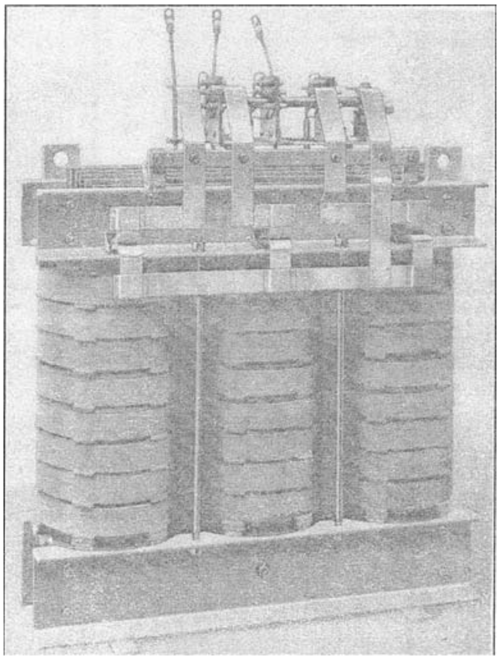


Fig. 13.7. Photograph of a 3-Phase core type transformer, 750 kVA, 11000/433 V, viewed from LV side-star connected

13.5 TANK FABRICATION

The tanks are fabricated from MS sheets, angles, channels, pipes etc. The materials are cut to size as per design and then electrically welded to form a tank.

MS sheet forms the tank body. Angles, flats etc. are used for supports and stiffeners. Channels are used as base supports. Elliptical tubes are used as radiators. In some cases, pressed steel radiators are also used in the place of elliptical tube radiators.

Fittings like drain valve, conservator, lifting hooks, air release plug, oil level indicator, oil filling hole with cap, inspection cover etc. are provided as per requirement.

The complete tank is then subjected to an air pressure test at 0.8 kg/sq. cm to remove possibility of welding leakage.

13.6 PAINTING

The tanks are required to be cleaned thoroughly before the application of paint. Surface preparation is very important. Manual cleaning sometimes do not create satisfactory results. It is suggested to provide automatic cleaning by sand/shot blasting.

Tanks are placed in the inverted condition inside a closed de-humid chamber. Sand/shots are sprayed on the tank surface at a very high velocity. This removes the rust/welding scales automatically leaving behind a smooth surface for the application of paint.

Immediately after cleaning, a coat of hot oil resistant, zinc chromate based paint is applied on the internal surface of the tank. The outside surface is painted with a coat of red oxide primer and subsequently with a coat of air dry ready mix paint as per IS-5. However the selection of colour code should be as per customer's requirement. Sufficient time (atleast 24 hours) should be given for drying the paint before the tanks are taken for box-up operation.

13.7 BOX-UP OR TANKING

Coil assembly and tank are the inputs of box-up dept. The next operation is box-up or tanking.

The processes of box-up operation are listed below:

(*a*) Coil assemblies are kept in the oven for drying.

(*b*) The dry assemblies are taken out from the oven.

(*c*) Final tightening, dressing of leads are done at this stage.

(*d*) Insulation resistances between the windings and windings to earth are checked and recorded.

(*e*) Upon achieving required I/R values, the assemblies are put into their respective tanks and are locked with the tank body, atleast at two opposite diagonals, to eliminate probability of movement of the active part during transit. Ratio switch, if provided, is coupled with the operating handle.

(*f*) Filtered oil with required di-electric value is then poured into the tank up to a level to immerse the active part only.

(*g*) Connection of the primary and the secondary leads to the respective terminal bushings are made.

(*h*) The top cover is then bolted to the main tank with required gasket in-between and balance oil is poured into the tank up to the oil level indicator.

(*i*) The transformer is now ready for final test. However sufficient time (atleast 24 hours) should be allowed, before the transformer is taken for final test, to ensure proper soaking of oil by the insulating materials.

13.8 FINAL TESTING

All routine and type tests are carried out as per recommendation of ISS/IEC/BS as well as requirements of the customer. In case, impulse and short-circuit withstand tests are necessary to be carried out, the same are also done at the customer’s approved test laboratory (CPRI, NTH, ERDA etc.). Buyer’s pre-shipment inspection is also arranged at this stage.

13.9 FINISHING AND DESPATCH

(*a*) Fittings and accessories as per customer’s requirement as well as approved drawings are provided. Oil is topped up to the normal level marking.

(*b*) Air pressure cum oil leakage test is done to ensure no leakage and seepage from any joint.

(*c*) External phase clearances are checked with go and no-go gauge.

(*d*) A coat of paint, if necessary, is applied.

(*e*) Cleaning of porcelain bushings, name plate, oil level indicator etc. are done.

(*f*) Loose accessories like earthing terminals, bi-metallic connectors, dial type thermometer, silicagel breather etc. are also checked for proper fittings.

(*g*) Transformer is ready for despatch.

13.10 CONCLUSION

This chapter has covered in brief the essential aspects of the manufacturing processes of the transformer to provide an idea to the working engineers about the sequence of activities. The quality of finished product depends on the adoption of right processes. Since most of the manufacturing processes in the production of transformer are manual, care should be taken to prevent human errors.

Each process should be described clearly in the work instructions, preferably in a language easily understood by most of the workers. Local language may be the right one to use in work instructions. Work instructions could also be used with illustrative photographs and drawings. The work instructions, illustrative drawings/photographs, process flow charts etc. should be displayed at appropriate places in the workshop.

Inprocess checking of components produced by each department is one of the methods to regulate the quality of the finished products. The components which are found beyond the quality norms during stage inspection are taken out for rework. Only the good components are sent for final assembly. As a result, the quality of the finished products become uniform without much rework/rejection.

This will not only reduce the failure rate of finished products at the final inspection, but will also improve productivity and reduce the manufacturing cost by way of less rework/rejection.

Every effort is to be made to improve the quality of the ultimate product so that it is comparable with the products of other internationally reputed firms.

The quality of a product cannot be improved by way of inspection or quality checks alone. Inspection and quality checks will only segregate the bad materials from the good ones. But the overall quality will be the result of team efforts together with good design, good materials, healthy machines and skilled operators. Unnecessary delays in production should be avoided so that timely delivery of the product is possible.

Section III

CHAPTER 14

Special Process

FOOD FOR THOUGHT

The holidays are over, relaxation is history and now is the time to march on. One more year of experiments, problems, opportunities, analysis, and results; the future is full of opportunities. Strengths and weaknesses are assessed and new year's resolutions are made. Resolutions are made: to quit smoking, get in shape, improve diet, save money, reduce stress, read more, be understanding and many others.

Is making a resolution itself a sign of weakness?

Resolutions are not needed where signs of continuous improvements are evident We should use our strength to achieve desired results. The question of whether to make a resolution remains unanswered if continuous improvement, ambition, strong desire and willingness can bring the desired result.

Last year's failures should not discourage us from venturing down new path. They can be used as a positive experience. Failure is in a sense, the super-highway to success. Every new experience teaches us how to avoid error in the future.

Weaknesses, passions and narrowness have to be transformed into strengths.

How can weaknesses be overcome?

By paying attention to our strengths, we can achieve new heights. One can't be a jack of all trades, but can be a master of one, in other words, specialize. A racing car driver does not know how to design or build a car, she/he is only an expert at driving. More enjoyment is derived from working on strengths, rather than working on weaknesses.

Ultimately, a resolution should increase one strengths. The ultimate pay-of will be a better future with positive results.

14.1 INTRODUCTION

Manufacturing processes which are directly linked with the quality of the ultimate products are called special processes. Few of them are:

(*a*) Welding
(*b*) Leak testing by ultraviolet rays
(*c*) Sand/shot blasting
(*d*) Brazing

(*e*) Operation of oven for de-moisturisation

(*f*) Oil filtration.

We shall discuss in brief each of the above processes, their effectiveness on ultimate quality and guideline for selection of skilled operators to handle such processes.

14.2 WELDING

Welding is a process by which two mild steel metal sheet of the tank body are joined together in such a way as to eliminate the probability of leakage or seepage of oil in service. Bad quality of welding will leave porosity in the joint or develop cracks causing harmful leakage of oil and lead to the failure of the transformer in due course of time. The following points are important in achieving satisfactory welding:

(*a*) Right kind of welding machine which can generate continuous arc.

(*b*) DC welding machine, rectifier type, is preferred

(*c*) Step-less smooth control of current will help uniform leak proof welding

(*d*) Selection of make and gauge of electrodes with respect to the object to be welded, is an important aspect of welding

(*e*) Selection of proper current with respect to a particular gauge of electrode is to be looked into

(*f*) Use of long welding lead is to be avoided

(*g*) Engage operators with adequate job knowledge.

Good materials may not always yield good products unless the process is correct. Qualification criteria should be prepared and operators should be selected according to that to handle jobs. A list containing names of the qualified welders should be made available in the fabrication department.

The cracks and leakage in the welded joints should be checked with the application of the process, 'fluorescent dye penetration through ultraviolet rays'. In case, the facility for such a process is not available with the manufacturer, then the leakage may be checked by pressurising the tank with ordinary air from a compressor and by the application of soap-water on the welding joints.

14.3 LEAK TESTING BY ULTRAVIOLET RAYS

Leak testing may be done by the conventional 'air pressure and soap-water method'. But this may not yield satisfactory results everytime. Leak testing by 'fluorescent dye penetration through ultraviolet rays' process is the safest way of ensuring perfect leak proof joint.

Fluorescent dye is sprayed along the welded joints, preferably from the inside of the tank. During the passage of time, in case there is any leakage or crack in the welded joint, the fluorescent dye will penetrate and will appear on the other side of the tank. The entire process of penetration of dye will take approximately 20 to 30 minutes. However, it is not visible to the naked eyes.

Ultraviolet rays generated by a specially built source is then flooded on the periphery of the welded joints. In case, there is a minute pin hole or crack in any of the joints, the fluorescent dye will come in the path of ultraviolet rays resulting in bright illumination for easy identification.

The faulty joints are marked with either permanent marker or chalk for further rectification. The process is commonly called 'Metal X-ray'.

The following operations in this process ensures absolutely leak proof welded joints:

(*a*) First, clean the joints by chipping-off the welding flux deposited during welding.
(*b*) Ensure that the fluorescent dye has covered the entire welded joint.
(*c*) Allow a settling time of 20 to 30 minutes.
(*d*) After cracks are identified by the ultraviolet ray, ensure that the rectification work is done successfully.

In the case of sealed type tank with corrugated wall panel, leak testing by air pressure with soap-water is not recommended, since it destroys the flexibility of the corrugated panel. Such tanks should be checked for leakage either by hydraulic test or by fluorescent dye penetrating process as described above. Since it is a special process which affect the quality of the product directly, it should preferably be done by skilled operators with pre-determined qualification criteria.

14.4 SAND/SHOT BLASTING

MS materials like sheets, angles, channels, pipes, radiators etc. are usually stored in open yards, leading to rusting and pitting of their surface. It is difficult to remove the rust after the tank is fabricated with such materials. Since cleaning by emery paper is not sufficient, the tank should be cleaned by sand/shot blasting.

To organize such cleaning, a closed de-humid chamber and a high power compressor is necessary. The tanks are placed up side down inside the chamber. Sand/shots are sprayed on the tank surface at a very high velocity, resulting in the removal of rust and welding scales. In this process, lightly pitted surface of the tank wall also gets cleaned leaving behind a bright smooth surface. For tank with medium rating transformer with moderately rusted and pitted surfaces, 20 to 30 minutes is essential to get it cleaned completely.

The following points are to be taken care of to achieve satisfactory cleaning:

(*a*) Select appropriate size of shots/mesh of sand
(*b*) Choose adequate compressor air pressure to create the required speed of injecting sand/shot
(*c*) Ensure the quality of sand or shot for re-cycling
(*d*) Fix the time for cleaning on the basis of the surface condition
(*e*) After the cleaning operation, apply first coat of paint without much loss of time, definitely not later than 2 hours
(*f*) Ensure that only qualified workers are employed for this process.

14.5 BRAZING

The process of brazing is almost the same as that of welding. In the case of welding two or more MS materials are joined together. Joining of two or more copper/brass materials is called brazing. Welding arc is developed by electricity, whereas, brazing is done by oxygen-acetylene flame and a specially built electrode. Thin brass rod with approximately 14 per cent silver content is generally used as electrode for gas brazing. Commercial name of such an electrode is 'rupatem rod.'

In transformers with copper winding, taps of coils, delta and line leads, star point, termination of leads on the bushing etc. are few examples where gas brazing is employed.

Following are a few of the essential checks while carrying out gas brazing:

(*a*) Surfaces which are to be brazed should be properly cleaned.
(*b*) Select the right kind of electrodes with proper silver content.
(*c*) Use right kind of torch for mixing oxygen and acetylene gases.
(*d*) Considering the size of the objects to be brazed, control the oxy-acetylene flame.
(*e*) Objects to be brazed should be red hot first before application of electrodes as filling material.
(*f*) After brazing operation, the job should be allowed to cool-down naturally. Movement of the brazed object under hot condition is not recommended.
(*g*) Use of wet cloth in the brazed joint, when hot, is to be avoided.
(*h*) In case, the surface to be brazed is not properly cleaned, there is every possibility of a dry joint which may result in abnormal contact resistance.
(*i*) Use of asbestos clay in the right location may protect the major insulation from burning.

The operators should be sufficiently skilled. Appropriate job related training by way of demonstration by the expert, illustrative drawings etc. should be provided to the operators.

14.6 DE-MOISTURISING

Active part of the transformer, *i.e.*, core-coil assembly is de-moisturised in an electrically heated oven. Insulating materials like pressboard, paper etc. contain approximately 4 to 6 per cent water by weight. The water content in the insulating materials is even higher during monsoon. For example, a 5 MVA, 33/11 kV transformer has about 100 kg of paper insulation and pressboard and contains approximately 6 kg of water particles. Water is very harmful as it deteriorates the di-electric property of the insulating materials. It is therefore necessary to ensure that the water particles are completely dried out before adding oil to the transformer.

Electrically heated oven is employed for such de-moisturisation process. The oven is basically a steel chamber with a door at the front and fin type concealed heaters. Blowers and exhaust fans of adequate capacity are placed in suitable locations. Water particles turn into vapour due to heat and are taken away by the blowers and exhaust fans.

Time and temperature are the two controlling parameters which are to be monitored during the process. Operation of the heaters are controlled through thermostat so that the inside temperature of the oven does not rise beyond 80°C. Control of time depends on the value of insulation resistance between windings and earth. The operation of the oven should continue till the insulation resistance attains its maximum value.

Continuous monitoring during the entire operation of de-moisturising is very essential. Time vs Insulation resistance may be plotted on a linear graph sheet which will give a fair idea of the time required to attain desired insulation resistance. Since the controlling factors in the operation of the oven are temperature and insulation resistance, we must use calibrated temperature gauges and megger to measure these parameters. Motorised megger is preferred to measure insulation resistance.

Qualified operators with adequate job knowledge only should be engaged for this operation.

14.7 OIL FILTRATION

Filtration of oil is done to improve the breakdown value. It is done using a special purpose machine, commonly known as 'stream line oil filter machine'. Suspended foreign particles are removed through a strainer. Moisture is removed through heating and application of vacuum. The temperature should remain between 60 to 70°C. Temperature beyond 70°C may deteriorate other properties of the oil.

Temperature and vacuum are the two controlling parameters which are to be monitored during filtration. The operation should continue till its BDV attains the required value.

Sub-standard oil or used oil should not be filtered through the machine, because when bad oil passes through the machine it leaves offensive foreign materials on the filter disc, which will later adversely affect the quality of the good oil when it passes through the filter disc. Periodic maintenance and change of filter disc after a pre-determined time is very essential.

Qualified operators with adequate job knowledge only should handle this operation.

14.8 CONCLUSION

It is seen that some of the special manufacturing processes have direct effect on the quality of transformer. These processes should be well defined in such a way that it is easily understood by the operators. Necessary description of the processes along with the work instructions should be displayed in the respective work places. In case, demonstration by way of illustrative photographs, drawings, models etc. are necessary to explain the procedure, the same should also be done.

It is essential to highlight certain points which have a direct impact on the quality.

Example:

(*a*) Set the current with respect to sheet thickness during arc welding

(*b*) Control the operating temperature during oil filtration and operation of heating chamber

(*c*) Set the required jet speed during sand/shot blasting

(*d*) Set the appropriate air pressure during leak testing.

The most important aspect in the operation of special processes is the function of the operators. Skilled workmen having sufficient job knowledge and working experience only should be engaged to handle such processes. It is necessary to identify the qualification requirements of the operators and then we need to ensure that only such workmen are engaged who satisfy the qualification criteria. These workmen are termed as 'qualified operators'. A list of qualified operators should be readily available in the work premises.

The outcome of such special processes should be closely monitored to ensure quality output. Job related training by way of development of samples or through demonstration by the experts are some of the methods of improving the skills of the operators.

Section III

CHAPTER 15

Design Process

FOOD FOR THOUGHT

Design, Conformance and Costs

Before any discussion on quality can take place, it is necessary to be clear about the purpose of the product or service, in other words, what the customer requirements are. The customer may be inside or outside the organization and his/her satisfaction must be the first and most important ingredient in any plan of success. Clearly, the customer's perception of quality changes with time and an organization's attitude to quality must, therefore change with this perception. The skills and attitudes of the people in the organization are also subject to change, and failure to monitor such changes will inevitably lead to dissatisfied customers. Quality, like all other corporate matters, must be continually reviewed in the light of current circumstances.

The quality of a product or services has two distinct but interrelated aspects:

(*a*) Quality of design

(*b*) Quality of conformance to design

(*c*) Cost of quality.

(*a*) **Quality of design:** This is a measure of how well the product or services is designed to achieve its stated purpose. If the quality of design is low, either the service or product will not meet the requirements, or it will only meet the requirement at a low level.

A major feature of the design is the specification. This describes and defines the product or service and should be a comprehensive statement of all aspects which must be present to meet the customer's requirements.

A precise specification is vital in the purchase of materials and services for use in any conversion process. All too frequently, the term 'as previously supplied', or 'as agreed with your representative', are to be found on purchase orders for bought-out goods and services. The importance of obtaining materials and services of the appropriate quality cannot be overemphasized and it cannot be achieved without proper specifications. Published standards should be incorporated into purchasing documents wherever possible.

There must be a corporate understanding of the company's quality position in the market place. It is not sufficient that the marketing department specifies a product or service, 'because that is what the customer wants'. There must also be an agreement that the producing departments can produce to the specification. Should 'production' and 'operations' be incapable of achieving this, then one of two things must happen: either the company finds a different position in the market place, or substantially changes the operational facilities.

(*b*) **Quality of conformance to design:** This is the extent to which the product or service achieves the specified design. What the customer actually received, should conform to the design, and operating costs are tide firmly to the level of conformance achieved. The customer satisfaction must be designed into the production system. A high level of inspection or checking at the end is often indicative of attempts to impact in quality. This will achieve nothing but spiralling costs and decreasing viability. Conformance to a design is concerned largely with the quality performance of the actual operations. The recording and analysis of information and data play a major role in this aspect of quality.

(*c*) **The cost of quality:** Obtaining a quality product or service is not enough. The cost of achieving it must be carefully managed so that the long-term effect of 'quality cost' on the business is a desirable one. These costs are a true measure of the quality effort. A competitive product or service based on a balance between quality and cost factor is the principal goal of responsible production/ operations management and operator.

AT A GLANCE

Before to start with a working design, a brief specification of a 1250 kVA, 11/0.433 kV copper-wound transformer has been conceived.

The first step of the design is to select the number of turns of coils and proceed further towards estimating the coil configuration, up to arriving at the window height of the core frame. Based on the calculated window height, the design of the secondary coil is done. Further, core diameter, limb centre, step width, core stack, core area, flux density etc. are calculated with the available design output.

The next step of design is the formation of coils and limb centre of the core frame. Based on the window height and limb centre of the core frame, detailed design of core up to the weight of the complete set of core is estimated. Manufacturing details of low and high voltage windings, tappings, placement of coils, internal clearances, weight of conductor etc. are done.

Next come the calculation of performance figures. The process of calculation of resistance, losses, no-load current, percentage impedance, ratio error, efficiency, regulation etc. have been dealt with.

After the design of internal active part, the chapter has covered the process of tank design with different types of radiators. A few paragraphs have been added to demonstrated the procedure of designing the core frame part, core stud, tie rod, conservator etc. Calculation of oil volume, overall weight and dimensions have also been discussed.

The chapter ends with the procedure of filling up the guaranteed technical particulars with relevant calculation of performance parameters and generation of various drawings for submission. The thermal ability to withstand an external short-circuit has also been shown.

15.1 INTRODUCTION

We are here in the process of establishing a working design of a 1250 kVA medium rating copper wound 11 kV distribution transformer. Since it is a tailor made job, a complete specification incorporating electrical, mechanical and environmental requirements must be available in advance to the designer.

Selection of number of turns is the first choice. It is calculated from the formula $\frac{E}{T} = K\sqrt{Q}$, where 'E' is the rated voltage, 'T' is the number of turns per phase, 'Q' is the rated kVA of the transformer, 'K' is a constant. It is the choice of the designer to select any value of 'K' between 0.25 to 0.55 to find out the number of turns. The value of 'K' should be judiously selected as wrong choice may lead to effect the performance parameters like no-load and full-load loss, impedance, efficiency, regulation etc. The manufacturing cost of the transformer may also get effected due to incorrect estimation of the value of 'K'.

The working flux density and current density are two valuable inputs which are also to be assumed on the basis of targeted no-load and full-load losses. Flux density and current density help us to estimate the requirement of core area and size of conductor respectively.

Internal clearances at various locations are also to be conceived by the designer. This is assumed on the basis of the system voltages and basic insulation level.

The following pages will help us to understand the various steps of designing a transformer.

15.2 PROPOSED SPECIFICATION

We have taken up a task to design a 1250 kVA copper wound distribution transformer having following specification:

(*i*) Rating	1250 kVA ; oil cooled
(*ii*) No-load voltage ratio	11000/433 V
(*iii*) No. of phase	3 Phase
(*iv*) Frequency	50 Hz
(*v*) Winding material	Electrolytic copper
(*vi*) Tappings on HV	± 2% to ± 8% (off-circuit)
(*vii*) No. load/load loss	1850/12750 watt
(*viii*) Impedance	5.5%
(*ix*) Flux density	1.6 Tesla (max.)
(*x*) Current density	2.6 A/sq. mm (max.)
(*xi*) Connection	Delta/star, vector group Dyn 11
(*xii*) Temperature rise	45/55°C
(*xiii*) Other specifications	As per IS-2026

15.3 DESIGN OF PRIMARY COIL

A three-phase transformer is designed on per phase basis. Phase voltage and current are calculated keeping in mind the connection and vector group. Here primary winding is connected in Delta. The following paragraph will help us to understand the process of calculating the conductor area of primary coil based on the available current density of 2.6 A/sq. mm.

(*i*) Voltage per phase (V_p)	11000 V (being delta conected)
(*ii*) Current per phase (I_p)	$\frac{1250}{3 \times 11}$ = 37.88 A (being delta connected)
(*iii*) Current density (C_d)	2.6 A/sq. mm
(*iv*) Conductor area (A_i)	37.88/2.6 = 14.57 sq. mm

Number of Turns

Voltage, number of turns and rated kVA are interlinked by a formula as $E/T = K\sqrt{Q}$

where E = Rated voltage per phase

T = No. of turns per phase

Q = Rated kVA of the transformer (1250 kVA)

K = A known constant.

The value of 'K' for copper wound transformer may be taken between 0.25 to 0.55. Let us assume 0.44 as the value of 'K'.

Therefore $E/T = 0.44 \times \sqrt{1250} = 15.55$

No. of secondary turns per phase (T_S),

$$T_S = E/15.55$$

Since the secondary voltage is 433 V and is connected in Star, the per phase secondary voltage is

$$433/\sqrt{3} = 250 \text{ V}$$

Therefore secondary turns/phase = 250/15.555

= 16.07 (which is rounded off to 16)

No. of primary turns per phase (at normal tap)

$$= \frac{\text{Primary phase voltage}}{\text{Secondary phase voltage}} \times \text{Sec. turns}$$

$$= \frac{11000}{433/\sqrt{3}} \times 16 = 44 \times 16 = 704$$

Add 8% additional turns for tapping voltage

Total primary turns per phase = 704 + (704 × 0.08)

= 704 + 56 = 760

We have so far achieved the following:

(*i*) Secondary turns/phase	16
(*ii*) Primary turns/phase	760
(*iii*) Primary conductor area	14.57 sq. mm (min.)

In the event the conductor area is more than 7 to 8 sq. mm, we should not go for round conductor. The alternative choice is to select a rectangular strip with the formation of continuous disc coil and one coil per phase.

It has been decided above that the primary coil will be designed in the shape of continuous disc having 760 turns per coil.

Let us assumed the number of discs as 44 which include both plain and tap discs.

The specification has sought for a tapping range of (–) 8% to (+) 8%, *i.e.* 16% of the total turns (or discs), the number of tap disc will be 44 × 0.16 = 7.04 which is rounded off to the next whole number, *i.e.*, 8 discs. Automatically the number of plain disc will be (44 – 8) = 36 discs.

Let us conclude the following in a tabulated form:

No. of primary turns per phase at normal tap	704
Add 8% towards tapping voltage	704 × 0.08 = 56
No. of primary turns per phase at (+) 8% tap	704 + 56 = 760
No. of discs	44
No. of plain disc	36
No. of tap disc	8

The specification has desired a tapping step of 2% with a maximum tap voltage of 8%, *i.e.* the ratio is 4.

The turns per tap disc is 56/4 = 14. With this combination the tap terminals from the winding will come as the last turn of the tapping disc.

8 tap disc will cover	8 × 14 turns per disc = 1|2 turns
Total turns per phase	760
No. of plain disc	36
Turns per plain disc	(760 – 112)/36 = 18
No. of plain disc	36
Turns per plain disc	18
No. of tap disc	8
Turns per tap disc	14

Size of Strip for Plain Disc

Very first approach should to estimate the size of the strip of plain disc. Size of tap disc will come later. To calculate the strip size we need to assume approximately the window height of the core frame. 10% plus or minus approximation of window height may not effect much on the performance figures. Beyond this limit the performance parameters may remain well out from the specified requirements. This is where the designer has to judiciously select a reasonable window height based on his experience.

Let us assumed a window height of the core frame as 620 mm.

At the initial part of the discussion, it has been stated that various internal electrical clearances on the basis of voltage class are to be conceived as a part of design input.

Let us conceived the following:

(*i*) Gap at the centre of the coil (tap break) (between disc nos. 22 and 23)	15 mm × 1 gap = 15 mm
(*ii*) Gap between tap disc (between disc nos. 19 and 20; 20 and 21; 21 and 22; 23 and 24; 24 and 25; 25 and 26; *i.e.*, 6 gaps	10 mm × 6 gaps = 60 mm

(*iii*) Gap between plain disc (36 gaps)	3 mm × 36 gaps = 108 mm
	43 gaps = 183 mm

These gaps are maintained by paper blocks which shrink during ovening. It has been estimated that the blocks made out of pre-compressed pressboard shrink around 6% of its nominal thickness.

A shrinkage of 6% over 183 mm *i.e.* 11 mm is estimated.

Top and bottom yoke insulation is estimated as 30 mm each for 11 kV transformer.

A pressure plate of 10 mm thickness is provided at the top for uniform pressing the coils.

Let us tabulate the various gaps as under:

Total gaps between the disc after compression (Shurnk height)	(183 – 11) = 172 mm
Top and bottom yoke insulation	30 mm × 2 = 60 mm
Thickness of end ring (steel)	10 mm × 1 = 10 mm
Approximate window height (assumed)	620 mm
Space left for disc winding	620 – (172 + 60 + 10) = 378 mm
No. of disc	44
Width of insulated strip of plain disc	378/44 = 8.59 mm
Width of bare strip taking into consideration of 0.5 mm TPC covering	(8.59 – 0.5) = 8.09 mm (rounded-off to 8 mm)

Based on a current density of 2.6 A/sq. mm, it has been estimated an area of 14.57 sq. mm for the primary conductor.

$$\text{Depth of the strip} = \frac{\text{Area of conductor}}{\text{Width}} = \frac{14.57}{8.0}$$

$$= 1.82 \text{ mm (rounded off to 1.9 mm)}$$

Thus we have arrived at the strip size of the plain disc as 8 × 1.9 mm

Area of conductor = (8 × 1.9) – 0.36 = 14.84 sq. mm

Effective current density = 37.88/14.84 = 2.56 A/sq. mm.

Size of Strip for Tap Disc

The most important aspect of designing disc winding is to maintain the external diameter equal for both plain and tap disc. In other words the radial built of both plain and tap disc should be equal. Keeping this requirement in mind, let us estimate the size of strip of tap disc as follows:

Width of strip for plain disc	1.9 mm (bare)
Insulation covering	0.5 mm (TPC covering)
Covered width of strip	2.4 mm
No. of turns per plain disc	18
Radial built of plain disc	2.4 × 18 = 43.2 mm (rounded off to 44 mm)
No. of turns per tap disc	14
Depth of strip (Insulated) for tap disc	44/14 = 3.14 mm
Assuming a covering thickness of 0.5 mm, the depth of strip (bare) for tap disc	(3.14 – 0.5) = 2.64 mm (rounded off to 2.6 mm)

Width of strip (bare) for tap disc	14.84/2.6 = 5.7 mm (rounded-off to 6.0 mm)

Let us now form the disc coil with the following available design output:

No. of plain disc	36
Turns per plain disc	18
Size of strip for plain disc	8 × 1.9 mm (bare)
Covering	0.5 mm (TPC)
Size of insulated strip for plain disc	8.5 × 2.4 mm
No. of tap disc	8
Turns per tap disc	14
Size of strip for plain disc	6 × 2.6 mm (bare)
Covering	0.5 mm (TPC)
Size of insulated strip for tap disc	6.5 × 3.1

Plain Disc

	Width	***Depth***
Bare conductor	8	1.9
Covering	(+) 0.5	(+) 0.5
Size of covered conductor	8.5	2.4
No. of plain disc - 36	× 36	↓
Total height of plain disc	306	
Turns per plain disc - 18	↓	× 18
Radial built of plain disc		43.2
		↓
Rounded off to next whole number	310 mm	44

Tap Disc

	Width	***Depth***
Bare conductor	6	2.6
Covering	(+) 0.5	0.5
Size of covered conductor	6.5	3.1
No. of tap disc – 8	× 8	↓
Total height of tap disc	52	
Turns per tap disc-14	↓	× 14
Radial built of plain disc		43.4
		↓
Rounded-off to next whole number	55	44

Window Height of Core Frame (W/H)

The window height of the core frame may be calculated from the available parameters designed in the previous paragraphs as follows:

Width of conductor for plain disc	310 mm
Width of conductor for tap disc	55 mm
Gap between disc after compression	172 mm
Axial height of coil after compression	(310 + 55 + 172) = 537 mm
Top and bottom yoke insulation	30 mm × 2 = 60 mm
A steel plate of 10 mm thick is placed at the top of the coil for uniform pressing	10 mm × 1 = 10 mm
Therefore window height of the core frame	(537 + 60 + 10) = 607 mm rounded off to 610 mm

Though it has been estimated a window height of 620 mm during the initial stage of design, we have now arrived at the correct window height as 610 mm and henceforth all our design will be based on a window height of 610 mm.

15.4 DESIGN OF SECONDARY COIL

According to the design practice, the axial length of secondary coil should be equal to the axial height of primary coil which has been estimated in the previous paragraph as 537 mm. This is essential to reduce the axial dynamic forces to minimum.

Therefore, we fix the axial length of secondary coil as 537 mm.

Phase voltage (V_p)	$433/\sqrt{3}$ = 250 V
Phase current (assuming secondaries are connected in star)	$1250/\sqrt{3}$ × 0.433 = 1666.7 A
Current density (assumed)	2.6 A/sq. mm
Conductor section (based on assumed current density)	1666.7/2.6 = 641 sq. mm
As per design convention the cross sectional area of single strip should be limited to	45 sq. mm
Based on the above assumption, number of strips run in parallel	641/45 = 14.24 (rounded off to next whole number as 15 strips)
Disposition of 15 strips	5*W* × 3*D*
Axial length of coil	537 mm
No. of turns per phase (as estimated earlier)	16
No. of layer	2
Turns per layer	8
To lay 8 turns/layer with a transposition in between, we need to keep a space of	10 turns/layer

Therefore $5W$ is equivalent to	$5W = 537/10 = 53.7$ mm $W = 53.7/5 = 10.74$ mm
Assuming a TPC covering of 0.5 mm and a working tolerance of 0.1 mm between each strip, the width of bare strip would be	$10.74 – (0.5 + 0.1) = 10.14$ mm (rounded off to nearest whole number as 10 mm)
Total area of 15 strips	641 sq. mm
Depth of each strip	$641/15 \times 10 = 4.27$ mm

The calculated depth of strip may be increased approximately by 3 per cent to account for the reduction due to corner radius.

Hence the width of the bare strip $= 4.27 \times 1.03$

$= 4.4$ mm

The secondary strip has been calculated as 10×4.4 mm having 15 strips run in parallel with a disposition of $5W \times 3D$.

Spiral Secondary Coil

The low voltage secondary coils, having multiple strips run in parallel, are generally wound in spiral fashion.

Let us establish the axial length and radial built of the coils as under.

	Width	***Depth***
(*i*) Bare size of strips	10 mm	4.4 mm
(*ii*) Conductor covering	(+) 0.5	+ 0.5
(*iii*) Size of covered conductor	10.5 mm	4.9 mm
(*iv*) Working tolerance of 0.1 mm between consecutive strip	(+) 0.1	(+) 0.1
(*v*) Size of covered conductor with tolerance	10.6 mm	5.0 mm
(*vi*) Conductor disposition – $5W \times 3D$	× 5	× 3
(*vii*) Size of each turn taking 15 strips in a bunch	53 mm	15 mm
(*viii*) No. of turns per layer – 8 turns To accomodate 8 turns with a transposition at each layer, a space of 10 turns is needed.	× 10	× 2
(*ix*) Therefore the approx. axial length of secondary coil	530 mm	
(*x*) Radial built of the coil taking 2 layers in consideration		30 mm
(*xi*) An oil duct of 4 mm has been considered between the layers Therefore the final radial built of the coil	↓	+ 4 ↓
(*xii*) Rounded-off to match the HV coil	537 mm	35 mm

So far we have established the following:

Window height of core	610 mm
Size of bare conductor–Primary (for plain disc)	8 × 1.9 mm – covering 0.5 mm
Size of bare conductor–Primary (for tap disc)	6 × 2.6 mm – covering 0.5 mm
No. of plain disc	36
No. of tap disc	8
No. of turns per plain disc	18
No. of turns per tap disc	14
Axial height of primary coil (after compression)	537 mm
Radial build of primary coil	44 mm
Size of secondary conductor (bare)	10 × 4.4 – covering 0.5 mm
Turns per coil	16
Layer	2
No. of turns per layer	8
Transposition	At the centre of each layer
Axial height of secondary coil	537 mm
Use end packing on either side of the coil	10 mm
Effective length of secondary coil	537 + 10 + 10 = 557 mm
Radial build of secondary coil	35 mm

With the above informations and flux density available in the specification, let us establish the core diameter, coil diameter and limb centre of the core frame.

15.5 CORE DIAMETER

To estimate the core diameter, we are first required to know the core area which is calculated on the basis of voltage per turn, flux density and supply frequency.

Voltage per turn (E/T)	$433/\sqrt{3}/16 = 15.62$
Flux density (available from the specification) (B_m)	1.6 tesla (Max.)
Stacking factor (assumed)	0.97
Gross core area (to be calculated)	A_g in sq. cm
Formula used for calculating A_g	$E/T = 4.44 \times f \times B_m \times A_g \times 0.97 \times 10^{-4}$
The above equation may be rewritten after putting the value of frequency as $f = 50$ Hz	$E/T = 4.44 \times 50 \times B_m \times A_g \times 0.97 \times 10^{-4}$ $= 2.22 \times 10^2 \times B_m \times A_g \times 0.97 \times 10^{-4}$ $= 2.22 \times B_m \times A_g \times 0.97 \times 10^{-2}$
Therefore, A_g	$\dfrac{E/T \times 10^2}{2.22 \times B_m \times 0.97}$ sq. cm $= \dfrac{15.62 \times 10^2}{2.22 \times 1.6 \times 0.97} = 453.35$ sq. cm

Let us conceived a core limb with 11 steps having a rounding-off factor 0.94 (assumed).

Therefore $\pi \times d^2/4 \times 0.94 = 453.35$ sq. cm, where 'd' is the core diameter.

$$d = \sqrt{\frac{453.35 \times 4}{\pi \times 0.94}}$$

$$= 24.78 \text{ cm}$$

$$= 248 \text{ mm.}$$

15.6 WIDTH OF CORE STEP

The core diameter has been calculated as 248 mm and number of steps as 11. The first and 11th steps may be taken as 240 mm and 65 mm respectively. The rest 9 steps may be chosen as 230 mm, 220 mm, 205 mm, 190 mm, 175 mm, 155 mm, 135 mm, 115 mm and 95 mm.

While selecting the step width, we should bear in mind that there must be at least a difference of 10 to 15 mm between two consecutive steps and those should be in decending order.

Let us write the width of steps in a tabulated form.

1st step – (L_1)	240 mm
2nd step – (L_2)	230 mm
3rd step – (L_3)	220 mm
4th step – (L_4)	205 mm
5th step – (L_5)	190 mm
6th step – (L_6)	175 mm
7th step – (L_7)	155 mm
8th step – (L_8)	135 mm
9th step – (L_9)	115 mm
10th step – (L_{10})	95 mm
11th step – (L_{11})	65 mm

15.7 CORE STACK

Core stack (K) may be calculated as

$$K = \sqrt{(d^2 - L^2)}$$

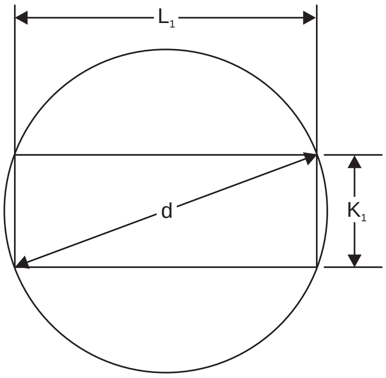
where d = core diameter

L = width of step.

The core dia., width of step and stack have been represented in Fig. 15.1.

The stack height of 1st step $K_1 = \sqrt{248^2 - 240^2} = 62.48$ mm

where $L_1 = 240$ mm



d = Core diameter
L_1 = Width of step
K_1 = Core stack = $\sqrt{d^2 - L_1^2}$

Fig. 15.1. Calculation of core stock

The stack height of 2nd step $K_2 = \sqrt{248^2 - 230^2}$ (–) 62.48

where L_2 = 230 mm

= 92.75 – 62.48 = 30.27
= 30.27 mm

The stack height of 3rd step $K_3 = \sqrt{248^2 - 220^2}$ (–) 92.75

where L_3 = 220 mm

= 114.47 – 92.75
= 21.72 mm

The stack height of 4th step $K_4 = \sqrt{248^2 - 205^2}$ (–) 114.47

where L_4 = 205 mm

= 139.56 – 114.47
= 25.09 mm

The stack height of 5th step $K_5 = \sqrt{248^2 - 190^2}$ (–) 139.56

where L_5 = 190 mm

= 159.38 – 139.56
= 19.82 mm

The stack height of 6th step $K_6 = \sqrt{248^2 - 175}$ (–) 159.38

where L_6 = 175 mm

= 175.72 – 159.38
= 16.34 mm

The stack height of 7th step $K_7 = \sqrt{248^2 - 155^2}$ (–) 175.72

where $L_7 = 155$ mm

= 193.59 – 175.72

= 17.87 mm

The stack height of 8th step $K_8 = \sqrt{248^2 - 135^2}$ (–) 193.59

where $L_8 = 135$ mm

= 208.03 – 193.59

= 14.44 mm

The stack height of 9th step $K_9 = \sqrt{248^2 - 115^2}$ (–) 208.03

where $L_9 = 115$ mm

= 219.72 – 208.03

= 11.69 mm

The stack height of 10th step $K_{10} = \sqrt{248^2 - 95^2}$ (–) 219.72

where $L_{10} = 95$

= 229.08 – 219.72

= 9.36 mm

The stack height of 11th step $K_{11} = \sqrt{248^2 - 65^2} - 229.08$

where $L_{11} = 65$ mm

= 239.33 – 229.08

= 10.25 mm

The total stack of core = K

$K = K_1 + K_2 + K_3 + K_4 + K_5 + K_6 + K_7 + K_8 + K_9 + K_{10} + K_{11}$

= 62.48 + 30.27 + 21.72 + 25.09 + 19.82 + 16.34 + 17.87 + 14.44 + 11.69 + 9.36 + 10.25

= 239.33 mm

We should keep a check on the total stack of core which should preferably be less than the width of first step.

15.8 CORE AREA

The gross core area is calculated from the available core steps and calculated core stack. The total core area calculated in this section must be equal to or more than the area calculated in section 15.5.

Table 15.1. Gross core area

Step no.	*Step width (mm) (L)*	*Core stack (mm) (K)*	*Gross core area (sq. mm) (L × K)*	*Total gross core area (sq. mm)*
1.	240 (L_1)	62.48 (K_1)	14995.20	46123.5
2.	230 (L_2)	30.27 (K_2)	6962.10	
3.	220 (L_3)	21.72 (K_3)	4778.40	
4.	205 (L_4)	25.09 (K_4)	5143.45	
5.	190 (L_5)	19.82 (K_5)	3765.80	
6.	175 (L_6)	16.34 (K_6)	2859.50	
7.	155 (L_7)	17.87 (K_7)	2769.85	
8.	135 (L_8)	14.44 (K_8)	1949.40	
9.	115 (L_9)	11.69 (K_9)	1344.35	
10.	95 (L_{10})	9.36 (K_{10})	889.20	
11.	65 (L_{11})	10.25 (K_{11})	666.25	

Gross core area (A_g) = 46123.5 sq. mm = 461.235 sq. cm

Net core area (A_n) = Gross core area × stacking factor

Stacking factor may be estimated as 0.97 for all practical purposes

Therefore net core area A_n = 461.235 × 0.97

= 447.39 sq. cm.

15.9 FLUX DENSITY

The flux density is calculated utilising the following equation:

$$E/T = 4.44 \times f \times B_m \times A_g \times \text{Stacking factor} \times 10^{-4}$$

or

$$B_m = \frac{E/T \times 10^4}{4.44 \times f \times A_g \times \text{Stacking factor}} \text{ tesla}$$

where B_m = Flux density in tesla

E/T = Voltage per turn = 250/16 = 15.625

f = Frequency = 50 Hz

A_g = Gross core area = 461.235 sq. cm

Stacking factor = A constant and may be taken as 0.97

Therefore
$$B_m = \frac{15.625 \times 10^4}{4.44 \times 50 \times 461.235 \times 0.97}$$

= 1.573 tesla.

15.10 COIL DIAMETER AND LIMB CENTRE OF CORE

The coil diameter and limb centre of core can be find out from the following available parameters:

Core diameter	248 mm
Radial build of secondary coil	35 mm
Radial build of primary coil	44 mm
Radial gap between core to LV coil	5 mm (assumed)
Radial gap between LV and HV coils	15 mm (assumed)
Clearance of HV coils between limbs	10 to 12 mm (assumed)

The above clearances have been assumed on the basis of system voltages *i.e.*, 11 kV for HV coil and 433 V for LV coils. We have further assumed that the low voltage coil will be placed nearer to the core, which remains at earth potential and HV coils will be placed over low voltage coil co-axially further away from the core.

Based on the above assumptions and available parameters, let us calculate the internal and external diameter of coil as below:

	Radius	***Diameter***
Core diameter (R × 2)	124 × 2	248 mm
		(+) 5
Radial gap between core to LV	(+) 5	253
		+ 5
LV coil inside diameter	129 × 2	258
Radial build of LV coil	(+) 35	(+) 35
		293
		(+) 35
LV coil outside diameter	164 × 2	328
		(+) 15
Radial gap between LV and HV	(+) 15	343
		(+) 15
HV coil inside diameter	179 × 2	358
		(+) 44
		402
	(+) 44	(+) 44
HV coil outside diameter	223 × 2	446
Gap of HV coils between limbs		(+) 14
Core limb centre		460

The following informations have been yield in the above calculations:

(*i*) Internal diameter of LV coil	258 mm
(*ii*) External diameter of LV coil	328 mm
(*iii*) Internal diameter of HV coil	358 mm
(*iv*) External diameter of HV coil	446 mm
(*v*) Core limb centre	460 mm

15.11 CORE DETAILS

The following parameters have been calculated in the pre paragraphs :

Core diameter	248 mm
Window height (W/H)	610 mm
Limb centre (C/L)	460 mm
Gross core area (A_g)	461.235 sq. cm
No. of core steps	11
Width of core steps	240 | 230 | 220 | 205 | 190 | 175 | 155 | 135 | 115 | 95 | 65 mm
Stack of each steps	62.48 | 30.27 | 21.72 | 25.09 | 19.82 | 16.34 | 17.87 | 14.44 | 11.69 | 9.36 | 10.25 mm
Total core stack	239.33 m
Grade of core	27 M4 (assumed)

The general view of the core assembly is shown in Fig. 15.2.

Approximate Weight of Core

The approximate of core is calculated with the following formula:

Weight of complete set of core = W_T (kg)

$$W_T = [(3 \times W/H + 4 \times C/L) + (2 \times \text{width of 1st step} \times 0.86)]$$
$$\times \text{ Gross area of core } (A_g) \times \text{ Density of core material}$$
$$\times \text{ Stacking factor} \times 10^{-3} \text{ kg}$$

where

W/H	61 cm
C/L	46 cm
Width of 1st step	24 cm
A_g	461.235 sq. cm
Density	7.65 g/c.c
Stacking factor	0.97

Therefore $$W_T = [(3 \times 61 + 4 \times 46) + (2 \times 24 \times 0.86)] \times 461.235 \times 7.65 \times 0.97 \times 10^{-3}$$
$$= 1398 \text{ kg}$$

The above formula for calculating weight of core is fairly accurate for core having yoke flushed from inside and steps are projected outside. In the case of stepped yoke from both inside and outside, the core weight may be increased by 3 per cent.

Fig. 15.2 shows that the core assembly has five arms—two identical arms on outer legs and are designated as '*A*' ; one centre leg, designated as '*B*' ; and two identical arms at top and bottom, designated as '*C*'. Arms '*A*' and '*B*' are called leg and arm '*C*' is called yoke. With this understanding, let us calculate the weight of each arm in the following paragraphs.

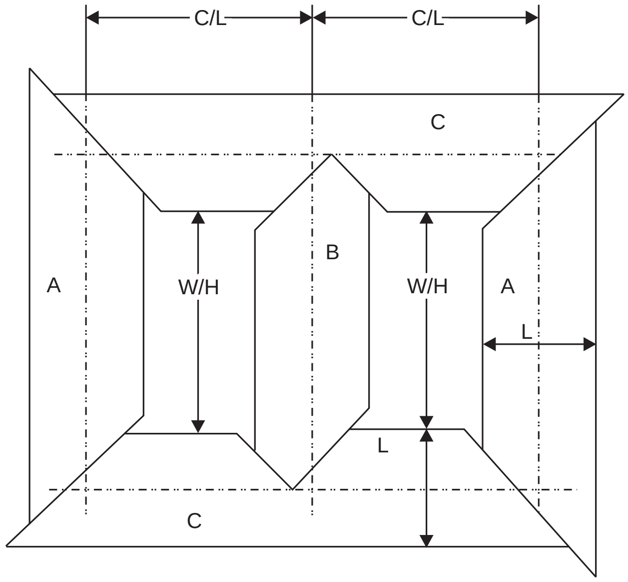


Fig. 15.2. Core assembly details

Stepwise Weight of Core

Fig. 15.3 shows the shapes of various parts of a core assembly. While calculating the weight of core laminations, the following parameters have been assumed:

(*i*) Thickness of core lamination	0.27 mm
(*ii*) Length of core lamination	*L*
(*iii*) Width of core lamination	*W*
(*iv*) Density of core material	7.65 g/c.c
(*v*) Stacking factor	0.97

Part A

Length of lamination (L) is calculated as ($W/H + 2W$) mm where W/H and W are in mm.

Similarly, weight is calculated as $2 \times [(L - W) \times W \times \text{core stack} \times \text{density} \times 0.97 \times 10^{-3}]$

where '*L*', *W* and core stack are in cm.

Length of 1st step $= (610 + 2 \times 240) = 1090$ mm

Weight of 1st step $= [(109 - 24) \times 24 \times 6.248 \times 7.65 \times 0.97 \times 10^{-3}] \times 2$

$= 189.16$ kg

Similarly, the lengths and weights of other steps have been calculated and tabulated in Table 15.2.

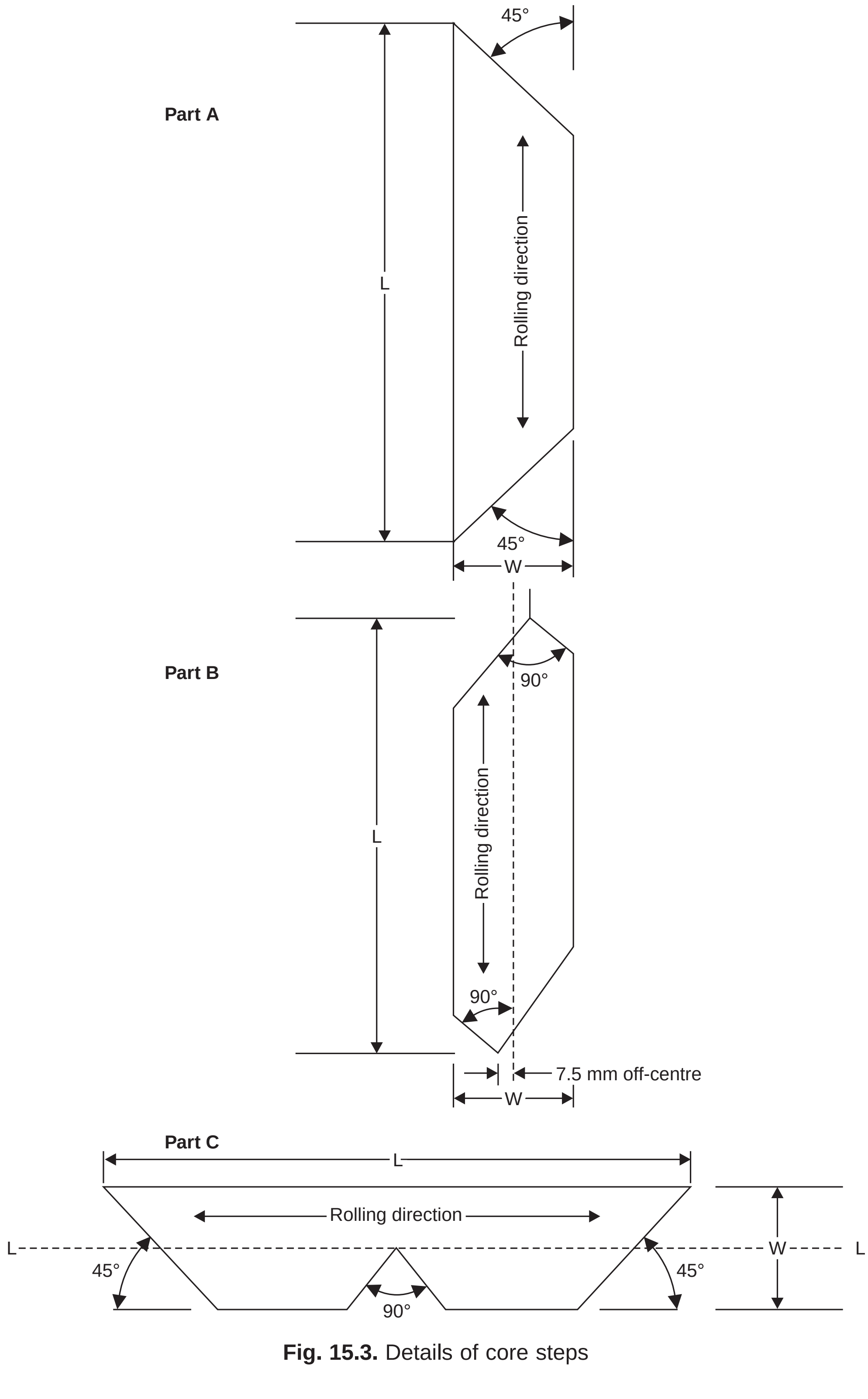


Fig. 15.3. Details of core steps

Table 15.2. Length and weight of step A

Step no.	*Step width (W) (mm)*	*Step length (L) mm*	*Step stack (K) (mm)*	*No. of piece (no.)*	*Weight (kg)*
A_1	240	1090	2 × 62.48	2 × 232	189.16
A_2	230	1070	2 × 30.27	2 × 112	86.79
A_3	220	1050	2 × 21.72	2 × 80	58.86
A_4	205	1020	2 × 25.09	2 × 92	62.21
A_5	190	990	2 × 19.82	2 × 72	44.71
A_6	175	960	2 × 16.34	2 × 60	33.31
A_7	155	920	2 × 17.87	2 × 68	31.44
A_8	135	880	2 × 14.44	2 × 52	21.55
A_9	115	840	2 × 11.69	2 × 44	14.46
A_{10}	95	800	2 × 9.36	2 × 36	9.30
A_{11}	65	740	2 × 10.25	2 × 40	6.67
		Total	2 × 239.33	2 × 888	558.46

Number of pieces are rounded-off to a nearest number which is divisible by ‘4’.

Part B

Length of lamination (L) is calculated as ($W/H + W$) mm where W/H and W are in mm.

Similarly weight is calculated as

$$(L - 1/2\ W) \times W \times \text{core stack} \times \text{density} \times 0.97 \times 10^{-3}$$

where L, W and core stack are in cm.

Length of 1st step = (610 + 240) = 850 mm

Weight of 1st step = [(85 – 12) × 24 × 6.248 × 7.65 × 0.97 × 10^{-3}] kg

= 81.22 kg

Similarly the lengths and weights of other steps have been calculated and tabulated in Table 15.3.

Table 15.3. Length and weight of step B

Step no.	*Step width (W) (mm)*	*Step length (L) (mm)*	*Step Stack (K) (mm)*	*No. of Piece (no.)*	*Weight (kg)*
B_1	240	850	62.48	232	81.22
B_2	230	840	30.27	112	37.45
B_3	220	830	21.72	80	25.52
B_4	205	815	25.09	92	27.19
B_5	190	800	19.82	72	19.70
B_6	175	785	16.34	60	14.80
B_7	155	765	17.87	68	14.13
B_8	135	745	14.44	52	9.80
B_9	115	725	11.69	44	6.65
B_{10}	95	705	9.36	36	4.33
B_{11}	65	675	10.25	40	3.02
		Total	239.33	888	243.81

The number of pieces are exactly the half than that of part '*A*'.

Part C

Length of lamination (L) is calculated as ($2\ C/L + W$) mm where C/L, W are in mm

Similarly, weight is calculated as

$$2 \times [(L - W) \times W - 1/2\ W^2] \times \text{Core stack} \times \text{density} \times 0.97 \times 10^{-3}\ \text{kg}$$

where L, W and core stack are in cm.

Length of 1st step = (2 × 460 + 240) = 1160

Weight of 1st step

$$2 \times [(116 - 24) \times 24 - (1/2 \times 24)^2] \times 6.248 \times 7.65 \times 0.97 \times 10^{-3}\ \text{kg}$$

$$= 191.38\ \text{kg}$$

Similarly the lengths and weights of other steps have been calculated and tabulated in Table 15.4.

Table 15.4. Length and weight of step C

Step no.	*Step width (W) (mm)*	*Step Length (L) mm*	*Step stack (K) (mm)*	*No. of piece (no.)*	*Weight (kg)*
C_1	240	1160	2 × 62.48	2 × 232	191.38
C_2	230	1150	2 × 30.27	2 × 112	89.11
C_3	220	1140	2 × 21.72	2 × 80	61.34
C_4	205	1125	2 × 25.09	2 × 92	66.31
C_5	190	1110	2 × 19.82	2 × 72	48.76
C_6	175	1095	2 × 16.34	2 × 60	37.18
C_7	155	1075	2 × 17.87	2 × 68	36.22
C_8	135	1055	2 × 14.44	2 × 52	25.64
C_9	115	1035	2 × 11.69	2 × 44	17.78
C_{10}	95	1015	2 × 9.36	2 × 36	11.82
C_{11}	65	985	2 × 10.25	2 × 40	8.93
		Total	2 × 239.33	2 × 888	594.47

Number of pieces are exactly equal to that of steps-*A*.

Total Weight of Core

Weights of Part *A*, *B* and *C* together give the total weight of core.

Weight of Part *A* = 558.46 kg

Weight of Part *B* = 243.81 kg

Weight of Part *C* = 594.47 kg

Total weight of core = 1396.74 kg

15.12 WINDING DETAILS

(A) Low Voltage Winding

Table 15.5. Details of low voltage winding

No.	*Description*	*Design parameters*
1.	Conductor material	Electrolytic grade copper
2.	Type of coil	Spiral winding
3.	Connection	Star
4.	Size of bare conductor	10 × 4.4 mm × 15 nos. in parallel
5.	Covering	Paper covering -TPC-0.5 mm
6.	Size of insulated conductor	10.5 × 4.9 mm
7.	Disposition of conductor	5 width × 3 depth (5*W* × 3*D*)
8.	Transposition	Provided at the centre of each layer
9.	Turns per phase	16 T
10.	No. of coil per phase	1 no.
11.	Turns per coil	16 T
12.	No. of layer	2 layers
13.	Turns per layer	8 T
14.	Inter-layer insulation	4 mm oil ducts at 10 equally spaced
15.	Tappings	Nil
16.	Inside diameter of coil	258 mm
17.	Outside diameter of coil	328 mm
18.	Winding length of coil (axial)	537 mm
19.	End packing	10 mm on either side
20.	Overall length of coil	557 mm
21.	Weight of bare conductor per transformer	254.5 kg (Calculation shown afterword)
22.	Weight of covered conductor per transformer (including leads)	254.5 kg × 1.1 = 280 kg

(B) High Voltage Winding

Table 15.6. Details of high voltage winding

No.	*Description*	*Design parameters*
1.	Conductor material	Electrolytic grade copper
2.	Type of coil	Continuous disc
3.	Connection	Delta
4.	Size of bare conductor	8 × 1.9 mm for plain disc 6 × 2.6 mm for tap disc
5.	Covering	Paper covering-TPC-0.5 mm
6.	Size of covered conductor	8.5 × 2.4 mm for plain disc 6.5 × 3.1 mm for tap disc
7.	Disposition of conductor	Single conductor
8.	Transposition	Single conductor
9.	Turns per phase	(704 + 56) = 760 T
10.	No. of coil per phase	1 no.

Contd.

No.	Description	Design parameters
11.	Turns per coil	760 T
12.	Total no. of disc	44
13.	No. of plain disc	36
14.	No. of tap disc	8
15.	Turns per plain disc	18 T
16.	Turns per tap disc	14 T
17.	Inside diameter of coil	358 mm 446 mm
18.	Outside diameter of coil	446 mm
19.	Axial length of coil	
	(*a*) Unshrunk	548 m
	(*b*) Shrunk	537 m
20.	Gap between disc	
	(*a*) between 1 and 19th disc	18 gaps × 3 mm each
	(*b*) between 19th to 22nd disc	3 gaps × 10 mm each
	(*c*) between 22nd and 23rd disc	1 gap × 15 mm (break)
	(*d*) between 23rd and 26th disc	3 gaps × 10 mm each
	(*e*) between 26th to 44th disc	18 gaps × 3 mm
	(*f*) Total no. of gaps	43 gaps
	(*g*) Total height of paper block	3 × 36 + 10 × 6 + 15 × 1 = 183 mm
21.	Weight of bare conductor per job	3.325 kg + 57 kg
22.	Weight of covered conductor per job	325 + 1.06 + 57 × 1.06 = 345 kg + 61 kg = 406 kg

Axial Length of Coil

Axial height of 36 nos. plain disc	310 mm 55 mm
Axial height of 8 nos. tap disc	
Total height of paper block (unshrunk)	183 mm
Approx. compression of precompressed paper block	6% of 183 mm = 11 mm
Total height of compressed paper block	(183 – 11) = 172 mm
Axial length of coil	
(*a*) unshrunk	(310 + 55 + 183) = 548 mm
(*b*) shrunk	(310 + 55 + 172) = 537 mm

Disc Coil Winding Instruction

kVA	1250
Voltage ratio	11/0.433 kV
Tappings	(+) 8% to (–) 8% in steps of 2%
Coil I.D.	358 mm
Coil O.D.	446 mm
Radial depth of coil	44 mm
Core *W*/*H*	610 mm
Core *C*/*L*	460 mm
Core dia.	248 mm

Axial height of coil	
(*i*) Unshrunk	
(*ii*) Shrunk (compressed)	537 mm

Conductor Details	***For Plain disc***	***For Tap disc***
Bare size	8 × 1.9 mm	6 × 2.6 mm
Covered size	8.5 × 2.4 mm	6.5 × 3.1 mm
Weight of Copper/Job		

Table 15.7

Sl. no. of Disc	***No. of turns***	***Spacer after Disc (mm)***	***Turns counter reading***
1	18	3	18
2	18	3	36
3	18	3	54
4	18	3	72
5	18	3	90
6	18	3	108
7	18	3	126
8	18	3	144
9	18	3	162
10	18	3	180
11	18	3	198
12	18	3	216
13	18	3	234
14	18	3	252
15	18	3	270
16	18	3	288
17	18	3	306
18	18	3	324
19	14	10	338
20	14	10	352
21	14	10	366
22	14	15	380
23	14	10	394
24	14	10	408
25	14	10	422
26	14	3	436
27	18	3	454
28	18	3	472

Contd.

Sl. no. of disc	*No. of turns*	*Spacer after disc (mm)*	*Turns counter reading*
29	18	3	490
30	18	3	508
31	18	3	526
32	18	3	544
33	18	3	562
34	18	3	580
35	18	3	598
36	18	3	616
37	18	3	634
38	18	3	652
39	18	3	670
40	18	3	688
41	18	3	706
42	18	3	724
43	18	3	742
44	18	—	760

Table 15.8 Tap disc details

Sl. no. of disc	*Tap turns*	*Tap letters*	*Short/Tapping%*
20	324	12	8 – 7/ + 8%
	338	11	7 – 9/ + 6%
21	356	10	9 – 6/ + 4%
	366	9	6 – 10/ + 2%
22	380	8	10 – 5/ Normal
	Tap break		5 – 11/ – 2%
23	380	7	11 – 4/ – 4%
	394	6	4 – 12/ – 6%
24	408	5	12 – 3/ – 8%
	422	4	
25	436	3	

Note: No. of spacer per circle : 8 nos.

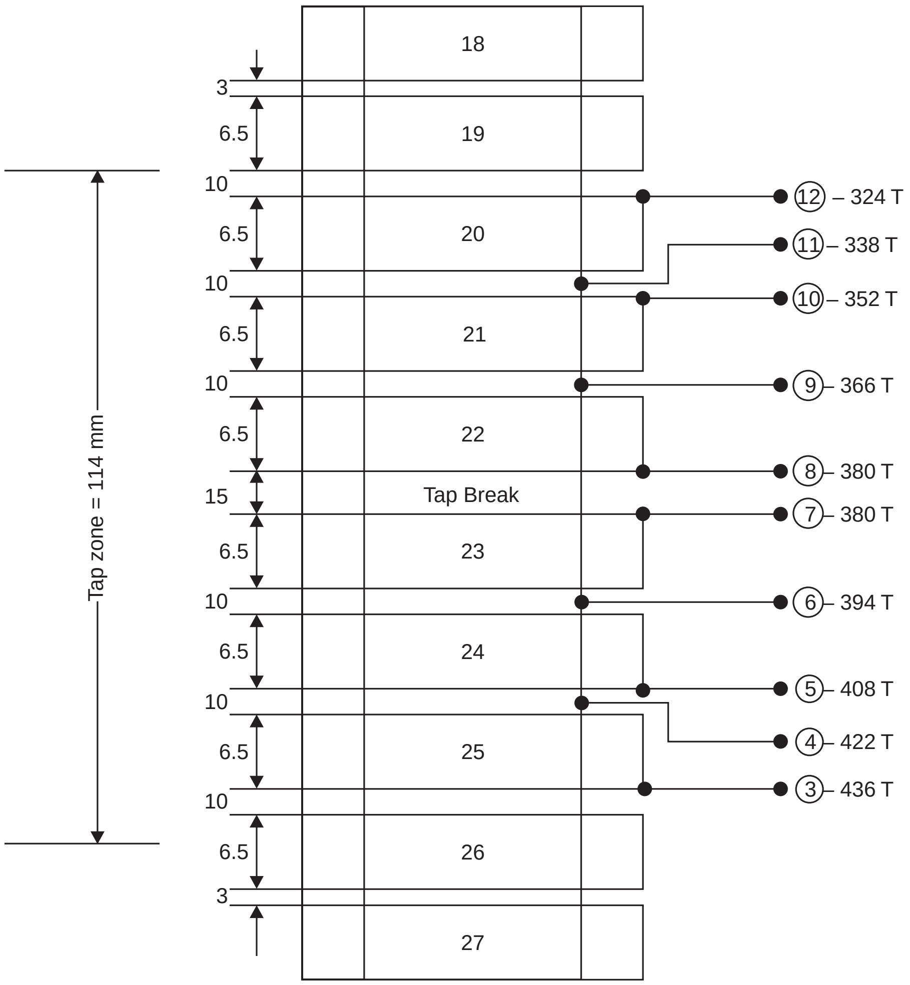


Fig. 15.4. Details of tap disc

15.13 WEIGHT OF LV AND HV COPPER

While calculating copper weight we assume the density of copper as 8.9 gram/c.c.

Table 15.9. Calculation of weight of LV and HV copper

Particulars	*LV coil*	*HV coil*	
		Plain disc	*Tap disc*
Inside diameter of coil (D_1)	258 mm	358 mm	358 mm
Outside diameter of coil (D_2)	328 mm	446 mm	446 mm
Mean diameter of coil (D_m) $D_m = (D_1 + D_2)/2$	293 mm	402 mm	402 mm
Mean length of turn (mlt) mlt = $(\pi + D_m)$	920.49 mm	1262.92 mm	1262.92 mm

Contd.

Particulars	*LV coil*	*HV coil*	
		Plain disc	*Tap disc*
Turns per phase (T)	16	648	112
Length of conductor (L) L = (mlt × T)	14727.84 mm	818372.16 mm	141447.04 mm
Density of copper (d)	8.9 gram/c.c.	8.9 gram/c.c.	8.9 gram/c.c.
Cross-sectional area of conductor (A)	647.1 sq. mm	14.84 sq. mm	15.05 sq. mm
Weight of bare conductor for 3-phases ($L \times A \times d \times 10^{-6}$) × 3 kg	254.46 kg	324.26 kg	56.84 kg
Weight of covered conductor (including leads)	254.46 × 1.1 280 kg	324.26 × 1.06 = 344 kg	56.84 × 1.06 = 60 kg

15.14 WINDING RESISTANCE AND LOAD LOSS

The resistance of winding having taps is calculated at normal tapping.

While calculating resistance of copper windings, we assume resistivity of copper as 0.0215 ohm. cm per metre^{-2} at 75°C.

Table 15.10. Calculation of winding resistance and load loss

Particulars	*LV coil (16 T/Ph)*	*HV coil*	
		Plain (648^t)	*Tap (56^t)*
Length of conductor (L) L = (mlt × T) taking from table 15.9	14727.84 mm	818372.16 mm	70723.52 mm
Resistivity of electrolytic copper (K) assumed at 75°C	0.0215 ohm. cm	0.0215 ohm. cm	0.0215 ohm. cm
Cross-sectional area of conductor	647.1 sq. mm	14.84 sq. mm	15.05 sq. mm
Winding resistance per phase at normal tap and at 75°C (R)			
$R = \left[\dfrac{L \times K \times 10^{-3}}{A}\right]$	0.000489334 ohm	1.185647 ohm	0.1010336 ohm
Current per phase (I)	1666.7 A	37.88 A	37.88 A
$I^2R \times 3$ for 3-phase at 75°C	4078 W	5104 W	435 W
Total I^2R (LV + HV) at 75°C	(4078 + 5104 + 435) = 9617 W		
Approx. stray loss at 75°C (assumed 30% of I^2R)	(9617 × 0.3) = 2885 W		
Load loss at rated load and at 75°C	(9617 + 2885) = 12502 W		
Load Loss (guaranteed)	12750 W		

15.15 NO-LOAD LOSS

No-load loss depends largely on the grade of electrical steel being used and its magnetic characteristic at designed flux density. Let us estimate the no-load loss based on widely available grade M4-0.27.

Table 15.11. No-load loss calculation

Particulars	***Design parameters***
Core diameter	248 mm
Core window height	610 mm
Core limb centre	460 mm
Gross core area	461.235 sq. cm
Net core area	450.308 sq. cm
Working flux density	1.573 tesla
Grade of material being used	M4-0.27
Specific loss (W/kg) at 1.573 tesla for M4-0.27 grade core steel (Value taken from standard core characteristics Curve available from Nippon Steel Corporation Catalogue)	1.0 W/kg
Handling factor (assumed) **Note:** On account of slitting, shearing, notching, air gap between joints and human error during assembly, the no-load loss tends to increase by approx. 25% than that of specified value	25%
Effective core loss per kg taking handling factor into account	(1.0 × 1.25) = 1.25 W/kg
Total weight of core being used	1396.74 kg
Calculated no-load loss	1396.74 × 1.25 = 1746 W
No-load loss (guaranteed)	1850 W

15.16 NO-LOAD CURRENT

No-load current is derived by the vectorial sum of magnetising current (I_m) and hysteresis and eddy current (I_{h+e}). I_{h+e} remain in phase whereas I_m is at 90° to the induced e.m.f. Phaser diagram of a single-phase transformer on open-circuit is shown in Fig. 15.5.

Since cos 90° is zero, the magnetising component of no-load current does not add any wattage to the no-load loss. Hysteresis and eddy current component is responsible to creat no-load loss. This could be the reason why good magnetic materials having low hysteresis and eddy current loss are preferred.

The magnetising current is many times higher than I_{h+e}. In the case of a transformer is to perform satisfactorily even at over voltage (112.5%), the magnetising current should remain as low as possible. Otherwise the core gets saturated at a low voltage and the magnetising current will go many folds and may lead to buring the winding insulations.

The following paragraphs will help us to calculate the no-load current at various voltages.

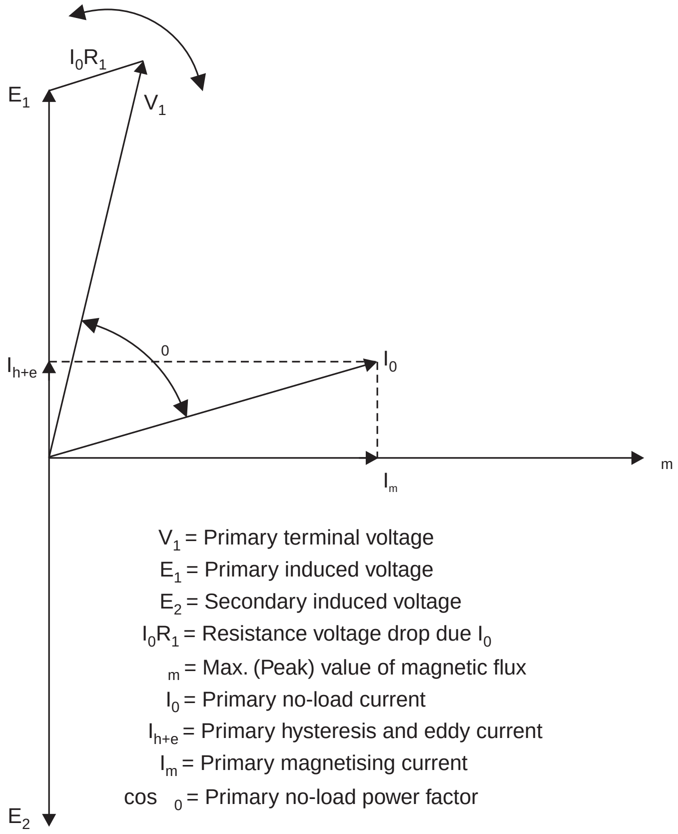


Fig. 15.5. Phaser diagram of a single-phase transformer on open-circuit

(*a*) No-load Current at rated voltage

Since the measurement of current is done on low voltage side, we shall establish the reference of secondary phase voltage for calculating the no-load current.

(*i*) ***Magnetising component of no-load current (I_m)***

Magnetising VA/kg at 1.573 tesla available from the characteristics curve supplied by Nippon Steel Corporation, Japan	1.6 VA/kg
Weight of complete set of core	1396.74 kg
Secondary being star connected, the per phase secondary voltage	$433/\sqrt{3} = 250$ V
Therefore per phase magnetising current (I_m)	$\dfrac{1.6 \times 1396.74}{3 \times 250} = 2.98$ A
Add 200% towards handling factor for stress developed during slitting, shearing, knotching and thickness variation	
Therefore I_m	(2.98 + 2 × 2.98) = 8.91 A

(*ii*) ***Hysteresis and eddy current (I_{h+e})***

I_{h+e} is calculated from the guaranteed no-load loss and phase voltage of the winding under consideration.

Guaranteed no-load loss	1850 W
Rated secondary phase voltage	250 V
Therefore I_{h+e}	$\dfrac{\text{No-load loss}}{3 \times \text{Phase voltage}}$
	$= \dfrac{1850}{3 \times 250} = 2.47$ A

(*iii*) ***No-load current at 100% voltage (I_0)***

No-load current I_0	$I_0 = \sqrt{(I_m^2 + I_{h+e})}$
where I_m	8.91 A
I_{h+e}	2.47 A
Therefore I_0	$\sqrt{(8.91^2 + 2.47^2)} = 9.25$A
No-load current at 100% voltage as	$\dfrac{9.25 \times 100}{1666.7}$
percentage of full load current	= 0.56%

(*b*) **No-load Current at 112.5% voltage**

(*i*) ***Magnetising component of no-load current***

Flux density at rated voltage	1.573 tesla
Flux density at 112.5% voltage	1.573 × 1.125 = 1.77 tesla
Magnetising *VA*/kg at 1.77 tesla available from the characteristics curve supplied by Nippon Steel Corporation, Japan	7 *VA*/kg
Note: *VA*/kg is the product of voltage multiplied by the magnetising current devided by the weight of core. We know '*V*' and 'kg'. *A* is to be calculated	
112.5% of phase voltage (*V*)	250 × 1.125 = 281.5 V
Weight of core	1396.74 kg
Therefore per phase magnetising current (I_m)	$\dfrac{7 \times 1396.74}{3 \times 250} = 13.04$ A
Add 200% towards handling factor for stress developed during slitting, shearing, knotching and thickness variation	
Therefore per-phase magnetising current (I_m) at 112.5% voltage	(13.04 + 2 × 13.04) = 39.12 A

(*ii*) ***Hysteresis and eddy current component (I_{h+e})***

I_{h+e} is calculated from no-load loss at 112.5% voltage and at 112.5% phase voltage.

No-load loss at 112.5% voltage is calculated from the specific loss/kg of core material at 1.77 tesla, weight of core and handling factor (assumed)

Specific loss (W/kg) at 1.77 tesla for M_4-0.27 grade material	1.9 W/kg
Weight of complete set of core	1396.74 kg
Handling factor	25%
Therefore no-load loss at 112.5% voltage	1.9 × 1396.74 × 1.25 = 3318 W
Therefore I_{h+e}	$\frac{3318}{3 \times 281.5}$ = 3.93 A

(*iii*) ***No-load current at 112.5% voltage (I_0)***

No-load current (I_0)	$\sqrt{(I_m^2 + I_{h+e}^2)}$ $= \sqrt{(39.12^2 + 3.93^2)}$ = 39.32 A
No-load current at 112.5% voltage as a percentage of full load current	$\frac{39.32 \times 100}{1666.7}$ = 2.36%

15.17 PERCENTAGE REACTANCE, RESISTANCE AND IMPEDANCE

Limb assembly of primary and secondary coils is shown in Fig. 15.6.

(*a*) **Percentage Reactance**

The formula commonly used for calculating percentage reactance is as follows:

$$x\ (\%) = \frac{7.91 \times f \times I_s \times T^2 \times \pi \times D}{V_S \times A_L} \times \left(a + \frac{b_1 + b_2}{3}\right) \times 10^{-6}$$

where

f = Rated frequency	50 Hz
I_s = Rated secondary current	1666.7 A
T = No. of secondary turns per phase	16
D = Mean dia. of LV and HV coil	(293 + 402)/2 = 347.5 mm
V_S = Rated secondary voltage per phase	$433/\sqrt{3}$ = 250 V
A_L = Average length of LV and HV coil	537 mm

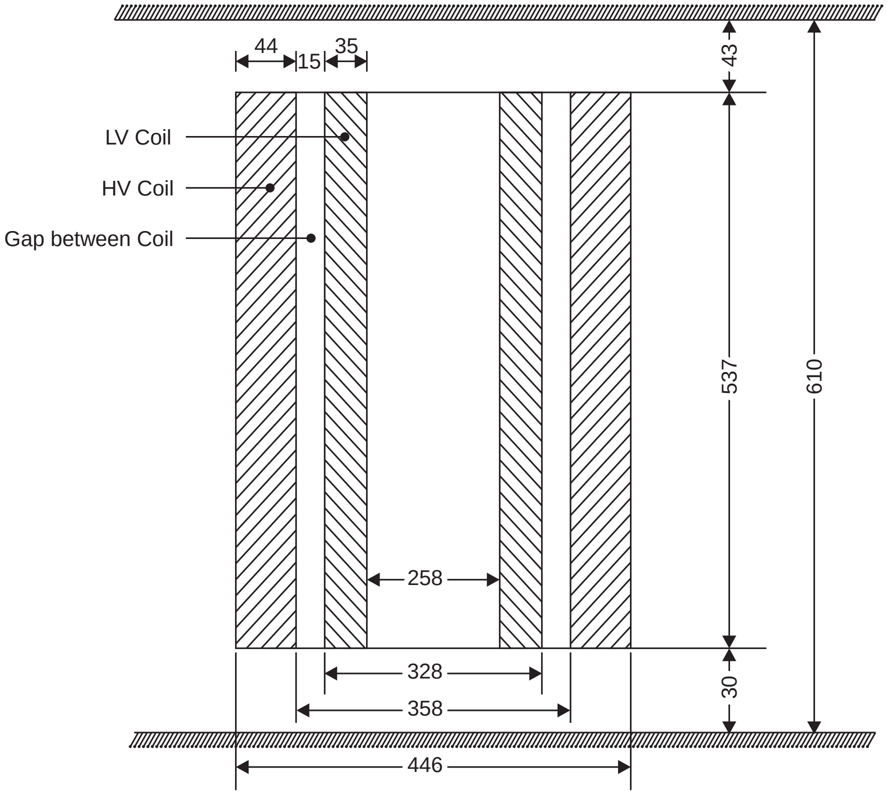


Fig. 15.6. Limb assembly of primary and secondary coils

a = Radial gap between LV and HV coil in cm	1.5 cm
b_1 = Radial build of LV coil in cm	3.5 cm
b_2 = Radial build of HV coil in cm	4.4 cm

Therefore $$x\% = \frac{7.91 \times 50 \times 1666.7 \times 16^2 \times \pi \times 347.5}{250 \times 537} \times \left[1.5 + \frac{(3.5 + 4.4)}{3}\right] \times 10^{-6}$$

$$= 1.372 \times 4.133 \times 10^{-6}$$
$$= 5.67$$

(*b*) **Percentage Resistance**

The formula commonly used for calculating percentage resistance is as follows:

$$R(\%) = \frac{\text{Calculated load loss in kW}}{\text{Rated kVA}} \times 100$$

where

Calculated load loss	12.502 kW
Rated kVA	1250 kVA

Therefore $$R(\%) = \frac{12.502}{1250} \times 100 = 1.$$

(*c*) **Percentage Impedance**

Percentage impedance is the vectorial sum of percentage reactance and percentage resistance and is represented as

$$z(\%) = \sqrt{x(\%)^2 + R(\%)^2}$$

$$= \sqrt{(5.67^2 + 1^2)} = 5.76$$

Precentage impedance as guranteed is 5.5% with a tolerance of ± 10% as recommended in IS-2026.

15.18 RATIO ERROR AT DIFFERENT TAP POSITION

Ratio error is calculated from the voltage ratio and turns ratio for that particular tap. The transformer has nine position taps with having voltage variation from (+) 8% to (–) 8% in steps of 2%. The following table will indicate the percentage ratio error at different tap position.

Table 15.12. Ratio error at different tap position

Tap Position	*% Tapping*	*Voltage ratio*	*Turns ratio*	*% Error*
1	(+) 8%	$\frac{11000 \times \sqrt{3} \times 1.08}{433}$ = 47.52	760/16 = 47.50	$\frac{(47.52 - 47.50) \times 100}{47.52}$ = 0.042%
2	(+) 6%	$\frac{11000 \times \sqrt{3} \times 1.06}{433}$ = 46.64	746/16 = 46.625	$\frac{(46.64 - 46.625) \times 100}{46.64}$ = 0.032%
3	(+) 4%	$\frac{11000 \times \sqrt{3} \times 1.04}{433}$ = 45.76	732/16 = 45.75	$\frac{(45.76 - 47.75) \times 100}{45.76}$ = 0.022%
4	(+) 2%	$\frac{11000 \times \sqrt{3} \times 1.02}{433}$ = 44.88	718/16 = 44.875	$\frac{(44.88 - 44.875) \times 100}{44.88}$ = 0.011%
5	Normal	$\frac{11000 \times \sqrt{3}}{433}$ = 44.00	704/16 = 44.00	$\frac{(44 - 44) \times 100}{44}$ = 0
6	(–) 2%	$\frac{11000 \times \sqrt{3} \times 0.98}{433}$ = 43.12	690/16 = 43.125	$\frac{(43.12 - 43.125) \times 100}{43.12}$ = (–) 0.011%

Tap Position	*% Tapping*	*Voltage ratio*	*Turns ratio*	*% Error*
7	(–) 4%	$\frac{11000 \times \sqrt{3} \times 0.96}{433}$ = 42.24	676/16 = 42.25	$\frac{(42.24 - 42.25) \times 100}{42.24}$ = (–) 0.023%
8	(–) 6%	$\frac{11000 \times \sqrt{3} \times 0.94}{433}$ = 41.36	662/16 = 41.375	$\frac{(41.36 - 41.375) \times 100}{41.36}$ = (–) 0.036%
9	(–) 8%	$\frac{11000 \times \sqrt{3} \times 0.92}{433}$ = 40.48	648/16 = 40.5	$\frac{(40.48 - 40.5) \times 100}{40.48}$ = (–) 0.049%

Note: Permissible tolerance as per IS-2026 is ± 0.5% or 10% of measured impedance whichever is smaller.

15.19 EFFICIENCY

The following paragraphs will help us to calculate the efficiency at different percentage of load and at different power factors.

Efficiency is defined as $\frac{\text{output}}{\text{input}}$ and is expressed as percentage.

The above expression may be rewritten as $\frac{\text{output}}{(\text{output + losses})}$ × 100 where output is the rated kVA of the transformer and losses are equal to sum total of no-load and load loss in kW. kVA = 1250; No-load loss = 1.746 kW; load loss = 12.502 kW.

(*i*) Efficiency at rated load and at unity power factor	$\frac{1250}{(1250 + 1.746 + 12.502)} \times 100 = 98.87\%$
(*ii*) Efficiency at 75% load and at unity power factor	$\frac{(1250 \times 0.75)}{(1250 \times 0.75) + 1.746 + (0.75^2 \times 12.502)}$ × 100 = 99.07%
(*iii*) Efficiency at 50% load and at unity power factor	$\frac{1250 \times 0.5}{(1250 \times 0.75) + 1.746 + (0.5^2 \times 12.502)}$ × 100 = 99.23%
(*iv*) Efficiency at 25% load and at unity power factor	$\frac{1250 \times 0.25}{(1250 \times 0.25) + 1.746 + (0.25^2 \times 12.502)}$ × 100 = 99.2%
(*v*) Efficiency at rated load and at 0.8 power factor	$\frac{1250 \times 0.8}{(1250 \times 0.8) + 1.746 + 12.502}$ × 100 = 98.60%

(*vi*) Efficiency at 75% load and at 0.8 power factor	$\dfrac{1250 \times 0.8 \times 0.75}{(1250 \times 0.8 \times 0.75) + 1.746 + (0.75^2 \times 12.502)} \times 100$ $= 98.84\%$
(*vii*) Efficiency at 50% load and at 0.8 power factor	$\dfrac{1250 \times 0.8 \times 0.5}{(1250 \times 0.8 \times 0.5) + 1.746 + (0.5^2 \times 12.502)} \times 100$ $= 99.04\%$
(*viii*) Efficiency at 25% load and at 0.8 power factor	$\dfrac{1250 \times 0.8 \times 0.25}{(1250 \times 0.8 \times 5) + 1.746 + (0.25^2 \times 12.502)} \times 100$ $= 99.0\%$

15.20 MAXIMUM EFFICIENCY

No-load loss of a transformer is constant and has no effect with the variation of load. However the load loss varies with the change of load and is proportional to the square of the load. The transformer will have maximum efficiency at a load then the no-load loss become equal to load loss and is represented as

Load at which maximum efficiency will occur = K

$$K = \sqrt{\frac{\text{No-load loss}}{\text{Load loss}}} \times 100$$

and maximum efficiency

$$= \frac{\text{kVA} \times K}{(\text{kVA} \times K) + \text{No-load loss} + K^2 \times \text{load loss}} \times 100$$

In this case, no-load loss $= 1.746$ kW

Load loss $= 12.502$ kW

kVA $= 1250$ kVA

Therefore, $K = \sqrt{\dfrac{1.746}{12.502}} \times 100 = 37.37\%$

and maximum efficiency

$$= \frac{1250 \times 0.3737}{(1250 \times 0.3737) + 1.746 + (0.3737^2 \times 12.502)} \times 100$$

$$= \frac{467.125}{(467.125 + 1.746 + 1.746)} \times 100 = 99.26\%.$$

15.21 REGULATION

The voltage ratio of power and distribution transformer is defined at no-load. During loading, the voltage drop down in accordance with its percentage reactance and percentage resistance.

For any assumed load, other than rated load and at any power factor, the percentage regulation is approximately equal to

$$n \,.\, E_r\,(\%) \,.\, \cos\theta + n \,.\, E_x(\%)\sin\theta + \frac{(n\,E_x(\%)\cos\theta - n\,.\,E_r(\%)\sin\theta)^2}{200}$$

where n = Percentage of loading
$E_r(\%)$ = Percentage of resistance
$E_x(\%)$ = Percentage reactance
$\cos\theta$ = Power factor
$\sin\theta$ = Sine component of power factor angle.

(*a*) **Regulation at Rated load and at Unity Power Factor**

Using the above formula, the regulation can be calculated with the following available parameters:

$$n = 1.0$$
$$E_r(\%) = 1.0$$
$$E_x(\%) = 5.67\%$$
$$\cos\theta = 1.0 \text{ (unity power factor where } \theta = 0)$$
$$\sin\theta = 0$$

Therefore, Regulation at rated load and at unity power factor may be rewritten as

$$= E_r(\%)\cos\theta + \frac{(E_x(\%)\cos\theta)^2}{200}$$

$$= (1.0 \times 1.0) + \frac{(5.67 \times 1.0)^2}{200} = 1.16\%.$$

(*b*) **Regulation at rated load and at 0.8 power factor**

Here $n = 1.0$

$$E_r(\%) = 1.0$$
$$E_x(\%) = 5.67$$
$$\cos\theta = 0.8 \quad \text{where} \quad \theta = 36.86°$$
$$\sin 36.86° = 0.6$$

Therefore, regulation at rated load and at 0.8 power factor

$$= (1.0 \times 0.8 + 5.67 \times 0.6) + \frac{(5.67 \times 0.8 - 1.0 \times 0.6)^2}{200}$$

$$= 4.202 + 0.077 = 4.279\%.$$

15.22 VARIOUS PERFORMANCE FIGURES

Calculated performance parameters are tabulated in the following table:

Table 15.13. Performance figures

No.	*Particulars*	*Calculated performance value*	*Guaranteed performance value*
1.	No-load loss at rated voltage and frequency	1.746 WW	1.85 kW
2.	No-load loss at 112.5% voltage	3.318 W	—
3.	Load loss at rated load and at 75°C	12.502 kW	12.75 kW
4.	No-load current at rated voltage	0.56%	2%
5.	No-load current at 112.5% voltage	2.36%	4%
6.	Percentage resistance	1.0	—
7.	Percentage reactance	5.67	—
8.	Percentage impedance	5.76	5.5% ± 10%

Contd.

No.	Particulars	Calculated performance value	Guaranteed performance value
9.	Regulation at UPF	1.16%	—
10.	Regulation at 0.8 PF (lagging)	4.279%	—
11.	Efficiency at UPF and		
	(*i*) At 100% load	98.87%	—
	(*ii*) At 75% load	99.07%	—
	(*iii*) At 50% load	99.23%	—
	(*iv*) At 25% load	99.20%	—
12.	Efficiency at 0.8 PF and		
	(*i*) At 100% load	98.60%	—
	(*ii*) At 75% load	98.84%	—
	(*iii*) At 50% load	99.04%	—
	(*iv*) At 25% load	99.00%	—
13.	Load at which max. efficiency occurs	37.37%	—
14.	Max. efficiency	99.26%	—

15.23 DESIGN OF TANK

The following clearances are assumed for calculating the inner dimensions of the tank which is rectangular in shape.

(*i*) Gap between HV coil to the inside of tank on length side	40 mm
(*ii*) Gap between HV coil to the inside of tank on width side (on low voltage side)	50 mm
(*iii*) Gap between HV coil to the inside of tank on width side (on HV delta side)	65 mm
(*iv*) Gap between yoke and tank bottom	40 mm
(*v*) Gap between yoke to ratio switch base	25 mm
(*vi*) Height of ratio switch	150 mm
(*vii*) Gap between ratio switch top to inside of tank cover	50 mm

Based on the above internal clearances, let us form the tank dimensions as below:

(*a*) Length of tank (inside dimensions)	(2 × C/L of core + HV coil O.D. + 2 × 40) mm = (2 × 460 + 446 + 80) = 1446 mm (rounded-off to 1450 mm)
(*b*) Breadth of tank (inside dimension)	(HV coil O.D. + 50 + 65) = 446 + 50 + 65 = 561 mm (rounded-off to 565 mm)
(*c*) Height of tank (from bottom of tank up to tank color)	(40 + Foot plate insulation + *W*/*H* of core + 2 × width of 1st core step + 25 + R/s height + 50) mm = (40 + 5 + 610 + 2 × 240 + 25 + 150 + 50) = 1360 mm

Therefore, the final tank dimension	Length (L) = 1450 mm Breadth (B) = 565 mm Height (Ht) = 1360 mm

15.24 COOLING RADIATOR

We shall discuss in brief the use of three different types of radiator for cooling purpose, they are:

(*a*) Elliptical tube radiator (*b*) Pressed steel radiator (*c*) Corrugated wall panel.

Elliptical tube radiator and pressed steel radiator operate on convection method of cooling where the oil is made to circulate through the cooling header pipe. However corrugated wall panel operates on radiation method of cooling.

(*a*) Elliptical Tube Radiator

The elliptical tube used for cooling radiators has a standard section of 75 × 15 mm which is internationally known as section-57. The standard length of elliptical tube available in the market is 6.1 metre. It is cut into number of pieces to form radiator banks. Each radiator bank has an inlet and outlet for free flow of oil. The section of a elliptical tube is shown in Fig. 15.7.

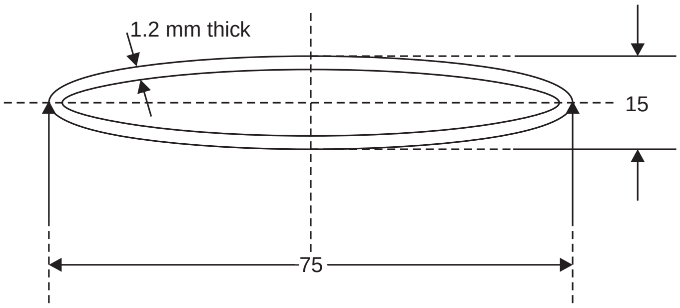


Fig. 15.7. Section of elliptical tube

The radiators are welded to the tank wall and are kept in such a height to remain the inlet header almost at the same level of HV coil. This is ensured by raising the inlet header upto a height from the tank bottom equivalents (height of foot plate + foot plate insulation + maximum width of core lamination).

In this case this height is equal to: (40 + 5 + 240) = 285 mm and is shown in Fig. 15.8.

The length of each tube is estimated in such a way to create a minimum wastage. Let us fix the length of each tube as 865 mm. Various other dimensions have been shown in Fig. 15.8. Here the wastage of tube is [6100 – (865 × 7)] = 45 mm only which will eaten up by the cutting edge of the blade.

Number of Elliptical Tube: Once the length of each tube is known, the number of elliptical tube required to dissipate the guaranteed no-load and full load loss is calculated using the following formula.

No. of tubes	$= \dfrac{1}{8.8 \times x \times y} \times \left[\dfrac{k}{L} - 12.5 \times A\right]$
where, A	= Tank surface area is sq. metre (only side walls to be considered)
K	= Total loss in watt (*i.e.* guaranteed no-load plus load loss)
L	= Average rise to oil temperature in degree C (maximum guaranteed oil temperature rise multiplied by 0.8)

y	= Unit length of each tube in metre
x	= Surface length of elliptical tube in metre

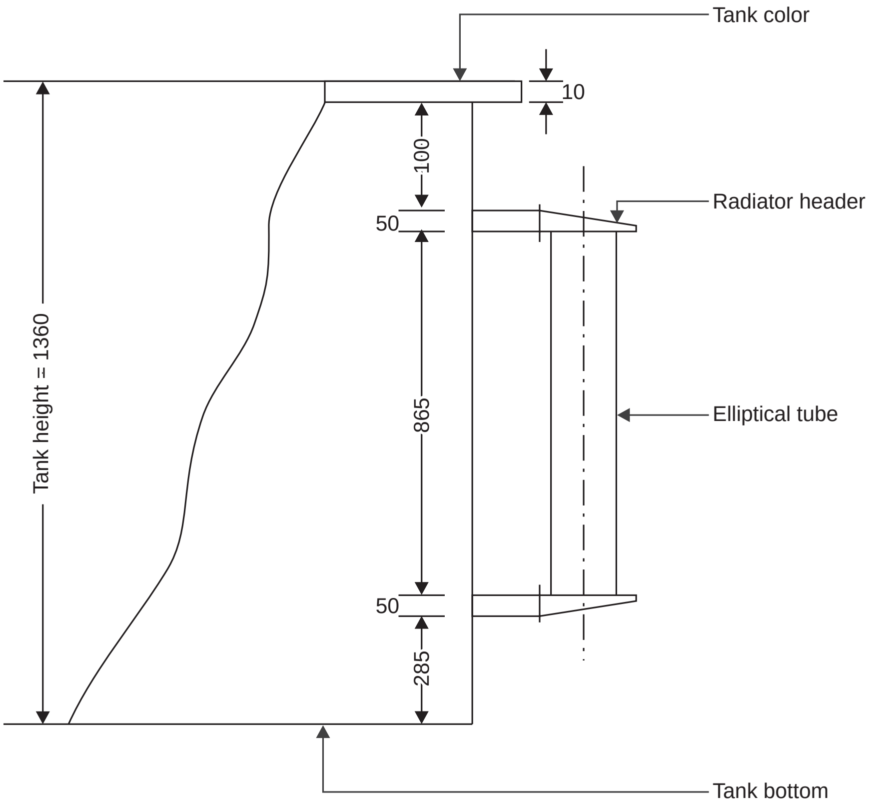


Fig. 15.8. Formation of elliptical radiator

Let us calculate the numerical values of the above factors

Tank dimensions as calculated earlier	Length (L) = 1450 mm
	Breadth (B) = 565 mm
	Height (Ht) = 1360 mm
Therefore surface area of the	$= 2 \times (L + B) \times Ht$
tank wall only (A)	$= 2 \times (1.45 + 0.565) \times 1.36$
	= 5.4808 sq. m
Total guaranteed loss (K)	= (No-load loss + load loss)
	= (1850 + 12750)
	= 14600 W
Average rise of oil temperature (L)	= Max. guaranteed rise of oil temp. × 0.8
	$= 45 \times 0.8$
	= 36°C
Unit length of each tube (y)	= 0.865 m

Surface length of elliptical tube (x)	$= 2 \times (75 + 15) \times 0.9$ = 162 mm = 0.162 metre
Therefore no. of tubes	$= \dfrac{1}{8.8 \times 0.162 \times 0.865} \times \left[\dfrac{14600}{36} - 12.5 \times 5.4808\right]$ = 274 nos. (*i.e.* 237.01 metre)

Let us form seven radiator banks, each having 40 tubes and the length of each tube is 865 mm.

Total length of tube is equal to ($7 \times 40 \times 0.865$) = 242.2 metre which is approx. 2% more than the bare minimum length of 237.01 metre.

(*b*) Pressed Steel Radiator

Pressed steel radiators are made from CRCA sheet having thickness 1.0 to 1.2 mm. The width of the fin has been standardized as 230 mm, 300 mm and 520 mm. The height of fin may any value between 400 mm to 3000 mm is steps of 100 mm. The number of fins is estimated from guaranteed losses.

While calculating the details of radiator, we shall take the help of 'standard loss dissipation chart' and loss dissipation factor from the exposed tank surfaces.

Tank surface area (as calculated in section 15.24 (*a*)	5.4808 sq. m
The tank surface can dissipate a loss equivalent to	500 W/sq. m
Therefore loss dissipated by the tank surface	5.4808 × 500 = 2740 W
Total loss to be dissipated (guaranteed loss)	(1850 + 12750) = 14600 W
Radiators to be employed to dissipate the loss in excess	(14600 – 2740) = 11860 W

Based on the tank height and various constructional dimensions of coil assembly, let us fix the centre distance of radiator header pipe. Fig. 15.9 indicates the C/D of radiator and other vital dimensions.

Centre distance of radiator header pipe (C/D)	1000 mm
Width of each fin having three channels of oil flow (assumed)	300 mm
Standard table available for heat dissipation per fin for oil excess temperature (*i.e.* temperature rise of oil)	
Loss dissipated per fin for a top oil rise of 45°C for 1000 mm C/D	220 W

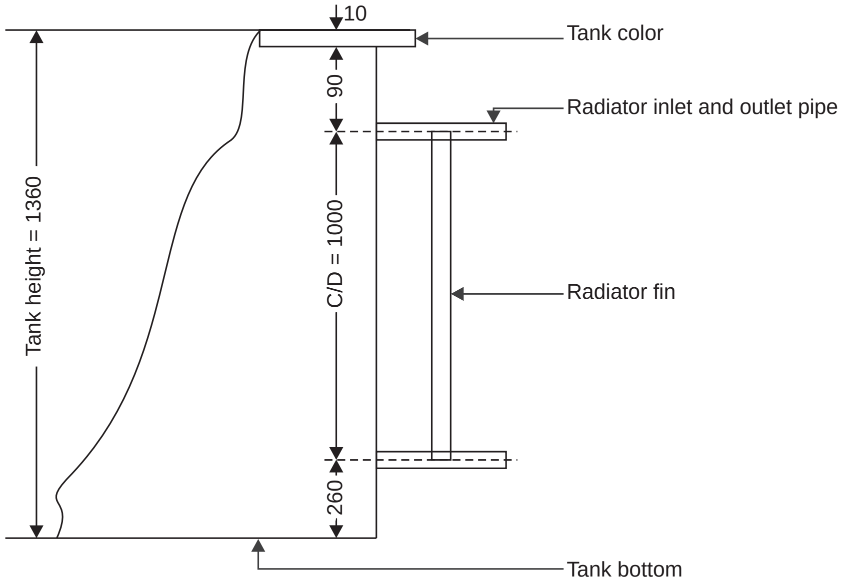


Fig. 15.9. Formation of pressed steel radiator

Correction Factor

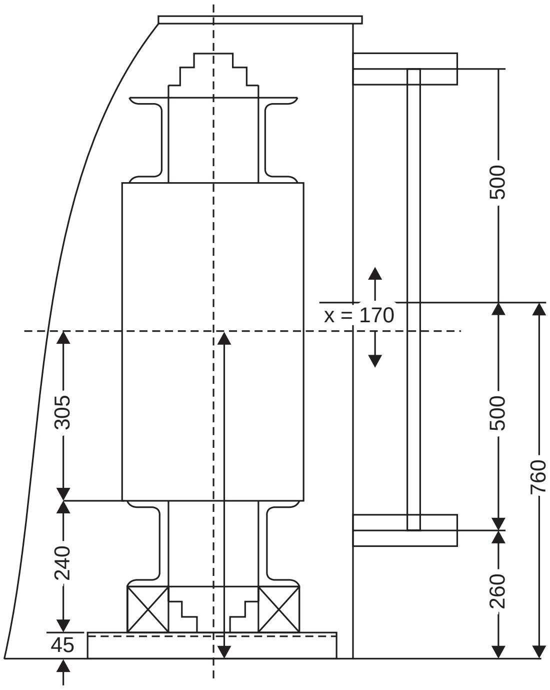


Fig. 15.10. Correction factor for difference between vertical distance of coil assembly and radiator

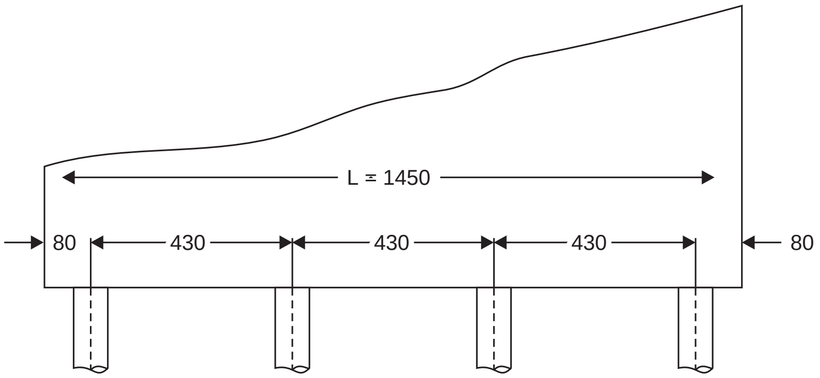


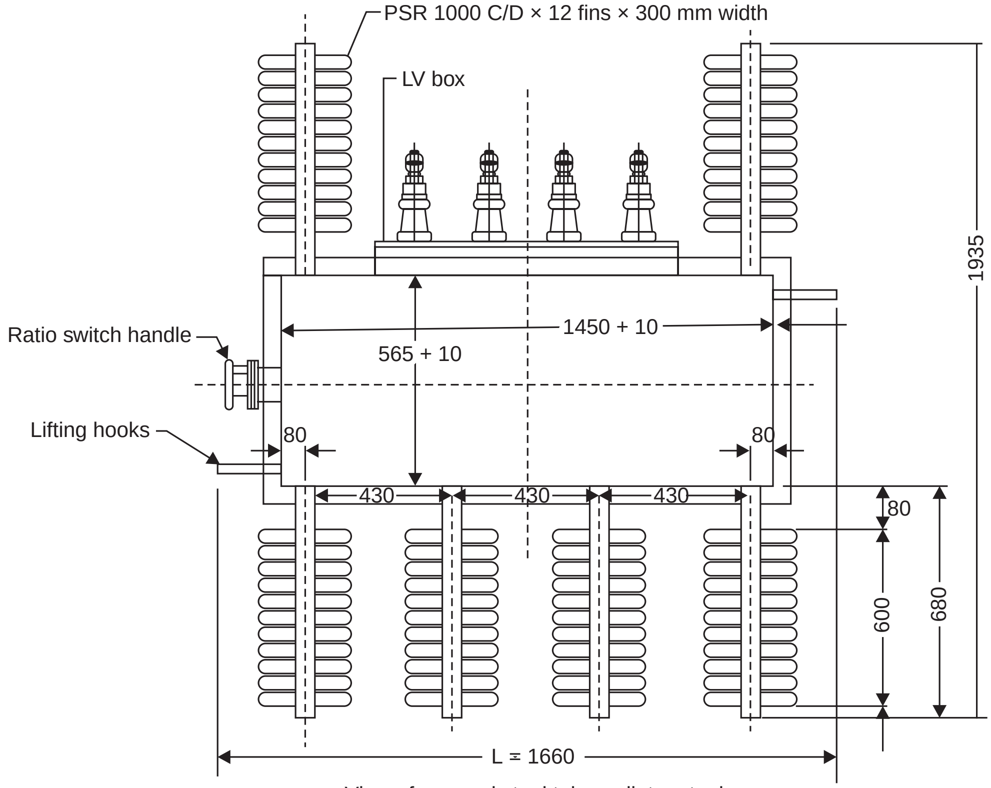
Fig. 15.11. Correction factor for horizontal distance of radiators

We shall come across three different correction factors.

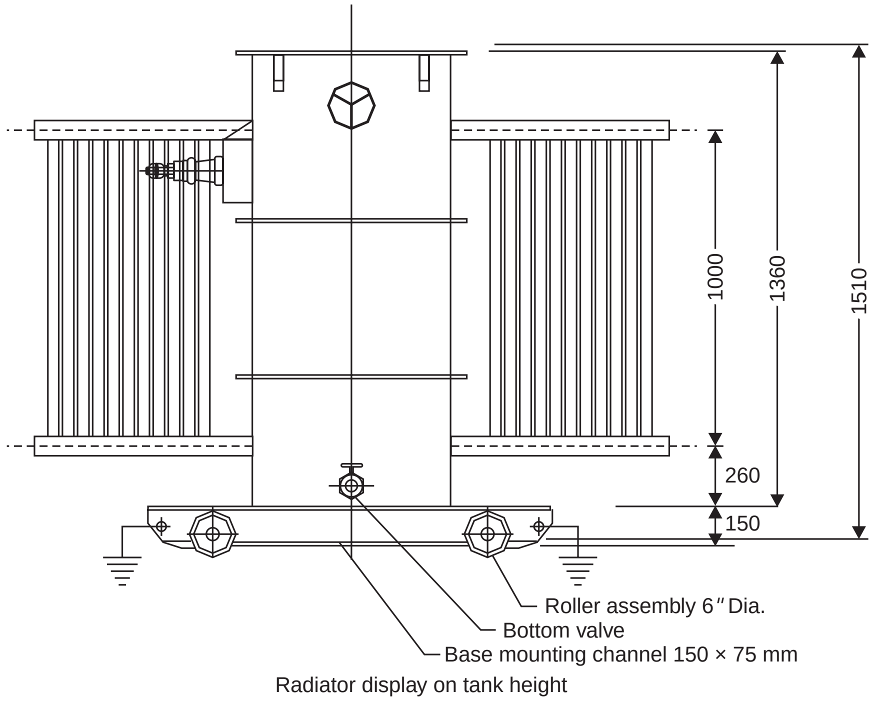
(*i*) Correction factor for difference between vertical distance of coil assembly and radiator	10 mm
Correction factor available from standard table	0.878
(*ii*) Correction factor for horizontal distance of radiators	430 mm
Correction factor available from standard table	0.91
(*iii*) No. of fins per radiator	12 to 14
Correction factor available from standard table	0.99
Therefore not correction factor	(*i*) × (*ii*) × (*iii*) = (0.878 × 0.91 × 0.99) = 0.791
Therefore effective loss dissipated by each fin	220 × 0.791 = 174 W
No. of fins required to dissipate 11860 W	11860/174 = 68.16
No. of radiators used (assumed)	6 nos.
No. of fins per radiator	68.16/6 = 11.36 (rounded-off to 12 nos.

We thus conclude the design of pressed steel radiator with an output to use 6 radiator banks having C/D-1000 mm and 12 no. fins per bank making a total no. of fins as 72 nos.

Location of fixing the radiators and various other dimensions have been shown in Fig. 15.12.



View of pressed steel tube radiators tank



Radiator display on tank height

Fig. 15.12. Location of fixing of pressed steel radiators

(*c*) Corrugated Wall Panel

In the recent times, in response to the increase in the cost of materials and labour, a new concept in heat exchange by use of built-in corrugations on transformer tank wall, has virtually eliminated the radiator concept, particularly for distribution transformers in all advanced countries.

The corrugated wall panels are manufactured from CRCA steel sheet of thickness ranging from 0.75 to 1.2 mm, using a special purpose machine. The rest of the tank side walls, tank bottom and top coller are made in the conventional manner using regular mild steel materials. Structural steel like angle, channel, rod, flat etc. are used wherever required for strength and support.

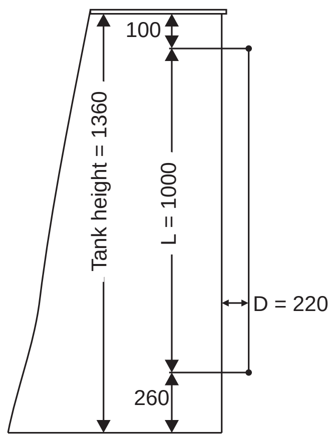
Apart from the benifit of compactness, elegant appearance, saving in steel, oil, freight cost and space etc. are the major advantages with such construction that lends itself ideally in making hermetically sealed transformer. Bellows action of the corrugations itself will accomodate the expansion and construction of the transformer oil. Thus with the elimination of contact of oil with the outside atmosphere, the whole arrangement becomes totally maintenance free.

Exotherm Pvt. Ltd., Mahadevpur, Bangalore and Kotson, Agra are equipped with all such special purpose machines and are in position to supply either complete tanks or just corrugated panel as per the design.

The following paragraphs will help us to understand the design aspect of corrugated wall panel.

While designing the panel, we shall assume the following:

No. and depth of corrugation are so calculated that total losses are dissipated fully across the fins	—
Gap between the end fin and tank wall	25 mm
Pitch distance of fins	45 mm
Height of fin is calculated from the available tank height	1000 mm (refer Fig. 15.13)



(a) Tank height = 1360 mm
(b) Panel height = 1000 mm
(c) Panel depth = 220 mm

Fig. 15.13. Location of fixing corrugated wall panel with respect to tank height

Guaranteed total loss	No-load loss + load loss $= (1850 + 12750) = 14600$ W
No. of fins on longer side of the tank	$\dfrac{(1450 - 2 \times 30)}{45} + 1 = 31$ nos.
No. of fins on shorter side of the tank	$\dfrac{(565 - 2 \times 30)}{45} + 1 = 12$ nos.
Total no. of fins on all four sides of tank	$2 \times (31 + 12) = 86$ nos.
Watt/Fin. metre	$\dfrac{14600}{86 \times 1.0} = 170$
where Watt = 14600 W Fin = 86 nos. Height of fin = 1.0 m in metre	
Let us refer to heat dissipation characteristics of corrugated wall panel (Fig. 15.17) to find out the depth of panel.	
Depth of panel corresponding to watt/Fin. metre 170 (for 45°C oil rise)	220 mm

Fig. 15.14, 15.15, 15.16 and 15.17 provides constructional details of corrugated wall panel showing various dimensions and heat dissipation characteristics.

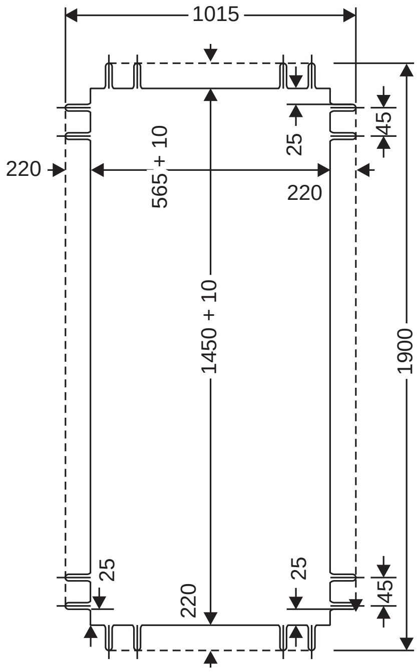
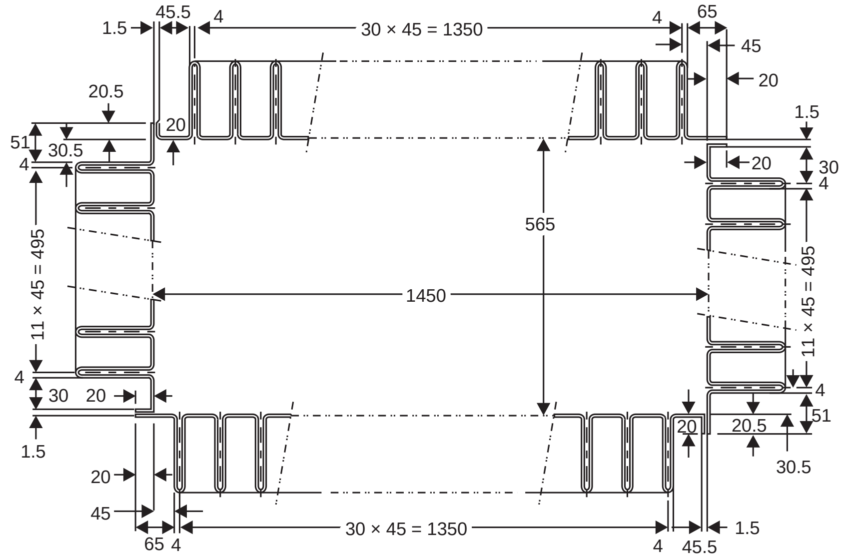
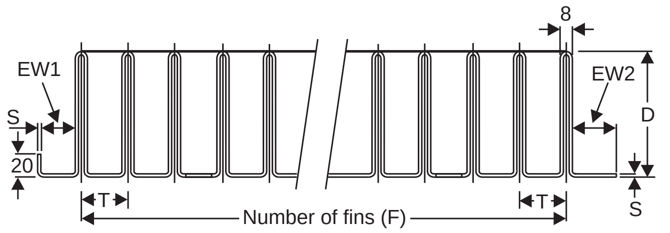


Fig. 15.14. Formation of tank with corrugated wall panel



Notes: 1. All dimensions are in mm 2. Tank length : 1450 mm 3. Tank width : 565 mm

Fig. 15.15. Details of corrugated wall panel



	Type—A	*Type—B*
S (Material thickness)	1.2 mm	1.2 mm
EW 1	45.5 mm	30 mm
EW 2	65 mm	51 mm
D (Fin depth)	220 mm	220 mm
H (Height)	1000 mm	1000 mm
T (Pitch)	45 mm	45 mm
F (No. of fins/rad.)	31 Nos.	12 Nos.
Quantity per transformer	2 Nos.	2 Nos.

Notes:

1. Wall panel corrugated radiators
   (*a*) Adopt standard practice for spot welding (*b*) Inside dimensions of tank are required
   Length – 1450 mm
   Width – 565 mm
2. Radiator depth (*D*) : 220 mm
3. Radiator height (*H*) : 1000 mm
4. All dimensions are in mm

Fig. 15.16. Fabrication details of corrugated wall panel

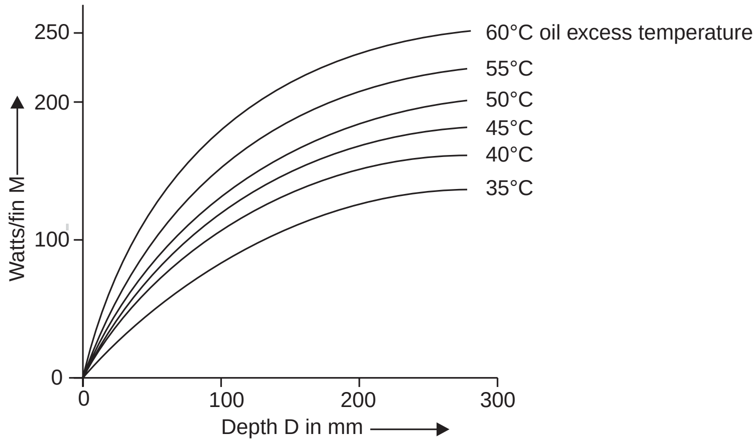


Fig. 15.17. Heat dissipation characteristics of corrugated wall panel for transformer tank

15.25 CONCLUSION

The process of designing a transformer has been briefly discussed in this chapter. Various design inputs have been assumed, like flux density, current density, value of '*K*' (or turns), approximate window height of core etc. Wrong selection of these values may lead to incorrect design. The design should be cost effective, otherwise we may loose customer's confidence because of stiff competition in today's market.

Reference may be drawn from the previous design available in the work place. In case a design is new and not been tested earlier in service, a proto-type transformer should be made to carry out all routine and type tests as recommended by the standards (IS-2026, IEC-60076, BS-171 etc.) before undertaking commercial production.

We should make a note of the available infrastructure and skills of the workmen while designing a transformer. This is what is known as workmen-friendly design. The design output should be clearly written in an understandable language to the supervisors and operators. Much should be explained with the help of process drawings and sketches. Work instructions available in the work place must be followed. Flow chart of each process should be maintained. Incoming material inspection at receiving end and inprocess verification at production stage reduces the probability of failure of finished product. In case any parameter whether mechanical dimensions or performance value go beyond Quality Assurance Plan (QAP), the matter should be brought to the notice of the design department immediately to offer corrective measures. Design review and validation at appropriate stages should be done.

Records of all verifications must be available on demand for preparation of data bank.

Section III

CHAPTER 16

Inprocess Inspection and Quality Checks

FOOD FOR THOUGHT

We have all been put into circumstance where we are challenged. Whether we like it or not, we need to accept and make the best of some challenges. For example, a test or examination is a challenge to students, while learning new tasks in our job environment is a challenge for adults.

Today we are faced with technological, social, political, economical and personal challenges. No one likes to be forced to make changes, but it's important to face challenges willingly so that we might learn from them.

Quality professionals are faced with meeting the requirements of ISO-9000, producing better quality and reliable goods and services and satisfying the customers. We are being asked to find new ways of doing things. As professionals, we are asked to find solutions to problems by a visionary approach.

Progress is not possible without accepting challenges. When challenging someone, it should be with the intension of helping, not defeating the person. Overall quality of life in the year ahead depends in large part upon the achievements made today.

16.1 INTRODUCTION

The easiest way to keep a check on the quality of the finished products is by carrying out inprocess inspection on the components produced by various departments. This is necessary to ascertain the quality of the components as well as to ensure that the components are made in line with the requirements of customer specifications. In case, any of the components is found defective or beyond acceptable quality norms, it is very easy to take corrective measures at the manufacturing stages. This will help to reduce the probability of failure of a complete product at the finished stage. Cost of rejection and/or rework is reduced by way of inprocess checking. Some of the performance figures like ratio, resistance etc. can very well be monitored during inprocess inspection.

The procedure of checking and recording the parameters of some of the inprocess components are shown in the following pages.

16.2 INPROCESS INSPECTION AND QUALITY CHECKS OF HV AND LV COILS

Format no. : Ten Date : ....

Customer : ....

kVA/kV : ....

Winding materials : Copper or aluminium

Inter-layer insulation :

Winding specification no. : ....

Table 16.1

Sl. no.	***Particulars***	***Design specn.***	***Verified as under***						***Remarks (acceptable or not)***
	Coil number		***1***	***2***	***3***	***4***	***5***	***6***	
1	Bare conductor								
2	Covered conductor								
3	Covering								
4	Inside dia. of coil								
5	Outside dia. of coil								
6	Axial length								

Remarks:

(*a*) Two HV coils produced by each workman shall be checked. In case of non-conformity in a coil produced by any workman, all the coils produced by that workman are to be checked.

(*b*) All the LV coils (100 per cent) should undergo the above checks.

(*c*) The format has been made in line with the requirement of coils for distribution transformer. However it may be modified to suit the requirement of disc coil or any other special coil.

Note: The report should be reviewed and certified by the quality assurance engineer before the coils are transferred to the assembly department.

16.3 INPROCESS INSPECTION AND QUALITY CHECKS OF CORE ASSEMBLY

Format no. : Eleven Date : ....

Customer : ....

kVA/kV : ....

Core drawing no. : ....

Table 16.2

Sl. no.	***Particulars***	***Design specn.***	***Verified as under***						***Remarks (acceptable or not)***
			1	***2***	***3***	***4***	***5***	***6***	
1	Core diameter								
2	Window height								
3	Limb stack								
4	Total stack								
5	Average thickness of core lamination								
6	Weight per set								
7	No. and size of core bolt								
8	Size of core channel and length								

Remarks:

(*a*) The average thickness of core laminations may be checked before starting the core assembly.

(*b*) One core assembly of each rating produced by each workman should be checked. In case of non-conformity, all assemblies produced by that particular workman are to be checked.

Note: The report should be reviewed and certified by the quality assurance engineer before the core assembly is passed on for further processing.

16.4 INPROCESS INSPECTION AND QUALITY CHECKS OF COIL ASSEMBLY

Format no. : Twelve Date : ....

Customer : ....

kVA/kV : ....

Tapping range : ....

Coil assembly drawing no. : ....

Size of neutral busbar : ....

No. and size of tie rods : ....

Size of delta and line leads : ....

Size of foot plate : ....

Table 16.3

Sl. no.	*Tap position*	*% Tapping*	*Turns ratio*			*Open circuit test at 1/2 voltage*	*Remark (acceptable or not)*
			Ph-A	*Ph-B*	*Ph-C*		
1							
2							
3							
4							
5							
6							

Remark: All assemblies shall be checked.

Note: The report should be reviewed and certified by the quality assurance engineer before the coil assembly is passed on for further processing.

16.5 INPROCESS INSPECTION AND QUALITY CHECKS OF TRANSFORMER TANK BODY

Format no. : Thirteen Date : ....

Customer : ....

kVA/kV : ....

Tank drawing no. : ....

Table 16.4

Sl. no.	*Particulars*	*Design specn.*	*Verified as under*						*Remarks (acceptable or not)*
			1	*2*	*3*	*4*	*5*	*6*	
1	Tank dimensions ($L \times B \times HT$)								
2	Sheet Thickness (side × bottom × top)								
3	Radiator details								
4	Mounting hole details								
5	Conservator dimensions								
6	Locking height								
7	R/S centrebolt								
8	Availability of all fitting as per OGA drawing								

Remarks:

(*a*) All tanks are to be checked.

(*b*) Location of fittings with respect to OGA drawing should also be verified.

Note: The report should be reviewed and certified by the quality assurance engineer before the tank is passed on for further processing.

16.6 INPROCESS INSPECTION AND QUALITY CHECKS OF TRANSFORMER AFTER BOX-UP

Format no. : Fourteen Date : ....

Customer : ....

kVA/kV : ....

Outline general assembly drg. no. : ....

External phase clearance (minimum) : ....

Table 16.5

Sl. no.	*Insulation resistance*			*External clearance (Go or No-go check)*	*Remarks (acceptable or not)*
	HV to E	*LV to E*	*HV to LV*		
1					
2					
3					
4					
5					
6					
7					
8					

Remarks:

(*a*) All transformers are to be checked.

(*b*) Since the average temperature of the active part as well as the temperature of insulating oil remain quite high during box-up, it is recommended to record the temperature of the top oil during the measurement of insulation resistance.

(*c*) Separate check list may be made to verify the location of all fittings in line with the requirement of OGA drawing.

Note: The report should be reviewed and certified by the quality assurance engineer before subjecting the transformer for final test.

16.7 INPROCESS INSPECTION AND QUALITY CHECKS OF TRANSFORMER AFTER PAINTING AND FINISHING (BEFORE DESPATCH)

Format no. : Fifteen Date : ....

Customer : ....

kVA/kV : ....

Outline general assembly drg. no. : ....

Note: The recording of this inspection report may be done in the form of check list.

Table 16.6

Sl. no.	***Air pressure cum oil leakage test***	***Oil up to mark***	***Final painting***	***Cleaning of bushing***	***Name plate fixing***	***Colour marking of terminals***	***Oil gauge cleaning***	***Check on overall dimensions***	***Remark (passed for despatch or not)***
1									
2									
3									
4									
5									
6									
7									

Remarks:

(*a*) All transformers are to be checked.

(*b*) External clearances are to be checked by the Go/No-Go gauge.

(*c*) Separate check list be made to verify the placement of all fittings and accessories in line with the OGA drawing.

Note: The report should be reviewed and certified by the quality assurance engineer before despatch.

16.8 DESIGN VALIDATION

This is a unique process of verifying the quality of design output. Many assumptions are made during the course of design. Flux density, current density, core handling factor, stray loss, internal clearances, heat dissipation factor etc. are examples where the designer has to conceive some pre-determined values. These are assumed on the basis of available characteristic curves of materials as well as the experience of the designer. Man, machine and material etc. also play a vital role on the performance of a transformer.

Considering these facts, a proto-type transformer should be built and its performance reviewed for conformance with the design values as well as customer's requirement and/or ISS. The results of the proto-type transformer should be reviewed by a committee headed by the quality assurance engineer for design validation.

In case, any of the performance figures is found beyond tolerance limit or the construction of the transformer is not friendly for mass production, the matter is discussed in the review committee. Suitable changes are made in the design and a proto-type sample, if necessary, is further made after incorporating the changes suggested by the review committee. The process of reviewing the design should continue till the members of the review committee are fully satisfied with the proto-type transformer.

The outcome of all such review meetings should be recorded. A good designer can draw maximum benefits out of such reviews. The differences between the design outputs and the actual results generated from the proto-type transformer can further be narrowed down to achieve the transformer of desired perfomance.

The quality of materials and skills of the workmen have decisive influence on the success of such tests. Development of proto-type transformer for conducting type tests is a great relief to the designer.

It is a common practice for the utilities like UPPCL and MPEB to allow mass production only after the proto-type transformer is cleared in the type test. However boards like PSEB, RSEB, HPSEB etc. select a sample transformer for type test from the offered lot.

Apart from the technical advantage, there are also some commercial advantages in developing a proto-type transformer before mass production. This is with respect to 'bill of quantity'. The weight of core and winding can be estimated in the design with ±1 per cent accuracy. But it may not be possible to calculate the weight of insulating materials, tank, oil volume etc. to that fine accuracy. Moreover the quantity of wastage depends on the working skill. The development of proto-type transformer will provide answers to all the questions on estimations of raw materials as well as the labour cost. Profitability can be workedout easily after the development of a proto-type transformer.

A sample format for recording the performance of a proto-type transformer is shown below:

Format no. : Sixteen Date : ....

Customer : ....

kVA/kV : ....

Transformer serial no. : ....

Tappings : ....

Winding reference no. : ....

Design reference no. : ....

Customer order no. : ....

Table 16.7

Sl. no.	*Particular*	*As per customer's specification and approved drawing*	*As per design*	*As physically verified*	*Remark*
A	**LV Coil Details:** (*a*) Size of LV strip (bare) (*b*) Size of LV strip (covered) (*c*) Covering (DPC/TPC/QPC) (*d*) Conductor material (*e*) Coil inside diameter (*f*) Coil outside diameter (*g*) Length of coil (*h*) Details of inter-layer insulation (*i*) Weight of conductor per transformer				
B	**HV Coil Details:** (*a*) Size of HV wire (bare) (*b*) Size of HV wire (covered) (*c*) Covering (DPC/TPC/QPC) (*d*) Conductor material (*e*) Coil inside diameter (*f*) Coil outside diameter (*g*) Length of coil (*h*) No. of coils per phase (*i*) Details of inter-layer insulation (*j*) Weight of conductor per transformer				
C	**Core Assembly Details:** (*a*) Core diameter (*b*) Window height of core (*c*) Limb centre of core (*d*) Total core stack (*e*) No. of core steps (*f*) Gross core area (*g*) No. of secondary turns				

Contd.

Sl. no.	*Particular*	*As per customer's specification and approved drawing*	*As per design*	*As physically verified*	*Remark*
	(*h*) Flux density (*i*) Grade and thickness of lamination (*j*) Weight of complete set of core (*k*) Source of core material (*l*) Size of core channel (*m*) No. and size of core studs (*n*) No. and size of tie rods (*o*) No. and size of foot plates (*p*) Total weight of complete set of core including core channel, core studs, tie rods, foot plates etc. (*q*) Weight of pressboard on core channel separator (*r*) Size of wooden block used between bottom yoke and foot plate				
D	**Coil Assembly Details:** (*a*) Type of spacer blocks (*b*) No. of spacer blocks per circle (*c*) Gap between LV and yoke (*d*) Gap between HV and yoke (*e*) Gap between core and LV (*f*) Gap between LV and HV (*g*) Gap between HV limbs (*h*) Size and no. of phase barrier (*i*) Gap between HV sections for plain coils (*j*) Gap between HV sections for tap coils (*k*) No. of HV coils per phase (*l*) Size and material of delta/line leads (*m*) Size and material of tap leads (*n*) Size of LV thimble (if provided) (*o*) Size of HV thimble (if provided) (*p*) Size of inline connector for star point (for aluminium wound transformer) (*q*) Size and weight of copper bus-bars for LV neutral and others (for copper wound transformer) (*r*) Rating and tap position of ratio switch (*s*) Source of ratio switch (vendor's name) (*t*) Weight of tap and delta leads (*u*) Weight of complete set of insulation (*v*) Weight of core-coil assembly				

Contd.

Sl. no.	*Particular*	*As per customer's specification and approved drawing*	*As per design*	*As physically verified*	*Remark*
E	**Tank Details:** (*a*) Tank dimensions ($L \times B \times HT$) (*b*) Shape of tank (*c*) Sheet thickness (side × top × bottom) (*d*) Size of stiffener and number (*e*) Size of tank collar (*f*) Size of conservator (dia. × length) (*g*) Mounting hole details (*h*) PSR radiator (centre distance of header pipe) (*i*) No. of fins per radiator (*j*) No. of radiator per transformer (*k*) Elliptical tube radiator (length of each tube and number) (*l*) No. of radiator per transformer (*m*) Complete weight of tank with elliptical tube radiator (*n*) Weight of tank without pressed steel radiator (*o*) Complete weight of tank with pressed steel radiator				
F **G**	**Overall Dimension and Other Details:** (*a*) Overall dimensions ($L \times$ B $\times HT$) (*b*) Weight of tank and fittings (*c*) Volume and weight of oil for first filling (*d*) Volume and weight of oil drain (*e*) Total weight of transformer **Test Results and Other Perfomance Figures:** (*a*) No-load loss at rated voltage and frequency (*b*) No-load current at rated voltage and frequency (*c*) No-load current at 112.5% voltage (*d*) Load loss at rated load and at 75°C (*e*) Percentage impedance at 75°C (*f*) Turns ratio at all taps				

Contd.

Sl. no.	*Particular*	*As per customer's specification and approved drawing*	*As per design*	*As physically verified*	*Remark*
	(*g*) Insulation resistance (*i*) HV to E (*ii*) LV to E (*iii*) HV to LV (*h*) Resistance at 75°C (*i*) LV winding (*ii*) HV winding (*i*) Temperature rise (oil/wdg.) (*j*) Impulse test carried out on identical design or not (Yes/No) (*k*) Short-circuit test carried out on identical design or not (Yes/No) (*l*) Any other information which the manufacturer wants to record				

Remarks:

(*a*) Format for recording information for proto-type transformer may be modified based on the requirement of the specification.

(*b*) Other information as deemed fit may be added for transformer with disc winding.

16.9 CONCLUSION

This chapter has dealt with the requirement of quality checks on inprocess components. The purpose of carrying out inprocess inspection is to reduce the rate of failure/rejection at the finished stage. Moreover, the inprocess checks at the manufacturing stages make the quality of the products uniform. Various methods of quality checks at different stages of production have been hightlighted. The inprocess checks include measurement of various electrical parameters alongwith the verification of other mechanical dimensions, such as coil I.D., O.D., length/phase clearances/internal gaps etc. Separate check-list may also be prepared to ensure the locations of all fittings and accessories in line with the requirement of customer's specification/approved drawings. For checking external electrical clearances, 'Go and No-Go' gauges may be employed.

Development of a proto-type transformer and conducting perfomance measurements on that is an excellent method of verifying the design output. During the course of design, many parameters are assumed. Flux density, current density, core handling factor, stray loss, internal clearances, heat dissipation factor etc. are few examples where the designer has to conceive some pre-determined values. These are assumed on the basis of available characteristic curves/charts of the materials as wel1 as designer's experience. "The design validation will give the correct answer to the applicability to all such assumed parameters."

The record of measurements on the proto-type transformer is reviewed by a committee headed by the quality assurance engineer for design validation.

Section III

CHAPTER 17

Allowable Working Tolerances

FOOD FOR THOUGHT

An error will cause a product to be defective and could result in total customer dissatisfaction. When there are many process steps and there is much handling of products, there are more opportunities for errors. Each process step increases the chance of errors. Similarly, additional handling of products will introduce more defects or physical damage to products. When system is not mistake-proof, errors are bound to occur.

All work in a process, and virtually every process can be improved. Focus should be on the elimination of errors or defects.

Continuous improvement, design for manufacturability and improvement in manufacturing capabilities are concepts which can easily be expanded to any process, including services that have some form of a quality measurement. Product or service identification, recognition of customer needs and importance, definition of processes, process with no error and insurance of continuous improvement by measurement analysis and control will yield mistake-proof products. It is important to select key measurements for defect elimination. Incremental improvement programmes will lead to continuous improvement. The potential for improving quality is limitless.

For producers, the opportunities for error are many, but customers accept error only once.

17.1 INTRODUCTION

In order to maintain uniformity in the finished products, the concept of tolerance has been introduced. Tolerances on materials are guided by various ISS. The performance figures are also subjected to the tolerance as per recommendation of IS-2026. But there is no guideline on the tolerances of inprocess components. For example, the diameter and axial length of coil may slightly differ from the design parameters. But in the absence of proper guidelines on the acceptability norms, the production engineer may take wrong decisions which may lead to the failure of the transformer during final testing. Based on the manufacturing experience and the skills of the workmen, the tolerance limits for inprocess components should be fixed. However, some of the working tolerances, applicable for inprocess components are given in this chapter.

17.2 TOLERANCE ON INCOMING MATERIALS

(*a*) CRGO Laminations

(*i*) ***Acceptability:*** Free from surface defects, such as holes, scabs, silver spots, dent, rust, sharp and short waves, buckles and also camber.

(*ii*) ***Tolerance on thickness:*** Preferably within ± 0.0125 mm over guaranteed thickness.

(*iii*) ***Tolerance on burr:*** 40 microns (max.)

(*iv*) ***Tolerance on width***

Table 17.1

Up to 100 mm	:	± 0.15 mm
Over 100 mm up to 230 mm	:	± 0.2 mm
Over 230 mm up to 380 mm	:	± 0.25 mm
Over 380 mm up to 580 mm	:	± 0.4 mm
Over 580 mm	:	± 0.5 mm

(*v*) ***Tolerance on length***

Table 17.2

Up to 300 mm	:	± 0.5 mm
Over 300 mm up to 700 mm	:	± 0.75 mm
Over 700 mm up to 1100 mm	:	± 1.0 mm
Over 1100 mm up to 1500 mm	:	± 1.25 mm

(*vi*) ***Tolerance on cutting angle:*** Limited to ± 0.5° on the declared angle.

(*b*) Winding Wires and Strips

(*i*) ***Acceptability:*** Mill's test certificates for basic materials in accordance with IS-12444 for copper rod and IS-5484 for aluminium rod should be made available along with each supply.

(*ii*) ***Tolerance on wire size (bare wire):*** In accordance with table given in IS-6162 (Part-I) for aluminium and IS-7404 (Part-I) for copper.

(These tables are included in Section-I, Chapter-2)

(*iii*) ***Tolerance on strip size (bare strip)***

Table 17.3

Up to 3.15 mm	:	± 0.03 mm
Above 3.15 mm up to 6.3 mm	:	± 0.05 mm
Above 6.3 mm up to 12.5 mm	:	± 0.07 mm
Above 12.5 mm up to 16 mm	:	± 0.1 mm

(*iv*) ***Rounding-off factor for corner radius of strip***

Table 17.4

Strip width	*Corner radius*	*Reduction in effective area*
Up to 1.6 mm	0.5 mm	0.2147 sq. mm
Above 1.6 mm up to 2.24 mm	0.65 mm	0.3629 sq. mm
Above 2.24 mm up to 3.55 mm	0.8 mm	0.54976 sq. mm
Above 3.55 mm	1.0 mm	0.859 sq. mm

(*v*) ***Tolerance on paper covering thickness for both wire and strip:***

Table 17.5

Increase in overall dimensions due to covering		
From 0.25 mm up to 0.5 mm	:	± 10%
Above 0.5 mm up to 1.3 mm	:	± 7.5%
Above 1.3 mm	:	± 5%

(*c*) Insulating Pressboard

(*i*) ***Acceptability:*** Mill's test certificates in accordance with IS-1576 should be made available along with each supply.

(*ii*) ***Tolerance on thickness:*** (+) Zero (–) 10% over declared thickness.

(*d*) Insulating Oil

(*i*) ***Acceptability:*** Supplier's test certificates in accordance with IS-335 should be made available along with each supply.

(*ii*) ***Tolerance on various properties:*** In accordance with 15-335.

(*e*) MS Materials

(*i*) ***Acceptability:*** The surface of the MS sheet/plate should be smooth. Materials with pitted surface and/or wavy surface may not be used.

(*ii*) ***Tolerance on thickness of sheets and plates:*** Tolerance on thickness is guided by IS-1852 and the reference values of a few of them are as follows:

Table 17.6

1.25 mm thick	:	± 0.13 mm
2.0 mm thick	:	± 0.18 mm
2.5 mm thick	:	± 0.2 mm
3.15 mm thick	:	± 0.22 mm
4.0 mm thick	:	± 0.25 mm

The above tolerance values are for sheets produced in hand mills. However tolerance for sheets/plates with higher thicknesses are drawn from the category of rolled in continuous hot strip mill as shown in Table 17.7.

Table 17.7

5 mm thick	:	± 0.35 mm
6 mm thick	:	± 0.4 mm
8 mm thick	:	± 0.4 mm
10 mm thick	:	± 0.4 mm

Tolerance on thickness of plates exceeding 10 mm may be agreed to between purchaser and supplier.

ISS has recommended varying tolerances on different widths of plates. But to make the issue simpler and to provide a convenient guideline to the inspection agencies, the maximum tolerance limits prescribed under the category, as referred to in Clause 8.22 of IS-1852 may be accepted. The values shown in Table 17.7 are drawn on maximum permissible limit over a width of 1850 mm.

(*iii*) ***Rolling tolerance on flats***

Table 17.8

On width: up to 50 mm		
Above 50 mm up to 75 mm	:	± 1.0 mm
Above 75 mm up to 100 mm	:	± 1.5 mm
Above 100 mm	:	± 2.0 mm
	:	± 2% of declared width up to maximum of 6 mm

Table 17.9

On thickness:		
Up to and including 12 mm thick	:	0.5 mm
Over 12 mm	:	± 14% of declared width up to maximum of 1.5 mm

(*iv*) ***Rolling tolerance on round rods***

Table 17.10

Up to 25 mm dia. rod	:	± 0.5 mm
Above 25 mm up to 35 mm	:	± 0.6 mm
Above 35 mm up to 50 mm	:	± 0.8 mm
Above 50 mm up to 80 mm	:	± 1.0 mm
Above 80 mm up to 100 mm	:	± 1.6% of the declared dia. of rod

(*v*) ***Tolerance on equal leg angles***

Table 17.11

Up to leg length 45 mm	:	± 1.5 mm
Above 45 mm up to 100 mm	:	± 2.0 mm
Above 100 mm	:	± 2% of the declared leg length

ISS is silent over tolerance on thickness of angle. But the tolerance for thickness may be considered same as that of tolerance on sheet thickness as given in:

Table 17.12

5 mm thick	:	± 0.35 mm
6 mm thick	:	± 0.4 mm
8 mm thick	:	± 0.4 mm
10 mm thick	:	± 0.4 mm

(*vi*) ***Tolerance on channels***

Table 17.13

On depth:		
Up to 200 mm	:	± 2.5 mm
Over 200 up to 400 mm	:	± 3.0 mm

Table 17.14

On width:		
Upto and including 100 mm	:	± 2 mm

Table 17.15

On out of parallel:
Tolerance of 1 mm in 60 mm width or proportionate thereof

Table 17.16

On flatness of outer face of web:		
Convexity	:	Not permitted
Concavity	:	15% of the nominal thickness of the web

Table 17.17

On camber or sweep:		
Camber or sweep	:	0.2% of the length

(*f*) Porcelain Bushing

(*i*) ***Acceptability***

Physical appearance: The external surface of the bushing should be uniform without any blister or surface crack. Entire external surface, except the recommended portions, should be brown glazed.

Recommended portions as suggested in IS-3347/8603 should remain flat/un-glazed to ensure proper sealing. Particularly the bushing areas which come in contact with the tank surface as well as metal fittings, should be checked for flatness.

Test certificate showing various electrical and mechanical test results must accompany each supply. In order to keep a check on traceability, it is suggested that the manufacturer's name and month/year of manufacture etc. are marked on the body of the bushing at a particular location.

(*ii*) ***Dimensional tolerance***

Table 17.18

Unless otherwise specified, tolerance on dimension of porcelain bushing shall be ± (0.03 *d* + 0.3) mm where, '*d*' is the dimension in millimetre.

(*g*) Bushing Fitting

(*i*) ***Tolerances on physical dimensions:*** Unless otherwise specified, the allowable tolerance on dimensions of any machined metal part and forged or cast metal part should be in accordance with

IS-2102 (with medium class of machined components and coarse class of forged or cast components). However, the tolerance may be restricted to ± 1 per cent of the declared dimensions.

(*ii*) ***Tolerances on weight:*** ISS is silent on the requirement of weight of the complete fittings. A proto-type sample may be assembled with all standard components as per IS-3347/2102. The weight of such samples shall be kept as reference for random checking and verification. It is suggested that a tolerance of ± 5 per cent on weight may be allowed for incoming materials.

This is a routine practice for PSEB inspecting officers while carrying out inspection in the manufacturer's premises.

(*h*) Other Materials

For other materials, like ratio switch, gasket, breather, valve, radiator, hardware etc. the users should prepare their own acceptable tolerance norms and the materials should be checked with reference to the declared tolerance limits. The component suppliers should be informed in advance about the tolerance requirements to enable them to comply with the requirements by taking care during manufacturing of the components.

17.3 TOLERANCE ON INPROCESS COMPONENTS

(*a*) High Voltage Coil

Table 17.19

Inside diameter	:	(+) 1.0 mm and (–) 0
Outside diameter	:	± 2.0 mm
Coil length	:	± 1.0 mm (after compression)

(*b*) Low Voltage Coil

Table 17.20

Inside diameter	:	(+) 1.0 mm and (–) 0
Outside diameter	:	+ 2.0 mm and (–) 1.0 mm
Coil length	:	± 1.0 mm (after compression)

(*c*) Core Assembly

Table 17.21

Tolerance on core diameter up to 100 kVA	:	± 1.0 mm
Tolerance on core diameter above 100 kVA	:	± 1.0%
Tolerance on core stack	:	± 1.0%
Tolerance on core weight	:	± 1.0%
Tolerance on window height and limb centre	:	± 2 mm

(*d*) Coil Assembly

(*i*) ***On physical parameters:*** All electrical clearances like core to LV, LV to HV, between HV limbs, LV to yoke, HV to yoke, between HV sections etc. are to be maintained as per specification. No negative tolerance is permitted on such clearances.

(*ii*) ***On electrical parameters:***

On ratio: ± 0.5%

If the resistance of the windings are recorded, it should be seen that the resistance should not exceed the guaranteed value, *i.e.*, no positive tolerance is permitted.

(*e*) Tank

(*i*) ***Acceptability:*** General appearance of the tank with regard to welding, finishing, location of various components, symmetry in the fixing of radiator banks etc. should be according to acceptable norms.

(*ii*) ***Working tolerance***

On tank dimensions	:	(+) 0.2 mm and (–) 0
On overall dimensions	:	± 2%

(*f*) Box-Up or Tanking

(*i*) ***Acceptability:*** General workmanship in respect to fixing ratio switch handle, locking of active part with the tank body, HV and LV terminations etc. should be according to acceptable norms.

(*ii*) ***Tolerance***

Insulation resistance: Over 2000 M ohms at 60°C or below. This is applicable for inprocess checking only.

Internal clearances: No negative tolerance is allowed on the specified clearances.

External clearances: No negative tolerance is allowed on the specified clearances. These clearances should be maintained with terminal connectors in position.

(*g*) Sand or Shot Blasting

Acceptability: Overall cleaning in respect of removal of welding flux, rust, surface finish etc. should be of acceptable quality.

(*h*) Oil Filtration

The breakdown value of six average readings should be above 60 kV.

(*i*) Painting and Finishing

Acceptability

(*a*) Overall dimension should be checked and should not go beyond ±2 per cent of the declared value.

(*b*) Overall weight should be checked and should not be less than (–) 2 per cent of the declared weight.

(*c*) No negative tolerance is allowed on external phase clearances (with terminal connectors being fixed in position while measuring).

(*d*) Cleaning, painting and finishing should be of acceptable quality.

17.4 APPLICABLE TOLERANCE LIMIT ON ELECTRICAL PERFORMANCE VALUES

(*i*) **Insulation Resistance:** Minimum acceptable insulation resistances for HV and LV windings should be 2000 M ohms and 1000 M ohms respectively (during factor test).

(*ii*) **Voltage Ratio:** ± 0.5% or 1/10th of the actual percentage impedance whichever is lower.

(*iii*) **Resistance:** The resistance should not exceed the guaranteed value, *i.e.*, no positive tolerance is permitted.

(*iv*) **BDV of Insulating Oil:** The average of six readings should not be less than 50 kV.

(*v*) **Separate Source and Induced over Voltage Test:** The values specified in IS-2026 are minimum.

(*vi*) **No-load Loss at Rated Voltage and Frequency:** Subject to a tolerance of (+) 15 per cent provided the total loss does not exceed (+) 10 per cent.

(*vii*) **No-load Loss at any Voltage other than Rated Voltage:** (+) 30 per cent of the guaranteed value.

(*viii*) **No-load Current at Rated Voltage and Frequency:** (+) 30 per cent of the guaranteed value.

(*ix*) **No-load Current at 112.5 per cent Voltage and at Rated Frequency:** The values specified are maximum.

(*x*) **Load Loss at Rated Load and at 75°C on Principal Tap:** Subject to a tolerance of (+) 15 per cent provided the total loss does not exced (+) 10 per cent.

(*xi*) **Load Loss at any Tap other than Principal Tap:** (+) 30 per cent of the guaranteed value.

(*xii*) **Percentage Impedance:** ± 10 per cent of the guaranteed value.

(*xiii*) **Un-balance Current on Neutral:** Should not exceed 2 per cent of the rated current.

(*xiv*) **Top Oil and Winding Temperature Rise:** Values specified are maximum.

(*xv*) **Zero Sequence Impedance:** Values, if specified, are indicative only and should not be covered under tolerance.

(*xvi*) **Magnetic Balance Voltage:** Should be within ± 5 per cent.

ISS has recommended a tolerance of (+) 15 per cent on the component losses, subject to a maximum of (+) 10 per cent on total losses. However, most of the power utilities do not go by such recommendations. It is, therefore, advisable to follow the customer's specification with regard to tolerance on losses and no-load current.

17.5 CONCLUSION

This chapter has dealt with the working tolerances on incoming materials, inprocess components as well as finished products. The manufacturers should follow such tolerances as a guideline for checking the uniformity of the product quality. However, it is advisable to estimate their own tolerance limits based on the customer's specification, ISS and experience. The quality assurance engineer should offer training to all workmen as well as vendors to follow such tolerance limits closely while manufacturing. However, the tolerance limits should be reviewed periodically and should be updated if necessary.

Section III

CHAPTER 18

Test and Inspection on Finished Products

FOOD FOR THOUGHT

The human being is innovative and creative. From the stone age to today's high technology era, innovations and creativity have played a key role in the quality of life. The automobile and mass production have increased consumption and reduced the cost of products. Aviation industry brought the world closer and telecommunication decreased the communication gap. Engineers gave us the computer and information system. Statistics was made simple for everyone through calculators and home computers.

All of these would not have been achieved without innovation and imagination.

Quality professionals have to be innovative and creative, the only way the quality profession can be made attractive is by injecting creativity, imagination and vision. Over the years, quality profession has grown from mere data crunching and analysis function to quality system and quality management. Now that quality has become a household word, both with industry and consumers, we should take advantage of this opportunity.

In this time of great economic changes, creativity and innovations are surely needed. Sometimes it is just impractical to try to solve today's problems with yesterday's solution. Going by "the book" discourages creativity. Common sense, logic and reason are useful attributes of creativity. Logic is an important thinking tool. A creative thinker breaks out of one pattern to discover another.

Instead of the old sampling plan, inspection, audit etc. we should find new way to extract useful information through Statistical Process Control (SPC). Using design reviews, early entry qualification, supplier partnership programme, we can avoid on going-routine tests. Prevention of defects is in itself another form of innovation.

18.1 INTRODUCTION

The test on finished transformer is a part of quality assurance. The performance parameters are checked and reviewed with respect to the guaranteed values and available tolerance limit. Before declaring a transformer healthy and ready for service, the transformer should undergo a series of tests which are categorized as under:

(*a*) Routine tests

(*b*) Type tests

(*c*) Special tests

Routine tests are those which are necessarily to be performed on all transformers. Type and special tests are carried out on the specific requirement of customers. In case, these tests have already been carried out in the past on a transformer and the available test certificates with certified drawings are not older then 5 years, the buyer may not insist on repetition of such tests.

However the buyer should review the original certificates, for all performance parameters, including tapping details, impedance, losses etc. of the proposed transformer before granting waival for further test.

18.2 CLASSIFICATION OF TESTS

The details of tests under each category may be classified as under:

(*a*) Routine Tests: The routine tests may be classified into two groups, *viz*.

(*i*) Di-electric tests (1 to 4) and

(*ii*) Parametric tests (5 to 8)

(*b*) Type Tests

(*i*) Temperature rise test (9)

(*ii*) Impulse test (10)

(*c*) Special Tests

(*i*) Short-circuit test (11)

(*ii*) Un-balance current on neutral (12)

(*iii*) Magnetic balance test (13)

(*iv*) Measurement of zero sequence impedance (14)

(*v*) Measurement of noise level (15)

Schedule of routine, type and special tests with individual details are shown in a block diagram Fig. 18.1.

Procedure of each test, as indicated in the schedule of test, is well defined in IS-2026 and the same is reproduced here in sequential order.

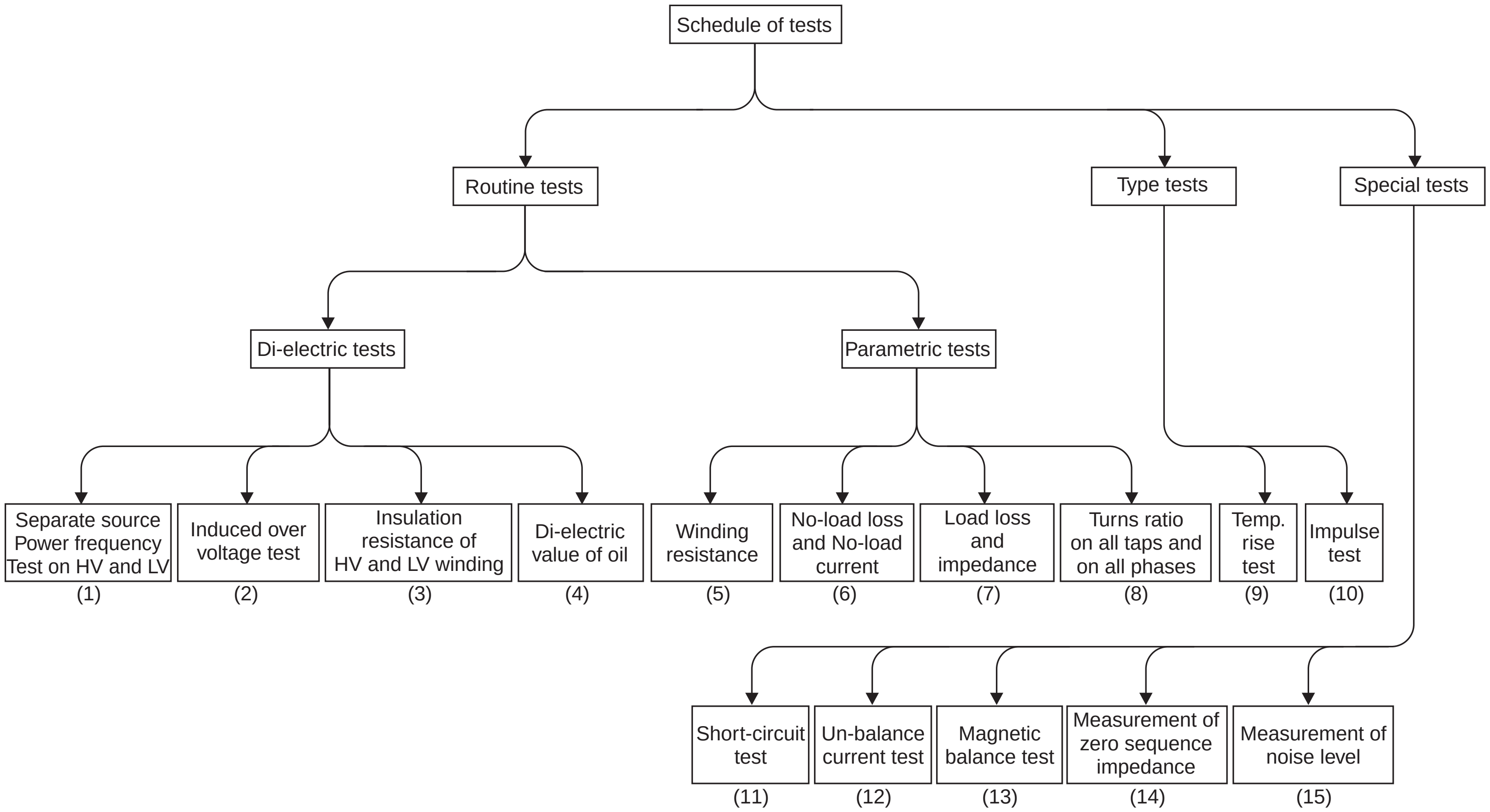


Fig. 18.1. Schematic diagram indicating the schedule of tests

18.3 TEST SL. NO. 1

Separate Source Power Frequency Test on HV and LV Windings (Routine Test)

This is required to be carried out on all transformers.

The separate source voltage test should be made with a single phase alternating voltage of waveform as nearly as possible to the sine wave and of any convenient frequency which is not less than 80 per cent of the rated frequency.

The peak value of the voltage should be measured. The peak value divided by $\sqrt{2}$, which is the rms value, is taken as the test value.

The test should be commenced at a voltage not greater then one-third of the specified test voltage and should be increased to the test value as rapidly as is consistent with the measurement. The rate of rise of voltage may be restricted to 2 kV/Second. At the end of the test, the voltage should be reduced to less than one-third of the test value before being switched-off.

The full test voltage should be applied between the windings under test and all terminals of the other winding, core frame and tank connected together to earth. The test should continue for 60 seconds.

The test shall be successful, if no collapse of the test voltage occurs. Rated withstand voltages as recommended by ISS for transformer windings with respect to highest system voltage are shown in Table 18.1.

Table 18.1

Rated system voltage (kV-rms)	*Highest system voltage (kV-rms)*	*Rated short duration power frequency withstand voltage (kV-rms)*	*Rated lightning impulse without voltage (kV-peak)*
0.433	1.0	3.0	Not applicable
3.3	3.6	10.0	40.0
11.0	12.0	28.0	75.0
15.0	17.0	38.0	95.0
22.0	24.0	50.0	125.0
33.0	36.0	70.0	170.0

Measurement of Leakage Current During Separate Source Test

ISS is silent on the requirement of limiting the leakage current between high voltage to low voltage and earth while carrying out separate source power frequency test. In fact, the magnitude of the leakage current will give a fair idea about the status of insulation between HV to LV and earth. Provision should be made to measure leakage current while carrying out this test. A milliammeter is connected in series between earth and remaining part of the winding, together with core frame, tank etc. The milliammeter should have an over current protection mechanism (MOTWANE type). A schematic diagram for measurement of leakage current is shown in Fig. 18.2.

It is better if the transformer is made isolated from the ground by insulating separators (as shown in Fig. 18.2).

The flow of leakage current will be more, in case the drying of insulation is not proper. If the transformer is built with sub-standard or inadequate insulating materials, or drying of insulation is not proper, the flow of leakage current will be high and will be recorded by the milliammeter.

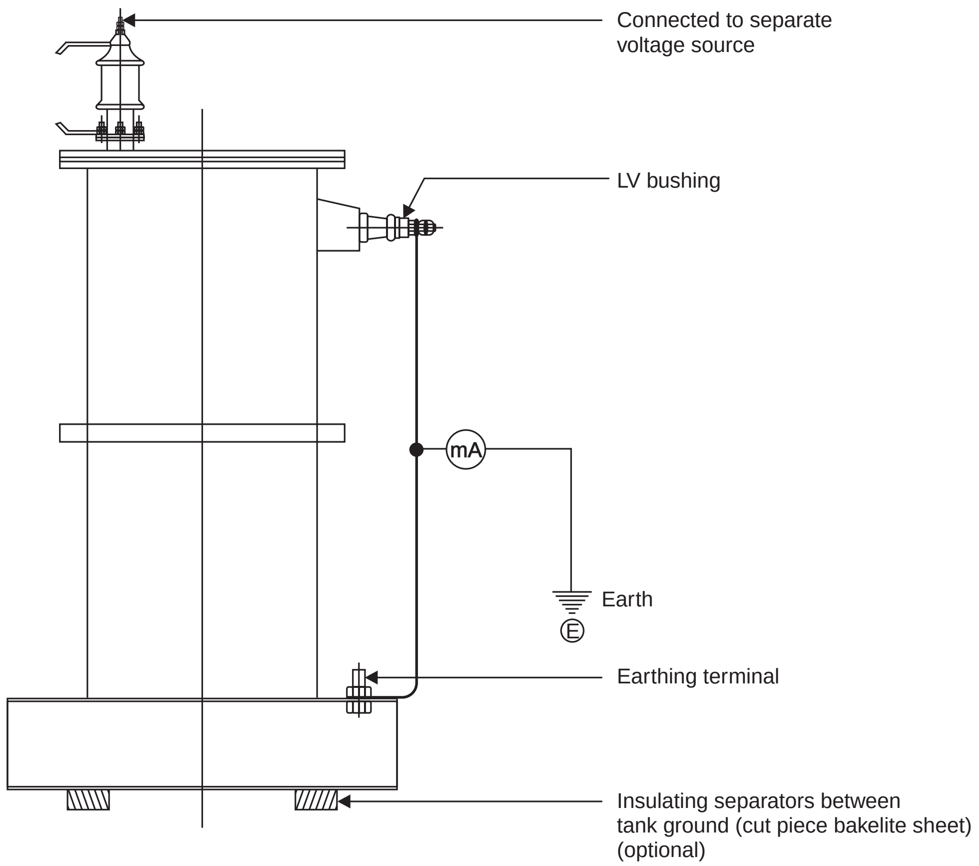


Fig. 18.2. Schematic diagram for measurement of leakage current during separate source test

18.4 TEST SL. NO. 2

Induced Over Voltage Test (Routine Test)

This test is required to be carried out on all transformers.

An alternating voltage is applied to the terminals of one winding of the transformer, keeping the other winding open circuited. The voltage waveform should be as nearly as possible a sine wave and the frequency suitably increased above the rated frequency to limit excessive excitation current during test.

The peak value of the induced test voltage is measured and the rms value is taken as the test value.

The test should commence at a voltage not greater than one-third of the test value and should be increased to the test value as rapidly as is consistent with the measurement. At the end of the test, the voltage should be reduced rapidly to less than one third of the test value before switching-off.

Unless otherwise specified, the duration of the test at the full test voltage should be 60 seconds for any test frequency upto and including twice the rated frequency. When the test frequency exceeds twice rated frequency, the duration of the test should be $120 \times \frac{\text{Rated frequency}}{\text{Test frequency}}$ seconds but not less than 15 seconds.

For transformer with uniformly insulated high voltage, the test voltage across an untapped winding should be twice the rated voltage, but line-to-line test voltage of any three phase winding should not exceed the rated withstand voltage as given in the Table 18.1. The measurement of test voltage should be done on high voltage side.

A three phase winding is tested preferably with symmetrical three phase voltage applied to the three windings. If winding has a neutral, the same may be earthed during test.

The test is successful if no collapse of test voltage occurs.

18.5 TEST SL. NO. 3

Insulation Resistance of HV and LV Windings (Routine Test)

This test is required to be carried out on all transformers.

The oil/air temperature should be recorded immediately prior to test. All HV and LV porcelain bushings should be cleaned with dry cloth, preferably soaked with thinner, prior to test. The insulation resistance of each winding to earth with all other windings, core, frame and tank connected together to earth, should be measured and recorded. The sequence of tests should be as given below:

(*a*) Between HV winding and earth—Keeping LV winding, core, frame, tank earthed.

(*b*) Between LV winding and earth—Keeping HV winding, core, frame, tank earthed.

(*c*) Between HV and LV winding—Keeping core, frame, tank earthed.

The recommended IR value during factor test is above 2000 M ohms at any temperature between (–)5°C to 50°C. However, 1000 M ohms for HV winding and 500 M ohms for LV winding are acceptable.

The instrument to be used for measuring insulation resistance should preferably be a motorised megger of minimum 2500 V.

18.6 TEST SL. NO. 4

Dielectric Value of Insulating Oil (Acceptance Test)

For in-house testing, the oil sample should be drawn from a couple of transformers in each day's production.

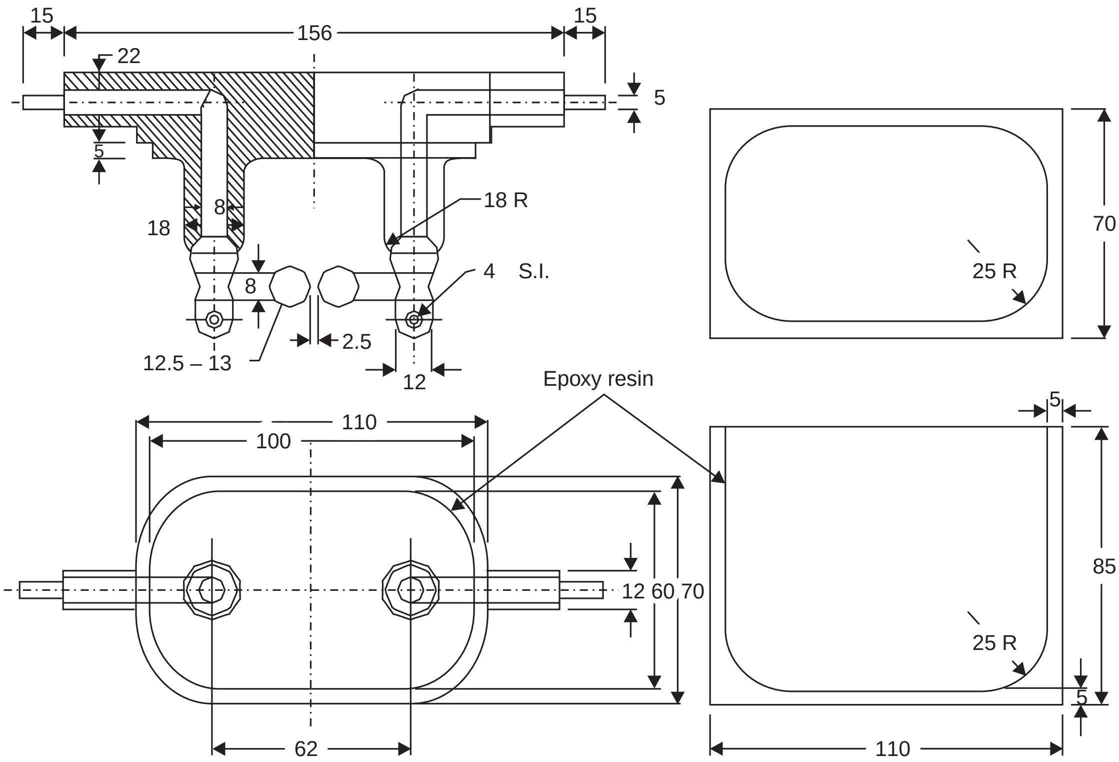
The test procedure is described in IS-335, IS-6792 and IS-1866.

The sample should be drawn in accordance with the procedure laid down in IS-6855.

The oil test cell, made with glass or plastic, should be transparent and non absorbent. It should preferably be closed with a removable lid.

Two types of cells, as illustrated in ISS, are reproduced in Figs. 18.3 and 18.4.

The electrodes can be of copper, brass, bronze or stainless steel. The shape of electrodes should be either spherical (12.5 to 13 mm dia.) or that of a mushroom of dimensions given in Fig. 18.4. The electrodes should be mounted on a horizontal axis 2.5 mm apart.



Note : All Dimensions are in mm.

Fig. 18.3. Oil tests cell type-A

The gap between the electrodes should be set to an accuracy of ± 0.1 mm by means of a thickness gauge. The axis of electrodes is immersed in oil to a depth of approximately 40 mm.

The electrodes are to be replaced as soon as pitting caused by discharges is observed.

Between tests, the cell should be cleaned of all oil and left in an inverted position to avoid deposition of dirt and moisture. Alternatively, the cell should be filled with an oil having higher dielectric strength and suitably covered.

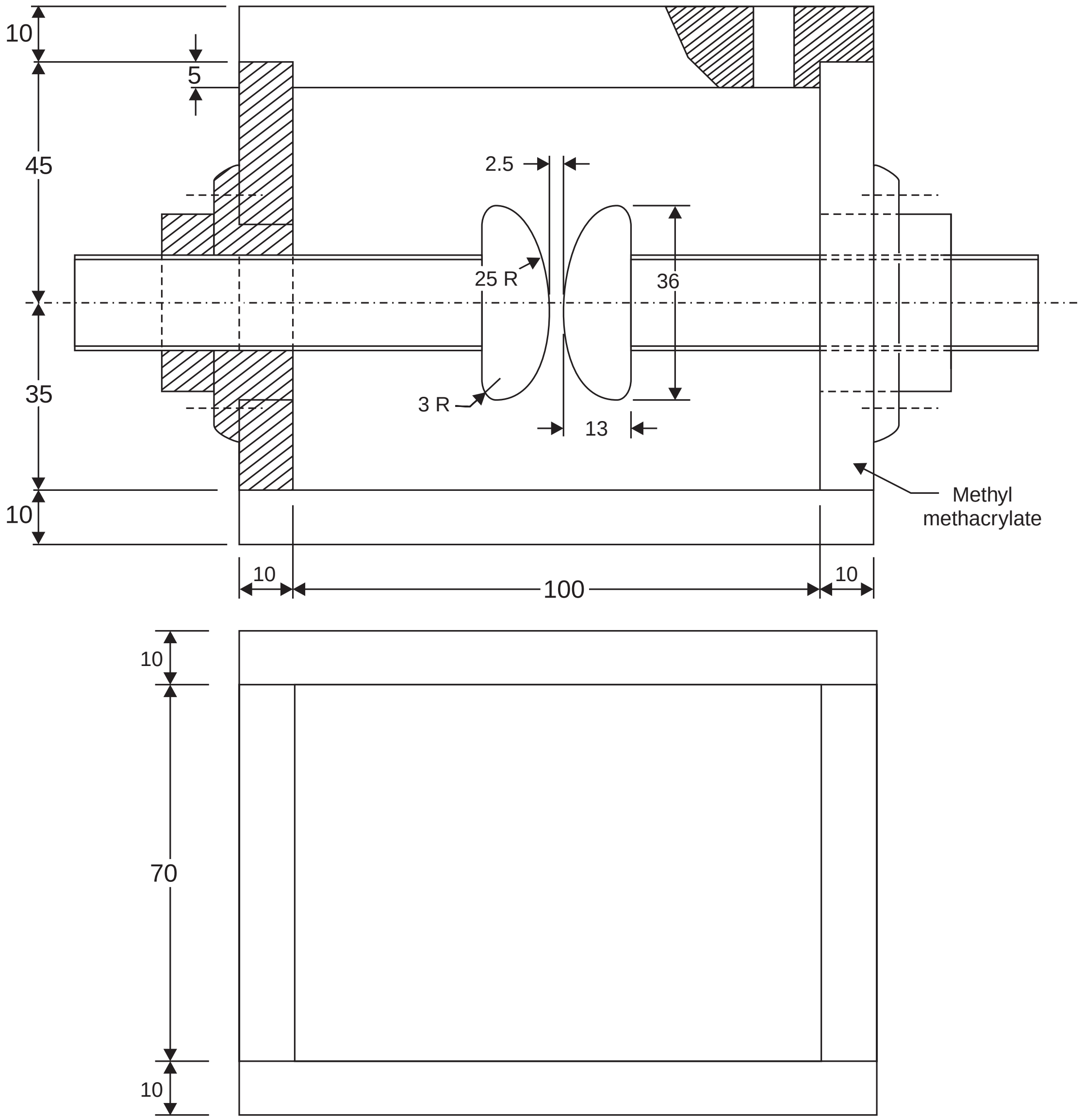
If the cell was not used for sometime, it should be thoroughly cleaned, the electrodes should be removed, cleaned and finally rinsed with dry, clean new oil. Replacement of electrodes should be carried out with great care, avoiding all direct contact with fingers.

Immediately before use, the cell should be rinsed with test oil (at least twice) before proceeding for final filling.

The vessel containing the sample test oil should be gently agitated and turned over several times in such a way as to ensure a homogeneous distribution of impurities contained in the oil without causing the formation of air bubbles.

Immediately after this, the sample should be poured into the test cell slowly, in order to avoid the formation of air bubbles (a clean glass rod could be used). The operation is carried out in a dry place free from dust.

The oil temperature at the time of test should be the same as that of ambient temperature, preferably around 27°C. The temperature should be recorded.



Note: All Dimensions are in mm.

Fig. 18.4. Oil test cell type-B

An increasing AC voltage of frequency 40 to 60 Hz is applied to the electrodes. The rate of increase of voltage should be uniform and equal to 2 kV/second (approx.) starting from zero upto the value causing breakdown.

The circuit is opened manually, if a transient spark (audible or visible) occurs between the electrodes or automatically, if an established arc occurs. In the later case, the automatic switch breakes the voltage within 0.02 second.

The breakdown voltage is the voltage reached during the test at the time the first spark occurs between the electrodes, whether it is transient or established.

The test should be carried out six times on the same cell filling.

The first application of voltage is made as quickly as possible after the cell is filled, provided there is no air bubble in the oil and latest at 10 minutes after filling. After each breakdown, the oil is gently stirred between the electrodes by means of a clean dry glass rod, avoiding as far as possible the production of air bubbles. For the subsequent five tests, the voltage is re-applied one minute after the disappearance of any air bubble that may have formed. If the disappearance of air bubble cannot be observed, it is necessary to wait for five minutes before a new breakdown test is started.

The di-electric strength is the arithmetic mean of the six results obtained. The recommended values as per IS-335 are as under:

(*i*) Di-electric breakdown voltage for new un-treated oil (sample drawn from drum or tanker) : 30 kV rms (min.)

(*ii*) Di-electric breakdown voltage for oil after filtration (before pouring into the transformer) : 60 kV rms (min.)

(*iii*) Di-electric breakdown voltage for oil sample drawn from the bottom of transformer (before energising the transformer) : 50 kV rms (min.)

IS-335 covers the characteristic properties of new un-filtered oil. After filling or re-filling, but prior to energising the transformer, the characteristic properties of oil is guided by IS-1866. It is a routine practice for the PSEB engineers, while carrying out inspection at the manufacturer's works, to draw two oil samples of approximately 51 each, one from storage tank for un-filtered oil and the other from the bottom of transformer. These samples are subjected to tests at PSEB's own departmental test laboratory located at sharand Patiala. The test results of the oil from the storage tank and transformer are reviewed in accordance with the requirements of IS-335 and IS-1866 respectively. The despatch clearances of the inspected transformers are issued only upon getting successful oil test reports.

18.7 TEST SL. NO. 5

Measurement of Winding Resistance (Routine Test)

This is required to be carried out on all transformers.

The resistance of each winding, the terminals between which it is measured and the temperature of the winding, should be recorded. Direct current is used for the measurement.

In resistance measurement, the time for measuring current to become steady shall be recorded and should be used as guidance while measuring hot resistance following a temperature rise test.

Wheatstone and Kelvin bridges are generally employed for the measurement of HV and LV resistances respectively. However, depending upon the value of resistance, Kelvin bridge may be employed in the measurement of both.

In case, tappings are provided on the HV winding, the resistances at all the taps, are to be measured.

This will ensure the quality of the electrical contacts of the tapping switch. It is preferable to measure the HV resistances of all the taps twice in a row, once during clockwise rotation and then during anticlockwise rotation. The values of the resistances measured both ways, for a particular tap, should match.

Example:

Table 18.2

Tap switch position	*Resistance measured during clockwise rotation*	*Resistance measured during anticlockwise rotation*	*Remark*
Tap-1	Value to be recorded	Value to be recorded	Whether the same or not to be recorded
Tap-2	-do-	-do-	-do-
Tap-3	-do-	-do-	-do-
Tap-4	-do-	-do-	-do-
Tap-5	-do-	-do-	-do-

If the value of HV resistance is within the measurable range of Kelvin bridge, it is preferred to employ Kelvin bridge only for such measurements. However, the resistance measured during clockwise and anticlockwise rotation may differ by one per cent which may be considered to be within the acceptable limit.

A tap switch having weak contacts will never yield the same resistance values at a particular tap position during clockwise and anticlockwise measurements. For star-connected winding, it is recommended to measure both line-to-line as well as line-to-neutral resistances. For all calculation purposes, line-to-line resistance should be taken into account. However, line to neutral resistance will indicate the quality of neutral termination.

18.8 TEST SL. NO. 6

Measurement of No-load Loss and No-load Current (Routine Test)

The test is required to be carried out on all transformers.

The no-load loss and current should be measured at rated frequency, at a voltage equal to the rated voltage. Other winding is left open-circuited. The voltage should be measured with a voltmeter responsive to the mean value of the voltage, but scaled to read the rms value of a sine waveform having the same mean value. The no-load currents of all the phases should be measured using rms ammeters and the average value of these readings should be taken as the no-load current.

The test may be carried out either by two wattmeter method or three wattmeter method. The ultimate results in both the cases are almost identical. The frequency should be maintained at the rated value. In case, the supply frequency is other than the rated frequency, the voltage may be drawn from a generator with a facility to generate rated frequency. In the event, generator is not available, or the generator does not have the provision of frequency regulation, then it is a difficult task for the testing engineer to record the no-load loss and current correctly.

If the supply frequency is other than the rated frequency, but within ±3 per cent, the no-load loss may be recorded at that frequency and appropriate correction factors applied to evaluate the loss at rated frequency. The results achieved after such corrections are fairly accurate and may be accepted for all industrial measurements.

West Bengal State Electricity Board during inspection at the manufacuturer's premises do apply such correction factors on specific occasions.

An example to establish such frequency correction factor while calculating no-load loss is given below:

Rated secondary voltage of the transformer	:	433 V
Rated frequency	:	50 Hz
Test frequency	:	49 Hz
Ratio of test and rated frequency	:	$\frac{49}{50} = 0.98$
Recommended voltage at which no-load loss is to be measured	:	$(433 \times 0.98) = 424.34$ V
Say, the no load loss measured at corrected voltage of 424.34 volts	:	W
Frequency correction factor	:	$\dfrac{\left(\frac{50}{49}\right)+\left(\frac{50}{49}\right)^2}{2} = 1.03$
Therefore, the no load loss at rated frequency after applying correction factor	:	$(W \times 1.03)$

In case, the test frequency is above the rated frequency, then the correction factor may be determined as follows:

The test frequency	:	51 Hz
Ratio of test and rated frequency	:	$\frac{51}{50} = 1.02$
Recommended voltage at which no-load loss is measured	:	$(433 \times 1.02) = 441.7$ V
Say, the no-load loss measured at corrected voltage of 441.7 V	:	W
Frequency correction factor	:	$\dfrac{\left(\frac{50}{51}\right)+\left(\frac{50}{51}\right)^2}{2} = 0.97$
Therefore, the no-load loss at rated frequency after correction factor applying	:	$(W \times 0.97)$

During the measurement of no-load loss, applied voltage on all the three phases should remain balanced, *i.e.*, a balanced three phase voltage is essential for measuring no-load loss.

But, it is very difficult to get a perfectly balanced voltage on all the three phases. On such occasions, it is recommended to employ three single phase voltage regulators (Variac) to create a balanced supply.

In case, the phase voltages are un-balanced by more than one per cent, the test should be discontinued.

In case we are required to carry out the test at an un-balanced voltage, but within ± one per cent, we would make use of average voltage.

Example:

If the voltage available across each of the phases are 430 V, 432 V and 437 V, the average voltage is

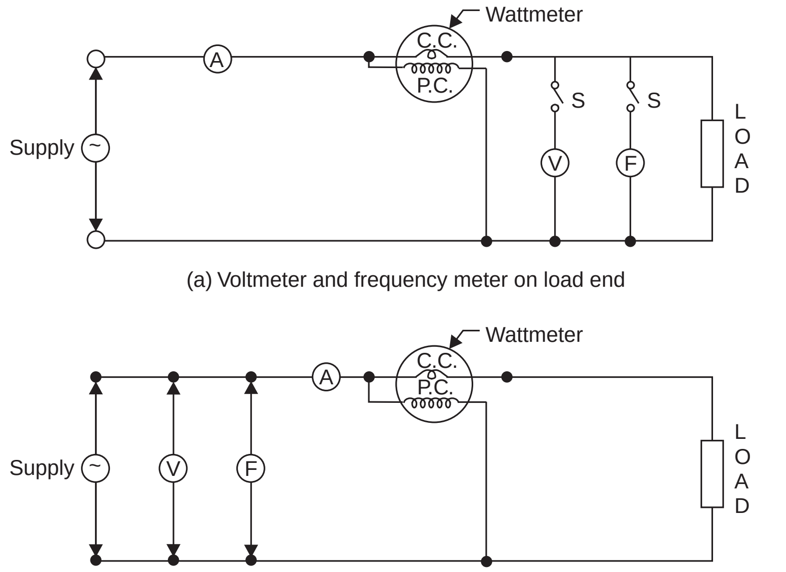
$$\frac{430 + 432 + 437}{3} = 433 \text{ V}$$

We may continue to measure the no-load loss at the average voltage. The losses measured under such average voltage are also fairly correct and are within ±1 per cent of the true value.

In the case of measurement of no-load loss by three wattmeter method under an un-balanced supply voltage, some of the power utility engineers insist on recording each phase wattage by maintaining the individual phase voltage as that of the rated voltage. The procedure is not correct, since, it disturbs the flux balancing in each measurement and is not recommended such for commercial measurements.

Location of Voltmeter and Frequency Meter During No-load Loss Measurement

Placement of voltmeter and frequencymeter plays a vital role in the measurement of no-load loss and current. This aspect can be demonstrated with two connection diagrams shown in Figs. 18.5(*a*) and (*b*).



(a) Voltmeter and frequency meter on load end

(b) Voltmeter and frequency meter on supply end

Fig. 18.5. Wattmeter connection for measurement of 3-phase power

This is a simple connection showing single phase supply with ammeter, wattmeter, voltmeter, frequencymeter and a load. The only difference between these two connections is the location of the voltmeter and frequencymeter.

In Fig. 18.5(*a*), the voltmeter and frequencymeter are placed in between the wattmeter and load (*i.e.,* the load end), whereas in the second figure [(Fig. 18.5(*b*)], these two meters are placed in between supply and wattmeter (*i.e.,* the supply end).

Each meter has its own VA loss which is approximately 2.5 VA for voltmeter and approximately 5 VA for frequencymeter. The total loss for one voltmeter and one frequencymeter together is approximately 7.5 VA.

Our intention is to record only the loss across the load and not to measure loss of the load together with the loss in the meters.

In the event the loss is measured as per the first connection diagram, since the voltmeter and the frequencymeter are placed after the wattmeter, the wattmeter will record the loss which is equivalent to (loss in the load + loss in the meters connected across load).

In the second connection diagram, since the voltmeter and the frequencymeter are placed before the wattmeter, the additional VA loss of these two meters will not reflect in the wattmeter reading and therefore the wattmeter will record only the loss in the load.

The second connection diagram is more appropriate and may be emplyed for all commercial measurements. However, first connection diagram can also be followed in case the switch(s) is put off just before recording the wattmeter reading.

It is theoretically true that there will be a drop in voltage across the current coils of the ammeter and the wattmeter, but since the resistance of current coil is too low, the IR-drop across current coil is in the range of millivolts and may be neglected.

The connection diagram for loss measurement by two wattmeter and three wattmeter methods are shown in Figs. 18.6 and 18.7 respectively.

Two Wattmeter Method of Connection for Measurement of 3-Phase Loss (Fig. 18.6)

The following parameters are to be recorded during loss measurement:

(*a*) Voltages across V_1, V_2, V_3 are to be recorded. The average of them should be the rated voltage.

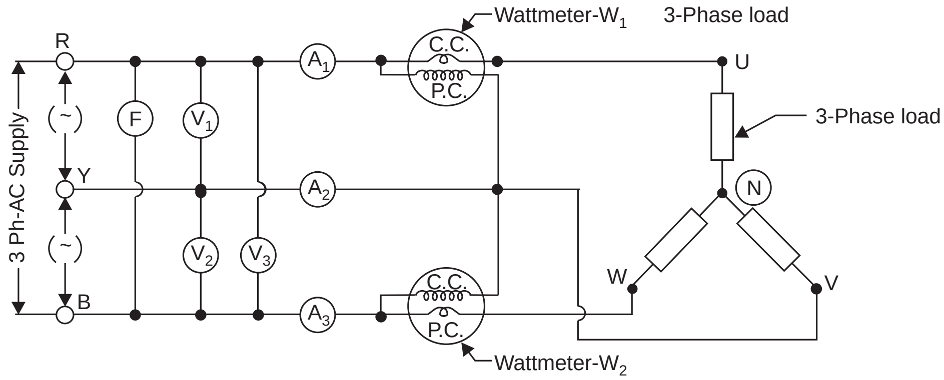


Fig. 18.6. Connection diagram for measurement of 3-phase power by two wattmetermethod

(*b*) Frequency is to be recorded. In case, the recorded frequency is other than the rated frequency, but within ± 3% of rated frequency, the corrections, as discussed earlier should be applied.

(*c*) The currents measured by A_1, A_2, A_3 should be recorded. The average of these readings is the no-load current.

(*d*) The readings of W_1 and W_2 should be recorded and added arithmatically to get the no-load loss. While recording the wattmeter readings, the polarity of the wattmeter pressure coil connection should be checked. In case, the connections to the pressure coil are made reverse in one of the wattmeter to register a positive detlection, we should record the reading of that wattmeter as negative. In that case, the net wattage is ($W_1 - W_2$). In almost all cases, the reading of one of the wattmeters is mostly negative for two wattmeter method except for transformers of very low rating.

However, to get the final numerical value of the wattage, the net wattmeter reading is to be multiplied by the wattmeter multiplier, which is suitably selected on the basis of the current and the voltage ratings. To arrive at an accurate value and to reduce the human error, it is always preferred to select a multimplier as low as possible.

Three Wattmeter Method of Connection for Measurement of 3-Phase Loss (Fig. 18.7)

The following parameters are to be recorded during measurement:

(*a*) In line with the two wattmeter method, we need to measure the average of the three voltmeter readings to get the rated voltage.
(*b*) Frequency correction, if needed, may be applied as discussed.
(*c*) The average of the three ammeter readings is taken as no-load current.
(*d*) The readings of W_1, W_2 and W_3 are recorded and added arithmetically to get no-load loss.
(*e*) For wattmeter polarity and selection of wattmeter multiplier, follow the procedure discussed in para IV of two wattmeter method.

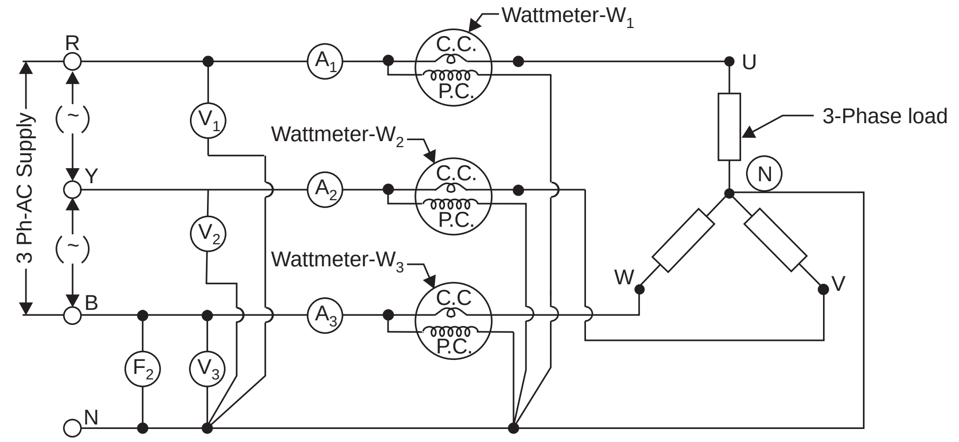


Fig. 18.7. Connection diagram for measurement of 3-phase power by three wattmeter method

No-load Current at Over Voltage

So for we have discussed the procedure of measuring no-load loss and current at rated voltage and frequency. However, it is essential to know the magnetic characteristics at over-voltage as well. Hence we should record the no-load current at 112.5 per cent voltage. During the measurement of no-load current at 112.5 per cent voltage, we should record the maximum no-load current in any of the phases. It is not recommended to record average current at over-voltage.

18.9 TEST SL. NO. 7

Measurement of Load Loss and Impedance (Routine Test)

This test is required to be carried out on all transformers.

Unless otherwise specified, the impedance voltage and load loss should be measured at principal tappings and at rated frequency by applying an approximate sinusoidal voltage to one winding with the other winding short-circuited.

The measurement may be made at any current between 25 to 100 per cent, but preferably not less than 50 per cent of the rated load current. Each measurement should be performed in the shortest possible time and the interval between them should be long enough to ensure that the temperature rise of the winding do not cause significant error.

The difference in temperature between top and bottom oil should be small enough to enable the average temperature to be determined with the required accuracy.

The measured value of the load loss should be corrected by multiplying it with the square of the ratio of rated current to test current. The values so derived should be corrected to reference temperature (75°C) taking I^2R loss ($R = DC$ resistance) as varying directly with temperature and other losses (stray) as varying inversely with temperature.

The measured value of the impedance voltage should be corrected by increasing it in the ratio of rated current to the test current. The value of the impedance voltage so derived should be corrected to the reference temperature (75°C).

The measurement of load loss may be done either by two wattmeter method or by three wattmeter method. However, both the methods are fairly accurate for commercial measurements. The connection diagram shown earlier (Figs. 18.6 and 18.7) may be employed.

The readings of A_1, A_2 and A_3 are recorded and the values are such that the average of the three readings is the rated current. In case, the test is carried out at reduced current, the average of the ammeter readings should be taken for further calculations.

For all practical purposes, low voltage winding is shorted and a voltage proportional to the load current is fed to the high voltage winding. Since during test, full rated current will flow through the low voltage windings, it is to be ensured that the bus bar being used for shorting the LV terminals (with neutral) should have sufficient cross-section so as not to generate too much of heat during test.

The average of the voltage is taken as impedance voltage at test condition. In case, test frequency is other then rated frequency, the impedance voltage measured should be corrected with the ratio of rated frequency to test frequency.

Sample Calculation of Load Loss Measured at Reduced Current

Example: 100 kVA, 11/0.433 kV, aluminium-wound transformer, connected in Delta/Star with rated current (HV/LV)—52.5/133.3 A.

Test condition: Low voltage terminals and neutral are shorted with a copper bus bar of section 50 x 6 mm. Voltage is applied from 11 kV side.

Ambient temperature: Top oil temperature is measured by an alcohol thermometer and recorded. Ensure that the difference in temperature between top and bottom oil is small enough to enable the average temperature to be determined with required accuracy.

Test Parameters

Current fed through primary	:	5 A
Load loss measured at 5 A current	:	1390 W
Ambient temperature	:	35°C
Test frequency	:	49 Hz
Cold HV resistance at 35°C		
1 U–1 V	:	20.8 ohms
1 V–1 W	:	20.7 ohms
1 W–1 U	:	20.9 M ohms

Cold LV resistance at 35°C (between lines)

2 U–2 V	:	21.6 M ohms
2 V–2 W	:	21.82 M ohms
2 W–2 U	:	21.56 M ohms

Sample Calculation

Table 18.3

1.	Load loss corrected to rated current at 35°C	$\frac{5.25}{5} \times 1390 = 1532$ W at 35°C
2.	Average HV resistance (between line terminals of delta connected winding) at 35°C	$\frac{(20.8 + 20.7 + 20.9)}{3} = 20.8$ ohm at 35°C
3.	Per phase HV resistance at 35°C	$20.8 \times 1.5 = 31.2$ ohms at 35°C
4.	Per phase LV resistance at 35°C	$\frac{(21.6 + 21.82 + 21.56)}{3 \times 2} = 10.83$ M ohms at 35°C
5.	HV-3 × $I^2 R$ loss at 35°C	$3 \times \left(\frac{5.25}{\sqrt{3}}\right)^2 \times 31.2 = 860$ W at 35°C
6.	LV-3 × $I^2 R$ loss at 35°C	$3 \times 133.33^2 \times 10.83 \times 10^{-3} = 578$ W at 35°C
7.	Total $I^2 R$ (HV + LV) at 35°C	(860 + 578) = 1438 W
8.	Stray loss at 35°C (1-7)	(1532 – 1438) = 94 W
9.	Total $I^2 R$ (HV + LV) at 75°C.	$1438 \times \frac{(225 + 75)}{(225 + 35)} = 1660$ W
10.	Stray loss at 75°C	$94 \times \frac{(225 + 35)}{(225 + 75)} = 82$ W
11.	Load loss at rated load and at 75°C (9 + 10)	1660 + 82 = 1742 W

Note: In the case of copper winding transformer, the procedure of calculation is same except for the absolute temperature which is 235°C for copper winding whereas it is 225°C for aluminium winding.

Impedance Calculation

Test parameters: Impedance voltage measured across the phases:

1 U–1 V = 466 V

1 V–1 W = 472 V

1 W–1 U = 470 V

Test frequency = 49 Hz

Table 18.4

1.	Average impedance voltage at 5 A and at 35°C at 49 Hz	$\frac{466+472+470}{3}$ = 469.33 V
2.	Average impedance voltage at rated current and at 35°C measured at 49 Hz	$\left(\frac{5.25}{5}\right)$ × 469.33 = 493 V
3.	Average impedance voltage at rated load and at 35°C corrected to 50 Hz	$\left(\frac{50}{49}\right)$ × 493 = 503 V
4.	Percentage impedance at 35°C	$\frac{503\times100}{11000}$ = 4.57%
5.	Percentage resistance at 35°C	$\frac{1532\times100}{100\times10^3}$ = 1.532%
6.	Percentage reactance	$\sqrt{(4.57^2-1.532^2)}$ = 4.31 %
7.	Percentage resistance at 75°C	$\frac{1742\times100}{100\times10^3}$ = 1.742 %
8.	Percentage impedance at 75°C	$\sqrt{(4.31^2-1.742^2)}$ = 4.65%

18.10 TEST SL. NO. 8

Voltage Ratio and Phase Relationship (Routine Test)

This test is required to be carried out on all transformers.

Voltage ratio: Voltage ratio is measured on each phase and on each tapping. Standard transformer turns ratio bridge is available for carrying out ratio error test. Ratio error is measured in percentage.

The limits of error are either ± 0.5% or a percentage of declared ratio equal to 1/10 of the actual percentage impedance voltage at the rated current.

An example with some numerical values is illustrated below:

Vector diagram (assumed): Dyn-11.

Connection: Connect (1U-2U) externally with a piece of thick wire as shown in Fig. 18.8.

Test procedure and measurement: 400 V, 3 phase supply is fed between (1 U – 1 V – 1 W) when delta and star vectors will superimpose as shown in Fig. 18.8.

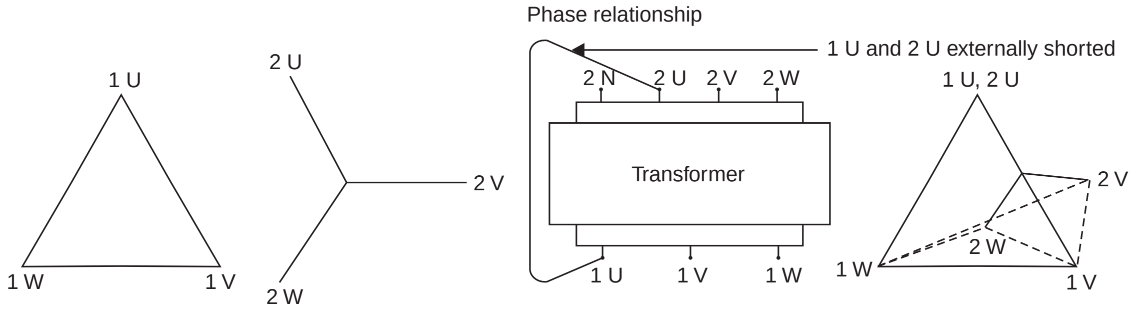


Fig. 18.8. Phase relationship having vector group dyn-11

The voltage across the following terminals are recorded:

(1 U–1 V) = (1 V – 1 W) = (1 W – 1 U) = 400 V (supply voltage)
(1 W–2 W) = To be measured and recorded
(1 W–2 V) = -do-
(1 V–2 W) = -do-
(1 V–2 V) = -do-
(1 U–2 W) = -do-
(1 U–2 V) = -do-

In case, the windings are truly connected as per vector group Dyn-11, then the voltage measured above must satisfy the following relations:

(*a*) (1 W – 2 W) must be less than (1 W – 2 V)
(*b*) (1 V – 2 W) must be equal to (1 V – 2 V)
(*c*) (1 U – 2 W) must be equal to (1 U – 2 V)

Since, the difference in magnitude between the voltages are very small, it is advisible to measure the voltage with a suitable voltmeter and preferably over a single scale.

18.11 TEST SL. NO. 9

Temperature Rise Test (Type Test)

This is required to be carried out on one unit of a particular design.

The procedure and other requirements of temperature rise test are covered in part-II of IS-2026.

Identification Symbols

The transformers are generally identified according to the cooling method employed. Letter symbols used in connection with each cooling method are as follows:

(*i*) *Kind of cooling medium*	***Symbol***
(*a*) Mineral Oil	O
(*b*) Non flammable synthetic liquid	L
(*c*) Gas	G
(*d*) Water	W

(*e*) Air	A
(*ii*) *Kind of circulation*	
(*a*) Natural	N
(*b*) Forced (oil not directed)	F
(*c*) Forced (directed oil)	D

Arrangement of Symbols

The transformers are identified by four symbols for each cooling method. The order in which the symbols are used are as follows:

1st letter : Kind of cooling medium indicating the cooling medium in contact with the winding (for conventional 100 kVA oil filled transformer, it is mineral oil '*O*'

2nd letter : Kind of circulation (in this case, it is natural '*N*')

3rd letter : Kind of cooling medium indicating the cooling medium in contact with the external cooling system (in this case, it is air '*A*')

4th letter : Kind of circulation of cooling medium (in the case, it is natural '*N*')

So the symbol of cooling arrangement may be written as ONAN (Oil Natural Air Natural)

Temperature Rise of Transformer Designed for Higher Altitude

In the case of a conventional transformer having cooling symbol 'ONAN' designed for operation at an altitude greater than 1000 m, but tested at normal altitude, the limit of temperature rise assigned by the purchaser should be reduced by 2% for each 500 m by which the intended working altitude exceeds 1000 m.

Example:

A transformer is required to be installed at an altitude of 1750 m and the temperature rise of oil/winding desired is 40/50°C, tested at normal altitude.

As stated above, for each 500 m by which the working altitude exceeds 1000 m, the temperature rise is to be reduced by 2%. So for 1750 m it is (2 + 2) = 4%, *i.e.* amended temperature rise limit is 38.5/48°C.

Selection of Tappings During Temperature Rise Test

The temperature rise test is performed at any tapping desired by the purchaser. If nothing is stated, the test is carried out as below:

(*a*) For tapping ranges less than or equal to 10 per cent on negative side, the test is performed on the lowest tap at appropriate current relating to this tapping.

(*b*) For tapping exceeding 10 per cent on negative side, the test is be performed at (–) 10 per cent tapping with appropriate current relating to this tapping.

Loading Method

Depending on the choice of the manufacturer, a two winding transformer may be loaded by:

(*a*) *Direct loading method:* One winding of the transformer is excited at rated voltage with the other winding connected to a suitable load such that rated currents flow in both the windings.

(*b*) *Back to back method:* Two transformers, one of which is the transformer under test, are connected in parallel and excited at the rated voltage of the transformer under test. By means of different voltage ratios or an injected voltage, rated current is made to flow in the transformer under test. No correction for average oil temperature need be applied to the winding temperature rise of oil immersed type transformers.

(*c*) *Short-circuit method:* Short-circuit method is commonly employed by most of the manufacturers.

To determine the temperature rise of oil under short-circuit method, power equal to the sum of the no-load and load loss at the reference temperature (75°C) is fed to the transformer. One of the windings is excited while the other is short-circuited at its terminals. The top oil temperature rise is recorded.

Measurement of Ambient Temperature

At least three thermometers should be placed at three different locations around the transformer at a level approximately half way up the cooling surface at a distance one to two metres away from the cooling radiator. The value of the ambient temperature is the average of the readings taken on these thermometers.

Duration of Test

The test shall be continued until it demonstrates that the top oil temperature rise does not vary more than 1°C per hour during four consecutive hourly readings.

Measurement of Top Oil Temperature

The temperature of top oil is measured by a thermometer placed in an oil filled pocket on the cover. If the tank is not completely filled with oil, the pocket should be long enough or placed in an appropriate position of the tank, to ensure true measurement of the top oil temperature. Alternatively, an opening should be provided on the tank cover through which the thermometer can be inserted.

Top Oil Temperature Rise

Top oil temperature rise is obtained by subtracting the average ambient temperature from the measured top oil temperature, when the transformer is supplied with power equal to the total losses. The input power should be maintained at a steady state.

Test at Reduced Load

Even if power equal to total losses, taken as sum of the measured load loss corrected to 75°C and measured no-load loss, cannot be fed, power not less than 80 per cent should definitely be supplied.

On such occasions, the following correction is applied to calculate the top oil temperature rise:

$$\text{Top oil temperature rise} = \text{Measured rise in temperature} \times \left[\frac{\text{Total loss}}{\text{Test loss}}\right]^{0.8}.$$

Temperature Rise of the Winding

After the top oil temperature rise becomes steady, as described under heading ‘duration of test’ , the input should be reduced to a value which results in the circulation of rated current at rated frequency, corresponding to the particular tapping. This current should be maintained for an hour.

The temperature of the winding is then determined by the resistance method. The drop in the top oil temperature during this one hour is taken into account while calculating the temperature rise of the winding.

Average Oil Temperature Rise

Average oil temperature rise is determined as the difference between the top oil temperature rise and half of the temperature drop in the cooling radiators.

For tank with tube radiators or PSR, the temperature drop is taken as the difference between the tank surface temperature at the top and bottom of cooling tube or fin elements.

For transformer having rated power upto 2500 kVA with natural circulation and radiator banks mounted on the side of the tank, the average oil temperature is approximately 0.8 times the top oil temperature rise.

Therefore, for transformer up to 2500 kVA,

Average oil temperature rise = 0.8 × Top oil temperature rise.

For transformers having rated power above 2500 kVA, the average oil temperature as represented in Fig. 18.9 may be calculated as below:

$$\text{Average oil temperature} = T - \frac{(T_1 + T_2)}{2}\,°\text{C}.$$

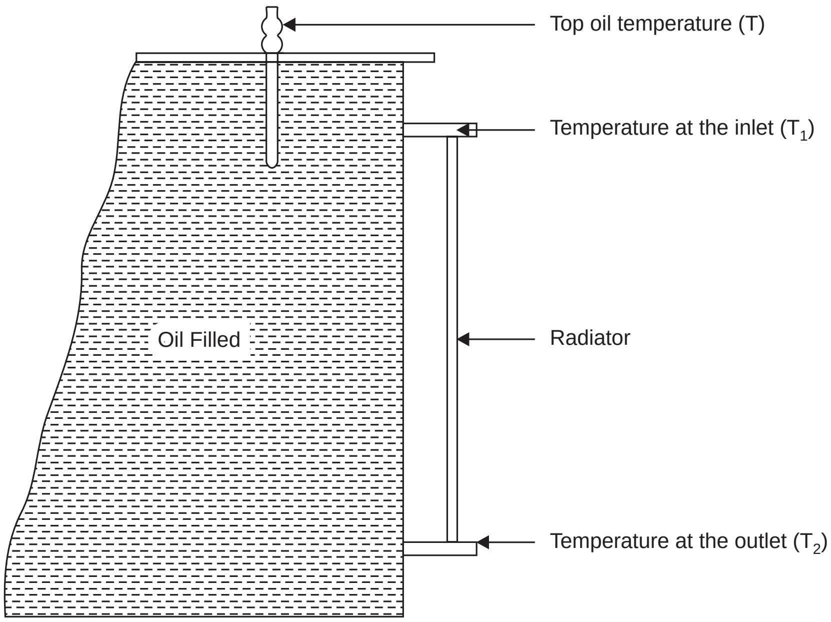


Fig. 18.9. Average oil temperature for transformer above 2500 kVA rating

Measurement of Winding Resistance

Winding resistance may be measured immediately after switching-off the supply, but allowing sufficient time for the inductive effect to disappear. At least 5 readings of resistance for each winding, are to be recorded. It is more accurate to determine the time for a fixed change of resistance, *i.e.* time required for the indicator of the pre-set resistance to pass through zero, is recorded.

Calculation of Resistance at the Instant of Switching-off the Supply (by Extrapolation Method)

A graph of resistance *vs*. time is plotted on a linear graph sheet as shown in Fig. 18.10. The graph is parabolic in nature. The changes in resistance (ΔR_1, ΔR_2, ΔR_3) are put down horizontally at the appropriate points in the ordinate which produces a straight line '*L*'. R_2 obtained by extending the *R vs. T* parabola to $T = 0$, is the resistance of the winding at the instant of switching-off the supply.

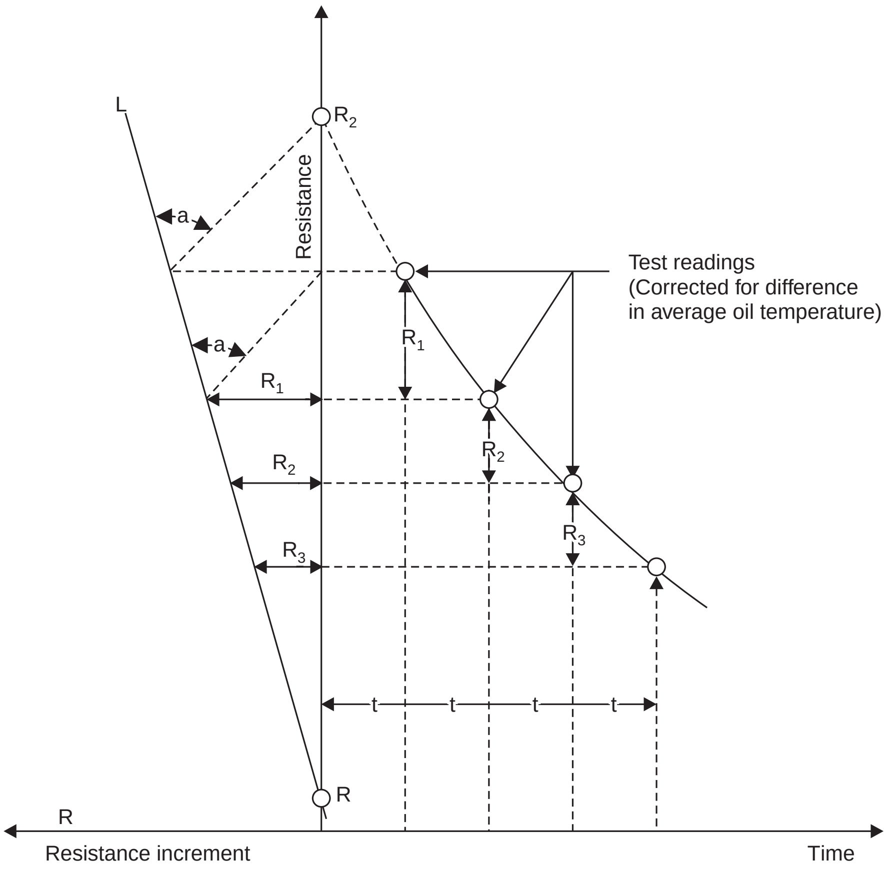


Fig. 18.10. Method for determining the winding resistance at the instant of switching-off the supply and the average oil temperature

Determination of Winding Resistance

The winding resistance is ascertained by using the resistance method.

The temperature of a winding (θ_2) at the end of the test is calculated from its measured resistance (R_2) at that temperature (T_1) and its measured cold resistance R_1 at some other temperature (θ_1) using the formula:

$$\theta_2 = \frac{R_2}{R_1}(235 + \theta_1) - 235 - T_1 \text{ (for copper winding)}$$

$$\theta_2 = \frac{R_2}{R_1}(225 + \theta_1) - 225 - T_1 \text{ (for aluminium winding)}$$

where, R_2 = Resistance of the winding at the instant of switching-off
T_1 = Average ambient temperature just before shut down
R_1 = Cold resistance of that particular winding of which hot resistance was recorded
θ_1 = Average ambient temperature at the time of measuring cold resistance

Correction Factor to Arrive at the Final Value of Temperature Rise of the Winding

The temperature rise of the winding above the average oil temperature rise determined in the second part of the test, added to the average oil temperature rise determined in the first part of the test gives the temperature rise of the winding above the cooling medium.

Example:

θ_2 = Temperature rise of the winding at the instant of switching-off
T_1 = Top oil temperature rise at the end of test with power equal to total loss
T_2 = Top oil temperature rise at the time of shut down
Therefore, the corrected temperature rise of the winding is equal to = $\theta_2 + (T_1 - T_2) \times 0.8$.

Limitation of Measuring Temperature Rise of LV Winding

If the windings have a resistance of 0.005 ohms or greater, the winding temperature rise shall be ascertained by means of the resistance method. Practical difficulties due to short time available for the measurement of hot resistance may affect the accuracy of such measurement by about one per cent.

For windings having resistance less than 0.005 ohm, the resistance method may be inaccurate.

18.12 TEST SL. NO. 10

Lightning Impulse Test (Type Test)

This test is required to be carried out on one unit of a particular design.

The procedure as well as other requirements are covered in Part-III of IS-2026.

In an impulse or surge test, it is required to apply to the transformer under test a high direct voltage, the value of which rises from zero to maximum in a very short time and dies down comparatively slowly, *i.e.* a voltage having a very steep wave front and a flat tail. This test determines the impulse strength of the various insulations of the transformer under test.

Fig. 18.11 shows a schematic diagram of a surge or impulse testing generator known as the 'Marx circuit.'

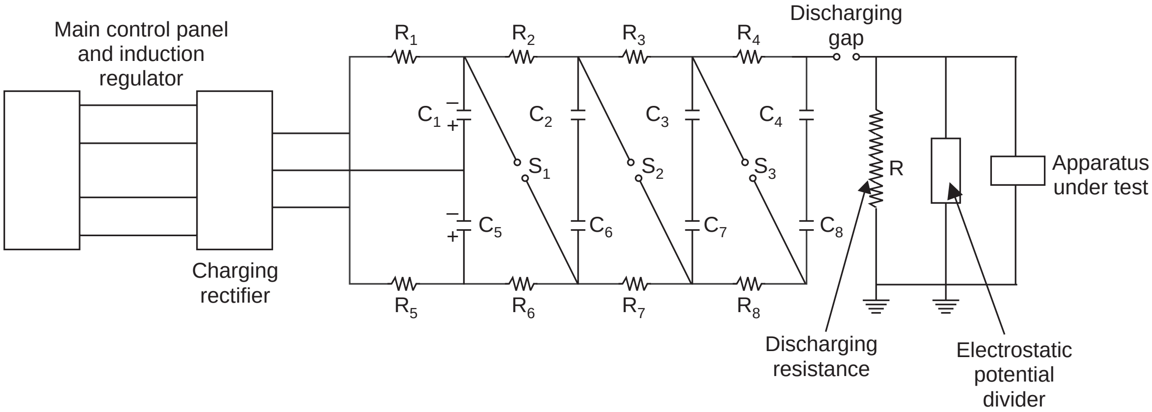


Fig. 18.11. Surge or impulse testing circuit

The 'Marx circuit' consists essentially of a group of condensers, spark gaps and resistors so connected that the condensers are charged from a relatively low voltage source in parallel and discharged in series to give high voltage across the test sample.

C_1, C_2, C_3, C_4, C_5, C_6, C_7 and C_8 are the condensers and R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, are high value resistances. S_1, S_2 and S_3 are trigger spark gaps. Although three gaps are shown in the figure, the number of gaps and condensers may be increased to give any desired multiple of charging voltage. The capacitors making up the surge generator are usually rated 100 kV each, and are charged in parallel through resistors. When the charge on each condenser reaches the predetermined breakdown voltage of the sparkgaps separating the condensers, the sparkgaps flash over connecting all condensers in series. A voltage impulse of either positive or negative polarity can be obtained by connecting the charging circuit to give the desired polarity. '*R*' is the discharge resistance in parallel with the transformer under test. Also a discharge gap is shown. These are for controlling the shape of the impulse wave.

In order to obtain a steep fronted wave, inductance should be avoided in the surge generator circuit. Also, the capacitance value should be at least 1000 pF. The time taken for the voltage to rise to its maximum value is generally less than 1 micro second and the time taken for it to die down to half its crest value is generally 20 to 50 micro seconds. The shape of the tail of the impulse voltage wave can be altered by varying the discharge resistance '*R*'. For high voltage measurement facilities, an electrostatic potential divider, which supplies a reduced voltage to the oscillograph, proportional to the test voltage, is used.

Test Polarity

For oil immersed transformer, the test voltage chosen shall normally be of negative polarity, as it reduces the risk of erratic flashover in the circuit.

Preparation of Equipment Before Test

(*a*) Oil level should be maintained upto the required level.
(*b*) The bushings should be cleaned to remove dirt, oil stain etc. with the help of dry cloth.
(*c*) In case hollow porcelain bushing of oil communicating type is used, the trapped air should be released before test.
(*d*) Trapped air inside the tank should be released through air release plug provided on the tank cover.

(*e*) Arcing horns, if provided, should be removed.
(*f*) In case the transformer is fitted with detachable radiators, it is not mandatory to fix the radiators during test.
(*g*) In case non-linear elements or surge arrestors are fitted on the transformer externally, they should be removed from the circuit, since the evaluation of the test may be difficult otherwise.

Wave Shape

The wave shape should be 1.2/50 micro seconds. Recommended tolerance are ± 30 per cent on wave front and ± 20 per cent on wave tail.

There are cases, where this standard impulse shape cannot be obtained, because of low winding inductance or high capacitance to earth. The resulting impulse shape is then often oscillatory. Wider tolerance may, in such cases, be permitted by agreement between the manufacturer and purchaser.

Test Sequence

The test sequence should consist of one impulse of a reduced voltage, between 50 to 75 per cent of full test voltage, and three subsequent impulses at full voltage. If during the application of voltage, an external flashover in the circuit or across a bushing gap occurs or if the oscillographic recording fails on any of the specific measuring channels, that test should be disregarded.

In the case of three phase transformer, it is customary to carry out impulse tests on all the three phases in succession.

Terminal Connection

Voltage is applied on each of the line terminals in succession, keeping other terminals earthed directly or through a low impedance such as a current limiting shunt (refer Fig. 18.12). In case the winding has a neutral, the same should be earthed directly or through a shunt. The tank should be earthed in all cases.

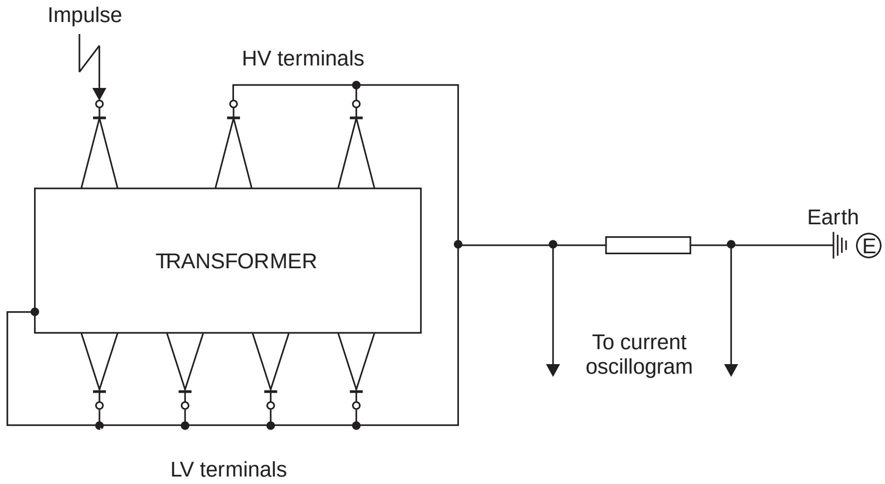


Fig. 18.12. Schematic diagram for terminal connection during impulse test

Records of Test

The oscillographic records of voltage obtained during calibration as well as the final test should satisfy the requirement of wave shape: 1.2 ± 30% micro seconds for wave front and 50 ± 20% micro second for wave tail.

The current wave flowing through earth from the tested winding should also be recorded in the oscillogram.

Successful Withstand Criteria

If the wave shape of the current and voltage recorded during full voltage application do not vary significantly from that recorded during application of reduced voltage, then the transformer may be declared as having withstood the test.

Lightning Impulse Test with Chopped Wave

While carrying out lightning impulse test with chopped wave, the use of a triggered type chopping gap with adjustable timing is recommended, although a plain rod gap is also allowed. The chopping circuit should be so arranged that the amount of over-swing to opposite polarity of the reduced impulse will be limited to not more than 30 per cent of the amplitude of the chopped impulse.

The recommended order of different impulse applications is:

(*a*) One reduced impulse
(*b*) One 100 per cent full wave
(*c*) One (or more) reduced chopped impulse
(*d*) Two 100 per cent chopped impulse
(*e*) Two 100 per cent full impulse

Other parameters like connections, record of tests, withstand criteria etc. are the same as that of the full impulse test described above.

18.13 TEST SL. NO. 11

Requirement and Procedure with Regard to Ability to Withstand Short-circuit Test (Special Test)

This test is to be carried out on one unit of a particular design.

The procedure as well as other requirements of short-circuit test are covered in part-I of IS-2026.

Requirements

The transformer should be designed and constructed to withstand without damage the thermal and dynamic effects of an external short-circuit under symmetrical fault condition.

Condition of Transformer Before Short-circuit Test

The test should be carried out preferably on a new transformer ready to be put into service. Mounting of accessories have no influence on the behaviour during short-circuit test.

Routine Test Prior to Short-circuit Test

Prior to short-circuit test, all routine tests including the percentage reactance and resistance should be measured at extreme negative, normal and extreme positive voltage tappings.

All reactance measurements should be done to a reproducibility of at least ± 0.2 per cent.

A report containing the results of the test should be made available.

Ambient Temperature During Test

At the beginning of the short-circuit test, the average temperature of the winding should be within 0 to 50°C.

Peak Value '*i*' of Two-winding Transformer

The amplitude '*i*' of the first peak of the asymmetrical test current is calculated as

$$i = I \times K\sqrt{2}$$

where, the symmetrical short-circuit current '*I*' is determined as

$$I = \frac{U}{(Z_t + Z_s)\sqrt{3}} \text{ kA}$$

Here, U = rated voltage of the asymmetrical current

Z_t = short circuit impendance of transformer referred to the winding under consideration

Z_s = short circuit impedance of the system.

And, factor $K\sqrt{2}$ depends upon X/R , where X is the sum of the reactance of the transformer and the system, *i.e.*, $(X_t + X_s)$ in ohm.

R is the sum of resistances of the transformer and the system, *i.e.* $(R_t + R_s)$ in ohm.

Unless otherwise specified, the factor $K\sqrt{2}$ is limited to $1.8.\sqrt{2} = 2.55$.

The following values of factor $K\sqrt{2}$ are used for different values of X/R.

Table 18.5

X/R	1	1.5	2	3	4	5	6	8	10	≥ 14
$K\sqrt{2}$	1.51	1.64	1.76	1.95	2.09	2.19	2.27	2.38	2.46	2.55

Value and Duration of Short-circuit Current for Two-winding Transformer

If the duration of test current is sufficiently long , the asymmetrical current having a first peak of amplitude (i) will change into symmetrical current (I).

The peak value of current obtained in testing should not deviate more than 5 per cent and the symmetrical current by more than 10 per cent from the specified value.

The duration of each test is 0.5 second with a tolerance of ± 10 per cent.

Short-circuit Testing Procedure for Transformer with Two Windings

In order to obtain a test current, the no-load voltage of the source may be higher than the rated voltage supplied to the winding. Short-circuiting of the winding may either follow or precede the application of the voltage to the other winding of the transformer. In the first case, the voltage should not exceed 1.15 times the rated voltage of the winding.

If the pre-set short-circuit is used for transformer with concentric windings, the supply should be connected to the winding further from the core. The winding nearer to the core should be short-circuited in order to avoid saturation of the magnetic core, which could result in an excessive flow of magnetising current which is superimposed on the short-circuit current during the first few cycles.

To obtain the initial peak of the current in the phase winding under test, the time of switching-on should be adjusted by a synchronous switch.

In order to check the value of the currents '*i*' and '*I*' , these currents should always be recorded by an oscillograph. To obtain maximum asymmetry of the current in one of the phase windings, the switching-on should occur at the time when the voltage of the winding passes through zero.

For star connected windings, the maximum asymmetry is obtained by switching-on when the phase voltage passes through zero. The factor '*K*' of the peak value '*i*' can be determind from the oscillograms of the line currents. For 3 phase tests on delta connected windings, this condition is obtained by switching-on when the voltage passes through zero.

One of the methods of determining the factor '*K*' is by switching-on during preliminary adjustment test at a maximum of the line-to-line voltage. In this case, the factor '*K*' is found from the oscillograms of the line currents.

Preliminary Checks

Preliminary adjustment tests shall be carried out at less than 70 per cent of the specified current to check the proper functioning of the test set-up with regard to the time of switching-on, the current setting, the damping and the duration.

No. of Tests and Duration

For 3 phase transformer, the total number of tests are nine, *i.e.* three tests on each limb, the duration of each test being 0.5 second with a tolerance of ± 10 per cent.

Unless otherwise specified, the tests on each limb of a transformer with tappings are made in different positions of the tap changer, that is:

(*a*) Three tests in the position corresponding to the highest voltage ratio in one of the outer limbs
(*b*) Three tests on the principal tapping on the middle limb
(*c*) Three tests in the position corresponding to the lowest voltage ratio on the third limb.

Detection of Fault

Before short-circuit test, measurements and tests are carried out as stated before. These measurements and tests serve as a reference for detection of faults.

During each test, including preliminary tests, oscillographic recordings are made of the following:

(*a*) The applied voltage (between line terminals)
(*b*) The currents

After each test, the oscillogram records made during the test are inspected. It is necessary to measure the short-circuit reactance after each test.

Any difference between the results of the measurements made before and after the tests may be a criteria for determining possible defects. It is of particular importance to observe during successive tests possible changes in the reactance measured after each test which may be progressive or tending to reach a stable value.

After completion of the tests, the transformer and the gas relay, if provided, should be inspected. The results of the short-circuit reactance measurements and the oscillogram recordings made during the different stages of the tests are examined for any indication of possible anomaly especially, any indication of change in short-circuit reactance.

For transformers under the category upto 3150 kVA, all routine tests are to be repeated. The dielectric routine tests should be at 75 per cent of the original value unless a higher value is agreed upon by the manufacturer and the purchaser.

The transformer is then untanked for inspection of the core and the winding, in order to locate possible defects, such as change in lead position, which, in spite of successful routine tests, might endanger the safe operation of the transformer.

The transformer is deemed to have passed the short-circuit test, if:

(*a*) The routine tests have been successfully repeated.

(*b*) The results of the short-circuit tests, measurements during short-circuit tests and out of tank inspections do not reveal any defects (displacement, deformation of windings, connections or supporting structures or traces of discharges).

(*c*) The short-circuit reactances measured after tests do not differ from the measured values in the original state by more than 2 per cent for transformer with circular concentric coils.

If the above three conditions for passing the short-circuit tests are met, the transformer is restored to its original state and any further routine tests necessary to prove fitness for service are repeated before despatch. If any of the three conditions are not met, it may be necessary to dismantle the unit as it is required to establish the cause of the defect.

For transformers beyond 3150 kVA, by agreement between the manufacturer and the purchaser, a report of the routine tests, normally carried out, may be postponed until further inspection. The result of routine di-electric tests should be 75 per cent of the original test value unless a higher value is agreed upon by the manufacturer and the purchaser.

If the transformer was initially subjected to di-electric tests, the voltage to be applied for induces over voltage and power frequency tests shall be subjected to the agreement between the manufacturer and the purchaser.

18.14 TEST SL. NO. 12

Unbalance Current on LV Neutral (Special Test)

This is under the category of special test and may be carried out on 10 per cent of the offered quantity.

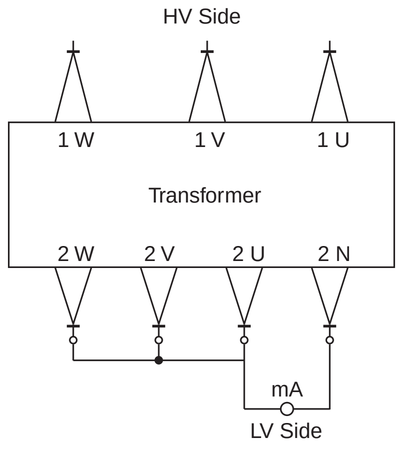


Fig. 18.13. Schematic diagram for un-balance current measurement on LV side

Connections

Secondary terminals are shorted together with a thick copper flat having cross sectional area sufficient for carrying the rated secondary current of the transformer. A milliammeter of suitable scale is placed between the shorted terminals and neutral. The schematic diagram is shown in Fig. 18.13.

Procedure

The primary side of the windings are energised with a three phase balanced voltage, the magnitude of which is such that it produces rated current in the primary winding.

Measurements

The unbalance current will appear on the milliammeter and it should be recorded.

Limit of Unbalance Current

For uniform windings with a balanced three phase input, the un-balance current is limited to a few milliamperes. However as a general practice, the un-balance current should be limited to 2 per cent of full load current.

18.15 TEST SL. NO. 13

Zero Sequence Impedance (Special Test)

This is under the catagory of special tests and may be carried out on 10 per cent of the offered quantity.

The procedure as well as the other requirements of measurement of zero sequence impedance are covered in Part-I of IS-2026.

Zero sequence impedance is measured at rated frequency between the line terminal of a star connected or zig-zag connected winding connected together and its neutral terminal. It is expressed in ohm per phase and is represented by $3V/I$, where V is the voltage and I is the test current.

The phase test current $I/3$ should be stated.

It should be ensured that the current in the neutral connection is compatible with the current carrying capability.

In the case of transformers with additional delta connected winding, the value of the test current should be such that the current in the delta connected winding is not excessive, taking into account the duration of application.

If a balancing ampere-turn is missing in the zero sequence system, *e.g.* in a star/star connected transformer without delta winding, the applied voltage should not exceed the line to neutral voltage at normal operation.

The current in the neutral and the duration of application, however, may be limited to avoid excessive temperature on the metallic parts.

In the case of a transformers with more than one star connected winding and neutral terminals, the zero sequence impedance is dependent upon the connection and the tests to be made are subject to un agreement between the manufacturer and the purchaser.

Measurements on windings with tappings should be made on the main tappings. Measurement on other tappings may be made if agreed between the manufacuturer and the purchaser.

Auto transformers with neutral terminal intended to be permanently connected to earth should be treated as normal transformers with two star-connected windings. The series winding and the common winding together form one measuring circuit. The measurements are carried out with the current not exceeding the difference between the rated currents on the low voltage side and the high voltage side.

In conditions where the balancing-ampere turns are missing, the relation between the voltage and current is generally not linear.

The zero sequence impedance depends upon the physical disposition of the windings and the magnetic parts and therefore measurements on different windings may not agree.

Connection

The low-voltage line terminals are shorted together. A single phase AC supply through a regulator is fed between shorted LV terminals and neutral. A voltmeter and an ammeter are placed in the circuit as shown in Fig. 18.14.

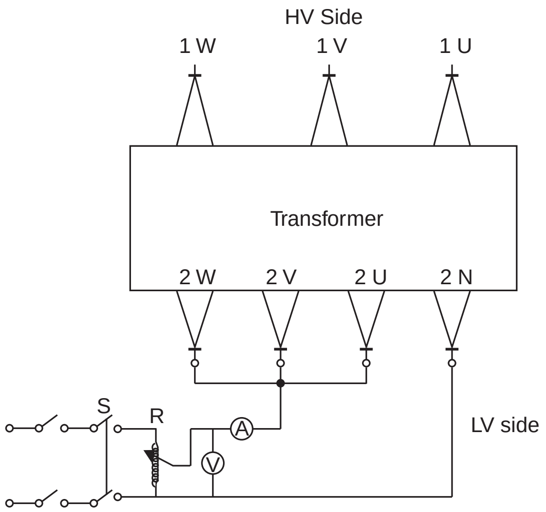


Fig. 18.14. Schematic diagram for measurement of zero sequence impedance

In case, the current flowing through the circuit is high and beyond direct measurement, a suitable current transformer (CT) may be placed.

As described above, the zero sequence impedance is represented as 3 V/I and is expressed in ohms per phase.

A typical case of measurement done on a 5 MVA, 33/11 kV transformer is given below:

(*a*) Voltage applied = 32 V

(*b*) Current measured against a CT ratio 60/5 (ratio 12) = 4.8 A

Therefore, zero sequence impedance = $\dfrac{3 \times 32}{4.8 \times 12}$ = 1.6 ohms per phase.

18.16 TEST SL. NO. 14

Magnetic Balance Test (Special Test)

This is under the category of special tests and may be carried out on 10 per cent of the offered quantity. In the case of power transformers, it is recommended to carry out this test on 100 per cent of the transformers.

Though this test is not covered under ISS, it is recommended to carry out this test, especially on power transformers, since it gives a clear indication on how the magnetic circuits are built.

Connection

Single phase voltage of pre-determind value is fed to one of the two primary terminals and voltage across each of the secondaries with respect to neutral are measured and recorded.

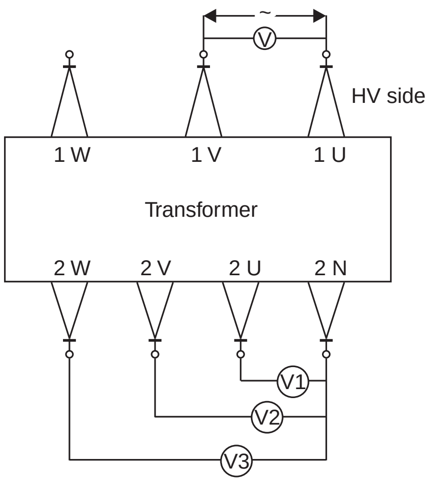


Fig. 18.15. Schematic diagram for magnetic balancing test

Test procedure and measurements (sequence of test)

(*a*) Single phase AC voltage of pre-determined value, preferably 400 to 500 V is applied between the primary terminals (1 U–l V) and voltage across all the secondaries with respect to neutral are recorded (refer Fig. 18.15).

(*b*) Single phase AC voltage of same magnitude as above is again applied between the primary terminals (1 V–1 W) and voltage across all the secondaries with respect to neutral are recorded.

(*c*) The test is repeated with single phase AC voltage of same magnitude applied between primary terminals (1 W–1 U) and voltage across all the secondaries with respect to neutral are recorded.

A typical case of measurement done on 5 MVA, 33.11 kV transformer is given in Table 18.6

Table 18.6

Test sequence	*Voltage applied between primary terminals*	*Voltage recorded across secondary terminals*
(*a*)	(1 U – l V) = 440 V	(2 U – 2 N) = 84 V (2 V – 2 N) = 56 V (2 W – 2 N) = 28 V
(*b*)	(1 V – 1 W) = 440 V	(2 U – 2 N) = 42 V (2 V – 2 N) = 84 V (2 W – 2 N) = 42 V
(*c*)	(l W – 1 U) = 440 V	(2 U – 2 N) = 32 V (2 V – 2 N) = 52 V (2 W – 2 N) = 8 V

Conclusion

(*i*) Sequence (*a*) (2 U – 2 N) = (2 V – 2 N) + (2 W – 2 N) ...(*i*)

84 V = 56 V + 28 V

and (2 V – 2 N) > (2 W – 2 N)

56 V > 28 V

(*ii*) Sequence (*b*) (2 V – 2 N) = (2 U – 2 N) + (2 W – 2 N) ... (*ii*)

84 V = 42 V + 42 V

and (2 U – 2 N) = (2 W – 2 N)

42 V = 42 V

(*iii*) Sequence (*c*) (2 W – 2 N) = (2 U – 2 N) + (2 V – 2 N) ...(*iii*)

84 V = 32 V + 52 V

and (2 U – 2 N) < (2 V – 2 N)

32 V < 52 V

However, the relations (*i*), (*ii*) and (*iii*) are subject to a tolerance of ± 5 per cent.

18.17 TEST SL. NO. 15

Measurement of Noise Level (Special Test)

Cause of noise: When a transformer is energised with load, noise is generated due to vibration in the magnetic circuit. The noise can be minimised by rigidly binding and clamping the core laminations.

But the noise cannot be made zero. Sometimes, because of over excitation or higher operating flux density, the transformer generates more noise. To know the operating condition as well as to restrict over-excitation, the measurement of noise level is essential, especially for power transformer, in which the volume of magnetic material is huge. Noise level is expressed in ‘dB’ (decibel).

Procedure: The measurement is generally done when the surrounding of the transformer is reasonably calm and quiet. Sharp metallic sound, especially hammering on metal surface, operation of

EOT crane etc. should be avoided during measurement of noise level. However, continuous and smooth sounds like that due to the operation of motor, fan blower etc. may be allowed.

Measurement: The measurement is done by a battery operated meter commonly known as 'noise level meter'. The noise level of the surrounding without energising the transformer is recorded. This will be taken as reference. Then the transformer is energised at its full voltage without load. The noise level of the energised transformer is again recorded at a distance approximately one metre away from the transformer.

The difference between the noise level measured with the transformer energised and the reference noise level is the noise level of the transformer under test.

In the case of medium sized distribution transformers upto 1000 kVA rating with good quality of core steel and designed at moderate flux density, the noise level is appreciably low. But, in the case of power transformer, since the volume of core steel is huge, it generates appreciable noise. The noise level of medium sized power transformers should be restricted to an acceptable value of approximately 50 to 55 dB.

In case, the noise level of a transformer is high, it is necessary to detect the cause so that suitable remedial measures could be employed at the manufacturing stage.

18.18 CONCLUSION

Any of the test procedures discussed above, may be substituted with the relevent paragraphs of the recommendation of ISS.

Testing engineers should be well conversant with the test procedures. Care should be taken to avoid any wrong test procedures so that no failure occurs at the final testing of the transformer.

Moreover, failure during the final test may be reduced considerably, if inspection and stage testing are done during the process of manufacturing the transformer. It is more cost effective to rectify a fault at the manufacturing stage instead of undertaking repair on finished transformer.

The test records should be made available, if necessary, to the design department. These feed backs help the designer to make more realistic assumptions in future designs.

Accuracy class and the calibration of testing instruments are vital consideration in transformer testing. For all commercial use, 0.5 class instruments are found acceptable by all power utilities. Calibration may be done at least once in a year in a Govt. approved test laboratory. Instruments with green stickers are always preferred. However, yellow sticker instruments, may also be used except in cases where the accuracies needed are beyond the class of the instrument. Instruments like current transformers (CTS), potential transformers (PTS) etc. may be calibrated once in 5 years. Further, in-house calibration of other meters with respect to green stricker instruments may be accepted in case of emergency. Calibrated thermometers should be used for measuring temperature. Micrometer, scale, vernier etc. should be calibrated in-house once in a year. Further, condition monitoring, as a part of the quality assurance should be done at frequent interval to avoid damage of the meters and instruments.

Section III

CHAPTER 19

Control of Non-conforming Products, their Review and Disposal

FOOD FOR THOUGHT

Excellence is a journey, not a destination. Maintaining the same standard is no guarantee against loosing the competitive edge. However, improving quality from product to product, will surely keep a company ahead of its competitors. Excellence can be achieved through quality only. Quality is indeed the backbone of excellence. Today quality is the number one imperative of top management virtually in every industry. Quality is today's most powerful corporate leverage point for achieving both customer satisfaction and lower cost.

Sir John Egan, CEO of Jaguar company, said "Quality is making money out of satisfying customers. Quality comes first."

On the other hand, John Akers, CEO of IBM corporation said, "Quality is everyone's job. Quality is essential merely to stay in the race. Everyone has to pitch in to obtain the desired level of quality. Everyone has to work hard to reach the level. Remember that achievement is 98% perspiration and 2% inspiration."

Inspection has been the traditional quality approach, but today the new quality approach is prevention and training. It is better to spend resources for prevention rather than detection. Instead of waiting for a disaster to occur, prevent it by conforming to requirements and by emphasizing perpetual quality improvement policies.

Give the customers what they want. The customer is the supreme and ultimate boss. Timeliness, accuracy and customer service responsiveness are important to the customer.

The most important quality for success in business is quality itself. Quality and customer are inseparable. Both should get priority. One cannot live without the other.

Quality is not only free, but it is one of the most profitable products. Quality is central to the achievement of the desired goals for an organization. Improving quality is the key to improve performance.

19.1 INTRODUCTION

The control of non-conforming products is one of the requirements of ISO-9000 quality procedure. Any item—raw material or inprocess component or finished product—may come under this category. As was discussed earlier, the acceptable quality norms of each and every item should be clearly defined in advance. It is one of the responsibilities of the design department to prepare acceptable quality norms for all items on the basis of the recommendation of BIS, customer's specification and experience. Clear guidelines on quality norms should be available to all the people who are responsible for the maintenance of quality.

In the case of bought out raw materials and components, the purchase department should incorporate all quality requirements in the purchase order so that the suppliers can make use of quality checks at their works before delivery. Even if it goes without the notice of the supplier, the users, at the time of incoming material inspection, may come across departures from the applicable specifications.

In the case of inprocess components and finished products, the quality requirement should be well defined and should be made available to all the personnel in the shop floor who are responsible for maintaining the quality of the products. During verification, all items in which quality parameters exceed acceptable tolerance limits and are detrimental to the ultimate functioning of the transformer, come under the category of non-conforming products.

19.2 PURPOSE

The purpose is to control the inadvertent use of the non-conforming products. Non-conforming raw materials should not be issued for production. Non-conforming inprocess components should not be processed further. Non-conforming finished goods should not be despatched.

19.3 SCOPE

The scope covers the identification of non-conforming products during incoming material check, inprocess component inspection and final testing on finished products.

19.4 RESPONSIBILITY

Responsibility to control such non-conforming products should be well defined. Since the activities are many, the responsibility to control each activity should categorically be identified. While alloting such responsibilities it must be ensured that no single responsibility is allotted to two different people. However one person may handle many responsibilities.

19.5 AUTHORITY

The procedure for controlling non-conforming products should be strictly followed. All decisions should be in accordance with laid down procedures. Only a very senior person in the organization should be given the authority to take any other decision after reviewing the nature of non-conformance. In case the non-conforming products do not have any significant effect on the ultimate performance of the transformer, he may issue concession for using such products. But proper records (such as transformer serial number, name of the vendor, workmen involved etc.) should be maintained for the purpose of traceability.

19.6 NON-CONFORMING RAW MATERIAL

Non-conformance in raw materials is observed during in-house inspection and they are kept in a separate identified area in the stores. In the case of non-conformance on some specific materials, like MS sheet, angle, channel, CRGO steel, tank etc. which are generally stored in open yards/workshop, it is recommended that they are identified with coloured tags. These identifications are essential to avoid use of such non-conforming materials inadvertently in production. Records of all such non-conforming materials should be made in a register. Nature of non-conformity, its analysis, corrective action proposed and final disposition should be made for each non-conforming material.

The vendors should be informed in writing, indicating the details of non-conformance to avoid recurrance in future supplies.

A sample recording of non-conformance on raw materiaH is illustrated below.

19.7 RECORDING OF NON-CONFORMANCE (INCOMING MATERIAL)

Non-conformance on Incoming Material

SI. no.: 155 Date : 14.5.2000

Nature of Non-conformance

During incoming material inspection, the diameter of the base winding wire of reel no. 62 was recorded as 1.3 mm against a requirement of 1.32 ± 0.013 mm.

Vendor’s name : Conductor and cable, Meerut

Invoice number : 3226 dated 11.5.2000

Analysis

The diameter of the base wire was found below the acceptable limit.

Corrective Action Proposed

Reel no. 62 containing 6.7 kg of under sized wire was rejected and stored in the quarantine area.

Disposition

Decision of rejection was conveyed to the supplier vide letter no. 133 dated 13.5.2000. Rejected material was returned through return slip no.: 23 dated 13.5.2000. The supplier was told to improve upon the quality in future supplies.

Signature Signature
(Q.A. Engineer) (Authority)

19.8 NON-CONFORMING COMPONENTS

Inprocess components, such as LV and HV coils, core and coil assembH!, tank and boxed-up transformer etc. having quality parameters exceeding acceptable limits come under this category. Precautions are taken to ensure that these non-conforming components are not taken up for further processing. For easy identification, coloured tags are put on such non-conforming components in a position which is easily visible. The records of such non-conformances are kept in a separate register. Nature of non-conformance, its analysis, corrective action proposed and final disposition should be made for each non-conformance.

A sample of such recording is illustrated below.

Non-conformance on Inprocess Component

Sl. no.: 154 Date : 12.5.2000

Nature of Non-conformance

During inprocess checking it was observed that the ratio error for transformer bearing Job no. 562 (Sl. no. 11952) was beyond permissible limit.

Rating	–	100 kVA
Ratio	–	11/0.433 kV
Customer	–	PSEB

Analysis

The cause of non-conformance was analysed and it was revealed that the ratio error in Phase-B was (+) 0.-`% as against the permissible tolerance of ± 0.5% and hence the job was not released for further processing. The number of turns on top HV coil for Phase-B was found to be 21 turns more than the design value. It was further identified that the coil was made by Sitaram Yadav (32).

Corrective Action Taken

The defective coil was replaced by a new coil. The ratio error was further checked for all the three phases and was recorded as follows:

AB/an = (+) 0.06% (within limit)

BC/bn = (+) 0.11% (-do-)

CA/cn = (+) 0.02% (-do-)

Disposition

(*a*) The job was released for further processing.
(*b*) On verification it was found that the turn counter of Sitaram Yadav's machine had developed some fault. The turn counter was replaced by a new counter.
(*c*) Sitaram Yadav was told to be more vigilant while making coil.

Signature Signature
(Q.A. Engineer) (Authority)

Similar non-conformances may occur in other departments, which are also to be analysed in the same manner. During analysis, the cause of non-conformance should be kept in mind and it should necessarily be eliminated from the system by proper corrective action.

In case the non-conformance is because of material, the concerned vendor should be informed in writing to improve upon the quality in future supplies.

In case the non-conformance has occurred because of malfunctioning of the machine, the same should be put under preventive maintenance.

The third probability is human error. In such cases, the skills of the workmen may be improved by job related training.

Time taken to analyse the cause of non-conformance depends on the size of the transformer and the nature of non-conformance. Final disposition can be done only after the analysis. During this period, a coloured tag which is easily visible should be fixed on the component to prevent its inadvertent use.

19.9 NON-CONFORMANCE ON FINISHED PRODUCT

With respect to the requirements of lSS and the customer specification, if the performance parameters (like losses, ratio, resistance etc.) are found exceeding acceptable limit, the tranformer should be treated as a non-conforming product. The procedure of analysing such non-conforming products upto disposition are almost same as stated above.

A sample of recording of such non-conformance is illustrated below.

Non-conforming Finished Product

Sl. no. : 156 Date: 18.5.2000

Nature of Non-conformance

During separate source power frequency test on primary side, the transformer failed to withstand the full test voltage beyond 32 seconds. The high voltage circuit was tripped-off. A cracking metallic sound inside the tank on the HV bushing side was noted.

Rating	:	100 kVA
Ratio	:	11/0.433 kV
Customer	:	PSEB
Job no.	:	596 (Sl. no. 11986)

Analysis

The top cover was removed for physical verification. It was noticed that the HV lead of Phase-B was close to the tank wall, causing flashover during test. It was a human mistake, occured due to negligence of the box-up operator (Ram Prasad, 69).

Corrective Action Taken

The HV lead was cleaned and reinsulated. The bushing terminations were redone with required clearance from the earth. The top cover was re-flxed and oil was filled.

Disposition

The transformer was tested again for separate source power frequency test at full voltage and it withstood for 60 seconds. The transformer was declared to have passed the test. Ram Prasad (69) and other box-up operators were told to remain watchful about electrical clearances in their future operations. A check-list with rating-wise internal electrical clearances was displayed in the box-up work station for easy reference.

Signature (Q.A. Engineer) Signature (Authority)

19.10 CONCLUSION

Effect of Control of Non-conformance Over Product Cost and Quality

So far we have discussed the definition of various categories of non-conformances, their analysis, corrective action and disposition. Now we shall discuss how the control of non-conforming products have a direct effect on the product cost and quality.

Product cost and quality are directly linked with each other. With continuous monitoring of non-conforming products, the quality of the product is bound to improve. Regular rejection of materials will make the vendors to improve upon the quality. Similarly job related training will improve the average skills of the workmen. With such regular checking, the occurrence of non-conforming products will come down considerably which will effect in reduction of wastage. Moreover rework at the inprocess stage and rejection at the final stage will also come down. Less wastage and rejection will ultimately effect in reduction of product cost. Furthermore quality improvement in the process of manufacturing will lead to un-interrupted production, effecting high productivity, less production cost and timely delivery.

After a fixed interval (say at the end of a month), we should review all the non-conformances occurred during this period and should prepare a summary sheet. Firstly, the non-conformances are categorised in terms of material, human mistake, and machine fault. Secondly, the vendor ratings are done on the basis of their performances and rejections of materials. Vendors with poor performance may be debarred from further business.

Thirdly, it is recommended to find out the workmen who have the habit of committing non-conformances of similar nature. Upon identification, they should be put to rigorous job related training. This will improve average skills of the workmen. Cause of non-conformance due to machine can be arrested by way of preventive maintenance on regular basis.

These summary sheets of various non-conformances over a considerable period of time (say at the end of the year) may be utilised for application of statistical technique, which we have discussed later in Chapter-26, Section-III.

Section III

CHAPTER 20

Job Progress Card

FOOD FOR THOUGHT

What is quality?

In today's highly competitive economy, businesses must face the challenge of continually improving the quality of goods and services. They know what quality generates: pride, the satisfaction that comes from a job well done, productivity, time saved when things are done right the first time, and profit, which results when customers equate a company with quality.

But what defines quality?

Quality is prevention—Constructing solution to problems before they occur, and designing excellence into product or service.

Quality is customer satisfaction—The customer is the ultimate judge of how well products and services measure up.

Quality is productivity—Help the employees who receive training, tools, and instructions they need to execute their jobs.

Quality is flexibility—The willingness to change to meet the demand.

Quality is efficiency—Doing things quickly and correctly.

20.1 INTRODUCTION

To keep a check on the product identification and traceability, maintenance of job progress card is essential. There are various activities done in different departments and various people involved in the manufacture of a transformer. The activities are:

(*a*) Making of LV and HV coils
(*b*) Core assembly
(*c*) Coil assembly
(*d*) Fabrication of tank body and core frame
(*e*) Box up or tanking
(*f*) Final testing
(*g*) Painting and finishing

Any mistake by an individual of a particular department may cause failure of the transformer. Since distribution transformers are produced on a mass scale, it is very essential to identify the names of the operators who participated in the manufacturing processes so that appropriate corrective action can be taken.

The second purpose of the job card is for easy identification during inprocess manufacturing. There may be a number of occasions when transformers having the same rating but with different specifications for two different customers are being manufactured at the same place and at the same time. For example, the active part of 100 kVA transformer as per UPPCL specification, looks almost same as that of PSEB. But the technical requirements of these two transformers are quite different. The no-load loss of UPPCL 100 kVA transformer is 260 W as against 220 W of PSEB. Once these two transformers are taken up for production in one shift, there is every possibility of UPPCL 100 kVA assembly going into PSEB tank during box-up operation. To restrict such occurrences, job card is essential.

20.2 SAMPLE JOB PROGRESS CARD

The job progress card is nothing but a brief history of the transformer under production. It should have the identification of the customer, rating/kV, job number and other related information. For traceability, the name of the operators who have contributed to the manufacture of the transformer should also appear in the job card. Scheduled delivery may also be marked on one corner of the card. Sample of a job card duly filled is shown in Table 20.1.

Table 20.1 Job progress card (Filled as reference)

<table>
<tr><td colspan="2">Customer : PSEB</td><td colspan="3">kYA/kV : 100 kVA/11 kV</td></tr>
<tr><td colspan="2">Work Order No. : 562</td><td colspan="3">Date of issue : 13.5.2000</td></tr>
<tr><td colspan="2">Job No. : 37</td><td colspan="3">Scheduled Delivery Date : 20.6.2000</td></tr>
<tr><td>Department</td><td>Operator</td><td>Date</td><td>Checked by</td><td>Remarks</td></tr>
<tr><td>HV Winding</td><td>Sitaram Yadav (32)</td><td>10.5.2K</td><td></td><td>Passed for next operation</td></tr>
<tr><td>LV Winding</td><td>Lalan Singh (79)</td><td>10.5.2K</td><td></td><td>-do-</td></tr>
<tr><td>Core Assembly</td><td>Vijay Pande (11)
Ajit Sharma (23)</td><td>13.5.2K</td><td></td><td>-do-</td></tr>
<tr><td>Coil Assembly</td><td>Kalyan Singh (103)
Prabir Das (169)</td><td>17.5.2K</td><td></td><td>-do-</td></tr>
<tr><td>Pox-up</td><td>Shyam Bahadur (82)</td><td>22.5.2K</td><td></td><td>-do-</td></tr>
<tr><td>Testing</td><td>A.K. Srivastav (Engg.)</td><td>24.5.2K</td><td></td><td>Tested OK</td></tr>
<tr><td colspan="5">Transformer Sl. No. : 1002K 1062
Despatched on : 16.6.2000</td></tr>
</table>

The following points may be noted while maintaining a job progress card.

Note:

(*a*) The preparation of HV and LV coils may be taken up prior to the issue of the job card.

(*b*) Number inside the bracket against the name of the operator is the employee's code number.

(*c*) The job card should be signed and maintained by the Q.A. Engineer.

Right from the start of the manufacturing activity of assembling the core, the job card should be fixed in a convenient position where it is easily visible. The operators should be trained to read the remark column before the job is taken up for further processing.

20.3 MATERIAL OF JOB CARD

Job card with ordinary paper or thick card board does not serve the purpose. Proper material should be used for the job card to prevent adverse effect when the assembly goes into oven for demoisturisation or when it is taken up for oil filling or painting. Further it is to be ensured that a polythene jacket resistant to heat and oil is used to cover the Job card. It is advisible to use proper material for job card as it suits the individual manufacturer.

20.4 RETENTION PERIOD

So long as the transformer remains in the manufacturer's premises, job card serves the purpose of identification only. But after the despatch of the transformer, the job card becomes **'history card'**. This card should be retained in safe custody till the guarantee period of the transtormer is over. In case a transformer fails during the guarantee period and is brought back to the workshop for repair, the job card gives the history of the manufacturing activities as well as the team of operators associated with it.

20.5 UTILITY OF JOB PROGRESS CARD

The job progress card is useful for identification and traceability. As has been discussed above, the job card becomes history card when a transformer returns back to the manufacturer for repair. On such occasions, the cause of failure should be critically analysed to know the actual reason of failure. In case the cause of failure is due to materials which could not sustain the service condition, the matter may be taken up with the design and purchase department for further review.

In case the failure is because of human negligence (for instance less clearance from HV delta leading to the inside of tank or the core bolt touching the core or the failure between the consecutive tap leads etc.), the matter may be taken up with the concerned operators who had actually made the transformer. Manufacturers can develop a data-bank out of such customer feedbacks and can make use for the development of skills of the concerned operators. Designer can also take necessary feedback from such occasions to correct his design output, if it is found not suitable with the service condition for which it was designed.

The utilities of a job progress card, may be summarised as below:

(*a*) Identification of power, voltage, customer etc.

(*b*) Production details of the transformer (*c*) Identification of operators responsible for its manufacturer

(*d*) Guaranteed delivery Vs actual delivery

(*e*) Acts as a job history card when customer gives some feedback about the performance of the transformer in service

(*f*) Provides traceability

(*g*) Helps the designer with feedback on the performance

(*h*) Training needs to the operators etc.

In lSO-9000 quality system, the job card is considered to be a quality record and must be retained in safe custody even beyond the guarantee period if necessary.

20.6 RE-WORK TAG

As was discussed earlier, non-conforming products should not be processed further untill proper corrective action is taken. Till such time, the job will remain in the manufacturing bay. To avoid inadvertent use of such non-conforming products, it is recommended to fix a coloured re-work tag (preferably red) close to the job card. Workmen should be trained not to undertake any further processing till the corrective action is taken. However such re-work tags should be removed as soon as rectification work is over. The importance of re-work may be understood from the following case study.

Case Study—Utility of Job Progress Card

The verification of physical parameters of core-coil assembly of one transformer out of an offered lot is a routine activity during customer's inspection at the manufacturer premises. To effect such verification during one of the inspections, the core-coil unit of one transformer was taken out from the tank from an offered lot of 130 numbers 63 kVA transformers. The assembly was stripped-off completely and the major physical parameters including the weight of core, winding, number of LV turns, flux density, conductor size etc. were checked and recorded.

As a part of the verification procedures, the tank cover along with all other external fittings including terminal bushings etc. were re-fixed, but without core-coil unit and oil. The dummy tank was further subjected to air pressure test at (+) 0.8 kg/cm^2 and vacuum test at (–) 0.7 kg/cm^2. Since there was no appreciable deformation in the tank body, the entire lot of 130 transformers were cleared for despatch by the inspecting officer.

So far nothing was wrong and things were moving as per the quality procedure. But the problem had started from this point onward. The job progress card was as usually fixed on the tank and there was no indication that the tank did not have the core-coil unit inside, nor the quality assurance engineer had bothered to affix a re-work tag on the job. The dummy tank was lying in the box up department and the person incharge for oil filling during his allotted duty in the evening shift had wrongly filled oil in anticipation that it could be a complete transformer.

Since the tank was fixed with a job progress card with 'Tested-ok' remark and a name plate but without a re-work tag, it was a clear indication that the unit was fit for despatch. The despatch department had wrongly despatched the transformer at night taking it as a complete transformer.

The fact came to the knowledge only when the transformer was taken for un-loading at the destination stores manually, as its weight was less compared to other transformers. It was a big humiliation to the manufacturer, which could have been averted simply by fixing a re-work tag on the tank of the inspected transformer.

20.7 JOB PROGRESS CARD FOR REPAIRED TRANSFORMER UNDER GUARANTEED PERIOD

So far we have discussed the procedure of keeping track of production of new transformers as well as non-conforming products. In case of repair of transformers during guarantee period, it is recommended to identify these transformers with separate tags for easy identification. It is needless to say that the shape and colour of such cards should obviously be different from that of the previous two cards.

Section III

CHAPTER 21

Condition Monitoring

FOOD FOR THOUGHT

The following is a quote from a Mobil Corporation advertisement dated December 1984:

"To strive for quality—even excellence—is part of the human condition. All of us seek the highest quality our means allow; we do so daily as we flock to the stores for our holiday shopping, in the food we eat, in where we live. The concept of excellence is also deeply embedded in our national aspirations—witness the ongoing concern for clear air and pure water, and the pride we feel with every successful flight in space. But seldom is the striving for excellence as important as when we educate our young. The quality of education an individual receives will be a major factor in the quality of life that individual will attain."

This is true for everyone, anywhere in the world. No matter what they do. But if we don't prepare ourselves for the future, we may still lag behind. We must prepare ourselves continually through the education process. Education should not stop with graduation from high school or college. Conventional schooling only equips us with the basics; application has yet to be learned.

If a child learns to crawl and walk, but not to run, he'll never be able to catch a thief (*i.e.* opportunity). Similarly, once a professional learns the basics, to take full advantage of all opportunities he must keep up with the latest trends through education.

At the beginning of every year we make our New Year's resolutions. Some resolve to be better at their jobs, some to improve their personal lives, and others to just generate good habits period. It is advisable that a New Year's resolution should serve as a guideline to make us better at living, which means behaving more often with both uniqueness and conscience.

Once we resolve to learn a subject, we must see it through to completion. As quality professionals we should make a yearly resolution to learn at least one new subject and use it advantageously in our every-day lives.

Rapid changes in technology coupled with increasing consumer quality demands and keen competition requires professional to supplement their training and skills continually. Learning should be a life-long obsession, a never ending job.

21.1 INTRODUCTION

In transformer industry very few materials and components are kept in stores. Major materials, such as CRGO steel, MS sheet, angle, channel, tank, oil drum etc. are stored either in the workshop or in the open yards. The raw materials and components kept in the stores, workshop or in the open yards, should be stacked properly so that the physical value of the materials are not abused. Precautions to be taken during storing of some of the vital raw materials and components are discussed here.

21.2 PORCELAIN BUSHINGS

Since porcelain bushing is a breakable item, it is recommended to stack them properly to reduce the probability of breakage. If possible it should be stored in a covered shed. In case bushing is procured from two or more different vendors, it is advisible to store them in separate places for easy identification and traceability.

21.3 INSULATING PAPER AND PRESSBOARD

Paper and pressboard are hygroscopic in nature and water and moisture cause deterioration of their electrical properties. Therefore these materials should be stored in a dry place, preferably a covered shed. Materials should be used on 'first come first serve basis'. Long storage may deteriorate the electrical properties of the materials considerably. Epoxy dotted insulating paper starts loosing its properties after one year. Due evaluation should be done before using such materials.

21.4 WINDING WIRES AND STRIPS

Since most of the winding wires and strips used are with paper insulation, it is recommended to store them in a dry place. Right kind of stacking is very important. Winding wires and strips made of copper should be stacked separately from those of aluminium. Moreover the size of wire and strip including gross/net weight along with the name of the supplier should be marked clearly on the body of the spool.

21.5 TRANSFORMER OIL

In most of the industries the transformer oil is stored in a specially built tanker, placed outside the main shed. Rain water should not be allowed to seep into the tank and mix with the oil. To prevent such mixing, the inspection cover on the top of the tanker should be properly tightened. The gasket in-between should be checked frequently. Moreover an umbrella type hinged cover should be kept over the inspection cover for further protection. The physical stock checking by 'dip-stick method' should be done only when the atmosphere is dry.

Atleast once in two years, the tanker should be subjected to overall cleaning. The entire oil should be drained out. The bottom portion of the tanker should be cleaned. The inside of the tanker should be coated with a zinc-chromate base paint.

In case the oil is stored in a sealed drum, the task is easy. It is to be ensured that the sealing of drums are perfect and the drums are placed on the ground horizontally. This is necessary to avoid accumulation of rain water on top of the drum.

21.6 CRGO LAMINATIONS

CRGO laminations are generally stored in the workshop in the crane bay. CRGO laminations, after processing, are sent in packed condition with wooden pallets. The packing is opened and the laminations are stacked in steel racks. While stacking, it is to be ensured that the laminations are stacked properly according to their steps and sizes so that there is minimum loss of time during assembly.

These laminations should be handled with care.

Excess laminations, after assembly, should be put back again to their respective racks.

Assembled core should be removed from the work area and stacked properly after the same has been cleared in inprocess inspection and the job progress card is fixed. The movement of job progress card starts from this process onwards.

21.7 MS SHEET, ANGLE, CHANNEL

It is advisable to store MS materials away from rain water. But due to paucity of space and handling equipments, the manufacturers are sometimes forced to store these materials in open yards.

MS materials, stored in open yard get rusted and pitted in a short time. Manufacturers should make arrangements, as far as possible, to overcome such problems.

Even if the MS materials are stored outside in the open yard, storing and stacking should be done according to the classification of the materials. Stacking of MS sheets of various thicknesses at one place should be avoided.

21.8 ELLIPTICAL TUBES AND PRESSED STEEL RADIATORS

Since elliptical tubes and pressed steel radiators are made out of mild steel, it is recommended to store them in a shed, if possible. In case of elliptical tube, both ends of the tube should be wrapped with polythene sheet while storing outside in the open yard to avoid penetration of rain water.

Similarly, the header pipes of pressed steel radiator should also be blocked with polythene caps. Vendors should be instructed to provide such caps fitted along with the radiators.

21.9 STACKING OF LV AND HV COILS

Stacking of coils after inprocess inspection is a vital operation towards quality implementaion. Based on the shape, size and weight of coil, the number of coils per stack is determined. In the case of HV coils with aluminium conductor, ten coils per stack may be considered safe. However for coils with copper conductor, stacking should be done on the basis of weight of each coil. It is to be ensured that the bottom most coil of the stack should not get over-compressed due to the weight of the total stack.

While stacking, care must be taken to ensure that the coils of similar rating for different customers are not mixed up. For example, 100 kVA coils of PSEB should be kept separate from that of UPPCL. For traceability purpose, the coils should be permanently marked with the name of the operator, date of manufacturing and the customer for whom the coils are made. However the manufacturers should make their own procedures for easy and quick identification as well as safe storage of coils.

21.10 COIL ASSEMBLY DURING INPROCESS MANUFACTURING

Generally the coil assembly is done keeping the job at the floor level. It is advisable to keep the assembly away from the floor by a separator so that dirt and dust may not get inside the coils. The separator may be either a steel tray or a piece of coir mat or something similar. The job card should invariably be fixed on each assembly. It was seen in many occasions that the coils, insulating blocks, separators, rings, cotton tape, SRBP tube etc. are kept on the floor during the process of coil assembly. Keeping such materials on the floor is against the quality norms of transformer manufacturing and should be discouraged.

In case an assembly is under re-work, the job progress card along with the re-work tag should also be fixed in a visible location of the job for easy identification. Proper stacking while placing the assemblies inside the heating chamber is to be ensured. In case it is necessary to keep the assemblies in the oven under double stacking system, strong base suitable for that should be made. Practice of keeping one assembly above the other, should be discouraged.

21.11 TANK

In case the complete tank body is stored outside the shed in open yards, it should be kept in inverted condition. This will eliminate the accumulation of rain water inside the tank. Moreover the oil filling hole in the conservator, breather pipe, thermometer pocket etc. should be pluged when tanks are stacked in the open yards.

The tanks which are stored outside should be flushed with oil for a considerable period of time before using them.

21.12 FINISHED PRODUCTS DURING TESTING

Though stacking of finished products during testing does not come under condition monitoring, it has included here for overall safety of the organization.

Transformers under test in the workshop should be kept inside a fenced area, so that the general workmen (except those who are engaged in testing) have no access to them without permission. This is essential for the safety of the people. Danger warning should be provided on all four corners of the fencing. Fire fighting equipments, suitable to fight electrical fire, should be made available. Workmen should also be trained to handle such equipments on emergency.

Stacking of Finished Products

Stacking of finished products should be done with sufficient space in between, so that a person can move around each transformer for physical verification.

21.13 CONCLUSION

So far we have discussed storing of different raw materials, components, inprocess products and finished goods.

An inspection team consisting of store incharge, one senior workman from each department and the person incharge of quality should monitor the condition of these items at frequent intervals (say once in a month). In case any of the items is found not stored as per the laid-down procedure, it may be considered as non-conformance and should be recorded in the NC register for taking suitable corrective action.

The involvement of workmen in the team of condition monitoring is essential as it may act as catalyst to improve the working of the system.

Following are some of the advantages of regular condition monitoring:

Regular condition monitoring will help to:

(*a*) maintain the physical and electrical properties of the materials
(*b*) reduce wastage
(*c*) reduce re-work
(*d*) improve the quality of the ultimate product
(*e*) improve the quality of house keeping
(*f*) increase the productivity
(*g*) reduce accidents and fire hazard
(*h*) discipline the entire workforce to reduce the cost of the product.

Section III

CHAPTER 22

Calibration Status

FOOD FOR THOUGHT

As years go by, we learn that experience is the best teacher. Knowledge and experience gives confidence and credibility.

Each year, we set goals and objectives; however, what comes first: goals or objectives?

Objectives are subjective statements. For example, we say we want to learn to use a computer. We do not say ‘when’ or ‘how’ we are going to accomplish this objective. We just remember that something is to be accomplished. But, when we say that we want to learn to use a computer by the end of this year, we have set a goal. When we have an objective and we associate that objective with a time frame, then that objective becomes a goal. Goals are important to win the race for quality. Our goal must be to eliminate all errors and improve all processes.

Likewise, it is difficult to distinguish between revolution and evolution. Evolution is a gradual process of change or development, whereas revolution is a sudden or radical change in a system of state of affairs.

Today, revolution is occurring in the way we do business, while changes in the quality discipline are evolution.

Do we want zero-defect or defect-free product? Is zero-defect an objective? Does zero-defect mean no-defect? Does defect-free mean perfect?

Zero-defect is a personal performance standard and indicates that we are to meet the requirements every time. Getting by with defective products anywhere along the chain of supplier-customer relationship produces a weak link in quality and integrity. The customer has no tolerance for defective products or services.

When we think of goals and objectives, revolution and evolution, zero-defect and defect-free, we use these words interchangeably without realizing their effect. These words appear synonymous. Regardless of the method of measurement or the quality being measured, one achieves high quality by making improvement to one’s method of operations at every opportunity. High standards and an uncompromising drive for excellence are required to achieve goals and objectives.

- Begin the year by setting goals and objectives.

- Revolution and evolution should be our way of operation.
- We must strive for zero-defect and defect-free products and services.

22.1 INTRODUCTION

All instruments, meters, gauges etc. which are used directly or indirectly for measuring the performance parameters of the products, should be calibrated. The frequency of calibration depends upon the type and use of the instruments. The following are some of the guidelines for the frequency of calibration.

(*a*) All indicating static instruments which are used for measuring the parametric values of transformer (such as voltmeter, ammeter,wattmeter, frequency meter, ratio meter, resistance bridge etc.)	→	Atleast once in a year.
(*b*) Rotary instrument (such as insulation tester, megger)	→	Atleast once in six months.
(*c*) Current and potential transformers	→	Atleast once in five years.
(*d*) Gauges (such as pressure and vacuum gauges)	→	Atleast once in six months.
(*e*) Master set of scale, vernier micrometer, thermometer etc.	→	Atleast once in five years.
(*f*) Weighing bridge	→	Atleast once in a year.

It is needless to say that the calibration of such instruments, meters, gauges etc. should be done in the Government approved test laboratory having National/International accreditation or as approved by the customer. Further, the calibration of high voltage source transformer may be done in house with ratio meter once in six months.

22.2 IN-HOUSE CALIBRATION

The instruments, meters, gauges etc. which are used for measuring the quality parameters of the finished products should have a calibration schedule as per the above guidelines. All these instruments and meters should be kept under the custody of the quality assurance engineer. These instruments and meters should not be used on a regular basis for in-house inprocess measurements.

A separate set of instruments and meters should be used during inprocess checking. The calibration of such instruments need not necessarily follow the above calibration schedule. It is recommended that these instruments may be calibrated in-house with respect to the available ‘green sticker instruments’ which are already calibrated in the government test laboratory. Frequency of such in-house calibration should be atleast once in six months.

The quality assurance engineer should issue in-house calibration certificates for all such instruments which are used during inprocess checking.

22.3 MASTER SET

In ISO-9000 quality procedure, all gauges, scale, vernier, thermometer, micrometer etc. which are used for quality checking, should come under regular calibration. One set of such instruments are calibrated in the government approved test laboratory. This set of calibrated instruments are called ‘Master Set’. These calibrated instruments are used only to calibrate other similar instruments and gauges which are issued to different departments for checking the inprocess components.

The Master Set instruments should not be used for regular measurements.

Unless otherwise specified, the calibration certificate of such Master instruments should remain valid up to five years.

22.4 CALIBRATION PLAN

The purpose of calibration plan is to organize the calibration activities well in advance in such a way that one set of calibrated instruments are always available to all the departments including finished product testing. Wrong calibration plan leads to non-availability of calibrated meters for testing.

Breakage and non-functioning of instruments should also be taken into account while preparing the calibration plan.

In case the transformer manufacturer can afford to spend more on infrastructure, the ideal condition would be as follows:

(*a*) One set of calibrated instruments should be available for testing of finished products.
(*b*) One set of in-house calibrated instruments should be available for inprocess checking.
(*c*) One set of instruments should remain as spare for use only in an emergency.
(*d*) One set may remain with the repairing house and/or calibration agency.

With such arrangements, the manufacturer will never feel the absence of calibrated meters. The calibration plan should also indicate in advance the movements of all such meters.

22.5 INSTRUMENT CODE NUMBER

All instruments, meters, gauges etc. which come under calibration plan should be codified. The code number along with the date of expiry of calibration should appear in a visible position on the instrument. Instruments under in-house calibration, Master set, scale, vernier, thermometer, micrometer, gauges, weighing bridge etc. should also come under codification. The shopfloor engineers should be instructed not to use any instrument, the calibration period of which has expired.

22.6 CONDITION MONITORING OF THE INSTRUMENTS

Performance of instruments mostly depends on how they are handled. Rough handling will definitely reduce the life of the instruments. It has been seen in many occasions, where the instruments like resistance bridge or ratio meter etc. are kept on ground while use. Megger is sometimes placed on the top of the transformer while on operation for checking insulation resistance.

Proper trolley or test table or test panel, based on the type of instruments and their use, are to be employed. Ratio meter, resistance bridge etc. are generally kept on a trolley. Loose instruments like megger, multimeter etc. are kept on the test table. Wattmeter, ammeter, voltmeter etc. are kept on the test panel. The manufactures, at their convenience, should make suitable arrangements.

Instruments should be kept free of dust. While not in use, instruments should be kept covered to prevent accumulation of dust.

22.7 CONCLUSION

Coloured sticker pasted over the meter by the calibration agency indicates calibration status of the meter.

A green sticker on the meter indicates that the calibration results satisfy the requirement of the specified class of accuracy over the entire range of the instrument. These meters are safe for use for the measurement of performance parameters without any doubt.

An yellow sticker indicates that the calibration results in some of the scales/ranges are not meeting the requirement of the specified class of accuracy. These meters may also be used in measurements, avoiding its use in such ranges/scales where the accuracy is not meeting the specifications. Another option is to use them with proper correction factors to derive the final test value.

However instruments with red stickers should not be used for testing, since these instruments do not satisfy the requirement of accuracy at all.

Correct instruments with proper connecting leads tend to yield fair measurements of the test parameters. Current carrying leads should be thick enough to reduce the probability of voltage drop across the leads. Moreover, the length of such leads should be as minimum as possible. The instrument should be placed perfectly level during measurement for its proper functioning. Parallax should be avoided during meter reading.

Section III

CHAPTER 23

Customer Complaints and Feedback

FOOD FOR THOUGHT

"I haven't got time" or "I'm too busy" is a common complaint.

"My busy schedule doesn't leave me enough time for physical exercise" is another excuse heard many times.

A juggler bounding three or more balls in the air has an objective to keep an eye on all balls and not let any of them fall to the ground. Every time the balls fly through the air, the audience admire the juggler's act. As soon as one of the balls falls to the ground the audience get disappointed.

Similarly, all professionals are jugglers and they are required to maintain a balance between their business, professional activities, family and social lives. They are required to act promptly with a specific priority in mind.

Professionals should keep up with technological changes; otherwise they will be labelled obsolete. Education classes are must to keep up with the newer developments.

Health cannot be ignored due to lack of time. Some time must be taken out from the busy schedule to maintain a healthy status and to enjoy future life. Work or a job cannot be neglected, as the livelihood depends on it.

Life in the fast lane does not leave much time, and it cannot be used repeatedly as an excuse not to maintain a balance between various activities. It does not mean that quality and professional attitude should be sacrificed to maintain a balance. It also does not mean that personal quality standards should be lowered to satisfy one and neglect others. Again, as a professional, all activities should be performed with excellence in mind while maintaining a personal set of quality standards.

It is important to maintain a balance and change the course as it suits a particular circumstance. For each activity there is a customer and there a need to delight that customer with superior service. We do physical exercise, our body is the customer whom we want to satisfy by offering good health.

23.1 INTRODUCTION

Customer complaints and feedback play a vital role in the improvement of product quality. Based on customer specification and service condition, a transformer is designed and manufactured. In case, a transformer fails to perform at the customer's end, the transformer should be called back to the manufacturer's works for analysing the cause of failure. Detailed investigation report on the cause of failure of each transformer should be recorded for the preparation of data-bank.

Transformer is a vital equipment which bridges the generator to the load. Right kind of design, manufacture, test, operation and protection increase the normal life of the transformer. All power utilities are worried these days because of the unusually high rate of failure of distribution transformers in service. For example, the failure rate of transformers in UPSEB (UPPCL) is in the order of 18 per cent as against less than one per cent in the developed countries. The steady increase of failure rate of distribution transformers is a great concern to all Indian SEBs.

However, in most cases, the causes of failure are not analysed.

According to manufacturers, users often run the transformers on overload, on single phase, or in unbalanced condition. Users, on the other hand believe that the failures are due to faulty design or bad materials or poor workmanship. But in fact the responsibility should be shared equally by both the users and the manufacturers. It is necessary to identify the causes on the basis of failure analysis to take subsequent corrective measures. It is essential that there should be enough interaction between the manufacturers and the users to create better understanding and to develop a sense of joint responsibility towards successful performance of the products.

The manufacturers should accept the feedback from the utilities without any prejudice and take remedial measures while the users, on their part should ensure that the equipments are not abused and correct feedback on the product performances are passed onto the manufacturers.

A data-bank should be developed and problems analysed to identify the reasons of failure. Collection of failure data is the first major task. In fact, no such data is prepared or maintained by most of the SEBs. In the event of a failure within the guaranteed period, the utility sends the transformer back to the manufacturer for free repair. Alternatively, if the failure occurs beyond the guaranteed period, the transformer is repaired departmentally or by an agency under a repair contract. However, on both the occasions, very little effort is made by the utilities to find out the root cause of the failure. This could be one of the reasons why a new transformer which replaces the damaged one also fails immediately or within a very short period of time.

23.2 TYPES OF FAILURES

Failure of a transformer is caused either due to fault within the transformer or due to operational hazards. Majority of the failures, roughly 80 to 90 per cent of the total, are due to winding failure, out of which, nearly 60 to 65 per cent manifest as HV winding failure, 10 to 12 per cent as LV winding failure and 15 to 17 per cent as failure of both the windings. These may be due to various electrical or mechanical reasons. Incorrect electrical and mechanical designs, use of improper and inadequate insulating materials, insufficient impregnation, curing, drying of the winding insulation, poor workmanship etc. lead to such failures.

Loose soldering, bad crimping, uneven temperature rise due to insufficient cooling etc. also fall under the causes of failures. Loose clamping of core lamination results in vibration and hence in abrasion due to burrs creating short-circuit in the laminations, thereby, permitting development of heat due to saturation of magnetic circuit. Uneven placement of spacer blocks, improper placing of wooden spacers, poor quality of wood, inadequate pre-compression of the windings, poor quality of pressboard etc. make the coils more prone to displacement and deformation and hence, dislodging during short-circuit.

Nearly 3 to 4 per cent of failures are due to failure of HV bushings. Sparking takes place at the termination joints resulting in damage of the metal parts of bushing fittings. Aluminium fittings oxidise fast and become mechanically weak. Inadequate brazing of lead is another cause of failure. Approximately 2 to 3 per cent of failures are due to the ratio switch. It usually happens because either the quality of switch is bad or the switch is operated by an inexperienced operator. The resistance between the contacts of the ratio switch becomes high due to loose contact caused by insufficient spring tension.

Roughly 4 to 5 per cent of the faults are due to transformer oil. Low oil level, pilferage, leakage through bad and porous welding, spilling of oil due to rough handling during transit or installation, flushing-out due to pressure generated out of overheating etc. lead to failure of transformer. Poor quality of oil used, degradation of oil due to over heating/ageing, entry of moisture through porous gasketed joints or absence of sufficient silicagel etc. result in deterioration of the insulation strength of oil.

The causes of failure are numerous, but in most of the cases, the effect is burning of windings. It is, therefore a difficult task to ascertain the root cause of failure simply by looking at it. Failure analysis, to detect the root cause, requires lots of expertise. For example, the burning of windings are the effect of the following causes:

1. Low oil level 2. Over load 3. Single phasing 4. Unbalance load 5. Insulation failure 6. Inter-turn short 7. External short-circuit 8. Loose joint 9. Less internal clearances 10. Ingress of moisture.

It is therefore recommended to investigate the root cause of failure before preparation of data bank.

23.3 CAUSE OF FAILURE

The cause of failure of distribution transformer may be broadly classified into two categories:

(*i*) Failure attributed to users

(*ii*) Failure due to reasons at manufacturer's end.

Failure Attributed to Users

Various causes for the failure of transformer at the user's end may be classified as follows:

(*a*) Continuous overloading

(*b*) Single phasing

(*c*) Unbalancing

(*d*) Effect of cable terminations on performance of transformer

(*e*) Theft of power by unauthorised consumers

(*f*) Earth connection to tank body and LV neutral

(*g*) Failure due to external short-circuit

(*h*) Inadequate maintenance

(*i*) Failure due to ratio switch

(*j*) Selection of low voltage cable

(*k*) Problem in the installation of transformer and fixing of accessories.

Failure Due to Reasons at Manufacturer's End

Various causes for the failure of transformers at the manufacturer's end may be classified as follows:

(*a*) Faulty design
(*b*) Bad quality of materials
(*c*) Poor workmanship
(*d*) Improper transportation.

There may be various other reasons also for the failure of distribution transformers. Manufacturers have very little control on causes of failures which are attributed to the users during service. It is advisable to keep constant checks on such causes which result in the failure of transformer. In the case of any shortcoming from the manufacturer's end, which is noticed by the users, it should be brought to the attention of the manufacturer for applying corrective measures in subsequent supplies. Improvement on product quality depends on the mutual understanding and co-operation between the users and manufacturers. Longer life for the transformer can be expected only when the manufacturers and users join hands together for the common cause, *i.e.* quality assurance.

23.4 FAILURE ANALYSIS AND REVIEW (USER'S END)

The main purpose of this procedure is to bring out the defects after analysing the causes of failure and then to apply corrective measures to prevent further failure during service.

Each of the causes of failure mentioned above alongwith their probable remedial measures are discussed below:

Continuous Overloading

Continuous overloading is one of the main causes of failure of distribution transformers in service. Though distribution transformers are not recommended to run under continuous overload, in few occasions, the power utilities are constrained to operate the transformer with overload to maintain service to the locality.

In early seventies, there were transformers (of few specific makes running in the power system, delivering 30 to 40 per cent excess load continuously for a long duration without much of quality problems. With the increased competition in the market it is observed that the safety margin of distribution transformers are brought down to a bare minimum, just sufficient to satisfy the requirement of the standard specification as well as ideal loading conditions. Availability of ideal loading condition is again very unusual in the Indian distribution network, especially in the Metro and suburban cities. As a result, with the service conditions prevailing at the distribution network, the performance of distribution transformers under overload remain unsatisfactory.

Due to the above factors, users are required to run the plant within the specified capacity throughout the year. It is difficult for urban electric supply undertaking to maintain such an ideal network condition throughout the year due to either unpredictable load growth during festive seasons or outage of an adjacent source in the thickly populated area.

To permit certain amount of continuous overloading, there are two options available with the utilities:

(*i*) The first option is to under utilise the transformer during normal use. For example, it is recommended to use a 100 kVA transformer where the connected load is around 63 kVA rating. The additional 37 kVA may be kept for safe loading towards emergent situation.

The proposal does not sound good since it will ultimately lead to uneconomical network.

(*ii*) The second option would be the introduction of safety margines within the specification which can allow the transformer to run under prolonged overload in case of emergency without sacrificing the life of the equipment.

Considering the economics, the second option sounds good and may be opted with slight changes in the technical specifications. The changes are:

(*a*) Reduced permissible temperature rise of oil and winding from 50/55°C (as specified in IS-2026) to 35/45°C to take care of poor ventilations in some locations and to permit marginal overloading.

(*b*) Positioning the thermometer pocket at the centre of tank cover (not in the corner, in the vicinity of radiator) which is the hottest zone of top oil temperature. This will enable recording of the maximum possible top oil temperature during temperature rise test. Further, it is advised to use thermometer pocket as per IS-3639.

(*c*) The manufacturers are advised to submit successful temperature rise test certificate from CPRI with a copy of certified drawing indicating tank dimensions, radiator details etc.

(*d*) The power to be fed during temperature rise test are corrected to 100°C, as is already practiced by some of the SEBs. To account for additional losses during temperature rise test, we are deviating from the test procedures laid down in ISS. The procedure of measuring the temperature rise of winding should be reviewed. The rise in temperature of the winding can be calculated in the following manner:

(*i*) Rated current of the transformer : I_r

(*ii*) Test current recorded during : I_t
(test with total power loss corrected to 100°C at steady top oil temperature rise)

(*iii*) Shutdown is taken at thermal equilibrium condition when top oil temperature rise becomes steady with power fed corresponding to 100°C

The rise in temperature at this condition: R_t

(*iv*) The calculated temperature rise in the winding at rated condition:

$$R_r = \mathrm{R}_t \times \left(\frac{I_r}{I_t}\right)^{1.6}$$

It is expected that with the inclusion of the above amendments in specification and methods of measurements, the overload performance of the transformer will definitely improve to a great extent. But routine maintenance regarding the use of proper size of fuse elements, frequent checking of load current etc. should religiously be monitored by the field staff. If the load current indicates phenomenal increase of load in a particular locality, it is recommended to replace the existing transformer with a bigger rating, or else, a second unit may be run in parallel.

Single Phasing

Three phase transformers fail while running three phase heavy duty irrigation pumps with two phase supply. The current on one phase goes drastically high, causing operational problem and leading to the failure of transformer.

There is no way to curb this kind of failure other than educating the agricultural consumers to stop running three phase pumps when two phase supply is available to them from a three phase transformer. The consumers should bring such incidents to the notice of the local power authority for attending to the fault and restoring the three phase supply on priority.

The second option is for the consumers themselves, to own transformers as has been initiated by PSEB.

Unbalancing

The ideal loading condition for a Delta/Star connected transformer is a three phase balanced load which is rarely achieved with the distribution network available in suburban and metro cities is India. The transformers are put to unbalanced loading frequently. On such occasions, the low voltage neutral will experience a floating voltage, which is externally earthed. This floating voltage with earth neutral will cause a circulating current in the closed loop of the delta winding on the primary side.

So long as the unbalanced loading is in the range of 10 per cent among the phases, the effect may be ignored, as the same may not create an operational problem in the transformer. However, it becomes critical when the unbalanced loading goes beyond 10 per cent.

It is not an easy task for the power utilities to keep constant checks on the sources of unbalanced loading. However, the field staff should be advised to measure the unbalanced current on the neutral at frequent intervals and it should be recorded in the history card. In case, the unbalanced current for a particular transformer goes beyond 10 per cent, the cause may be investigated for applying remedial measures on priority.

Effect of Cable Terminations on the Performance of Transformer

On many occasions, non-engineering practices are adopted in the usage of incoming and outgoing terminations. Conductors and cables are connected to the bushing terminals without proper connectors, thereby creating loose joints and causing sparks during the passage of current. The heat generated by the sparks causes melting of the terminal gaskets resulting in the leakage of oil.

It is essential to use proper lugs and connectors for terminations. ISS/REC/CBIP have recommended the use of lugs and connectors with detailed dimensional drawings which could be used as reference. If aluminium cables or conductors are required to be connected to brass/copper terminals or vice versa, it is recommended that a proper bi-metal be kept in between.

Theft of Power by Unauthorised Consumers

It is a common practice for the unauthorised consumers to steal power by hooking or tapping from the sources.

Apart from loosing huge revenue, power theft is one of the reasons for the failure of transformers by way of overloading and unbalanced loading.

Chapter-4 of Section-III deals with the various aspects of power theft and probable remedial measures to curb such occurrences.

Earth Connection to Tank Body and LV Neutral

The effect of weak earth connection at proper places is more dangerous to the field staff rather than creating operational problem for the transformer. As per the provision in the Indian Electricity Rule, the tank body is to be earthed at two places from the safety point of view. It is further recommended that the tank cover should be earthed with the cooler flange of the tank through a thin strip of copper foil, applicable for transformers having HV bushings on top cover. This is essential to eliminate the chances of cover bolts getting loose and weakening the earthing of the tank cover. The paint in and around the earth bolts should be removed for proper earthing. G.I. strip having a minimum cross-section of

25 × 3 mm is recommended for all earth connections. If the transformer has a neutral available on the LV side externally, it is to be ensured that the same is also earthed directly.

Failure Due to External Short-circuit

Failure due to external short-circuit in distribution transformer is quite common with the type of system available in the present distribution network. It is understood that the transformer is supported to be designed to withstand short-circuit forces for very short durations. In case, the external short-circuit persists for more than 2 to 3 seconds, the transformer may get damaged due to excessive short-circuit current.

To improve upon the performance of transformer against short circuit current, it is recommended to use only such products which are proved to be successful in the short-circuit test. Moreover, suitable protection, like ACB on LV side, OCB on HV side, HRC fuse, drop out fuse, re-wirable fuse etc. as deemed fit, are to be provided

Enhance the Life of Transformer by Preventive Maintenance

Distribution transformers are generally offered very little maintenance during service. It comes to notice only when a transformer fails during operation. Only then, the users offer best possible maintenance (break down maintenance) for putting the dead transformer back into life. It is a usual practice for most of the SEBs in India and the practice should be discouraged.

Regular preventive maintenance of transformer and oil definitely enhance the life of a transformer. Based on the rating and service condition, the frequency of maintenance is to be determined. A checklist in this regard should be made and subsequently the schedule of maintenance should be followed religiously.

Failure Due to Ratio Switch

Though the instances are few, it is observed that at times the transformers fail (2 to 3 per cent) because of the ratio switch. The failure may be due to inadequacy of the ratio switch or may be due to faulty operation of switch with load. Failure of ratio switch due to low oil level is also a common cause.

Since the ratio switch is seldomly operated for voltage adjustment, it is suggested to stop the use of ratio switch for distribution transformers, especially upto 630 kVA rating, as recommended by some of the power utilities in India. Provision of tap-link board instead of rotary type switch may also be considered. Withdrawal of tap switch will reduce the cost of the transformer by about 3 per cent.

Selection of Low Voltage Cable

We have previously discussed how faulty terminations and cable joints affect the quality in the performance of transformers. Here, we shall discuss in brief the mode of selection of size and type of low voltage cables for distribution transformers.

The very first thing which the power utility should look into is the quality of cable. The use of poor quality cable with inferior grade of PVC covering should be avoided. The rating of the cable should be such that it is not over heated during service. Effect of bi-metallic action may also be looked into while making termination. It is recommended to provide proper cable supports to avoid unnecessary load on the bushing terminals.

In case, the transformer is of outdoor type with exposed bushings, the selection of cable is easy. Good quality PVC cable of either $3\frac{1}{2}$ core or single core with proper current rating are recommended.

In the event of transformer with LT cable box, proper care should be taken while selecting cables. If single core cable is used, the gland plate should preferably be non-magnetic type for 500 kVA and above. Otherwise, it will create unnecessary induction heating due to magnetic flux linking around the entry of cable in the box. MS gland plate cut and further welded with non-magnetic materials may also serve the purpose.

Installation of Transformer and Fixing of Accessories at the Right Locations

Proper installation with fixing of accessories at right locations is essential to enhance the life of a transformer. It is recommended to keep a check on the following:

(*a*) Sufficient earth clearances from exposed bushing terminals (applicable for outdoor pole mounted transformers)
(*b*) Breather and arcing horns are placed in their respective locations
(*c*) PVC tape provided to seal the air passage at the bottom plug of the breather is removed before energisation
(*d*) The oil tray inside the breather container is filled with oil
(*e*) The colour of silica gel should essentially remain blue
(*f*) In the case of outdoor transformer with exposed bushing terminals, it is to be ensured that the surroundings of the transformer are clear of trees, close to the exposed bushing
(*g*) The trapped air from the bushing is released
(*h*) The trapped air inside the tank cover is released through air release plug provided for this purpose
(*i*) Explosion vent diaphragm is checked to see if it is in proper condition
(*j*) Di-electric value of transformer oil is checked
(*k*) Insulation resistance of the windings are checked
(*l*) Rollers if provided, are locked in their positions
(*m*) Tap position of the transformer is correctly selected through the ratio switch depending on the available incoming voltage and the switch handle is locked in position
(*n*) Oil level is slightly above normal. The extra oil may be taken out to allow sufficient space for oil to expand during service
(*o*) The levelling of the transformer is checked with the help of spirit level.

23.5 FAILURE ANALYSIS AND REVIEW (MANUFACTURER'S END)

Faulty Design

As was discussed earlier, the life of a transformer depends a lot on good design. The good designs are those where all the performance parameters are within the specified limits and the designs are successfully tested for impulse, temperature rise and short-circuit. Performance parameters are those parameters which have direct effect on the performance of a transformer. They are mainly: no-load and load loss, impedance, oil and winding temperature rise, resistance, ratio etc.

Manufacturers should develop one proto-type transformer for verification of the performance parameters before going for batch production. Subsequently, all transformers should be manufactured in accordance with the design followed in the prototype transformer. Any deviation from the type tested design during batch production may lead to poor performance of the transformer in service.

When a complaint on product performance is received form an end user, it is critically analysed to determine if the fault developed is due to any short coming in the design. During the course of the design, a designer conceives lot of parameters based on the service conditions and rating of the transformer.

In case, these assumed parameters do not satisfy fully the requirement of service conditions, the transformer may fail in the long run. With proper analysis, the designer can update some of the inputs to improve his future designs.

All such corrective steps should be documented so that they remain as a reference to all designers. Electrical clearances (both internal and external), HV and LV terminations, cable boxes, location and size of conservator, size of silicagel breather, explosion vent diaphragm etc. are the key areas where the designer should concentrate so that the design suits the requirement of service conditions.

Moreover, the designer should be flexible enough to accept any positive suggestion which is a result of such reviews.

Poor Quality of Materials

Shop floor testing may not always reveal the quality of materials. Quality of materials can be ascertained rightly only after a transformer is in service for a considerable period of time. Insulating blocks and rings made out of sub-standard pressboards may shrink during the passage of time in service and can leave considerable axial gap in the assembly which may be one of the causes of failure due to short-circuit. The ageing of transformer oil may be another cause of failure of transformer in service. Other materials, like paper insulated conductor, insulating kraft paper, gasket and *O*-ring, tap switch etc. may also cause failure of transformer in service. It is very much necessary to identify such materials whose physical and electrical properties deteriorate with time. The manufacturers may adopt suitable precautionary measures to verify the quality of such materials during inprocess inspection.

In case, a material is found defective during the repair of a transformer it should be documented and reviewed. The outcome of such review meetings should be communicated to the respective vendors for improvement in future supplies.

Poor Workmanship

About 35 to 40 per cent of failures are due to poor workmanship. This is a serious problem in all the transformer industries, especially in small manufacturing units, where production is usually done with contract labourers. It was discussed earlier that except preparation of coils, almost all other manufacturing activities are done manually, where skills of the workmen are very important. It should be ensured that all the workmen engaged in the production should have average skill so that the finished products exceed the basic quality requirements.

Various case studies made on customer complaints have revealed the following reasons for the failure of transformers in service. Also given are a few precautions to improve the quality of transformers.

(*a*) All coils must be soild both radially and axially. The radial build can be made soild by taking proper care while manufacturing the coils. Required tension in the winding machine should be kept while processing the coils. Axial build, of course, has to be taken care of during pre-compression, in the heating process.

(*b*) Transposition is a weak zone and often causes failure of transformer during short circuit. Each strip should be adequately insulated after bending. If necessary, a thick insulating paper may be provided at the junction where the actual transposition has taken place.

(*c*) All paper blocks and rings should be made out of pre-compressed boards only. Cooling ducts and cylinders etc. also should be made from pre-compressed board. Dovetailed type spacers instead of plain spacers should be used.

(*d*) The design of windings including their placement should be done in such a way that the out of balance Amp-turn is not more than 3 per cent at the extreme negative tap at any point over the full length of the coil. Proper thinning in the inner coil should be done accordingly.

(*e*) Coil assembly should be made very tight with proper supports for tapping and delta leads.

(*f*) Thick perm a wood or insulated steel ring may be used for uniform coil pressing.

(*g*) Use of torque wrench with pre-determined torque is very essential, especially for tightening the nuts and bolts in the coil assembly.

(*h*) The top yoke core stacking may be supported vertically down by insulated MS flats, at least at two places, to reduce the probability of the yoke laminations shipping out during axial short-circuit forces. For transformer with taps on HV side, the ratio switch may be fixed on such cross flats.

(*i*) Provision of 8 tie rods for medium size distribution and power transformers may be considered for uniform compression of coils on the outer limbs. In case, adjustable compression screws for coil pressing are used, the tie rods may be avoided.

(*j*) All nuts, after being fully tightened, should be locked by another nut. A centre punch on the end thread may also be made to prevent the nut getting loose during service.

(*k*) The transformers often fail due to failure of core bolt insulation. The stacked core of bigger transformers are sometimes clamped with bolts inserted through the holes in the core. These bolts are to be essentially insulated from the core as well as from the frame parts. In case, the insulation of one of the bolts fails, the bolt will touch the core laminations, causing local heating of the core laminations. If such faults occur in more than one bolts a heavy short circuit current will circulate between the bolts, causing generation of enourmous heat. The bulk of the yoke laminations may also get charred and may cause insulation failure of the windings.

(*l*) Excessive burrs in the cut edge of the laminations is also a common cause for the failure of transformer in service. Considerable amount of burrs in the cut edges of core laminations may cause excessive eddy current with abnormal heating. Burrs upto 40 microns are within acceptable limit.

In case, the burrs are above 40 microns, cutting blades and punching tools of core processing equipments should be sharpened.

(*m*) Failure due to loose core studs and tie rods: Core studs and tie rods are essentially to be locked with core frame channels, otherwise, during service core stack may get loose and may cause excessive vibration, resulting in deterioration of insulation coating and generation of eddy current and heat.

(*n*) Failure due to foreign metal parts in the coil assembly: Drilling or filing on assembled transformer may cause deposition of small fillings or turning particles on the surface of the windings. These foreign particles are not, generally, seen with naked eyes. But this may be enough for the failure of transformer through short circuit.

(*o*) Failure due to sharp edges on conductors: Due to the presence of sharp edges in the winding wires and strips, two consecutive turns in a particular layer may touch each other causing short-circuit in the windings. This effect is more serious, if such short circuit occurs in high voltage windings. In case, windings are loosely built or get loose due to repeated electromagnetic shocks, such sharp edges may cause cutting in the insulation of the adjacent turns, resulting in contact between metallic parts and finally failure due to short circuit.

The operators should be vigilant while making joints in the conductor. Generally such joints are avoided while making coils. However, in case, such joints are unavoidable, the joints should be cleaned and filled to remove sharp edges. All the joints are insulated properly before progressing with the windings. Care must be taken so that no two joints appear close in the consecutive turns in a single layer of winding.

(*p*) Inadequate pre-shrinkage of the windings: Insulating paper blocks used for vertical and horizontal support of coils are bound to shrink during service due to heat. This shrinkages are more in the case of disc coil. The shrinkage may loosen the coil assembly and may result in failure due to short-circuit.

To overcome such failures, good quality of insulating boards, preferably of pre-compressed type should be used. Moreover, the scope of any further shrinkage may be taken care of during coil assembly. In case of disc coils, it is recommended to pre-heat the individual coils after clamping them between two pressure plates. After heating to the required level, the coil is compressed judiciously by skilled workmen till it reaches the required stack height. Coil pressing plates or adjustable coil pressing screws are commonly employed in disc coil assembly. In the case of small and medium rated transformers, it is recommended to preheat the active parts in the oven before refilling the yoke laminations. Any shrinkage in the insulating blocks as well as in the coils are taken care of after the pre-heating. Yoke fillings are done only after the designed coil stack is attained.

Incomplete Drying

Insulating paper and paper blocks contain about 4 to 6 per cent moisture by weight. It is essential to remove the entire moisture by slow heating under vacuum before impregnating the assembly in oil.

By heating, 80 to 90 per cent of moisture is removed. If drying is not complete, the moisture which remains with the insulating materials may cause unwanted premature failure.

The manufacturer should prepare a chart ‘Time in hours *vs.* insulation resistance in Mohms’ at the maximum reasonable oven temperature. The insualtion resistance is maximum when it remains steady over a duration of several hours at the maximum reasonable oven temperature. After achieving the desired insulation, the transformer should be impregnated with dry filtered oil.

While drying out, it is essential to raise the vapour pressure in the layers of insulation and keep it down in the surroundings. The first requirement is satisfied by heating the insulation and the second by maintaining a vacuum in the drying oven or in the tank. Generally, distribution transformers are dried out without vacuum. To produce the required vapour pressure differential, the heating of the insulation in the course of drying out process is periodically interrupted and the outer surface of the core-coil unit is cooled abruptly with a jet of clean air. The process of accelerating the drying out by producing a temperature differential is based on the phenomenon of thermal diffusion.

Failure Due to Excessive Hot-spot Temperature

When a transformer is put into service, the windings get heated up. The heat is slowly taken away by the oil. Since the oil is in continuous circulation, by the process of natural convection heat is transferred to the tank body from which it dissipates to the surrounding atmosphere through radiation. The temperature of the windings and the oil go on increasing till a steady state is reached. At the steady state or equilibrium condition, any more heat generated by the windings is totally dissipated through the tank body with out retaining any additional heat by the oil. At this stage, the temperature of both the windings and the oil remain constant as long as there is a steady load and a fairly constant ambient temperature.

In case, by any means, the circulation of oil inside the winding gets blocked, the temperature of the blocked region will shoot up, creating a hot spot, causing burning of insulation and resulting in the failure of the windings.

To overcome such failures, adequate oil ducts should be provided between the coils as well as between the HV sections. End blocks at both LV and HV coils are also to be taken care of. Number of blocks per circle are also to be decided judiciously. The insulating paper cylinders between the coils are often found bent at the top due to excessive compression of the coils while tightening the tie rods.

The bend cylinders at the top is the main cause for blocking the circulation of oil and thereby creating hot spot.

Failure Due to Improper HV Lead Supports

Weak supports of HV delta leads as well as tapping leads may cause failure of transtormer because of its poor quality.

Failure Due to Inadequate Electrical Clearance

Failure of transformer occur due to inadequate electrical clearances from the tapping leads to inside of the tank wall.

Failure Due to Weak Joint in the HV Winding

Lower rated transformers, especially with aluminium windings, fail because of weak joints in the winding. In some cases, the delta leads are found broken.

Failure Due to Seepage of Water in the Winding During Formation of Star Point by Gas Brazing

Though such failures are rare, sometimes the transformers fail due to seepage of water in the winding during gas brazing. It is recommended to use asbestos clay to overcome such failures.

Failure Due to Improper Transporation

Since manufacturers are held responsible for safe delivery of transformers in good condition to the destination stores, the following are some of the important points, the manufacturers need to look into:

(*a*) The transformer should be complete in all respects except for the breather, rollers, arcing horns, thermometer etc. which are generally packed separately. Ratio switch, if provided, should be locked in normal position. Oil filling cap, breather pipe cap etc. should be tightened enough to ensure no seepage of oil during transit. Oil level should be slightly above normal.

(*b*) Safe loading on the truck and proper fastening with rope is essential to ensure no appreciable movement of the transformer during transit. Fragile accessories like bushings, ratio switch handle etc. should not be used for tying up the transformer with the frame of the truck.

(*c*) It is a common practice to hold on to the terminal bushings during loading a transformer at the manufacturer’s premises as well as during unloading at destination stores. This practice of handling the transformer should be discouraged.

(*d*) Manufacturer should ensure that the transformer reaches the destination stores safely without any breakage.

(*e*) Both the manufacturers and the users should look into safe unloading at the destination stores including proper stacking at the right place.

Mishandling of transformers during unloading and/or transit, may result in cracked bushings, damaged valves or oil leakage from the radiator fins. On such occasions, it is the responsibility of the manufacturer to carry out the rectification work including replacement of damaged bushings and valves, welding of radiator fins, topping up of oil etc. at site under open air. The life of these repaired transformers may not be as long as that of good transformers. Sometimes there is a delay in taking up these damaged transformers for rectification.

During this time gap, especially in the rainy season, the di-electric value of oil and insulation resistance of these damaged transformers go down. This may be one of the causes of reduced life span of such transit damaged transformers. We should evolve a procedure for loading, transportation and unloading at site of the transformers so that they reach the destination safely without any damage.

23.6 CONCLUSION

This procedure brings out the causes for the customer complaints on transformers so that proper corrective measures can be taken to improve the quality in future supplies.

Data-bank for each failed transformer should be prepared. In case, the failure is because of the users mishandling the equipment during service, the same should be brought to their notice. However, if the failure is because of the mistake at the manufacturer's end, the following corrective measures should be taken for quality upgradation in future supplies:

(*a*) If the failure is due to bad/design construction, the designer should be informed to make a note of it so that proper corrective measures are taken in the future designs.

(*b*) If the failure is due to bad materials or components, the vendors should be invited to see the specific instance of such failures which will enable them to offer necessary corrections in their future supplies.

(*c*) In case, the failure is due to human error, the concerned workman should be informed of it. In all the cases, the cause of a failures and the mode of communication to the respective people/department should be documented for future reference. The manufacturer should take necessary action so that such mistakes are not repeated.

Section III

CHAPTER 24

Use of Reference Standards

FOOD FOR THOUGHT

In general, change is seldom welcomed whole heartedly. Change often appears unfamiliar and uncomfortable—it disrupts the familiar and accepted style. Making changes in behavioural pattern is difficult. In fact, more people fail than succeed in that.

Why is it that we find change so difficult when we desperately need the change?

Is it because we perceive change as a threat to our security? The threat may be imaginary, but it is a serious barrier against success.

When considering change, we usually wonder about our ability to perform. We may be uncertain about our willingness to accept new ideas and unsure about the benefits of the change.

Clear thinking is needed to counteract negative feelings. Above all, an objective analysis may reduce or eliminate the perceived threat.

A positive attitude and an objective mind are most receptive to change. We must recognize that during the learning period mistakes are possible, and that failure often provides another opportunity.

Our hopes and dreams may be tempered a bit by change, but change is what makes success and survival possible in today's business world.

24.1 INTRODUCTION

Various National and International standards are available worldwide which are used as reference for carrying out quality checks on the finished products as well as on different components, accessories and raw materials relating to the transformer industry. These standards provide generalised guidelines for the quality checks, their procedures of measurements and controlling tolerance limits of various test parameters. Some standards also provide information on dimensions of basic raw materials and components.

Example:

- IS-2026/BS-171/IEC-60076 etc. provide reference to the requirements and test procedures of finished transformers.

- IS-3347/IS-8603 etc. gives the dimensional requirements of porcelain bushings and their fittings of various voltage classes and current ratings.
- IS-335 relates to the requirement of insulating oil.
- IS-6160/IS-6162/IS-7404 etc. provide information on insulated winding wires and strips IS-1576 is for solid insulating boards.
- IS-3024 is for CRGO steel.

There are various other standards available which provide complete information on the requirements of the transformers and components.

Indian Standards Specifications, Handbooks and other publications of the Bureau of Indian Standards can be procured from its Headquarters at New Delhi or from any of its Regional/Branch office at Ahmedabad, Bangalore, Bhopal, Bhubaneswar, Calcutta, Chandigarh, Chennai, Coimbatore, Hyderabad, Jaipur, Kanpur, Mumbai, Nagpur, Patna, Pune and Thiruvananthapuram. Outside India, these may be obtained by placing orders through the National Standards bodies of those countries.

As a part of its specialized service, the Bureau of Indian Standards procures and supplies copies of standards published by overseas Nations and International Standards. To get such International Standards through BIS, an order accompanied with an advance payment by cheque/demand draft drawn in favour of Bureau of Indian Standards, New Delhi, should be deposited.

24.2 VALIDATION OF STANDARDS

The purpose of the procedure is to highlight the need for the validation of these standards which are the only reference guide for manufacturing and testing of transformers. Each publication of Indian Standards Specification is controlled and monitored by a sectional committee. The committee is headed by the Chairman along with few members who are known to be the experts either from the industries or from the Govt. bodies. Whenever there is a scope to update the specification with new information, or to amend a particular requirement, or to reaffirm some specific clauses, the committee decides to incorporate tho se changes in the form of amendments, issued from time to time.

Under such circumstances, the old Standards which do not comply with the amendments should necessarily be withdrawn and replaced by the amended Standards. The procedure of issuing amended Standards is same as that followed by the Bureau of Indian Standards. Similar International committees are also there to take care of necessary amendments in other International Specifications.

The problems of most of the SSI industries in India start from here. In fact, most of them do not find a proper system by which they can update their reference standards as recommended by the BIS with proper amendments. In a few occasions, the BIS altogether withdrew some of the standards without offering proper replacement. There are engineers who refer to such standards, which had been withdrawn by BIS or amended by other International Standard. For example, IS-6160: Rectangular conductor for electrical machines, which had been withdrawn by BIS in their catalogue published in 1999. But this standard is very much popular among most of the designers and working engineers who still follow this standard as reference. Quality is bound to affect if we refer such standards, which are already amended or reaffirmed or withdrawn. A similar incident related to this discussion is quoted here:

A 1000 kVA, 11/0.433 kV distribution transformer was subjected to short-circuit test at the Internationally reputed test laboratory CESI, ITALY. As per the recommendation of the old IEC standard-60076, Part-5, the di-electric tests after the dynamic short-circuit test were to be performed at

75 per cent of the test voltage. But this requirement of the standard has been amended in the recent publication of the year 2000 with a recommendation to carryout dielectric tests at 100 per cent test voltage as against 75 per cent mentioned earlier. However, the firm's engineer who had been accompanied with the transformer to witness the type test at CESI, ITALY, was not aware of such amendments. The transformer had withstood all the tests including the 75 per cent dielectric tests after short-circuit test, but failed to withstand 100 per cent test voltage. Finally the transformer was declared failed by the testing authority as per amended specification.

24.3 HOW TO KEEP A CHECK ON VALIDATION?

'How to keep a check on updated validation of reference standards' is again a part of ISO: 9000 quality system. BIS publishes a catalogue every year which consists of all amendments, and notifications on reaffirmed or withdrawn Standards. It is one of the responsibilities of the quality assurance engineer to update all his standards as per the recommendations of current published catalogue of BIS. In case any of the Standards is found amended as per the current publication, we should collect the amended standard from BIS and withdraw the old standard from the works with a specific remark 'withdrawn' on the cover page with ink of specific colour.

This will restrict the use of such withdrawn standards. In the case of International standards, there are approved agencies available in all metro cities including a special department in BIS who undertake to provide such information for overseas publications of International standards.

24.4 MAINTENANCE OF DOCUMENTS

Maintenance of documents is again an activity requiring skill on the part of the quality assurance engineer. All standards which are known to be already updated should be codified with a controlled copy number and date. There should be a register in which a note should be kept of all such controlled standards including the circulation status of each of them. In case, a photocopy of a specific standard is issued to a particular department, the same should also be recorded in the register. On the whole, the register should have the data about the stock of standards available with the Q.A. Engineer along with the status of circulation of such controlled standards.

As has been discussed in the earlier paragraph, in case an amendment has been directed by the BIS publication in their new catalogue for a particular standard, the quality assurance engineer must replace the old one by the amended standard with the same controlled copy number but with suffix-A. The old standard along with the photocopy, if any, must be withdrawn with a clear withdrawn indication on the cover page of the old standard. For example, if the controlled copy number of a particular standard was 57 before, which has been replaced by an amended standard, the controlled copy number of the amended standard should be marked as 57-A.

This will help the Q.A. Engineer to identify easily the number of amendments that had been taken place over a duration of time on a particular standard.

It has been seen in many occasions that the maintenance staffs, electricians and similar other staffs etc. follow some engineering diaries relating to the fuse rating *vs.* motor H.P., conversion table between inch and millimetre, pound *vs.* kg, centigrade *vs.* fahrenheit, insulation resistance *vs.* temperature etc. This practice should be discouraged. In the event, such tables are essential for them to take independent decision during maintenance work, the same should be prepared by the Q.A. Engineer with the help of design department and should be circulated with specific controlled copy number. Such documents should also be updated from time to time, if necessary. This additional effort by the Q.A. Engineer will reduce the probability of committing mistakes, often due to misprinting in such diaries.

24.5 CONCLUSION

The withdrawn standards should be kept away from the working engineers. But they should not be destroyed. These withdrawn standards should be kept in safe custody. One can study the changes that have taken place on a particular standard over a period of time. This will give a fair idea about the quality improvement of a particular standard.

Section III

CHAPTER 25

Training

FOOD FOR THOUGHT

Today, quality is considered vital to improve productivity and to be competitive. Making employees conscious of quality related subjects is the first challenge that many companies face as they strive to be world class and global producers. The quality improvement depends upon environment, system, education, training, rules, responsibilities and cost of quality. All quality gurus emphasize education and training to improve quality and productivity.

Education is not about memorizing or possessing knowledge. It is the ability to recognize your strengths and shortcomings, ability to find sources for updating your skills and knowing how to use the information once it's acquired. There are differences between education and training. Education is the knowledge obtained through learning basic principles. It is a formal process of learning by attending classes, seminars and so forth, and it does not add any value if it is not applied appropriately. Education is a self-initiated process where a person desires to learn and advance and satisfy curiosity.

Training means becoming proficient through special instructions and drills. It is teaching someone else how to avoid making the same mistakes. Training provides very specific skills intended to close the gap between current and desired abilities. Training can be mandatory or voluntary.

Education and training require practice, patience, and a desire to learn. Mastery is achieved after education and training are put into practice. Education helps understand the 'whys' and training 'how to.' Understanding and knowing the underlying concepts allow instant and intelligent course correction.

25.1 INTRODUCTION

The purpose of training is to develop the skills of the individuals and to make them perform more actively to produce better quality products. The process of manufacturing a transformer is mostly manual in nature where the individual skill plays a very vital role towards the ultimate quality of finished product. The weak areas of the personnel should be identified and they should be strengthened through training.

Training is one of the tools of the management which helps build skills among the individuals. There is a common saying: 'learn by mistake', which means, the mistake should be first identified and then the concerned person is communicated through training to curb reoccurrence of mistake in future.

25.2 MANAGEMENT'S ROLE

Managements of small industries are often blamed for low quality products, on the lack of quality consciousness and poor work culture among the workers. A deeper analysis of this issue shows that the workers can be held responsible only if the management:

(*a*) has thoroughly trained the operators in using the process equipments.

(*b*) has established the means to verify or assess the results of the employee's action.

(*c*) has provided the means for regulating equipments or processes, if results are found to be unsatisfactory.

Honest appraisals of most of the manufacturing units in developing countries show that the managements have failed to provide these vital inputs in most of the work stations. Rather than finding scapegoats, companies need to examine weaknesses in their management system.

The entrance fee to the world economy is quality. Real quality is like the engines of a jet plane. Without them, there is no flight. Quality is the engine of the economy. The responsibility for quality lies in the hands of the managements of the organizations, whether they are involved in manufacturing or service.

When their products or services do not meet the customer's needs the management usually feels, the problem is with the workers, the customers or with the competitors and treat quality as something vague.

When offered the chance to take necessary actions for improvement, management often finds excuses in their national culture, purchase policies, service conditions etc. for its problems and throws up its hands.

Yet, at times these management teams are successful in casting aside their pre-conceived notions and get serious about quality. This comes about after they have a clear understanding of why quality is a problem and what they have to do in order to make it an advantage. It is a hard work that is never ending, but a pleasant experience. Comprehending quality management concepts has a positive effect on our personal life as well as professional. We learn to lead a less strenuous and more purposeful life.

25.3 ROLE OF INSPECTION

Inspection is the first formal quality control mechanism. But inspection alone cannot build up the quality of a product. Most manufacturers still believe that quality can be improved by strict inspection, which is not correct. Inspection has very little to do with the ultimate quality of the product. It should be clearly understood that inspection can only lead to the segregation of good from the bad pieces. It cannot by itself improve the quality of a manufactured product. Recent studies have shown that 60 to 70 per cent of the defects detected on the shopfloor are directly or indirectly due to lapses in areas such as design, process engineering and purchase.

It is, therefore, necessary to develop a quality culture through need based training among all personnel.

25.4 WHO SHOULD BE TRAINED?

All individuals whose contribution affect the quality of the product should be covered under the training scheme. All personnel from the departments of design, marketing, planning, purchase, stores, production, testing, inspection and despatch of finished goods should be trained in a planned manner. Training may be provided on individual basis or collectively, departmentwise, as required.

All members of the organization including the topmost executive of the organization should have a clear understanding of the quality requirement, its operation and the criteria for assessing the effectiveness. To achieve this, they could attend seminars, lectures, undergo special orientation and appreciation programmes and visit industries known for quality.

The middle management in functional areas affecting quality, play a crucial role in the implementation of quality system. Their training should cover two aspects. First is their professional competence in areas such as design, process engineering, testing, planning and purchase etc. The second aspect is company’s quality policy, quality system, and documented areas of responsibility.

When training in quality system is planned, attention should also be given to provide training in statistical techniques, such as process capability studies, statistical sampling, statistical process control, data collection and analysis as well as problem solving techniques. Preparation of troubleshooting chart is also a part of training.

The main group to be covered under training scheme is the production supervisors and workers. The basic work elements in all functional areas are carried out by the workers under the guidance of the supervisors. Their skills and competence have a decisive effect on the quality of the end products. These workers and their supervisors should be thoroughly trained in the skills required for their tasks. They need to know how to operate machines, tools and instruments. They should be able to read and understand specifications, drawings and other documents of the quality related activities. The persons to undertake special processes such as winding, welding, oil filtration, shot blasting, brazing etc. need to be certified after proper assessment. Training in elementary statistics are also desirable to create awareness in the quality of their working styles and to raise their confidence in producing quality products.

25.5 WHAT TO OFFER IN TRAINING?

Skill is required to identify the needs of training. The requirement is generally identified through performance appraisal by the seniors. This comes under the individual training scheme towards specific needs.

In case, a workman is slow in acquiring a desired skill, he should be given frequent training; either on the job training or demonstration by a skilled operator who is known for quality work in that particular process.

In the case of introduction of a new process in the manufacturing activities or a new machine, a collective training, taking all responsible workmen together as a group, may be imparted. Process flow charts, sketches, description in understandable language, work instructions, precautions, merits and demerits etc. should be used as training materials.

In case, a specific training need has emerged from the customer complaint data-bank, the same should also be covered.

25.6 FREQUENCY OF TRAINING

Training plan is done in advance. Scheme for imparting training is made in such a way that the personnel of all the departments are covered. Frequency of training depends upon the type of jobs they are handling, but a minimum of once in every alternate month. In transformer manufacturing, two groups of personnel are generally involved:

- One group of decision making people
- Other group, which implements the decision.

Training is required for both the groups. For the second group, in-house training is enough to build up the skills. But decision making people should take part in outside seminars, engineering exhibitions, lectures by experts, group discussions etc. on a regular basis.

25.7 ORGANIZING AND DOCUMENTING TRAINING PROGRAMME

Whatever may be the nature of training, it is to be documented. The documentation should cover the training materials, record of discussions and the names of participants. In the case of training of decision-making personnel, seminar papers, books etc. along with the remarks of the individual should be documented.

Depending upon the size of the company, either a person or a functional group should be given the responsibilities for organizing training at various levels. In large companies, the human resource development department may be assigned this task. In smaller companies, a personnel officer or Management Representative (MR) should be responsible.

Every departmental head, concerned about quality, is required to assess the training needs as well as the scope and the level of training required for the personnel working under him. Departmental heads should identify the personnel to be trained.

On the basis of this information, the officer incharge of training should organize sessions/classes in a systematic manner so that the person concerned can be trained within a definite time frame.

Particular attention should be paid to the training of newly recruited workers and personnel at higher level.

Training can be imparted in the form of organized courses, but most of it will be on the job, with employees working as understudies to their seniors. A full record of persons trained, the scope and duration of training and qualifications attained should be documented centrally. These records should be made available to various departments so that persons can be deployed for some specific work on the basis of their qualifications.

25.8 MOTIVATION OF PERSONNEL

Although ISO: 9000 does not cover motivation as a part of its programme, yet motivation is very important for the effective implementation of a quality system. A well organized quality management system will fail, if the management is unable to create enthusiasm for the system among the personnel and to secure their full co-operation.

The meaning of motivation is different for different groups of personnel in an organization. Some may work for money. Others may work for the security of job, and money may not provide any motivation. The motivation for the middle management group may be a promotion. The top executives generally look for fame.

A rickshaw puller demanded from a passenger a service charge of Rs.15 to reach the railway station in 20 minutes. But the passenger was in hurry to catch a train which was scheduled to leave the station within 10 minutes. He offered Rs. 25 to the rickshaw puller with a request to reach the destination by 10 minutes. The additional Rs.10 had motivated the rickshaw puller to drive faster than usual to reach the station before time.

In a manufacturing organization, the motivation for the workmen is the job security and promotion. Engineers and managers can be motivated by promotions. Money may not be a motivation factor for the decision-making people. For them job satisfaction, a sense of achievement, fame etc. may be the factors of motivation.

Involving personnel at various levels when activities in their areas are reviewed, will make them identify themselves with the new system. No attempt should be made to impose a new system or procedure on a department. In the early stages of a system's development, the shop floor engineers of all concerned departments should be encouraged to analyse their existing activities, come up with suggestions for improving standard operating procedures and instructions and propose mechanisms for monitoring and control. However, such suggestions should be critically reviewed before implementation. This mechanism of exchanging thoughts will encourage the middle management personnel and give them a sense of participation in the management programme.

25.9 INVOLVEMENT AND PARTICIPATION OF WORKERS

Involving workers in quality management is the most effective means of stimulating their interest in performing to quality standards. Genuine participation can be expected only if they are given full opportunity to express constructive criticism and suggest methods of improvement. Workers should be encouraged to make suggestions and these should be given serious consideration. If found practicable, the suggestions should be implemented immediately and the author should be acknowledged publicly. If the suggestion is not found useful, its drawbacks should be discussed with the workers and the difficulties in implementation should be explained. The author or some other workers may be able to make further suggestions to solve the problems presented. In no case, a suggestion should be brushed aside at first glance. In fact the workers should be encouraged to offer any solution which comes to their mind without fear of being ridiculed.

The above approach can be practiced by constituting shop quality committees, which could meet periodically to review the implementation of quality programme. These meetings, if properly conducted, will draw upon the experiences and ideas of actual operators and will be invaluable in highlighting areas of weaknesses as and will be a source of possible solutions. This mechanism of joint consultation will give the workers a sense of participation and generate enthusiasm for the quality programme.

25.10 HRD-PIVOT OF THE MANAGEMENT

Human Resource Development (HRD) emerged as an important subject in all management programmes. It is very important to know the various aspects of HRD and its relevance in today's work culture. HRD means development of human resources through awareness, training and behavioural changes in a continuous and planned manner. It is used to sharpen skills and exploit inner potential of employees for their own and organizational development. Manpower planning, proper selection of personnel, training, updating the skills periodically, motivation, appraising their performance and caring for their welfare

are considered very important aspects of HRD. The human resource is now recognised as the most valuable of all organizational assets.

A HRD personnel needs to have a thorough understanding of the subject, like organizational behaviour, organizational development, personnel management, industrial relations, labour laws, management of training programme, wages and salary administration and some other quantitative application of HRD as well. The major challenges to the HRD personnel is to tackle problems like the emerging role of women, child labour, maintaining creativity and innovation, retaining employees, motivating people, transparency in the organization, building teams and training the employees. The key role of the HRD personnel is in conducting short and long term training programmes, improving communication skills and relationship among employees, performance counselling, manpower planning etc.

25.11 CONCLUSION

Today’s world takes no pity on the person who is lazy to learn. There is a need to continue education, to protect one’s career.

It does not take long for skills and knowledge to get outdated in a fast-changing world. Technological advances and the flood of new information make it hard to keep up with what’s going on. College graduates can find even their most advanced technical skills outdated in a matter of years. Craftsman must constantly adopt new tools and techniques. There is a need to constantly update knowledge to avoid becoming out-dated.

Continuous learning is the only way to remain competitive in the market. We should invest in our own growth and development. We should do this the way a company invests in research and development, and come up with new and better products or services.

Future employability as a job candidate depends on the relentless drive to update the credential, acquire new skills and stay abreast of what is happening.

Reading, attending workshops and seminars should become a regular part of our weekly routine.

The more we know how to do, the better we can do it. Thus, we become more valuable and greater in our job security.

So education is an unending process. We should defend our career by developing a better package of knowledge and skills than the other person.

Section III

CHAPTER 26

Statistical Technique

FOOD FOR THOUGHT

''Stress For Quality–but Don't Make Quality Stressful''

The country, the economy, supply and demand, and environment do not influence a quality culture. Rather, quality is an inner feeling for one to perform the best. It creates a conducive environment for everyone to provide the best. Culture relates to customs or beliefs guiding an organization or a society. An organization's culture is the best of values, beliefs and behaviours that form its core identity.

The basic Total Quality Management (TQM) principles should be installed in children as a way of life. Quality culture and ethics go hand in hand.

Quality culture helps in eliminating defects. It injects the urge for continuous improvement and prevention of faults. Healthy competition and quality culture will bring out the best in everyone. Inheritance of quality culture will open the doors to opportunities.

A company wide effort to develop a flexible and responsive corporate culture is required to succeed and progress in the 21st Century. Developing an open and more responsive culture is a key to future competitiveness or even survival.

26.1 INTRODUCTION

The manufacturers should be able to establish the procedure for identifying adequate statistical techniques for verifying the acceptability of process capability and product characteristics. It is seen that the application of such techniques is beneficial to the manufacturer in a wide variety of circumstances. These techniques are cost effective means of data analysis, assessing product quality, establishing product tolerances and process limits and controlling the processes.

The most commonly used statistical technique is sample inspection. This is most often employed to establish the quality of a batch on the basis of small samples. However, emphasis has now been shifted to the preventive aspect of quality control. Attempts are made to solve problems by eliminating the root causes of non-conformity. For this purpose, seven important tools have come into prominence during recent years.

26.2 SEVEN TOOLS

The application of seven tools of statistical technique do not require much statistical computation and can be easily understood and employed on shopfloor. A brief description of the seven tools are given in Table 26.1.

Table 26.1

Technique	*Details*
Check sheet	Proforma sheet for recording data during inspection or checking. Facilitates product and process analysis and the identification of appropriate corrective measures.
Pareto analysis	Tabulating the source or cause of incidence of a problem or of factors contributing to a problem.
Histogram	Vertical bar chart showing frequency distribution of data; Helps in narrowing down the search for problematic areas by showing the pattern of variation; Deviation from the desired average level. The presence of an assignable cause of variation which needs detection and elimination.
Cause and effect diagram	A structure like a fish bone in which the problematic quality characteristic is indicated by the backbone and the major factors (*e.g.* materials, methods, men, machines) which are primary causes of the problem are represented in the form of arrows emerging from the backbone. The secondary causes are represented by small arrows emerging from the primary causes. Causes are identified in brainstorming sessions attended by all concerned. The diagram helps in the systematic search for the root cause of the problems.
Stratification	Tabulating the incidence of the problems according to category to narrow down to the problem area. For example, occurrence of problems by shift, operator or period.
Scatter diagram	Scatter of points on an *xy* plane in a graph representing pairs of observations on the influencing variable *x* and the dependent quality characteristic *y*. This helps in understanding the relationship between variables for control and for prediction purpose.
Graphs and control charts	Graphs are simple charts of quality characteristic Vs time. Control charts consist of a central line corresponding to the desired average level and two lines called the upper control limit and lower control limit. The control limits indicate the limits of natural variation of the sample statistics. The sample statistics are usually average, range or individual measurements of some dimensions or characteristics, per cent defectives, number of defects per item etc. Control charts help in deciding when to look for trouble with the process and when to leave the process undisturbed.

26.3 VARIOUS OTHER TOOLS FOR STATISTICAL TECHNIQUE

In addition to these seven tools, there are a number of other statistical techniques that can be employed for the optimization of product design, refinement of the processes and the development of sources of supply. Some of the more widely used techniques are listed in Table 26.2.

Table 26.2

Technique	*Details*
Statistical tolerancing	To arrive at realistic tolerances for components or to achieve desired tolerance levels in random assemblies or clearance of mated components.
Sampling inspection	To assess the quality of a lot by inspecting a sample of a pre-determined size and using established criteria for acceptance.
Probability plotting	To ascertain the nature of data and estimate characteristics, like Standard Deviation, average etc. on the basis of a small number of observations.
Process capability	To determine the inherent variability of a process due to random causes which cannot be isolated.
Tests of significance	To judge whether the observed differences are due to sampling fluctuation.
Multiple regression analysis	Identification of the important factors influencing a response and their quantitative impact.
Reliability techniques	These seek to improve reliability which is defined as the probability_that equipment will perform an intended function for a stipulated time under specified environmental conditions.
Design of experiments	Identify optimum process parameters and their levels for improved performance.
Operation research	Optimize the effectiveness of operation or activities.
Analysis of variance	Comparison of more than two sample averages or assessment of the contribution of different factors to the overall variability.

The above mentioned statistical techniques can be applied in many of the company's functional areas, depending on the type of product, complexity of processes and volume of operation.

26.4 COLLECTION OF DOCUMENTS

The application of statistical techniques requires well documented procedures for sampling, collection and analysis of data as well as decision-making. The concerned personnel also need proper training in the application of statistical techniques.

When planning the use of statistical techniques for process control, one should carry out a careful study to assess the need for such techniques. Unless statistical data are analysed and the necessary corrective action is taken, statistical techniques by themselves will not result in the improvement of quality. Statistical techniques are most effective when the process is amenable to regulation and a reasonable homogeneity of manufacturing conditions can be maintained.

26.5 APPLICABLE STATISTICAL TECHNIQUES FOR TRANSFORMER INDUSTRIES

So far, we have discussed statistical techniques in general, applicable to various manufacturing units. Out of the above, few techniques are very useful for transformer industries. They are:

(*a*) Pareto analysis
(*b*) Fish-bone chart (cause and effect)
(*c*) Graphs and control charts.

Applicability of Pareto Analysis for the Improvement of Quality

We shall restrict our discussion on a sample case study of non-conformance in the winding department. The non-conformance may be due to the following reasons:

(*a*) Axial length of the coil beyond tolerance
(*b*) Thickness of the inter-layer insulation
(*c*) Bare conductor size
(*d*) Covered conductor size
(*e*) Inside and outside diameter of finished coil
(*f*) Failure due to machinery.

To prepare a pareto chart, we need to analyse the causes of non-conformances during a specific period of time. Similar types of non-conformances are clubbed together and placed on the vertical axis of the graph. Nature of non-conformance will appear on the horizontal axis. Some typical case studies done in a transformer industry from January 1998 to June 1998 are shown in Figs. 26.1 to 26.6.

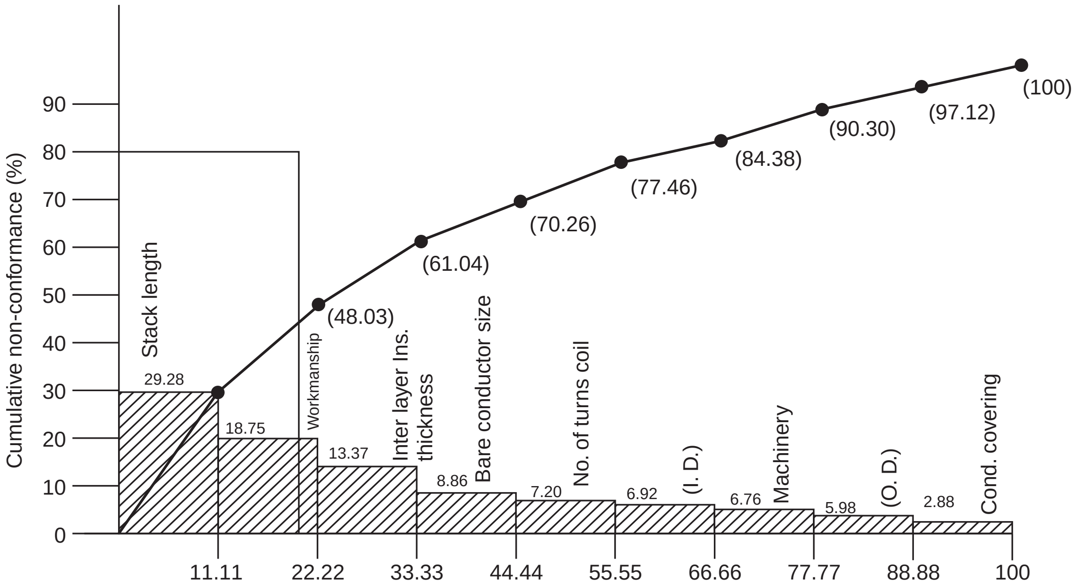


Fig. 26.1 Pareto analysis of non-conformance of winding dept.
(Period from Jan. 1998 to Jun. 1998)

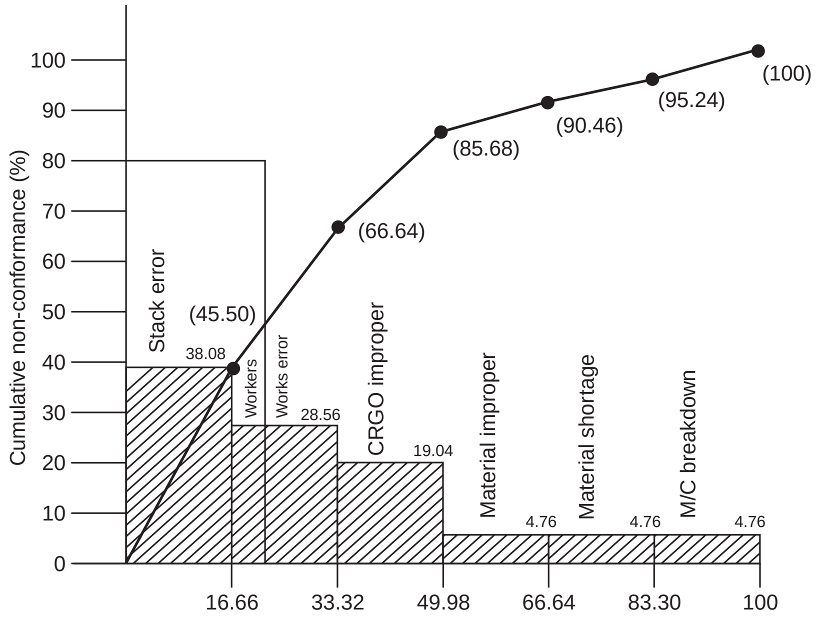


Fig. 26.2. Pareto analysis of non-conformance of core assembly dept. (Period from Jan. 1998 to Jun. 1998)

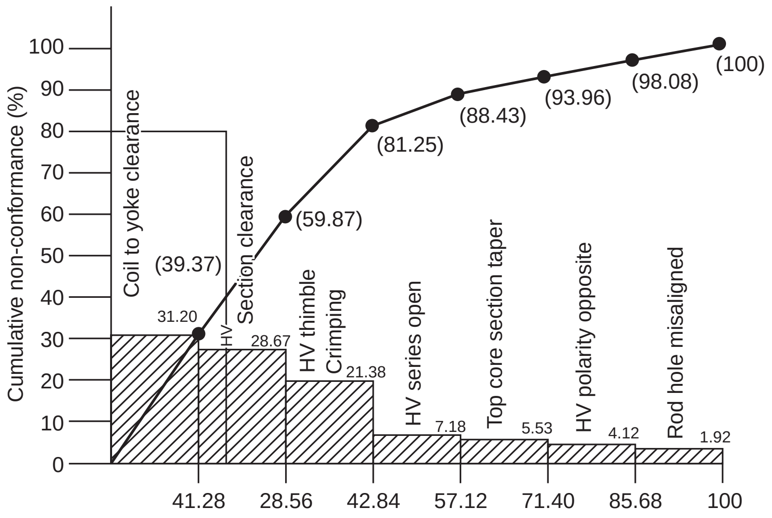


Fig. 26.3. Pareto analysis of non-conformance of coil assembly dept. (Period from Jan. 1998 to Jun. 1998)

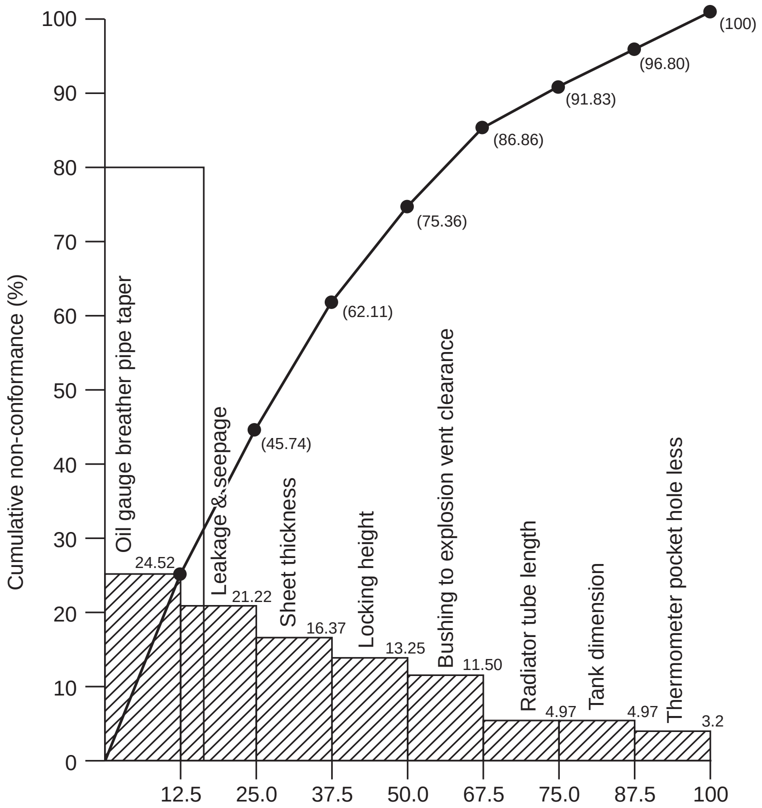


Fig. 26.4. Pareto analysis of non-conformance of fabrication dept. (Period from Jan. 1998 to Jun. 1998)

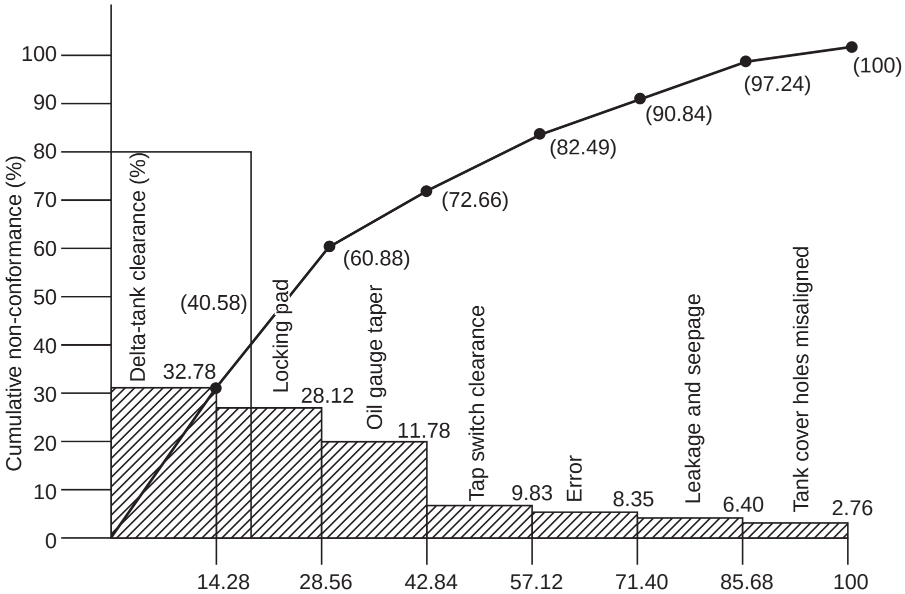


Fig. 26.5. Pareto analysis of non-conformance of box up dept. (Period from Jan. 1998 to Jun. 1998)

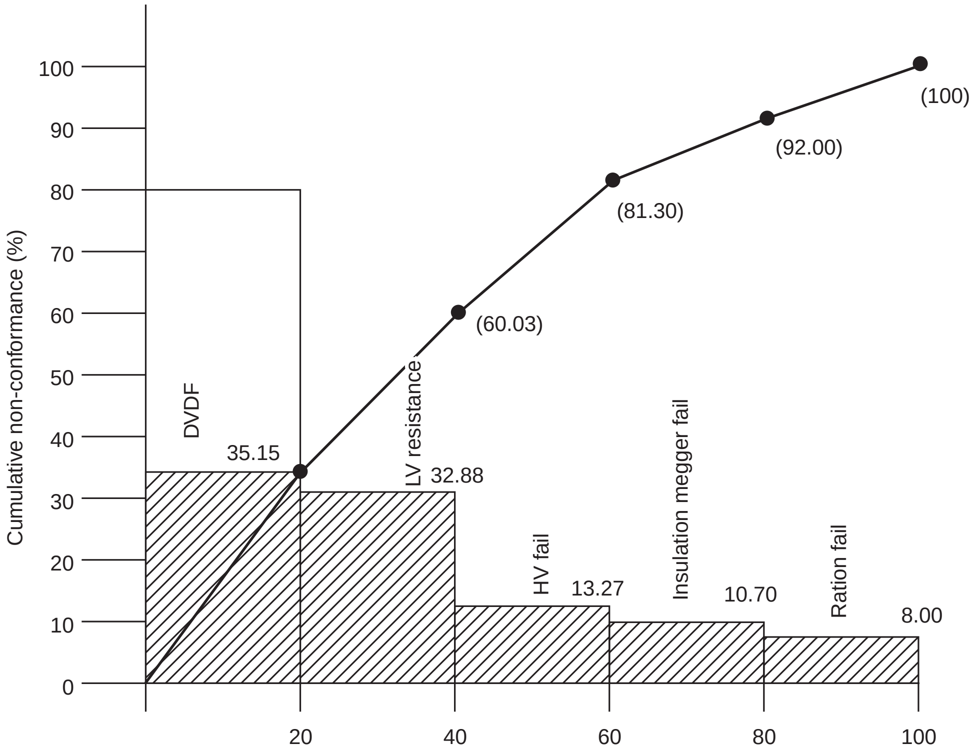


Fig. 26.6. Pareto analysis of non-conformance of testing dept.
(Period from Jan. 1998 to Jun. 1998)

From the pareto chart, we may conclude that the failure:

(*i*) due to axial length of coil (which is the highest) 29.28%

(*ii*) due to workmanship 18.73%

(*iii*) due to inter-layer insulation 13.37%

Now, it is the responsibility of the management to find out the reasons for such huge failure due to axial length. It may be due to wrong manufacturing process being followed, where the operators have no control on the axial length or may be due to workmanship or due to materials.

Proper corrective measures should be applied to curb the occurrence of such non-conformances in future production. The effectiveness of such corrective measures may be observed from the pareto chart made during the next half of the year.

Similar pareto charts and their analysis may be done for other departments also.

Applicability of Fish-bone Chart for the Improvement of Quality

We shall restrict our discussion on a sample study of non-conformance in the box-up department. The main causes and their sub causes are listed in Table 26.3.

Table 26.3

Main causes	*Sub causes*
Tank and radiator	Poor workmanship Not cleaned properly Moisture and/or rain water Leaking due to bad joint Inside poorly painted
Damage	Leads Coil insulation Delta connection Radiator
Clearances	Less between the HV coil and tank on both sides (lengthwise and widthwise) Tapping leads not placed properly Bushing alignment Job not properly placed inside the tank
Oil	Material quality Sample testing Filter machine — Filter, Vacuum, Heater
Insulation resistance	Human error Instrument not functioning
Connection/ termination	Bushings and metal fittings Quality of gaskets
Loose connection	Human error Poor quality of brazing

With the above available information, a fish-bone chart as shown in Fig. 26.7 to 26.11 may be prepared to identify the various causes and sub causes of failures and to offer remedial measures for future productions.

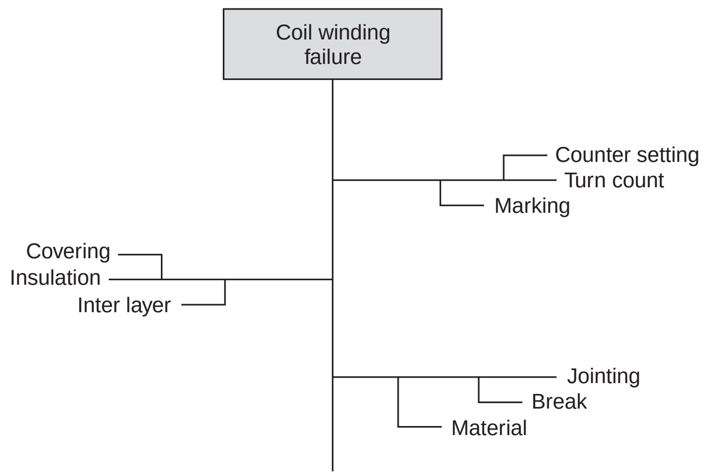


Fig. 26.7. Fish-bone chart coil winding process

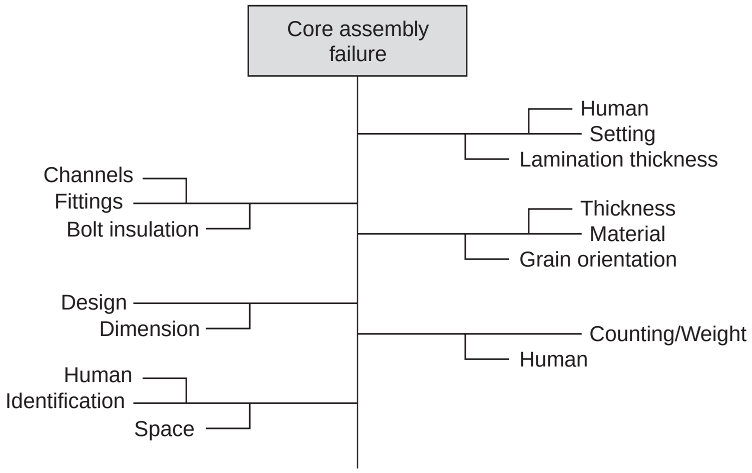


Fig. 26.8. Fish-bone chart core assembly process

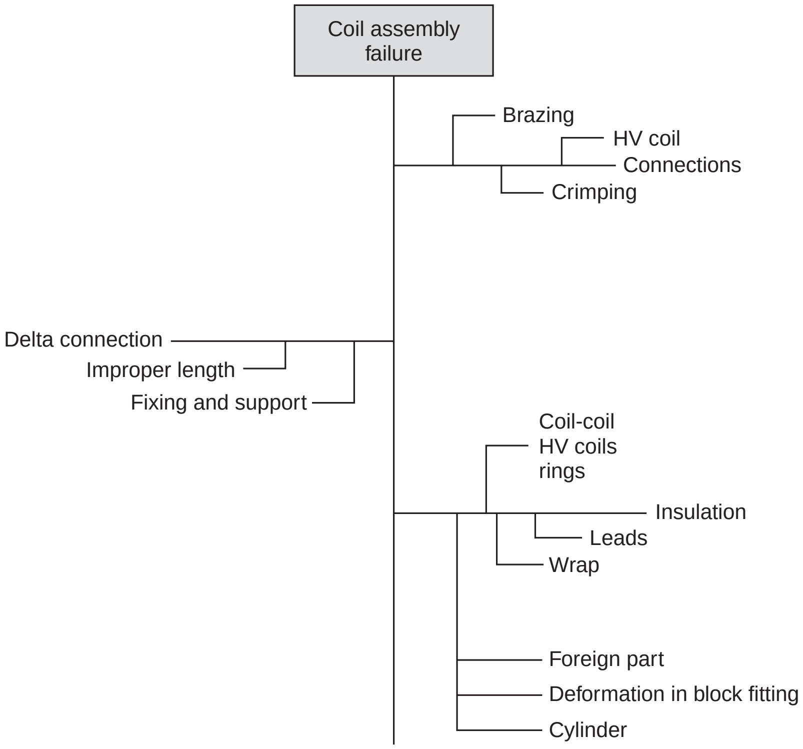


Fig. 26.9. Fish-bone chart coil assembly process

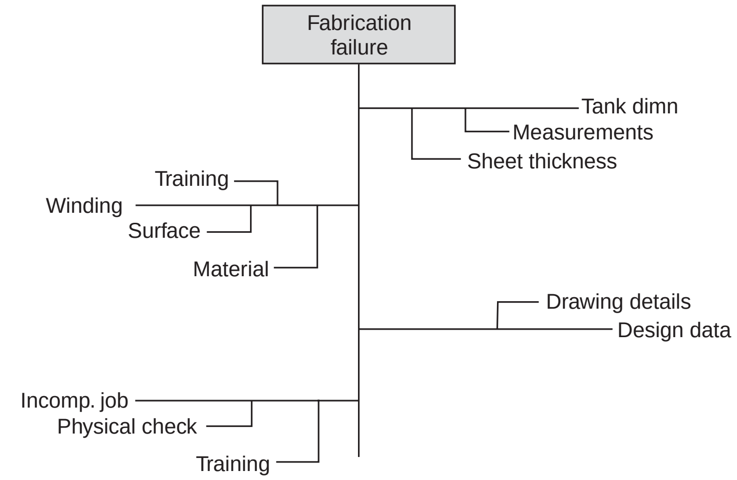


Fig. 26.10. Fish-bone chart fabrication process

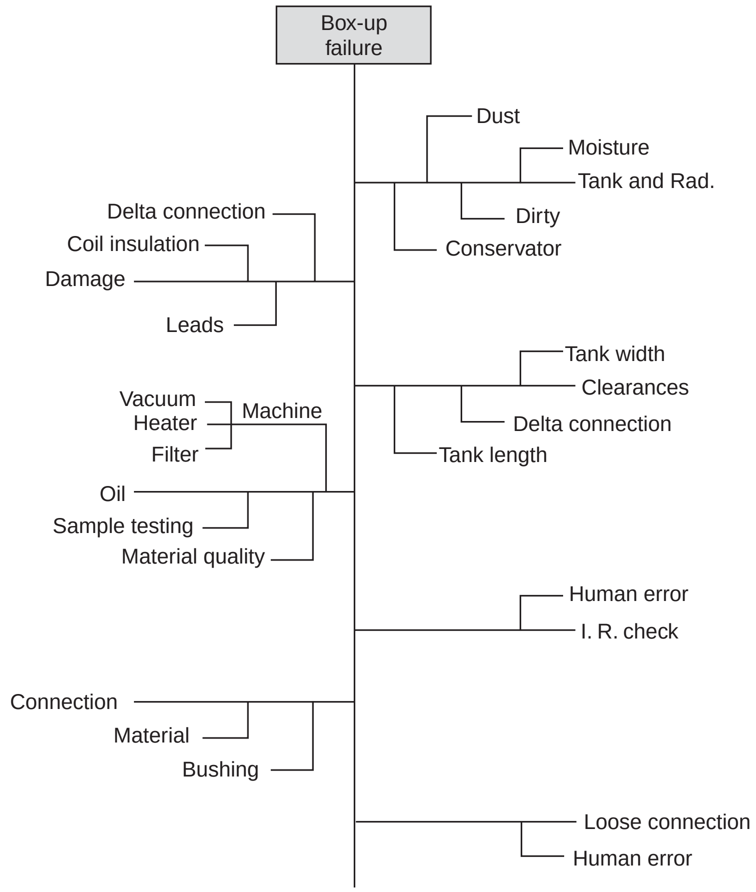


Fig. 26.11. Fish-bone chart box-up process

26.6 APPLICABILITY OF CONTROL CHARTS FOR THE IMPROVEMENT OF QUALITY

Controlling the quality of the products to maintain it at a given level is a major problem with all the manufacturers. From the early days of industrial production, manufacturers have tried to use the same men, machines, methods and similar raw materials in the hope of turning out products of uniform quality. But neither men nor machines are infallible and causes of irregularity often creep in inadvertently. As a result, rejections in the finished products are rarely eliminated and inspection and screening become necessary to varied extents determined by the nature of the product, goodwill and policy of the manufacturer.

Since screening is not an effective method of control, various other systems of controls were devised from time to time.

In 1924, Dr. W.A. Shewhart of Bell Telephone Laboratories, USA developed the control chart method of controlling the quality during production which is meant to be an intergal part of the production process. This technique based on statistical methods, however, did not provide an automatic corrective action in the way mechanical and electrical systems do.

Instead, it gave a warning signal to the operator that he must take care and corrective action on his machines or processes is necessary to ensure maintenance of quality in further production. Its effectiveness, therefore, depends on the promptness with which the warning is heeded to and action taken, keeping in view the fact that the work involved in applying the method is largely based on judgement, knowledge of the process and technical skill in tracing down unwanted causes of variation to their sources.

Control chart is essentially a graphical method representing a sequence (in time) of sample statistics. It consists of a control line (CL) denoting the average value of the statistics being plotted and it has two control limits on either side of the central line which are called upper control limit (UCL) and lower control limit (LCL). The control limits are determined statistically from the probability distribution of sample statistics.

The purpose of control chart is to obtain a state of statistical control by locating and eliminating the assignable causes and then to maintain the production in this state so as to ensure the manufacture of uniform products of acceptable quality. For this purpose, the variations due to unassignable causes are estimated and then used as the basis for the detection of the variation due to assignable causes by plotting the sample statistics on the control chart.

As long as the plotted points are within the control limits, the process is left alone. However, if a point falls either below the lower control limit or above the upper control limit, there is a possibility of the existence of some assignable cause and an investigation is made and action taken for the elimination of such causes.

Quality upgradation through control chart is not very much applicable to transformer manufacturing industries. But charts can be made to see the status of the performance figures with respect to guaranteed performance.

For example, a unit has produced a single lot of 150 transformers of 100 kVA rating. The guaranteed impedance voltage was 4.5 per cent with ±10 per cent as tolerance. As per the requirement of control chart:

Central line (CL)	:	4.5%
Upper control limit (UCL)	:	4.95%
Lower control limit (LCL)	:	4.05%.

The performance of 150 transformers were plotted to form a control chart as shown in Fig. 26.12.

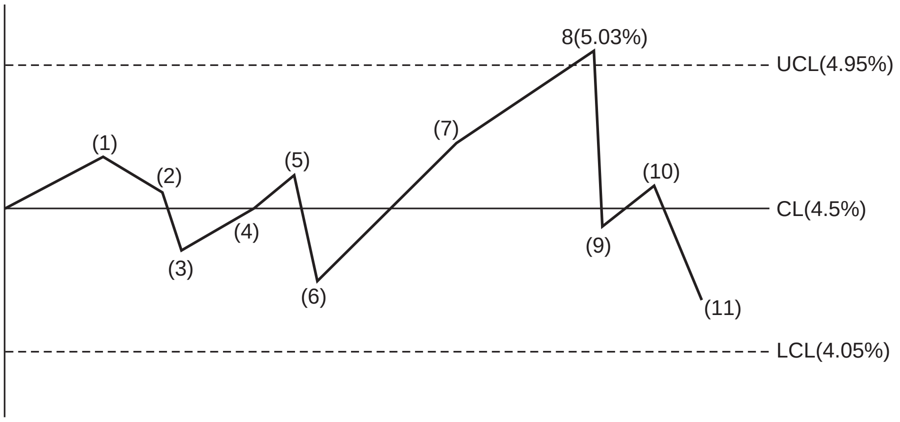


Fig. 26.12. Control charts

The impedance of unit no. (8) crossed upper control limit and hence declared failed in the stage testing. The core-coil assembly was taken out to locate the cause of high impedance beyond UCL. It was noticed that the effective stack length of LV and HV coil had reduced because of over compression.

Such control charts may also be made for the measurement of ratio error, resistance, losses etc.

26.7 CONCLUSION

Statistical charts for the activities of all other departments may also be made in line with the quality performance figures and targeted output and may be analysed for not achieving the target.

These are:

(*a*) No. of transformers produced per month against a targeted schedule

(*b*) MVA produced per month with respect to plant capacity

(*c*) Year-wise turnover for last ten years

(*d*) Rate of success in type testing

(*e*) Year-wise customer complaint

(*f*) Rating-wise percentage failure at customer's end during service

(*g*) Tender participated Vs achieved per month

(*h*) Transformer produced Vs failures during final test

(*i*) Monthly power failure in hours.

In case of non-achievement of any of the above cases, it may be analysed to find out the cause for future improvement.

Section III

CHAPTER 27

Basic Concept of ISO : 9000

FOOD FOR THOUGHT

The holidays are over, relaxation is history, and now is the time to march on. The customers of today are more informed and knowledgeable and as a result are asking more in functions, performance and price reduction. Customers have wide range of choices to select from. Some 90% of unsatisfied customers don't complain, but they do not offer further business. Additionally, it costs five times more to get a new customer than it does to keep a current customer.

During the 1980s, our challenges were to stay ahead in utilizing principles of quality. If we think the 80's were demanding, take a look at what we'll be facing in the future. Here are some of the challenges we can expect during this century.

- Customers (both internal and external) will establish more stringent requirement.
- Service industries will increase faster than the manufacturing industries.
- Automation will be added to the existing manufacturing line.
- Zero inventory will be a way of business.
- Highly sophisticated manufacturing systems will come into existence.
- Statistical control will replace 100% inspection.
- Technological innovation will pave the way to more high-tech industries.
- Techniques will be developed to qualify system and application software.
- A global market will require effective communication with people from different background and cultures.
- Closer relationship will have to be developed with the suppliers.
- Zero-defect requirements at all levels will have to be met.
- A scientific approach will be required to increase efficiency and effectiveness.
- One uniform standard will replace multiple standards.

In order to meet these and other challenges, we have to be prepared through education, self-development and training. We cannot afford to stay with the same level of competency and productivity we are at right now. Additional training and skill development is critical to maintain a competitive edge. Progress will be more important than mere survival. Continuous improvement will be a way of life.

27.1 INTRODUCTION

So far, we have discussed some of the practical aspects of ISO:9000 quality procedures for the upgradation of quality of the end products. Here, we shall take up the definition of various elements of ISO:9000 quality system. People working closely with the manufacturing and the servicing industries are familiar with the word ISO:9000. Basics of ISO:9000 quality management systems, registration approach and registration benefits etc. are highlighted here to provide guidance to a company wishing to pursue ISO:9000 quality system.

International quality management and quality standards, known as ISO:9000 series of standards, are produced by the technical committee (TC 176) of the International Organization for Standardization (ISO). Though the ISO:9000 series of international quality standards is relatively young, its root can be traced back to the founding of the International Organization for Standardization (ISO) in 1946. Geneva, Switzerland, based ISO was established to develop a common set of manufacturing, trade and communication standards.

The objectives of these standards is to facilitate international exchange of goods and services. One hundred countries are participating in the International Organization for Standardization—76 full voting privilege members, 20 (observers) correspondent members and 4 (documentation) subscribers. The ISO organization has 182 active technical committees, 630 subcommittees, 1918 working groups and 24 ad-hoc study groups. While ISO publishes thousands of standards, five documents in ISO:9000 series (ISO:9000 to 9004) are having a growing impact on international trade.

ISO:9000 quality system is the collective plans, responsibilities, procedures and resources which ensure the interest of the customers with respect to quality and delivery. ISO:9000 stands for system standarization and certification rather than for product standardization and certification.

27.2 ISO:9000 DOCUMENTS

First published in 1987 and revised in 1994 and 2000, ISO:9000 consists of five documents, which are:

ISO:9000 : Describes and clarifies quality concepts and provides guidelines for the selection and use of a series of International Standards on quality systems.

ISO:9001 : Provides a model for quality assurance in design, development, production, installation and servicing.

ISO:9002 : Describes quality assurance procedures in production, installation and servicing (design activities not included).

ISO:9003 : Model for quality assurance in final inspection and test.

ISO:9004 : Describes each of the quality system elements of ISO:9000 helping users to understand the entire operation in sufficient details to select the appropriate elements in designing quality system for a particular facility.

ISO:9000 is written in general terms to accomodate the full range of activities undertaken by the manufacturers and service providers. Companies that achieve quality system registration can look forward to improved relations with the customers, better control over paperwork and processes and increased marketability for products and services. It indicates the requirements of all major activities, such as (*a*) responsibilities of top managements, (*b*) setting up documentary evidence, (*c*) systems to prevent and/or correct non-conformance and specific action needed etc.

Quality manual describes the elements of the quality system. It is the 'top level' quality document and is supplemented by specific procedures and work instructions, which describe business processes to produce quality products and services.

The twenty elements of ISO:9001 quality system is divided into three groups under heading (*a*) System management (*b*) System methodology and (*c*) System maintenance. The twenty elements are :

(*a*) System management

4.1 Management responsibility
4.2 Quality system
4.14 Corrective and preventive action
4.17 Internal quality audit

(*b*) System methodology

4.3 Contract review
4.4 Design control
4.5 Document and data control
4.6 Purchasing
4.7 Control on customer-supplied products
4.8 Product identification and traceability
4.9 Process control
4.10 Inspection and testing
4.13 Control of non-conforming products
4.15 Handling, storage, packaging, preservation and delivery
4.18 Training
4.19 Servicing
4.20 Statistical techniques

(*c*) System maintenance

4.11 Control of inspection, measuring and test equipments
4.12 Inspection and test status
4.16 Control of quality records

27.3 APPROACH TO ISO:9000

ISO:9000 is the beginning for establishing quality efforts. ISO:9000 merely stipulates where the documentation is needed to validate the processes and different approaches towards implementation of ISO:9000 system, but never indicates how much is required.

ISO:9000 is not a product certification standards. Registration in no way measures or recognises the quality, good or bad, of a company's final product, or does not mean that two companies with ISO:9000 registrations are equivalent.

ISO:9000 is simple but not too easy. It requires:

(*a*) Management to be committed, involved, focussed and responsive
(*b*) People to be orgainsed, responsible, authorised, competent, empowered and knowledgeable
(*c*) Processes to be visible, traceable, consistent, repeatable, measurable and documentable

(*d*) Documents to be appropriate, relevant, simple, understandable and consistent with the processes in use.

ISO:9000 standards have basically three requirements:

1. The company must document the quality system and business processes in detail and identify and document all the processes that affect quality. This includes everything from training to customer feedback. In ISO language, it is called 'Plan what to do.
2. The company must ensure that each employee understands and follows the guidelines put forth by the documentation and to develop and implement a quality assurance programme. In ISO language, it is called 'Do what you have planned."
3. The documented quality system must constantly be monitored through internal and external audits and changed or updated when necessary. Audit means to verify and monitor the implementation, review and improve where needed. In ISO language, it is called 'Verification of activities with respect to what have been planned.'

Three step process to ISO-9000 registration includes

(*a*) Management involvement and organizational commitment along with team spirit

(*b*) Preparation of process:

- Understand the requirement
- Develop a good assessment of current compliance (gap analysis)
- Establish internal audit system
- Document the process

(*c*) Audit preparation.

- Stimulation
- Understanding the quality policy by all concerned
- Professional attitude
- Good working relationship with the external auditors.

IS0:9000 audit system includes first party audit and third party audit. The first party audit is performed by trained persons internally according to the established standards and documentations. The third party audit involves the concept of independent review and certification by an external organization. The second party audit which is performed by customer at the supplier's location may easily be eliminated, if the supplier is ISO:9000 registered. ISO:9000 registration assures that the quality processes are implemented and followed by everyone in the organization and ensure that they are documented and maintained to a degree that can be demonstrated to an outside agency.

Inherent in ISO:9000 standards is the concept of two party contractual relationship. ISO:9000 offers the most fundamental and basic aspects of quality to demonstrate that the company is doing what it says, so that the customer needs are satisfied. Governmental purchasing agencies of more and more countries are insisting on ISO:9000 compliance for their suppliers.

27.4 ISO:9000 REGISTRATION ROAD MAP

ISO:9000 registation steps include the following:

(*a*) Plan your work first

(*b*) Do your work according to the planning

(*c*) Check the product quality according to the standard

(*d*) Know what you and others are doing

(*e*) Involve management and make them understand the concept and obtain their commitment
(*f*) Establish a quality steering committee with empowerment
(*g*) Train management and employers
(*h*) Communicate registration plan
(*i*) Develop implementaion plan
(*j*) Create self-assessment questions
(*k*) Establish quality manual and procedures
(*i*) Establish an internal auditing system
(*m*) Measure compliance to the procedures
(*n*) Establish a comprehensive corrective action system
(*o*) Review results and act appropriately
(*p*) Call independent assessors to audit.

27.5 ISO:9001 CLAUSEWISE DEFINITION AND GUIDELINES

The following paragraphs will help to understand the clause-wise requirement of ISO:9001/1994 in relation to a particular type of business activity. It will also help to pinpoint areas where you need to strengthen your system further. There are twenty (20) elements which are applicable for ISO:9001 quality system. ISO:9002 has nineteen (19) elements. ISO:9001 and 9002 are identical except for exclusion of design element from the latter. ISO:9003 has only sixteen (16) elements. Four elements viz. Design control, Purchasing, Process Control and Servicing are not covered in ISO:9003. The selection of ISO:9003 is not common as it concentrates mostly on testing aspects which is really not a model for full quality assurance.

CLAUSE 4.1: MANAGEMENT RESPONSIBILITY

4.1.1. Quality Policy

Purpose: *To ensure the firm's commitment to quality implementation.*

This clause requires the chief executive to state in writing and to make known the firm's aims and objectives with regard to quality and customer satisfaction. All employees should understand the firm's quality policy and know exactly what is expected from them to achieve its aims and objectives.

4.1.2. Organization

Purpose: *To establish who is responsible for what*

4.1.2.1. It must be clearly stated in writing which personnel have the responsibility and the authority to carry out work affecting quality, correcting mistake and preventing problems from recurrence.

4.1.2.2. The business has to have right equipment and staff. The latter should be appropriately trained or have the requisite experience to carry out and check the work assigned to them.

4.1.2.3. A senior staff member should be given the responsibility for making sure that the quality system works correctly. This person is referred to as the 'Management Representative.'

4.1.3. Management Review

Purpose: *To establish that the quality system is working*

It is necessary to review periodically the firm's quality policy and the supporting quality system arrangement to ensure that they are effective and continue to satisfy the customer's requirements and the need of the business. Records of such review must be kept. These should address all points in the agenda together with any action taken and target dates for its implementation. It should be noted that review and audit are not the same. In fact the results of audit are the inputs for review

(*a*) Establish a quality policy

(*b*) Ensure that the policy is understood, implemented and maintained at all levels

(*c*) Identify and provide adequate resources

(*d*) Appoint a management representative

(*e*) Provide for a management review of the quality system to ensure its effectiveness.

CLAUSE 4.2: QUALITY SYSTEM

Purpose: *To setdown in writing what the firm does to obtain quality*

4.2.1. General

Where the clause says 'establish, document and maintain a quality system', it means that having put the quality system into place, write down what is done and keep an up-to-date record. For this, there should be a 'qualilty manual' which will act as a road map of your quality system. The quality manual should normally include or make reference to:

(*a*) A brief description of the activities of the business

(*b*) The quality policy

(*c*) A statement of responsibility and authority

(*d*) An outline of the procedure.

For the preparation of quality manual, choose a format appropriate for the business. However, guidelines may be drawn from ISO:10013 "Guidelines for developing quality manuals.''

4.2.2. Quality System Procedures

Purpose: *To set procedures and to ensure that they are followed.*

The need for quality system procedures to describe how our business operations are performed should be examined. Existing documentation may be adequate and can be referred in the quality manual. Many clauses in the standard require the availability of documented procedures.

The statement of procedures should specify who does what, where, why and how. Some companies may prefer to answer "how" in a different type of document called 'work instructions' and make reference to these in their procedures.

The amount of detail in the procedures and instructions would depend largely on the method used, the skills needed, the training undertaken and the extent of supervision required. Procedures and instructions should not be a wish list of what is desirable to happen in our business. They should accurately reflect what really happens.

4.2.3. Quality Planning

Purpose: *To establish what the firm is going to do to achieve quality*

A planned approach is essential to achieve quality in our products and services. For small businesses and routine products and services, the approach could be spelt out in the quality manual and procedures. Quality plans could be written in the form of checklist or flow chart which may include the reference to existing procedures.

In brief, the quality system (clause 4.2) should provide the following:

(*a*) An outline of the structure of the documentation in the quality manual

(*b*) The formulation of procedures, work instructions and formats for records

(*c*) The preparation of quality plan for each product and service

(*d*) The effective implementation of all the above.

CLAUSE 4.3: CONTRACT REVIEW

Purpose: *To ensure that the firm understands and meets its customer's requirements.*

This clause requires the firm to understand the customer's requirements before work begins. There should be written procedures to ensure that each contract or order, whether written or oral, is reviewed before it is accepted.

The review should confirm what the firm agrees to supply, when and how it should be supplied and that the customer is informed if any requirement cannot be met.

Where changes to an order or tender arise for whatever reason, the changes should be reviewed and agreed to in exactly the same manner as the original order or tender. If changes are accepted, it is important that every one in the organization who is affected by the changes is informed.

The clause also requires that a record of the review should be maintained. This record can be as simple as a signed note on the order by the authorised reviewer that the order can be fulfilled. Any other method (such as minutes of the meeting of the order review committee) decided by the organization is acceptable.

In brief, contract review (clause 4.3) provides for the following:

(*a*) A review of each order, contract or tender to ensure that the requirements are defined and documented, and that there is a capability to meet these requirements

(*b*) The establishment of amendment procedure

(*c*) Records on the various aspects of the contract for future reference.

CLAUSE 4.4: DESIGN CONTROL

Purpose: *To translate customer's needs into specification*

This clause will apply to the business only if it carries out design or development work and if the firm is setting out to meet the requirements of ISO:9001. The steps to be followed are outlined below:

(*a*) There must be documented procedures to plan and control the design process. These should clarify who is responsible for the various design tasks and ensure that all concerned have the information and resources they need.

(*b*) It should be clear what is to be designed and what regulations or requirements should be taken into consideration as design inputs.

(*c*) Formal review of the design results should be held at appropriate stages.

(*d*) The complete design specification should be checked to ensure that it meets all the customer's specified and implied needs and any other requirements.

(*e*) It should be possible to demonstrate that the designed product or service is capable of meeting the requirements of the actual users.

(*f*) Any subsequent change in the design must be controlled to ensure that the modified design is satisfactory.

In brief, design control (clause 4.4) covers:

(*a*) Design and development planning

(*b*) Identification and allocation of resources

(*c*) Organizational and technical interfaces

(*d*) Definition and control of design inputs, outputs and interfaces

(*e*) Design verification

(*f*) Design review

(*g*) Design validation

(*h*) Review, approval, recording and control of design changes.

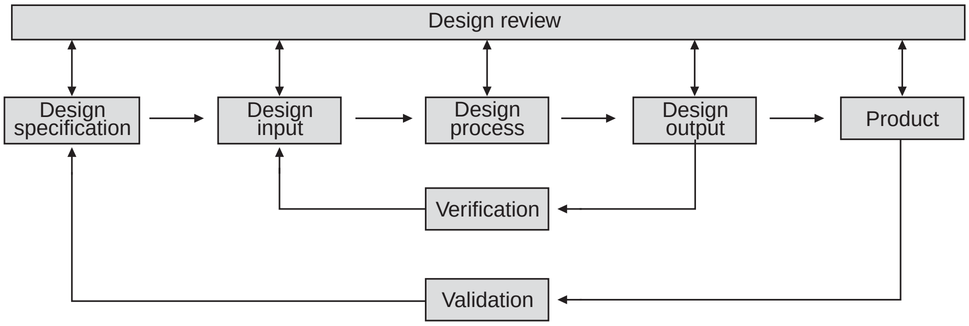


Fig. 27.1. The design control process

CLAUSE 4.5: DOCUMENT CONTROL

Purpose: *To provide people with precisely the document or information they need*

The clause requires a procedure to ensure that persons who need to refer to documents, as an aid for doing their jobs properly, have access to the correct and updated version of that document and such that documents are approved by the authorised person(s). It should be clear who has the authority to change such documents and how such changes should be implemented.

Document control should include:

(*a*) Review and approval of documents by authorised person(s)

(*b*) Making available the updated version of necessary documents at appropriate locations

(*c*) Removal of obsolete documents

(*d*) Authorisation and recording of changes in documents.

CLAUSE 4.6: PURCHASING

Purpose: *To avoid problems caused by purchased materials*

This clause is to ensure that the raw materials and components bought from the subcontractors, conform to the actual requirements.

Failure to state our requirements fully and accurately and using unsatisfactory subcontractors can only add to the risk of our business and our customer not getting what they wanted. This clause requires:

(*a*) The assessment of subcontractors and monitoring their performance and capability

(*b*) Keeping records of the acceptable subcontractors

(*c*) Formal written definition in the purchase order of requirements and specifications

(*d*) Verification of the purchased products by the customer, if required in the contracts.

CLAUSE 4.7: CONTROL OF CUSTOMER-SUPPLIED PRODUCTS

Purpose: *To ensure that customer-supplied products are fit for use*

If the customer supplies something that becomes part of the final product or service, there must be a procedure to ensure that it is acceptable and is fit for the purpose for which it is intended. If for any reason it is unsuitable, this must be recorded and the customer be informed. Examples are to be found in laundry business, where the goods to be laundered are customer supplied, motor vehicle workshop where the vehicle for repair is customer supplied.

CLAUSE 4.8: PRODUCT IDENTIFICATION AND TRACEABILITY

Purpose: *To enable the firm to keep track of supplies, components and finished products.*

Where the customer or the firm needs product or component parts to be identified or traced, the methods to be used and records to be kept should be defined. The reasons for requiring identification and traceability are varied. Some applications are described below:

(*a*) In the clothing industry, materials from the same dye lot is usually processed as a batch to avoid a colour mismatch.

(*b*) In the pharmaceutical industry, the batch number of each lot of drugs manufactured must be traceable to the date of manufacture, the source, and quality of raw materials used.

(*c*) In transformer industry, materials like CRGO laminations, winding wires and strips, insulating oils etc. which are received from different vendors should be identified. The use of job card is a unique method of identification of transformers in progress.

CLAUSE 4.9: PROCESS CONTROL

This is a core requirement of quality control in the quality management system. It requires all activities affecting the quality of the products to be planned, controlled and carried out with suitable equipments and facilities. The best method for carrying out these processes should be established with detailed procedures and instructions, if necessary. The operation being carried out should be monitored to ensure that they are under control, with the aid, for example, of statistical techniques, such as control charts etc.

Some processes require operators to be trained or specially qualified or the process itself to be approved. In such cases, records should be maintained as appropriate. An example of such a process is 'welding.' The welder is required to be trained or qualified to perform welding according to the correct procedure in order to provide assured welding strength.

In brief, process control requires the following:

(*a*) Identify and plan processes

(*b*) Use suitable equipments and set up an adequate processing environment

(*c*) Prepare work instructions where their absence would adversely affect quality

(*d*) Comply with reference standards and quality plan

(*e*) Monitor key characteristics and features during production

(*f*) Approve processes and equipments as required

(*g*) Establish criteria for workmanship (by way of samples, illustrations etc.)

(*h*) Establish suitable equipment maintenance procedure

(*i*) Maintain records on qualified personnel and special processes.

CLAUSE 4.10: INSPECTION AND TESTING

Purpose: *To check that the incoming goods, inprocess components, finished products etc. meet established requirements.*

Incoming goods should not normally be used until they are checked and ensured that they satisfy the requirements (*i.e.* conform to the specification). The extent of incoming inspection and testing is at the firm's discretion, but it should reflect the firm's confidence in the supplier. Where items are released for processing before checking is completed, the procedure must ensure that those items can be retrieved and replaced should arise problems during processing.

The checks that are required at various stages should be identified, during preparation and processing, to ensure that the end-product or service is capable of meeting the customer's requirements.

A final check should be carried out before releasing the goods or services and records maintained as evidence that inspection and testing were satisfactorily completed.

CLAUSE 4.11: CONTROL OF INSPECTION, MEASURING AND TEST EQUIPMENTS

Purpose: *To ensure that the right equipment is used to check the quality of the product.*

This clause is applicable only to industries using measuring and testing equipements to verify that what is manufactured conforms to specifications. If our inspection procedures consist entirely of visual checks (say readymade garments), there is no need for measuring equipments and then this clause is not applicable.

However, if measuring and testing equipments are used, they will have to be controlled, stored and used properly and their accuracies are maintained at the level needed.

To make sure that the measuring equipment operates effectively and gives reliable results, it is required to:

(*a*) Ensure that it is regularly calibrated and adjusted as needed.

(*b*) Describe how the calibration is to be done and how it is to be recorded.

Calibration should be traceable to the National Standards. The records should show when the equipment was last calibrated, who did the calibration, what was the acceptance criteria, what was the result, its acceptability and how this affects the suitablity of the equipment, calibration status and when the next calibration is due. The frequency of calibration depends on the type of the equipment, its usage and how critical the measurements are towards product quality and performance.

(*c*) Ensure that it is possible to identify which equipment is calibrated and is suitable for use.
(*d*) Ensure that if an equipment is found faulty, the validity of earlier checks using that equipment is reviewed and appropriate action taken.

CLAUSE 4.12: INSPECTION AND TEST STATUS

Purpose: *To identify products that are ready to be passed on to subsequent stages of processing or despatch.*

The clause requires that it should be possible to identify quickly:

(*a*) Whether the required inspections and tests are satisfactorily completed

(*b*) Whether the product is ready to pass to the next stage or to be despatched

The following are a few of the examples that can be used to identify inspection and test status:

(*a*) The use of markings, tags, levels or similar identification

(*b*) The use of routing cards, inspection records, job cards and similar items

(*c*) The use of physical location.

CLAUSE 4.13: CONTROL OF NON-CONFORMING PRODUCTS

Purpose: *To establish ways to identify and deal with non-conformity.*

The clause is required to establish ways of identifying non-conformity, deciding what to do about it and how to keep the non-conforming product separate from acceptable products. It is also required to keep records of non-conformity to show what happened along the way and the final decisions made, *i.e.* disposition of non-conformity. Everyone affected by the problem needs to be kept informed of what happened.

When a non-conforming product is detected, the product may be:

(*a*) Reworked or repaired to meet specified requirement

(*b*) Accepted under concession, with or without repair

(*c*) Assigned for alternate usage

(*d*) Rejected or scrapped.

The management representative or any other person who is authorised should decide which of the above options is applicable for each instance of non-conformity.

CLAUSE 4.14: CORRECTIVE AND PREVENTIVE ACTION

Purpose: *To ensure that the problems are removed and to prevent their recurrence.*

It is essential to understand the difference between the following concepts:

Disposition of Non-conformance (or Fixing a Non-conformity)

This is about removing the problem (or improving the product) by repair, rework or any of the other ways described in clause 4.13.

Corrective Action

This is concerned with the finding out of why the non-conformity occurred and making sure that the problem does not recur.

Preventive Action

This is about predicting the likely occurrence of a problem (non-conformity) and taking action to prevent it.

Thus, both corrective and preventive action lead to quality improvement.

This clause also specifies that the persons responsible for authorising and carrying out the corrective and preventive action should be identified.

Corrective action may be the result of:

(*a*) Customer complaints

(*b*) Non-conformity

(*c*) Rework or repair

(*d*) Audit reports.

Triggers for preventive action include:

(*a*) Market survey

(*b*) Sales figures

(*c*) Suggestion from employees

(*d*) Audit reports

(*e*) Quality records.

Taking preventive action may necessitate change in the quality manual, procedures, work instructions etc. It should also be reported in the management review meetings.

CLAUSE 4.15: HANDLING, STORAGE PACKAGING, PRESERVATION AND DELIVERY

Purpose: *To ensure that goods are appropriately handled.*

In all the stages of processing, provisions should be made for appropriate handling, storage and preservation of goods. Similarly, procedures for packaging and delivery should ensure that the product reaches the customer in the condition in which it left the firm.

CLAUSE 4.16: CONTROL OF QUALITY RECORDS

Purpose: *To establish proofs (records) of action taken.*

Records should be kept to show that the required controls were applied and that customer requirements were met. The following should be provided for record keeping:

(*a*) Retention time for records

(*b*) Storage conditons, retrievability and identification

(*c*) Method of disposal when no longer required.

CLAUSE 4.17: INTERNAL QUALITY AUDIT

Purpose: *To establish that the firm is doing what it said it would do.*

It is required to carry out scheduled periodic checks to ensure that what is stated in the quality manual, procedures and instructions are actually being done.

These checks (internal audits) should be carried out by a person(s) who is not directly responsible for the activity being audited.

A record of the findings of audit, including its follow-up-actions should be maintained and important issues discussed in the management review meetings.

CLAUSE 4.18: TRAINING

Purpose: *To ensure that your staff is adequately trained.*

All staff members who have an influence on the quality of a firm's products or services must be qualified for the work they do. They must have the appropriate education (technical knowledge, skill etc.), training and experience. In small firms where formal education and training of workers may not always be possible, it is important to ensure that they have full knowledge of the activities they are performing and are able to follow written procedures, drawing, sketches and work instructions.

It should be ensured that the training needs of the staff are identified, the necessary training planned, given and records maintained.

The management review (clause 4.13), corrective action (clause 4.14) and internal quality audit (clause 4.17) are all likely to identify problem areas which may indicate a lack of training.

CLAUSE 4.19: SERVICING

Purpose: *To set up procedures for after-sales service.*

Where servicing is undertaken as a part of the contract with the buyer or if the product provides a warranty and service is included as part of the warranty, then there must be a procedure to make sure that the necessary activities are performed correctly and that reports or records are available to confirm this.

CLAUSE 4.20: STATISTICAL TECHNIQUE

Purpose: *To establish whether your firm requires sampling and statistical techniques.*

It is required to establish if there is a need to use any statistical techniques. If there is no need for such techniques (to be stated with reasons), then clause 4.20 does not apply. The need for statistical techniques arises when it is required to make sure that the processes are capable of consistently meeting the customer's needs or to confirm that the product is satisfactory.

Some common techniques are:

(*a*) Sampling plan

(*b*) Control chart

(*c*) Pareto chart

(*d*) Fish-bone chart.

Statistical techniques could also be used for the analysis of market research, stock control, analysis of defect levels etc. The clause requires that, having identified the needs for statistical techniques, procedures should be prepared to establish how each technique is to be effectively applied in practice.

27.6 THE HIDDEN STRUCTURE OF ISO:9001

Figure 27.2 shows how the 20 clauses of ISO:9001/1994 can be grouped under four areas.

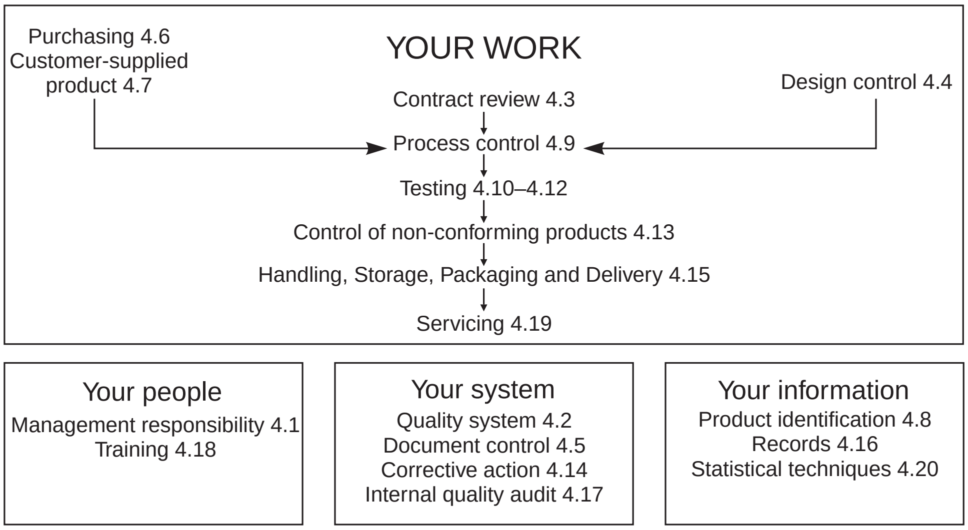


Fig. 27.2. The hidden structure of ISO:9001

The clause on ‘‘your work’’ starts when you receive an order or request for tender and finish the moment you deliver the product or service. Clauses 4.3, 4.4, 4.6, 4.7, 4.9, 4.10, 4.11, 4.12, 4.13, 4.15 and 4.19 fall under this category.

Two clauses (*i.e.*, 4.1 and 4.18) relate to ‘‘your people.’’ These clauses require the staff to be managed in such a way that everyone knows what is going on.

Four clauses on ‘‘your system’’ (*i.e.*, 4.2, 4.5, 4.14 and 4.17) make sure that you prepare your quality system documents, control them and audit their implementation so that your business runs smoothly.

Three clauses concerning ‘‘your information’’ (*i.e.*, 4.8, 4.16 and 4.20) make sure that your decisions are based on soild information. They ask you to identify your products and to keep records.

27.7 ISO:9000:2000 QUALITY MANAGEMENT SYSTEM REQUIREMENT

The ISO standard was first published in the year 1982 and subsequently revised in 1987, 1989 and 1991. The standard further underwent some minor revisions in 1994. Finally fifth revision, ISO 9000:2000 has been adopted to give users the opportunity to add value to their activities and to improve their performance continually by focusing on the major processes within the organization.

Extensive surveys have been performed on a world wide basis to understand the needs of all the users of the quality management system standards. The new revisions are based on previous experience with quality management system standards and emerging insights into generic management systems. This has resulted in a closer alignment of quality management system with the needs of the organization and better reflect the way the organization runs its business activities.

The major reasons for the year 2000 revision of the standards are the need to monitor customer satisfaction, meeting the need for more user-friendly documents, assuring consistency in quality management system requirements and guidelines, prompting the use of generic quality management principles by the organization and enhancement of their compatibility with ISO:14001 (Environmental Management Systems—Specification).

The current revision of the year 2000 is a major structural and strategic revision of the standards. It incorporates several concepts that will tend to bring the standards into better alignment and harmony with those that are generally considered ''best practice'' in contemporary strategies for successful quality management systems.

Quality Management Principles

To lead and operate successfully, it is essential to manage the organization in a systematic and transparent manner. Success can result from implementing and maintaining a management system that is designed to continually improve performance by addressing the needs of all interested parties. Managing an organisation encompasses quality management amongst other management disciplines.

In June 1997, the committee had published a guideline document featuring eight principles of quality management, to facilitate the achievement of quality objectives. They are listed below.

Customer focus: Organizations depend on their customers and therefore should understand current and future customer needs, should meet customer requirements and should strive to exceed customer expectations.

Leadership: Leaders establish unity of purpose, direction and the internal environment of the organization. They create the environment in which people can become fully involved in achieving the organization's objectives.

Involvement of people: People at all levels are essence of an organization and their full involvement enables their abilities to be used for the organization's maximum benefits.

Process approach: A desired result is achieved more efficiently when related resources and activities are managed as a process.

System approach to management: Identifying, understanding and managing a system of interrelated processes for a given objective contributes to the effectiveness and efficiency of the organization.

Continual improvement: A permanent objective of the organization is continual improvement of its overall performance.

Factual approach to decision making: Effective decisions are based on the logical or intuitive analysis of data and information.

Mutually beneficial customer-supplier relationships: The ability of the organization and its suppliers to create value is enhanced by mutually beneficial relationship.

Model of process based quality management systems: Any activity or operation, which receives inputs and converts them to outputs, can be considered as a process. Almost all activities and operations involved in making a product or providing a service are processes.

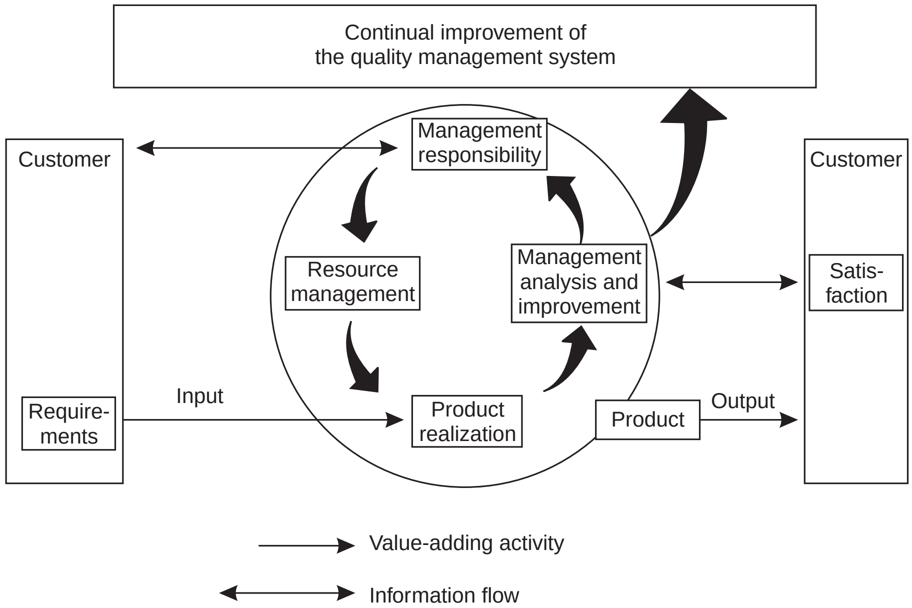


Fig. 27.3. Model for process based QMS

For organizations to function, they have to define and manage numerous inter-linked processes.

Often the output from one process will directly form the input to the next process. The systematic identification and management of the various processes employed within an organization, and particularly the interactions between such processes, may be referred to as the 'Process approach' to management.

The revised quality management system standards are based on just a process approach, in line with the guiding quality management principles.

The model shown in Fig. 27.3 above is intended to function similar to the Plan-Do-Check-Act (PDCA) model for the continual improvement process of business management popularized by W. Edwards Deming in the year 1980.

ISO:9000:2000 Series of Standards

The new standards consist of three basic documents in Quality Management System (QMS):

(*a*) ISO:9000:2000
Fundamentals and Vocabulary
(This replaces ISO:8402:1994)

(*b*) ISO:9001:2000

Requirements (for certification) (This replaces following standards:

ISO:9001:1994/ ISO:9002:1994 and ISO:9003:1994)

ISO:9001:2000 specifies the requirements of the quality management systems that can be used for internal application by the organization, or for certification, or for contractual purposes. It focuses on the effectiveness of Quality Management System in meeting the customer requirements.

In the new version of ISO:9001:2000, the familiar 20 elements that form the structure of the earlier ISO:9001:1994 series standards fold into a structure with four main clauses:

Clause-5: Management responsibility

Clause-6: Resource Management

Clause-7: Product realization

Clause-8: Measurement, analysis and improvement.

These four clauses describe the four phases of a fundamental concept for the new standards referred to as the process model.

ISO:9004:2000

Guidelines for Performance Improvement

ISO:9004:2000 gives guidelines on wider range of quality management objectives than ISO:2001, particularly for the continual improvement in overall performance efficiency and effectiveness of the organization. This, being a guidance document, is not intended to be used for third party certification purposes, and acts as a guide for management of the organizations who wish to move beyond requirements of ISO:9001. A key element in the ISO:9004 will be the ability to perform self-evaluation.

In addition, a new auditing guidance standard, ISO:19011, is in early draft stage and will replace ISO:10011 (part 1, 2, 3) as well as the environmental auditing guideline standards ISO:14010, 14011 and 14012.

Both ISO:9001:2000 and ISO:9004:2000 are organized to have the same structure and sequence. These two documents now form what ISO calls a ''consistent pair'' of quality management systems standards.

(*a*) The ISO:9001:2000 document defines the minimum requirements and

(*b*) ISO:9004:2000 provides guidance for companies to go beyond the minimum requirments by a process of continual improvement.

Fundamental changes in ISO:9001:2000 series of Standards

(*i*) 2000 series is a process oriented structure and is a more logical sequence of the contents helping to establish vital connection of quality management systems to organizational processes.

(*ii*) The new series requires the organization to define continual improvement process and establish important means to enhance the equality management system. This concept of continual improvement is one of the new additions to the old standard's requirements. In 1994 standards, customer complaints, self-audit, corrective and preventive action components are pointed in the direction of continual improvement, but now it is a fundamental theme.

(*iii*) The evaluation of customer satisfaction is the key information for improvement. Another fundamental difference in the new standard's requirements is the extension of the customer awareness and concern beyond a customer complaint system to the requirement for actual evaluation of customer satisfaction. The concept of customer satisfaction as a measure of quality system performance is a fundamental feature of most modern quality management systems and Total Quality Management (TQM) models.

(*iv*) The new series demand increased attention to an organization's key resources, such as communication and work environment. The major new requirement is in the area of resources management—the need to provide and make available specific types of resources. These will include elements such as information, communication, infrastructure and work environment.

(*v*) The new standard with its simpler and clearer language, which is readily translatable and easily understandable is more compatible with the environment system standards (ISO:14000). There is a high probability that at the next revision of these two standards, they will become unified into a single management standard.

(*vi*) The new services require increased emphasis on the role of top management, which includes its commitment to the development and improvement of the quality management system, consideration of legal and regulatory requirements, and establishment of measurable objectives at relevant functions and levels.

Time Limit for the Implementation of ISO:9000/2000

The validity of certification of the standard ISO: 9000/1994 has been extended upto 31st December, 2003. Till then it is open to follow ISO:9000/1994 standards or ISO:9000/2000 standards. But beyond December, 2003, ISO:9000/1994 standards will be permanently withdrawn, leaving behind only one standard, *i.e.* ISO:9000/2000. It is, therefore, necessary to study the requirements of the new standards and see how quickly it can be implemented in the Quality Management Systems.

27.8 PROCESS OF AUDIT

What is an Audit?

Quality audit is an independent evaluation of various aspects of work performed. It is a professional evaluation of the processes to determine the degree of compliance.

Why are Audits Performed?

Audits are performed to verify, by examination and evaluation, whether certain applicable elements of engineering/quality have been effectively implemented in accordance with the specific requirements.

An audit is a systematic prevention/appraisal activity that examines the policies, practices, records and the general activities to determine their adequacy in relation to a predetermined goal. Audits are performed to detect problems/deficiencies before the conditions deteriorate.

Briefly audits help to:

(*a*) measure quality through observations.

(*b*) detect errors and trends.

(*c*) identify areas where special attention is required.

(*d*) judge the adequacy of the plan.

(*e*) keep a process under control.

Quality audits are comparable to accounting audits that verify a company's assets and issue reports to pinpoint problem areas.

Who Performs an Audit?

Normally, a process or a product audit programme is administered by a quality organization. For example, the quality engineering group plans and writes procedures to perform an audit, and the quality control organization implements the plan and performs audits.

Team audits are performed by representatives from quality groups, manufacturing, product engineering and product assurance, functions with the quality group representatives acting as team leaders.

Audit Programme Problems

The following are some of the problems that are encountered during an audit programme:

(*a*) Failure to heed the previous audit reports

(*b*) Insufficient skill and knowledge of auditors

(*c*) Inadequate training of auditors

(*d*) No verification of findings

(*e*) No value added perspective

(*f*) Lack of technical details in reporting

(*g*) Too many disciplinary discrepancies

(*h*) Abrasive relationship between auditors and managers

(*i*) Lack of correlation between audit results and process yields etc.

A sure way to cause deterioration in human relations is to look for scapegoats instead of solutions. With systematic audit planning, effective feedback tracking, and training programmes, these problems can be eliminated.

Elements of an Audit System

Audits are usually structured to carry out planned goals and are conducted under specific rules. Because audits are the basis for a good deal of managerial action, they an entrenched in rules of conduct to ensure objectivity and validity.

Due consideration should be given to planning, since planning is a pre-requisite for directing and controlling audit activities. Some of these activities are related to:

(*a*) Strategic points where audits can be performed

(*b*) Audit frequencies

(*c*) Audit procedures/approach: sample size and tools to be used

(*d*) Training requirements

(*e*) Audit classification and criteria

(*f*) Verification of factual findings

(*g*) Audit results analysis and reporting

(*h*) Subsequent follow-up on plans for corrective action (*i*) Escalation procedure

(*j*) Database and historical evaluation.

The main purpose of planning is to provide a programme to measure conformance with engineering and quality requirements. Audits are subjected to control and must meet principles of efficiency and economy. Once plans and schedules are established, procedures written and approved, and essential training provided, the task of implementation becomes easier. Key points to be considered are feedback for corrective actions, follow-up audits to ensure effectiveness of corrective actions, and comparison with team audit results.

The scope and objectives of audits can influence the frequency of auditing. In principle, new system, procedures, operations, and products will be subjected to a relatively high audit frequency until users of audits gain sufficient confidence.

Types of Audits

Audits can be divided into routine audits and team audits.

Routine audits: Routine audits are sometimes called periodic or scheduled audits and are performed on a daily/weekly schedule by quality control personnel who are part of the organization.

Team audits: Audits can be periodic but random and unscheduled. Team audits performed in conjunction with manufacturing and other engineering personnel can alleviate (lessen) many problems. Representatives from manufacturing, quality engineering, test engineering, purchasing, or other disciplines may join as team members. A quality engineering representative acts as team chairman. Team audits should be performed at least once a year.

An auditing team is formed for one particular audit assignment or project, but the quality control department is a permanent organizational unit designed to manage and administer audits.

Subsystem of Audit Programme

Quality personnel may be called upon to perform the following types of audits:

Process audits: Process audits consists of verifying the process flow of a product, ensuring that the process is capable of producing a product as intended. Individual process steps, as well as the aggregate of steps, produce the product as required.

Equipment/tester/tool audits: Audits for equipments/testers/tools are performed to verify the settings, calibration procedures/intervals/status, associated softwares, performance, adequacy of preventive maintenance, and the capability of producing a desired product. Specification limits are checked and assurance is obtained that intended purpose is served; that is, defective products are not accepted and good products are not discarded.

Operator audits: Operator audits make sure that operators follow the procedures and understand the basic process/product flow. These audits are not intended to provide data on worker performance.

Documentation/record audits: These kinds of audits are necessary to ensure conformance to current practices.

Documented changes are normally made through process change notices or bulletins. Process change notices are generated as a result of reactions to problems or improvements made to enhance yield, quality or reliability of the product. No matter how a change is made, an unbroken audit-trail of the original process must exist. The documents should be checked for the following criteria:

(*a*) Existence of adequate job instructions

(*b*) Availability of documents for line personnel (*c*) Standardized documents

(*d*) Clarity and accuracy of content.

The following types of documents should be audited:

(*a*) Process operating documents

(*b*) Maintenance manuals

(*c*) Calibration/monitoring documents

(*d*) Process control charts

(*e*) Environmental recording charts

(*f*) Experimental work procedures

(*g*) Rework procedures

(*h*) Data recording/log books.

Records are objective evidence of performance and conformance. Records of measurements, schedule visual observations, work-in-progress etc. are maintained. It is the intent of the documentation audit to verify that there is proper control over documents, the system is adequate to provide information on quality to all concerned and that written procedures are adequate and are being followed.

Calibration/standards audits: Standards audits indicate types of the available standards on the manufacturing floor and traceability requirements of the standards. Standards are used to verify tester/ equipment settings and monitor their performances against known values. Workmanship standards in the form of photographs are provided as visual aids to the operators. Calibration audit is an independent unbiased audit to verify that equipment/tester used to produce a product has been calibrated and is not overdue for calibration. Audits are performed to verify the existence of calibration procedures and the degree to which these are met.

Product (subassembly/assembly) audits: Product audits are performed to make sure that components meet intended specifications.

Process control status audit: Process control status is verified through control charts. Control charts are observed for any noticeable trends and are then checked for accuracy to make sure that these charts are current.

Environmental audits: Environmental audits are performed to verify that acceptable levels of temperature, humidity, cleanliness, vibration, noise etc. are maintained, and that work areas are kept free of static charges through proper grounding procedures.

Chemicals/materials audits: Chemicals/materials audits are performed to ensure that the right types of chemicals/has not exceeded. In addition, the audits make sure that adequate care is being taken to prevent chemical hazards.

Vender purchased parts/components audits: These types of audits are performed to assure that acceptable quality level parts/components are used and that they can be traced to the original source in case of a problem.

Software system audits: These audits are performed to assure that adequate software change control is existing and adequate flow charts and documents do exist. System back-up software is available in case of a disaster. Software system includes tester/equipment control software and data collection software.

Material review board audit: The purpose of material review audit is to ensure that parts have been properly identified and segregated. Reasons for rejecting parts and the subsequent disposition of these parts must be accurately recorded.

Audit Results

Targets and goals should be established to measure the effectiveness of product and process controls and to identify conditions and trends that warrant corrective actions. When targets have been met consecutively for three months, a target-tightening practice can be implemented to increase efficiency of production.

Normally, deviations found during auditing can be classified as follows:

(*a*) Disciplinary type deviations. Example: not following procedures or simply violating the guidelines.
(*b*) Lack of training or knowledge. Example: lack of awareness of the basic facts.
(*c*) Equipment/tester tool malfunction. Example: inherent measurement error not accounted in the specifications, out of calibration condition, or loose guard bands.
(*d*) Process capability limitations. Example: process not suitable to meet product requirements.
(*e*) Poor workmanship. Example: operator related, tool related, material related, due to subjective specifications, due to unsuitable components.

Auditors are generally expected to review with the line supervisors any deficiencies found during the audit. The supervisory staff and auditors should agree on the finding before it gets reported to the higher management. The audit reports and recommendations should be problem-oriented rather than person-oriented. Audit observations should be based on agreed-upon classification, and the tabulated results should be made available for review.

Sufficient facts should be obtained through inspection, observation, inquiries, and confirmation to afford a reasonable basis for an opinion. Evidence should be collected on all matters related to the audit objectives. Check-list and procedures should be used to ensure depth and continuity to audits. The auditor must rely on evidence that is both persuasive and convincing. Statistical methods may be used to judge and establish facts. The audit should be thorough in the search for evidential matter and objective in its evaluation.

The following are some possible audit results:

(*a*) Acceptance or rejection of statements
(*b*) Identification of control deficiencies and inefficiencies
(*c*) Non-conformances
(*d*) Inadequate resource utilization
(*e*) Goal achievements against the targets
(*f*) Identification of strengths.

Corrective Actions

Manufacturers should have prime responsibility in seeking and driving for corrective actions and should be totally responsible for operator-related deviations.

Immediate feedback of the results is an important aspect in obtaining attention and corrective action. A permanent solution should be sought in place of a temporary ‘band-aid’ approach.

Follow-up audit should be scheduled to assure that corrective actions have been effective and no additional action is required.

Auditor’s Training

Professional auditors should preferably be knowledgeable in the following fields through one-on-one training, class room training, video-tapes, and reading:

(*a*) Product itself
(*b*) Product characteristics
(*c*) Product/process flow
(*d*) Process documents/records
(*e*) Identification and control of materials, parts and components
(*f*) Product handling procedures and limitations
(*g*) Test control
(*h*) Operating environment
(*i*) Feedback system
(*j*) Engineering/quality requirements
(*k*) Corrective action
(*l*) Record keeping requirements
(*m*) Personnel interface.

With an effective audit programme, problems should be detected early. The actual purpose of audit is prevention. Good audits are the key to productivity. The aim of the audit is to remove deficiencies by taking corrective actions and identifying opportunities for improvements. In every quality audit programme, the main thrust should be to follow-up with corrective action. An audit is viewed as a constructive service to the function when it furnishes enough detailed facts so that necessary actions can be taken.

An experienced and alert auditor is often able to discover opportunities for improvement as a by-product of his/her search for discrepancies.

Audit Rating System

The audit rating system is designed to bring consistency to the evaluation of audit results across the business units. Operation of rating is as follows:

- Each discrepancy will be classified as either major or minor.

Major: A deviation from product specification or from procedural requirements, which may cause major malfunction or yield loss at higher level assembly, for example, components not meeting test criteria; or procedure of corrective and preventive action not followed or calibration status of instruments and meters not clear.

Minor: A deviation that could create some unwanted variability in the product or process or which presents a slight risk, for example, unqualified operator working on a product; or documents that are not updated; or preventive maintenance not done on a machine as per maintenance schedule.

All audit discrepancies will be rated in the following manner:

Major	:	4 points
Minor	:	1 point
Recurrence of major deviation (from last audit)	:	8 points
Recurrence of minor deviation (from last audit)	:	2 points
Consecutive recurrence of minor deviation three times (becomes major deviation)	:	4 points

The overall audit rating is obtained by adding the points for the observed discrepancies, divided by the total number of audits and subtracting from 100.

$$\text{Rating} = 100 - \frac{\text{Total point}}{\text{Total number of audits}}.$$

(*b*) Overall audit ratings are established as shown below:

95–100% : Excellent

90–94%: Satisfactory

Below 90 % : Unsatisfactory and require immediate attention and corrective action.

(*c*) All major discrepancies require immediate corrective action with written response.

27.9 CONCLUSION

In summary, organizations may be required to cope with a host of challenges at any given time. Some of the challenge's can be met with pre-planning. Employee's education and training should be given prime importance. Top management commitment, support and dedication are also essential for success. A systematic approach to utilize customer surveys and feedbacks on service and processes should be established. Assessment against ISO: 9000 standard will help to identify the weaknesses and strengths in coping with challenges.

Emphasis must be placed on the prevention of defects, not on inspection, audit or rework. Quality implementation should be emphasized at all levels. Quality must be viewed as not just a programme, but a process and not an instant cure. Quality must be an organization wide activity. Excellence, as a way of life in every activity, must be a guiding factor. Continuous improvement emphasizes that prevention is the strategy for improving performance through ongoing training and system changes. Dr. Deming, one of the quality gurus, once stated that the useful management tool for success is PDCA (PLAN-DO-CHECK-ACT).

Programmes that are well managed tend to show a high degree of success. Quality is vital to the successes of a company. Quality should become the religion, logic and culture of the organization.

Lastly ISO:9000 is not a destination, it is a journey.

Section III

CHAPTER 28

Benchmarking and Process Improvement

FOOD FOR THOUGHT

What is involved in making 'Made in India' level a symbol of quality ? It is an enormous task starting with the spread of awareness for quality. It involves educating people in the ways and means of achieving, maintaining and improving quality of their products and services. It also involves teaching tools and techniques of quality management to the masses in this vast country in as simple a manner as possible. In short, it involves the spread of the culture of Total Quality in the country to make Indian companies more competitive in the worldwide market place.

AT A GLANCE

The chapter deals with a combination of two important TQM (Total Quality Management) tools—Benchmarking and Process Improvement.

Benchmarking, to put it very simply, is comparison with someone recognised as a standard with a view to cause improvements. Comparison is as old as competition, but benchmarking makes it a structured process.

Process improvement is also not new to the quality professionals. It has been practiced in one form or another for a long time. It was given a structure in the mid 1980s and named Business Process Quality Management (BPQM). The name was rightly choiced as it conveys that the tool deals with the management of the quality of business processes. Prior to that attempts at improvement of processes were restricted to manufacturing processes. BPQM targeted for improvement of all processes in an organization including business processes for the first time. BPQM did not achieve the success it deserved and was soon forgotten. It got revived under another name—Business Process Reengineering (BPR). The success rate of BPR is also not very high. It is the belief of quality gurus that both BPQM and BPR are good tools. They were not successful as the implementation was not well handled in most cases. Finally BPQM and BPR have been marged and a new name has been suggested as 'Benchmarking and Process Improvement.'

The two tools are covered in this chapter together as they work best in a combination. Benchmarking and Process Improvement work as, what is known as synergetic combination.

28.1 INTRODUCTION TO BENCHMARKING

A dictionary meaning of the word ‘Benchmarking’ is – anything used as a standard or a point of reference. Thus Benchmarking would be comparison with some standard or with some point of reference. People have always been making comparisons from time immemorial. These comparisons have now been structured and made systematic. This systematic structured tool for comparison has been given the name ‘Benchmarking’. Benchmarking differs from competitive comparison in its objective—to adopt or adopt a better process to improve one’s own process.

28.2 DEFINITION OF BENCHMARKING

Benchmarking is the continuous, systematic process of measuring one’s output and/or work processes against the toughest competitors, or those companies recognized as industry best. The key words and phrases in this definition are ‘Continuous’, ‘Systematic’, ‘Work Processes’, toughest competitors, and ‘industry best’. Thus for a comparison to get a status of Benchmarking, it must be systematic and continuous and the comparison must be against the best. It may further be defined as ‘Benchmarking is a process of comparing company performance continuously against those recognised as best with a view to cause improvements.’ The work ‘process’ implies that it is systematic. Like other definition, this too talks of ‘continuous’ comparison with the ‘best’. It brings up a very important issue by including ‘with a view to cause improvement’. This definition provides a purpose to the process and makes it an important tools for continuous improvement, an essential component of TQM.

The first definition is better as it talks of comparison of work processes. The second is preferred as it speaks of improvement as the purpose of Benchmarking. In short, it involves a comparison with ‘best practices’ aiming ‘Superior performance’. In words of Robert Camp, Benchmarking is the search for industry best practices that lead to superior performance.

It may be necessary to clarify that ‘best’ should be interpreted as substantially or significantly better’. One need not waste a lot of time and effort to determine who is ‘the best’. It one comes across a significantly better process, one can start the Benchmarking against it without waiting to find out if it is the best.

Now let us see if the exhortation to a child to score more than 80 per cent marks scored by another child in a particular subject is Benchmarking or not. If the child is explained how the other child scored 80 per cent after understanding his ‘process’ of studying and prepairing for the examination and is provided necessary resources and any other help needed to score 85 per cent marks, it is Benchmarking. Understanding the other person’s process of studying and improving one’s own process to achieve the desired level are essential elements of Benchmarking. Without these elements, it may be anything else but it is not Benchmarking.

Comparison can sometimes lead to undesirable emotions and consequently disastrous results. For instance someone who compares his car with a new more expensive model of car procured by a neighbour, envies him and to keep up with him, changes his car even if he cannot afford it, is certainly not Benchmarking. The purpose of comparison was ‘Keeping up with Joneses’, not to cause improvement and hence it is not benchmarking. Benchmarking has to be constructive, it must lead to improvement, not envy and financial ruin.

28.3 BACKGROUND OF BENCHMARKING

Wile comparison is as old as the hills, structured and systematic benchmarking was developed in the early 1980s. The credit for developing the tool goes to Xerox, the company known worldwise for its photocopying machines. They found their Japanese competitor was selling machines at prices lower than their own manufacturing costs. To understand how they do it, they studied the design of the machines and several processes of the competitor that led to their excellent results. As a result of this study, they set improvement goals to catch up with the competition and do better than them in five years. The credit for the company’s turn around goes to their process of benchmarking. The best known book on Benchmarking is written by Robert Camp who was among the people at Xerox who developed the tools. It is natural that the first company to use the tool in India was Modi Xerox Ltd., the Indian affiliate of Xerox.

28.4 NEED FOR BENCHMARKING

In competitive business environment, it is not enough for a company to be doing well. The performance has to be seen in comparison with its best competitors. A company growing at the rate of 10 per cent in an industry with an average growth rate of 15 per cent is in fact loosing market shares slowly but surely to its competition. In such a situation, 10 per cent growth is not good enough. However the same growth rate may be considered very good in another industry which grows at an average rate of 3 per cent and where the best competitor is growing at the rate of only 5 per cent. Thus it is necessary to have a point of reference to know how well one is doing. Need for keeping a constant watch on the competition is necessary for achieving and maintaining leadership position. This is well illustrated in a long distance race. The leader keeps looking from the corner of his eyes how far ahead of the next competitor he is. If he sees him closing in, he steps up his pace to retain or even increase his lead. The runner in the second position may have a strategy to keep with in the striking distance of the leader with a plan to shoot ahead towards the end of the race with a burst of pace. He ensures that the lead remains upto a predetermined level which he can make up in the final burst.

In a dynamic business environment where customer expectations are changing fast, it is not enough to meet current expectations of the customers. Competition is constantly trying to improve its products and services to true one’s customers away. A company in the lead, like the leader in a race, has to keep a watch on the closely following competitor, to maintain its lead. Constant vigilance and an attitude of continuous improvement are extremely essential to do well in such an environment. Benchmarking which helps an organization to do just that is therefore a very useful tool in the hands of the management of a company that desires to be more competitive. Benchmarking in necessary for companies in the lead in their own field for retaining their competitive edge. It is even more useful for companies who have yet to achieve leadership position in their industry.

28.5 FOCUS OF BENCHMARKING

While discussing the definitions of benchmarking, we had laid special emphasis on certain key words or phrases. It is important to remember a couple of them to understand the focus of benchmarking.

These are 'work processes' and 'with a view to cause improvement'. Comparing the results with a competitor helps one set an improvement goal that is both desirable and achievable but provides no clue on how the goals can be achieved. It is the comparison of work processes that tells us how the competitor achieves better results and what one should do to improve one's processes to achieve comparable and better results. Thus the focus of benchmarking is not results or output of processes, but the processes which produce outstanding result. This is a major change from the good old comparison. In competitive comparison of earlier times, the focus was on products and business results. In benchmarking as we understand today the focus is on processes and work practices.

To understand this better let us revert to the example of a child who is being exhorted to score more than 80 per cent marks scored by a child in the neighbourhood. Knowing that the other child had scored 80 per cent, helps one to set a goal of securing 85 per cent mark in the subject at the examination. However it provides no guidance to the child on how to do it. If on the other hand one finds out how the child studied, what books he read, which extra classes he attended, how he retained the knowledge acquired from various sources, how he prepare himself for the examination and how he timed himself while answering the question paper, one understands what one must do to achieve a high percentage marks. Thus comparison of processes and work practices with a view to arrive at a superior process and better work practices are necessary to effect desired improvements.

28.6 LEVEL OF BENCHMARKING

There are three levels of benchmarking:

(*a*) Internal benchmarking

(*b*) Competitive benchmarking

(*c*) Functional benchmarking.

Internal benchmarking is comparison against another department or division within the company or another company within the same group of family of companies. This is the first level of benchmarking and can provide excellent results with relatively less effort. It is futile to go halfway across the globe in search of a better process when one is available in one's sister company. Thus benchmarking, like charity, should begin at home. It is much easier to collect information from an internal source and hence the effort needed for internal benchmarking is substantially lower than other level of benchmarking. The improvement can bring in significant benifits. It is much easier to implement the changes. The cost benifit ratio in case of internal benchmarking tends to be more favourable than other levels of benchmarking. The scope of internal benchmarking is a lot more than what people realise. In a group of companies, one company may be extremely good in fabrication department, another in making coils and still another in design and development methods. The companies can learnt a lot more one another through a process of internal benchmarking. If an appropriate mechanism is created and a culture of co-operation and free exchange of information within the group is developed, internal benchmarking can be a great success and can prepare the company executives for other levels of benchmarking.

Competitive benchmarking is comparison with one's direct competitors. This is the most common type of benchmarking. It is difficult to get information from direct competitors and hence this type of benchmarking requires maximum efforts. In spite of that this type of benchmarking is most common as it is considered essential for improving one's competitiveness in the market place as compared to one's direct competitors. To get information about the processes of a direct competitor one has to take help of benchmarking clearing house which have a data base on all common processes.

A company that is the best within its own industry, has to look beyond the industry for a benchmarking. The company can benchmark its process with a company in another industry which is the best in that process. This is known as functional benchmarking. The company serving as a benchmark has to be the best in that function not only in its own industry, but also in all industries or best-in-class. Hence this type of benchmarking is also known as best-in-class benchmarking. A special word in Japanese – 'DAN TO TSU' meaning best of the best describes this world class process.

When one is benchmarking a process which is not exclusive to an industry, one need not restrict to the industry for a benchmark. Examples of such processes are Billing. Distribution, Recruitment, Employee motivation, Customer satisfaction measurements etc. Thus a manufacture of transformer may benchmark its distribution process against a manufacturer of generator, or an insurance company may benchmark its recruitment process against a bank. A hospital may benchmark its process for urgent check-in of emergency cases against the express check-in in a hotel. A well known and frequently quoted example of this type is Xerox benchmarking, its order filling process with L.L. Bean, a mail order company. The 'pick and pack' practice used by L.L. Bean was adopted by Xerox successfully to improve its order filling process.

Some people suggest one more level of benchmarking – Generic benchmarking. Example cited are Caterpillar, a manufacturer of earth moving equipment benchmarking its hydraulic systems against Disneyland and manufacturer of bullet benchmarking their shell making process against a manufacturer of lipsticks. However these examples can be included in functional benchmarking and hence we don't feel the need for one more level, which in any case is extremly rare.

One should select an appropriate level of benchmarking. One starts with internal benchmarking of a process. After improving one's processes to a level that is best in the group of companies, one can try competitive benchmarking. After being the best in one's own industry, one can do functional benchmarking against a world class company. This is similar to the field of sports and games. One has to start with a city level competition and do well in it before one can play at district, then state and later national level competition. Outstanding performance at national level is necessary before one qualifies to enter world championship tournaments.

A question is often asked ''Why should one go through all these levels of benchmarking ? Why cannot one benchmark straight with a world class company and save time ?''

The answer is that if the difference between one's process and the benchmark process is too great, the big gap can dishearten one. If the process is totally different or its scale is very much larger, one may find it difficult to relate to it and to learn from it. In the field of sports one will not be permitted to compete in world class tournaments unless one has progressively qualified from lower level tournaments. One can do world class benchmarking directly as unlike the field of sports, there are no qualification rules here, but it world not be advisable. To get best results, one has to compare one's processes with those whose processes are better, even substantially better, but not with those who are totally in a different class.

The only cases where there are some sound arguments for jumping several levels at a time is change to a more modern technology. Every change in technology means a lot of investment and hence many argue that if you are going for a new technology, go for the latest. The difficulty in absorption of ultramodern technology and problems of retaining of managers and other employees must be fully considered before bringing in revolutionary changes in technology.

28.7 BENEFITS OF BENCHMARKING

The biggest single benefit of benchmarking is the extent of improvements one can make by learning from the processes of others. One does not have to reinvent the wheel. Someone has a better process which one can adopt with necessary modifications. It takes considerably less effort than designing an entirely new process. Benchmarking makes goals for improvement more acceptable as they are seen as practical and achievable. If one's own process is very bad, the improvement can be dramatic as experienced by a computer education institute who benchmarked their process of importing equipment with a company for which import of equipments was a routine. They soon realised that they were literally following standard procedures without knowing the tricks of the trade and short cuts. Learning these tricks they could bring down the cycle time to one-fifth of the original. The benefits become all the more when one combines benchmarking with process improvement. These benefits are covered later in this chapter.

The benefits of benchmarking are so great that in a short period, it has become one of the most used management tools and techniques. A recent study by L.L. Bean showed that benchmarking is the third most frequently used management tool, much ahead of Business Process Reengineering (BPR), Total Quality Management (TQM) etc.

28.8 PREREQUISITE CULTURE OF BENCHMARKING

A certain culture is essential for the success of benchmarking. The management of the company must renounce its feeling of self-importance and complacency and be prepared to learn from others. It must be prepared to accept, adopt and adopt ideas from others. In other words it must say good bye to 'NIH' (Not Invented Here) syndrome and accept the 'SIS' (Steal It Shamelessly) syndrome. This requires humility on the part of the senior management of the company. The management must be honest to admit that someone is better than them. It must have the courage to accept ideas totally new to the organization. It must be totally committed to continuous improvement through the process of benchmarking the company's processes against the best. The following quotation from Mr. Ralph Larsen, Chairman and CEO, Johnson & Johnson sums up the culture necessary for the success of benchmarking —''Benchmarking is both a journey in humility and a recipe for change with three main ingredients — honesty, courage and total commitment.''

28.9 IMPORTANCE OF PROCESS IMPROVEMENT

One of core elements quality management is process orientation. It requires one to be oriented towards process rather than results. It shows firm belief in the theory that if a process is good, the results are bound to be favourable. One aims at better results through more capable processes. This belief naturally leads one to the importance of improving one's processes. Another facet of process orientation is orientation towards process rather than people. Quality gurus have long been saying that 85 per cent of quality problems are system related and are under management control, and only 15 per cent are people (employee) related. Dr. Deming put the figure for management controllable problems as 94 per cent. It should therefore be obvious that to reduce quality problems or to improve quality level, one must concentrate on improving the processes.

28.10 DEFINITION OF PROCESS

A process is defined as a series of activities or tasks performed to produce a desired result. The process, by a series of operations, converts available inputs into desired outputs. All work one does is a process. While most people can relate to processes in manufacturing, they do not see work in offices or in administrative functions as processes. To cite a few examples, recruitment of an employee is a process, preparation of a financial statement is a process and creating a computer programme is also a process. At the home front preparation of a cup of coffee is also a process.

The essential features of a process are inputs of various types used to produce an output or outputs by a series of value adding activities. The inputs are provided by the suppliers and the output goes to the customers. There has to be an agreement between the processor and his customers about the requirements that the output must meet. Similarly there has to be an agreement between the processor and his suppliers about the requirements that the inputs must meet.

28.11 PROCESS MODELS

Every company, however small it may be, carries out a large number of processes. These processes are connected to one another by linkage between internal customers and internal suppliers. The output of one process becomes the input of the next process. This relationship is how in a model of Corporate Macroprocess (ref Fig. 28.1). Each of the circles in the model of corporate macroprocess represents a process. These processes may further be devided into smaller sub-processes, which in turn may be devided into several micro level processes. Even at the micro level a process may consists of several activities and tasks performed to convert inputs into outputs. Fig. 28.2 shows the model of a process at the micro level. Like the macroprocess, it starts with inputs coming from suppliers and ends with the output going to customers.

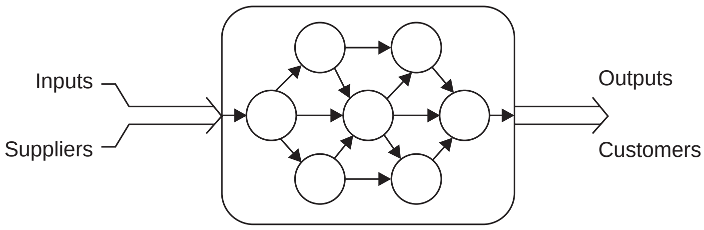


Fig. 28.1. Corporate macroprocess

The model differentiates between inputs of various types which are placed at specific points on the circumference of the circle representing the process. The direction of the arrows indicate what goes into the process (inputs) and what comes out of the process (output). The output and the consumable inputs are connected to the circle by double lines; the other inputs by a single line. Other inputs to the process are:

(*i*) Equipments, Facilities, Furnitures etc.

(*ii*) Systems and processes

(*iii*) Skill and knowledge

(*iv*) Quality Performance Standard

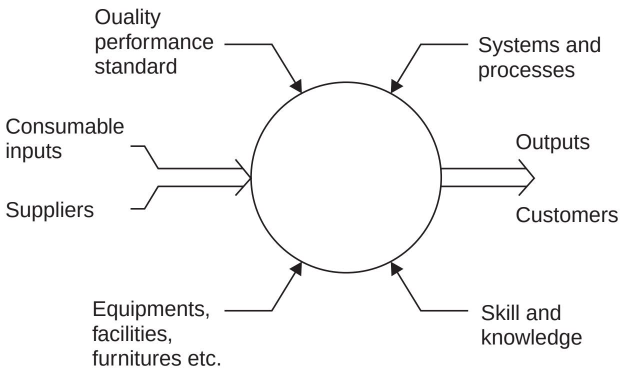


Fig. 28.2. Micro level process

It is obvious that the process and the various activities that constitute the process add value to the inputs. Thus the value of outputs from a process should be considerably higher than the values of all the inputs consumed and the notional value of other (non-consumable) inputs used.

28.12 HIERARCHY OF PROCESSES

The division of corporate macroprocess into micro level processes goes through a number of intermediate levels. The corporate macroprocess is first broken down into key functional processes or Mega processes, we may call them as level one processes. Examples of this level are Business Planning, New Business Generation, Revenue Generation, Product Generation. The next level or level two processes are the major processes. For instance level two processes in product generation can be Scheduling, Material Procurement, Storage, Assembly, Testing, Packaging, Delivery. The major processes are divided into processes and sub-processes and finally lead upto micro level processes. Even these processes may have several activities in them and each activity may involve more than one task. This hierarchy may be seen in Fig. 28.3.

Corporate macroprocess
↓
Mega processes or level one processes
↓
Major processes or level two processes
↓
Level three processes
↓
Sub-processes or level four/five processes
↓
Micro level processes
↓
Activities
↓
Tasks

Fig. 28.3. Hierarchy of processes

28.13 APPROPRIATE LEVEL FOR IMPROVEMENT

We have just seen the hierarchy of processes from the corporate macroprocess to the smallest tasks performed in an organization. A question likely to arise on one's mind is 'which is the appropriate level of process one should aim to improve'. The corporate macroprocess, level one process and even some level two processes are too complex to tackle in a single improvement project. One has to select level two or three or in some cases even a level four process for process improvement efforts. At this level the process would consist of several sub-processes involving a few departments which a cross-functional team can tackle to bring about improvements. Looking at the subject from the other end, a macro level process may involve a single individual or only one department. Processes at this level can be reviewed periodically by the concerned individual or department for any need for improvement and the improvement effort can be undertaken by the individual or a team set up by the department. Improvement at such levels may not need a cross-functional team as the activities are restricted to a single individual or a single department. The improvement of such processes would be relatively simple and can be tackled by simpler tools.

28.14 PREREQUISITE CULTURE OF PROCESS IMPROVEMENT

Process improvement methodology should result in processes that are more effective, more efficient and more adaptable to changing customer requirements. It is a good tool and should result in immense benefits due to improved productivity, enhanced customer satisfaction and shorter cycle time if it is used properly and if a supportive culture exists in the organization.

The success of process improvement methodology requires a specific type of culture in the organization. Essential elements of the required culture are process orientation, goal congruence among different departments or division of the company and cross-functional teamwork. All processes at the level for which the methodology is recommended involve interdepartmental co-ordination and hence the team to work on process improvement will have to be cross-functional. Unless there is a culture in the organization that supports cross-functional teamwork, such team would not succeed in their process improvement projects. In companies which have an organization structure that is strongly divided on functional lines, cross-functional team work will not work for common corporate goal. They will work for their department's objectives and priorities. In view of this a culture of co-operation among different departments in the company is so essential for success of process improvement. A matrix or network type organization structure is ideal, but not essential. However, goal congruence and high level of interaction among different departments are absolutely essential for the success of process improvement. The low success rate of process improvement methodologies is probably due to organizations failing to creat the prerequisite culture.

28.15 SYNERGY BETWEEN THE TWO TOOLS

Benchmarking and process improvement work in synergy which means that the two used in combination result in benefits for in excess of the total of the benifits that one would get from them if used singly. In fact the two tools need each other for their effectiveness. As we have seen earlier, the focus of benchmarking should be processes and work practices. Once a process has been selected and the more superior process of benchmarking partner has provided an improvement goal and some ideas about the direction the improvement efforts can take place, one will have to work on the improvement of the processes. This is when the process improvement methodology will be required. Similarly when one is working on a process improvement project, benchmarking provides a practical goal for improvement. Thus the tools are incomplete without one another and produce excellent results if used in combination.

An excellent example of this synergy is provided by the automobile giant FORD. They were working on improving their Accounts Payable Process. Their objective was to simplify and streamline the process to reduce the number of employees from 400 to 360. Around that time they had a tie-up with MAZDA of Japan. When a high level delegation from FORD visited MAZDA, one of the member inquired how many employees they had in their Accounts Payable department. The answer ''12 Persons'' shocked them. Of course the process used by MAZDA could not be adopted by FORD, but the fact that someone is managing the function with only 12 people made them revised their own objectives. They reduced the number from 400 to 250 in one year and to 60 in four years. Without benchmarking with MAZDA, they would have improved at the rate of 10 per cent a year. Now they set themselves targets for improvement which would have been unthinkable earlier. In other words, process improvement used along may result in an 'incremental' improvement, but in combination with benchmarking it may yield 'break through' or leap-frogging improvement.

28.16 STEPS AND PHASES OF BENCHMARKING PROCESS

In the following paragraphs we will see four phases and ten steps of the Benchmarking Process. There is a great variation in the number of phases and steps in the process recommended by various quality gurus. However the principle of the process is more or less the same.

The four phases of the process are:

- Planning Phase—Steps 1, 2, 3
- Analysis Phase—Steps 4, 5
- Integration Phase—Steps 6, 7
- Action Phase—Steps 8, 9, 10.

To get the best results out of the benchmarking process, it is essential to follow the systematic and structured approach outlined in these ten steps. A benchmarking project needs to be handled by crossfunctional teams so that all aspects of the process are properly discussed threadbare at all phases.

The process will involve a number of people from various departments at different levels. The composition of the teams to handle different phases and sometimes even individual steps within a phase will have to be decided according to the tasks involved in the phases and the steps.

Planning Phase

The planning phase has the following three steps:

1. Identifying Opportunities and Prioritising
2. Deciding the Benchmarking Partner
3. Studying the Superior Process.

This is a very important phase. As it is the first phase, any error or incompleteness in this phase will affect the later Phases. It is therefore necessary to pay sufficient attention and devote enough time and effort to this phase to ensure that we see the steps in brief.

Step 1: Identifying Opportunities and Prioritising

The involvement of the top management is essential for this extremely important step. The senior management with its overall knowledge about the company should decide which processes are critical to the success of the company and in which there is ample scope for improvement by comparing the processes with an appropriate partner. Once a short list of processes to be benchmarked is ready the priority has to be decided as per a predetermined set of criteria. Thus step-1 deals with 'What to Benchmark'.

Step 2: Deciding the Benchmarking Partner

After selecting the process to be benchmarked, the next step is to decide the partner that would serve as the benchmark. The first question to tackle is the ideal level for benchmarking—Internal, Competitive or Functional. Several candidates are short listed and information is gathered from various sources to decide the one most suitable among the short listed partners. While deciding on the partner, it is necessary to make sure that more detailed information about the selected partner would be accessible and that the comparison with the partner's process would be relevant and useful. Step-2 deals with 'Whom to Benchmark with'.

Step 3: Studying the Superior Process

This is the most difficult, most time consuming and perhaps the most important steps in the entire process. It involves completing the task of data collection started in step-2, planning a visit to the partner, visiting the partner's facility and preparing a comprehensive report after the visit. These activities involve planning a great details and careful execution of the prepared plan. As one cannot visit a partner often, the preparations have to be thorough so that all necessary informations are collected in one visit. This is the core step and the success of the entire process will depend on how well this step is carried out.

Analysis Phase

The second phase or the analysis phase has just two steps.

4. Finding reasons and devising improved process
5. Setting goals for improved process.

This phase involves the analysis of the detailed information collected in the planning phase. This phase will require the involvement of the people closest to the process selected for benchmarking. The work done in this phase is not as time consuming and not as laborious as the planning phase, but it is equally important. The benefits that the company derives from benchmarking will depend on the improved process devised in step-4. A brief outline of the two steps is provided below.

Step 4: Finding Reasons and Devising Improved Process

After studying the superior process of the partner, the company tries to find the reasons why the partner's process results in better performance. The team working for this step should compare the processes to find the differences in the processes with a view to identify the reasons for better results. On the basis of this analysis, the member's knowledge of the process and innovative thinking, an improved process that will perform better than the partner's process is developed.

Step 5: Setting Goals for Improved Process

Once an improved process expected to perform better is developed, the next step is to set goals for improvement. The first estimate of the benefits the company can derive from the project will now be available to the management. This should provide an impetus to carry the project to its logical conclusion.

Integration Phase

The third phase or the integration phase also consists of only two steps

6. Communication findings and securing commitment
7. Revising performance goals.

This is a small phase but nevertheless it is an important link between the preparatory phases of Planning and Analysis on one side and the Action phase on the other. It seeks the acceptance of the results of the earlier phases by the management and secures the commitment of the management on the recommended action plan. Integration phase is essential as acceptance of proposed process revisions by concerned individuals and departments is necessary for the success of the project. However good the revised process, it cannot succeed if there is resistance to its implementation. A brief outline of step 6 and 7 is given below.

Step 6: Communicating Finding and Securing Commitment

After completion of the analysis phase the team presents to the management and the heads of the concerned departments, its proposals for the improved process. The proposed changes in the process have to gain approval from everyone concerned or likely to be affected by the changes. Unless a total commitment is secured, there will be impediments in the implementation of the action plan in the next phase.

Step 7: Revising Performance Goals

Once the proposed revisions to the process are accepted, the acceptance of the revised performance goals is the next logical step. At the conclusion of this step the company is ready for taking steps to improve the process as per the recommendation from step 4.

Action Phase

The fourth and final phase, the action phase, has three steps

8. Developing an action plan for implementation
9. Implementing the action plan and monitoring progress
10. Keeping the process continuous

This is the phase where all improvement takes place. The earlier phases had set the stage for the improvement to start. The benefits a company derives from benchmarking will depend on how well this phase carries out the plan for improvement prepared in the earlier phases. Step 10 ensures that the benchmarking process is kept continuous in the organization. A brief outline of the three steps of this phase is given below.

Step 8: Developing an Action Plan for Implementation

Once the improved process has found company wide acceptance, one has to prepare a detailed action plan listing all the activities or tasks to be performed. The action plan should include a time schedule for all activities and the name of the individuals responsible for ensuring that the tasks are completed as per the schedule. All members must be committed to carry out their assignments in time.

Step 9: Implementing the Action Plan and Monitoring Progress

When the individuals charges with the responsibility to ensure that the tasks are performed as per the schedule someone has to ensure proper co-ordination of various activities and monitor the progress of the implementation plan. Once the implementation is complete and the revised process is in place, a terminal report has to be prepared to document the benefits of the revised process comparing them with the expectations at the time of approval of the proposed revision of the process.

Step 10: Keeping the Process Continuous

The successful completion of one benchmarking project should be seen as an important milestone. It should be a good occasion to start another more ambitious benchmarking project. One also has to set up a mechanism to review the performance of the improved process periodically to ensure that the benefits are retained.

28.17 STEPS FOR PROCESS IMPROVEMENT

The proposed process improvement methodology has seven steps. These are:

1. Documenting the process
2. Identifying customer requirement
3. Analysing the process
4. Revising the process

5. Developing an action plan
6. Validating the new process
7. Keeping the improvement continuous.

The following paragraphs will discuss these steps briefly.

STEP 1: Documenting the Process

There are two ways to document a process—descriptive and pictorial. The descriptive document of the process involves documenting the mission, the boundaries or the beginning and the end of the process and the task in between the two. It also identifies the Process Owner. The pictorial document of the process is its flowchart. Two types of flowcharts are used in Process Improvement, the first comprising of flowcharting of the corporate macroprocess and taking it down at least a couple of levels to reach to a stage where process improvement is effective. The second type is the flowchart of the process selected for improvement. The flowcharting of the selected process and preparation of the process document are done side by side. The technique of flowcharting and symbols used are similar to traditional flowcharting. The structure of the two types of charts, however is different from traditional flowcharts.

STEP 2: Identifying Customer Requirement

Once the process has been documented and flowcharted as it is carried out, the next step is to define requirements for the output at different stages of the process and to identify where it is necessary to establish measurements to ensure that the customer is satisfied every time.

STEP 3: Analysis the Process

It involves analysis of the process documents, prepared in step 1 and the information about customer requirements collected in step 2. The analysis should result in the identification of tasks that do not add value for the customer and can be eliminated. It should also identify the tasks that need to be simplified.

STEP 4: Revising the Process

This is the most important step in the entire process. It comes right at the centre of the process and is the core step. It uses the results of the analysis of the process done in step 3 to develop a revised process that is simpler, more effective, more efficient and more adaptable to changing customer requirements and changing business environment.

STEP 5: Developing an Action Plan

Once a revised process is developed, one lists out the actions required to change from the old to the proposed new process. A time bound action plan is prepared listing all the activities with the name of the individual who will be responsible to carry them out according to an agreed schedule.

STEP 6: Validating the New Process

Once the action plan developed in step 5 is implemented, the revised process should be in place. The next step is to follow-up to check the improvements achieved and to compare them with the objectives and the plans. This study validates the process and the process is ready to be institutionalised.

Step 7: Keeping the Improvement Continuous

Just as the last step benchmarking process was keeping the process continuous, the last step in process improvement is keeping the improvement continuous. It involves retaining the gains due to the revised process by institutionalising it and installing controls to ensure that there is no relapse to the earlier process. It also involves selection of one or more new projects for process improvement. This step is similar to step 10 in the benchmarking process.

28.18 CONCLUSION

Completion of one project should be an occasion for celebration of success and recognition of the efforts of all those who worked on teams for different phases and steps of the process. It should also be treated as an occasion for the company to rededicate itself to benchmarking by starting one or more new or more ambitious projects. The knowledge and experience gained by the first project should be well documented so that the future project team can benefit from past experience. The document should not only record, successes but also record failures so that future team can avoid the pit falls.

The management has to demonstrate its continued interest in and commitment to benchmarking to ensure the success of new project. The type of recognition and reward own by the key persons for the first project will have an impact on the level of enthusiasm of the members of the teams for the later projects.

After the benchamrking project gets completed, the process continues with the start of one or more new and ambitious projects. One goes back to phase one and step one for the new project. The end of one project signals the beginning of another making benchmarking a never ending process in the company. Commitment of the senior management plays a very important role in ensuring this.

To keep the benchmarking process continuous, it is essential that the benefits secured by the company are retained permanently by institutionalising the revised process and keeping a constant vigil to ensure that the leadership position gained is not lost due to the progress made by competition. Celebration of success and recognising and rewarding the contributors to this success is an extremely important activity to be undertaken by the senior management which will ensure the success of future projects.

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SECTION IV

Preventive Maintenance Transformers

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Section IV

CHAPTER 29

Key Notes on Preventive Maintenance

AT A GLANCE

If a transformer has to give long and trouble free service, it should receive a reasonable amount of attention and maintenance. A rigid system of inspection and maintenance ensures longer life, trouble free service and low maintenance cost. Maintenance consists of regular inspection, testing and reconditioning, where necessary. The principal objective of maintanance is to maintain the insulation in good condition. Moisture, dirt and excessive heat are the main causes of insulation deterioration and avoidance of these will in general keep the insulation in good condition.

Means and methods are to be adopted not only to avoid the transformer failure, but to extend useful life by condition monitoring and taking remedial measures or by carrying out proper maintenance. Condition monitoring can be defined as predictive technique for the assessment of the transformer condition to estimate its useful life and also to decide on the course of next maintenance. Condition monitoring encompasses the life mechanism of the whole equipment or the individual parts, application and development of special purpose equipments, means of acquiring data and thereafter analysis of the data to predict degenerative trends. The condition monitoring reduces maintenance cost, limit the probability of major failures, provides information on plant operating life, enabling techno-commercial business decisions on plant refurbishment or replacement.

29.1 INTRODUCTION

This is an introductory chapter of ‘Section-IV’ covering the outline of maintenance of power transformer. Transformer makes an important link in the transmission and distribution network of electrical energy. Transformer, being static equipment and of robust construction, is normally stable and reliable link in the network. It is capable of withstanding a lot of abuses and lack of maintenance, but if it becomes defective or fails, the result is disruption of normal life and industrial activities. As such protection of transformers assumes importance.

29.2 TRANSFORMER LIKE A HUMAN BODY

Transformer is like a human body as functionary system present in both are quite common in nature. The significance of various system of transformer can be early understood by co-relating them with system of human body.

(*a*) **Circulatory system:** Blood circulation system is identical to oil circulation system. Blood sample and its tests used for diagnosis of human body—whereas oil sample and tests for diagnosis of transformer health.

(*b*) **Respiratory system:** Human body breadths oxygen—whereas transformer breadths air. Although transformer with Nitrogen sealing and air cell breather have much better life than silicagel breather, as the former does not provide entry to oxygen and moisture.

(*c*) **Nervous system:** Brain detects any abnormality in the body after it has developed a symptom to the detection level of brain, and protection system also detect abnormality in the transformer after it has developed to the threshold level of the relay.

(*d*) **Skeletal system:** Skeleton in body is identical to the core in the transformer.

(*e*) **Muscular system:** Tissues and skins can be compared with coils. Residual life assessment is carried out through tissue test in body and in case of transformer it is through proper tests.

(*f*) **Excretory system:** Kidney controls various levels by removing excretory waste from the body, in the same way, 'Thermo Syphon filter' controls moisture content and acidity in the transformer.

The human body and transformer are alike to each other functioning wise. As such, three steps, mainly prevention (better than cure), corrective measures based on regular check up and remedial steps based on check up against symptoms which help a human to live long and healthy life and also avoid untimely demise, may also be adopted for keep up of the transformer to have reliable and long life and to prevent frequent failure of transformers. Accordingly, three steps for proper keep up of transformer may be adopted as under:

(*a*) Preventive measures

(*b*) Maintenance based on periodic condition monitoring through various tests

(*c*) Remedial measures against abnormality detected by the protection and annunciation system.

29.3 PREVENTIVE MAINTENANCE

The main causes of the failure of transformer are design defect, manufacturing defect, material defect, poor operation and maintenance, surges and short-circuits, and last not the least loose-contacts. The primary factors that contribute to the deterioration of vital constituents and lead to eventual failure can be categorized into two groups:

(*a*) **External factors**

(*i*) Through faults specifically the sustained one

(*ii*) Overloading

(*iii*) Over voltage condition

(*iv*) System condition of high voltage and low frequency (*v*) Breaker fails to operate

(*vi*) Moisture and oxygen ingress from outside.

(*b*) **Internal factors**

(*i*) High temperature and hot-spot

(*ii*) Moisture and oxygen already persist in the insulating medium

(*iii*) Deterioration of oil and solid insulation

(*iv*) Mechanical looseness and deformation

(*v*) Insulation failure.

The former *i.e.* failure due to external factors can be prevented by providing suitable protection such as high set instantaneous protection on 33 and 11 kV lines, first operating distance protection scheme on outgoing 66 kV and above lines, definite time high set over current protection on transformer, LA protection for surge voltage, over current protection for controlling overloading and over fluxing relay to protect over excitation conditions. The ingress of moisture and oxygen which create havoc to the operation of transformer can be prevented during expansion/contraction by providing nitrogen sealing or providing air cell breather.

The later *i.e.*, failure due to internal factors may be protected by providing suitable protection schemes, such as differential relay, restricted earth fault relay, neutral displacement relay, buchholz relay, oil and winding temperture sensing devices, MOG device etc. This can further be protected by various electrical tests and tests on oil to detect abnormality in the transformers.

29.4 PERIODIC CONDITION MONITORING—MAINTENANCE BASED

The external factors responsible for damage of transformer can be checked by adopting requisite preventive measures stated above, but internal factors can be taken care through effective maintenance of transformer. Now maintenance based upon condition monitoring of the transformer arrived at by carrying out periodical tests on the transformer and its oil gaining ground. Condition monitoring of power transformer in service has been a continuous process and has seen many improvement over the years. Although several diagnostic tests such as dielectric loss angle, dissolved gas analysis, furan analysis are available, but pre-commissioning test form the basis for subsequent periodic tests to be conducted at site. The per-commissioning / periodic tests to be carried out at site are as under:

(*a*) **Electrical tests:** The values recorded during pre-commissioning electrical tests given here-under are compared with the test results recorded at manufacturer's works. These values form basis for comparision with the test results obtained during subsequent preiodical testing of the transformer.

Table 29.1

Test description	*Purpose*
I.R. value	To check overall condition of insulation
Vector group	To check correctness of winding connections
Turn ratio	To check correctness of voltage ratio
Magnetising current	To check inter-turm insulation
Short-circuit current	To check continuity of windings
Magnetic balance	To check core assembly and flux distribution
Winding resistance	To check tightness of windings and joints
Capacitance Tan Delta of bushings	To check condition of capacitance bushings
Capacitance and Tan Delta of windings	To check insulation of windings.

(*b*) **Oil tests:** The oil is tested for electrical properties, DGA analysis and Furan content analysis periodically to access condition of insulation. The periodicity of oil test for electrical properties and DGA is two years for transformers up to 10 years of life and annually therafter. The Furan test is got conducted based on the condition of transformer.

The condition assessment of liquid insulation can be made by periodic testing of oil for test like Interfacial Tension, Flash point, Neutralization value, Dielectric Dissipation Factor, Specific resistance, Water contents and Sludge content. The permissible values of these tests are available in the relevant ISS.

Dissolved Gas Analysis (DGA)

Electrical faults such as short-circuit, loss of cooling, overloading and over voltage lead to the decomposition of cellulose forming hydrogen (H_2), methane (CH_4). ethane ($C_2 H_6$), acetylene (C_2H_2), carbon monoxide (CO) and carbon dioxide (CO_2) as gaseous products. Those gases are ultimately absorbed in the insulating oil in transformer. The analysis of dissolved gases in insulation oil is useful not only to detect electrical faults but also to determine hot spot temperature and their source. The relative amount of these gases are generally determined by gas chromatography. The technique is well established and has been in practice for years in most power supply stations for assessing the internal condition of the transformer. The interpretation of results of dissolved gases based upon key gas method and various ratio methods helps to pin point exact nature of fault in the transformer. The permissible concentration of dissolved gases and the limited of dissolved gases recommending continuous monitoring of fault grass and viewing the results seriously in case these exceed the certain higher limits given in table 29.2 (*a*) to 29.2 (*e*).

Table 29.2: (*a*) Dissolved gas analysis: Permissible concentration of dissolved gases in the oil of healthy transformer in 'ppm' as per transformateren Union AG

Gas	*Less than 4 yrs. in service*	*4 to 10 yrs. in service*	*More than 10 yrs. in service*
H_2	100–150	200–300	200–300
CH_4	50–70	100–150	200–300
C_2H_6	30–50	100–150	800–1000
C_2H_4	100–150	150–200	200–400
C_2H_2	20–30	30–50	100–150
CO	200–300	400–500	600–700
CO_2	3000–3500	4000–5000	9000–1200

Table 29.2: (*b*) Recommendation for monitoring if concentration of fault gases are within following limits and view seriously if exceed the highest limit

C_2H_6	50–150	150–500	up to 800
CH_4	150–300	200–400	400–600
C_2H_2	30–70	50–70	70–100

Table 29.2: (*c*) The nature of fault vis-a-vis gases produced as per IEEE standard C.57.104.1991

Type of fault	*Key gases*
Arcing	Accelylene (C_2H_2), Hydrogen (H_2)
Corona	Hydrogen (H_2)
Overheated oil	Ethylene (C_2H_4), Methane (CH_4)
Overheated	Carbon mono-oxide (CO) and Carbon Dioxide (CO_2)

Table 29.2: (*d*) Relationship of evolved gases with temperature

Gas	*Range of temperature*
CH_4	> 120°C
C_2H_6	> 120°C
C_2H_4	> 150°C
C_2H_2	> 700°C

Table 29.2: (*e*) Method recommended by CIGRE Task force (ELECTRANO. 186, Oct. 99) Key gas concentration indication

Characteristic gas	*Concentration (ppm)*	*Indication*
C_2H_2	> 20	Power discharge
H_2	> 100	Partial discharge
$\Sigma CxHy$	> 1000 (x = 1, 2, 3) > 500 (y = 1, 2)	Thermal fault
CoX (x = 1, 2)	> 10000	Cellulose degradation

Table 29.3: Gas Concentration Ratio

Ratio	*Value*	*Indication*
C_2H_2/C_2H_6	> 10	Partial discharge
H_2/CH_4	> 10	Partial discharge
CO_2/CO	> 10	Cellulose overheating
	< 3	Cellulose degradation by electric fault
C_2H_2/H_2	> 2 (With C_2H_2 > 30)	Fault gases diffusing into main tank from OLTC

Furan Analysis:

The condition of paper insulation can be assessed in three ways:

(*i*) By analysing dissolved carbon oxides

(*ii*) Measurement of degree of polymerization

(*iii*) Furan analysis.

The measurement of degree of polymerization suffers from draw backs regarding difficulty in collecting paper samples, location of specific nature of test and complexity and accuracy factors involved in test. The overheating of solid insulation leads to cellulose decomposition and evolution of CO and CO_2 gases. These two gases are also produced during thermal decomposition of oil. Therefore, measurement of CO and CO_2 can not be used as an un-ambiguous indication of paper degradation.

The furan test overcomes much of these difficulties as the test is similar to the conventional DGA test with which the utilities are familiar. The ageing of paper produces several oil soluble by-product most predominant the furanoid compounds. The furan analysis by periodical sampling of oil of the old transformer helps to determine condition of paper insulation of the winding and leads.

Other Tests

Other tests like partial discharge, frequency response analysis and recovery voltage measurement are not most common tests. However these may provide very useful information in some of the cases.

(*a*) **Partial discharge test:** Partial discharge occur in oil filled transformer due to presence of voids or cavities in the solid insulation, conducting particles in paper or oil, wet fibers and gas bubbles in oil, sharp conductors or electrode edges against papers. The partial discharges also occur due to poor processing, ingress of moisture, trapped air due to incorrect oil filling, long term degradation of the insulation and design defects. For enhanced reliability of transformer in transmission network, on site PD measurement and location has become of increasing interest. On-site PD detection by electrical technique is associated with considerable problems due to radiated and coupled interference by surrounding conducting objects, noise and radio signals. Through some types of PD signals are radily identified but still interpretation of PD test results requires great ideal of experience and experimentation. Electrical detection also requires a PD free HV test source, a coupling capacitor and outage time for the transformer under test. However this technique is time consuming, costly and extremely disturbed by electrical noise.

Acoustic methods have been proved to be more sensitive for PD detection at site. Acoustic techniques have the advantage that can be used on energized transformer for both detection and location of PD and these methods are not susceptible to interference from outside sources when properly applied. The preferable frequency bandwidth for acoustic detection is between 50 kHZ to 150 kHZ to avoid external interference and noise. It is advisable to conduct PD measurements at several locations on the transformer with acoustic detector to estimate the total discharge effects and also to determine the location of PD inside the transformer.

(*b*) **Frequency Response Analysis (FRA):** FRA or Frequency Spectrum Analysis is an effective diagnostic tool used for finding out any possible winding displacement and any other mechanical deterioration inside the transformer. Each winding has a characteristic frequency response determined by the winding configuration and any movement in the winding will change the frequency response due to change in the inductance and capacitance.

Interpretation of the test results is based on subjective comparison of FRA responses taken at different intervals. If changes are observed in the later FRA spectrum with respect to the reference FRA spectrum, it is left to the experience of the analyst for quantitative condition assessment of the transformer. The specific types of damages detected are shorted turns, open winding, core grounding, core movement, axial and radial (buckling) deformation of winding, partial winding collapse and broken or loose clamping structure.

(*c*) **Recovery Voltage Measurement (RVM):** The Recovery Voltage Measurement yields the percentage of moisture within the transformer's paper insulation system, by evaluating the characteristics of the paper insulation. The insulation of the transformer is stressed through a sequence of voltage applications, in which it is charged to a D.C. voltage, then discharged (short-circuited) for a short period and finally open-circuited during which recovery voltage is measured. The source of the recovery voltage are the relaxation process inside the dielectric material *i.e.*, the de-polarization current, which builds up voltage on the electrodes of the test object. The magnitude of recovery voltage and the time taken to recover, provide a polarization spectrum which quantify the moisture content in the paper/pressboard of the insulation system. RVM technique can be used as acceptance test in new or repaired transformer to verify drying process and ageing process evaluation.

(*d*) **Infra-red Thermography Test:** Thermovision Imaging System is used to determine surface hot point temperature by measuring Infra-red rays radiated by the hot spot. Any abnormal high temperature spot at the external surface of the tank indicates a possible high temperature zone just inside that particular location. Based on the temperature of the hot spot, the transformer can be inspected and cause of hot spot may be set right.

29.5 MEASURES AGAINST ABNORMALITY DETECTED BY PROTECTION AND ANNUNCIATION SYSTEM

Despite preventive measures taken and maintenance based on condition monitoring through various electrical, oil and other tests suggested, any fault/abnormality developed during intervening period of two consecutive periodical testing schedule remain undetected. To arrest such type of abnormality at an early stage the sensitive protection scheme and annunciation system is required to be provided so that extent of damage may be reduced. The details of protection and annunciation system required to be provided for effective protection of transformer and periodical testing thereof is as under:

Testing of protection, control and annunciation system.

The protection schemes, control system and indication/alarm schemes are tested during per-commissioning as well as periodically to ensure security and reliability of operation during any fault or abnormality. Unreliable protection system and annunciation schemes will let the abnormality/fault go un-attended. The periodicity of testing for protection, control and annunciation is normally once in six months.

(*a*) **Protection scheme:** The following relays and protective devices are tested for their operation just above the threshold value and restraint below the threshold value. The safeguards provided by these are given below:

(*i*) Percentage bias differential relay	:	All types of internal electric fault
(*ii*) Circulating current high impedance restricted earth fault	:	Only internal earth fault with very high sensitivity
(*iii*) IDMT over current relay (HV and LV)	:	Overload and back up protection for fault
(*iv*) Over fluxing relay	:	Damage/over heating of core due to over fluxing
(*v*) Definite time high set over current relay	:	Stressing of transformer due to prolonged un-cleared through faults
(*vi*) LBB relay	:	Stressing due to un-cleared electric fault as a result of HV breaker stuck-up

(*vii*) Neutral displacement relay (For 400/220/33 kV Transformers	:	Earth fault iN tertiary winding
(*viii*) Bechholz relay	:	Gas formation due to internal fault and hot spot etc.
(*ix*) Oil temperature trip device	:	Over heating due to various reasons
(*x*) Winding temperature trip device	:	Over heating due to various reasons
(*xi*) Pressure relief device	:	Excess gas pressure due to severe internal fault
(*xii*) Master trip relay	:	Low current rating and insufficient number of contacts of aforesaid protection relay

With the introduction of numerical relays in the system, the procedures have added advantage in respect of self-diagnostic feature, disturbance/event recording, front and rear port communication, time synchronization, accuracy and sensitivity and other in-built features *i.e.*, LBB, High set over current, over fluxing etc. These features in numerical relays help in precise analysis of fault and reduce outage time.

(*b*) **Control system**

(*i*) ***OLTC control:*** The electric operation of OLTC is tested from remote and local by checking raise and lower operation with their limits. Step by step operation, interlock through manual handle, emergency stop, independent/slaver/master mode, operation of OSR during parallel operation in master/slave mode and operation of tap changer indicator.

(*ii*) ***Fans and pump control:*** The manual and auto control of fans and pumps from both local and remove, change over of stand by pumps to 'ON' in the event of tripping of any fan/pump in service or any other relevant control to the concerned scheme is checked.

(*iii*) ***Circuit Breaker control:*** The opening and closing operation from local and remote is checked for breaker. The tripping through all the protection schemes alongwith trip circuit supervision for monitoring pre-close and post close status of trip circuit is also checked.

(*c*) **Alarm and indication scheme:** Alarm and indication Scheme is very essential for the operator to know any abnormality in the system. The trip and non-trip alarm and status indications to be checked are given below:

(*i*) ***Trip alarm:*** Relating to all the relays and protective devices

(*ii*) ***Non-Trip alarm:*** Relating to Buchholz relay, OTI, WTI, MOG, non flow of oil, abnormality in OLTC, fan/pump control system, AC/DC Supply failure etc.

(*iii*) ***Indication:*** Status indication of OLTC tap position, OLTC operation in progress, fan/pump on, DC and AC Supply controlling breakers, isolators etc. healthy.

29.6 ON-LINE MONITORING

Although sensitive protection system is provided to detect fault developed in the transformer during the intervening period of two consecutive periodical tests, but this stage of fault detection is much delayed vis-a-vis incipient stage. The only answer to fault detection at incipient stage is on-line monitoring of the transformer which will bring revolution in this direction and the damage rate shall be reduced to minimum. On-line monitoring of transformer is in fact a future trend. Critical transformers in the system which requires frequent DGA testing may be provided with very simple and basic on-line hydrogen-monitor.

Hydrogen is one of the fault gases produced by most types of faults. Hydrogen monitor consists of a selected permeable membrane coupled with an electrochemical gas detector. H_2 dissolved in oil, permeate through membrane and react with O_2 from ambient air. This reaction generates electrical current that is measured as a voltage drop across a load resistor. Signal generated by detector is proportional to the rate at which H_2 permeates through membrane. This rate varies according to concentration of dissolved combustible gases and temperature. The electronic circuit, which amplifies detector signal, introduces an appropriate temperature correction to produce a reading solely based on concentration of dissolved combustible gases. H_2 monitors are already in use. These are early warning devices that alart maintenance personnel regarding developing fault conditions that could lead to failures. In time, as the need for monitoring evolved, the manufacturer of H_2 monitor developed the product to improve its operatioNal reliability, under varying thermal and environmental conditions and included CO as an additional monitored fault gas. H_2 and CO have been selected as they provide very early signs of degradation in insulation system. H_2 is indicative of degradation of oil and CO that of solid cellulose insulation.

29.7 CONCLUSION

The transformer is a key component of any electric power system. Its high reliability is vital virtually to every users of electric power. Unfortunately the maintenance of this vital equipment is often given a secondary importance in our country until a problem or failure occurs. Approximately 30% of distribution transformers fail in service due to poor maintenance. 30 to 35% of the failures are caused due to misuse of transformers at the users end. Rests are due to cause at the manufacturer's end.

We shall discuss the following topics in section-three:

- Installation, erection and commissioning (Chapter-30)
- Preventive maintenance and corrective action (Chapter-31)
- Transformer repair aT site (Chapter-32)
- Life of transformer—User's guide (Chapter-33)
- Failure analysis of transformer during short-circuit test—case study (Chapter-34)
- Loading guide for oil immersed transformer (Chapter-35)
- Protection of distribution transformer (Chapter-36)

Section IV

CHAPTER 30

Installation, Erection and Commissioning

FOOD FOR THOUGHT

'Charity begins at home'. Similarly, quality begins with each individual employee. Person not believing in quality is not going to convince either his colleagues or subordinates on issues of quality. Top down approach from management will be bought by the whole organization.

Quality has to start from within. Person with unhygienic habits will have hard time to keep the residence clean. Person with cluttered desk will not be able to keep the office neat and tidy. If there is no water in the well, can we draw water from it? The inner soul has to believe in personal quality such as keeping good health, showing positive attitude, desire to learn, looking for innovative ideas, managing time wisely and showing empathy for others. When these personal qualities are ingrained in all actions, success will be within easy reach. The heart has to believe and the brain has to execute the ideals to enhance quality of work.

Gandhiji, the father of our nation, firmly believed in nonviolence. He showed nonviolence in his speech, thought and action. With that firm belief, he convinced others to join him in the nonviolence movement. And the results was freedom for India from the British shackles without any blood drop. It goes without saying that actions speak our thoughts and beliefs. Children learn habits from their parents. Knowledge gained by student from teachers is dependent on the teachers. Workers listen to supervisors. A sculptor with an inner desire to excel will always come out with models superior to others works.

The body listens to the mind and the heart. It means feelings are always expressed in words and actions. Hence, quality flows from inside out. If excellence is practised on the factory floor, the customer will get an excellent product.

30.1 INTRODUCTION

Transformer is a key component of any electric power system. Its high reliability is vital virtually to every user of electric power. Unfortunately, the maintenance of this vital equipment is often given a secondary importance in our country. Approximately 30 per cent of distribution transformers fail in the service due to poor or no maintenance. 30 to 35 per cent of the failures are due to the misuse of transformers at the user's end. The rest are problems caused by defective manufacturing.

As the continuity of supply is of prime importance in modern power systems, it is most essential to take all possible precautions during erection and commissioning of transformers, and to follow it up with regular preventive maintenance to ensure continuous supply.

30.2 TRANSPORTATION

While transporting transformers to the installation site, parts which are liable to be damaged in transit should be removed and despatched in separate cases. The oil filled transformers are transported mostly by road.

In the case of distribution transformers with medium ratings, the following accessories are usually packed separately during transportation:

- Base rollers
- Silicagel breather
- Arcing horns
- Dial type thermometer
- Terminal lugs and connectors

In the case of small and medium rated power transformers, apart from the above accessories, the following items may also be included:

- Radiator banks
- Additional oil for topping up at site

In the event the radiators are sent separately, they should be well protected so that dust and rain water cannot seep into the radiator during transportation and during storage at site. Similarly, the oil drums should be properly sealed and stored horizontally to prevent accumulation of rain water on top of the drum.

30.3 INSPECTION

Predespatch inspection is very essential to ensure despatch of the transformer in perfect condition. Oil level should be kept slightly above normal.

At site (external): A thorouGh external examination should be made immediately on arrival of transformer at site. If damage is suspected, it should be brought to the notice of the manufacturer at the earliest.

At site (internal): An internal examination is recommended to be carried out to the maximum possible extent through the inspection cover, if provided. The tightness of nuts and bolts should be checked. Core and coil assembly should be lifted out and checked if there is a good reason to suspect internal damage.

30.4 HANDLING

The transformer should be lifted only by the lifting lugs provided for this purpose. Simultaneous use should be made of all such lugs or shackles in order to avoid any unbalance during lifting. Apart from the main lifting points designed to take the total load of the unit, the transformer has subsidiary lifting points suitable for particular components (such as tank cover, radiator, conservator etc.). Care must be taken to distinguish between them.

Safe load for the wire ropes and the multiplying factor to be Uced corresponding to lifting angles are shown below.

Safe load of wire rope

Table 30.1

Dia of wire rope (mm)	*Safe loading (kg)*
8	600
12	1,300
16	2,300
20	3,500
24	5,000
28	7,000
32	9,000
36	11,000
40	14,000
44	17,000
56	24,500
34	33,500
70	40,000

Multiplying factor for different lifting angles

Table 30.2

Lifting angle (degree)	*Multiplying factor*
0	1.0
20	1.015
40	1.065
60	1.155

Where it is necessary to use jacks for lifting, only the projections provided for the purpose of jacking should be used. Jack should never be placed under valve or cooling tubes or stiffener. Not more than two jacks should be operated at the same time. When two jacks are being operated, the opposite corners of the transformer should be firmly supported by sleepers. Jacks are also not to be left in position with the load for a long time. The transfonner should always be handled in the normal upright position. During the handling operation with jacks in position, care must be taken to prevent overturning or even tilting.

30.5 STORAGE

After arrival at site, it is desirable to erect and commission the transformer with minimum delay. In case this is not possible, the transformer should be stored in a pollution free area. This will minimise the possibilities of corrosion taking place.

Equipment meant for indoor use, should be stored indoor. Fragile components are to be stored carefully. Tap changer, if provided, should be operated at a regular interval (once in six months) two or three runs from one end of the range to the other. Loose accessories like arcing horns, dial type thermometer, connecting lugs, breather etc. are to be stored indoor.

In case, transformers of same ratings, but of different makes are lying in stores, the loose accessories for each of them should be stored with proper identification in specific areas to eliminate chances of mixup during use.

Transformer oil when received in drums should be stored under cover. The drums should not stand on and, but are to be placed on their sIdes to eliminate probability of accumulating rain water during monsoon.

30.6 ERECTION

No special foundation is necessary for installation of transformer except a strong structure to support the weight for polemounted transformer and a level concrete floor to prevent accumulation of rain water for ground-mounted transformer.

All tools, cables and other equipments required for erection work may be arranged at site before the work starts.

The installation of transformer should be made in such a way that the ratio switch, breather, thermometer, oil level indicator, rating plate, explosion vent etc. are properly placed at convenient location for easy monitoring. The operating mechanism of off-circuit tap switch, marshalling box, equipment like OTI, WTI, MOG, Buchholz relay, radiator valves etc. should be checked for their proper functioning.

For indoor transformer, the size of the building should be big enough to provide approximately one metre air clearance between the transformer and the adjacent wall for free circulation of air as well as to facilitate routine inspection.

30.7 FAULTY TERMINATION

The incoming and outgoing terminations should be done through proper connectors. ISS and REC have detailed recommendations with drawings for lugs and connectors. Users must ensure that the cable connections are made with proper lugs and connectors. During cable termination, the effect of bi-metallic action should also be kept in mind. If aluminium cables or conductors are used with brass/copper terminals or vice versa, a proper bi-metal should be kept in between. Otherwise due to the bi-metallic action, a small voltage is generated in between the contacts which will initiate a localised current and this may deteriorate the current carrying threads.

30.8 EARTHING OF TANK BODY AND NEUTRAL

As per Indian Electricity Rule, the tank body is to be earthed at two diagonally opposite points. This is to ensure that, in case one of the earths fail to act, the other will serve the purpose. The earthing should be done through GI strip having a minimum cross-section of 25 × 3 mm. Moreover painted surfaces in and around the earth bolts should be cleaned to ensure proper earthing. The LV neutral should also be properly earthed.

30.9 SIZE AND RATING OF CABLE FOR TERMINATION

LV Cable Box

The size and rating of LT cable plays a vital role in the successful performance of the transformer. Users should make a note of it while selecting the cable. Effect of bi-metallic action may also be looked into while making terminations.

In case a transformer is having LT cable box, care should be taken while selecting cable for termination. If a single core cable is used, the gland plate should preferably be of nonmagnetic material (either brass or aluminium) for transformer of 500 kVA and above. Otherwise, it will create unnecessary heating due to magnetic flux linkage around the entry of cable in the box. MS gland plate cut and welded with nonmagnetic material may also serve the purpose.

It is recommended to provide suitable cable supports to eliminate chances of creating unnecessary load on the bushing terminals.

HV Cable Box

Connection of cable ends to the bushing terminals are done either through heat shrinkable termination kit or through M-seal type terminating joints. In both the cases, proper clearances should be ensured.

30.10 HV OUTDOOR TERMINATION

In case of pole mounted transformer with exposed HV outdoor bushings, sufficient earth clearances are to be maintained. Breather, arcing horns etc. should be placed in their respective positions. Generally the breather is sent separately in sealed condition. The PVC tape provided to seal the air passage at the bottom plug of the breather should be removed before putting the breather in service. Moreover, the oil tray inside the breather container should be filled with oil before energization. The colour of silicagel should be checked which essentially should remain blue.

In case there is a growing tree near the bushing, necessary precaution should be taken to ensure that even when fully grown there is enough clearance between the bushing and the tree.

Electrical Clearance

Electrical clearances between the phases and phase to earth should be checked after the cable terminations are completed. Recommended minimum air clearances for 11 kV distribution system are shown in Table 30.3.

Table 30.3

HV to HV	*255 mm*
HV to earth	140 mm
LV to LV	75 mm
LV to earth	40 mm

In case the electrical clearances are less than the above, insulated barriers may be provided in between.

30.11 CHECKLIST FOR SUCCESSFUL COMPLETION OF ERECTION WORK

To ensure the successful completion of erection work, a checklist as shown below may be prepared for compliance:

Table 30.4

Sl. No.	*Work to be done*	*Remark*
1.	External damage, if any	Nil
2.	Tightening the mounting bolts.	Done
3.	Terminations done through bi-metallic lugs and/ or connectors	Yes
4.	Space around transformer for indoor installation.	Sufficient
5.	Opening of radiator valves for detachable radiators	Done
6.	Transformer body is earthed at two opposite diagonals through GI strip	Done
7.	Removal of paint in and around earthing terminals	Done
8.	LV neutral solidly earthed	Yes
9.	Loose accessories like breather, arcing horns, dial type thermometer etc. are placed in their respective positions.	Yes
10.	Rollers, if provided, are locked or removed	Yes
11.	Sampling valve, rating plate, ratio switch handle, dial type thermometer, explosion vent, oil level indicator etc. are visible as well as easily accessible for operation/ maintenance.	Yes
12.	Leakage or seepage of oil	No
13.	External air clearances after terminating cable/conductor	Ok
14.	Explosion vent diaphragm	Healthy
15.	Sealing of breather at the bottom plug removed	Yes
16.	Breather cup is filled with oil	Yes

Contd.

Sl. No.	*Work to be done*	*Remark*
17.	Colour of silicagel	Blue
18.	Both HV and LV bushings are cleaned with dry cloth	Yes
19.	Chance of getting disturbed by a growing tree in the near future	Checked
20.	Trapped air released from bushings	Yes
21.	Trapped air released through air release plug provided on tank cover	Yes
22.	Oil level slightly above normal	Yes
23.	Cable support provided	Yes
24.	Cable box cover refixed	Yes
25.	Position of ratio switch at normal or any other tap position (as required)	Checked
26.	Ratio switch handle is locked at a particular tap position	Yes
27.	Non magnetic gland plate, in case of single core cable, is provided for 500 kVA transformer and above.	Provided
28.	Wiring of alarm and trip contacts of OTI, WTI, MIOG, Buchholz relay etc. upto marshalling box.	Done

30.12 COMMISSIONING

After successful erection, some development work is to be done before starting precommissioning test. The development work includes the following:

- **Topping up of oil:** Final topping up is done with clean, dry and tested oil upto a level in the conservator commensurate with filling oil temperature.
- **Air release:** Since bushings used in distribution transformer are of oil communicating type, the trapped air inside the bushings should necessarily be removed before commissioning in order to allow the oil to come upto the top of the bushing terminals. This will reduce the possibility of corona discharge considerably.
- Trapped air inside the tank cover should also be removed through air release plug, if provided, on the tank cover.
- If radiators have air release plugs on top, the same should be operated to release trapped air, if any, from the radiators.
- Air from buchholz relay and explosion vent (if equalizer pipe not provided) should be released at this stage.
- Any other plug for releasing trapped air from the transformer, if provided, should also be operated.
- After completion of all the release operations, the oil level should be checked further to see that it is up to normal level.
- **Test on buchholz relay:** The slope of mounting angle of buchholz relay is checked with a spirit level to ensure that the inclination of pipe is approximately 5 to 10°. Further the status of alarm and trip contacts are checked by injecting dry air through the test petcock.

- **Test on magnetic oil level gauge:** The float of the oil level indicator is moved up and down between the end positions to check that the mechanism does not stick at any point. The low oil level alarm contact of the oil gauge should also be checked.
- **Temperature indicator:** The contacts of.OTI and WTI for alarm and trip are checked and set at required temperature depending upon ambient temperature and loading conditions.

Explosion Vent Diaphragm

Explosion vent is designed to offer rapid release of pressure from the tank and thus saving the tank from bursting and consequent hazard of liquid escaping. The vent is generally designed for an operational bursting pressure of approximately 1 kg/sq. cm. An air release plug of petcock type is essentially be provided at the bend portion of the vent pipe for releasing any trapped air inside the pipe.

Further, it is very important to ensure the quality of the vent material as well as its thickness. Some of the small transformer manufacturers are not able to ascertain the right kind of diaphragm material. In some cases, 3 mm thick perspex sheet is used as diaphragm. A few of the manufacturers use 6 mm cork sheet also as vent material. Correct material for the diaphragm for power transformer is 1/128 inch (0.2 mm) thick hylum sheet which breaks almost at a pressure of 1 kg/sq. cm. Any other material of equivalent property can also be used as vent material. Manufacturers as well as buyers must ensure the use of the right kind of diaphragm material with appropriate bursting pressure. The check may be done by applying dry air pressure on a complete transformer filled with oil upto the required level. The diaphragm must burst at a predetermind pressure.

The purpose of including the above paragraph in the precommissioning check is to facilitate the buyer to ensure the use of right kind of vent material before energizing the transformer.

Precommissioning Tests

If the foregoing instructions have been carefully followed, the transformer may be subjected to the following precommissioning test before final energization.

Checking of ratio, polarity and phase relationship: The ratio should be checked at all taps and the results should match with the factory test results. For such measurements, turns ratio bridge is employed. In case of OLTC, continuity during tap change is to be ensured.

Polarity and the inter phase connections should be checked.

Resistance measurement of the windings: Wheatstone/Kelvin bridge should be used for the measurement of winding resistances. In the case of tapped winding, the resistance at all tap positions should be measured. The values obtained should match the factory test results.

Insulation resistance (IR): IR values between the windings as well as windings to earth are checked. While checking IR, no external connection to the bushing terminals, including surge arrestor, should remain in the circuit.

Bushings are thoroughly cleaned before measuring IR value. It is preferred to use motor driven insulation tester (commonly known as megger) for such measurements. For 11/0.433 kV distribution transformer, 2500 V megger may be used for measuring IR values of both primary and secondary windings. Properly insulated leads with no crack or joint should be empolyed during measurement.

There is no proper guideline for minimum acceptable value of insulation resistance of the windings. Punjab State Electricity Board has come out with some reference values for II kV transformer.

Table 30.5

Particulars	*Minimum acceptable insulation resistance in Mohms at*				
	20°C	*30°C*	*40°C*	*50°C*	*60°C*
HV to earth	800	400	200	100	50
LV to earth	400	200	100	50	25
HV to LV	1000	60	400	200	100

Magnetising current: A three phase, 415 volts supply is fed to the HV windings of a three-phase transformer and the current drawn by the three phases are recorded. The currents should be uniform in nature. The currents on two side phases should be more or less equal while the middle phase current should be slightly less. In case, the currents in the phases are disproportionate *i.e.*, one of the phase currents in quite high with respect to the others, it is a clear indication of failure either interturn or interlayer, in any of the windings.

Breakdown value of the oil sample: Oil takes up moisture rapidly and that is why the condition of oil should always be checked before commissioning.

Oil of muddy colour is certain to be wet. Water mixed or water saturated oils are heavier than dry oil and sink to the bottom of the tank. Sample should, therefore, be taken from the bottom sampling valve of the transformer. Sample should not be taken unless the oil is allowed to settle for 24 hours, if from a drum or two/three days, if from a transformer.

Dirt from the draw-off valve or plug should be removed. To ensure that the valve is cleaned, sufficient quantity of oil (at least 2 or 3 litres) should be allowed to flow into a separate container before collecting the sample for testing. The sample should be collected in a clear glass container with glass stopper. Cleanliness is essential as small amount of dirt or water affect the accuracy of the test results. Wax should not be used for sealing the bottle containing the sample oil. However, the stopper can be covered with a pack of silicagel tied in a piece of dry and clean cloth.

The sample so drawn should be subjected to dielectric breakdown test as per the laid-down procedure discussed earlier or as per ISS. The acceptable value is above 50 kV.

Crack test of transformer oil: A rough test may be made by closing the end of a steel tube, heating the closed end to just under dull red hot and plunging it into the oil sample with the ear close to the open end. If the oil contains large amount of moisture, a sharp crackle sound will be heard. Dry oil will only sizzle.

30.13 ENERGIZATION

If all the above tests/ checks are found satisfactory, the transformer should be allowed atleast 4/6 hours so that the oil settles. The protective devices should be set to the minimum possible.

Now the transformer may be switched on to the full voltage at no-load. Any abnormality during commissioning, such as vibration of radiator part or abnormal hum etc. should be noted. After few hours of energization at no-load, the transformer should be switched off. Abnormality noticed, if any, should be corrected. All protective devices should be reset to normal values. Transformer can now be re-energized safely and loaded gradually.

After successful commissioning, the following details should be furnished to the manufacturer for maintaining a data-bank:

- Details of the transformer including its serial number
- Date of commissioning with precommission test results
- Location of installation
- Protection given to the transformer, such as ACB or fuse on LT side, dropout fuse on HV side etc.
- Loading details.

Precommissioning Checklist

Once the cycle of erection, precommissioning test and energization is completed, a checklist as shown below may be prepared for compliance to cover the precommissioning activities.

Table 30.6

Sl. No.	***Work to be done***	***Remark***
1	Trapped air is released from – Bushings – Tank cover – Radiators – Explosion vent – Buchholz relay – Any other part	 Yes Yes Yes Yes Yes N.A
2	Buchholz relay fitted at some angle	Yes
3	Alarm and trip contacts of – Buchholz relay – MOG – OTI – WTI	 Checked Checked Checked Checked
4	Alarm and trip contacts of OTI and WTI are set to normal operating value	Checked
5	Explosion vent diaphragm	Checked
6	Oil level upto normal	Yes
7	Precommissioning test carried out – Checking of ratio, polarity and phase relationship. – Winding resistance – Insulation resistance – Magnetizing current at reduced voltage – Breakdown value of oil	 Satisfactory Satisfactory Satisfactory Satisfactory Satisfactory
8	The transformer was successfully commissioned and loaded on dated May 29, 2000	

The checklist of erection and precommissioning work should be certified by a senior engineer prior to commissioning.

These checklists along with the precommissioning test results should remain as history for the transformer. In the event of any problem during service, this record may be used as reference.

Section IV

CHAPTER 31

Schedule of Maintenance and Proposed Corrective Action

FOOD FOR THOUGHT

The philosopher Santayana said that those who do not remember the past are condemned to repeat it. Those nations who are beginning to take their place in the world economy by developing business culture need to examine the past. The cost of finding out what is wrong and then doing things over (the price for non-conformance) is staggering. In manufacturing companies, this expense eats up at least 25 per cent of the revenues. But there is no need for these undesirable characteristics to exist in the first place. Problems should be prevented, which is much easier and far less expensive than finding and fixing them. The key to prevention lies in the hands of the senior managers.

Quality is not a game or toy that can be tossed out to the crowd for their pleasure. It is a deadly serious business.

31.1 INTRODUCTION

When compared to other electrical apparatus, transformer requires relatively less maintenance. The extent of inspection and maintenance required is governed by the size, regularity of service, the location of installation service and operating conditions such as ambient temperature, unusually dirty atmosphere, heavy fog, frequent rain etc. It is recommended to consult the supply authority if heavy single phase load or unbalanced load are to be connected.

Distribution transformers or small power transformers usually receive less attention than large transformers which require much greater investment. However, small transformers sometimes supply power to the industrial loads where continuity of service is of utmost importance. In such cases, it is required to give more attention to it, for example, distribution transformers connected to the hospital loads should undergo frequent checking and maintenance to ensure uninterrupted supply.

The history card containing the checklist of erection, precommissioning and commissioning data should be made available to the maintenance operators.

A rigid mechanism of inspection and preventive maintenance will ensure longer life, trouble free service and low maintenance cost. Maintenance consists of regular inspection, testing and reconditioning, where necessary. The amount of attention required and type of maintenance vary with the service conditions and load cycle of the transformer.

Records shall be kept in the history book of each transformer giving full details of all inspection and testing made and unusual occurrences, if any.

The principal object of maintenance is to keep the insulation in good condition. Dirt and excessive heat in contact with oxygen are the main causes for the deterioration of insulation and avoidance of these will, in general, keep the insulation in healthy condition. The critical factor is the ageing of insulation and decline in the quality of the insulation during the ageing process due to chemical and physical effect. The decay of the insulation increases the rate of chemical reaction. In the case of oil immersed transformer, if the sustained operating temperature of the insulation exceeds the normal operating temperature of 75°C by about 8 to 10°C, the life of the transformer will be shortened by almost half.

Proper maintenance definitely increases the life span of transformer. But following are some of the cases where maintenance may not be so effective in enhancing the life span of the transformer:

- Faulty design or construction
- Improper installation or use
- Overloading or pecularity of loading conditions
- Neglect
- Wear and tear and other deterioration
- Accidents
- Failure of auxiliary equipments.

31.2 FACTORS AFFECTING THE LIFE OF A TRANSFORMER

Effect of Moisture

Transformer oil readily absorbs moisture from air. The effect of water when mixed with oil, is to decrease the di-electric strength of the oil as well as the insulating paper which absorbs and stores the moisture due to higher affinity of water to paper over oil. All possible preventive steps should, therefore, be taken to guard against moisture penetration to the inside of the transformer. This includes the blocking of all openings for free access of air during long storage and frequent reactivation of breather in service.

Effect of Oxygen

Oxygen may be present inside the transformer due to air remaining in oil, air pocket trapped in the windings etc.

The oxygen reacts on the cellulose of the insulation and the decomposition products of the cellulose lead to the formation of organic acids, soluble in oil and sludge which blocks the free circulation of oil. The adverse effect of oxygen, which may be aggravated by catalytic action between hot oil and bare copper, increases the operating temperature.

Effect of Solid Impurities

The di-electric strength of oil is diminished appreciably by minute quantities of solid impurities present in the oil. New transformer may contain particles of insulating materials and other solid impurities. It is, therefore, a good practice to filter the oil after it has been in service for a short time, especially for the units of higher voltage class.

Effect of Varnishes

Some varnishes, particularly of the oxidizing type, enter readily into reaction with transformer oil and precipitate sludge on the windings. Synthetic varnishes having acid inhibiting properties, generally delay the natural formation of acid and sludge in the oil. This aspect should be borne in mind by the maintenance engineer when rewinding and replacing the coils during repair of transformers.

Effect of Slackness of Windings

Slackness of windings may cause failure due to repeated movement of coils which may wear the conductor insulation at some places and lead to an interturn failure. The coils may also get displaced under load conditions or during momentary shortcircuit which may cause electric and magnetic unbalances and produce even greater displacement. It is, therefore, a good practice to lift the core and winding of a transformer and remove any slackness which may have developed by tightening the tie rods or pressure screws provided for this purpose at the first inspection. In all cases, the instructions provided by the manufacturer should be followed closely. However, the maintenance schedule given at the end of this chapter will provide a general guideline to the users. Additional maintenance procedures should be adopted where transformers are working under abnormal conditions.

31.3 MAINTENANCE PROCEDURES

Arrangements should be made to carryout safe procedures for the maintenance of transformers. Before starting any maintenance work, the transformer should be isolated from the supply and the terminals should be earthed. Oil level should always be kept under observation when undoing nuts and bolts and unsealing the tank. There should not be any fire near the transformer while maintenance work is on.

Insulating Oil

Transformer oil is subjected to deterioration or contamination during storage and service. Accordingly, a periodic treatment to maintain it in fit condition is required and eventually when it becomes no longer usable, it may have to be replaced with new oil.

All leaks should be repaired as quickly as possible so as to avoid possible trouble due to low oil level.

Oil for topping up should comply with IS-335 and should preferably be from the same source as that of the original oil, because, the oil refined from different crudes may not mix completely and may separate into layers. Furthermore, there may be a great tendency to form acidity or sludges in a mixture than in an oil from a single source of supply. Used oil should not be mixed with the original oil. New oil may be added as make up only, not exceeding 10 per cent. It is desirable not to mix oil taken from a switchgear to top up a transformer.

Samples of oil should be taken on regular intervals and tested for compliance with specifications. It may be mentioned that the di-electric strength does not give a true indication of the deteriorated condition. Even an oil which is highly deteriorated may give a high dielectric strength, if dry. Normal method of purifications maintain only the di-electric strength, but do not give indication of the deteriorated conditions of the oil.

It is, therefore, suggested not to depend solely on the di-electric strength of oil. In addition to electrical tests, other tests as recommended in IS-1866 should also be carried out at frequent interval.

As per recommendation of IS-1866, the following checks are also to be done periodically. The quantity of oil to be taken as sample is atleast 4 litres.

Colour and Odour

Cloudiness of oil may be due to suspended moisture or sediments, such as iron oxide or sludge. Undissolved water present in oil may be determined by crackle test. However, total moisture content can be determined from water content test.

Dark brown coloured oil indicates the presence of dissolved asphaltenes.

Green colour indicates the presence of dissolved copper compounds and a rapid deterioration of the oil may be expected.

Acrid smell indicates the presence of volatile acids which can cause corrosion. This may render the oil unsuitable for treatment on site.

Test for sludge, either in the form of sediment or precipitate may also be carried out depending on the condition of oil.

Polar Substance

These are oil soluble compounds resulting from oxidation of the oil itself or from the solution in the oil and external contaminants or materials used in the construction of the equipments. Measurement of dissipation factor and to a lesser extent resistivity and interfacial tension of the oil enable such contamination to be detected and periodically assessed.

Dielectric Dissipation Factor

This characteristic is very sensitive to the presence in the oil of soluble contaminants and ageing products.

Specific Resistance

For any given oil, there is generally a relationship between dissipation factor and resistivity. If the dissipation factor increases, there is a tendency for resistivity to reduce. Useful additional information may be obtained by carrying out the resistivity test both at ambient temperature and at 90°C. A satisfactory result at 90°C coupled with an unsatisfactory value at the lower temperature is an indication of the presence of water or cold precipitable materials, without undue chemical deterioration or general contamination. Unsatisfactory results at both temperatures indicate a greater extent of contamination than a poor value at the lower temperature only. The oil is likely to be restored to a satisfactory level by drying and low temperature filtration.

The measurement of resistivity may be more easily carried out at site than of di-electric dissipation factor.

Interfacial Tension Test

The rate of change of interfacial tension is fairly rapid during the first stages of ageing. Afterwards, the rate of change decreases as the values themselves become lower.

The interfacial tension value of oil against water content provides a very sensitive means of determining the degree of oil contamination. This test has gained considerable importance during recent years. New oil, before they are accepted for service, should have an IFT value of over 0.4 N/ m. This value falls during service and the decrease is proportional to the concentration of the contaminants, particularly in the initial stages of service. This test is used largely as a field test for assessing the oil quality. Tests carried out on an oil available have revealed the following:

The interfacial tension value of an oil falls to about 0.02 to 0.025 N/m in the initial stages due to dissolution of varnish etc. from within the equipment. This fall is not to be interpreted as a case of excessive oil deterioration.

The interfacial tension test is applicable to both the oil with and without additives.

Sludge formation in the oil is possible if the interfacial tension value falls below 0.018 N/m. It would be seen from the various results that oil with IFT value of 0.018 N/m or above are free from sludge.

Neutralization Value (Total Acidity)

The acid products formed by the oxidation of the oil actively encourage deterioration of insulating paper and pressboard. It is, therefore, essential to detect and monitor this process. For quick determination of total acidity in insulating oil, a portable kit for carrying out the test has been devised. This kit helps the test for total acidity of oil to be done at site with ease.

Free and Dissolved Gases

Under normal service conditions, only small quantities of CO, CO_2 and very small quantity of hydro-carbons are formed. Large amount of dissolved gases, other than atmospheric components, may be an indication of an incipient fault in the equipment.

Sampling and analysis of free and dissolved gases should be done in accordance with the method described in IS-9434.

Flash Point

Light hydrocarbons are formed during the degradation of oil under the influence of heat and/or electrical stresses. Large amount of these hydrocarbons may be an indication of an incipient fault in the, equipment. The presence of some lower hydrocarbon deterioration products may be detectable by measuring the flash point of the oil.

Flash point tests should be done frequently if the oil is subjected to high temperature due to internal faults or has any unusual odour.

A slow fall in flash point of oil in a transformer is not harmful. A fall exceeding 15°C or a flash point below 125°C may indicate unsatisfactory working condition, such as electrical discharge, excessive high internal temperature, core fault or foreign matters providing a conducting path between life parts and frame. In such cases, the transformer should be taken out of service for examination. Special precautions should be taken to avoid risk of fire or explosion, particularly when oil is drained out from the tank.

Oxidation Stability

Oxidation stability test for uninhibited oil may be carried out in accordance with the method described in Appendix-C of ISS-335.

Compatibility of Insulating Oil

Compatibility test may be required to determine the feasibility of mixing new oil of different types and origins or new oil with oil in service, if the make up is more than 10 per cent.

Frequency of Examination of Oil in Service

The frequency of examination depends on the power, loading, construction and other service conditions of the equipment. Hence, a recommendation cannot be made which is applicable to all types of oil-filled equipments.

The application and frequency of tests suitable for oil-filled transformer is given in IS-1866 which is reproduced below.

Table 31.1

Characteristics	*Frequency of test*	*Recommended value*
Electric strength (Breakdown value)	(*i*) After filling or refilling prior to energization (*ii*) After 3 months of (*i*) (*iii*) After 1 year of (*ii*)	30 kV (min.)
Water content (PPM)	(*i*) After filling or refilling prior to energization (*ii*) After 3 months of (*i*) (*iii*) After 1 year of (*ii*)	35 PPM (max.)
Specific resistance (resistivity) at 90°C	(*i*) After filling or refilling prior to energization (*ii*) After 3 months of (*i*) (*iii*) After 2 years of (*ii*)	0.1×10^{12} ohm cm (min.)
Dielectric dissipation factor at 90°C	(*i*) After filling or refilling prior to energization (*ii*) After 2 years of (*i*)	1.0 (max.)
Neutralization value (total acidity)	(*i*) After filling or refilling prior to energization (*ii*) After 2 years of (*i*)	0.5 mg KOH /gram (max.)
Sediment and/or precipitable sludge	(*i*) After filling or refilling prior to energization (*ii*) After 2 years of (*i*)	No sediment or precipitable sludge should be detectable.
Flash point	(*i*) After filling or refilling prior to energization (*ii*) After 2 years of (*i*)	Decrease in flash point 15°C (max.) of the initial value, subject to a maximum value 125°C
Interfacial tension at 27°C	(*i*) After filling or refilling prior to energization (*ii*) After 2 years of (*i*)	0.018 N/m (min.)
Dissolved gas analysis	(*i*) Atter filling or refilling prior to energization (*ii*) After 3 months of (*i*) (*iii*) After 1 year of (*ii*)	If offensive gas found, the matter should be investigated, recommended to reclaim or replace the oil.

Action to be Taken on the Basis of Report of Oil Test Results

The following cases are considered as a function of the degree of deterioration of the oil:

- The characteristics are normal—No action necessary.
- Only the value of di-electric strength is too low—Remove water and solid particles by reconditioning, for example, filtration, centrifuging or vacuum dehydration.

  The efficiency of the treatment should be controlled. In the case of abnormal increase of water content in oil and abnormal decrease of electric strength beyond permissible limit after 3 months or after 1 year or so on, it is necessary to dry the solid insulation of the transformer, provided that there is no other external factors responsible for abnormal increase of water content, for example, condition of breather.
- One or more characteristics of the oil change rapidly—Conduct further test of the oil.
- If one or more characteristics are unsatisfactory—According to economic factor and local circumstances, it should be decided to examine the oil more thoroughly, in order to reclaim the oil or to replace it altogether.

Rollers: For small and medium rated distribution transformers, the rollers are generally taken out after the equipments are installed.

In the case of small power transformers, the roller may remain with the base in locked position. In such cases, after the transformer is in service for a long time, rollers should be greased for easy movement.

Transformer tank body: The tank and other parts should be inspected for any rust and leak. Rusted portion, if any, should be cleaned thoroughly and repainted with quality paints. Transformer should be completely painted after a long interval. If any leak is found, it should be investigated. If it is due to defective welding, the same should be rectified by cold process. Good quality long lasting adhesives are available which may be employed instead of electric welding. Leaking joints can be rectified by tightening the bolts to the correct pressure or by replacing the gaskets.

Internal inspection: The core and winding may be lifted from the tank, if necessary, only in suitable climatic conditions. The surrounding atmosphere should not be humid and should be free from dust and dirt. Under no circumstance, the lifting of core-coil assembly should be done during rain. Suitable lifting device, depending on the weight of core-coil assembly should be arranged. Before disturbing any thing, the insulation resistance of the transformer should be recorded.

The tank contains oil and oil vapour. Therefore, care should be taken to prevent fire. Naked lights and flames should be kept well away from the transformer when the tank is opened.

If an inspection lamp is required, only a protected electric lamp, preferably an extra low voltage lamp should be used. The lamp should be kept off when not in use.

Before opening the tank cover, it should be properly cleaned removing any dust, moisture etc. from the top. The persons opening the tank cover should not have any loose objects in their breast pocket and they should not be wearing wrist watch or ring. The spanners used for opening the cover bolts should be cleaned from all metal fillings and should be held by a cotton strap or string tied securely round the waist or wrist of the person opening the tank cover. Cast iron spanner should not be used as they may break and fall inside the tank. All nuts and bolts should be removed from the top before removing the tank cover.

The method of removing the cover depends on the construction of the transformer. If the core and winding is separated from the cover and there are bushings mounted on the top, then the bushings should be dismantled first and stored carefully and then the tank cover should be removed carefully. If, however, the core-coil unit is suspended from the tank cover, substantial number of lifting lugs, usually in the form of eye bolts are provided on the cover. While lifting, care must be taken so that the core-coil assembly is removed vertically.

Core and winding: The core and winding, if not suspended from the cover, are held in the tank body by bolts or other suitable devices at each end near the tank top. These locking arrangements should be removed after undoing the connections.

Mechanical connection to the tapping switch handle, if provided, should be removed.

The core and winding should then be lifted vertically by slinging it from the lifting lugs provided on the core frame, making sure that the sling does not foul against terminal leads, tapping switch etc. as it pulls tight. After allowing sufficient time for the oil to drain off into the tank from the coil assembly, it should be lowered preferably onto two cross beams placed in a metal tray.

After removing the core-coil assembly from the tank, the following items should be carefully checked to make sure that nothing is disturbed unnecessarily and that the leads are not pulled out of their places unless they are unsatisfactory:

- All bolts and nuts should be adequately tightened but not too tight to cause bend in the clamps, or windings, insulation etc.
- The coils should be cleaned to make them free from sludge. Slight traces of sludge should be cleaned by flushing fresh transformer oil. If there are heavy deposits, it is likely to block the oil ducts. In such cases, the cleaning should be done as per the guideline of the manufacturer.
- The windings should be clamped firmly without any possibility for movement. There should be no loose spacer or end block. If loose windings or spacers are noticed, the vertical tie rods which put pressure on the coil spacers should be adjusted properly.
- The tap changing switch should be checked to ensure that it is functioning well.
- All connections should be tight and clear.
- If the insulation resistance test done before untanking gave low value, the test should be repeated. If now, the test gives satisfactory value, the low value can be attributed to some other causes. However, if the test still gives low value, hot oil circulation may be done after retanking to improve [*I-R*] value.
- If there is sludge deposition at the bottom of the tank, in the conservator or in the radiators, the same should be cleaned.

Bushings and cable boxes: It is recommended to clean the porcelain bushing and examine them for cracks and chips. Very slight chips may be ignored. But any serious damage will require replacement with a new porcelain bushing which must be identical to the one already used. In case non standard bushings are used, it is recommended to keep spares for emergency.

If the bushings are placed below oil level, the oil level should be lowered until it goes down below the bushing hole.

If leakage is observed from the bushing gaskets, the same should be replaced with a new one. Visual inspection of cable boxes, especially the terminations and cable supports, is to be done.

External connections: All connections should be tight. If they appear blackend or corroded, undo the connection and clean it with emery paper. Remake the connection and apply an anti-oxide spray. It is particularly important that heavy current carrying connections should be maintained properly. If the metal has a characteristic bluish tinge which indicates that it was hot, then most probably the connection is not satisfactory. Either it has become loose or dirty or the conductor is not suitable for carrying the required current.

The earth connection should be maintained properly. A small copper loop to bridge the top cover of the transformer and the tank may also be provided to avoid earth fault current passing through the fastening bolts when there is a lightning surge, high voltage surge, or failure of the bushings.

Conservator and magnetic oil gauge: The conservator is so arranged that the lower part act as sump in which the impurities entering the conservator will collect. A valve /plug is fitted at the lowest point of the conservator for draining and sampling. The inside of the conservator should be cleaned or flushed with oil once in every 2 to 3 years. A removable end conservator is generally recommended for this purpose.

The oil level indicator should be kept cleaned.

Generally, the oil level is visible through a transparent material. In case of breakage, immediate replacement is essential. In the case of magnetic oil level gauge, the mechanism of oil gauge should be inspected and cleaned when the conservator is stripped off.

Breather: The silicagel breather is fitted with a sight glass so that the colour of the crystals is visible. The colour changes from blue to pink as the crystals absorb moisture. When the crystals get saturated with moisture, they become predominantly pink and should, therefore be reactivated. The body of the breather should be removed by unfastening the nuts. The silicagel crystals are baked at a temperature of about 200°C until the whole mass is at this temperature and the blue colour is restored. Clean the breather and replace the dry crystals and renew the oil in the sealing cup at the bottom.

Buchholz relay: Mechanical inspection and tests should be carried out at one and two year intervals respectively.

During operation, if a gas is found to be the cause of alarm, it should be tested and analysed to find out the nature of fault. Buchholz may also give alarm/trip due to the oil level falling below buchholz level.

Explosion vent: The diaphragm, which is fitted at the exposed end of the vent should be inspected at frequent intervals and replaced, if found damaged. Failure to replace the diaphragm quickly may allow the ingress of moisture which will contaminate the oil. If the diaphragm is found broken because of some fault in the transformer, an inspection should be carried out to determine the nature and cause of the fault.

Gaskets: Gaskets sometimes shrink during service. It is, therefore, necessary to check the tightness of all bolts fastening gasketed joints. The bolts should be tightened evenly around the joints to avoid uneven pressure. Leaking gaskets should be replaced as soon as circumstance permit.

Small pipe work: The pipe work (example-radiator header pipe, equiliser pipe, conservator connecting pipe, pipe for valve etc.) should be inspected once a year. Leaks may be due to slack unions, which should be tightened or due to badly seated joints caused by misalignment. In the later case, the pipe should be aligned and joints remade.

Temperature indicators: During each yearly maintenance inspection, the level of oil in the pocket holding thermometer bulb should be checked and oil replenished, if required.

The capillary tubing should be fasten again if it has become loose. Dial glasses should be kept cleaned and if broken, replace as soon as possible to prevent damage to the instrument. Temperature indicators, if found to be reading incorrectly, should be calibrated with standard thermometer immersed in hot oil bath.

Cooling radiators: Maintenance of radiators primarily consist of replacing damaged elements, cleaning the outer surface to remove settled dust and repainting. In the case of detachable radiator, isolation valves between the tank and radiators should also be checked. The ‘O’ ring in the drainout plug and air release socket should be replaced, if found damaged.

On Load Tap Changer (OLTC): Since all On Load Tap Changers (OLTC) are not of same design and construction, special instructions of the manufacturer should be followed. However a few points are illustrated as follows:

- **Diverter switch:** The maintenance primarily consists of servicing of diverter switch contacts, checking of oil level in the diverter switch chamber and replacement of diverter switch oil when the same becomes unsuitable for further service.
- **Motor driven mechanism:** Do not allow dirt to accumulate between contact rings of notching controller.
- Do not use oil/grease on contact rings of notching controller.
- Check the operation of anti condensation heater.
- If the contacts are silver faced, no touching up need be done, but should be replaced when they are worn out. Copper contacts may be lightly touched up with a file when they become rough. The pole faces of electromagnet should be kept cleaned.
- Do not oil/grease the contact surface of radial multicontact switches, unless a special contact lubricant is used. The space between the rings should be cleaned occasionally. If necessary, few drops of benzine may be used.

Spares: It is a healthy practice to have essential spares, like one number of each type of bushing, one spare limb winding, one thermometer, a set of gaskets etc. Supplier’s recommendation may also be followed regarding spares.

31.4 MAINTENANCE SCHEDULE AND TROUBLE SHOOTING CHART

Recommended maintenance schedules of all types of transformers of rating less than 1000 kVA and for 1000 kVA and above are illustrated in ISS, which are reproduced here for reference.

Trouble Shooting in Transformer

Faults observed during the periodic maintenance schedule are to be rectified as per suggested actions. However, certain troubles and major faults in performance of the transformer may have to be handled in a particular sequence. Guidance to manage electrical and mechanical troubles, normally encountered in all types of transformers, is given in ISS which is also been reproduced here for reference.

Table 31.2: Recommended maintenance schedule for transformers of capacity less than 1000 kVA (As recommended by ISS)

Sl. No.	*Inspection frequency*	*Items to be inspected*	*Inspection notes*	*Action required if inspection shows unsatisfactory conditions*
1.	Hourly	(*i*) Load (amperes) (*ii*) Temperature (*iii*) Voltage	Check against rated figures Oil and ambient temperature Check against rated figures	Nil Nil Nil
2.	Daily	Dehydrating breather	Check the air passages and colour of silicagel	If silicagel is pink, replace it with spare. The pink silicagel may be reactivated for reuse.

(*Contd.*)

Sl. No.	*Inspection frequency*	*Items to be inspected*	*Inspection notes*	*Action required if inspection shows unsatisfactory conditions*
3.	Monthly	(*i*) Oil level in transformer (*ii*) Connections	Check oil level Check tightness	If low, top up with dry oil. Examine transformer for leak If loose, tighten.
4.	Quarterly	Bushings	Examine for physical cracks and dirt deposits	Clean or replace
5.	Half yearly	(*i*) Non conservator transformer (*ii*) Cable box. gasketed joints (*iii*) Gauges (*iv*) Painting	Check for moisture under cover Inspect Inspect Inspect	Improve ventilation, check oil remove defects remove defects remove defects
6.	Yearly	(*i*) Oil in transformer (*ii*) Earth resistance (*iii*) Relays, alarms and their circuits etc.	Check for dielectric strength and water content. Check for Examine the relays and alarm contacts, their operations, fuses etc. check relay accuracy	Take suitable action to restore quality of oil. acidity and sludge Take suitable action if earth resistance is high. Clear the components and replace contacts and fuses if necessary, change the setting, if necessary
7.	2 Yearly	Non conservator transformer	Internal inspection above core	Filter the oil regardless of condition
8.	5 Yearly		Overall inspection and lifting of core-coil assembly	Wash by hosing down with clean dry oil

Table 31.3: Recommended maintenance schedule for transformers of capacity 1000 kVA and above (As recommended by ISS)

Sl. No.	*Inspection frequency*	*Items to be Inspected*	*Inspection notes*	*Action required if inspection shows unsatisfactory conditions*
1.	Hourly	(*i*) Ambient temperature (*ii*) Winding and oil temperature (*iii*) Load (ampere) and voltage	 Check the temperature rise whether reasonable Check against rated figures	Nil Shutdown the transformer and investigate if the temperatures are persistently higher than normal. Nil

(*Contd.*)

Sl. No.	*Inspection frequency*	*Items to be Inspected*	*Inspection notes*	*Action required if inspection shows unsatisfactory conditions*
2.	Daily	(*i*) Oil level in transformer	Check against transformer oil level	If low, top up with dry oil, examine the transformer for leaks
		(*ii*) Oil level in bushing	–	Nil
		(*iii*) Relief diaphragm	–	Replace if lound cracked or broken.
		(*iv*) Dehydrating breather	Check air passages for free, check the colour of the active agent	If silicagel is pink, replace If with spare. The old one may be reactivated for reuse.
3.	Quarterly	(*i*) Bushing	Examine for cracks and dirt deposit	Clean or replace
		(*ii*) Oil in transformer	Check for dielectric strength and water content	Take suitable action to restore quality of oil
		(*iii*) OLTC	Check oil in OLTC and driving mechanism	Replace burnt or worn contacts or other parts
		(*iv*) Indoor transformer	Check ventilation	Nil
4.	Half yearly	Oil cooler	Test pressure	Nil
5.	Yearly or earlier	(*i*) Oil in transformer	Check for dielectric strength, water content, acidity and sludge	Take suitable action to restore quality of oil
		(*ii*) Oil filled bushing	Test oil	Filter or replace
		(*iii*) Cable boxes	Inspect	Nil
		(*iv*) Gasket joint	–	TigHten the bolts evenly to avoid uneven pressure
		(*v*) Surge diverter	Examine for cracks and dirt deposits	Clean or replace.
6.	Yearly or earlier	(*vi*) Relays, alarms and their circuits etc	Examine relays and alarm contacts, their operation, fuses etc. Check relay accuracy etc.	Clean the components and replace contacts and fuses, if necessary Change the setting, if necessary
		(*vii*) Earth resistance	–	Take suitable action, if earth resistance is high.
7.	(*a*) 5 yearly	1000 to 3000 kVA	Overall inspection including lifting of core and coil	Wash by hosing down with clean dry oil
	(*b*) 7–10 yearly	Above 3000 kVA	-do-	-do-

General Precaution

(*a*) In the event of maintenance of on Load tap changer, the manufacturer’s recommendation should be followed.

(*b*) The silicagel may be reactivated by heating it from 150 to 200°C.

(*c*) No work should be done on any transformer unless it is disconnected from all external circuits and the tank and winding ends are properly earthed.

(*d*) In the event of any abnormal problem during service, the manufacturer should be contacted for suitable guidance.

(*e*) Dismantling and oil filling of transformer under moist air or during rain must be avoided.

Table 31.4: Trouble shooting chart for all transformers (As recommended by ISS)

Trouble	***Cause***	***Remedy***
High temperature	(*a*) Over voltage	Select proper high voltage tappings to avoid over excitation.
	(*b*) Over current	If possible, reduce load. Heating can often be reduced by improving power factor of the load. In case the transformer is put in parallel with another transformer, circulating current may flow due to improper ratio or impedance.
	(*c*) High ambient temperature	Either improve ventilation or relocate the transformer to a place where the ambient temperature is lower.
	(*d*) Insufficient cooling	If the unit is artificially cooled, make sure that the cooling is adequate.
	(*e*) Lower liquid level	Fill upto proper level.
	(*f*) Oil with sludge	Use filter press to wash-off core and coils. Filter the oil to remove sludge.
	(*g*) Short circuited core	Test for excitation current and no-load loss. If high, inspect core and winding to identify the cause and then repair.
Winding failure	(*a*) Lightning (*b*) Short circuit (*c*) Over load (*d*) Oil of low di-electric strength (*e*) Foreign materials	Usually when a transformer winding fails, the transformer is automatically disconnected from the power sources by the opening of the supply breakers or fuses. Smoke or cooling liquid may be expelled from the tank, accompanied by noise. When there is any such evidence of a winding failure, the transformer should not be re-energized at full rated voltage, because this might result in additional internal damage. Also it may introduce a fire hazard in the transformer.
Core failure	Core insulation breakdown (core bolts, clamps or between laminations)	After disconnecting from both source and load, the following observations and tests are recommended: (*i*) External mechanical or electrical Damages to bushings, leads, potheads, disconnecting switches or other accessories. (*ii*) Level of insulating liquid in all compartments. (*iii*) Temperature of the insulating liquid wherever it can be measured. (*iv*) Evidence of leakage of insulating liquid or sealing compound.
High excitation Current	(*a*) Short circuited core (*b*) Open core joints	Test core loss. If high, it is probably due to a short circuit of core. Test core lamination. Repair, if found damaged. High excitation current may be due to appreciable air gap in the core joints. The core may be re-set and re-tightened to the clamping structure.

(*Contd.*)

Trouble	***Cause***	***Remedy***
Incorrect voltage	(*a*) Improper ratio (*b*) Supply voltage abnormal	Change terminal board connection or ratio switch position to give correct voltage. Change tap connection or re-adjust supply voltage.
Audible internal arcing and radio interference	(*a*) Isolated metallic parts (*b*) Loose connection (*c*) Low liquid level exposing live parts	The cause should immediately be identified. Make sure that all normally grounded parts, such as the clamps, core etc. are grounded properly. Tighten all connections. Maintain proper liquid level.
Bushing flashover	(*a*) Lightning (*b*) Dirty bushing	Provide adequate lightning protection. Clean porcelain bushings. Frequency depends on dirt accumulation.
Leakage through screw joints	(*a*) Foreign materials in thread (*b*) Oval nipples (*c*) Foor threads (*d*) Improper filter (*e*) Improper assembly	All joints (screws or gaskets) to be checked and ensured that they are satisfactory.
Leakage at gasket	(*a*) Poor joints (*b*) Insufficient or uneven compression (*c*) Improper preparation of gaskets and gasket surfaces	To be set right on priority.
Leakage in welds	Mishandling during transportation or imperfect weld	Repair leaks by cold welding.
Crack in pressure relief diaphragm	Improper assembly or mechanical damage	Replace diaphragm. Inspect inside of the pipe for evidence of rust or moisture. Be sure that the transformer is dry. If there is any chance that drops of water have settled directly on the windings or other vulnerable locations, as oil test may not always reveal presence of free water, it is required to dry out the transformer.
Pressure relief diaphragm ruptured	Internal fault	Investigate the cause of fault and rectify.
Low dielectric strength	(*a*) Condensation in open type transformers with improper ventilation (*b*) Broken relief diaphragm (*c*) Leaks around cover accessories	Necessary repair to be done.

(*Contd.*)

Trouble	***Cause***	***Remedy***
Badly discoloured oil	(*a*) Contaminated by varnish (*b*) Carbonized oil due to switching (*c*) Winding or core failure	Retain oil if di-electric strength is satisfactory, otherwise filter or reclaim or replace.
Oxidation (sludge or acidity)	(*a*) Exposed to air	Filter or re-claim or replace.
	(*b*) High operating temperature	

Section IV

CHAPTER 32

Transformer Repair at Site

FOOD FOR THOUGHT

Each person within the organization must learn a common language where quality is concerned. Quality means conformance to the requirements. The requirements are the commitments involved in giving the customers what was agreed. People must learn their jobs and the requirements that are involved and then learn how to do them exactly. Quality must be achieved by prevention rather than detection. Think vaccine instead of medicine. The standard has to be: zero defect, or defect free. This means doing things right the first time and every time, with no allowable error. When something goes wrong, we need to find out the root cause in order to prevent it from happening again. We should not accept error in any form. We should not disappoint our customer.

Quality is not the result of tricks or fads, it comes from developing a culture of integrity, openness, and hardwork. In short, quality is what we make, not the result of technical applications that require no work by management.

32.1 INTRODUCTION

Transformers are sufficiently reliable in operation, provided they are periodically maintained and serviced. But due to long operation and poor service conditions prevailing at site, the transformer often needs frequent repair. Even old, unreliable transformers also need to be repaired as well.

Low and medium capacity transformers are usually repaired at specialized works, while high capacity ones are repaired at the site itself. Some transformer parts are repaired at transformer building works. Site repair requires highly skilled personnel capable of organizing their work place correctly. It is especially important that the workers for site repair are skilled in several trades, like winding, assembling, fitting, welding etc.

For timely and efficient repair work, it is essential that the personnel have a high standard in technical skills. This chapter outlines the amount of technical knowledge necessary for the operators in transformer repair.

The guidelines for repair work on transformers at site are framed by Z. Khaudyakov, an eminent engineer of Russian origin in his book titled:

"Repair of power transformer" published by Mir Publication, Moscow.

The construction of transformers described in his book are mostly based on Russian technology, which are seldom followed in India. Effort is made to review the requirements and amend the same to suite construction of Indian transformers.

32.2 SCOPE

The scope of repair work depends on the technical condition of a given transformer and the character of its failure. It is customary to subdivide the transformer repair into:

- Minor repair (maintenance and servicing).
- Medium repair (inspection)
- Major repair (overhaul).

Minor Repair

Minor repair is purely a preventive work of narrow scope carried out without opening the transformer. It includes external inspection, detection and elimination of minor defects in the fittings, radiators and hang on devices, tightening up of fasteners, elimination of oil leaks and adding oil to capacity, wiping of external surfaces, checking of winding insulation resistance and any other minor operations. Minor repair work is carried out by the operating personnel of work stations and substations.

Medium Repair

Medium repair involves the opening up of the transformer and withdrawal of core-coil assembly from the tank. This type of repair includes inspection and minor repair of accessible internal assemblies and also repair or replacement of individual devices or components (*e.g.* tap changer, lead insulation, lead supports etc.). It is carried out with the transformer de-energized for a relatively short period of time. Such repair work is usually necessitated by internal defects revealed in service that may later cause a major breakdown.

Minor and medium repairs fall into the category of planned repairs (preventive), the execution dates of which are decided based on the appropriate operating and servicing instructions. In practice, medium repair is customarily referred to as inspection. The duration of inspection involving the opening up of the transformer and also, conditions for its execution are specified in repair instructions.

Major Repair

Major repair involves replacement of the windings and insulation, reinsulation, of core laminations, resoldering of the winding connections and other similar operations including redesign.

32.3 ORGANIZATION OF REPAIR WORK

Before starting repair work, it is necessary to determine the scope of work to be carried out. The necessary work to be done on the transformer in operation, on the basis of the defects that were detected by visual inspection and tests should be drawn up in a register before the transformer is put out of operation. Such a register containing a draft list of the repair operations required, serves as an initial document for determining the labour forces, repair time, materials, spares, tools and accessories. The scope of additional work (if required) is revealed by inspection after opening up the transformer.

As a rule, major repair work of high capacity transformer is carried out directly at site. For this purpose, power substations are generally provided with special towers equipped with electric hoists. Low capacity transformers are either repaired directly at site or taken away to the specialized repair works. Inspections are carried out at the temporary premises or sometimes even outdoor. Large units are usually repaired by specialized organizations with skilled repairmen at the place of installation of the transformers.

Actual repair is preceded by some preparatory and organizational work. First of all, suitable premises are selected which should be protected against dust and precipitation and should be equipped with hoisting mechanisms or permit suspension of such mechanisms. There should be enough space to accommodate the tank of the transformer, its core-coil assembly, shelves to keep dismantled assemblies and components, appliances, scaffolds, ladders and other equipments.

The premises must have electric service board, must be well lighted and ventilated and must meet all the fire prevention requirements.

Hoisting mechanisms and their installations are of special importance. They must ensure safe work and facilitate laborious operations. Hoisting mechanisms must be installed and checked at the beginning of repair work, and if the running tests are overdue, they must be tested in accordance with the accident prevention requirements. The load shifting capacities of the mechanism, slings and wire ropes are selected according to the mass of the given transformer, which is indicated in its name plate and certificate.

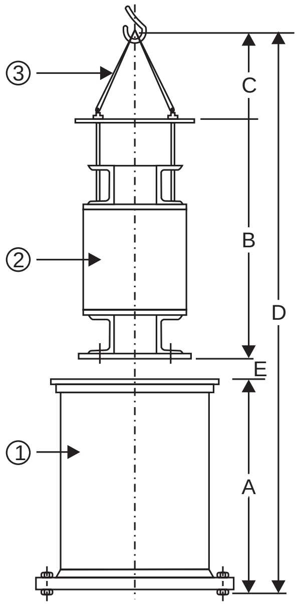


Fig. 32.1. Arrangement for lifting core coil assembly from tank

When core-coil assembly is removed from the tank, hoisting mechanisms are hung at a height which ensures that the distance D from the hook to the floor is not less than the sum of distances A, B, C and E.

The distance E is taken approximately as 100 to 150 mm. The distance C is determined by the length of the slings selected.

Depending on the type of repair and the type and capacity of the transformer, use is made of various tools, appliances and materials, which cannot be manufactured or arranged during repair. To avoid delay, such equipments and materials are delivered to the repair ground in advance. For example, before beginning a major repair, one should ensure the availability of the metal scaffolds, platforms, an appliance for removing and mounting the windings, brazing apparatus, slings for lifting the transformer and core-coil assembly, an oil tray for resting core-coil unit and necessary spare parts.

Lot of preparatory work is involved in the treatment of transformer oil. In medium and major repairs, used oil should be either replaced by fresh oil or purified. Therefore, it is necessary to bring fresh oil and oil purifying apparatus to the repair ground. Here, special attention must be paid to fire preventing measures and the work place must be provided with fire fighting equipments.

Work Place

The quality and productivity of repair work largely depend on the maintenance of the work place. When tools, appliances and materials are placed correctly at the repair site, the labour involved is minimized, time is not wasted and safe work is ensured. Only the tools and materials which are necessary to do the given job should be kept in the work place. The tools and the mateials must be within easy reach, those used more frequently being placed closer. Tools and appliances must be categorized and arranged in different drawers of the work bench. Small tools which are used more frequently must be kept in the upper drawers, while heavier ones, which are used rarely, in the lower drawers. Bulky devices must be placed on shelves and at a specially allotted place. Measuring instruments must be kept in a special drawer, in boxes or cases. Upon completion of a day's work, the tools and appliances must be kept back in their respective drawers/shelves.

The work place must be equipped with a drill machine, an electric tool grinder and a vise. The technical papers, drawings etc. are to be kept on a desk or in a bookcase. At the work place, near the core-coil unit and tank, there must be receptacles for connecting portable hand lamps operating at a low safe voltage.

Plan of Organization

To ensure that all repair operations are carried out at a high technical level and with shortest possible delay, a plan for the organization of repair work is drawn up. This plan is worked out several days before the beginning of the actual repair work, so that there is enough time to carryout all the preliminary operations envisaged.

The plan includes:

- A brief description and specifications of the given transformer, including its characteristics, dimensions, masses of assemblies and components and other specific features
- A list of necessary technical papers, the repair work register, a repair process chart indicating the labour consumption in each job/process
- A list of required materials, tools and equipments
- A repair schedule giving particulars of the trades and skills of the required personnel and the number of shifts
- A plan of preparatory operations including their complete list and date of execution
- A list of spare parts and raw materials indicating their grades, sizes, type designations, drawings, suppliers and delivery dates
- A list of industrial equipments, tools and appliances, drawings of nonstandard mechanisms, devices and special tools
- The repair ground layout.

The problems associated with the delivery of the transformer to the repair ground and back to its foundation, which involves the most labour consuming hoisting operations, are also considered in detail in the plan of organization of repair work.

The actual repair work starts after the preparatory operations envisaged by the plan, are carried out.

32.4 DISASSEMBLING THE TRANSFORMER UNDER MEDIUM REPAIR

For disassembly, the transformer is brought to the repair ground and placed under the hook of a hoisting mechanism. If the transformer is equipped with detachable radiators, the same is dismantled and repaired at the place of installation of the transformer. Prior to disassembly, the transformer is carefully inspected for any external fault, such as oil leaks and mechanical damages to the tank, oil conservator, terminal bushings etc. The defects detected are entered in the register under technical conditions of the transformer.

After that, the thermometer, temperature indicator, alarm and trip circuits are dismantled. When removing the temperature alarm, the hose with the capillary tube is carefully wound into a coil without making sharp bends.

Then the external surface of the transformer is cleaned. If very dirty, it is cleaned with steel scrapers, wire brushes and rags wetted with solvent. Sometimes only the cover is cleaned before disassembly, the rest of the tank surface is cleaned while repairing core-coil unit.

If during inspection and cleaning, oil leakage through welds, flanged joints or at other places are detected, the transformer is subjected to an excessive oil pressure to determine the defect more accurately. After that, oil is drained off partially or completely.

Oil is drained-off partially, if the withdrawal of the core-coil unit from the tank is not to be done on the same day and the external devices are dismantled and the tank cover unfastened. Oil is drained-off only down to the level of the top yoke of the core, so as to ensure that the insulation and windings remain submerged in oil.

Oil is drained-off completely when it is contemplated to end the repair of the core-coil unit and the tank simultaneously. Oil is drained-off through the bottom valve by gravity. If the oil is suitable for further use, it is drained into a clean vessel. Spoilt oil is drained into a waste oil container.

Components, like buchholz relay, conservator, explosion vent and other accessories are removed first. Then the bolts fastening the tank cover are undone. After the bolts are removed from the holes, they are made complete with washers and nuts and then placed in buckets or boxes along with the washers and nuts and wetted with kerosene.

The next most improtant operation is the slinging of the core-coil unit and its withdrawal from the tank. For this purpose, the lifting lugs provided on the top core frame should be used. In the case of a cover mounted transformer, lifting lugs provided on the tank cover should be used. However in both the cases, core-coil unit is slightly lifted to ensure that the coil assembly is not displaced relative to its initial position in the tank. If the core-coil unit is inclined and there is a possibility of its brushing against the tank, it is necessary to lower it back into its original place and check once more the correctness of slinging *i.e.*, check that the length of the slings on either side of the hook are equal and position of the hook relative to the centre of gravity of the transformer is proper.

To make sure that the operation of the hoisting mechanism and its brake is reliable, the core-coil unit is lifted 100 to 200 mm and held suspended for a few minutes and then lowered back into the tank bottom.

If the oil is drained-off completely, the core-coil unit is lifted to a level above the tank convenient for washing it. Before washing, the core-coil unit should be inspected, paying attention to sludge and dirt deposits in the windings, on the core steel and in the oil ducts.

The core-coil unit is washed with a jet of warm, clean oil using a rubber hose. The washing begins from the top and gradually goes down as the core-coil unit is lifted. When washing, one should try to flush thoroughly the oil ducts in the windings and core, as well as accessible units and parts of the transformer.

After the washing is finished and the washing oil is drained-off, the core-coil unit is lifted 50 to 60 mm above the top of the tank frame. If the hoisting mechanism can move horizontally, the core-coil unit is conveyed to a specially prepared floor where it is lowered on to wooden planks placed in an oil tray. But if the hoisting mechanism cannot travel, the tank is then moved aside and the core-coil unit is lowered into a steel tray. The lower part of the core-coil unit must occupy stable vertical position without any inclination. Then the slings are released and the repair work on the core-coil unit, tank and cover and other transformer unit is started. Usually, the core-coil and the tank are repaired simultaneously in order to keep the unit in air for short period as possible. As soon as the core-coil unit is ready, it is installed in the tank and the tank is immediately flooded with oil.

32.5 REPAIRING THE WINDING UNDER MEDIUM REPAIR

The repair of the windings begin with their inspection with a view to check the tightness of the axial clamping, their deformation and displacement relative to the normal position, the presence of sludge in the oil ducts, the condition of the soldered joints and contacts in the lead connection and the condition of interlayer insulation, *i.e.*, its intregrity, mechanical strength and colour. In long term operation, the axial clamping of the windings tend to weaken, mainly as a result of shrinkage of the pressboards and paper insulation (spacers, inter turn insulation, and winding insulation) on drying. Also, there occurs some reduction of the axial dimensions of the coils and the end winding insulation, as a result of shocks due to short-circuit in service. The reduction may also result from the fact that the possible clearances in the inter turn and end winding insulation of stacked up pressboard components are sometimes not taken up completely when clamping the windings during manufacture.

Weak axial clamping of the windings may lead to their destruction in the event of short-circuits causing heavy mechanical forces (specially axial) between the coils. This condition can easily be detected through reeling of the insulation strips, spacers and other components by trying to displace them by hand. To eliminate this condition, the windings are compressed between the yoke clamps by tightening the nuts of the vertical tie rods.

If the axial clamping of the windings gets weakened, the top yoke is unclamped by loosening the nuts of the yoke studs and vertical tie rods and additional insulation in the form of slotted rings and spacers are inserted into the windings. If the HV and LV windings differ in the axial size, and as an effect the inner coils are clamped badly, and additional insulation should be made to compensate for this difference. Then the windings are clamped by tightening the nuts on the tie rods and after that, nuts on the clamping studs of the top yoke are tightened. After the clamping is finished, it is necessary to measure the insulation resistance of the clamping studs by means of a megohm-meter (insulation tester).

In the transformer having no special device for clamping the windings, the windings are pressed, if necessary, by packing out *i.e.*, by driving additional insulating spacers, wedges between the coil end and yoke insulation at the top of the windings. These wedges are made of dried pressboards and paper base laminations. All stacks of inter disc spacers are packed out uniformly around the circumference of the winding, one stack after another. The packing out is done with the aid of an auxilary wooden wedge which is driven between the spacers of one stack to loosen the spacers in the adjacent stacks so as to permit additional insulating spacers to be driven between them. Then the wooden wedge is removed and the next stack of the inter disc spacers are packed out in the same way. The wedges are driven in with a hammer. To prevent their ends from splitting, a pad made of wood, pressboard or fabric base laminate should be used.

Quite frequently it happens that the outer windings are slackened much faster than the inner ones. In this case, additional insulating strips are driven between the main inter disc spacers of the outer windings. This operation should be carried out with great care and attention, so as not to damage inter turn insulation.

The packing out of the windings should be carried out with the slings kept taut, so that the wedging strips can be driven somewhat easier. When packing out the windings, one should consider the following rules:

- The packingout must be uniform and tight over all the vertical stacks of spacers and circumference of the windings (the wedges must not move when trying to displace them by hand)
- All the stacks of the inter disc spacers must be strictly vertical and free from displaced spacers.
- The additional strips must run the whole length of the main spacers and not be displaced relative to them. After packingout, the axial dimensions of the HV and LV windings must be as close as possible.

Axial Clamping with Pressure Rings

In medium sized transformer, the axial clamping of the winding is effected by means of steel pressure rings placed at the top of windings and clamping screws installed in the flanges of the top yoke clamps as indicated in Fig. 32.2.

A flat steel pressure ring (7) is placed on the coil end insulation (8) of the windings (9). The ring is cut so that it does not form a closed turn. Round coller bushes (3) in which the clamping screws (2) are driven, are welded into the flanges of the top yoke clamp (1). If the screws press directly on the pressure rings, a shortcircuited turn would be formed. To insulate the steel ring from the yoke clamps, use is made of plastic or laminated (fabric or paper base) supporting saddles (6). The saddles are provided with steel inserts (5), which protect them from breakage, uniformly distributing the pressure exerted by the screws when they are being tightened. Lock nuts (4) prevent the clamping screws from working loose during operation. To ensure uniform clamping of the windings, 4 to 6 clamping screws are used for each end ring. High capacity transformer may use even more number of clamping screws.

All the windings placed on one core limb are mainly clamped with a single, common pressure ring. Each pressure ring is earthed by means of a flexible jumper which connects it to the top yoke

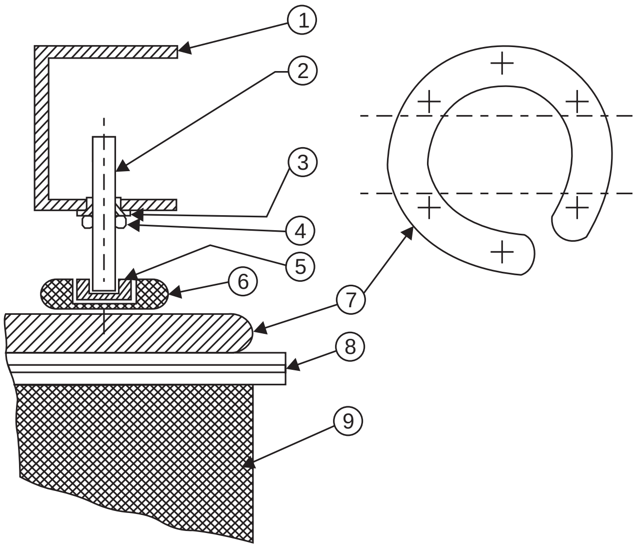


Fig. 32.2. Axial clamping of the winding with pressure ring

clamp. Lately, lot of work is done to replace the steel pressure rings by perma wood in order to eliminate risk of failure.

During inspection, the axial clamping of the windings provided with the pressure rings and clamping screws is improved in the following order:

- First, the lock nuts are slackened uniformly in a criss-cross order *i.e.*, every other nut is slackened across the diameter. Then the clamping screws are driven in as far as they will go in the same order and finally, the lock nuts are retightened.
- After that the fastenings of the earthing jumpers that connect the pressure rings to the top yoke clamps are tightened up.
- The insulation resistance of the pressure rings with respect to the yoke clamps and core steel are measured with the earthing jumpers disconnected from the yoke clamps.

When inspecting the windings, the interturn insulation is checked for damaged spots and if there are any, the turns at these spots are additionally insulated.

This operation is carried out using dried tape made of oil resistant varnish cloth (or any other suitable materials) which is passed between the coil turns.

If the inter turn insulation is sufficiently strong and elastic, the outer turns at the place where the insulation is to be renewed can be moved apart with a pressboard wedge to facilitate the passage of tape. Should the inter turn insulation be damaged at a place far from the coil face, a pressboard strip of 0.3 mm to 0.5 mm thick is inserted betwecn the turns of damaged insulation.

At the place where the inter turn insulation is renewed, the coil is wrapped half-lap with linen finished tape (or any other suitable materials). This operation should be carried out very carefully so as not to damage the insulation of the other turns. The sequence of the renewal of damaged inter turn insulation is illustrated in Fig. 32.3.

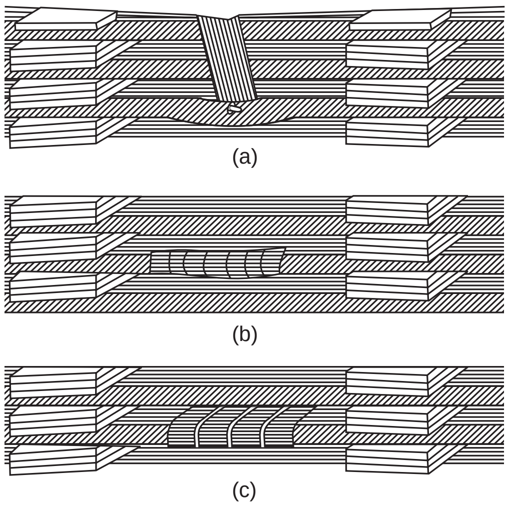


Fig. 32.3. Sequence of renewal of damaged inter turn insulation (a) Separating the turns with a wedge (b) Applying paper tape insulation (c) Applying linen-finished tape

During inspection, it is necessary to evaluate the mechanical strength and degree of ageing of the inter turn insulation. Unfortunately at present, there is no accurate method for such an evaluation. In practice, the insulation is considered to be good, if it is elastic, has a light colour and neither breaks nor cracks when being bent or folded. The insulation is considered to be bad, if it is fragile, breaks when being bent, can easily be removed from the conductor and is dark in colour. A transformer with such an insulation is unreliable.

32.6 REPAIR OF CORE UNDER MEDIUM REPAIR

The repair of the core begins with the checking of its cooling ducts for sludge and the surface for hot spots. Signs of hot spots are oxide tints (changes in the normal colour of steel to yellow, violet, blue etc.) and the presence of the products of decomposition of oil is in the form of a black, sintered mass. In such cases, they are washed with a jet of hot transformer oil.

Then the core is checked for the tightness of clamping of the yokes, the quality of insulation of the lamination, the insulation resistance of the clamping studs, the condition of insulation between the yoke clamps and the core steel and for minor external defects.

The tightness of clamping of the yoke is usually checked with a knife blade. If the clamping is good, the blade cannot pass between the laminations. The tightness of the clamping is improved by tightening the nuts of the clamping studs.

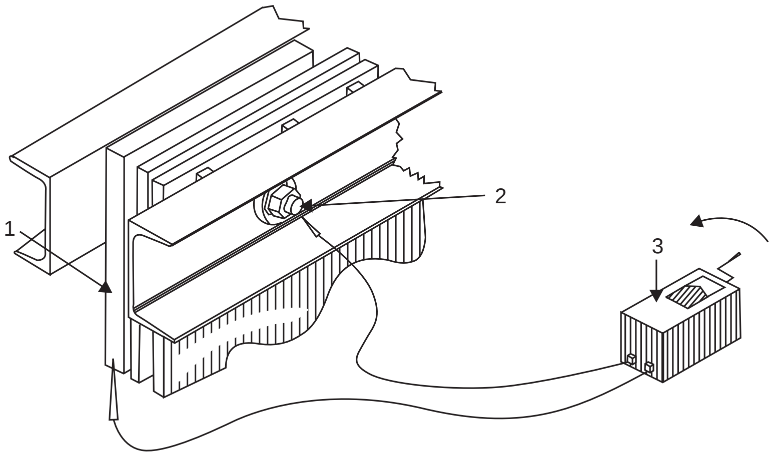


Fig. 32.4. Measuring the insulation resistance of a core clamping stud 1-core steel; 2-clamping stud; 3-Megohm-meter

The insulation resistance of the top and bottom yoke clamping studs is measured by means of an insulation tester. One probe of the instrument is pressed by turns against each clamping stud as shown in Fig. 32.4 above. The other probe is pressed against the core lamination. The magnitude of the insulation resistance of each of the clamping studs are recorded. If the insulation resistances of one or more of the clamping studs is substantially lower than that of the others or is equal to zero, the studs are redone. The insulated paper base laminated tubes are removed from the holes in the yoke and inspected.

If a stud and its insulating tube show signs of overheating (charring, oxide tints, fused spots etc.) and shorted laminations are detected when inspecting the yoke holes with a portable lamp, the yoke is then disassembled to eliminate the faults and if necessary, its laminations are reinsulated. Faulty clamping studs and their paper base laminated tubes are replaced by new ones.

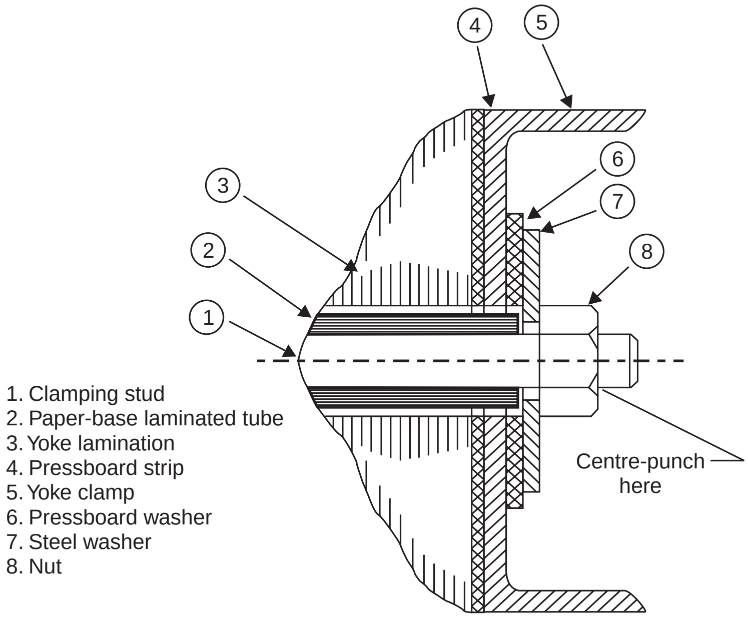


Fig. 32.5. Insulation of a yoke clamping stud

Before installing the clamping studs in place, the holes in the yoke are carefully inspected and cleaned. If there are bent laminations or sintered lamination stack, the yoke is disassembled and repaired. After the studs are made complete with insulating tube and pressboard as well as steel washers, they are inserted into the holes in the yoke, nuts are run onto them and the yoke is clamped by tightening the nuts uniformly on both sides. When doing this, one should see to it that the studs do not rotate in the holes and are extended equally on both sides of the yoke. Fig. 32.5 shows the construction of a yoke clamping stud. The insulating tube (2) must not touch against the steel washer (7) when the yoke is in the clamped state, but at the same time, it must overlap the wall of the yoke clamp (5). Whenever necessary, the tube is shortened so as to ensure that the clearance between its end and the steel washer does not exceed 1.5 to 2 mm when the yoke is tightly clamped.

Prior to final clamping of the yoke, the earthing strip on the LV lead side is separated from the yoke clamp and the insulation resistance of the yoke clamp relative to core steel is measured with a megohm-meter. In this way, a check is made on the insulation quality and proper placement of pressboard strips installed between the yoke steel and clamp. For this purpose, one probe of the megohm-meter is pressed against the yoke clamp and the other against one of the yoke stacks. At this time, the yoke clamp must be tightly pressed against the yoke. If the quality of insulation is satisfactory, the earthing strip is refitted and the nuts of the clamping studs are tightened home and then centre punched to prevent them from working loose.

The centre punching is done by placing the point of a centre punch between a nut and a stud and damaging the threads by striking against the punch with a hammer. Nuts are usually centre punched at three points as shown in Fig. 32.6.

Finally, the clamped yokes are checked for the clamping tightness. The insulation resistance of the clamping studs are measured once more and the earthing circuit is checked by means of a megohm-meter. One probe of the instrument is pressed against core steel and the other against yoke clamp. If the circuit is safe, the instrument will read zero. The earthing strip must be held firmly between the yoke laminations and clamp.

When inspecting the core-coil unit whose cores are clamped without the use of through clamping studs, the clamping tightness is improved by tightening the nuts on the external clamping studs. The tightening is done with long handled wrenches (preferably of the torque indicator handle type), capable of producing the required clamping force.

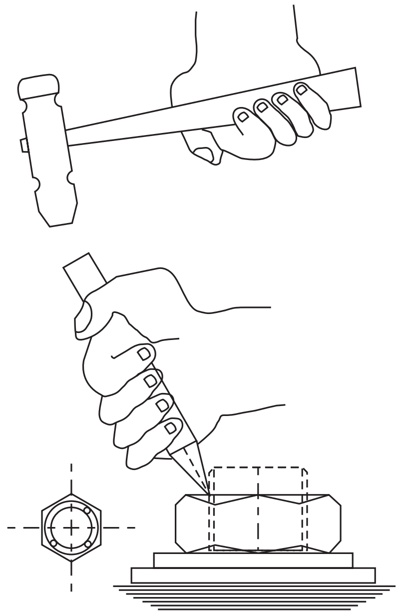


Fig. 32.6. Centre-punching a unit

32.7 REPAIR OF THE TAP CHANGER UNDER MEDIUM REPAIR

(a) Off-Circuit Tap Changer (OCTC)

If the fixed and the moving contacts in a tap changer fit loosely, or if the tap contacts are bad (loose screw connections, poor soldered, brazed or welded connections), this will cause a local increase in resistance. The flow of current through such a poor contact causes its intensive heating, oxidation and burning. As the process develops, the circuit eventually breaks, giving rise to an electric arc which causes a major breakdown. To avoid this, all the contacts and the lead connections of the tap changer are carefully checked when inspecting the core-coil assembly.

The contact pressure is checked in various ways depending on the tap changer construction, *e.g.* by applying pressure to the movable contact segments or rings by hand. The absence of spring action indicates that the pressure springs of the contacts are broken and must be replaced. The looseness of spring tension may be examined by using a feeler gauge or by measuring the contact resistance.

Special attention is paid to the condition of contact surfaces. If there are signs of pittings or fusion, the tap changer is replaced. Sometimes depending on the nature of failure, it is dismantled and repaired. When dismantling a tap changer, each lead must be marked with a tag so as not to confuse the lead connection during reassembly.

When a tap changer operates in oil after a long period of time, its contact surfaces become covered with a thin deposit in the form of an yellowish film. This film increases the resistance across the contacts, which causes overheating and burning. To remove the deposit, the contact surfaces are carefully wiped with a piece of clean cloth wetted with acetone or gasoline or any other similar liquid. The rest of the tap changer is washed with clean transformer oil. All the nuts holding the leads to the fixed contacts of the tap changer are tightened. After that, the distance between the flexible portions of the leads are checked, for the leads may be displaced during tightening and may come too close to one another. Then the fastenings, screwing the tap changer to the yoke clamps are tightened and finally the operation of the tap changer is checked by shifting it from position to position (the tap changer must shift with a snap).

(b) On-Load Tap Changer (OLTC)

The repair work on the tap changer involves cleaning, washing and wiping of the internal and external surfaces of their units and components, checking of the contact surfaces of the selector switches, diverter switches and drive control switches and adjusting or replacing the driving gear components. Pitted contacts are carefully ground and then checked for fit (the cause of pitting should be identified and eliminated). Ceramic contacts are neither ground nor filed, but replaced by new ones, if found burnt out to a depth of 3 mm or more.

The main cause of the pitting of selector and diverter switch contacts is the mal adjustment of the operating mechanism due to excessive backlashes, resulting wear and tear of components and loosening of the joints between the various shafts of the mechanism. The backlashes are eliminated by tightening the joints and replacing badly worn components.

After it is repaired, reassembled and wiped clean, the tap changer is checked for proper joining of all the components of the operating mechanism and contact systems. While reassembling and adjusting the tap changer, the match marks punched on the matching parts during their assembly should be followed.

During repair, special attention should be paid to check the connection of the leads to the tap changer contacts, since a wrong connection may cause failure of the tap changer and thus put the transformer out of operation. To exclude any possibility of mistake in the lead connection, a circle diagram is plotted which shows the operating sequence of the tap changer contacts.

After repair, the operation of the tap changer is checked by shifting it several times from position to position throughout the entire voltage control range in forward and reverse direction, both by hand and by means of motor driven gear. Then the contact pressure in the selector and diverter switches is checked.

The oil in the diverter switch tank is usually replaced. According to the relevant instructions, it must be replaced as soon as its breakdown voltage falls down to 20 kV. Other characteristics of the oil in the diverter switch tank are not so important.

32.8 THE LEADS UNDER MEDIUM REPAIR

While inspecting the leads, special attention is to be paid to their insulation at places where they are connected to one another and to the windings.

The signs of bad connection of leads operating in oil are the darkening of their insulation and the deposition of a black, sintered mass on their surfaces.

The detected faulty connections are resoldered. Usually, in transformer which was in service for as long as 10 years, the cotton insulation placed over the main insulation of the leads become useless. Therefore, it is recommended to reinsulate it with a single layer of linen-finished tape wrapped half-lap. In this method of insulation the lead is taped in such a manner that each subsequent turn of the tape overlaps the preceding one by half of the tape width. The start of the tape is made first by putting the second turn concentrically around the first and its finish is passed under the last turn (it being loosened before hand) and then tightened and cut-off. Insulating a conductor with a tape wrapped half-lap has been shown in Fig. 32.7.

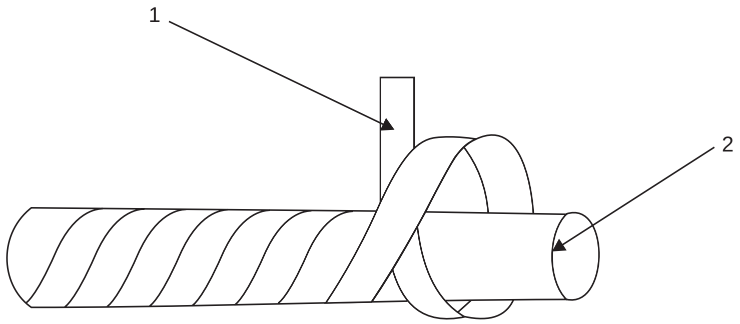


Fig. 32.7. Insulating a conductor with tape wrapped half-lap 1. Tape 2. Conductor

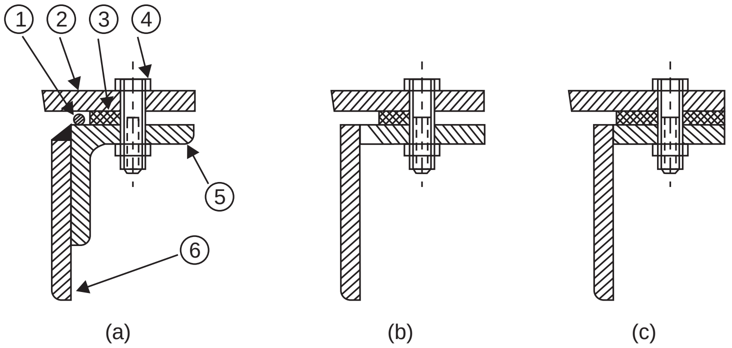
The fastenings of the entire lead support structure are then tightened. Care should be taken while tightening wooden nuts, for their threads may get stripped or the nuts themselves may break, if excessive force is applied by the wrench. Most reliable is the method of fixing the leads between the supporting cleats by means of fabric base laminated studs and plastic nuts.

32.9 REPAIRING OF TERMINAL BUSHING UNDER MEDIUM REPAIR

During medium repair (inspection), the terminal bushings are dismantled from the tank cover, carefully inspected and checked for breakage and cracks in porcelain bushings. The condition of sealing gaskets and safety of the threads of the terminals and nuts are also checked. Damaged porcelain bushings are replaced, while the current carrying parts and fasteners are mended, if necessary. After cleaning and washing, the bushings are reassembled, the rubber sealing components being, as a rule, replaced by new ones. All the repaired bushings are made complete with washers and nuts. There must be three nuts on each end of the terminals. The third, last (lock) nut serves to prevent the first two from working loose.

32.10 REPAIRING OF TANK, CONSERVATOR AND OTHER FITTINGS UNDER MEDIUM REPAIR

When repairing the tank, it is emptied of oil, all the fittings installed on its walls are dismantled and its internal and external surfaces are wiped clean. If oil leaks were detected when inspecting the tank, the cracked or otherwise damaged welds are mended by arc welding. When welding operations are done, the tank wall must be wiped dry, while implementing fire prevention rules strictly. Old sealing gaskets are removed from the flange of the top tank frame, as well as from the flanges of the dismantled fittings, and the flange surfaces are carefully cleaned. Then a new sealing gasket is placed on the flange of the top frame of the tank.



(a) Welding a steel rod to the top tank frame
(b) Welding the top frame to the protruding tank wall
(c) Using a wide gasket

1. Steel rod
2. Tank cover
3. Gasket
4. Bolt holding the cover to the tank
5. Top tank frame
6. Tank wall

Fig. 32.8. Method of installing the sealing gasket under the tank cover of transformer

To prevent the gasket from being forced inside the tank, when tightening the nuts on the cover, various methods may be used. Fig. 32.8 (*a*) illustrates a method whereby a steel rod (1) having a diameter of 3 to 4 mm is welded to the top frame (5) over its entire periphery. A similar method is shown in Fig. 32.8 (*b*), but here the top frame is welded to the tank wall extending above the frame surface. In some cases, a wide gasket made of rolled rubber is placed as shown in Fig. 32.8(*c*).

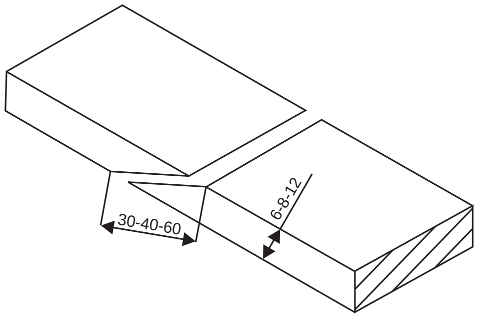


Fig. 32.9. Butting gasket strip

When making gaskets of strip rubber, the joints between separate strips are so arranged that they are in between the holes in the tank frame. Fig. 32.9 illustrates one of the most common methods of butting the gasket strips. Here the length of the joint is shown as a function of the gasket thickness. In distribution transformers, dovetailed joints as illustrated in Fig. 32.10 are used in tank cover gaskets.

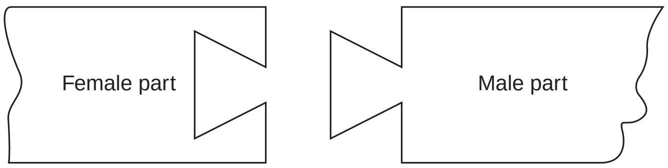


Fig. 32.10. Dovetailed joints of tank cover gasket

When the oil conservator is inspected, first the condition of its internal surface is checked. During operation of the transformer, the upper portion of the conservator surface is in prolonged contact with warm and at times damp air and therefore, is subjected to corrosion. If corrosion is negligible, the oil conservator is washed and rinsed several times with clean oil and painted with hot oil resistant paint. All the plugs, valves, oil gauge etc. are inspected. The rubber gaskets and other packing of the gauges are replaced with new ones, all the parts are cleaned and washed with dry oil/thinner.

32.11 RETANKING OF CORE-COIL ASSEMBLY

Before retanking, the core-coil assembly is carefully wiped and finally inspected. It is necessary to ensure that there is no tool, especially knife, screw driver, wrench etc. left on the core-coil unit during repair. Then the insulation resistances of the windings and clamping studs, if any, are measured. With this, the inspection of core-coil unit is completed and the laboratory personnel carry out preliminary tests. If the test results are found satisfactory, it is prepared for tanking.

The unit is slinged, lifted 100 to 200 mm from ground and left suspended to check the correctness of slinging and operation of the hoisting mechanism and its brake, in particular. At the same time, the quality of cleaning, washing and fastening of leads and parts should be checked, especially those at the bottom of the core-coil unit, that can be additionally inspected and cleaned while the assembly is held suspended. The support planks are carefully wiped with clean sweat rags, their fastening to the yoke clamps checked and if necessary, the fastening nuts tightened and centre punched.

Then the core-coil assembly is lifted with care without jerking and swaying and located above the tank. If its position with respect to the tank is correct, the assembly is slowly lowered while being held and directed in such a manner as to ensure that the support planks do not brush against the tank walls.

For transformer upto 250 kVA, the core-coil assembly is generally fixed to the tank by means of angles and brackets, welded to the tank walls and the yoke clamps. In those ranging from 400 to 1600 kVA or more, it is fixed by means of brackets and hooks tied to the yoke clamp and the tank walls. In those of 2500 kVA and above, it is fixed by means of set screws driven into special sockets welded to the tank walls, the free ends of the screws being pressed against thrust plates mounted on the yoke clamps.

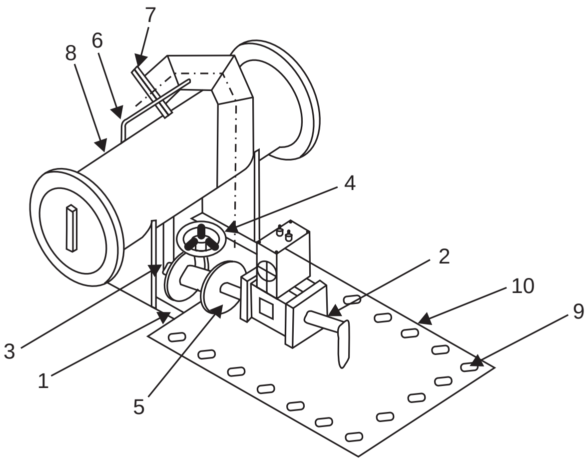
If the core-coil assembly is connected to the tank cover by the lifting rods, it is lowered into the tank until the cover is 50 mm above the top tank frame. Then several steel aligning rods are passed through the bolt holes in the cover and frame and the core-coil unit is further lowered until it rests on the tank bottom and the cover closely fits the sealing gasket on the tank frame. The cover together with the core-coil unit is directed by the aligning rods. When this is done, it is necessary to see that the sealing gasket is not displaced. After that, the bolts are inserted into the holes and tightened uniformly by hands, using nuts by making several rounds over the entire periphery of the cover.

Where there are joints in the gaskets, the nuts are tightened while going towards the joint from both sides. This ensures tighter butting of the joined ends of the gasket. Bolts and nuts with stripped threads or rounded corners are replaced with new ones.

After tanking the core-coil assembly and bolting the tank cover, the tank is filled with dry, clean oil slightly above the level of the top yoke through the centrifugal oil filter machine. The oil temperature should be around 50 to 60°C. To bleed air out of the tank when filling it with oil, one of the openings in the cover must be kept open, but it must be guarded so as to prevent any possibility of foreign objects getting into the tank inadvertently. Transformer having no oil conservator are filled with oil upto the level indicated by an appropriate line marked on the tank near the oil gauge.

32.12 MOUNTING THE OIL CONSERVATOR, BUCHHOLZ RELAY AND OTHER FITTINGS

Next comes the mounting and fastening of the oil conservator, buchholz relay, explosion vent and other fittings. Light fittings are lifted and mounted by hand, while heavy ones by means of hoisting mechanism. All these fittings are installed in the order opposite to that of their dismantling. Mounting of conservator brackets with other accessories are shown in Fig. 32.11.



1. Bracket 2. Buchholz relay 3. Flange 4. Valve 5. Top flange
6. Equalizer pipe 7. Explosion vent pipe 8. Oil conservator 9. Bolt holes 10. Transformer cover

Fig. 32.11. Mounting the oil conservator, buchholz relay and explosion vent tube on a transformer

First, brackets (1) are fastened to the transformer cover (10) and then the oil conservator (8) is lifted and mounted on them. The valve (4) is fixed to the flange (3) of the conservator connection. All sealing gaskets are replaced with new ones. After that, the buchholz relay (2) is installed between the valve and the flange of the tank connection so that the arrow on the top flange (5) of the relay points towards the conservator. When bolting the relay, it is necessary to see that the connecting flanges of the relay, the flange on its tank connection and the surface of the valve are parallel to one another and that the sealing gaskets between them have uniform shrinkage.

To facilitate the installation of the relay, the conservator brackets are loosely fastened to the tank cover, so that the conservator can be somewhat displaced, if necessary. When installing the relay, one should use a spirit level to make sure that the top flange of the relay is strictly horizontal. Then all the fasteners on the relay connections and on the conservator brackets are tightened home and after that the explosion vent pipe (7) and equaliser pipe (6) connecting it to the conservator are mounted and fixed in place. However, in all cases new sealing gaskets are used. Then the operation of the buchholz relay is checked. The temperature indicator meters are usually installed on the transformer after they are tested for their accuracy in a laboratory.

32.13 TESTING THE TRANSFORMER FOR LEAK TIGHTNESS

After the transformer is fully assembled, the required amount of oil is added and the transformer is tested for leaks. Additional oil must be of the same batch as that used previously for filling the tank. To make the tank communicate with the ambient air and to let the fittings fill with oil, it is necessary to open the valve between the buchholz relay and the oil conservator and remove the top plug of the conservator, as well as all the air bleed screws and plugs on the terminal bushings, radiators, thermosiphon filter and other devices where such screws and plugs are provided.

As soon as oil starts leaking through the air bleed holes, the plugs and the screws are driven home while they are sealed by wrapping asbestos cord impregnated with phenolic varnish around them under their threads. Should some joints prove to be leaky, the leaks are stopped by tightening up the corresponding fasteners. Oil is added until it reaches the normal level in the conservator, the oil level being watched with the help of the oil gauge.

After filling it with oil to its full capacity and bleeding air form its tank and fittings, the transformer is tested for leak tightness by subjecting it to an excessive oil pressure. For this purpose, a piece of pipe of a certain definite length and 30 to 40 mm in diameter is fitted vertically on the tank cover or on the top of the conservator. In the former case, the pipe is mounted over one of the openings in the tank cover and therefore its lower end must be provided with a flange, while in the later case it is screwed onto the filler hole in the conservator, so its lower end must be threaded. The top end of the pipe must be equipped with a funnel.

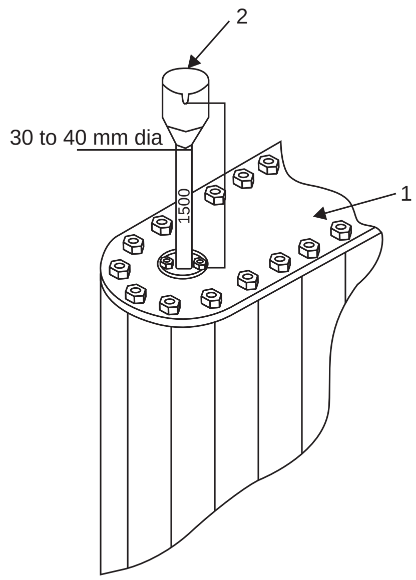


Fig. 32.12. Testing of transformer for leak tightness 1. Tank cover; 2. Pipe with funnel

The pipe is filled with transformer oil and the transformer is kept pressurized for at least 4 hours. If during this time, not a single leaky seal or weld is detected, the transformer is considered to be leak proof. Should some seals prove to be leaky, the leaks are eliminated either by tightening up the fasteners or by replacing the sealing gaskets.

When testing a transformer with plain and tubular tanks, the height of the oil column in the pipe is taken at 1.5 metres from the level of the tank cover or 0.6 metre from the upper most point of the oil conservator, whereas when testing those having corrugated tank, it is lowered down to 0.9 and 0.3 metres respectively. The oil level in the pipe is checked with reference to the marks inscribed on the inner surface of the funnel.

Transformers are sometimes tested for leak tightness by using air to build up the required pressure. However, on such occasions, care must be taken to ensure that the air used for filling the transformer is dry and without any moisture. Otherwise, condensation of moisture may cause the deterioration of the di-electric strength. Compressed air from a compressor should be first passed through an air dryer before injecting it into the transformer.

After the transformer is fully assembled and tested for leaks, it is painted on the outside surface with grey paint (or any other suitable colour). Then the transformer is subjected to final eletrical test. Upon successful completion of electrical tests, the transformer is moved to the place of installation.

32.14 MAJOR TRANSFORMER REPAIR (OVERHAUL)

Major repair of the transformer involves complete or partial replacement of the windings and insulation, repair of core, modernization or replacement of individual devices, cooling system, tap changer etc.

During major repair, the core-coil unit is to be disassembled completely. Before disassembling the core-coil unit, the transformer is knocked down in the same sequence as in the case of medium repair (inspection). Oil is drained-off completely, the terminal bushings, explosion vent pipe, buchholz relay, oil conservator, thermosiphon filter and cooler etc. are dismantled, the tank cover is unfastened and the core-coil assembly is slinged and withdrawn from the tank. If the tank cover is mechanically connected to the core-coil unit, all the fittings installed on the cover are dismantled and the cover is removed from the lifting rods. If the tank is of the bottom split type, the tank is removed from its bottom. Then the top yoke is unbladed, the windings are removed from the core limb, and their insulation is knocked down. If it is necessary to reinsulate the core lamination, the entire core is disassembled.

After the transformer is completely disassembled, all the dismantled fittings, units, parts are carefully inspected, repaired if necessary, or rejected and replaced by new ones, if badly damaged. Then the transformer is reassembled. This type of repair also involves all the operations that are carried out during medium repair. The drying out of the core-coil assembly and purification of oil are obligatory. During major repair, use is made of various appliances, platforms and scaffolds depending on the size of transformer.

32.15 DISMANTLING THE TAP CHANGER, BUSHINGS,TANK COVER AND LEADS UNDER MAJOR REPAIR

The disassembly of the core-coil unit which is connected to the tank cover by the lifting rods begins with disconnecting the regulating and line leads from the tap changer and terminal bushings. Before disconnecting them, the leads are numbered by slipping identification tags over them. The terminal bushings and tap changer may be dismantled either before removing the cover from the core-coil unit or after that. The cover is removed by means of slings fastened to special lifting eyes or lugs provided on the cover. If there is no such lifting arrangement, use is made of temporary eye-bolts secured in the bolt holes in the cover.

Before removing the cover, it is necessary to measure the distance between the cover and top yoke. This distance is usually measured at each lifting rod and the results obtained serve as reference when reassembling the core-coil unit. If the cover is installed in such a way that its height with respect to the top yoke is not correct, either the core-coil unit will hang from the cover and not rest on the tank bottom or the cover will not reach the top tank frame.

After slinging the cover and tightening the slings so that there is no slack in them, the lifting eyes of the transformers are removed in turn from the lifting rods and then the top nuts are run-off the rods with a wrench and the washers are removed. Then without jerks, the cover is lifted. When doing this, it should be seen that the cover does not brush against the threads on any lifting rod and that it is removed from all the rods at the same time.

The cover is lifted 100 to 200 mm above the lifting rods and moved to a specially prepared place. If the terminal bushings and the tap changer are not removed before that, the cover is placed on trestles so that these fittings do not touch the floor. Then the nuts on the flanged joints of the terminal bushings, tap changer and other fittings installed on the cover are undone, the fittings are dismantled, inspected in the usual way and put in their allotted places on a rack. After that, the nuts securing the lifting rods to the top yoke clamps are undone, the rods are removed, made complete with their nuts, washers and lifting eyes and put away.

Before dismantling the leads, it is necessary to draw a sketch of their layout and fastening. Then the lead support cleats are unbolted and put on racks, the HV and LV lead cleats being placed separately. The insulation from the leads to winding connections are stripped-off with a knife over a length of 50 to 200 mm, depending on the conductor diameter and insulation thickness. The remaining insulation is tapered towards the connection from both sides.

To disconnect taps of large section, their connections are desoldered by heating them with gas/ electric brazing. Connections of light gauge wires are cut, rather than desoldered. If the windings or leads are not to be replaced, their connections are cut with a chisel precisely at the place where the winding strips are joined with the leads, so as not to damage their ends. Leads that do not need mending, are placed on racks.

Damaged leads with fused, burnt or otherwise injured insulation are placed separately.

If all the leads have good insulation and do not need replacement, they are not disassembled completely, but are dismantled together with their support structure. This materially cuts down the amount of work involved in the reassembly of the transformer.

32.16 DISMANTLING THE TOP YOKE CLAMP AND UNBLADING THE TOP YOKE UNDER MAJOR REPAIR

After removing the leads, the top yoke clamps are unfastened and the yoke is unbladed. This job begins with unclamping the windings and the yoke.

If the windings are clamped by steel pressure rings, the clamping screws are slackened and the insulating saddles and steel inserts are removed. Where there is no such ring, the unclamping of the winding begins with unfastening the nuts (2) on the vertical tie rods (5) (Fig. 32.13).

Then the nuts (4) on the clamping studs of the top yoke clamp (3) are first loosened uniformly and then run-off the studs.

The studs together with their paper base laminate and steel washers and paper base tubes are removed, inspected, made complete with their tubes, washers and nuts and placed on racks.

After that the top yoke clamps and the pressboard separators (1) that insulate them from the yoke are removed. In small transformers, the clamps are removed by hand, while in large unit, they are dismantled by means of hoisting mechanism with wire rope slings. In the later case, the yoke clamps are first slinged and only then are unfastened and removed.

It should be born in mind that the yoke may spring back when being unclamped. Therefore, when removing the top yoke clamps of medium and large transformers, the yoke laminations should be temporarily kept from springing apart by means of U-clamps which are to be inserted between the laminations in a staggered pattern over the entire surface of the yoke after the yoke clamping studs are broken loose. Moreover, temporary clamping studs with extra long threads should be inserted into specially provided holes at the end of the yoke clamps. These studs with nuts on them will restrict the springing action of thE yoke and hold the yoke clamps on the core until they are taken-off. Failure to follow the procedure may lead to an accident as a result of the yoke clamps suddenly getting thrown away due to the spring action of the yoke.

The yoke clamps on HV and LV sides are not interchangeable. Therefore, they should be marked with the inscriptions 'HV Side' and 'LV Side' when being dismantled. The dismantled yoke clamps are usually placed on wooden blocks on the floor.

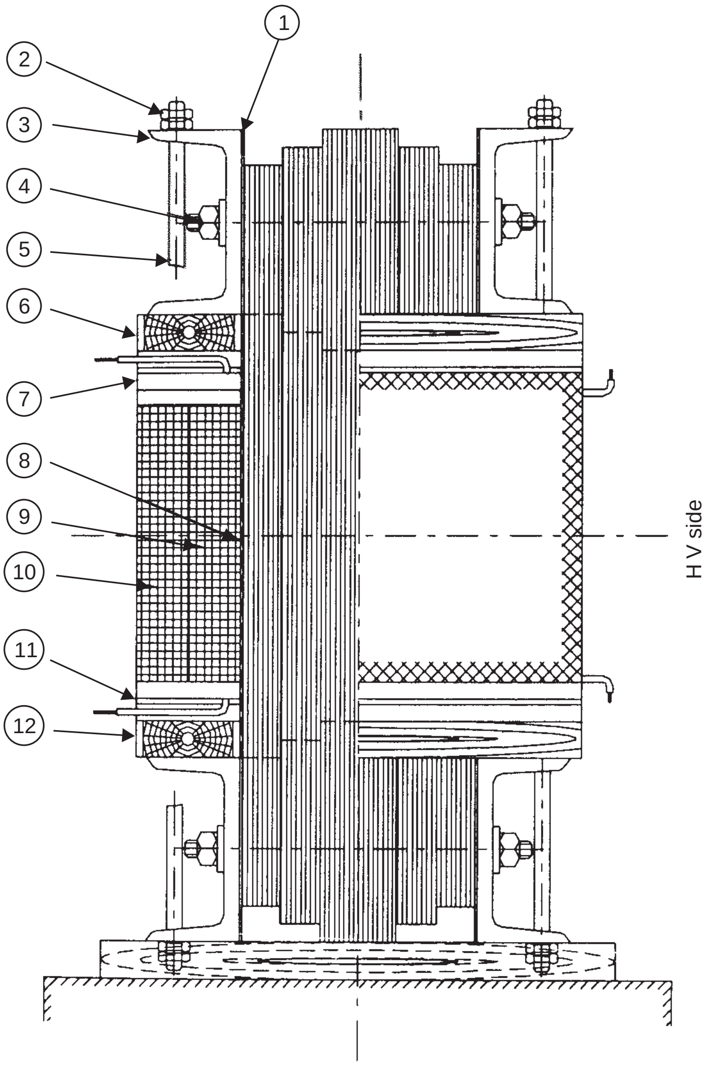


Fig. 32.13. Core-coil unit of a transformer (side view)

Then the core earthing strip is removed and the top coil end insulation (6) is dismantled. If the entire core is to be dismantled, the vertical tie rods (5) are then removed. During disassembly, all the dismantled parts are carefully inspected and replaced, if badly damaged.

After that the top yoke is unbladed from both sides (HV and LV) simultaneously (4 to 6 laminations or even more for small transformers at a time). The removed laminations are placed in the same sequence one upon another in sTacks on a plank or on special portable racks.

32.17 DISMANTLING THE WINDINGS AND INSULATIONS UNDER MAJOR REPAIR

After unblading the top yoke, the loose ends of the limb laminations protruding above the windings are tightly banded with lengths of surgical tape or soft wire in order to prevent them from interfering with the dismantling of the windings. Then the top yoke insulation (7) is removed. If the insulation is proposed to be used again, it is carefully placed on a rack and covered with paper or a piece of tarpaulin. Damaged insulation which is to be replaced or repaired, should be kept separately.

Then the dismantling of the winding is started. In most cases, even if a single winding of a transformer is damaged, all the windings would have to dismantled, because the metal runs and soot, formed as a result of arcing, spread all over the windings and insulation. The dismantled windings are carefully inspected and washed. First the outer HV windings (10) are removed, keeping the top ends of the inner LV windings (9) bent vertical so that they do not touch the outer windings.

The windings of transformers upto 1000 kVA in capacity are dismantled by hand, while those of above 1000 kVA by means of a hoisting mechanism as shown in Fig. 32.14. Heavy windings are removed by means of a special puller comprising of draw bars (1) provided with grips at their ends and a two bar spread frame (2) with a lifting eye at its centre, which serves to hitch the puller on the hook of a hoisting mechanism. Similar devices for removing coils for big sized transformers are designed with three bar spread frames spaced at 120°.

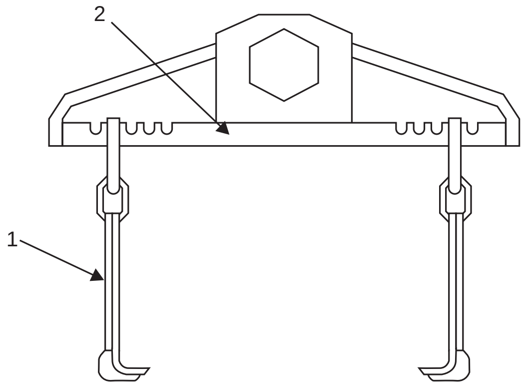


Fig. 32.14. Two bar spread frame for removing and mounting the winding

The grip on the draw bars are brought under the winding and made to engage with its support ring at places where there are stacks of inter turn spacers. The draw bars are placed in such a way that they do not touch the adjacent winding or its insulation. While doing this, one must be careful not to damage the winding insulation and turns. The winding, together with the draw bars, iQ tightly tied with a rope in a staggered fashion along its entire height and then the hook of the hoisting mechanism is brought precisely above the centre of the winding and the spread frame is suspended from it.

The winding is lifted 50 to 100 mm and then it is checked to make sure that the draw bars are not inclined and the puller is hitched properly. If the winding is fastened properly and the grip of the draw bars do not catch the inner winding or the insulating cylinder, the winding is removed from the core limb. The dismantled winding is moved aside and lowered on wooden blocks on the floor and then the draw bars are released. All the windings including the LV windings are removed from the core limb in the same way. Prior to dismantling the LV windings, the draw bars are rearranged on the spread bars of the puller to suit the diameter of the windings to be removed.

After all the HV and LV windings are dismantled in turn from each core limb, the bottom yoke insulation (11) and the coil end insulation (1-) are removed. Light windings and their packing components are placed on a rack, while heavy ones are put on a plank on the floor. Then the pressboard cylinders (8) and other insulating strips used to pack the LV windings are taken out. If the windings are replaced since their insulation is unfit for further operations, the cylinders and strips are also usually replaced. The new components are made either similar to the old ones or according to drawings.

32.18 INSPECTING THE CORE UNDER MAJOR REPAIR

After dismantling the winding and insulation, the core is inspected. First it is cleaned of dirt and sludge with rags wetted with some solvent and then checked for the quality and mechanical strength of lamination insulation and condition of insulation between the yoke clamps and core sheet.

Then the insulation resistance of the clamping studs of the bottom yoke and core limb is measured and some of the studs are taken down at random for inspection. If there are no signs of over heating and sintering on the Sduds and laminations, the insulation of the studs and laminations is strong mechanically and if the holes in the core limbs and yoke are clean, the core is considered to be fit for reassembly and further operation. Should some minor defects be revealed in the lamination insulation, these are to be eliminated.

If the safety of the core is doubtful, it is to be reassembled, with the top core normally clamped and subjected to electrical and thermal tests.

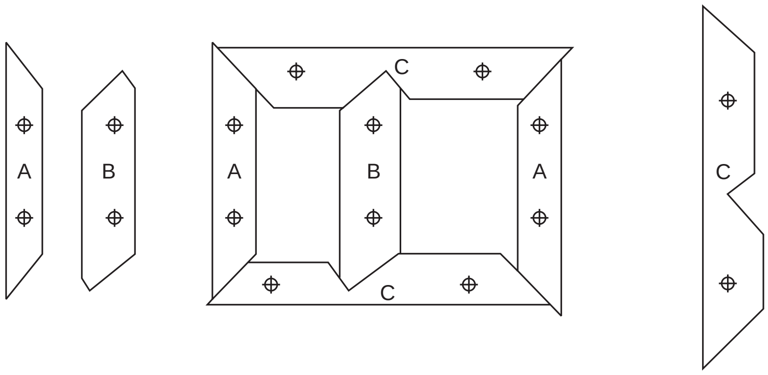


Fig. 32.15. Various steps in the configuration of core assembly

The cores of transformers upto 1000 kVA are reassembled by two workers, while those of bigger transformers require two or more workers to reassemble. All the insulating components, clamping studs complete with their insulations, washers, nuts, earthing strips and core laminations must be brought into the work place for reassembly before hand. The stack of laminations must be located at the workplace in such a manner as to ensure that each workman on the spot can easily get laminations of any sIze without unnecessary movements.

Fig. 32.15 illustrates a most advisable way of keeping the laminations in the work place while reassembling the cores of medium sized transformers. The reassembly starts with placing the end laminations intended to overlap the first butt joint. The core of medium sized transformers is usually stacked with two laminations in a single layer.

The laminations must be placed in such a way that they do not distort the shape of the frame. There should not be any protruding ends and the laminations should not be sitting one on top of the other. Any irregularity and wide gaps in the butt joints between the laminations are eliminated in the process of reassembly with a hammer and vulcanized fiber pad.

Before clamping with the studs, the core is somewhat swollen, because its laminations do not fit one another tightly. Therefore, the core is initially compressed either by placing weights on it or by clamping it with temporary extra long studs. Then the thickness of the entire core is checked, and it is loosely clamped using paper base laminated studs and nuts screwed on them. After that, all the irregularities are finally eliminated with a hammer and a vulcanized rubber pad and the core is clamped until its thickness reaches the size indicated in the sketch by tightening the nuts on the clamping studs.

The reassembled core is slinged, lifted and put into a vertical position with sleepers or wooden blocks placed under the support planks. Then the vertical tie rods are installed in place, just as they were mounted before disassembly, and all the nuts on the clamping studs are finally tightened up and the insulation resistance of the yoke clamp is measured with a megohm-meter. If there is no defect, the core is sent for test. Should the test results prove satisfactory, the top yoke is unbladed and the work on mounting the windings in place is started.

Specific features of repairing and reassembling transformer core, clamped without the use of through studs

These cores, like those clamped using through clamping studs, are positioned, disassembled and reassembled with the aid of a tilter or on a channel frame. They are unclamped by removing the external clamping studs. The process of restoring the laminations in this case does not differ much from the one described above.

The reassembly of the core requires great deal of care and attention, as the laminations here cannot be aligned by means of aligning bars. So the quality of stacking wholly depends on the thoroughness on the part of the repairmen. The laminations in each packet which is 15 to 20 mm thick are aligned with a mallet. After the laminations are stacked, the core is compressed by means of C-clamps and the yokes are clamped with clamping channels, external clamping studs etc. However weight should not be applied to compress the core.

32.19 REPAIR AND MAKING THE WINDINGS UNDER MAJOR REPAIR

The mechanical strength of the windings decreases with time and properties of their insulation gradually deteriorate (the insulation ages). The aging of inter-turn insulation is particulary adverse, since its wear is the most frequent cause for turn-to-turn short-circuits.

Therefore windings with such insulation are either replaced or rewound, with the winding conductors completely reinsulated and the insulating components replaced. An accidental damage to the windings usually entails the burning out of the conductor and the insulation due to a turn-to-turn shortcircuit. Such windings are partially rewound.

The main operations in repairing the transformer windings include reinsulating the winding conductor, preparation of insulating components and materials, winding of coils, drying, impregnating and compressing the finished windings.

Reinsulation of the Winding Conductor

The process of reinsulating the winding conductor consists in removing old insulation from it and then annealing, dressing and further insulating the bare conductor. To remove old insulation and anneal the conductor, the winding is unwound into separate coils which are then heated up to a temperauture of 500 to 600°C in a closed top furnace where the insulation burns out and the internal stresses in the conductor are relieved, so that the conductor copper becomes soft. To prevent the conductor from entangling during annealing, the coils are initially bound with wire and mounted on special support.

Also widely used in repair practice is a mechanical method of removing old insulation from the winding conductors, whereby, the conductor is drawn through a device where its insulation is cut length wise and then removed by scrapers and dressed. This device may also use drawing dies making it possible to redraw the conductor to another size. After redrawing, the conductor is subjected to stress relief annealing.

The annealed conductor, while still hot, is washed with clean water. It is thus well cleaned of burnt insulation and does not loose its softness. Then the conductor is dressed by drawing it through a system of steel rollers and carefully wound turn by turn around drums. To avoid excessive bending, use is made of drums not less than 300 mm diameter. Badly deformed section of the conductors are dressed with a mallet.

The ends of the conductor of separate coils are lapped and electric brazed with a silver spelter. The brazed connections are carefully filed and ground with emery paper. The conductor thus prepared is then insulated on a special paper covering machine.

The conductor is unwound from a drum and is drawn by a pulling device through a dressing device consisting of horizontal and vertical rollers and then through a paper braider which orbits round it and then it is wound around a receiving drum. While it passes through the paper braider carrying rolls of cable paper, the conductor is braided with paper tapes upto the required thickness (the turns of the paper tapes can be made to overlap one another by one-half of the tape width or by one-third of the tape width etc.). Use is made of cable paper tapes 10 mm to 25 mm wide and 1.5 mil to 2 mil thick in various combinations, depending on the required insulation thickness and the sizes of the conductor. If there are only a few metres of the conductor to be reinsulated, the same is done by hand manually.

Repairing of Insulating Components and Materials

Before starting the work on rewinding the coils, whether partially or completely, all the required insulating components and materials should be prepared. Their list and the quantity of each item depend on the type of windings and the scope of work.

In the case of single and double layer windings, it is necessary to prepare paper base laminated edge blocks, cleats for forming oil ducts between the winding layers, pressboard wedges for making edge blocks, strips of varnish clothes, insulating tapes etc. For multilayer cylindrical windings, one should prepare new paper base laminated cylinders, should the old one prove to be damaged, press-board strips, edge insulation strips, cable paper for interlayer insulation, spacer bars for forming cooling ducts etc. In any case, the list of insulating components which need to be replaced is specified when inspecting the damaged winding.

No matter what type the windings are, the work place should be supplied with linen-finished and surgical tapes, strips of varnish cloths, and cable paper. Soldering and brazing equipments with solder and brazing materials should also be made available.

Winding of Coils

The winding of coil is one of the most skillful operations in repairing a transformer. To do this job, the winding specifications and drawings should be available. The coils are wound on special winding machines equipped with a spindle which carries a template (former). Typical shape of such a winding machine is shown in Fig. 32.16.

1. Electric motor
2. Driving belt
3. Bed
4. Revolving counter
5. Clutch
6. Spindle
7. Paper base laminated plates
8. Template
9. Template fastening nut
10. Control pedal

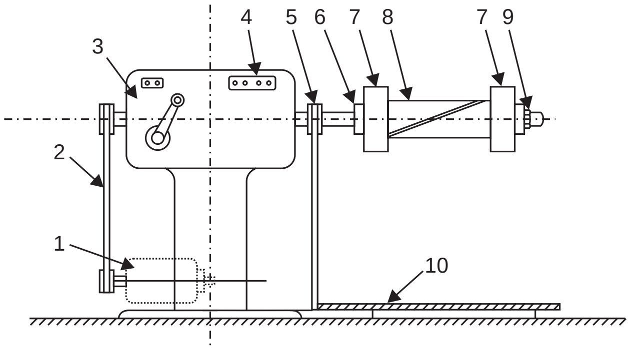


Fig. 32.16. A machine for winding coil

The winding machine is driven by an electric motor and is controlled by means of a pedal (10). For counting the number of turns, the machine is provided with revolution counter (4). When making helical and continuous disc coils, use is made of a solid template which is collapsible in nature, while a split wooden template (8) with a diagonal cut is employed for making small layer-by-layer windings. The template is mounted on the spindle of the machine and is clamped with two paper base laminated plates (7). Such a template design facilitates easy removal of the finished coil.

Along with the winding machine, a number of small devices and tools are used to make coils. These include special appliances for clamping and bending the conductor, electric brazing lugs for making copper conductor joints, appliances for welding aluminium conductors, wire and ordinary shears, files, hammers, knives etc.

If the drum holding the conductor is located behind the winder facing the machine, a right hand coil is wound starting from left to right, while a left hand coil is wound, in the opposite way from right to left.

If the conductor drum is located in front of the winder (behind the machine), the winding direction is reversed.

Before starting the work of winding the coils, one should check the size of the conductor with micrometer.

The finished coils are removed from the machine and placed on a special felt covered support. The winding of coil is a very laborious operation, requiring practice and skill. Under plant conditions, the coils are wound by specially trained persons (winders), whereas when repair of transformers are undertaken at the place of installation, this operation is carried out by highly skilled workers performing both as assembler and winder. Proper supervision is necessary when coils are wound at site.

Compression and Drying of Windings

After the helical or continuous disc windings are made, insulation rings are mounted on them and the ends of the conductors are bent as required and insulated. These coils, immediately after winding, have an axial length, which is more compared to the design value. Therefore, they are clamped between two metal plates held together by steel rods and then dried. In this condition, the coil gets compressed as their insulations get dried and shrunk.

In the plant, the windings are dried in a special oven which may not be available at site. A typical method of compressing a continuous disc coil under hydraulic press in the plant is shown in Fig. 3.17.

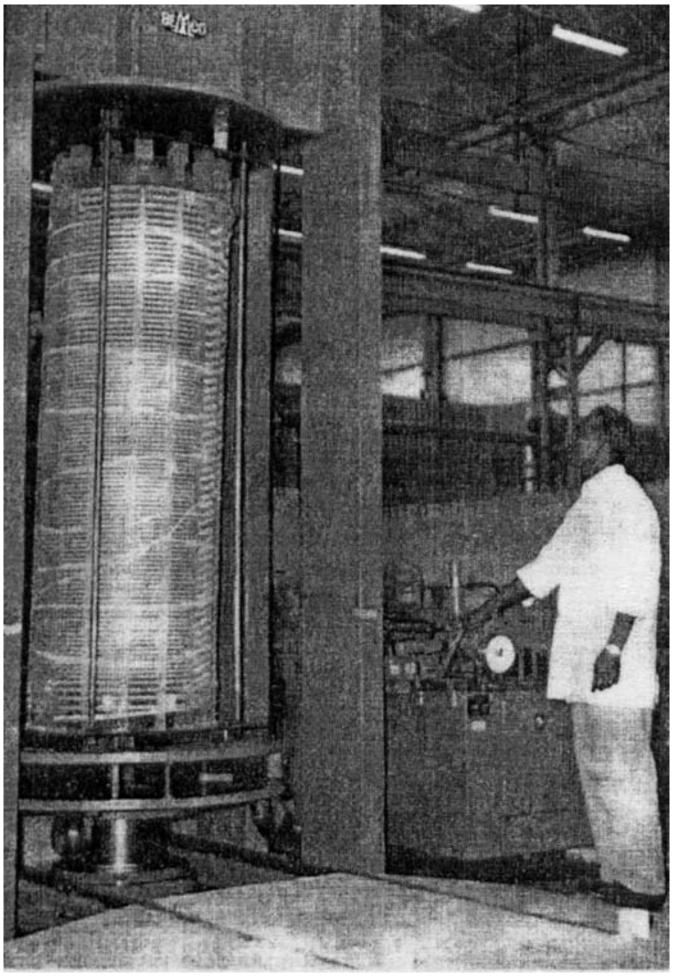


Fig. 32.17. Transformer winding undergoing shrinking process in hydraulic press

Such sophisticated, compression equipments may not be available at site, where the coils are dried in an ordinary oven or in a closed metal tank provided with an induction heating system. After drying for 10 to 15 hours at a temperature of 80 to 90°C, the winding is additionally compressed by tightening uniformly till the design value for the axial length of the winding is achieved.

32.20 REPAIRING AND MAKING THE MAJOR INSULATION

When transformer repair includes the replacement of the windings, the major insulation, as a rule, is also replaced by a new one. Where windings are restored, the major insulations are repaired by replacing its individual components with newly made ones. The yoke and coil end insulations are, as a practice, made new. While repairing major insulation, quite frequently only the annular discs are replaced, and spacer blocks, if they are not damaged and have not lost their mechanical strength, are retained for use.

32.21 COIL ASSEMBLY

Before fitting the insulation and mounting the windings in place, the top yoke of the core is unbladed and the ends of the core limbs are tied with cotton tape as shown in Fig. 32.18. The LV and HV windings complete with their insulation are brought to the work place. If the windings are new, their voltage rating, capacity and type of transformer they are intended for should be checked by reading the tags affixed to them.

If these datas correspond to the characteristics of the transformer under repair, the windings are visually inspected for external defect, and tested for short-circuit between the parallel conductors. These are tested using series bulb method.

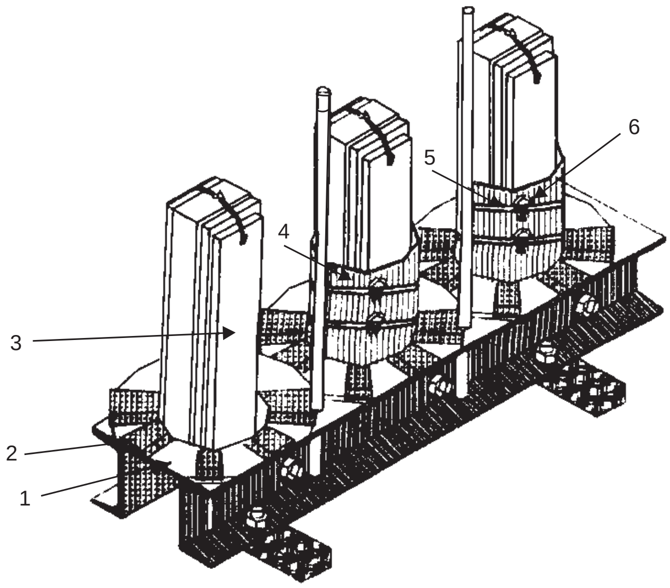


Fig. 32.18. Mounting the coil end and yoke insulation on transformers upto 1000 kVA at 11 kV

Then the bottom coil end insulation (bottom liner) is placed on the flanges of the bottom yoke clamps. In transformers upto 1000 kVA with 11 kV system voltage, bottom liner is generally made with 3 mm pressboard sheet. This is placed on the yoke clamps along the perimeter of the core and checked to see whether their surfaces are flush with the yoke surface. The rings with spacer blocks are fitted on the core limbs and made lie with the yoke liner so that the spacing blocks do not sag.

If the windings have no rigid cylinder, use is made of soft pressboard cylinders. The soft cylinders are made from pressboards 1 to 1.5 mm thick, which are bend in the form of a half cylinder and fitted around the core limb in such a manner as to ensure that they form an even cylinder and overlap each other at the joint. The lap joint of the cylinder must be located on the side surface of the limb and be placed at the centre of the core limb. The pressboard cylinder should be smoothly bent along the grain so that a proper cylinder free from corners and fractures is obtained.

The cylinders are fixed on the core limbs with cotton tape or they are temporarily tied around with cord which is removed when the windings are mounted.

The height, thickness and outside diameter of the cylinders are checked with a ruler, sliding caliper and outside caliper respectively. All dimensions of the cylinder must correspond to those indicated in the drawings or sketches of the old cylinders.

When mounting the LV windings, it should be ensured that their line ends face the side where LV leads will be arranged. The windings must tightly fit the insulating cylinder on the limbs. If the winding offers too great a resistance when being mounted, it is necessary to check its dimensions and the problem should be identified and eliminated. After the LV windings are fitted in place, the HV windings are mounted concentrically on them, beginning with the end coil first. Adequate paper cylinder with oil ducts are placed over LV coils as per design. In the case of sectional HV coils, rings and blocks are placed between the two consecutive coils. The line ends and voltage control taps of the HV windings are so arranged that they are opposite to the LV leads and facing the side of the tank where the HV leads will be arranged. After the coils are placed, the top yoke insulation (which necessarily is the same as that of bottom one) are fitted on the core limbs and then refilling of top yoke starts.

Specific Features of Mounting the Windings of Big Transformer

The work of mounting the LV windings on the core limbs start with wrapping insulating cylinder around the core. The thickness of wrapping depends upon the kVA and voltage class of the transformer. During wrapping, an over lap in the order of 40 to 80 mm should be ensured.

The cylinder, thus assembled according to the design, are fastened by tying them around with surgical tape applied in a staggered fashion over their entire height. After fastening the cylinder, the outer diameter is measured and checked with the drawing for the winding.

The windings are mounted on the core limbs with the aid of the same lifting fixture, a three bar spaced frame with draw bars and grips, as is used during dismantling them. Prior to mounting, the windings are checked for defects and for conformance to the design dimensions. The inner and the outer diameter of the windings and their axial length are measured. The size of the conductors are also measured with a micrometer. The windings are checked for broken conductors and for short circuits between parallel conductors.

While checking the windings for short circuits between the parallel conductors, the ends of the conductors are moved apart and stripped of paper insulation with a knife. One probe of the megohm-meter is connected to one of the parallel conductors. When the crank of the megohm-meter is turned, the instrument should not read zero. If the windings are checked with a lamp connection, the lamp should not glow.

Then the fixed probe of the megohm-meter is connected to the next parallel conductor of the winding and the other probe is connected in turn to the rest of the parallel conductor, except for the one that was previously checked. In this way, all the parallel conductors of the winding are checked.

When broken conductors are checked, all the parallel conductors at one end of the winding are connected together, while the conductors on the other end are checked in pairs with the megohm-meter. If there is no breakage, the instrument will always read zero. If there is short circuited or broken parallel conductors, the fault should be located and eliminated before mounting the winding.

Helical and continuous disc windings come in for assembly clamped down to the axial size specified in the drawing. So they must be checked for short circuits prior to unclamping, because when unclamped, the parallel conductors may change their relative positions and the short circuit, if there is any, may be cleared and will reappear only on reclamping.

After testing, the windings are unclamped, visually inspected on the outside and inside and blown through with compressed air. Once the preparatory work is ended, the grips on the draw bars of the three bar spread frame are brought under the winding, the winding together with the draw bars is tied with a rope and then it is lifted and moved to the corresponding core limb.

The winding is aligned with the centre of the core limb and turned in such a manner, as to ensure that its start and finish are located in the appropriate spaces between the spacing blocks of the yoke insulation. To improve the sliding of the windings during mounting, the insulating cylinders on the core legs are rubbed with paraffin or french chalk powder.

Then the winding is smoothly lowered on the core leg, while being guided by hand so as to ensure that the columns of the inter turn or inter disc spacers are in line with the spacing blocks of the yoke insulation. The winding must fit its cylinder tightly so that one or even two workers may have to make some effort to mount it in place. If the winding offers too great a resistance, it should be lifted and the reasons for this should be found out. The inner size of the winding should be checked across its bars and the outer diameter of the cylinder, and should be ensured that no insulating parts or conductor ends extend inside the winding. If the winding goes too easily, it should be lifted and the diameter of the cylinder should be enlarged by adding pressboard sheets.

The inner windings, usually the LV ones, are not lowered home at once. When the winding comes to a distance of 100 to 150 mm from the bottom yoke insulation, temporary wooden blocks are placed under it, the lifting fixture is removed, and the bottom end conductor is bent and insulated. If there are several parallel conductors, their ends are aligned and laid according to the drawing of the winding.

In transformers ranging from 1000 kVA to 6300 kVA at 33 kV, the winding ends are insulated with tapes of crape paper applied half lap upto a thickness of 4 to 6 mm on one side. The layers of insulation must tightly fit one another and must taper all the way to the end. The top conductor end of the LV windings are bent, laid and insulated after mounting the HV windings.

Once the bottom conductor end of the LV winding is insulated, the temporary wooden blocks are removed from under the winding and the later is tightly set on the yoke insulation so that the bottom conductor end lies in the space between the appropriate spacing blocks of the yoke insulation. If the winding does not get home under its own weight, it is then set down with a dead weight.

After the LV windings are placed on the core limbs, they are packed out with shaped pressboard strips or treated wood strips driven between the limb steps and the insulated cylinders of the windings.

Soft insulated cylinders for the HV windings are assembled on the LV windings in the same way as the LV cylinders are assembled on the core limbs.

Then the HV windings are put on the core limbs, after they are inspected and prepared as in the caste of LV windings. The HV windings are lowered on to the limb with the aid of the same lifting fixture, with its grip applied to the winding in exactly the same manner. Again, it should be ensured that the columns of the inter-turn or inter disc spacers are in line with the spacing blocks of the yoke insulation. The line end and the voltage control taps should be arranged as per the sketches drawn before dismantling.

Because of the spring quality and some swelling of the insulation, the axial size of the unclamped winding is somewhat increased and as a result, the top yoke laminations while reblading butt against the insulation and do not adjoin the limb core lamination. Therefore after mounting, the LV and HV windings of each phase should be separately driven down with a special device or a dead weight which is lowered by a hoisting mechanism on special support blocks set up on the windings. When the winding is compressed to their normal axial size, the top conductor ends of the LV windings are bent and insulated.

Then the set of top insulation components is fitted, pressboard rings and steel pressure rings etc. are placed on the yoke insulation of the windings. After that the top yoke is rebladed.

Reblading the Top Yoke

The top yoke laminations, yoke clamps, clamping studs, yoke clamping insulation and earthing strips etc. should be brought to the place of assembly at the start of work.

The reblading starts with inserting the smallest width yoke lamination in its place and continuing in the order of increasing width. Two or even more laminations together can be inserted at a time, depending on the manner the top yoke was assembled formerly.

The yoke laminations should be inserted in such a way as to ensure that they neither overlap nor form gaps in the butt joints and that the holes, if any, in them exactly coincide with each other. Otherwise, the clamping studs will not go into the holes of the rebladed yoke.

To reduce the gaps in the butt joints between the laminations and to level laminations that form ridges on the yoke surface, each layer of lamination is hammered down, tapping the hammer against a pad of insulating material placed along the laminations. One should never strike blows directly against the laminations or use a steel pad. The lamination projecting at the yoke ends are hammered in so as to reduce the gaps between the corner and the successive plates of the yoke.

32.22 CLAMPING THE WINDINGS AND THE TOP YOKE

Despite hammering down during reblading, the top yoke lamination (3) sometimes cannot reach the limb laminations, because they butt against the yoke insulation clamping the windings and the top yoke as shown in Fig. 32.19.

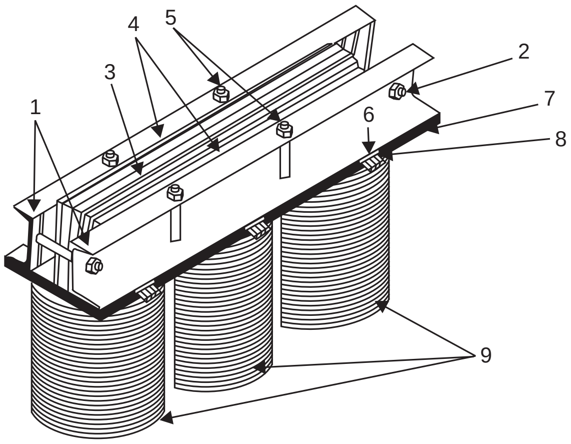


Fig. 32.19. Clamping the windings and the top yoke

To finally set all the yoke laminations in place, the windings (9) are compressed by yoke clamps and vertical tie rods (5), the yoke being loosely clamped with core studs (2) inserted into the two extreme end of the clamping channels. The gaps in separate butt joints between yoke and limb laminations cause an increase in the no-load current and core loss. This is revealed during tests and may lead to the repeated unblading and reblading of the yoke.

After the yoke laminations are finally set in place, the nuts on the studs (2) are slackened and the insulating strips (4) of the yoke clamps are inserted. In small transformer, these are simply pressboard strips. In large transformer, the strips are provided with transverse spacers, also of pressboard, which form vertical cooling ducts between the yoke and the yoke clamps. In the case of yoke with holes, the yoke clamps and insulating strips are installed in line with the holes in the yoke laminations.

After that the yoke is clamped by uniformly tightening the nuts. The holes in the yoke are inspected and if there are displaced laminations, they are aligned with a steel tapered drift. Then the yoke clamping studs together with their paper base laminated tubes are inserted into the holes of the yoke, insulated and steel washers are slipped onto the studs from both ends and then the nuts are run onto them.

The core earthing strip is installed on the LV side. One end of the strip is inserted to a depth of 50 to 60 mm between the laminations of the first yoke stack, while its other end is bolted on the face of the core clamp. It is necessary to remove the paint from the surface of the steel clamp to ensure proper earthing. Then the top yoke is finally clamped by tightening all nuts of core studs and tie rods. The nuts are centre punched and insulation resistance of the clamping studs is checked with a megohm-meter.

32.23 SOLDERING AND WELDING THE LEADS

The windings assembled on the core are connected to one another, to the tap changer and terminal bushings by means of leads. The windings of a transformer are connected delta in HV and star in LV with neutral brought out (usually seen). However, in each case the connection diagram of the winding should be referred to.

In the case of copper-wound transformer, current carrying leads are connected mainly by soldering or gas brazing. However, electric (resistance) brazing with spelters is also widely used.

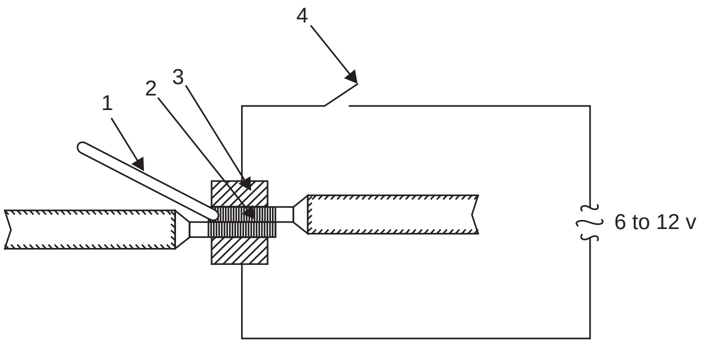


Fig. 32.20. Schematic diagram of electric (resistance) brazing of conductors

Schematic diagram of electric (resistance) brazing of conductors is shown in Fig. 32.20.

In electric brazing, the prepared lap joint (2) of the conductors to be connected is clamped between carbon electrodes (3) which are supplied with a voltage of 6 to 12 V via a pedal operated foot switch (4).

When the circuit is completed by the switch, a current starts flowing through the joints and the carbon electrodes. Since the resistance of the carbon electrodes is high, they become heated and in turn heat the joint. As soon as the joint is raised to melting point, a spelter stick (1) is brought into contact with the edges of the heated conductors and as a result, the spelter melts and fills the gap between the conductors. Then the current is switched off. The joint cools down and spelter solidities, thus firmly joining the conductors.

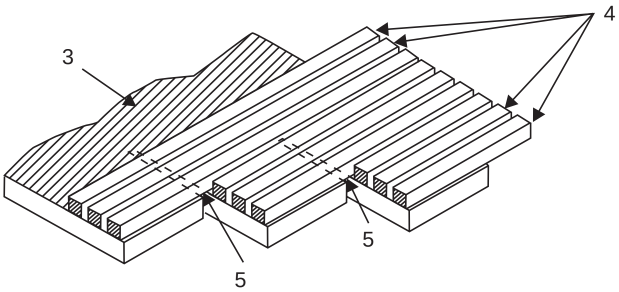


Fig. 32.21. Method of connecting heavy leads to the ends of windings wound with several parallel conductors

It is more troublesome to prepare heavy bar leads for brazing when connecting them to the ends of windings wound with large number of parallel conductors.

Methods of connecting heavy leads to the ends of windings wound with several parallel conductors have been shown in Fig. 32.21 (see page 419).

Since such joints are difficult to heat during brazing, the end of the bar leads (3) are split into separate elements, slits (5) are cut on the bar leads and the parallel conductors (4) of the winding end are distributed among the separate elements of the lead end. The winding conductors are placed on the bar lead either edgewise or flatwise. To prevent the elements of the prepared joints from being moved apart, they are temporarily fastened with fine wires which are removed after brazing.

After all the joints of the HV and LV leads are prepared for brazing, electrical tests are carried out with a view to determine the phase displacement group of the winding connection and the transformation ratio. Then the necessary tools and devices are prepared and the lead joints are brazed one after another.

Compared to brazing, soft soldering with tinbase solders suffers from a number of drawbacks. They are:

- Low mechanical strength and thermal stability
- Relatively high resistance joints produced
- High cost of solder.

Therefore, soft soldering is only used when brazing cannot be employed. Solder is done with a soldering iron or blow lamp using soldering materials and rosin as flux.

32.24 INSULATING AND FASTENING THE LEADS

After brazing/soldering, burnt insulations are stripped off and then the leads are insulated. First crape or cable paper and then linen-finished tape are used for insulating the leads. The lead connections are insulated manually by applying half lap layers upon layers of insulating paper until the thickness of the main lead insulation is reached. When doing this, the strips are tensioned and smoothened by hand in the winding direction so as to ensure that the layers are applied tightly without any folds and voids between them. For mechanical protection, one layer of half lapped linen-finished tape is applied over the main insulation. The leads are additionally insulated at places where they pass between support cleats. LV leads and their connections are usually not insulated. The insulated leads are clamped in the support cleats and the core-coil assembly is subjected to electrical tests after all its screw fastenings have been finally tightened.

32.25 DRYING OUT OF ASSEMBLED TRANSFORMER

After it is assembled and tested, the core-coil unit is dried out. The physical essence of the drying out process is that on heating the insulation, the moisture contained in the material moves from its internal pores to the surface, from where it goes into the surroundings. The transfer of moisture is due to the difference in temperature between adjacent layers of insulation, as a result of which moisture is driven off from the more heated layers in to the less heated ones. This is explained by the fact that. depending on the temperature, the pressure of water vapour over the surface of material is lower than that in its outer layers, so moisture moves from places where the so called partial pressure is higher to places where it is lower.

Therefore when drying out, it is essential to raise the vapour pressure in the layers of insulation and to keep it down in the surroundings. The first requirement is satisfied by heating the insulation and the second, by maintaining a vacuum in the drying oven or in the tank where the drying out takes place. The practice during repairs is that the transformers are dried out without vacuum. To produce the required vapour pressure differential, the heating of the insulation in the course of the drying out process, is periodically interrupted and the outer surface of the core-coil unit is sharply cooled with a jet of clean cold air. The process of accelerating the drying out by producing a temperature differential is based on the phenomenon of thermal diffusion.

The main characteristics affecting the drying out process are the insulation resistance and heating temperature. During drying out, the core-coil assembly is heated to a temperature of 80 to 90°C which is maintained at a constant level as far as possible. Heating to a higher temperature is impermissible since this will cause deterioration of the properties of insulation and its eventual failure. In the course of drying out, the temperature is measured at several characteristic points.

The process of moisture removal in drying out is characterised by the curve depicting the change of insulation resistance with time at a constant temperature.

At the beginning of the operation, the insulation resistance sharply drops and then remain almost constant for about 5 to 8 hours. As the moisture is removed, the insulation resistance rises and by the end of the drying out cycle, it is sustained at a certain definite value specific to the given type of transformer. The drying out is considered to be complete, if at the end of the process, the insulation resistance of the transformer windings at the highest steady state temperature remain unchanged for a continuous period of 5 to 6 hours.

In the course of drying out, the insulation resistance is measured by means of megohm-meter operating at a voltage of 1000 to 2500 Volts, the former being used to measure resistance below 100 Meg. ohms and the later, 100 Meg. ohms and above. The insulation resistance and temperature are measured hourly and recorded in a register.

Method of Drying out without Vacuum

Depending on the actual condition and available equipments, various methods for drying out the core-coil unit of transformer may be employed. Let us discuss some of the common drying methods without using vacuum.

(*i*) Drying out by induction method: This method is widely used during repair for drying out medium and large transformers. In this method, the core-coil assembly is placed in a tank with magnetising coil wound around its perimeter on the outside. The drying out of a transformer in its own tank by induction heating, without vacuum, is shown in Fig. 32.22.

The coil is supplied with AC supply and it produces a magnetic flux which has its path through steel walls of the tank, inducing eddy currents in them. This current heats the tank and from the tank the heat is transferred to the core-coil assembly (1). Usually, the tank of the transformer itself is used for this purpose.

To improve the heat conservation ability of the tank, it is blanketed with asbestos cloth (3). The magnetising coil (2) of insulated wire is wound directly around the thermal insulation blanket. lf bare wire is used for the coil, the wire is then secured to porcelain blocks arranged vertically around the periphery of the tank. The necessary number of turns in the coil and the size of the wire are determined approximately by calculation. The final number of turns is ascertained in the course of heating and if necessary, some extra turns may be added or surplus turns removed.

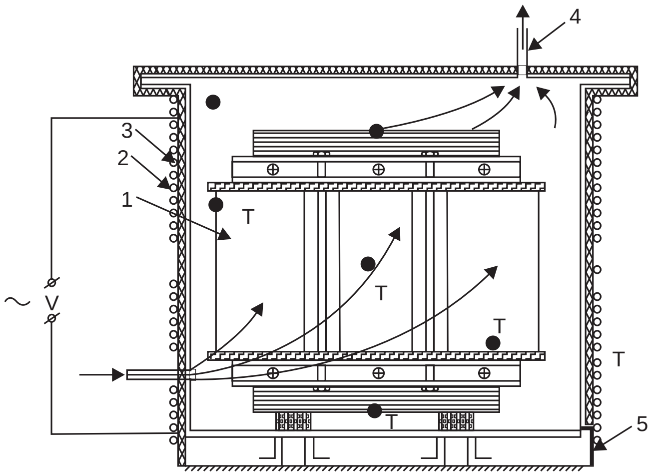


Fig. 32.22. Drying out a transformer in its own tank by induction heating without vacuum

To provide uniform heating of the core-coil assembly, the turns of the coil are so arranged on the tank that 60 to 70 per cent of their total number fall on its lower half. At the very bottom of the tank and on its top, the turns are wound as close as possible to one another. The tank should be wiped dry before putting the core-coil assembly into it. To avoid condensation of water vapour, the tank bottom should be heated and its cover is blanketed in the best way possible. For safety reason, the tank should be earthed.

For ventilation, a vent pipe (4), 1.5 to 2 metre high, is installed on the tank cover and one of the openings at the tank bottom is kept open. A most effective means for removing moist air from the tank is the use of an exhaust fan on one of the opening in the tank cover. Favourable conditions for thermal diffusion are provided by operating the fan periodically.

When drying out without vacuum, the temperature is controlled by means of thermocouples embedded in various locations, such as winding, tank, core yoke etc. The temperature of the winding and core yoke is maintained at 80 to 90°C, while that of the tank wall within 110 to 120°C, depending upon the distance between the tank wall and the windings.

The transformers are dried for a period of twenty four hours without interruption and all thermo-couples and megohm-meter readings are entered in the register every hour.

The insulation resistance is measured between HV and LV windings with the tank earthed and also between each winding to tank with the other windings earthed. Once drying out is completed, heating is ceased and the core-coil assembly is cooled to a temperature of 60 to 65°C and then flooded with oil.

(*ii*) Drying out in an oven: The core-coil assembly is placed in a drying oven where it is dried out in the usual manner. This method is mainly used at the manufacturing and repair plant. Small oven may be used for drying out comparatively small transformers. Drying oven may be heated up by electric heaters, hot air circulation etc.

(*iii*) Drying out by infrared rays: In this method, use is made of special infrared lamps which are capable of transforming 80 to 90 per cent of the input electrical energy into radiant heat energy.

Heat from the lamp is transferred by radiation. Therefore, to direct the heat flux onto the coil assembly, the lamps are placed against reflectors and mounted on some suitable supports at a distance of approximately 300 mm from the core-coil assembly in such a manner as to ensure that the rays are uniformly spread over the entire surface of the coils.

Temperature Measurement

When drying out transformers, the temperature of the individual components of the core-coil assembly is measured by means of thermometers, temperature indicators and thermocouples. Thermocouples are most widely used during repairs.

A thermocouple consists of a pair of wires of dissimilar metals, joined at each end. One junction (hot) is at the point where the temperature is to be measured and the other (cold) is kept at a lower fixed temperature. Owing to the difference in temperature between the junctions, a thermal emf is generated, causing an electric current to flow in the circuit. This current can be measured by means of a galvanometer in the circuit, or the thermal emf can be measured by a potentiometer. The wires are usually from 0.5 to 1.0 mm in diameter and are joined at the end which is exposed to the temperature to be measured, the other end being free to connect to an instrument for measuring the emf, the scale of which is graduated to read temperature in degree celsius. The hot junction is made in the form of a bead by welding or soldering and the wires are insulated from each other. Different combinations of metal produce different emfs for the same temperature intervals, their absolute value ranging from 3 to 7 mV for a temperature difference of 100°C.

The various thermal emf's for a temperature difference of 100°C are produced by thermocouples of the following combinations of conductor materials:

Chromel and Copel	6.95 mV
Iron and Copel	5.75 mV
Chromel and Alumel	4.1 mV
Copper and Constantan	4.0 mV

Preparation for drying out and drying out conditions: If it is contemplated to dry out the core-coil assembly of a transformer unit in its own tank, two or three terminal bushings are then mounted on the tank cover, their number depending on the number of the windings in the transformer. A lead from each of the winding is connected to its respective bushing and thermocouples are fitted at the requisite spots on the windings, core and tank wall. The connecting wires from the thermocouples are brought out through one of the free openings in the tank cover and connected via a selector switch to a galvanometer set up on the desk of the man on duty. The wires must not touch the cuP`ent carrying parts and the body of the transformer. Where they pass through the opening of the cover, the wires are spread apart and clamped between rubber packings.

All the openings except one for mounting vent pipe in the cover, are closed with blind flanges. To measure insulation resistance of the windings, well insulated leads are brought from the terminal bushings mounted on the tank cover and from the tank to the desk of the man on duty. Then the tank is earthed and the drying out is commenced by switching on the magnetising coil (induction heating).

The man in charge to supervise the drying out process, must have on his desk the instruction manual for the drying out process a register, a clock, megohm-meter and instruments for measuring current and voltage.

So long as the core coil assembly is being heated upto a temperature of 70 to 80°C, the exhaust for moist air is kept closed. Then it is opened and a vent pipe is installed on it. One of the opening at the bottom of the tank is opened to provide fH natural ventilation.

Accident and Fire Safety

The drying out of transformer involves the use of supply voltage 120 to 400 V. Some parts of the transformer gets heated in this process to a temperature as high as 120 to 130°C. Therefore to provide for accident and fire safety, the following rules must be strictly adhered to:

- The transformer tank and other electrical equipment cabinets must be earthed.
- Electric wiring must have good insulation and reliable connection.
- The area where the actual drying out takes place, must be fenced with cotton rope and must be provided with warning signs bearing inscriptions like ‘caution’, ‘danger’, ‘live equipment’ etc.
- The room where the transformer is to be dried out must be well ventilated and must be provided with means for fire fighting, such as a box with sand, shovels, fire extinguishers etc.
- Smoking or open fire should not be allowed in the room where the transformer is being dried out.
- The man on duty must stay close to the transformer and must never leave it unattended.
- The tank and ovens used for drying out the transformer must be provided with sufficient exhaust ventilation to rule out any possibility of explosion due to concentration of oil vapours.
- The use of open coil electric heaters for heating the tank bottom is prohibited.

32.26 OIL FILLING

When the drying out is completed, the magnetising coil is switched off, the core-coil unit is allowed to cool down to a much lower temperature and the tank is then filled through the top valve with dry clean transformer oil to a level at which it fully covers the core-coil unit. Before filling the tank, the oil should be subjected to breakdown test.

The core-coil unit is kept covered with oil for sufficient period of time for it to become impregnated with oil. The length of the period depends on the capacity and class of insulation of the transformer. Then the core-coil assembly is slinged and pulled out of the tank for inspection. The drying out entails substantial shrinkage of the transforme insulation and loosening of the windings, leads and other units. The scope of inspection is to verify the clamping of the windings as well as the extend to which it has become loose during drying. The windings are packed out and all the nuts on the clamping studs are also checked. After that the core-coil unit is put back to the tank and filled with oil. Rubber sealing gaskets on the tank cover is replaced and the transformer is assembled in the usual way. Connections and terminations are made, external fittings on the tank cover like conservator, buchholz relay, explosion vent etc. are placed in their respective positions. The oil is filled up to the required level. Then the transformer is tested for oil leakage. The oil is allowed to settle for at least 24 hours before subjecting the transformer to electrical test.

32.27 ELECTRICAL TEST ON FINISHED TRANSFORMER

It is recommended to carryout all routine tests as per IS-2026. But due to limitation in the availability of test equipments, it may not be possible to organize all recommended tests on a repaired transformer at site. Some compromises should be made on such occasions. However, following tests must be carried out:

- Di-electric breakdown value of oil
- Insulation resistance
- Voltage ratio and phase relationship
- Winding resistance
- Operation of tap switch (only mechanical check)
- Electrical contacts of the gauges, like MOG, OTI, WTI, Buchholz relay.

In case facilities are available to measure the no-load and load loss, the same should be carried out. Otherwise, the magnetising current at reduced voltage should be checked. Separate source power frequency test and induced over voltage test, if carried out, should be done at 75 per cent of the test voltage.

After the successful completion of the above tests, the transformer is sent back to the place of installation.

Section IV
CHAPTER 33

Life of a Transformer—User's Guide

FOOD FOR THOUGHT

Today's customer is more informed and knowledgeable and as a result expects more functions, better performance and lesser price. Customers have wide range of choices to select from. Approximately, 90% of unsatisfied customers do not complain. They simply shift to a new brand. Additionally, it costs, five times more to get a new customer than to retain a current customer.

Customer surveys and feedback are important in determining satisfaction levels. The voice of customers are seldom loud and clear. Mostly, they mumble and murmur. Customer needs and requirements must be met, whether defined explicitly or implicity.

Customer partnership will yield growth for the organization. A customer can play important role if they are made part of the business planning process. Mutual trust and confidence are important in building long lasting partnership. It should never be forgotten that the customer is the final arbitrator and judge.

33.1 INTRODUCTION

As was discussed in section 2 of this book, a harmonious relation and mutual understanding between the manufacturers and the users is very productive as it helps in reducing the rate of failure of distribution transformers in service. A good transformer may not run longer in a bad service condition. We have discussed at length the various causes of failures at the manufacturer's end. Here we shall take up the user's contribution towards longer life span of transformer in service. The following are some of the causes of failures of transformers in service which are attributed to the users. Probable remedial measures are also highlighted.

- Prolonged overloading
- Single phase loading
- Unbalance loading
- Faulty terminations
- Power theft by hooking
- Faulty earth connection to the LV neutral as well as tank body

- Prolonged short circuit beyond permissible limit
- Less maintenance
- Faulty operation of off-circuit tap switch on load
- Poor quality of LT cable
- Improper installation.

We shall discuss in brief each of the above causes of failures, as well as few remedial measures to curb such unhealthy premature failure.

33.2 PROLONGED OVERLOADING

Distribution transformers are generally not recommended for continuous overload. However, overloading for a short duration may be permitted. It is one of the prime responsibilities of the utilities to keep constant checks on the loading of a transformer and should record the loading pattern on a history card. In the case of overloading, the additional loss generates more heat which burns the winding insulations, causing ultimate failure of the transformer.

In most of the cases, it is seen that the line operators use rewirable fuse of higher rating. This is to avoid frequent requirements of attending the trippings, caused by overloading and replacing the fuses.

Proper sizes of fuse elements on both HT and LT side will definitely reduce the probability of failure of transformer due to overload. Measurement of load current with a 'tong-tester' at frequent intervals, especially during peak loading hours will give a fair idea about the load demand of the locality. In case the over loading is more than 20 per cent of the rated load and if it persists for more number of days, it is recommended to replace the existing transformer with one with a bigger rating, or else a second unit may be run in parallel.

Furthermore, the line operators should have some elementary knowledge of the size of fuse elements to be used according to the current rating. The sizes of HT fuse elements, as recommended by PSEB in their maintenance manual, is illustrated in table 33.1 for reference.

Table 33.1

Capacity of transformer	*Recommended fuse element for 11 kV side*
25 kVA	38 swg
63 kVA	33 swg
100 kVA	32 swg
200 kVA	26 swg
300 kVA	22 swg
500 kVA	19 swg

The utilities should make their own standard for fuse elements and their rating and should communicate the same to the line operators. Moreover, utilities must ensure the availability of proper size of fuse elements at the appropriate time. Quite often the operators use two thin fuse wires instead of a thick fuse element, because of the non availability of the correct one. This practice is wrong and must be discouraged.

Table 33.2 provides a reference to the recommendation of PSEB for the kVA rating with respect to BHP.

Table 33.2

kVA	*BHP*
100 kVA	80 BHP
63 kVA	51 BHP
50 kVA	40 BHP
25 kVA	20 BHP

33.3 SINGLE PHASE LOADING

A distribution transformer should ideally be loaded uniformly on all the three phases. But there are few occasions, like running of irrigation pumps in the State of Punjab, where three phase heavy duty pumps are made to run on single phase supply from a three phase transformer. As a result, the load on one phase goes drastically high causing operational problems and lead to the failure of transformers.

Transformers should not be abused this way. The ultimate users should be educated on the effect of single phase loading on the performance of transformers.

It is seen that in most cases, it is the agricultural customer who uses power, are responsible for single phase loading on three phase transformers. It is better to encourage such customers to own their transformers including the overall maintenance responsibility (recently introduced by PSEB). Only then, the failure due to single phase loading will be reduced except in cases where the system runs on single phase inadvertently without the knowledge of the users.

33.4 UNBALANCE LOADING

In a Delta/Star connected transformer with earthed neutral system, it is recommended that all the three phases be uniformly loaded. This is, infact very difficult to achieve with the distribution network we are having in the suburban and metro cities. However, an unbalance loading upto 10 per cent may not be that serious to create an operational problem for a Delta/Star connected transformer. For a three phase balanced load, the potential on LV neutral is zero. In the case of unbalanced loading, a voltage is generated on the neutral, which will remain floated between neutral and earth. Since the neutral is solidly earthed through external link, a circulating current will flow through the closed loop of delta winding. This additional circulating current will superimpose on the main branch current of delta winding and will cause additional heat which may lead to the failure of winding insulation.

It is recommended to keep a check of load current including the current flowing through the neutral at frequent intervals and record it in the history card. As long as the neutral current is within 10 per cent of the load current, the matter may be ignored. In case the neutral current exceeds 10 per cent limit, remedial measure should be taken to bring down the neutral current within acceptable limit.

33.5 FAULTY TERMINATIONS

On many occasions heavy electric sparks appear at the bushing termination joints, especially on LV connections. In most of the cases, these sparks are because of loose terminations either during installation or due to bad service conditions. Once spark occurs at the cable termination, it melts the bushing sealing gasket, effecting oil leakage from the bushing top. This results in the failure of transformer in due course because of low oil level.

The incoming and outgoing termination should be done through proper connectors. ISS and REC have recommended details of termination with drawings of lugs and connectors. Users must ensure that the cable connections are done with proper lugs and connectors. Direct connection of cable/ conductor to the bushing terminal studs should be avoided. During terminations, the effect of bi-metallic action should not be forgotten. If aluminimum cables or conductors are to be connected to brass/copper terminals or vice versa, a proper bi-metal as discussed in the previous chapter should be kept in between. Otherwise, due to bi-metallic action, a voltage in the order of a millivolt will be generated which will cause a localised current and thus may deteriorate the current carrying threads.

33.6 POWER THEFT BY HOOKING

Stealing of power by hooking from the main line is a regular phenomenon in some of the unauthorised colonies. Power utilites do not pay much attention to this. But the transformer manufacturers are affected by this practice, since such hooking make the transformers to run on overload causing failure in due course of time.

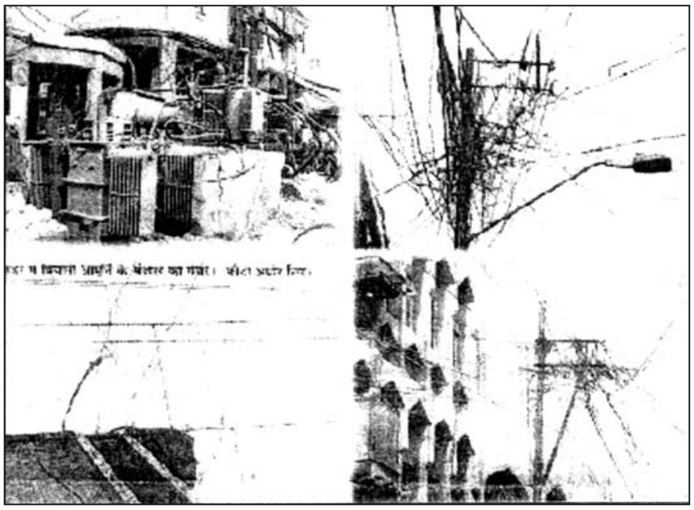


Fig. 33.1. Photograph showing power theft by hooking in a suburban city

Figs. 33.1 and 33.2 illustrate how the distribution networks of suburban (Kanpur) and metro (Delhi) cities are subjected to power theft by hooking. This is one of the major causes of failure of distribution transformers for which the manufacturers are usually blamed. This is a serious problem and the utilities must take steps to stop this practice.

The following paragraphs provide a generalised picture of transmission and distribution losses along with the statistics of power theft occurring in various SEBs in India. Valuable comments by some of the very eminent personnel of the power architects are also given.

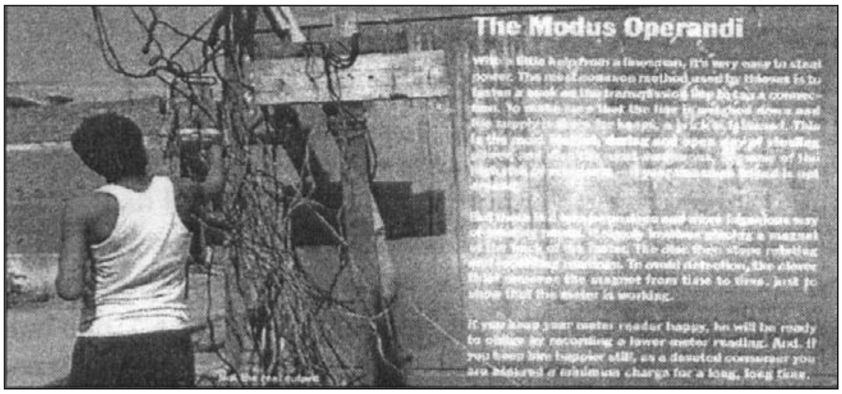


Fig. 33.2. Photograph showing the power theft directly from the mains in a metro city

In the year 1996–97, between 40 to 60 billions units of electricity were stolen all over India, aggregating to Rs.72 to 108 billion in terms of money. Former chairman of DVB Mr. Navin Chawla said "Nobody live without power. The more the metros expand and people flock to urban areas, the greater will be the demand for power. And if a person can't secure a legal connection, he will not wait but just steal power directly from the mains."

Delhi alone loses about Rs.14 billion annually to power theft, though DVB officials claim that Rs. 4 to 4.5 billion is lost each year in pilferage. About 40 per cent of 4000 MW fed into the capital's transmission network is stolen daily by industrial, commercial and domestic consumers.

By all accounts, Delhi theft record is the bleakest. Contrary to popular perception, industrial and commercial consumers plunder much more power than shanty dwellers, who account for a fraction of the electricity pilfered.

But why do power thefts continue unabated?

Former Power secretary Mr. P. Abraham hits the nail on the head. "Bad supervision and official connivance with the offenders are the principal causes for large scale pilferage of power." A fact that Mr. Navin Chawla endorses.

To reduce *T* and *D* losses, according to Mr. Abraham, what we need is a better transmission network. This may be difficult, in a short time, as it involves major investment. On the other hand. curbing theft is purely a managerial issue. "This can only be done through vigilance" he says.

That's easier said than done. For if there is one thing that SEB officials seem reluctant to do, it is to take action on this. In fact SEB officials are not even in the mood to admit the gravity of the problem. Most of the SEBs are of the opinion that not more than 5 to 6 per cent of the power distributed is stolen.

This is simply not true, contend power experts. They reckon that in the 25 to 30 per cent of all India *T* and *D* losses (official figures put these losses around 22 per cent) theft accounts for half of it.

But the Grid Corporation of Orissa (Grid Co.) was refreshingly open. It confessed to *T* and *D* losses of 47 per cent theft accounting for around 29 per cent and technical losses responsible for remaining

18 per cent. However the planning commission's figures on *T* and *D* losses seem wide off the mark, very much on the lower side. For instance, the planning commission puts Orissa's *T* and *D* losses at 22 per cent, less than half of Grid Co's estimate. SEBs, like Uttar Pradesh, Maharashtra, Gujarat and Karnataka do not want to disclose the actual *T* and *D* losses and pilferage. But wherever the SEBs did make an attempt, the figures they quoted were incredibly low. For instance, in Andhra Pradesh theft 5 per cent and *T* and *D* losses 19 per cent, in West Bengal theft 6 per cent and *T* and *D* losses 21 per cent, in Assam theft 7 per cent and *T* and *D* losses 27 per cent, in Madhya Pradesh theft 3.5 per cent and *T* and *D* losses 19.6 per cent. Maharastra State Electricity Board gave pilferage figures only with regard to detected theft cases. This was 55.27 million units in 1995–96, which gets translated to Rs. 110.5 millions.

According to experts, the thumb rule is that theft is generally half of *T* and *D* losses. A couple of SEBs did disclose the truth. The Haryana State Electricity Board admitted to commercial losses (read pilferage) of 13 to 15 per cent, out of a total *T* and *D* losses of 32 per cent. In monetory terms, this works out to Rs. 2.9 billion annually.

The Bihar State Electricity Board disclosed that their losses owing to theft were in the range of 12 to 14 per cent, and *T* and *D* losses were 23 to 24 per cent. The board apparently lost Rs. 3.06 billion because of pilferage.

As stated by Mr. Navin Chawla, Exchairman, DVB, the theft component in DVB is about 20 to 21 per cent. Around 7 per cent revenue loss is due to inadequate billing. Line or technical losses are about 20 per cent. This takes the total loss to 48 to 50 per cent.

The power distribution in DVB is divided into five circles. They are East, West, Central, South and North. The average *T* and *D* losses including power theft is approximately 50.34 per cent. Losses for East circle is as high as 63.5 per cent whereas, for North circle it is as low as 39.5 per cent.

DVB's 50 per cent *T* and *D* losses include 18 per cent technical losses and 32 per cent commercial losses. The 32 per cent includes theft in unauthorised colonies, industrial areas and lastly in the slum clusters. These losses also include those of the posh colonies where people have taken loads higher than what is sanctioned.

DVB which conducted an energy audit found that certain areas account for extremely high *T* and *D* losses. In April and May, 2000, *T* and *D* losses in the East and West circles touched 63.5 and 62.4 per cent respectively. The reason for such high losses was theft in unauthorised colonies. The number of unauthorised colonies excluding slums is the highest in these two circles. Losses in other circles were much less as compared to East and West. The energy audit shows that central circle has losses of about 44.3 per cent, while the losses in south circle touched about 42 per cent. By way of the *T* and *D* losses, DVB losses hundreds of crores of rupees every month.

Half of the problems of power theft would be solved by meeting the problem headlong rather than evading the truth. When the country is short of power, we cannot afford to lose power through theft. Rajasthan State Electricity Board has recovered millions of rupees in settlement of pilferage cases. But it is essential that other states follow suit.

Is it then the end of the road? Are there no solution? Yes, there are.

Firstly, meters are required at every substation to find out how much pilferage is actually taking place and what amount is really lost due to technical problems related to transmission. Quite a few SEBs claim that they are in the process of installing tamper proof electronic meters. These record the time at which theft has taken place and how much has been stolen. But it needs huge investment. But there are other ways of checking power theft. A significant part of the revenue loss is due to inadequate billing. This can certainly be rectified by minimum investment.

All that is needed is more determination and sincerity on the part of power engineers. Regular energy audit and surprise raids can mitigate the evil to some extent. Other solutions include periodic replacement of nonworking meters, and sealing of consumer's installation rather than leaving them open for easy tampering.

While all these measures sound good, to combat theft more effectively, long term options should be examined. The best way to combat theft is to privatise distribution. Take the case of Mumbai where there is a private distribution. The losses on account of *T* and *D* and pilferage together are only 10 to 12 per cent, half of the national average. Similiar is the case with Noida Power Company Limited (NPCL) who undertake distribution of power in Greater Noida where the total loss including theft is less than 5 per cent.

33.7 FAULTY EARTH CONNECTION TO THE LV NEUTRAL AS WELL AS TANK BODY

The earthing of LV neutral will prevent the presence of any voltage above the normal appearing in the LV circuit and therefore, the possible danger to human life will be reduced to a minimum. Secondly, earthing the neutral point eliminates the possibility of arcing and therefore the possibility of fire, while it also ensures the rapid disconnection of faulty apparatus from the system without undue delay.

Due to high voltage discharge, the tank may be charged to an abnormal potential, causing danger to the life.

In both the cases, provision of proper earth is extremely essential. Earthing should be done as per the details given in section III. It is advisable to check the earthing at regular intervals.

33.8 PROLONGED SHORT-CIRCUIT BEYOND PERMISSIBLE LIMIT

In case of an external short-circuit on LV side, a fault current, approximately 20 to 25 times the rated current will flow through the windings. The windings are designed to take such fault current for 2 to 3 seconds. The transformer is bound to fail if there is a prolonged short-circuit. beyond permissible limit.

Necessary protections, such as OCB on HV side, ACB on LV side etc. are recommended. In the case of small transformers, HRC fuse of appropriate size should be provided. But under no circumstances, ordinary thick wires are to be used.

33.9 LESS MAINTENANCE

A well maintained transformer always enjoy a longer life. Transformer is a capital intensive equipment and we must provide regular maintenance. However, the frequency of maintenance depends on the type of installation, its kVA rating, connected load and place of installation. Users should prepare their own maintenance schedule along with the frequency of maintenance. A general maintenance schedule for transformers is given below for reference.

Table 33.3

Sl. No.	*Nature of work*	*Time schedule*	*Remark*
1.	Oil level	Once in a month	If needed, fresh filtered oil should be topped up
2.	Oil leakage	-do-	Leakage should be attended to on priority
3.	Breakdown value of transformer oil	Once in six months	If the value is low, the oil should be filtered / reconditioned
4.	Cable terminations and their supports	-do-	If needed, it should be attended to on priority
5.	Oil level indicator and /or gauge	-do-	If needed, it should be attended to on priority
6.	Silicagel	-do-	If needed, it should be replaced or reactivated
7.	Gasket	-do-	If found damaged or leaky, it should be repaired or replaced.
8.	Explosion vent diaphragm	Once in 12 months	If found damaged, it should be replaced
9.	Acidity, resistivity and tan-delta test on transformer oil	Once in 12 months	Ifvalues are beyond limit, the oil should be reconditioned or replaced
10.	Transformer tank body	Once in 12 months	If needed, the tank body should be cleaned and repainted.
11.	Bushings	-do-	Surfaces should be cleaned and the fixing studs should be checked for proper tightening. If bushing is found broken or cracked, the same should be replaced with an identical bushing. Small chipped off portion on the external surface of the bushing may be ignored.
12.	Earthings	-do-	Earthing surfaces should be cleaned and earthing connections should be checked for proper tightening. Moreover, if the neutral of star point of LV winding is earthed, the same should also be attended to.
13.	Buchholz relay	-do-	If gas is found, it should be analysed.
14.	Rollers	Once in 24 months	This is applicable for power transformers which are generally installed on rail gauge. In such cases, the roller bearings and shafts are to be greased for free movement.
15.	Conservator	Once in 36 months	Inside of the conservator should be cleaned to remove sludge and a coat of zinc chromate base paint should be applied.
16.	Core and winding	Once in 60 months	The assembly should be flushed with fresh oil to remove sludge or any other impurities. Loose nuts and bolts, if any, should be tightened.

33.10 FAULTY OPERATION OF OFF-CIRCUIT TAP SWITCH

Approximately 2 to 3 per cent of failure of transformers are due to the failure of tap switch because of its poor quality. Sometimes failure occur due to faulty operation of tap switch with load by an inexperienced operator. Low oil level below tap switch, can cause voltage failure. If the selection of tap position with respect to input voltage does not properly match, the transformer may fail due to over excitation.

Manufacturers should own the responsibility for the failure of the tap switch because of its bad quality and should look for further improvement in their future supplies. Failure due to faulty operation and low oil level should be owned by the field staff.

In case, it is necessary to operate the off-circuit tap switch during service, the transformer should be disconnected from the incoming supply before operation. The operating handle should be moved from position 1 to 5 and back before putting the switch to the desired tap position.

This will eliminate the alignment problem, if any, in the male-female contacts of the tap switch. However after operation, one should not forget to lock the switch in position.

Tap switches are seldom used for voltage adjustment during service, especially in small and medium sized distribution transformers. It is, therefore, for the buyer to decide if the tap switch is required in their future transformers. It will not only eliminate the failure of transformer due to tap switch, but will also reduce the overall cost, of the transformer by 3 to 4 per cent. BEST, Bombay has stopped using tap switch for transformers upto 990 kVA. BSEB, UHBVNL (HSEB) have already withdrawn the requirement of tap switch for their 200 kVA transformers. UPPCL (UPSEB) do not specify tap switch for 160 kVA transformers. Other SEBs may also propose to eliminate tap switch in transformers upto 630 kVA.

Even if the customer want to incorporate tappings on HV side to regulate constant secondary voltage, the constructional details as recommended by the Calcutta Electric Supply Corporation (CESC) may be followed. CESC recommends the use of a tap link board.

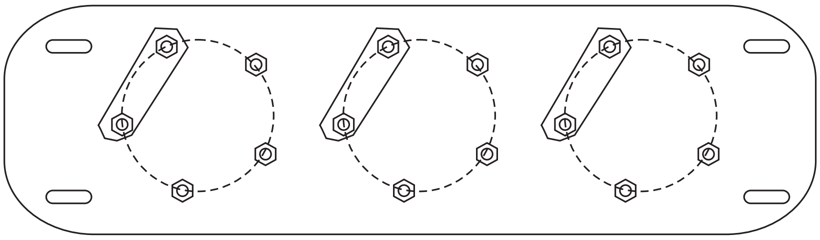


Fig. 33.3. Tap link board

It is a glass fibre board having a minimum thickness of 10 mm, fitted above the yoke with the help of four studs. Tappings of each phase are terminated on the board and two of the tappings of each phase are shorted with an external link. (as shown in Fig. 33.3).

Studies on the use of rotary tap switch and their failures revealed that although these switches are the easiest means of changing tap at site, they are seldom used. On the contrary, loose contact due to sludge deposition on the contacts are very common and at times it leads to failure of transformer. This necessitates regular maintenance at site.

Tap link boards instead of tap changer switches were introduced by CESC in 1970s to avoid failure of tap changer switches, accepting the inconveniences involved during tap changing operation, which of course, are few and far between. With the introduction of tap link boards, the failure rate of transformers due to tap switch at CESC has gone down to less than 0.2 per cent as against 3 per cent of national average.

33.11 POOR QUALITY OF LT CABLE

Poor quality PVC LV cables as well as under-rated cables cause failure of transformers. The PVC insulation melts or get charred due to heat, causing short circuit in the transformer. It sometimes affect the insulation resistance of the transformer also. Users should select the size of the cables appropriately. Effect of bi-metallic action may also be considered while connecting aluminium cables with copper/ brass terminals or vice versa. Cable supports should be provided so that the cable does not create unnecessary load on the bushing terminals.

It has been seen in few occasions that the LV cables are hanging against the terminal bushing without any cable support, pulling the terminal down due to its own weight and effecting leakage of oil from the sealing gaskets of the bushings. Such practices are not healthy and should be avoided.

In the case of transformers with LT cables box, care should be taken while selecting the cable. It is safe to use three and half core cable. As suggested in section III if single core cables are used, the gland plate should preferably be of non magnetic material (either brass or aluminium) for transformers ranging from 500 kVA and above. Otherwise, it will create unnecessary heating due to magnetic flux linkage around the entry of the cable in the box. MS gland plate cut and welded with non magnetic materials may also serve the purpose.

33.12 IMPROPER INSTALLATION

For proper installation, refer section III/Chapter-2. Since the bushings used in distribution transformers are of oil communicating type, the trapped air inside the bushings should be released before commissioning. The trapped air inside the tank cover or in the radiators should also be released through air release plug provided for this purpose. Oil level of the transformer upto the normal marking should be ensured only after the air release operation is done. In case a transformer is installed after a long storage (generally beyond one year), the di-electric breakdown value of oil may be checked with respect to the requirement of IS-1866. Explosion vent diaphragm should be checked for its quality. All these, including the pre-energizing insulation resistances, should be recorded in the history card.

If rollers are provided for pole mounted transformer, the same should be removed before installing the transformer on the H-pole or should be locked in their position after installation.

If possible after installation, the levelling of the transformer may be checked with the help of a spirit level.

33.13 CONCLUSION

With increased competition in the market, it is observed that the safety margins in the distribution transformers are brought down to a bare minimum, just sufficient to satisfy standard specifications and ideal loading conditions. As a result users are constrained to run the plant within the specified capacity throughout the year. It is difficult for an urban electric supply system to maintain an ideal network condition throughout the year due to unpredictable load growth during festival seasons or outage of an adjacent source in the thickly populated areas. In such a situation, two options are open to the utilities.

- Under utilise the transformers which would result in an uneconomical network.
- Introduce safety margins within the specifications.

Considering the economical factors, it is better to review the specifications which may include the following:

(*a*) Reduced oil and winding temperature rise from 50/55°C (as specified in IS-2026) to 30/45°C to take care of poor ventilation in some locations and to permit marginal overloading.

(*b*) Stipulation on the grade and type of core material and the maximum flux density in view of the switching surge due to load shedding and to permit a certain degree of overfluxing.

However, further studies are necessary on the effect of overfluxing and the possibility of specifying the maximum level.

(*c*) Restrictions on the number of HV coil sections per phase and limitation on the winding current density to enhance the cooling and reduction of winding gradient and hot spot temperature.

(*d*) It is observed that despite specifying flux and current densities, the loss figures of the transformers vary widely. Since it is difficult to check the current and flux densities of finished transformers, specifying loss figures including weight of core and copper instead of densities may be considered for implementation in the specifications.

(*e*) Temperature rise test to be carried out (with total loss)-corrected to 100°C.

Section IV

CHAPTER 34

Failure Analysis of Transformers During Short Circuit Test—A Case Study

FOOD FOR THOUGHT

Quality is a company wide activity. The emphasis should be on controlling the process and not the product. Prevention of product defect is the key area. Comprehensive management practices with an accent on quality will provide the desired results. Process control is important, not people control. This will result in fear being replaced by trust, openness and integrity. All problems are viewed as opportunities.

‘Problem prevention and not problem discovery’ is the main thrust of today’s competitive environment. Prevention is the key rather than detection. One cannot do much except to do it all over again. Preventive strategy not only saves money for the organization, but can enhance its image and reputation.

The final product and finally, all process equipment/test instruments must be under preventive maintenance programmes and all measurements must be traceable to an established standard. Most importantly, product traceability and customer feed back system must be established.

An independent audit must be conducted to detect any flaw or deficiencies in the system or on the product. The procedure will reduce problems and prevent major disasters.

34.1 INTRODUCTION

Before taking up the case studies on the failure of transformers during short circuit test, a brief discussion may help in understanding the effect of various short circuit forces on transformer.

When an external short circuit occurs in service, a fault current in the range of 20 to 25 times the rated current (depending upon its impedance) will flow through the windings.

The flow of sudden inrush current in the conductor has the following effects:

- Electro-dynamic forces due to the interaction of currents and the associated magnetic field
- Generation of heat due to resistance offered by the current carrying element.

When short circuit occurs, the energy in the supply system gets released in the form of heavy current resulting in enormous electrodynamic forces and heating effect which tend to damage the connected elements.

34.2 ELECTRO DYNAMIC FORCES

The severity of the electro dynamic forces depend upon the instantaneous value of current. The maximum force is, therefore experienced when the instantaneous value of the current attains the peak value. The peak is maximum when the current wave is fully asymmetrical. A truely asymmetrical wave is obtained when the fault occurs at the instant when the voltage of the system is passing through zero as represented in Fig 34.1.

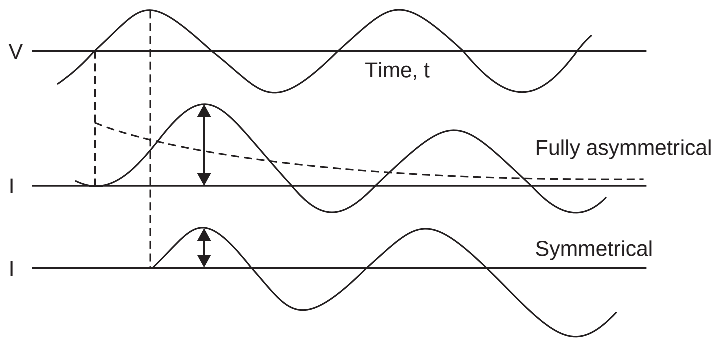


Fig. 34.1. Current waveforms under short circuit condition

The order of asymmetry of the current wave further depends upon the ratio of *X/R*, where' *X'* is the sum of the reactances of the transformer and the system and '*R*' is the sum of the resistances of the transformer and the system. Under short circuit conditions, the fault current is predominantly inductive. The amplitude of the first peak of the asymmetrical test current *(i)* is calculated as $i = IK.\sqrt{2}$.

Unless otherwise specified, the factor $K\sqrt{2}$ is limited to 1.8 $\sqrt{2}$ = 2.55.

The following values of factor $K\sqrt{2}$ is used for different values of *X/R:*

Table 34.1

X/R	1	1.5	2	3	4	5	6	8	10	≥ 14
$K\sqrt{2}$	1.51	1.64	1.76	1.95	2.09	2.19	2.27	2.38	2.46	2.55

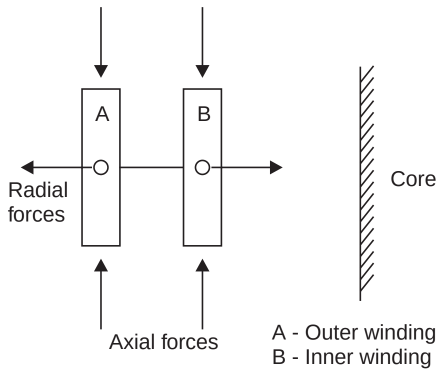


Fig. 34.2. Radial and axial forces

For other values of X/R between 1 to 14, the factor $K\sqrt{2}$ may be determined by linear interpolation. In a transformer, the primary and secondary Ampere-Turns are in magnetic opposition with reference to core, but act cumulatively with respect to the space between the windings. The forces produced comprise of radial and axial forces as shown in Fig. 34.2 (See page 438).

34.3 RADIAL FORCES

Radial forces are due to the flux in the space between the coils. Consequently, the outer coil is subjected to an internal pressure tending to burst it. The inner coil is subjected to an external pressure and tend to crush the core. The effects of leakage flux and radial forces are represented in Figs. 34.3 and 34.4 respectively.

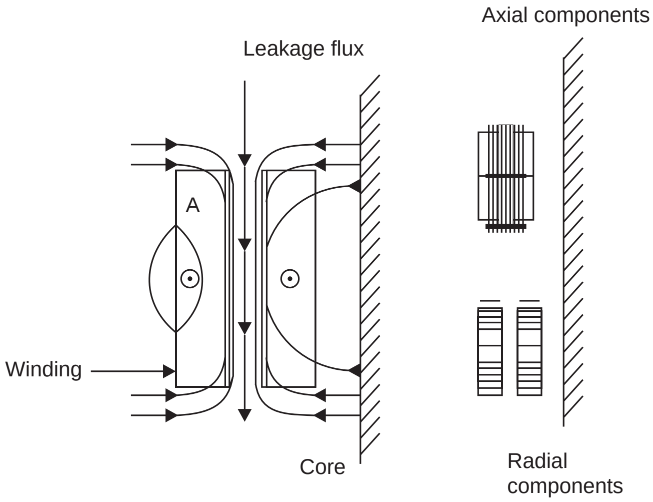


Fig. 34.3. Components of leakage flux

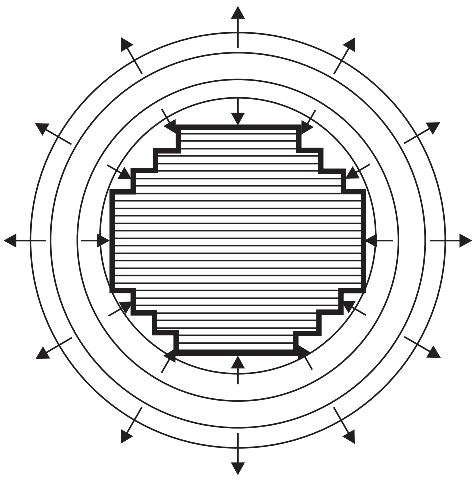


Fig. 34.4. Radial forces on transformer winding

34.4 AXIAL FORCES

The axial forces are due to the radial components of the flux wHich cross the winding mostly at the ends. These give rise to axial compressive forces tending to squeeze the windings together in the middle. If the windings are of the same length and accurately positioned, then each winding is subjected to moderate compression. Accurate position of the windings by mechanical means is, however, almost impossible. Since the windings are carrying currents flowing in the opposite directions and there is large repulsive forces between them, any displacement from the exactly balanced position may lead to large axial component of force tending to separate the windings in the axial direction. Two windings repel each other with a force which is proportional to the displacement. Ampere-Turn asymmetry due to tapping in one winding or due to windings of different length, therefore, results in large axial forces which tend to increase further the asymmetry of the windings. Effect of asymmetrical ampere-turns is shown in Fig. 34.5.

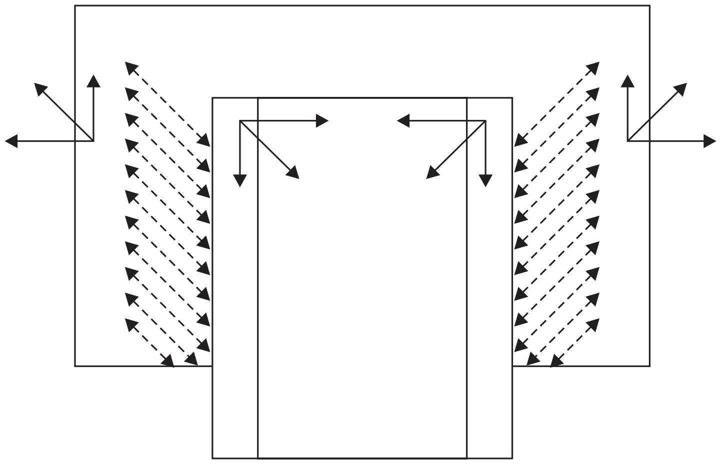


Fig. 34.5. Effect of asymmetrical ampere-turns

Since the forces due to axial displacement tend to increase the displacement, any movement of the winding, due to elasticity of the end insulation and the winding insulation, increases the forces which in turn give rise to further displacement and so on. Both the forces and displacement increases indefinitely at a critical value of Ampere-Turns. No matter how small the initial displacement, the increase in forces due to any movement is greater than increase in resistance to movement and failure occurs.

34.5 RESONANCE

The windings of a transformer together with the supporting clamps constitute a mechanical system having mass and elasticity, which must be taken into account in studying the displacements and stresses produced by short circuit forces.

In the case of radial forces which produce a hoop stress in the outer winding, the elasticity of copper is high and the mass is small, so that the natural frequency is large in comparison with 50 Hz or 100 Hz. Thus there is little chance of displacements being increased by resonance effects. The short circuit forces may be considered as applied slowly and producing a stress corresponding to the peak of the first loop of fault current.

However, forces in the axial direction act upon paper and pressboard which is easily compressible. It is seen that the natural frequency may be close to the component frequencies of the short circuit forces which are equal to power frequency and twice power frequency. Thus in calculating stresses, it is necessary to take into account the response of the windings, as a mechanical system, to the periodic forces applied to them, and it is one of the problems of the designer to avoid amplification of stresses by resonance effect.

34.6 HEATING EFFECT

A limiting temperature of 250°C for copper and 200°C for aluminium is normally specified to limit the ageing of insulation in contact with the conductor.

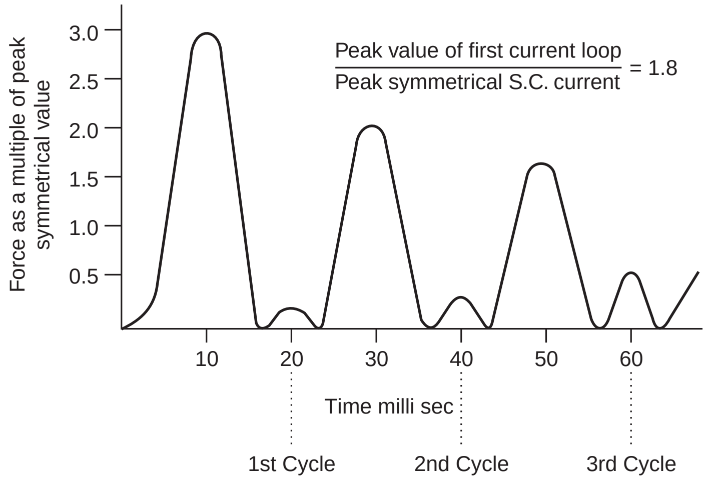


Fig. 34.6. Variation of S.C. forces with time for a fully asymmetric current

For the forces developed during the maximum asymmetrical current loop, the conductor will be considerably weaker at the specified temperature. The maximum force is, however, practically reduced to one third within a few cycles before the conductor attains the maximum limiting temperature as represented in Fig. 34.6.

34.7 SHORT CIRCUIT TESTING OF TRANSFORMER

Central Power Research Institute, commonly known as CPRI, a Govt. testing laboratory, has been extending the facilities for short circuit testing of distribution and power transformers for more than 30 years. The facilities provided have been beneficially used both by the manufacturers and the utilities for the development of reliable transformers before they are put to use in the distribution network.

As per National and International standards, the ability to withstand damaging effects of short circuit is verified with regards to the:

- Dynamic ability to withstand the external short circuit
- Thermal ability to withstand the external short circuit.

The dynamic ability is verified by conducting actual tests subjecting each of the phase windings to the maximum asymmetric peak current. The thermal ability is demonstrated by calculations assuming the flow of current for 2 seconds duration. What can be demonstrated by calculations should hold good in actual testing. However, the thermal ability of some small units are also verified by actual tests at the instance of certain Electricity Boards.

Performance Evaluation

The performance of the unit under test is evaluated on the basis of the variation in electrical characteristics and also assessment of the mechanical damages caused to the windings and other components.

As per the standards, a variation in the reactance value more than the permissible limit by 2 per cent is considered as an indication of failure. Table 34.2 represents a typical list of transformers tested by CPRI and the order of variation recorded in the reactance values as well as the kind of mechanical damages observed.

Table 34.2 Typical failure test results of short circuit testing of transformers at CPRI

kVA/kV	*Type of test*	*Variation in X*			*Physical condition during/after test*	*Remark*
		Before test	*After test*	*Variation*		
16 kVA, 11/0.433 kV	Dynamic ability	3.49%	Not measured	Not measured	Explosive noise, flushing out of oil through tank cover gasket	Declared failed, test discontinued.
25 kVA, 11/0.433 kV	-do-	4.12%	4.23%	2.67	No physical damage noticed	Variation in *X* more than specified. in the standard and declared failed.
25 kVA, 11/0.433 kV	-do-	4.33%	Not measured	Not measured	Wide difference in HV winding resistance, HV open circuited	Declared failed, test discontiuned.
63 kVA/11/0.433 kV	-do-	4.46%	-do-	-do-	Huge emission of fumes, HV winding burst out	Declared failed, test discontiuned.
63 kVA/11/0.433 kV	-do-	4.21%	4.33%	2.85%	Inter turn failure in W phase	Variation in *X* more than specified in the standard and declared failed
63 kVA, 11/0.433 kV	Dynamic ability	4.55%	4.6%	1.1%	End spacers at the top of HV coils of phase V and W displaced	Though the reactance variation was within limits, the transformer was declared failed due to physical deformation.
100 kVA, 11/0.433 kV	-do-	4.29%	4.28%	0.233%	The transformer failed to withstand HV power frequency test conducted after short circuit test. It was noticed that there was no proper anchor of HV line leads. The U phase lead was very close to the tank side wall causing spark during HV test	Though the transformer satisfied all the requirements of S.C. test it failed in HV test and hence declared failed.
-do-	Thermal ability	4.3%	Not measured	–	Groaning noise, axial displacement of HV windings, windings open circuited, oil carbonised	Test discontinued declared failed.

(Condt.)

kVA/kV	Variation in X				Physical condition during/after test	Remark
	Type of test	Before test	After test	Variation		
200 kVA, 11/0.433 kV	Dynamic ability	4.12%	4.26%	3.4%	HV coil twisted and tapping coils of phase W bulged out	Declared failed
200 kVA, 11/0.433 kV	-do-	4.09%	3.98%	2.7%	Insulation failure between LV and core, all HV coils in V phase dislodged. Many spacers found loose	-do-
250 kVA, 11/0.433 kV	Thermal ability	4.72%	Not measured	–	Huge emission of flames and fumes. Transformer tank damaged	-do-
300 kVA, 11/0.433 kV	Dynamic ability	4.48%	5.94%	32.6%	LV windings moved up and touched the core channel. I.R between LV to Earth found zero.	Declared failed
1000 kVA, 11/0.433 kV	-do-	4.98%	Not measured	–	Heavy flushing out of oil, tank body deformed	-do-
1600 kVA, 33/11 kV	Dynamic ability	5.87%	6.21%	5.8%	No visible damage	Variation in X more than specified in the standard and hence declared failed.
1600 kVA, 33/11 kV	-do-	6.58%	Not measured	–	Exploded and caught fire.	Declared failed

34.8 NATURE OF FAILURE AND REMEDIAL MEASURES

A review was conducted on the test results which indicate the following types of failures:

- LV winding shorted to ground, winding crushed to core or core clamping structures
- HV windings open circuited, failure in the joints, especially for aluminium winding
- Radial displacement /deformation of HV windings (failure under radial forces)
- Axial displacement of the windings (squeezing of windings due to axial forces)
- Turn-to-turn short at the transposition zone of LV coil, causing abnormal no-load current
- Asymmetric displacement of coils, higher variation of reactance value
- Insulation failure, failure during power frequency and induced over voltage tests
- Dislocation of end supports and spacer blocks between section of HV coils (impact due to electro-dynamic forces)
- Tank body cracked/damaged
- Explosion and catching fire.

Remedial Measures

Consequent to the short circuit testing and analysis of the test results, most of the manufacturers have developed reliable units adopting improved design manufacturing processes. To indicate a few:

- Thorough analysis of the magnetic field and electro magnetic forces using computer
- Correct choice of conductor hardness according to the forces to be withstood
- Correct choice of wedge materials
- Judicious compression applied in the windings after heat treatment
- Proper terminations
- Adoption of efficient axial clamping
- Proper Ampere-turn balancing
- Sound joints with proper lead supports.

Mechanical robustness while assembling the units and the joints and terminations, especially, in the case of aluminium-wound transformers, are the key areas to be looked into for the improvement of performance in short circuit test.

It is needless to point out that the quality control in respect of raw materials, components and workmanship should be of high standard, otherwise, the best possible design may also fail under short circuit condition.

Ensuring the reliability of any electrical supply system apparatus under short circuit conditions is not possible by mere desk work. Every design will have to be tested in a well equipped laboratory to understand the unpredictable phenomenon associated with the short circuit effects. It is also important that there should be regular monitoring of the failure data in the system. Without such valuable data obtained from the field as well as from regular testing at well equipped laboratories, the manufacturers may not be able to produce reliable units. CPRI/ERDA are taking all possible efforts to provide the required testing facilities for the benefit of the indigenous manufacturers and the utilities.

34.9 CASE STUDY OF FAILURE OF TRANSFORMERS UNDER SHORT CIRCUIT TEST

Various types of failures occur during external short circuit causing deformation of coils, displacement of insulating blocks and spacers resulting in reactance variation, interturn short circuit, snapping of delta and tapping leads etc. Few case studies given below will give a fair idea to the manufacturers to take necessary precautions against failure due to short circuit.

(a) Deformation of HV Coils of a 630 kVA, 11/0.433 kV Transformer

Among all medium rated transformers, 630 kVA transformer looks to be very critical in getting it cleared in the short circuit test. In one of the short circuit dynamic withstand tests, the transformer failed in the 3rd shot at extreme positive tappings. During physical verification, it was noticed that the tapping coils in U phase had burst out. This could be an ideal example of failure of transformer due to radial electromagnetic forces *i.e.*, hoop stress. This happened due to poor workmanship.

This failure could have been avertad by making tight windings with locking of end turns at each layer.

(b) Displacement of Insulating Blocks and Spacers of a 3.15 MVA, 33/11 kV Power Transformer

The transformer had failed in the 7th shot on extreme negative tappings. The reactance measured after 7th shot was abnormally high and was well beyond the permissible limit. On examining, it was noticed that some of the top yoke laminations had come out approximately by 5 mm from their original settings, resulting in the displacement of the insulating blocks and spacers of W phase. This could be a ideal example of failure due to axial forces.

The failure could be because of the unbalancing of Ampere-turns at the extreme negative taps. Since a portion of the winding had been cut out from the total windings, the Ampere-Turns of the primary and secondary windings were mismatched, causing excessive axial forces, resulting in the displacement of the insulating blocks at the tap zone. The tappings were provided at the centre of the HV leg.

The failure may be due to the defect in design. The design was made without proper attention to the Ampere-Turns balancing along with thinning of inner windings. It is understood that absolute balancing of Ampere-Turn at all tap positions *i.e.*, extreme positive, normal and extreme negative, are very difficult to achieve. But trial should be made to reduce the gap of unbalancing within 3 per cent. Accordingly, thinning of the inner windings are also to be done for proper matching.

(c) Interturn Short Circuit Resulting High No-Load Current

An example of a typical failure due to radial electromagnetic forces acting inward and collapsing the inner coil is given below:

A 1000 kVA, 11/0.433 kV transformer was declared failed in short circuit test at the second shot due to excessive no-load current. The test had to be discontinued. On opening, no significant deformation was noticed anywhere in the assembly.

The blocks and spacers were intact without any displacement. The transformer was taken back to the manufacturer's works for further investigation. After detailed analysis, it was noticed that the failure was due to interturn short circuit in one of the low voltage windings at the transposition zone. This was an ideal example of failure of LV coil due to inward electromagnetic forces.

Such types of failures are very common for medium sized distribution transformers. This may not be a case of design defect, but may be termed as poor workmanship. Since radial forces act inward on the inner winding, no loose space should be allowed in between core and LV coil. The coils should be placed reasonably tight around the core using cylinders and ducts. Moreover, proper transposition with adequate insulation at the bend must be ensured to overcome such failures.

(d) Failure Due to Tapping Switch

In the testing of a 200 kVA, 11/0.433 kV transformer, during trial shots, the current recording oscillogram for U Phase was erratic. The test had to be discontinued. On opening it was noticed that the gunmetal spring loaded ring of U Phase was out of gear and was hanging loose on the operating shaft.

This was a case of pure negligence of the vendor. The quality of the tapping switch should always be ensured. It is advisable to operate the switch five runs from one end to the other and back and measure the DC resistances of the HV windings at all tappings with resistance bridge having spot deflection galvanometer to record any deviation from the reference values. In the case of a switch having weak contacts, the value of resistances are bound to differ.

(e) Snapping of Delta Leads

In the case of a 25 kVA, 11/0.433 kV aluminium-wound distribution transformer one of the joints of delta lead was found broken after 5th shot.

This was a clear evidence of poor workmanship. Proper supports at a number of places should be provided for delta and tapping leads. Long length of leads without proper supports may lead to failures.

34.10 SUMMARIES

From the review of the above case studies, the following points emerge, which may help in preventing failure of transformers during external short circuit.

(*a*) All coils must be solid, both radially and axially. The radial build can be made solid by taking proper care during manufacture. Required tension in the winding machine should be maintained while processing the coils. End turns at each layer should be properly locked. Axial build, should be taken care of during compression under heating process.

(*b*) Transposition is another cause for failure of transformers during short circuit. Each strip should be adequately insulated after bending. If necessary, a thick insulating paper may be provided at the junction where the actual transposition has taken place. Proper rounding-off the corners of rectangular strips also reduces the chance of short circuit failure.

(*c*) All blocks, spacers, rings etc. should be made out of precompressed boards only. Cooling ducts and cylinders are also to be made from precompressed boards. Dovetailed type spacers instead of plain spaces should be used.

(*d*) The design should be made in such a way that the out of balance Ampere-Turns is not more than 3 per cent even at the extreme negative tap at any point over the full length of the coil. Proper thinning on the inner coil should be made accordingly.

(*e*) Coil assembly should be made reasonably tight with proper supports for tappings and delta leads.

(*f*) In the case of medium sized power transformers, the tappings may be taken out at two locations instead of from one place at the centre.

(*g*) Thick permawood or insulated pressure ring may be used for uniform coil pressing.

(*h*) Use of torque wrench with predetermined torque is very essential, especially, while tightening the nuts and bolts in the coil assembly.

(*i*) The top yoke stack may be supported vertically down by insulated straps, at least at two places to reduce the possibility of slipping out of the yoke laminations during axial forces.

(*j*) Provision of 8 tie rods for medium sized distribution transformers and power transformers may be made for uniform compression of coils on the outer limbs. In case adjustable compression screws for coil pressing are used, the tie rods may be avoided.

(*k*) All nuts after being fully tightened, should be locked by another nut and finally punched at three places by a centre punch.

The success of getting a transformer passed in the short circuit test depends 90 per cent on the quality of the transformer and the rest 10 per cent on various other factors.

The following photographs indicate the various types of failures due to external short circuit.

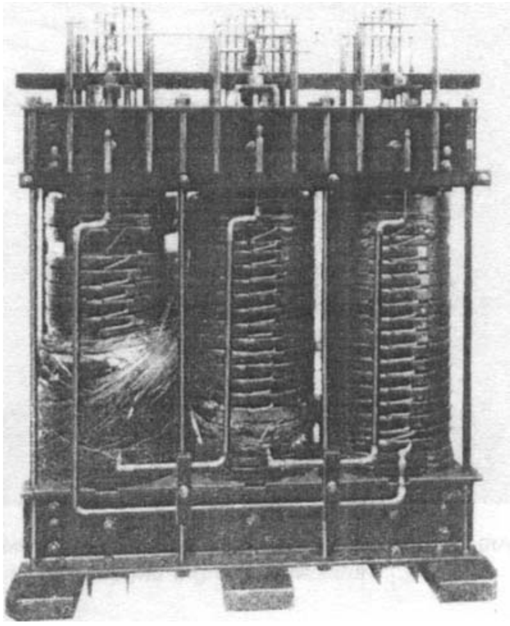


Fig. 34.7. Photograph showing the effect of an external short circuit on a 3-phase 500 kVa transformer

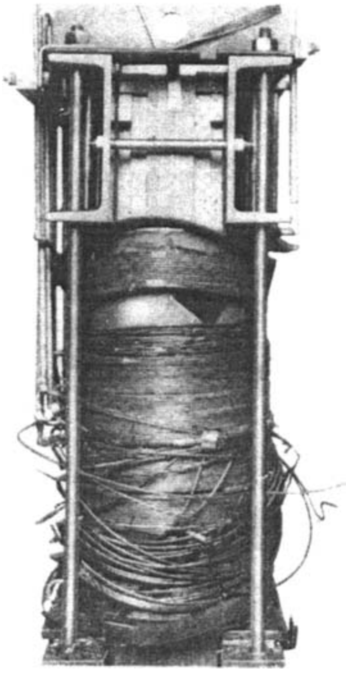


Fig. 34.8. Photograph showing the effect of an external short circuit on a teaser unit of 400 kVA, 3/2 phase, scot-connected transformer

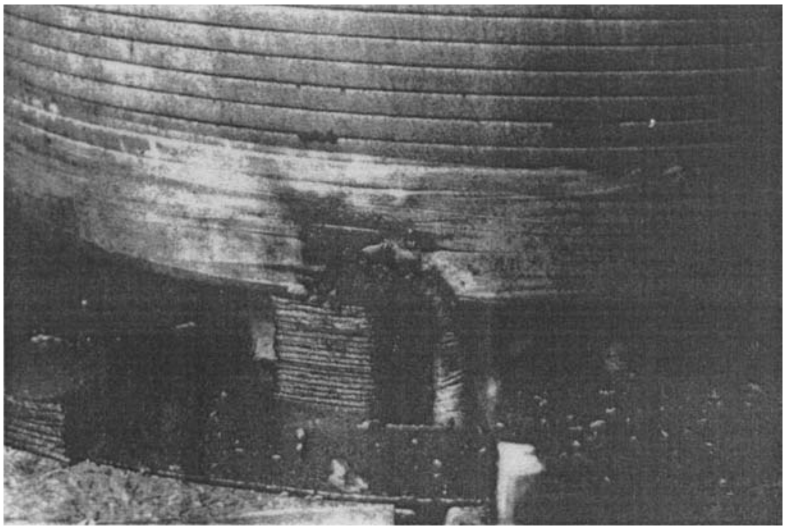


Fig. 34.9. Photograph showing the damage at bottom of LV winding due to a puncture in HV to LV major insulation caused by the ingress of moisture

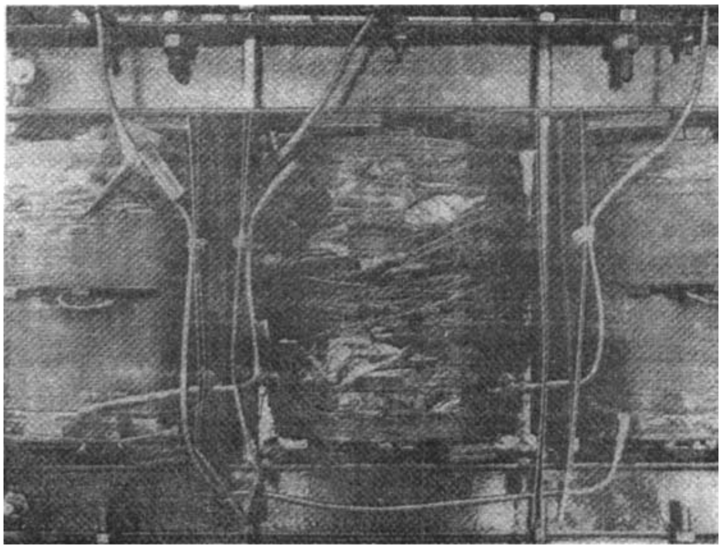


Fig. 34.10. Photograph showing the failure of outer winding under radial forces

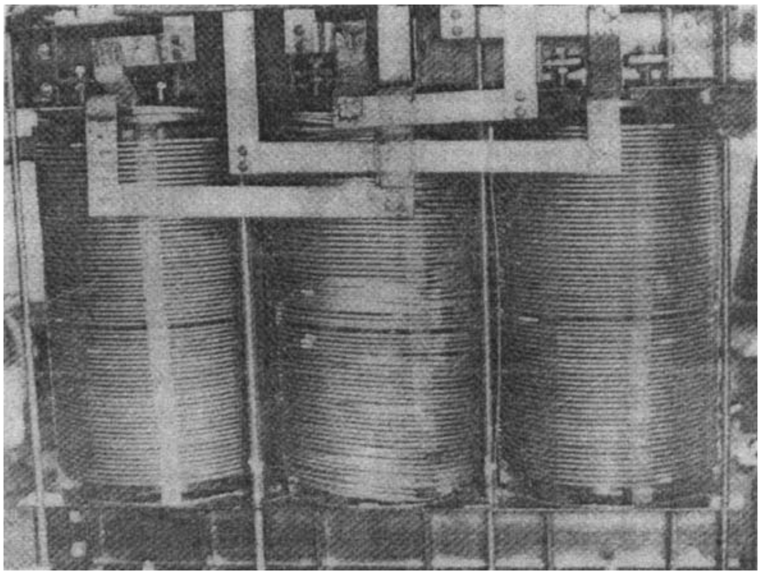


Fig. 34.11. Photograph showing axial displacement of winding (middle limb)

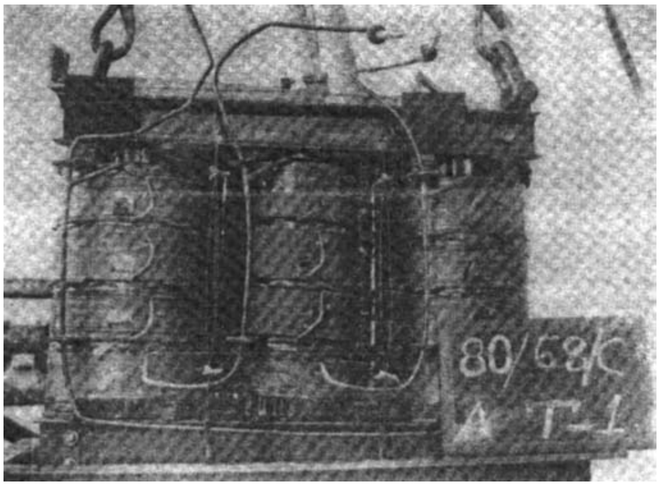


Fig. 34.12. Photograph showing asymmetric displacement of coils (middle limb)

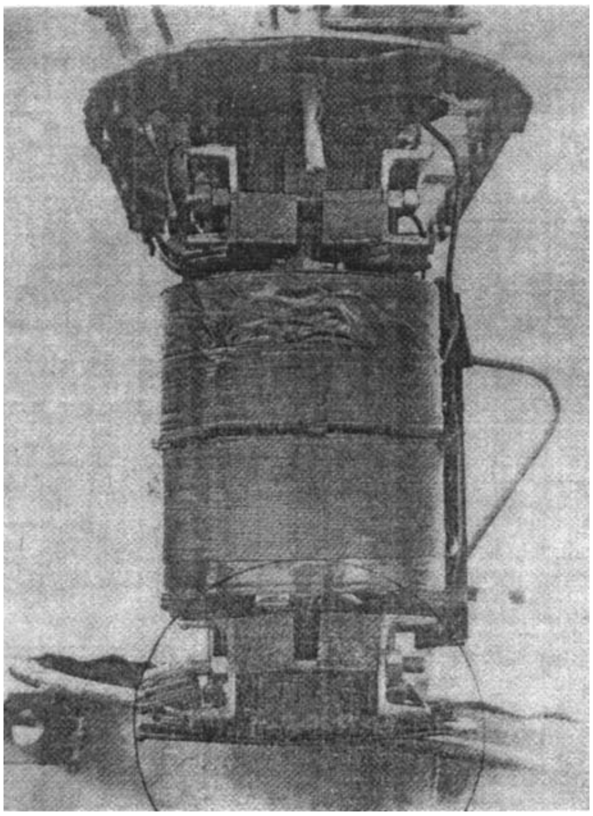


Fig. 34.13. Photograph showing failure of end support

Section IV
CHAPTER 35

Loading Guide for Oil-Immersed Transformer

FOOD FOR THOUGHT

Across the world, managers face constant challenges and hence, some of them shows signs of business burnout. Many suffer from 'Priority Problems'. Put simply, they make the error of attending to the urgent rather than important tasks. Some of these people function for exceptionally long hours, with no time for them or their family members or other people in their lives. Their working methods are disorganised, affecting their communication skills. This results in difficulty, in communicating effectively with their team members. This situation can have an enormous impact on their own moral and productivity as well that of their teams. This is the result of not paying enough attention to the priority problems. All one has to do to improve one's life is to emulate what successful manager do.

1. Highly successful executives are splendid and distinguished role models. They put into practice what they insist on.
2. Highly successful managers invest time and money in their team and themselves. They develop their people and themselves through education and coaching.
3. Highly triumphant managers are methodical. They know how to control their time. They have arrangements in place which enable them and their team to work on crucial issues.
4. Highly successful managers take care of their health, so that they are fit and healthy. They recognise that only a healthy mind and body can improve efficiency and general happiness.
5. Highly succesfful managers make time for their personal lives. It is a priority because they appreciate that it makes them happier and more successful.

Everybody can put these tried and tested secrets into action. We should learn to get our priorities right about people, work and home to enjoy a longer and better life.

AT A GLANCE

Distribution transformers are generally not recommended for overloading. However during festive seasons or outage of an adjacent transformer, distribution transformers are oftenly being overloaded for hours together and are caused for prematured failure.

The chapter provides us a guide to determine how oil-immersed transformer can be operated for different ambients and overload duties without exceeding the acceptable limit of deterioration of insulation through thermal effects.

The chapter concludes with five examples to determine the rating and the overload capacity of a transformer in service having a mixed variety of load and operating in a weighted average ambient temperature either less or more than 32°C. Few graphs and tables have been shown to determine the values of various constants at varying ambient from 0 °C to 90 °C.

For very large transformers, for example 100 MVA and above, the advice of the manufacturer should be followed.

35.1 INTRODUCTION

The loading guide for oil-immersed transformers has been elaborately discussed in ISS-6600. This is a very handy and useful documents for the power utility engineers for over-loading a transformer during peak hours of service.

This Indian Standard was adopted by the Indian Standards Institution on 28 March, 1972, after the draft finalized by the Transformer Sectional Committee has been approved by the Electrotechnical Division Council.

This guide covers general recommendation for loading of oil-immersed transformers conforming to IS-2026.

While it is not possible to present accurate data for all conditions of use and variations of transformer design, it is the purpose of this guide to enable the user when planning or operating, to determine the range of permissible loads under given conditions.

Modern transformers are generally designed to permit loading in line with this guide, but if there is any question as to the capability of the transformer, either old or new, to carry the desired load, the manufacturer should be consulted.

The tables given in this guide have been drawn up in a manner as to be useful to the system planner as well as the operator. Whereas a system planner may be looking for an optimum size of transformer for a given load condition, the load controller or operator may like to know what overloads can be allowed on any day on existing transformers.

35.2 SCOPE OF THE GUIDE

The guide is applicable to oil-immersed transformers of types ‘ON’ and ‘ON/OB’ complying with IS-2026.

IS-2026 does not take into consideration either temperature different from normal or variations in the load, which only exceptionally correspond to uninterrupted continuous operation at rated kVA.

This guide indicates how oil-immersed transformers may be operated for different ambients and duties without exceeding the acceptable limit of deterioration of insulation through thermal effects.

For very large transformers, for example 100 MVA and above, the advice of the manufacturer should be followed.

35.3 TERMINOLOGY OF THE GUIDE

For the purpose of this guide, the following definations in addition to those given in IS : 2026 shall apply.

Hot-Spot Temperature

The maximum temperature that any part of the winding reaches under given load conditions and ambient.

Weighted Ambient Temperature

The temperature which, if maintained continuously during the period of time under consideration, would result in the same ageing of insulation as that occurring under the actual ambient temperature.

35.4 APPLICATION OF THE GUIDE

This guide gives the permissible loading, under certain defined conditions, in terms of the rated kVA of the transformer, for the guidance of users and to help planners in choosing the rated kVA required for new installations. The rated kVA defined in IS-2026 is a conventional referrence basis for uninterrupted continuous operation (with defined limits of cooling medium temperature) with normal expectation of life.

Basically, the cooling medium temperature is 32°C, but deviations from this are provided for, in such a way that the increased use of life when operating with a cooling medium temperature above 32°C as in summar, is balanced by the reduced use of life when it is below 32°C in winter.

Experience indicates that normal life is some tens of years. It cannot be stated more precisely, because it may vary even between units, owing in particular to operating factors which may differ from one transformer to another.

In practice, uninterrupted continuous operation at full rated kVA is unusual, and this guide gives recommendation for cyclic daily loads, taking into account seasonal variations of ambient temperature. The daily use of life due thermal effects is indicated by comparison with the normal use of life corresponding to operation at rated kVA in an ambient of 32°C.

Table 35.1 to 35.6 shows the permissible load, for a normal daily use of life, in the two following sets of conditions :

(*a*) Continuous duty, with different cooling medium temperature ; and

(*b*) Cycle duty, with different cooling medium temperature.

35.5 LIMITATION OF THE GUIDE

In preparing this guide, the following limitations on the operation of transformer have been assumed :

(*a*) For normal cycle duty, the current does not exceed 1.5 times the rated value.

If currents up to this limit and for the durations permitted by this guide are to be carried out safely, it is necessary for the terminal outlets, the tap-change device and similar attachments also to be suitable for the duty. Because IS-2026 does not define the loading possibility of these fittings, their suitability should be determined by reference to the manufacturer and, if they found not suitable, lower limits of loading and duration will need to be accepted. The users shall ascertain the thermal capability of associated equipment, for example, cables, circuit-breakers and current transformers.

(*b*) That is no case a hot-spot temperature in the windings of 140°C is exceeded.

It has been mentioned by various authors that above 140°C, the Arrhenius law is not completely in accordance with the phenomena, owing to accelerated deterioration effects, either because the formation of deterioration products is too fast for them to be taken away by the oil, or because a gaseous phase is started sufficiently rapidly to lead to over-saturation and the formation of bubbles which may endanger the electric strength.

Attention is drawn to the fact that a transformer that has been operating at loads greater than the rated kVA may not comply with the thermal requirements on short-circuit specified in IS-2026.

35.6 VARIOUS SYMBOLS USED IN THE GUIDE

Only the following four symbols are used in the tables 35.1 to 35.6:

k_1 = Initial load as a fraction of rated kVA

k_2 = Permissible load as a fraction of rated kVA (may be greater than unity)

h = Duration of k_2 in hours

Q_a = Temperature of cooling medium (weighted average).

Note: $k_1 = s_1/s_r$ and $k_2 = s_2/s_r$

where s is any value of power, and s_r is rated kVA.

35.7 BASIS OF LOADING GUIDE

The basis for establishing the table in this guide is as follows :

(*a*) Thermal Deterioration of Insulation

In a temperature zone exceeding upto 140°C, the rate at which transformer insulation deteriorates increases exponentially with temperature ; it doubles for every temperature increase 6°C.

(*b*) Normal Rate of Insulation Deterioration

At a winding hot-spot temperature of 98°C, insulation deterioration is occurring at a normal rate; the rate of deterioration at other temperature is compared with this normal rate.

The temperature of 98°C corresponds to operation in an ambient temperature of 32°C at the rated kVA of a transformer having a temperature-rise at the winding hot spot of 66°C. The normal rate of insulation deterioration is obtained in practice, in particular, when a transformer installed in a place where the annual effective ambient temperature (weighted average) is 32°C, operates continuously at rated kVA.

Periods of accelerated ageing when the ambient temperature is greater than 32°C (and the winding hot-spot temperature greater than 98°C) are then compensate for by periods of slow ageing when the ambient temperature is below 32°C (and the winding hot-spot temperature less than 98°C.

(*c*) Winding Hot-spot Temperature

Winding hot-spot temperatures above 140°C are prohibited.

(*d*) Typical Load Diagram

The basis of the tables in this guide is the simplified load diagram for cyclic daily duty shown in Fig. 35.1, where 'k_1' is the initial load, followed by k_2 for a period of 'h' hours and returning to 'k_1' for the remainder of the 24 hours.

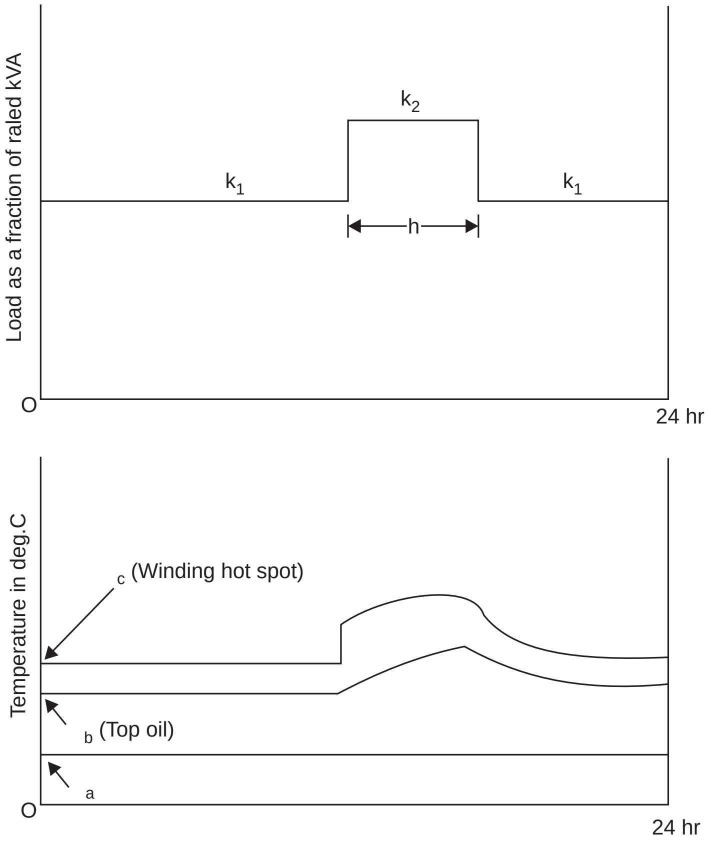


Fig. 35.1. Simplified load diagram for cycle daily duty

The tables give permissible cyclic duty with a normal life consumption of 24 hours per day, equal to that consumed during 24 hours at 98°C.

If there are two or more periods of high load separated by periods of low load, the high loading time '*h*' as represented in the diagram is the summation of the high loading times. This condition is less onerous than a single high load for the total time '*h*'.

To use the guide, the actual fluctuating load cycle shall be converted to thermally equivalent simple rectangular load cycle such as is represented in Fig. 35.1. A transformer supplying a fluctuating load generates a fluctuating loss, the effect of which is about the same as that of an intermediate load held constant for the same period of time. This is due to heat storage characteristics of the materials in the transformer. A load which generates losses at the same rate as the average rate caused by fluctuating load, is an equivatent load from a temperature point of view.

Equivalent load for any portion of a daily-load cycle may be expressed by equation :

$$\text{Equivalent load or r.m.s. value} = \sqrt{\frac{s_1{}^2t_1 + s_2{}^2t_2 + s_3{}^2t_3 + \ldots\ldots\ldots\ldots + s_n{}^2t_n}{t_1 + t_2 + t_3 .+ \ldots\ldots\ldots + t_n}} \ldots\ldots \qquad \ldots(1)$$

where s_1, s_2, s_3, etc. are various load steps in actual kVA ; and t_1, t_2 t_3, etc. are the respective duration of these loads.

Equivalent initial load is the r.m.s. load obtained by Equation 1 over a choosen period preceding the peak load.

Experience with this method of load analysis indicates that quite satisfactory results are obtained by considering the 12 hours period preceding the peak in determination of the equivalent initial load. Time intervals (t) of 1 hour are suggested as further simplification of the equation which, for a 12 hours period, becomes :

$$\text{Equivalent initial load} = 0.29\sqrt{s_1^2 + s_2^2 + \ldots\ldots + s_{12}^2} \qquad ...(2)$$

where $s_1, s_2, \ldots\ldots, s_{12}$ is the average load by inspection for each 1-hour interval of the 12-hours period preceding peak load.

Equivalent peak load for the usual load cycle is the r.m.s. load obtained by Equation 1 for the limited period over which the major part of the actual irregular peak seems to exist. The estimated duration of the peak has considerable influence over the r.m.s. peak value. If the duration is overestimated, the r.m.s. peak value may be considerably below the maximum peak demand. To guard against overheating due to high, brief overloads during the peak period, the r.m.s. value for the peak load period should not be less than 90 per cent of the integrated half-hour maximum demand.

(*e*) Parameters of the Table

(*i*) Type of cooling	: ON and ON/OB
(*ii*) Oil-air thermal time constant	: 3 hours for ON and ON/OB
(*iii*) Temperature of cooling medium	: 6 cases (0°C, 10°C, 20°C, 30°C, 32°C and 40°C)
(*iv*) Initial load (k_1)	: 6 values (0.25, 0.5, 0.7, 0.8, 0.9, 1.0)
(*v*) Duration of load (k_2)	: 8 values (0.5, 1, 2, 4, 6, 8, 12, and 24 hours)

Sufficient accuracy is obtained by having a single set of tables for ON and ON/OB type cooling, the deviation in the value of k_2 being only of the order of 1 to 2 per cent.

The effect of oil-air thermal time constant is negligible for long-time loads. Even for short-time loads the effect is only 2 per cent between 2.5 and 3.5 hours.

(*f*) Determination of the Rated kVA (s_r) of a Transformer for a Given Service

The curves given with each table can be used for determining the rated kVA of a transformer (with normal life duration) for a load defined according to Fig. 35.1 for $s_1 = k_1\, s_r$ of duration (24-*h*) and $s_2 = k_2\, s_r$ of duration '*h*'. It is only necessary to find the intersection of the curve with the line of constant slope.

Therefore, $k_2/k_1 = s_2/s_1$ which defines k_1 and k_2 whence s_r.

In order to find this line, corresponding points should be marked on ordinate k_1 : 1 and abscissa k_2 : 1 and these points should be connected.

35.8 SELECTION OF APPROPRIATE TABLE AND EXAMPLE OF CALCULATION

(*i*) Select the table for the value of Q_a. If the value of Q_a lies between two tables, either select the nearer one above or interpolate between nearest table.

(*ii*) For transformers rated for both ON and ON/OB cooling, use tables in terms of rated kVA for ON cooling if the fans are not brought into operation and in terms of the rated kVA for ON/OB if fans are brought into operation.

These tables can also be used for ON cooling if the oil pumps are not brought into operation.

The fans and oil pumps are normally put into service by a temperature sensitive device (thermal immage corresponding to winding hot-spot temperature or thermometer corresponding to top-oil temperature). It is recommended that pumps and fans (where their use is not restricted by other considerations, such as noise) are put into service before the hight loading occurs, in order to have the hot-spot temperature of the winding low enough to slow down the ageing process. The power taken by these auxiliaries is at least partially compensated by the decrease in load loss resulting from a lower temperature.

Loading the transformer on the basis of the annual weighted average ambient temperature permits the transformer to be loaded to the same extent allowing for variations of 'k_1' and 'k_2' (refer Table 35.1 to 35.6) in such a way that the increased use of life when operating with cooling medium temperatures above Q_a (as in summer) is balanced by the reduced use of life when it is below Q_a (as in winter).

If the load cycle demands higher loading during winter than in summer, this can be achieved by finding the daily or monthly permissible loading cycles from tables corresponding to daily or monthly values of Q_a respectively.

In such a case, it is essential that the loading cycle for each day or month has to be ascertained from the tables corresponding to Q_a for the day or month in question and followed for the entire years.

Example 1

To determine rating of a transformer from a known load cycle at a location where the weighted average annual ambient temperature of cooling medium is 32°C.

An 'ON' transformer is required to carry a load of 1400 kVA for six hours and 800 kVA for remaining 18 hours each day.

$$Q_a = 32°\text{C}, \quad s_2/s_1 = 1400/800 = 1.75$$

Therefore, $$\frac{k_2}{k_1} = \frac{s_2/s_r}{s_1/s_r} = \frac{s_2}{s_1} = 1.75$$

Line of slope $k_2/k_1 = 1.75$ is shown dotted on curves for Table 35.5 for $Q_a = 32°\text{C}$, at the intersection of this line with $h = 6$ curve, the value of k_2 is 1.14 and that of k_1 is 0.65.

Therefore $\quad s_r = s_2/1.14 = 1400/1.14 = 1228$ kVA.

Example 2

To determine rating of a transformer for a known load cycle at a location where the average annual ambient temperature of cooling medium is lower than 32°C.

An 'ON' transformer is required to carry a load of 1400 kVA continuously for 24 hours each day at a location where the weighted average annual ambient temperature is 20°C.

$$Q_a = 20°\text{C}, \quad h = 24 \text{ hours}, \quad s_2 = 1400 \text{ kVA}$$

Therefore, from Table 35.3, $\quad k_2 = 1.11$

Therefore, $\quad s_r = s_2/k_2 = 1400/1.11 = 1261$ kVA.

Example 3

To determine the rating of a transformer from a known load cycle at a location where the weighted average annual ambient temperature of cooling medium is higher than 32°C.

An 'ON' transformer is required to carry a load of 1400 kVA continuously for 24 hours each day at a location where the weighted average annual ambient temperature is 40°C.

$$Q_a = 40°\text{C}, \quad h = 24 \text{ hours}, \quad s_2 = 1400 \text{ kVA}$$

Therefore, from Table 35.6, $k_2 = 0.92$

Therefore, $s_r = 1400/0.92 = 1521$ kVA.

The above examples illustrate as to how the rating of an 'ON' transformer having a temperature rise of 45 to 55°C at rated load is selected when the ambient temperature is different from the standard temperature of 32°C.

This method of selecting the rating of a transformer having the temperature-rise of 45 to 55°C at rated load is preferable to selecting a transformer rating with different temperature-rise varying with ambient temperature. The loading of such transformer cannot be determined from this guide.

Example 4

To calculate overload capacity of an existing transformer at a location where the weighted average annual ambient temperature of cooling medium is 32°C.

A 1000 kVA 'ON' transformer has a load of 500 kVA throughout the day except for a period of 2 hours. What is the permissible overload for a duration of 2 hours ?

$$\theta_a = 32°\text{C}, \quad k_1 = 500/1000 = 0.5, \quad h = 2 \text{ hours}$$

From Table 35.5 for $\theta_a = 32$°C gives $k_2 = 1.43$.

Therefore, the permissible overload for 2 hours is 1.43 × 1000 = 1430 kVA.

Example 5

To calculate the overload capacity of an existing transformer at a location where the weighted average annual ambient temperature of cooling medium is 32°C.

A 1000 kVA 'ON' transformer has a mixed variety of load of 500 kVA for 3 hours, 600 kVA for 4 hours, 770 kVA for 5 hours, over load for 3 hours, 800 kVA for 3 hours, 950 kVA for 3 hours and 880 kVA for 3 hours.

What could be the permissible overload for a duration of 3 hours ?

$$\text{Equivalent load} = \sqrt{\frac{\left(500^2 \times 3 + 600^2 \times 4 + 770^2 \times 5 + 800^2 \times 3 + 950^2 \times 3 + 880^2 \times 3\right)}{(3+4+5+3+3+3)}}$$

$$= 759.23 \text{ kVA}$$

$$\theta_a = 32°\text{C}, \quad k_1 = 759.23/1000 = 0.76, \quad h = 3 \text{ hours}$$

From Table 35.5 for $Q_a = 32$°C gives $k_2 = 1.27$

Therefore, permissible overload for 3 hours = 1.27 × 1000 = 1270 kVA.

To determine short-term overload on an 'ON' transformer, the following parameter should be known:

(*i*) Weighted average annual ambient temperature

(*ii*) Loading cycle for 24 hours including overload hours

(*iii*) Desire hours to be overloaded.

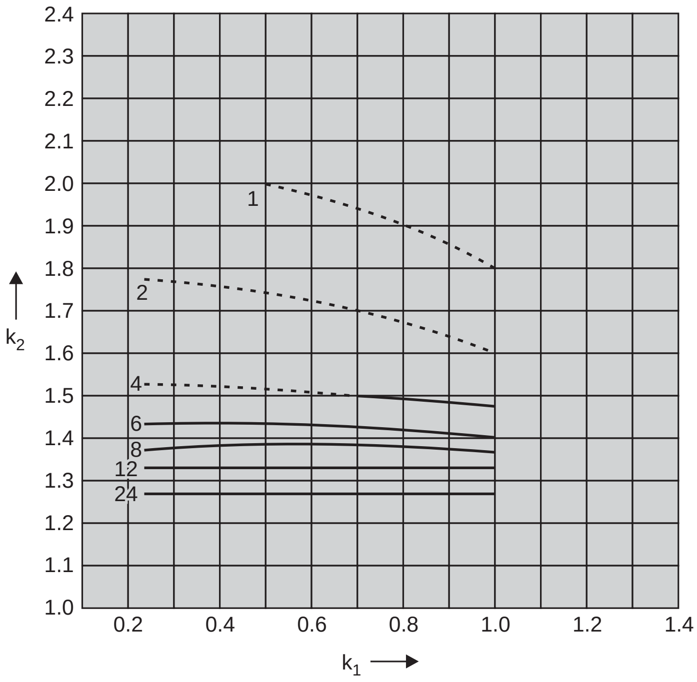
35.9 CONCLUSION

A transformer may be put to overload provided the initial load is less``han the rated kVA and the loading cycle for past 24 hours is known. The duration of overload depends mostly on the weighted average annual ambient temperature of the cooling medium. In case of overloading a transformer which is in service for more than 10 to 15 years, the manufacturers should be consulted.

Table 35.1

Permissible values of k_2 at θ_a = 0°C

(*Clauses 3.4 and 7.2*)



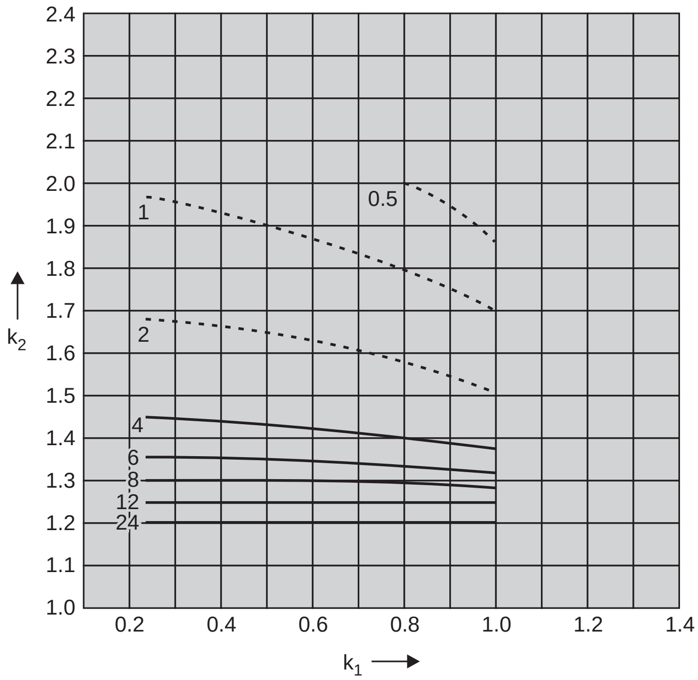
k_1 / h	0.25	0.5	0.7	0.8	0.9	1.0
	Values of k_2					
0.5	+	+	+	+	+	<u>1.99</u>
1	+	<u>1.99</u>	<u>1.93</u>	<u>1.90</u>	<u>1.85</u>	<u>1.80</u>
2	<u>1.77</u>	<u>1.74</u>	<u>1.70</u>	<u>1.67</u>	<u>1.65</u>	<u>1.61</u>
4	<u>1.53</u>	<u>1.52</u>	1.50	1.49	1.48	1.46
6	1.43	1.43	1.42	1.41	1.40	1.40
8	1.38	1.38	1.37	1.37	1.37	1.36
12	1.33	1.33	1.33	1.33	1.33	1.33
24	1.28	1.28	1.28	1.28	1.28	1.28

Note: In normal cyclic duty the values of k_2 should not be greater than 1.5. The sign '+' indicates that k_2 is higher than 2.0. The values of k_2 greater than 1.5 are underlined.

Table 35.2

Permissible values of k_2 at θ_a = 0°C

(*Clauses 3.4 and 7.2*)

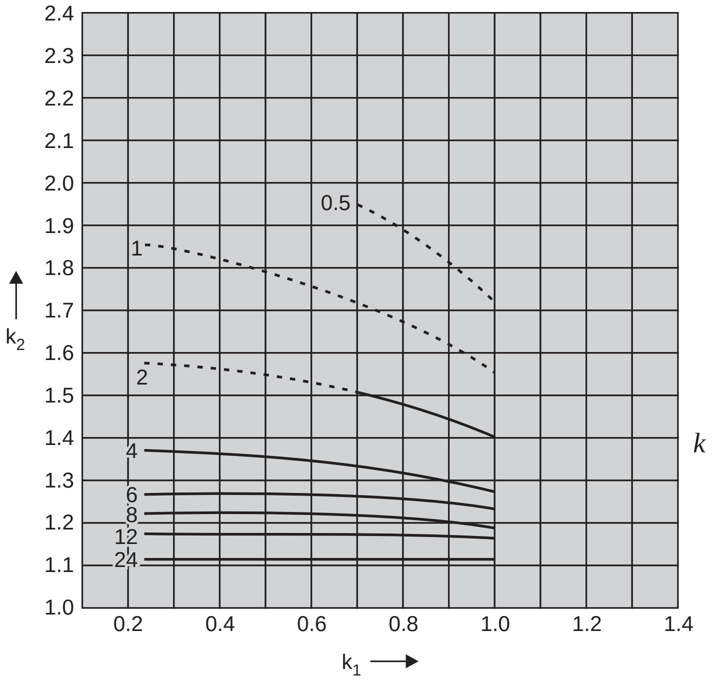


h \ k_1	***0.25***	***0.5***	***0.7***	***0.8***	***0.9***	***1.0***
	Values of k_2					
0.5	+	+	+	<u>2.00</u>	<u>1.94</u>	<u>1.87</u>
1	<u>1.95</u>	<u>1.90</u>	<u>1.83</u>	<u>1.79</u>	<u>1.74</u>	<u>1.69</u>
2	<u>1.68</u>	<u>1.65</u>	<u>1.61</u>	<u>1.58</u>	<u>1.55</u>	<u>1.51</u>
4	1.45	1.44	1.42	1.41	1.39	1.37
6	1.36	1.35	1.34	1.33	1.32	1.32
8	1.30	1.30	1.30	1.29	1.29	1.28
12	1.25	1.25	1.25	1.25	1.25	1.25
24	1.20	1.20	1.20	1.20	1.20	1.20

Note: In normal cyclic duty the values of k_2 should not be greater than 1.5. The sign '+' indicates that k_2 is higher than 2.0. The values of k_2 greater than 1.5 are underlined.

Table 35.3

Permissible values of k_2 at $\theta_a = 20°C$
(*Clauses 3.4 and 7.2*)

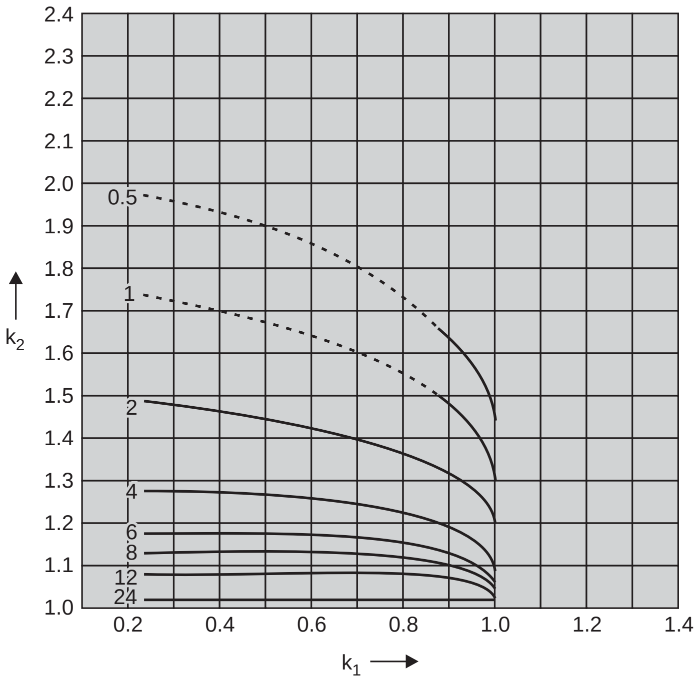


h \ k_1	***0.25***	***0.5***	***0.7***	***0.8***	***0.9***	***1.0***
			Values of k_2			
0.5	+	+	<u>1.94</u>	<u>1.88</u>	<u>1.81</u>	<u>1.72</u>
1	<u>1.85</u>	<u>1.79</u>	<u>1.72</u>	<u>1.68</u>	<u>1.63</u>	<u>1.55</u>
2	<u>1.59</u>	<u>1.55</u>	<u>1.51</u>	1.48	1.44	1.39
4	1.37	1.35	1.33	1.32	1.30	1.27
6	1.27	1.26	1.25	1.25	1.24	1.22
8	1.22	1.22	1.21	1.21	1.20	1.19
12	1.17	1.17	1.17	1.17	1.16	1.16
24	1.11	1.11	1.11	1.11	1.11	1.11

Note: In normal cyclic duty the values of k_2 should not be greater than 1.5. The sign '+' indicates that k_2 is higher than 2.0. The values of k_2 greater than 1.5 are underlined.

Table 35.4

Permissible values of k_2 at θ_a = 0°C
(*Clauses 3.4 and 7.2*)



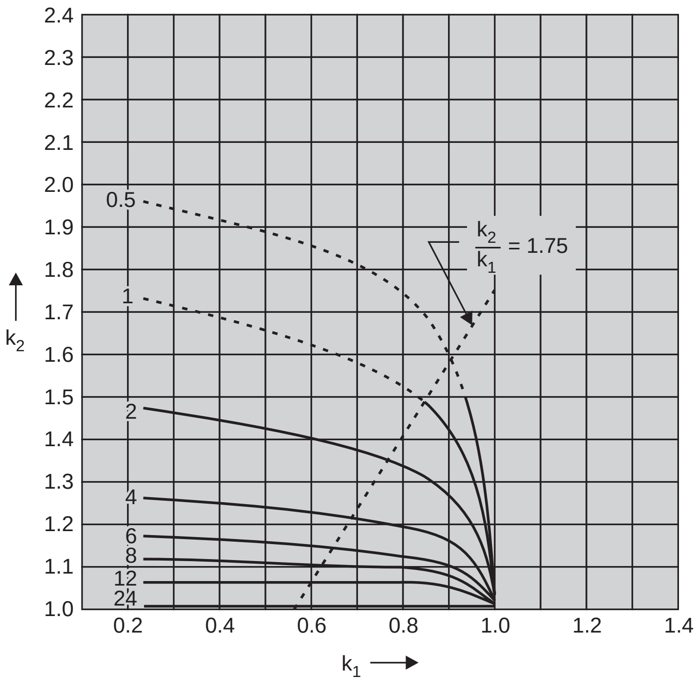
h \ k_1	***0.25***	***0.5***	***0.7***	***0.8***	***0.9***	***1.0***
			Values of k_2			
0.5	<u>1.98</u>	<u>1.90</u>	<u>1.81</u>	<u>1.75</u>	<u>1.66</u>	<u>1.42</u>
1	<u>1.74</u>	<u>1.68</u>	<u>1.61</u>	<u>1.56</u>	1.48	1.28
2	1.49	1.45	1.40	1.37	1.32	1.17
4	1.28	1.26	1.24	1.22	1.19	1.09
6	1.18	1.18	1.16	1.15	1.13	1.06
8	1.13	1.13	1.12	1.12	1.10	1.05
12	1.08	1.08	1.08	1.08	1.07	1.04
24	1.02	1.02	1.02	1.02	1.02	1.02

Note: In normal cyclic duty the values of k_2 should not be greater than 1.5. The values of k_2 greater than 1.5 are underlined.

Table 35.5

Permissible values of k_2 at θ_a = 32°C

(*Clauses 3.4 and 7.2*)

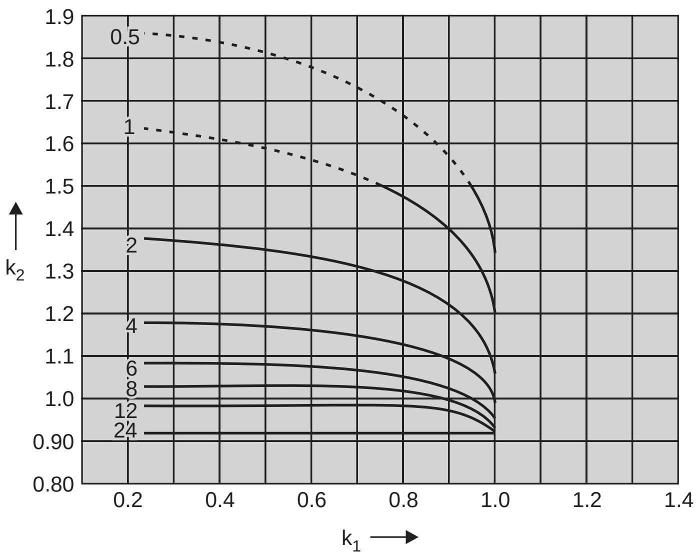


h \ k_1	**0.25**	**0.5**	**0.7**	**0.8**	**0.9**	**1.0**
			Values of k_2			
0.5	<u>1.95</u>	<u>1.88</u>	<u>1.78</u>	<u>1.72</u>	<u>1.62</u>	1.00
1	<u>1.72</u>	<u>1.66</u>	<u>1.58</u>	<u>1.53</u>	1.45	1.00
2	1.47	1.43	1.38	1.34	1.29	1.00
4	1.26	1.24	1.22	1.20	1.16	1.00
6	1.17	1.16	1.14	1.13	1.11	1.00
8	1.12	1.11	1.10	1.10	1.08	1.00
12	1.06	1.06	1.06	1.06	1.04	1.00
24	1.00	1.00	1.00	1.00	1.00	1.00

Note: In normal cyclic duty the values of k_2 should not be greater than 1.5. The values of k_2 greater than 1.5 are underlined.

Table 35.6

Permissible values of k_2 at θ_a = 40°C
(*Clauses 3.4 and 7.2*)



h \ ***k*₁**	***0.25***	***0.5***	***0.7***	***0.8***	***0.9***
			Values of k_2		
0.5	1.86	178	1.67	1.58	1.33
1	1.63	1.56	1.48	1.40	1.19
2	1.39	1.34	1.28	1.23	1.07
4	1.18	1.16	1.13	1.10	0.99
6	1.09	1.08	1.06	1.04	0.96
8	1.04	1.03	1.02	1.00	0.95
12	0.99	0.98	0.98	0.97	0.93
24	0.92	0.92	0.92	0.92	0.92

Note: In normal cyclic duty the values of k_2 should not be greater than 1.5. The values of k_2 greater than 1.5 are underlined.

Section IV

CHAPTER 36

Protection on Distribution Transformers

FOOD FOR THOUGHT

Temporary setbacks to the achievement of goals should not lead us to despondency. It should be regarded as a transient phenomenon. There is no question of permanent failure. Failure hurts everybody. But it can also make a positive contribution to our lives, if we learn to ask ourselves the question : Why did I fail? In situations like this there is a tendency to look for scapegoats and blame somebody else for our failures. An honest self-examination of failure can help us improve immensely. It can be a turning point in life. The honest answer can turn all our ventures into success and catapult us forward. Having failed and reached the bottom, there is no way to go, except upwords. Failure will also free us from risks, because there is nothing left loose.

AT A GLANCE

The protection of distribution transformers upto 100 kVA are guided by the REC specification no. 11/76. Beyond 100 kVA, references may be drawn from IS-2026.

Upto 100 kVA : Protective devices such as MCCB for overload protection and lightning arrestor for impulse surge protection are recommended to protect the transformer from external causes. HV HRC fuses are used to protect the high voltage winding against internal fault. Operaing characteristics of MCCB and fuse element have been briefly discussed. Silicagel breather is used to monitor the condition of oil.

Above 100 kVA : No specific protective equipment has been made mandatory by ISS, yet a few monitoring gauges, like OTI, WTI, MOG, Buchholz relay etc. have been recommended. OCB/VCB on high voltage side and ACB/MCCB on low voltage side are widely used for protecting the transformer from external causes.

The chapter highlights the application of various protection schemes.

At the end, a paragraph has been added on ammended specification to facilitate marginal overload on distribution transformers.

36.1 INTRODUCTION

The subject of transformer protection falls naturally under two major headings, which are :

(*i*) Protection of the transformer against the effects of faults occurring on any parts of the system; and

(*ii*) Protection of the system against the effects of faults arising in the transformer.

Considering first the means to be adopted for protecting the transformer itself against the effect of system faults, four distinct types of disturbances have to be provided for, these being (*a*) short-circuits; (*b*) high voltage, high frequency disturbance; (*c*) pure earth-fault; and (*d*) overload.

Considering next the means to be adopted for protecting the system against the effects of faults arising in the transformer, the principle faults which occur are: (*a*) breakdowns to earth either of thE windings or terminal gears, and faults between phases generally on the HV side; and (*b*) short-circuits between turns, chiefly of the HV windings.

We shall take up each category of protection against a particular fault in the later part of our discussion.

36.2 THERMAL CONSIDERATION

The losses which practically occurs in an unloaded transformer are the iron loss, copper loss due to flow of no-load current in the primary winding, and dielectric loss. In practice, only iron losses are of importance in transformer, and these losses are the sum of the hysteresis and eddy current losses, which are constant for a given applied voltage and unaffected by the load on the transformer. The dielectric losses are also a function of the primary and secondary voltages, but they vary slightly with the temperature of the winding as affected by the load on the transformer. The copper loss due to the no-load current is generally negligible and it is independent of the load for a given excitation.

No-load loss = Sum of [Hysteresis loss + Eddy current loss + Dielectric loss
+ Load loss due to no-load current]

The application of a load to the secondary side of the transformer produces considerable change in the internal phenomena. When the secondary circuit is loaded, a secondary load current flows, the value of which is determined by the secondary terminal voltage, magnitude of load and impedance of the load circuit.

By and large, load loss is the sum of the following losses :

Load loss = Sum of [copper losses (I^2R) in both primary and secondary windings + Losses due to eddy current set-up in the conductors + stray losses in the tank and core clamp].

To arrive at total loss of a transformer, it is the arithmetic sum of no-load and load losses corrected to 75°C. To calculate the load loss at reference temperature, it is prefered to calculate at 100 °C instead of 75°C while carrying out temperature rise test, as have been a routine practice of some of the power utilities in India.

It is highly desirable that the no-load loss of the transformer should be reduced to minimum since the loss is constant and continuous during the whole of the time the transformer is connected to the supply. While a low iron loss is undoubtedly a great advantage, it should not be obtained at the expense of a very high copper loss, and thereby the probable sacrifice of reliability.

It should be remembered that the operation of a commercial transformer of given proportions and for a given output entails the loss of a certain and fairly constant total amount of power, consisting generally of iron and copper losses.

Accepting of this statement implies, therefore, that if the iron loss of a commercial transformer is very very low, the copper loss will be correspondingly high and vice-versa. A high copper loss may represent distinct disadvantage to the coil insulation on account of the possibility of excessive undetermined local heating occurring in the interior of the coils, and therefore, it is far sounder practice to design for a closer agreement between copper and iron loss than to look for a very very low iron loss at the expense of the copper loss or the electrical and thermal design of the transformer. It is understood that a loaded transformer emits no-load and full load losses and the commercial ratio of no-load and full load losses is 1 : 6 up to 100 kVA transformers and 1 : 5 for transformers above 100 kVA up to 1000 kVA.

The purpose of discussing the various parameters of losses in the foregoing paragraphs is to highlight the effect of losses on the performance on transformers. We all know the universal law of transformation of energy. In the case of transformer, the watt-loss is converted to heat energy while on operation. Heat has a very detrimental effect on the successful performance of a transformer as it helps to deteriorate the insulating properties of cellulose materials and oil. Oil is used to insulate the transformer to a desired level and also as a coolant to cool down the transformer from overheating. Radiator banks are used to create an artificial circulation of oil which offer a faster rate of cooling in the transformer.

In case the rise of temperature is beyond certain limit, the transformer gets overheated, causing a faster rate of ageing of insulating materials, affecting an early death of the transformer. To limit the oil/winding temperature to a safer limit, some gauges are provided to protect the transformer from over heating. We shall take up this issue in the later part of our discussion.

36.3 TRANSFORMER PROTECTION

Protection scheme of transformers in service is categorised into two different varieties. They are:

(*a*) Transformers up to including 100 kVA/11 kV as per the provision of REC (Rural Electrification Corporation) ; and

(*b*) Beyond 100 kVA up to 1000 kVA as per the recommendation of ISS.

We shall discuss them separately.

36.4 MECHANISM OF PROTECTION UP TO 100 kVA TRANSFORMER

It has been elaborately described the protection scheme in REC specification no. 11/1976 under heading ‘‘sealed type distribution transformers upto and including 100 kVA rating’’. The salient features of the specification are only highlighted.

The purpose of the procedure is to protect the transformer from oil pilferage and loss of oil during service. The specification has stressed the need to keep the oil absolutely separated and prevent contamination from the outside atmosphere.

(*a*) The specification covers transformers of 16 kVA, 25 kVA, 63 kVA and 100 kVA ratings for used on system with nominal voltage 11 kV.

(*b*) Terminal arrangement shall be such that it is possible to replace the external bushings without opening the tank cover and also without affecting the sealing of the transformer. The arrangement shall meet the following requirements :

(*i*) The bushing shall be made in two parts. The internal part shall be made of tough insulating material like epoxy and shall be embedded brass stem. The outer porcelain bushing shall conform to the requirements of IS-3347.

(*ii*) In the case of HV bushing, a separate flexible interconnecting copper lead shall be provided between the brass stems of the internal and external porcelain bushings. The lead shall have adequate mechanical and electrical strength and shall have brazed or soldered connection on the lower end of the upper stem. In the case of LV bushing, a strong coupling connection properly screwed shall be used between the brass stem of internal and external bushings.

(*iii*) The lower end of the insulated portion of the internal 11 kV bushing shall remain dipped in oil under all operating conditions.

(*iv*) The external 11 kV porcelain bushing, after being lightened properly, should be filled with oil which remain locked in the bushing and does not get mixed up with the oil in the transformer tank.

(*v*) The transformer tank cover should be welded to the tank collar in such a manner that it should be possible to remove the weld and reweld the cover at least twice during its service life.

(*vi*) Drain valve is not recommended.

(*vii*) An oil filling pipe of extended length with welded cap is recommended on the tank cover.

The REC specification became unpopular among the utilities and manufacturers because of it's specific requirement of welded tank cover. If we have a wider look to the international specifications, they use sealed type transformers with bolted tank cover, but without oil conservator and silicagel breather. The oil volume and air space inside the tank should be such even under extreme operating conditions, the pressure generated inside the tank does not exceed 0.4 kg/cm^2 positive or negative.

Completely Self-protected Transformers up to and Including 100 kVA Rating

It has been elaborately described in REC specification no. 23/1983 under heading ''Completely Self-protected Transformer up to and including 100 kVA''. The salient features of the specification are only highlighted.

(*i*) The standard ratings of CSP transformers shall be 16, 25, 63 and 100 kVA.

(*ii*) The terminal (double bushings) arrangement in respect of sealed type transformer shall be as discussed earlier (refer REC specification no. 11/1976).

(*iii*) The transformer shall be fitted with a LT circuit breaker which shall be mounted externally in an enclosed chamber conforming to IS-2147 forming an integral part of the transformer or provided inside the transformer tank. In former case, moulded case circuit breaker shall be used.

The circuit breaker shall be capable of being operated from the ground level by means of a suitable operating rod. For this purpose, an operating hook shall be provided on the transformer tank in a suitable location for easy and safe operation of the circuit breaker from ground level.

In case of LT circuit breaker mounted internally, the outgoing terminals of the circuit breaker shall be connected to the LT bushings of the transformer through internal connections as in ordinary transformer. In case of circuit breaker mounted externally, suitable inter-connections is provided in the enclosure from the LT bushings to the incoming terminals of the LT circuit breakers. The terminal block and other wiring to be provided in the enclosure for connections to the outgoing cable shall conform to REC specification no. 18/1981.

For externally-mounted LT circuit breaker, the current setting, the time/current characteristics and all other electrical/mechanical features including test requirements shall conform to the REC specification no. 18/1981 except that the reference calibration temperature for the time/current characteristic shall be 50°C. A suitable shield shall be provided at the back of the enclosure to minimize the transfer of heat from the transformer tank to the circuit breaker enclosure.

LT Circuit Breaker

REC has recommended triple pole, 50 HZ, AC, LT moulded case circuit breakers suitable for protection of distribution transformers in rural electrification system.

Unless otherwise stipulated in the specification, the moulded case circuit breakers shall comply with the latest version of IS-2516 (Part I and II/Section 1), 1977.

It is further recommended that the circuit breaker for the transformer protection should have tripple pole construction so that all the three poles close or trip simultaneously.

The rated voltage of the circuit breakers shall be 415 V.

The standard current settings of the circuit breakers for use with the transformers of different ratings standardised by REC are as follows :

Table 36.1

Transformer rating (kVA)	*Current setting (Amps.)*
16	22
25	35
63	90
100	140

The above, standard current settings shall also apply if the circuit breakers are used for controlling individual LT feeders. An additional setting of 50 Amps. can also be adopted for the feeder breakers, where required.

In case circuit breakers are used only on individual feeders emanating from a transformer and there is no separate breaker on the secondary side of the transformer, the combined capacity of the feeder breakers should not normally exceed the full load current of the transformer. It should also be ensured that short-circuit breaking capacity of the feeder breakers is not less than that required for the transformer with which these are used.

Time/Current Characteristic

The circuit breakers shall have the following time/current characteristic :

Table 36.2

Multiple of normal setting	*Tripping time*
1.05	More than 2.5 hrs.
1.20	More than 10 minutes and less than 2 hrs.
1.30	Less than 30 minutes
1.40	Less than 10 minutes
2.50	Less than 1 minute
4.00	Not less than 2 seconds
6.00	Less than 5 seconds
12.00	Instantaneous (less than 40 milli second)

Time/current characteristic of the circuit breaker shall be tested in accordance with Clause 7.7.2.3 (*b*) (2) of IS-2516 (Part I and II/Section 1), 1977 and the test shall be made with all the three-phases loaded.

For the time/current characteristic, the reference calibration temperature of the breakers shall be 40 °C.

Rated Short-Circuit Breaking Current

The rated short-circuit breaking current of the circuit breakers shall be as follows:

Table 36.3

Transformer rating (kVA)	*Min. rated short circuit breaking current of the circuit breaker*
16	2.5 kA
25	2.5 kA
63	3.0 kA
100	5.0 kA

The short-circuit breaking capacity, as specified above, shall be based on the short-circuit test carried out at power factor not exceeding 0.4 (lagging). For the purpose of this test, the following operating sequence shall be followed :

"Break-3 minutes interval-make break-3 minutes interval-make break"

While the above stipulations regarding the test power factor and the sequence of operation shall be binding, the other procedure of making the short-circuit test and the test circuit shall be in accordance with IS-2516 (Part I and II/Section 1)-1977 or latest version thereof.

The metallic portions of the mechanism shall be either inherently resistance to or so treated as to make them resistant to the atmospheric corrosion.

The circuit breaker shall have trip-free mechanism.

The breakers should clearly indicate 'on' and 'off' position.

Enclosure

The circuit breaker shall be housed in a separate enclosure. With the lid closed, the enclosure shall comply with the requirements of IP 44 type as per IS-2147-1962 or the latest version thereof. Access to the circuit breaker including operating handle shall be available only after the enclosure is opened.

Suitable vents fittEd with wire gauze shall be provided to ensure that the temperature inside the enclosure is not substantially different from that of the atmosphere.

Fixing of circuit breaker inside the enclosure shall be such as to allow free circulation of air at its back and sides.

Cover of the enclosure shall be so provided that it cannot be left in open position and it gets latched when closed manually. In addition to the latch, an arrangement for providing pad-lock shall be made.

The enclosure shall be made of sheet steel of not less than 0.9 mm thickness.

The enclosure shall be painted both inside and outside with suitable weather proof and corrosion resistant enamel paint. The colour of the inside point shall be white, while that of the outer paint shall be dark admiralty grey.

Necessary fixing arrangement shall be provided at the back of the enclosure to ensure proper fixing.

Terminals and Wiring

A suitable terminal block in the enclosure below the circuit breaker shall be provided for termination of incoming and outgoing cables in order to prevent direct pressure on the circuit breaker terminals. The enclosure shall be fully wired up with insulated copper wire suitable for the rating of the transformer.

Aluminium terminal ends (Lugs) of adequate size appropriate to the kVA rating are necessary to connect the incoming and outgoing cables to the terminal blocks to facilitate proper connections. The sizes of lugs for various current rating of the circuit breakers are indicated below:

Table 36.4

Circuit breakers current setting	*Size of PVC aluminium cable*
22 A	10 mm^2
35 A	16 mm^2
50 A	25 mm^2
90 A	70 mm^2
140 A	150 mm^2

Necessary provision shall be made in the enclosure for a separate neutral link on the same terminal block, to which incoming and outgoing neutral conductor can be connected. The design of terminal block shall be such that all the incoming and outgoing terminals including neutral are in a line.

11 kV Lightning Arrestor

To protect the transformer against lightning impulse, it is recommended to mount a set of lightning arrestors on the transformer, clamping it securely to the tank.

9 kV, 5 kA Metal Oxide Lightning arrestors, one per phase, should be fitted under the HV bushings with GI earth strip, 25 × 3 mm, connected to the body of the transformer with necessary clamping arrangement.

11 kV Fuse Arrangement

Till adequate experience on CSP transformer is available and suitable designs are developed, the 11 kV fuse-tube, preferably made of fiber-glass shall normally be connected externally between the terminals of the lightning arrestor and the HV bushing. The fuse-tube shall be screwed in position by a flipper arrangement. This arrangement facilitates indication of the blown-out fuse (The flipper strip move back due to spring action). This arrangement shall be such that the fuse-tube remains in position when the fuse element inside the fuse-tube blows-off. The details of this arrangement are left to the manufacturers. Alternatively the purchaser has the option to accept the provision of internal fuses (mounting inside the bushing). In this case, it will be absolutely necessary to ensure that the fuse will blow-off only in the case of internal fault in the transformer and all external fault in the LT system will be cleared by the LT circuit breaker only. This will call for the use of circuit breaker of proven design and use of proper rating fuse.

Co-ordination of 11 kV Fuses and LT Circuit Breaker

Co-ordination of 11 kV fuses with LT circuit breaker is the most important features of a completely self protected transformer and shall be properly tested and proved. The time/current characteristics of the LT breaker and 11 kV fuse for various current multiplier shall be checked. The two characteristics shall be drawn on the same sheet to indicate co-ordination between the circuit breaker and fuse.

The basic needs of self protected transformers upto and including 100 kVA may be summarised as below:

(*i*) HV and LV bushings shall be of two-part type.

(*ii*) LT moulded case circuit breaker with various settiLc of multiplier shall be used. This will act as over-load protection as well as external fault.

(*iii*) HV lightning arrestors are provided to protect the transformer from external lightning strokes.

(*iv*) HV fuse with flipper arrangement is provided to protect the transformer from internal fault.

The self-protected transformer is not very popular among the Indian power utilities as the cost of the CSP transformer is on high side with respect to the conventional transformer. Baring the state like A.P., Gujarat, other states do not encourage this construction. Most of the boards prefer to provide fuse protection only on HV side. LV remains solidly connected to the load without any low voltage kit-kat HRC fuse.

On protection point of view in case the CSP concept is not acceptable to the power utilities because of its high cost, it is recommended to use the following to protect the transformer from overload and external lightning strokes :

(*i*) Use 9 kV, 5 kA metal oxide lightning arrestor of reputed make on HV side (as has been made mandatory by Haryana state).

(*ii*) Use correct rating LV HRC kit-kat fuse on LV side. The following ratings may be considered while selecting LV fuses :

Use 32 Amps fuse for 25 kVA transformer
Use 84 Amps fuse for 63 kVA transformer
Use 140 Amps fuse for 100 kVA transformer.

In case these ratings of fuses are not readly available in the market, these can be made standard for development by the reputed fuse manufacturers.

It is highly objectionable to use rewirable type fuse on LT side, as there is every possibility of using a thicker gauge wire in case of non-availability of a right size of HRC fuse.

(*iii*) Use correct size of rewireable fuse on HV side.

Data of sizes of fuse wires standardized by PSEB for different ratings of 11 kV transformers are as follows :

Table 36.5

kVA rating	*Recommended fuse wire (copper)*
25	38 swg.
63	33 swg.
100	32 swg.
200	26 swg.
300	22 swg.
500	19 swg.

To provide a reference of rating wise kVA with respect to BHP, PSEB has recommended the followIng:

Table 36.6

kVA rating	*Recommended BHP*
25	20
50	40
63	51
100	80

Every power utilities should make their own standards and should recommend size of fuse wires for various rating of transformers. The utilities must ensure the availability of fuse elements in their stores. The line-man should be told to adopt correct practices while replacing the fuses. In case of non-availability of correct size of fuse element at site, it has been experienced that the line-man uses thinner

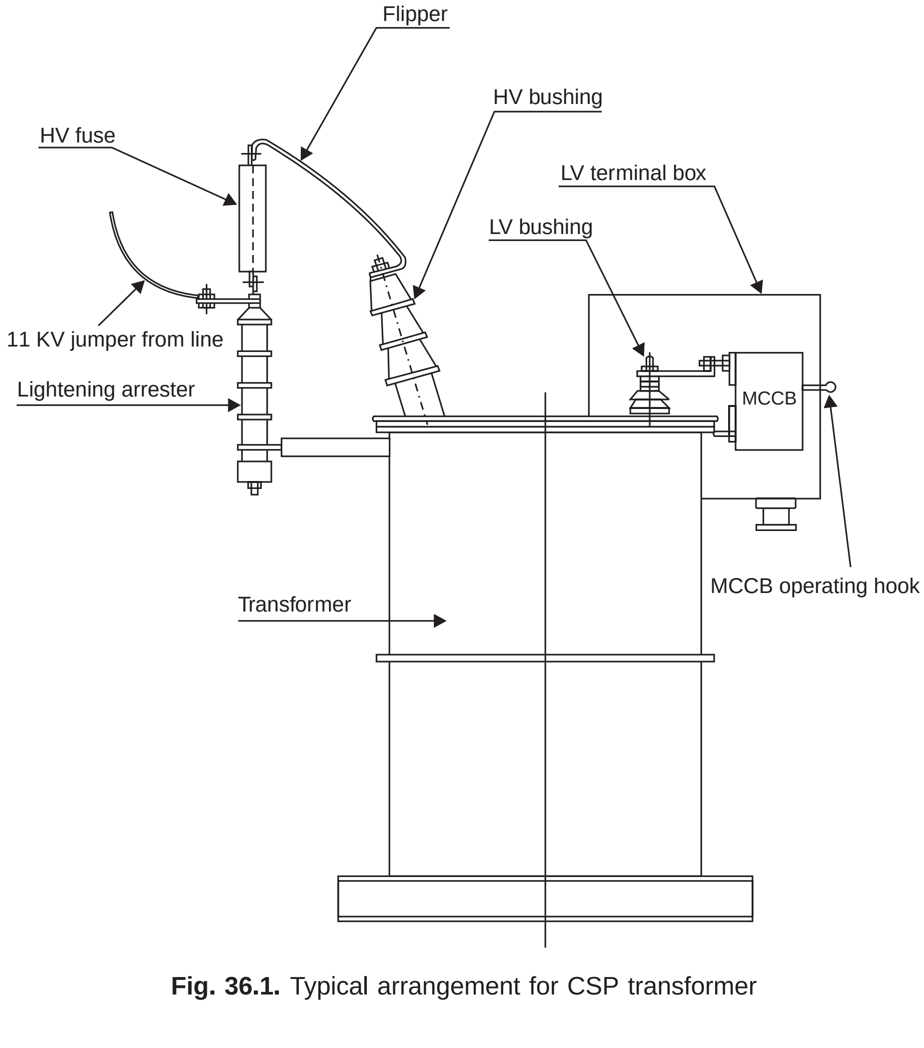


Fig. 36.1. Typical arrangement for CSP transformer

gauge fuse elements, two in parallel. This practice is wrong and should be discourged. Further, it has also been seen in many cases that the maintenance people purposely use thicker gauge of fuse wire for overload protection to reduce the probability of replacement very often. This act of injustice make the transformer to run at overload and causes early failure. A training scheme as deemed fit by the seniors may be made mandatory for the juniors, especially for the maintenance people. A regular monitoring of the transformers during service may also reduce the failure rate of transformers. Guidelines given IS-10028 may be followed for maintenance of transformers. A schematic view showing all the protecting devices has been shown in Fig. 36.1.

36.5 PROTECTION OF MEDIUM SIZED DISTRIBUTION TRANSFORMER

Various protection schemes and their applications are highlighted below.

(*a*) Earthing of Tank Body and Secondary Neutral

The earthing of LV neutral will prevent the presence of any voltage above the normal appearing in the LV circuit and therefore, the possible danger to human life will be reduced to minimum. Secondly the earthing to the neutral point eliminates the possibility of an arcing fault to earth and therefore of fire risk, while it also ensures the rapid disconnection of faulty apparatus from the system without undue delay (if recommended earth-fault relay provided). Due to discharge from high voltage, the tank may be charged to an abnormal potential causing danger to life.

In both occasions, provision of solid earth is extremely essential. As per Indian Electricity Rule, the tank body has to earthed at two diagonally opposite points. The earthing should be done through G.I. strip having minimum cross-section of 25 × 3 mm. Painted surface in and around the earth bolts should be cleaned to ensure proper earthing. It is advisible to check the earthing at regular interval.

(*b*) Silicagel Breather for Protecting the Transformer from Moist Atmosphere

The silicagel breather is fitted with a sight glass so that the colour of the silicagel crystals is visible. The colour changes from blue to pink as the crystals absorb moistures. When the crystal get saturated with moisture, they become predominantly pink and should therefore be reactivated. The body of the breather should be removed by undoing the nuts. The silicagel crystals are baked at a temperature of about 200°C until the whole mass is at this temperature and the blue colour is restored. The dust and small granules of silicagel are removed through a 100 mesh stainer. Clean the breather and replace the dry crystal and renew the oil in the sealing cup at the bottom.

(*c*) Explosion Vent as a Protecting Device Against High Internal Pressure

The diaphragm which is fitted at the exposed end of the vent pipe should have the right material value as it need to break at a pressure little higher than 1 kg/cm^2. Thick copper or brass or aluminium foil as diaphragm have no use for this purpose. Bakelite sheet of thickness 1/128th inch is the correct vent material. Other similar materials of equivalent properties may also be used.

The diaphragm should be inspected at frequent intervals and replaced if found damaged. Failure to replace the diaphragm quickly may cause ingress of moisture which will contaminate the oil. If the diaphragm is found broken because of fault in the transformer, an inspection shall be carried out to determine the nature and cause of the fault.

(*d*) Gas Operated Buchholz Relay as Protective Device Against Generation of Unwanted Gas Due to Arcing Inside Oil

Double float Buchholz relay has a float type mercury lever which connect a switch having two contacts, one is normally off and other is normally closed . The normally off contact is used to operate a hooter bell and normally closed contact is used to energised the breaker.

In case there is any arc inside the windings or in the tap switch, oil vapour is formed and travel upto the Buchholz relay through the connecting pipe. If the gas pressure is enough to topple the mercury lever, it helps to operate the hooter bell as well as disconnect the incoming supply to the transformer through the operation of the OCB. During operation, if gas is found to be the cause of above, the gas should be tested and analysed to find out the nature of fault. Buchholz may also give alarm/trip signals due to low oil level falling below Buchholz relay.

Since the scope of using Buchholz relay up to 990 kVA transformer is very rare (as not been recommended by ISS), we do not find much use of Buchholz relay in medium sized distribution transformers.

(*e*) Oil Temperature Indicator as a Caution Gauge for High Oil Temperature

Oil temperature indicator is a simple gauge which indicates top oil temperature at an instant of time and loading cycle. If the temperature of top oil found beyond permissible limit (*i.e.* beyond permissible oil temperature rise plus (+) ambient temperature of that instant), the transformer is understood to be operated under overload. Immediate steps are to be taken on priority to bring back the top oil temperature within limit. In case a transformer operates at a higher temperature beyond its permissible limit, the insulating materials and oil get deteriorate at much faster rate and may cause pre-matured failure at an early stage.

If the oil temperature indicator is fitted with alarm and trip contacts, the same may be used for operating a hooter bell and disconnection of OCB. OTI with alarm and trip contacts is not very common for medium sized distribution transformers and hence ordinary stem type oil temperature indicator without contact is used as a protective gauge only for recording high oil temperature.

(*f*) Winding Temperature Indicator as a Protective Device Against High Alarm

Winding temperature indicator with alarm and trip contacts is a very common instrument for protecting the transformer against high winding temperature. But this instrument is rarely used for distribution transformer.

(*g*) Magnetic Oil Level Gauge as a Protective Device Against Low Oil Level

Magnetic oil level gauge with low oil level alarm is also a very common instrument for protecting the transformer against low oil level. But this instrument is rarely used for distribution transformer.

(*h*) Lightning Arrestor as a Protecting Device Against Lightning Impulse

As discussed earlier, lightning arrestor is a very useful component to protect the transformer against lightning impulses and may be recommended to use on commercial basis.

(*i*) Overload Fuse Protection on Primary Side

Continuous overload is one of the prime causes of failure of distribution transformers in service. Though distribution transformers are not recommended to run under continuous overload, yet in number of occasions the power utilities are constrained to run transformer under overload to maintain the service of power to the locality. With the service prevailing at the distribution network, the performance of distribution transformers towards overloading remain unsatisfactory.

Overloading on transformers may be restricted by using a higher rating transformers than required or else use of a similar rated transformer in parallel. Considering the economic factor, none of the proposal sounds good. However, failure due to overload may be restricted to great extent with slight amendments in the governing technical specifications.

(*i*) Reduce permissible oil and winding temperature rise from 50/55°C to 30/45°C to take care of poor ventilation in some locations and to permit marginal overloading.

(*ii*) Thermometer pocket is proposed to locate at the centre of the tank cover which is the hottest zone of top oil.

(*iii*) Temperature rise test should be counter verified by CPRI at their testing laboratory (not at the manufacturer's premises).

(*iv*) Total loss to be fed during temperature rise test should be computed at 100°C instead of 75°C which is our regular practice.

(*v*) Use of correct size of HV fuse wire on primary side is to be ensured.

36.6 CONCLUSION

Distribution transformers are designed for a minimum life of 10 years plus. The materials, construction methods, test procedures makes it to meet that targeted life. Transformer is most reliable, safe and robust equipment. Adherence to periodical maintenance, acting on the tips from trouble shooting chart, good installation and condition monitoring shall enhance the availability of its service. The useful life and safe operation is in our hand. Use of protective equipments, as discussed in this chapter, add to the reliability of transformers. Adherence to IE rules and safety procedures to IS 6512 will keep us safe.

Adequate Fire Fighting equipments with due training keep the people and property safe.

SECTION V

Various Aspects of Quality Assurance

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Section V

CHAPTER 37

Abstract of the Quality Assurance of Distribution Transformers

FOOD FOR THOUGHT

Can you guess a seven letter word that has awakened all the nations, industries, and organizations around the world? The word is

"Q-U-A-L-I-T-Y"

The word 'quality' has many connotations. It includes concepts such as durability, price, value, performance, preference, suitability, fitness for use, and many others. When we provide a quality product, the news gets around. 'Quality' provides free advertisement for us. When we have a reputation for a quality product or service, quality and the name of the organization become synonymous.

37.1 INTRODUCTION

Quality has become a widely talked about subject now. In a manufacturing industry, quality suffers mainly because of inadequate skills either in the manufacturing activities or in the maintenance of the equipments.

Since various departmental activities are involved in the process of manufacturing a transformer, the mistake of any individual or any department may be enough to drastically reduce the life span of the transformer. For instance, a well designed and type tested transformer may fail during service within a short span due to generation of excessive hot-spot temperature in the winding. Inadequate care taken by the coil assembler while providing oil ducts is enough to generate excessive heat in the winding, which deteriorates the insulating materials, resulting in the sudden premature failure of the transformer. Such failures can be averted if adequate skilled man power is available.

Even though inadequate oil duct is a mistake of one individual, it affects the reputation of the entire orgaNization.

Quality cannot be achieved overnight. It is a lengthy process. The best way to achieve continuous improvement in quality in any manufacturing organization is to develop a quality path and the persons responsible for quality implementation should religiously follow the defined quality route. The quality route is sub-divided into four steps.

The first step towards quality implementation is to **"define the quality requirements"**. This is an exercise on paper.

The second step is **“planning”**—how to achieve the desired quality. It is essential to review the outcome of the planning made before starting the execution of work. The review is done by a group of expert professionals within the organization headed by the quality assurance engineer. The review is, indeed, essential to eliminate any flaw in the planning. However this is again a paper exercise.

The third step of the activities starts with the **“execution of work”** as per guidelines of quality planning.

The fourth and concluding phase of the activitieS start with the verifications of quality aspects of the outcome of work done vis-a-vis planning made during second phase. The purpose of verification is to identify deviations from the “the job planned and actually achieved.” Further the cause of deviation is reviewed and eliminated through non conformance analysis. This part of the exercise is known as “quality audit.”

Here, the first round of journey towards quality implementation is completed. During initial journey, one may find a huge gap between the planning made and the quality achieved. Subsequently, once we follow the above path regularly and religiously, the gap between the activities planned and achieved will be narrowed down. Ideal requirement is the situation where this gap is zero. This is what we call “quality improvement.”

37.2 LIFE OF A TRANSFORMER

Transformer is a static machine without having any moving part. Therefore, there is nothing in it which gets worn out as in the case of rotating machines. Copper and Iron can last indefinitely. It is, however subjected to many stresses and strains, such as impulse and power frequency withstand voltage, induced over voltage, natural occurrences like lightning surges, short circuits and over voltages. Each of the above leaves its indelible mark on the winding structures. Yet, being a sturdy equipment, transformer does survive all these and lives a longer life, if it is installed, operated and maintained intelligently.

The normal life of a well built transformer by a manufacturer of repute can be about 20 years, if it is well looked after. It can indeed serve much longer, perhaps 30–40 years, if it is operated with care.

Effect of High Temperature

However, it also follows that the transformer may die prematurely and its life span may get reduced to 10 years or even one year due to gross negligence. Excessive temperature rise and humid atmosphere are like poison for successful operation of transformer. It is estimated that every 8˚C rise above the permissible limit halves the life of the insulation. Abnormal over loading (hot-spot temperature exceeding 140°C) can char and destroy the insulation in a very short time. Therefore, over loading beyond capacity can be a very costly mistake.

Exposure to high temperature over a longer period results in progressive deterioration of the insulation. Its mechanical strength reduces gradually until it becomes quite brittle, even though the di-electric strength may still be high. Under such cases, the transformer ceases to be reliable and becomes weak. On further operation, the transformer will be unable to withstand any more short circuits. The ageing process is greatly accelerated at high temperature.

Effect of Short Circuit

Every time when a transformer is subjected to an external short circuit, the coils and turns do suffer some mechanical displacement which in course of time becomes noticeable.

Unless the resulting slackness is corrected periodically, the mechanical wear by repeated short circuits and vibration may lead to an interturn or interlayer failure.

Effect of Moisture

Presence of moisture in the insulation, even in very small quantity, has a surprisingly great effect on the de-composition and deterioration of the insulation. Oil should, therefore, be maintained in a high state of dryness and purity.

Effect of Sludge and Impurities

Sludge and impurities are the main cause for blocks in the passages and ducts in the assembly, resulting in obstruction to the free flow of oil and effective dissipation of heat. This will cause generation of excessive heat due to hot-spot in the winding and deterioration of insulation. Some varnishes, used for coil impregnation, react with hot oil and accelerate sludge formation. Copper is also one of the most active catalysts.

Effect of Dissolved Air

Air dissolves in oil to some extent. Its oxygen content reacts with the cellulose of the insulation and leads to the formation of sludge. The primary objective of providing an oil conservator tank is to reduce the area of oil exposed to oxygen and incidentally maintain thiS exposed surface at a low temperature. The constant breathing in and out of air replenishes the dissolved oxygen in the oil and therefore promotes 'ageing.'

The silicagel breather prevents only humid air from contaminating the oil, but it does not prevent oxygenation of the oil. The modern tendency is to omit the oil conservator and the breather, by completely sealing the transformer. Sufficient gas space is left above the oil in the tank and the effect of temperature variation is correspondingly transformed to pressure variation in this gas space. Excessive pressure, if any, is automatically released through pressure relief valve provided on the tank cover.

Sometimes the top space is filled up with nitrogen, by connecting it to a nitrogen cylinder kept outside the transformer tank through a suitable pressure regulating device. But such arrangements are expensive and are suitable for only very large transformers.

What is the Cause for Insulation Breakdown?

Application of voltage exceeding the insulation strength of a liquid or solid medium results in the formation of streamers, *i.e.* movement of loose ion existing in the medium. These streamers start from the high voltage electrode at a sharp point and move towards the other electrode, reaching after a short interval of time, when a complete breakdown occurs. The streamers die down if the voltage of the DC surge drops down substantially before it reaches the other electrode. The wave shape has a great effect on the breakdown value. Quite often the breakdown occurs in the wave tail, after the crest has passed, because of the time taken for the streamers to form and reach the other electrode.

Effect of Air Bubbles in the Insulating Oil Inside the Transformer

One more point to remember is that the presence of air bubbles materially reduces the breakdown value as ionisation can easily start. It is, therefore necessary to allow some time to elapse after centrifuging the oil by a purifier, to ensure that all air bubbles disappear, before the transformer is charged. Another point to note is that the di-electric strength of oil is much higher than that of air and the clearance between the live parts and the tank interior is usually less. Therefore a high voltage transfoP´er should not be charged with full voltage unless it is completely filled with oil and all air or gas bubbles inside are extracted or eliminated by appropriate means.

Effect of Voltage on Solid Insulating Materials

The breakdown of transformer winding insulation is also initiated by the formation of streamers at a local point, having a high potential gradient. There is, however, one important difference between solid and liquid insulating materials as far as the effect of the streamers is concerned. In a liquid, the streamers disappear when the applied voltage is removed. In a solid, it leaves a permanent mark on the insulation which gets extended on a subsequent exposure to higher voltage or for a longer duration.

The breakdown value is quite high for the insulating material itself, but the formation of streamers is greatly influenced by the porosity of the medium and the moisture content and other impurities in the oil surrounding it. The creepage path is, therefore kept adequately long and surface deposH`s like dust and sludge should not be permitted to accumulate.

37.3 PROPOSED ACTION PLAN FOR REDUCING THE FAILURES OF TRANSFORMER IN SERVICE

Unlike power transformers, which are located at substations, the distribution transformers are scattered all over the area of operation of a power utility. The number of distribution transformers in any electricity distribution company is generally so large, that it is impossible to exercise the same amount of monitoring, control and care as it is done for power transformers. Keeping this in view, it is desirable that the distribution transformers are more robust and sturdy so that they can provide reasonably good service with minimum maintenance. Based on the experience, to reduce failure rate of distribution transformers and to offer a longer life to the transformers in service, an action plan as follows is suggested:

Database

First and foremost action that is necessary on the part of the utilities is to make an exhaustive database which should have information on make, year of purchase, technical details, accessories and fitments, date of commissioning, location, history of maintenance/repair, annual load pattern during peak hours, core and winding inspection report subsequent to fault, if any, and if repair work was done, and all other relevant details.

Moreover, the database will have to be updated periodically and need to be discussed with the vendors for exchange of views.

Analysis of Database

Scanning the database from time to time along with generating reports periodically to ascertain overloaded and underloaded sources, analysis of failures, performance of different vendors, failure rates, cause of failures etc. will help the utilities in identifying the reasons for failures.

Feedback

All failed transformers need to be inspected thoroughly prior to repair/disposal to find out the cause of failure, since such an inspection provides vital feedback on design/manufacturing deficiency or any abuse that the transformer might have been subjected to. Depending on the outcome of such inspections, review and amendment of specifications may have to be initiated.

Protective Devices

Since transformers are exposed to frequent switching surges and short circuits, adequate protective devices like lightning arrestors, HT fuses, LT fuses, ACBs should be provided. The fusing characteristics should be so choosen that proper discrimination of up and down stream protection is ensured.

It is also desirable that prior to introducing any new make fuse/ACB in the system, checks like temperature rise and tripping time should be carried out at the utility’s end.

Specification Upgradation

Since distribution transformers are expected to encounter overloads at times due to seasonal variation of load, outage of adjacent sources etc. suitable provision for over loading should be kept in the specification so that such overloads do not curtail the life drastically. It is desirable that margins should be kept in specifying maximum temperature rise of oil/winding and temperature gradient˘ A distribution transformer may also be subjected to certain amount of overfluxing at times. Provision for this requirement should also be made in the specification. The provision of tap switch in smaller transformers upto certain rating may be deleted. Where the requirement of tapping is essential. it may be done through link board instead of spring loaded roller contact type rotary switch. Elimination of switch will not only improve the performance of the transformers, but also reduce the cost of transformer by approximately 3 to 4%.

Evaluation of Bid Through Loss Capitalization

Bidder should be encouraged to offer best possible low loss transformers when they submit their tenders. Loss figures quoted should be capitalised and the award of the tender should be done on the basis of ‘total capitalised cost.’

The cost for loss capitalisation shall be realistic and encourage lower losses. However, while selecting such offers, other factors like technical evaluation of the bids, performance records of the vendors, their quality awareness, after sales service, financial standing, concern for customer etc. should also be given due consideration. It is suggested to cross verify the losses of such transformers at the utility's end (a routine practice by TNEB).

Verification of Losses and Temperature Rise Tests at Customer's End

In case the utilities really desire to upgrade the quality and to improve the field performance of distribution transformers, it is recommended that they build their own testing set-up for carrying out loss measurements and temperature rise tests. In the event the losses are found beyond guaranteed values but within 10 per cent tolerance, the transformers may be accepted with a penalty of double the capitalization value. However, the transformer with temperature rise beyond guaranteed value may be rejected outright. Such tests may be carried out on transformer selected at random, one from each contract/batch, without prior knowledge of the manufacturers. This is, however, a routine practice of CESC Limited, Calcutta and they are able to maintain a failure rate of distribution transformer at 3 to 4 per cent only (as against a National average of approximately 14 to 15 per cent, and less than one per cent in the advanced countries).

Short Circuit and Impulse Tests on Randomly Selected Transformer from Stores

Short circuit and impulse tests are also needed to be carried out on randomly selected transformer after they have been delivered to the user's stores. Since this is a costly proposition, the test charges may be debited to the manufacturer's account, if the transformer fails to withstand the tests (which is a routine practice of DVB). Photographs of core-coil assembly along with the certified copy of drawing of the tested transformer may be taken for comparison during future supplies.

Role of Vendors

Frequent interaction between the manufacturer and users and visit to the manufacturer's works from time to time are necessary to ensure that the desired quality in manufacturing is maintained. Vendors are to be treated as a part of the team for product refinement and visits by the utilities will go a long way in the development of vendors.

To Define the Requirement of Weights of Basic Materials in the Specification

It is a nice way to restrict the manufacturers to supply substandard/under rated transformers. It is suggested to specify the minimum weight of core, copper/aluminium, oil etc. in the specification as is done by UPPCL for transformers up to 100 kVA ratings.

The quantity and quality of materials actually provided by the manufacturers should be critically verified by the customer during physical verification of transformer at the time of inspection.

These verifications may be done at the manufacturer's premises or at the customer's workshop as deemed fit.

To Improve Service Condition

It was discussed earlier that a harmonious relation and mutual understanding between the manufacturer and the users is very useful in reducing the rate of failure of distribution transformers in service. A good transformer may not run longer in bad service conditions. It is, therefore essential to identify the cause for the premature failure of distribution transformers in service.

Cost of Distribution Transformer

Utilities should essentially have a fair knowledge on rating wise reasonable cost of quality transformers which they buy against various tenders. It is seen that to get an entry, new vendors with limited resources, offer unworkable low prices with reduced rate of taxes and duties and stand lowest in the price comparison. In line with the purchase regulations of some of the power utilities, these low rates are then offered to the established regular vendors for acceptance. This is an unhealthy purchase procedure against quality implementation and should be discouraged.

Preshipment Inspection

Inspection of transformers at the manufacturer's premises before shipment is organized by the buyers. Generally, a group of engineers from the material inspection circle (MIC) usually carry out such inspection regularly. However RSEB, after being transformed into a company, has introduced an excellent system of conducting inspection at the manufacturer's premises by abolishing the inspection circle and instead, engaging engineers from stores, maintenance, distribution or other user departments. With such arrangements, the field engineers get enormous scope to upgrade their knowledge on the product performance and sometimes, exchange their views with the manufacturers for quality improvement.

Sometimes the SEBs engage third party inspection agencies to carry out inspection at the manufacturer premises on behalf of the buyers. The third party inspection agencies are neither buyer nor manufacturer. They cannot add anything to the product quality, but can only increase the cost of product by adding their service charges. Introduction of third party agencies for inspection to domestic purchase is not a positive approach towards quality implementation and may be discontinued. The procedures followed by RSEB (now JVVNL) is quite encouraging and it may be interesting for other SEBs to follow the same.

37.4 CONCLUSION

In the foregoing paragraphs, the probable life of distribution transformers and an action plan for reducing transformer failures in service were discussed. Monitoring the field performance and reviewing the action plan on regular basis will definitely help in reducing the failure rate of transfomers. In this respect, it is also necessary to mention the important role of the vendors. Frequent interaction with the quality vendors is considered to be a vital step towards quality implementation. However there is a lot more to be done still, when we see that in advanced countries, the failure rates are even less than one per cent. Therefore, it should be our endeavour to target such a level and to sustain it once it is achieved.

Section V

CHAPTER 38

Calculations of Various Performance Parameters

FOOD FOR THOUGHT

Continuous improvement—the Japanese call it 'Kaizen'—offers the best insurance for both our career and the organization. 'Kaizen' (pronounced KY' Zen) is the relentless quest for a better way, for higher quality craftsmanship. Think of it as the daily pursuit of perfection.

'Kaizen' keeps us stretching to outdo yesterday's performance. The continuous improvements may come bit by bit. But these small, incremental gains will eventually add up to a valuable competitive advantage. Also, if every employee constantly keeps an eye for improvements, major innovations are more likely to occur. Without 'Kaizen', we and our employer shall gradually lose ground. Eventually, we shall both be out of business, because the competition never stands still.

Nobody can afford to rest on a reputation any more. Circumstances change too quickly. Competition gets tougher and more global all the time. What we consider 'good' today may not be so tomorrow.

Every single employee should assume personal responsibility for upgrading his or her job performance. Our productivity, response time, quality, cost control, and consumer service should all show steady gain. And our skills should be in a state of constant renewal.

38.1 INTRODUCTION

This chapter covers the calculations of various performance parameters of distribution transformers. Though these are not a part of quality assurance, the calculations will provide a fair reference to the readers for evaluating correctly the performance parameters during design and manufacture. Procedures for measuring flux density and current density during inprocess checking are highlighted. Design parameters with respect to impedance, radiator details, resistance, reactance etc. are also shown. The calculation of efficiency and regulation will help the readers to fill up the technical data sheet while preparation of tender. Calculation of short circuit forces and temperature gradient of winding will help the readers to design a cost effective robust transformer. Examples with various numerical values of a 100 kVA, 11/0.433 kV, aluminium-wound transformer are provided.

38.2 FLUX DENSITY

Flux density is expressed by the formula:

$$V/T = 4.44 \times f \times B_m \times A_g \times K \times 10^{-6} \qquad ...(1)$$

where, V/T = Voltage per turn

f = Frequency in Hz

B_m = Flux density in tesla

A_g = Gross core area in sq. mm

K = Stacking factor

The expression (1) may be rewritten as

$$B_m = \frac{V/T \times 10^6}{4.44 \times f \times A_g \times K} \qquad ...(2)$$

Example: Let us calculate the flux density of a 100 kVA, 11/0.433 kV, aluminium-wound, Delta/Star connected transformer with the following assumed parameters:

Secondary turns (T) = 76 T

Secondary phase voltage (V) (star connected) = $\frac{433}{\sqrt{3}}$ 250 V

Frequency (f) = 50 Hz

Gross core area (A_g) = 9594.2 sq. mm

Stacking factor (k) = 0.97

Therefore, Flux density, $B_m = \dfrac{250/76 \times 10^6}{4.44 \times 50 \times 9594.2 \times 0.97}$ = 1.592 T.

In the event, the cross section of core limb and yoke are different, the core area of limb and yoke should be measured separately for calculating maximum flux density. The evaluation of gross core area is a typical mechanical measurement with the help of vernier calliper or other similar types of instruments.

The cross section of the core limb of a 100 kVA, aluminium-wound transformer is shown in Fig. 38.1.

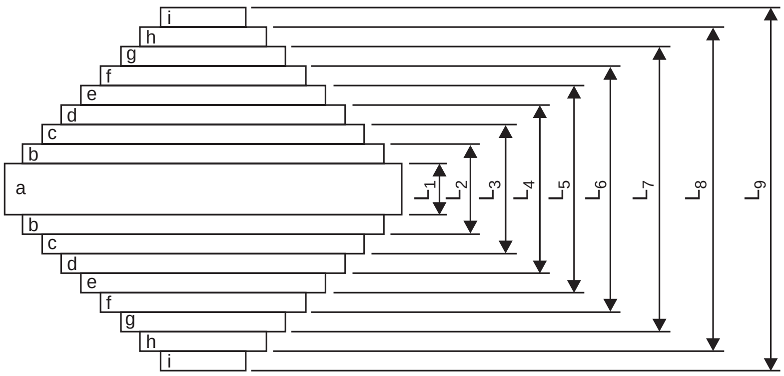


Fig. 38.1. Sectional view of a core limb

The limb has nine steps designated as *a, b,* c, *d, e, f, g, h* and *i.* The stack heights are designated as L_1, L_2, L_3, L_4, L_5, L_6, L_7, L_8, and L_9.

Procedure for Measurement of Gross Core Area (A_g)

The limb is held tight between the jaws of a 'C-clamp'. The step widths *a, b, c, d, ... i* are measured and recorded. The stack heights L_1, L_2, L_3, L_4... L_9 are also measured and recorded.

Gross core area, $A_g = a \times L_1 + b \times (L_2 - L_1) + c \times (L_3 - L_2) + d \times (L_4 - L_3) + e \times (L_5 - L_4)$
$+ f \times (L_6 - L_5) + g \times (L_7 - L_6) + h \times (L_8 - L_7) + i \times (L_9 - L_8)$

For instance, let us assume that the following parameters were recorded during the inprocess checking of a 100 kVA, 11/0.433 kV aluminium-wound transformer.

a =110 mm	L_1= 29.93 mm
b = 105 mm	L_2 = 44.39 mm
c = 100 mm	L_3 = 54.73 mm
d = 90 mm	L_4 = 69.97 mm
e = 80 mm	L_5 = 81.21 mm
f =70 mm	L_6 = 89.97 mm
g = 60 mm	L_7 = 96.93 mm
h = 50 mm	L_8 =102.45 mm
i = 40 mm	L_9 =106.75 mm

Therefore, the cross sectional area (A_g) :

$$A_g = 110 \times 29.93 + 105 \times (44.39 - 29.93) + 100 \times (54.73 - 44.39)$$
$$+ 90 \times (69.97 - 54.73) + 80 \times (81.21 - 69.97) + 70 \times (89.97 - 81.21)$$
$$+ 60 \times (96.93 - 89.97) + 50 \times (102.45 - 96.93) + 40 \times (106.75 - 102.45)$$
$$= 110 \times 29.93 + 105 \times 14.46 + 100 \times 10.34 + 90 \times 15.24 + 80 \times 11.24 + 70 \times 8.76$$
$$+ 60 \times 6.96 + 50 \times 5.52 + 40 \times 4.3$$
$$= 3292.3 + 1518.3 + 1034 + 1371.6 + 899.2 + 613.2 + 417.6 + 276 + 172$$
$$= 9594.2 \text{ sq.mm.}$$

Following points are to be considered while measuring core area:

(*i*) Measurement of gross core area by the above procedure is fairly accurate with a working tolerance of ± 1% towards human error and accuracy of the measuring instruments.

(*ii*) In case the laminations have excessive burrs at the cut edges, core stack measured by the above process may prove to be erroneous, as the burrs may lead to errors in measurement with vernier calliper. In such cases, it is suggested to dismantle the limb and measure individual stacks with a micrometer or any other suitable instrument.

(*iii*) Because of thickness variations in the laminations, the core area of all the three limbs as well as yokes cannot be equal. It is, therefore suggested to measure the total stack of core for all the limbs and yoke and the detailed exercise of measuring individual stack should be done on that limb (or yoke) which has yielded minimum stack. This will enable us to measure the minimum core area for evaluating the maximum flux density.

(*iv*) The instruments used for such measurements should have valid calibration certificates. Before measurement, the 'zero-error' of the instrument should be checked. In the event, the instrument has zero error, either positive or negative, each measurement should be corrected accordingly.

38.3 CURRENT DENSITY

Current density *(c/d)* is represented by the formula:

$$c/d = \frac{\text{Current in } A}{\text{Area of conductor in sq. mm}} \quad ...(3)$$

and is expressed as Ampere per sq. mm.

(a) Measurement of Current Density for Round Conductor

In the case of a transformer with round DPC/TPC covered conductor, the paper insulation is removed gently by hand without using knife or any sharp blade. The diameter of the bare conductor is measured with a micrometer at different locations to record minimum diameter. In the event the transformer is made with enamel conductor, to remove the enamel coating, a certain length of conductor is put under flame to ensure that the enamel coating is completely burnt. Further, sufficient time should be allowed to cool the conductor down to room temperature, since hot conductor may get elongate during cleaning.

The diameter of the bare round conductor is measured with a micrometer and the area of conductor is calculated as $\frac{\pi \times d^2}{4}$, where '*d*' is the diameter of the conductor.

Once the conductor area is known, the current density is calculated rising expression (3).

(b) Measurement of Current Density for Rectangular Strip Conductor

As discussed above, the conductor covering is removed gently without using knife or emery paper or any sharp material.

The width and depth of the bare strip are measured using a micrometer. The cross sectional area is calculated as: width × depth. However, the reduction due to corner radius should be taken into account. Once the area of the strip is known, the current density is calculated using expression (3).

Example: Let us calculate the current density of winding wire and strip of a 100 kVA, 11/0.433 kV, aluminium-wound, Delta/Star connected transformer with the following assumed parameters:

HV conductor (bare) = 1.7 mm dia.

LV conductor (bare) = 10 × 4.6 mm × 2 nos. in parallel

(*i*) HV current density $= \frac{\text{HV phase current in Amp}}{\text{Conductor area in sq. mm}}.$

For 100 kVA, 11 kV, Delta connected HV winding, the HV phase current $= \frac{100 \text{ kV A}}{3 \times 11 \text{ kV}} = 3.03$ A

$$\text{Conductor area} = \frac{\pi \times d^2}{4} = \frac{\pi \times 1.7^2}{4} = 2.269 \text{ sq. mm}$$

Therefore, HV current density $= \dfrac{3.03\,A}{2.269}$ sq. mm

$= 1.335$ A/sq. mm

(*ii*) LV current density $= \dfrac{\text{LV phase currentin A}}{\text{Conductor area in sq. mm}}$

For 100 kVA, 11/0.433 kV star connected LV winding, The LV phase current

$$= \frac{100 \text{ kVA}}{\sqrt{3} \times 0.433 \text{ kV}} = 133.34 \text{ A}$$

Conductor area = (Width × depth) – (Rounding-off factor for corner radius)

= [(10 × 4.6) – 0.86] × 2 = 90.28 sq. mm

Therefore, LV current density $= \dfrac{133.4\text{A}}{90.28 \text{ sq. mm}} = 1.477$ A/sq. mm

Following are some of the points to be considered while measuring dimensions of bare fare winding wire and strip:

(*i*) Dimension of the conductor should be measured at various locations and the minimum dimension should be recorded.

(*ii*) Removal of insulation should be done in such a way that the bare dimension is never affected.

(*iii*) While calculating the area of rectangular strips, the rounding-off factor as given below for various depths is deducted from the overall area of the strip:

Table 38.1

Depth of strip	*Reduction due to corner radius*
Up to a depth of 1.6 mm	0.21 sq. mm
Up to a depth of 2.24 mm	0.36 sq. mm
Up to a depth of 3.35 mm	0.55 sq. mm
Above 3.35 mm	0.86 sq. mm

(*iv*) Micrometer is generally recommended for such measurements. The instruments should have valid calibration certificates. In case the instrument has zero error, the same should be taken into account.

(*v*) The results of such measurements may be further subjected to a tolerance of ± 0.5% towards human error and instrumental error.

38.4 DESIGN CALCULATION OF IMPEDANCE

Impedance is the vectorial sum of reactance and resistance. In transformer, it is customary to represent the impedance as '*Z*' and is expressed as percentage, similarly the reactance as '*X*' and the resistance as '*R*'. The relation between '*Z*', '*X*' and '*R*' is:

$$\%Z = \sqrt{\left(\% X^2 + \% R^2\right)} \quad \text{...(4)}$$

(a) Calculation of Percentage Reactance

Before calculating reactance, let us make ourselves familiar with various constructional parameters and internal clearances which are shown in Fig. 38.2.

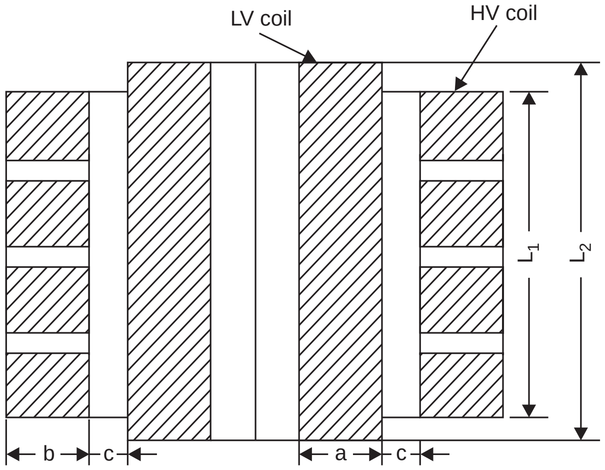


Fig. 38.2. Sectional view of a coil assembly

Figure 38.2 indicates a section of the coil assembly of a single limb for a three phase transformer. It has one LV coil and four HV coils. Various apartments shown are represented below:

L_1 = Stack length of HV coil

L_2 = Stack length of LV coil

a = Radial build of LV coil in cm, which is equal to

$$\frac{OD - ID}{2}$$

b = Radial build of HV coil in cm, which is equal to

$$\frac{OD - ID}{2}$$

c = Radial gap between LV and HV coil in cm, which is equal to

$$\frac{ID\ of\ \text{HV} - OD\ of\ \text{LV}}{2}$$

Formula commonly used for calculating percentage reactance is

$$X\% = \frac{7.91 \times f \times I_s \times T^2 \times \pi \times D}{I_s \times A_L} \times \left(c + \frac{a+b}{3}\right) \times 10^6 \qquad \text{...(5)}$$

where a, b, c are as discussed above

f is the frequency in Hertz

I_s is the rated secondary current in Ampere

T is the secondary turns per phase

D is the average mean diameter of LV and HV coils in mm

V_s is the rated voltage per phase in Volts

A_L is the average stack length of LV and HV coils in mm

For all practical purposes, a multiplying factor of approximately 0.95 to account for the effect of magnetic leakage is recommended while calculating the final value of reactance.

(b) Calculation of Percentage Resistance

It is calculated as load loss in kW, expressed in percentage of rated kVA and is represented as

$$\text{Percentage resistance } \frac{\text{Load loss in kW}}{\text{kVA}} \times 100 \qquad ...(6)$$

Once the percentage reactance and resistance are known, the percentage impedance is calculated using expression (4).

Example: An example to explain the procedures of calculation of impedance is shown below:

Rating = 100 kVA
Voltage ratio = 11/0.433 kV
Connection = Delta/Star
LV coil (*ID* × *OD* × L_2) = 120 × 162 × 470 mm (media dia. = 141 mm)
HV coil (*ID* × *OD* × L_1) = 182 × 252 × 440 mm (media dia. = 217 mm)
Load loss at 75°C = 1.7 kW
Secondary turns per phase = 76 T

Let us establish the various parameters of expression (5)

$$a = \frac{(16.2 - 12.0)}{2} = 2.1 \text{ cm}$$

$$b = \frac{(25.2 - 18.2)}{2} = 3.5 \text{ cm}$$

$$c = \frac{(18.2 - 16.2)}{2} = 1.0 \text{ cm}$$

$$f = 50 \text{ Hz}$$

$$I_s = \frac{100\,\text{kVA}}{\sqrt{3} \times 0.433\text{ kV}} = 133.34 \text{ A}$$

$$V_s = \frac{433}{\sqrt{3}} = 250 \text{ V}$$

$$A_L = \frac{L_1 + L_2}{2} = \frac{440 + 470}{2} = 455 \text{ mm}$$

$$T = 76 \text{ T}$$

$$D = \frac{\text{Mean dia of HV + Mean dia. of LV}}{2}$$

$$= \frac{217 + 141}{2} = 179 \text{ mm}$$

Therefore, percentage reactance,

$$X(\%) = \frac{7.91 \times 50 \times 133.34 \times 76^2 \times \pi \times 179}{250 \times 544} \times \left(1.0 + \frac{2.1 + 3.5}{3}\right) \times 10^{-6}$$

$$= 1505863.6 \times 2.867 \times 10^{-6} = 4.3173\%$$

Multiply the above by 0.95 towards leakage flux, $X\%$ = 4.3173 × 0.95 = 4.10%

Percentage resistance, $R(\%) = \dfrac{\text{Load loss in kW}}{\text{kVA}} \times 100$

$$= \frac{1.7}{100} \times 100 = 1.7\%$$

The value of $X(\%)$ and $R(\%)$ may be substituted in expression (4) for evaluating impedance.

Therefore, impedance, $Z(\%) = \sqrt{X(\%)^2 + R(\%)^2} = \sqrt{4.1^2 + 1.7^2} = 4.44\%$.

The purpose of the above example is to provide a general idea to the readers on the procedure of calculating percentage impedance from the available basic coil dimensions. Before proceeding to manufacture the coils of a transformer of a particular design, the design can be reviewed with the above calculations to see whether the impedance is within the reasonable tolerance limit or not.

Calculation of impedance from the test results of finished transformer, is given in detail in Section 38.14.

(c) Calculation of Reactance in Ohms

Rating = 100 kVA
Voltage ratio = 11/0.433 kV
Connection = Delta/ Star
Percentage reactance = 4.1%

Reactance in ohms per phase $= \dfrac{\text{Per unit reactance} \times \text{Primary voltage}}{\text{Primary phase current}}$

where, Per unit reactance = 0.041
Primary voltage = 11000 V

Primary phase current $= \dfrac{100}{3 \times 11} = 3.03$ A

Therefore,

Reactance in ohms per phase $= \dfrac{0.041 \times 11000}{3.03} = 148.84$ ohms.

38.5 HEAT DISSIPATION CALCULATION

When the total loss of a transformer is more than the loss dissipated by the tank wall, radiators are employed to cool down the heat generated due to excess loss, and to offer a longer life to the transformer. Construction of radiator should be such that it allows free circulation of oil for dissipation of heat. Various types of radiators are discussed in Chapter 8 of Section-II. Here we shall take up some of the design aspects to be considered for quality performance of transformer.

(a) Elliptical Tube Radiator

Thumb rule recommended by various SEBs for heat dissipation for 45°C rise in oil temperature is as below:

(*a*) Dissipation of heat by tank body: 500 W/sq. m (only through side wall).
(*b*) Dissipation of heat by elliptical tube: 55 W/m having section 57 (International code for elliptical tube of size 75 × 15 mm).

Though the above assumptions are fairly correct towards satisfactory performance of transformers, a different expression as stated below will give the readers some alternate access to verify the heat dissipation requirements.

$$\text{No. of tubes required} = \frac{1}{8.8 \times X \times Y} \times \left[\frac{K}{L} - 12.5\,A\right] \quad ...(7)$$

where, A = Tank surface area in sq.m (side and top only)

K = Total loss in watts (guaranteed no-load and load loss)

L = Average oil temperature rise (maximum guaranteed oil temperature rise multiplied by 0.8)

Y = Unit length of tube in metre

X = Surface length of elliptical tube in metre

= 2 × (major axis + minor axis) × 0.9

= 2 × (75 + 15) × 0.9

= 162 mm (0.162 m).

Example: Let us establish an example for calculating the details of elliptical tube radiators of a 100 kVA, 11/0.433 kV, aluminium-wound transformer with the following assumed parameters:

Tank dimensions *(L × B × HT)*	: 0.835 × 0.335 × 0.905 m
Guaranteed no-load and load loss	: 260 W and 1760 W
Length of each tube	: 0.590 metre
Maximum oil temperature rise	: 45°C.

Calculation to Derive Number of Tubes

(i) As recommended by SEBs

Tank surface area (side wall only)

= 2 × (0.835 + 0.335) × 0.905

= 2.1177 sq. m

Loss dissipated by per sq.m of tank surface	= 500 W (assumed)
Therefore,	
Loss dissipated by tank surface only	= 2.1177 × 500 = 1059 W
Total loss to be dissipated (total guaranteed loss)	= (260 + 1760) = 2020 W
Loss in excess which is to be dissipated by radiator	= (2020 – 1059) = 961 W

Elliptical tube having section 57 of size 75 × 15 mm can dissipate 55 W/m for an oil temperature rise of 45°C.

Therefore, length of tube to dissipate 961 W $= \frac{961}{55} = 17.5$ m

Length of each tube = 0.590 m

Therefore, no. of tubes $= \frac{17.5}{0.59}$ 30 tubes

Two radiators each having 16 tubes of length 590 mm per tube can be used.

(ii) As per expression (7)

$$\text{No. of tubes} = \frac{1}{8.8 \times X \times Y}\left[\frac{K}{L} - 12.5 \times A\right]$$

where, A = Tank surface area in sq.m which includes side and top only (excluding bottom).

= Side tank surface + Top tank cover

= 2.1177 + (0.835 × 0.335)

= 2.40 sq. m

K = Total loss 2020 W

L = 45 × 0.8 = 36° C

X = 0.162 m

Y = 0.59 m

Therefore,

$$\text{No. of tubes} = \frac{1}{8.8 \times 0.162 \times 0.59}\left[\frac{2020}{36} - 12.5 \times 2.4\right] = 31 \text{ nos.}$$

Two radiators each having 16 tubes of length 590 mm per tube can be used.

Though the approach for calculating the no. of tubes in the above two cases are different, the ultimate figures for no. of tubes in both the cases are almost same, *i.e.*, 30 tubes in case of: (*a*) and 31 tubes in case of (*b*). However, if we are required to design transformer for 40°C oil temperature rise, watt loss per metre tube may be taken as 42 W/m instead of 55 W/m.

Figure 38.3 will give a fair idea on the construction and layout of elliptical tube radiators for small transformer.

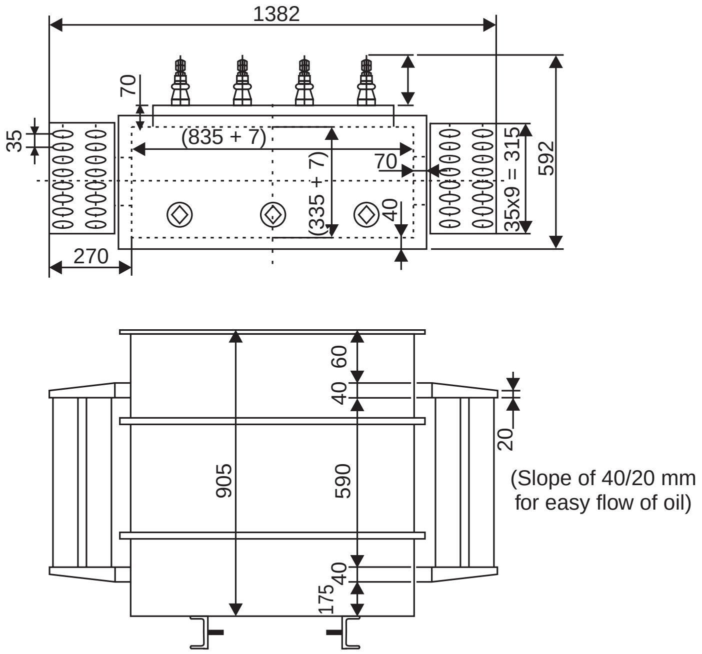


Fig. 38.3. Construction of tank with elliptical tube radiators

(b) Pressed Steel Radiator

These radiators are fabricated from 1.0 to 1.2 mm CRCA sheet having varying width of 230 mm, 300 mm and 520 mm. The centre height of the header pipe generally starts from 400 mm up to a maximum of 3000 mm in multiples of 100 mm, *i.e.*, 400, 500, 600, 700, 800 ... 2900, 3000. Number of fins per radiator are calculated on the basis of tank surface area and guaranteed loss.

It was stated earlier that the tank wall can dissipate a loss of 500 W/sq. m. Based on this assumption, loss dissipated by the tank wall is calculated first. Radiators are employed to dissipate the heat generated due to excess loss. Standard heat dissipation charts are available from the radiator manufacturers for various widths of fins and centre height of header pipe. Heat dissipation charts and various correction factors such as no. of fins, spacing between two consecutive radiators, thermo syphone height etc. are highlighted in Chapter-8, Section-II.

Example: The following is an example for calculating the no. of fins on the basis of available heat dissipation chart of a 100 kVA, 11/0.433 kV aluminium-wound transformer.

Tank dimension

($L \times B \times HT$) : 0.835 × 0.335 × 0.905 m

Maximum top oil temperature rise: 45°C.

Guaranteed no-load and load loss: 260 W and 1760 W.

Figure 38.4 will help to identify the centre height of header pipe as 700 mm.

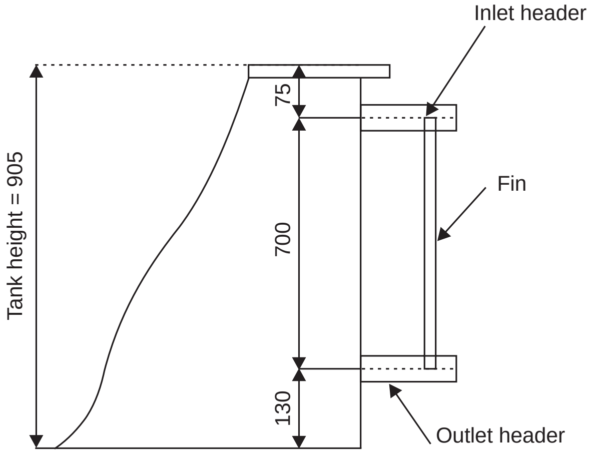


Fig. 38.4. Formation of pressed steel radiator

Calculation

Tank surface area (only side wall)

$$= 2 \times (0.835 + 0.335) \times 0.905$$
$$= 2.1177 \text{ sq. m}$$

Loss dissipated by per sq.m tank surface is assumed to be 500 W. Therefore,

Loss dissipated by tank surface only = 2.1177 × 500 = 1059 W

Total loss to be dissipated (total guaranteed loss) = (260 + 1760) = 2020 W

Loss in excess which is to be dissipated with the help of radiator = 2020 – 1059 = 961 W

To form a pressed steel radiator, the following values are assumed:

(*i*) Centre height of header pipe: 700 mm (*c/d*)

(*ii*) Width of fins (assumed): 230 mm having 3 channels for oil flow

(*iii*) Heat dissipation per fin for oil excess temperature of 45°C for 700 *c/d* (available from heat dissipation chart) : 127 W/fin

(*iv*) Correction factor for vertical distance between core centre line and radiator centre line of 80 mm (Fig. 38.5) is 0.85.

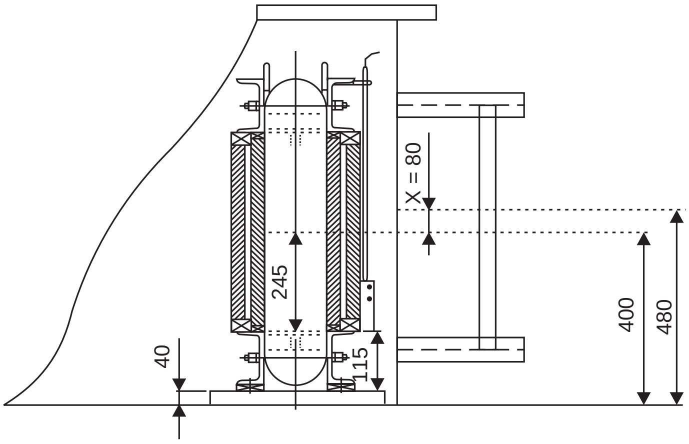


Fig. 38.5. Correction factor of vertical distance between transformer core and radiator centres line

(*v*) Horizontal distance between two consecutive radiators is approximately 500 mm (Fig. 38.6) Correction factor = 1.0.

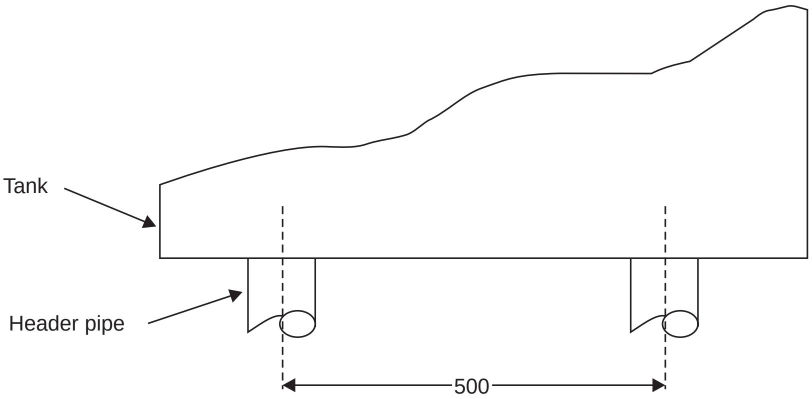


Fig. 38.6. Horizontal distance between two consecutive radiators

(*vi*) No. of fin per radiator (4 to 5 nos.)

Correction factor: 1.06

Therefore, heat dissipated by each fin after taking into consideration the above three correction factors: (0.85 × 1.0 × 1.06) × 127 = 0.901 × 127 = 114 W/fin.

To dissipate loss in excess of 961 W, we need to use

$$\frac{961}{114} = 8.4 \text{ fins}$$

It is proposed to use two radiators each having 5 tins with *c*/*d* 700 mm and width 230 mm as shown in Fig. 38.7.

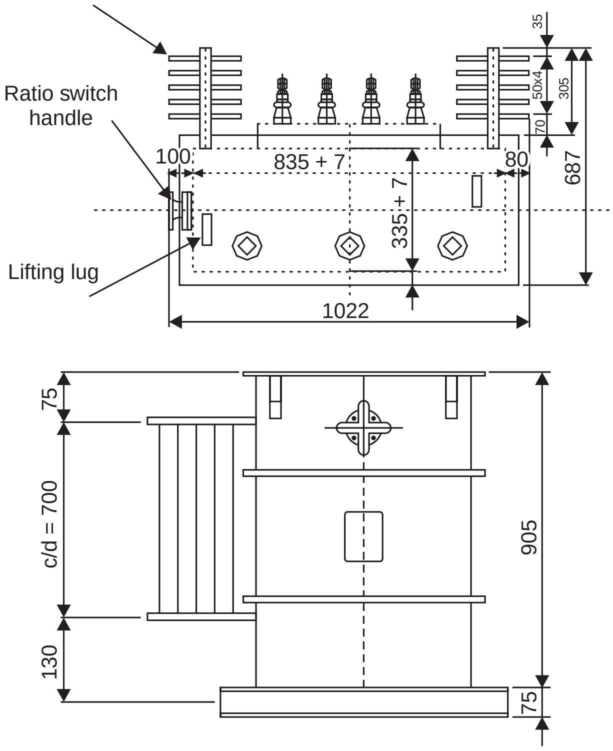


Fig. 38.7. Construction of tank with pressed steel radiators

(c) Corrugated Wall Panel

Since the corrugated wall panel covers almost 90% of the tank wall surface on all the four sides, leaving a small portion at the top and bottom, the entire loss in the transformer is required to be dissipated only by the corrugated panel. In the cases of elliptical tube radiator and pressed steel radiator, the dissipation of heat is effected by circulation of oil through convection process. Hot oil, being lighter, rises up, goes into the top header pipe, pushes the heavier oil down through the bottom header pipe, which again gets heated up and rises up. This is how it completes the circulation of oil as represented in Fig. 38.8.

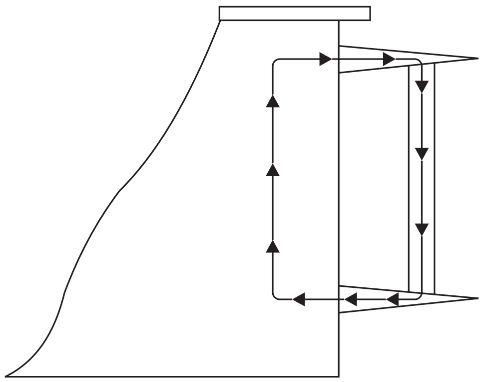


Fig. 38.8. Oil circulation by convection process through header pipe

But in the case of corrugated wall panel, the dissipation of heat is effected through radiation only. Due to corrugation, the radiating surface of the tank body increases many fold, resulting in easy dissipation of heat to the surrounding atmosphere. During service, the windings are heated up. The heat is taken away by the surrounding oil and released to the atmosphere through the corrugated wall surface. During the process of heat transfer, both the windings and oil get heated up and attain some temperature.

Once the transformer runs continuously at rated load without much variation in ambient temperature, the additional heat generated by the windings is taken away by the oil and dissipated completely to the surroundings through the corrugated wall panel, without retaining any heat in the winding and oil. This is called thermal equilibrium condition. At this stage, so long as the load and ambient temperature remain steady, the oil and winding temperature remain constant throughout any further operation.

Since corrugated wall panel dissipates heat through radiation only, calculation to arrive at the fin length and depth are entirely different from that of elliptical tube and pressed steel radiators.

Example: Let us examine a simple example for calculating the details of a corrugated panel on the basis of heat dissipation chart of a 100 kVA, 11/0.433 kV aluminium-wound transformer.

Tank dimension ($L \times B \times HT$) : 835 × 335 × 905 mm
Maximum top oil temperature : 45°C
Guaranteed no load and load loss : 260 W and 1760 W.

Calculation

Figure 38.9 will help to identify the height of corrugated fin as 700 mm.

Based on the manufacturing practice and standard pitch distance between two consecutive fins and end space, number of fins on longer and shorter sides of the tank are estimated. Here, the pitch is 45 mm and end space is 25 mm as represented in Fig. 38.10.

Therefore,
No. of fins on each of the longer sides

$$= \frac{835 - (2 \times 25)}{45} + 1 = 18.44 \text{ fins}$$

= 18 fins (round-off to lower whole number)

No. of fins on each of the shorter sides

$$= \frac{335 - (2 \times 25)}{45} + 1 = 7.33 \text{ fins}$$

= 7 fins (round-off to lower hole number)

Therefore, total no. of fins for all four sides

= (2 × 18 + 2 × 7) = 50 fins

Total guaranteed loss = (220 + 1760) = 2020 W

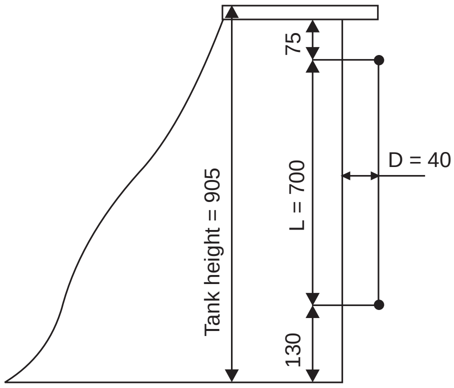


Fig. 38.9. Location of fixing of corrugated wall panel with respect to tank height

So far, we have estimated that the corrugated panel has a total of 50 fins, 700 mm is the height of each fin and loss to be dissipated is 2020 W.

Therefore, $$\frac{\text{W}}{\text{fin.m}} = \frac{\text{Loss in W}}{\text{No. of fin} \times \text{Height of fin in metre}}$$

$$= \frac{2020}{50 \times 0.7} = 58 = 60 \text{ (round-off)}$$

We shall now refer the heat dissipation curves (Fig. 38.14) which will provide us the depth (D) of fin corresponding to the calculated value of W/fin.m for various top oil temperature rise.

For 45°C top oil temperature rise, the depth of fin (D) is 40 mm corresponding to 60 W/fin.m.

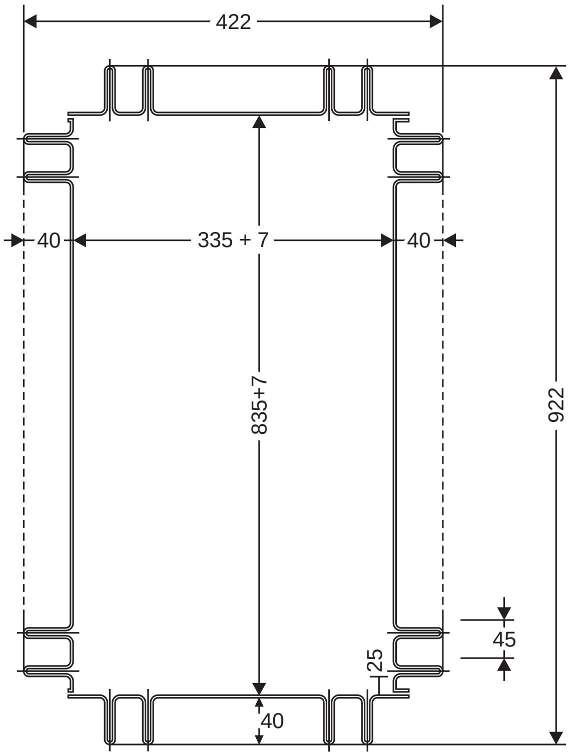


Fig. 38.10. Formation of tank with corrugated wall panel

The final result is that the tank has corrugated panels, two on longer sides, each having 18 fins and two on shorter sides, each having 7 fins. The depth and height of each fin is 40 mm and 700 mm respectively.

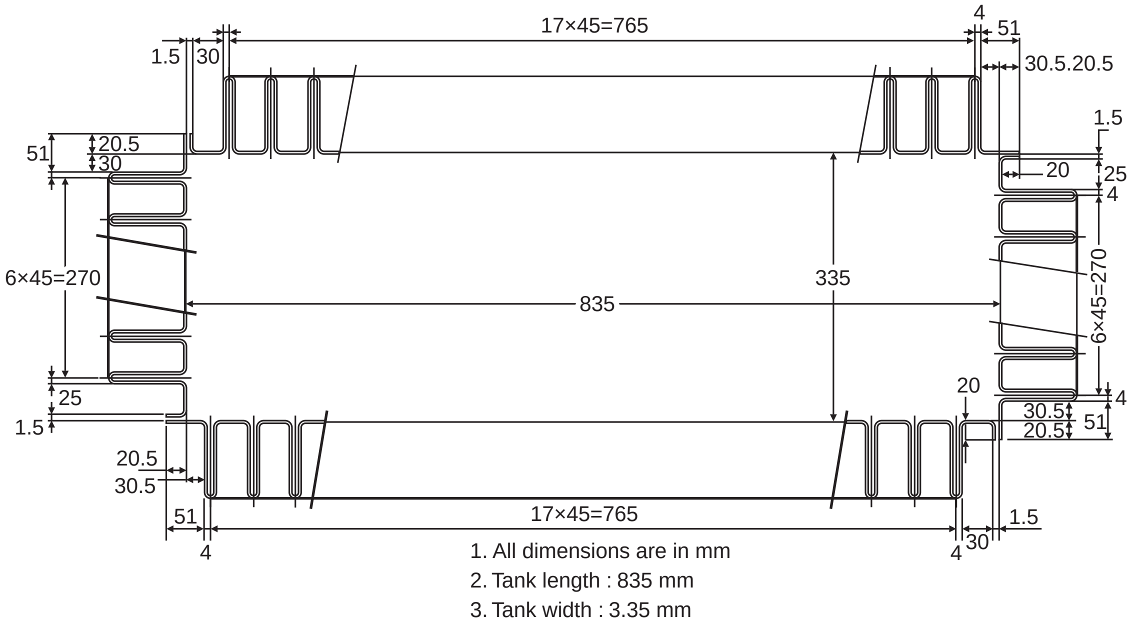
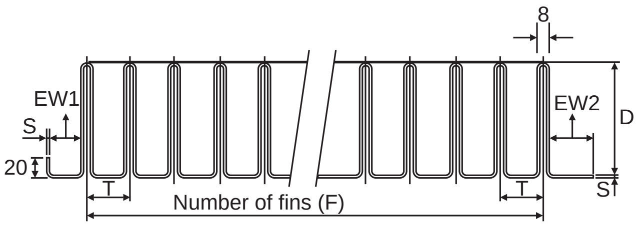


Fig. 38.11. Details of corrugated wall panel

Figures 38.11, 38.12 and 38.13 illustrate various constructional details of corrugated wall panel.



Notes:

1. Wall panel corrugated radiators
   (a) Please adopt your practice for sopt weld etc.
   (b) Inside dimensions of tank are required
   Length–835 mm
   Width–335 mm
2. Radiator depth (D) : 40 mm
3. Radiator Height (H) : 700 mm
4. All dimensions are in mm

	TYPE-A	TYPE-B
S (Material thickness)	1.2 mm	1.2 mm
EW1	30 mm	25 mm
EW2	51 mm	51 mm
D (Fin depth)	40 mm	40 mm
H (Fin length)	700 mm	700 mm
T (Pitch)	45 mm	45 mm
F (No. of fins/rad.)	18 Nos.	7 Nos.
Quantity per transformer	2 Nos.	2 Nos.

Fig. 38.12. Fabrication details of corrugated wall panel

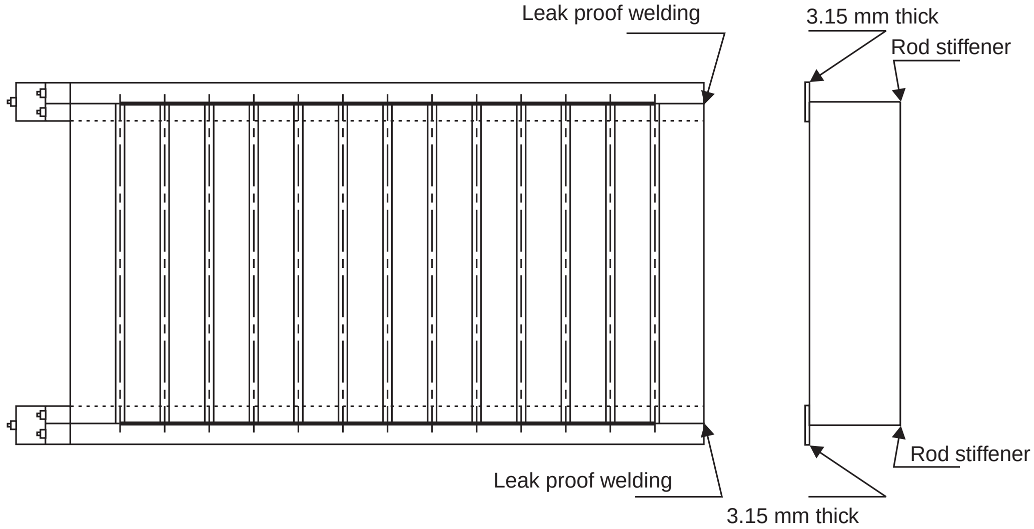


Fig. 38.13. Additional thick strip being welded at top and bottom for easy fixing of the panel to the tank body

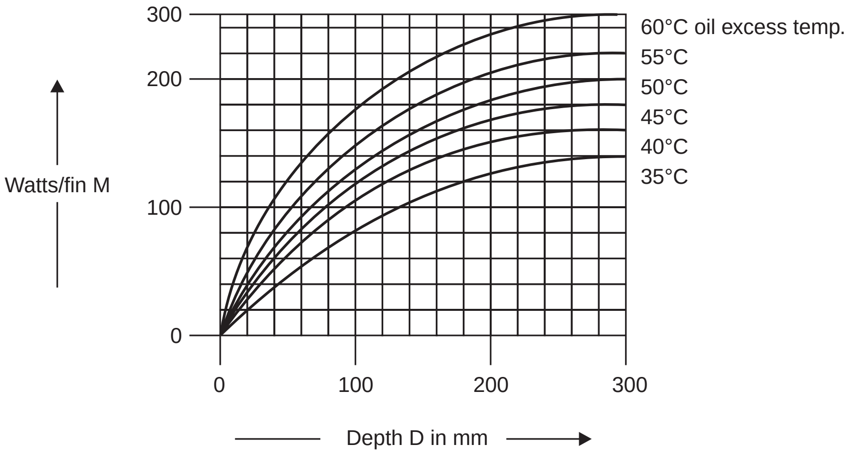


Fig. 38.14. Characteristic curve showing the depth of corrugated wall panel corresponding to W/fin.m

38.6 THERMAL TIME CONSTANT

Thermal time constant is the time which would be required for a transformer loaded at rated kVA and in a cooling medium at constant temperature, to reach the temperature rise attainable under steady state conditions, if the initial rate of temperature rise, when no heat was being dissipated, were maintained.

As per guideline of IEC – 76(2), the time constant (T_o) may be estimated as

$$T_o = \left(\frac{5 \times \text{Total mass of transformer} + 15 \times \text{Mass of oil}}{\text{Total loss}}\right) \times \left[\frac{\text{Top oil rise}}{60}\right] \text{hours.} \qquad ...(8)$$

where, mass of transformer and oil are in Tonne and total loss in kW.

The mass of oil in the conservator should be subtracted from the total mass of oil, since it does not take part in the exchange of temperature.

Example: A 100 kVA, 11/0.433 kV transformer has the following parameters:

Total mass of transformer	= 0.730 Tonne
Total mass of oil	= 0.196 Tonne
Mass of oil in the conservator	= 0.007 Tonne
Total loss	= 2.02 kW
Top oil temp. rise	= 45°C

Therefore, Time constant $T_o = \frac{[5 \times 0.73 + 15 \times (0.196 - 0.007)]}{2.02} \times \frac{45}{60}$ hours = 2.4 hours

More the time constant, better is the performance on overload.

38.7 HOT-SPOT TEMPERATURE

Winding is the cause of generation of heat and since oil remains around the winding, oil is heated up as an effect. However, during the transfer of heat from the winding to the oil, both winding and oil get heated up. At steady state equilibrium condition, the additional heat generated by the winding is totally dissipated by the radiators through oil without the winding or the oil retaining any further heat. This is an ideal condition where sufficient cooling ducts for free circulation of oil are arranged in the coil assembly. In case these ducts are not enough for free flow of oil or the ducts get blocked due to poor workmanship, the circulation of oil is affected resulting in the burning of insulation due to generation of hot-spot temperature, and hence ultimate failure of the transformer.

A close review of failure analysis will show that 70 to 80% of the failures are *HV* winding failure, as it always remains at higher potential. Hot-spot temperature beyond limit deteriorate the insulation quite sharply, resulting in voltage failure. However, the rate of failure of *LV* winding is substantially low, since it remains at low potential and are not so venerable like *HV* winding.

Calculation of Hot-Spot Temperature

Example: Let us examine the hot-spot temperature over an average ambient temperature of 32°C for maximum rise is temperature of oil/winding of 40/50°C

Maximum top oil temperature rise	: 40°C
Average rise of oil temperature (80% of top oil rise)	: (40 × 0.8) = 32°C
Maximum winding temperature	: 50°C
Gradient between winding and average rise of oil	: (50 – 32) = 18°C
Peak gradient (110% of average gradient)	: (18 × 1.1) = 19.8°C
Hot-spot temperature rise	: (19.8 + 40) = 59.8°C
Hot-spot temperature over average ambient temperature of 32°C	: (59.8 + 32) = 91.8°C.

38.8 APPROXIMATE WEIGHT OF FULLY ASSEMBLED CORE

During cost estimation, it is necessary to find out the complete weight of the assembled core without any detailed calculation. This is calculated with the following available information:

Window height of core	: *W*/*H*
Limb centre of core	: *C*/*L*
Gross sectional area of core	: A_g
Width of first step (maximum width of core)	: *L*
Specific gravity of core material	: *D*

Formula being employed for calculating the weight of core is:

$$\text{Weight} = [(3 \times W/H + 4 \times C/L) + 2 \times L \times 0.86] \times A_g \times D \times 0.97 \times 10^{-3} \quad \text{...(9)}$$

where, *W*/*H*, *C*/*L* and *L* are in cm and A_g in sq. cm.

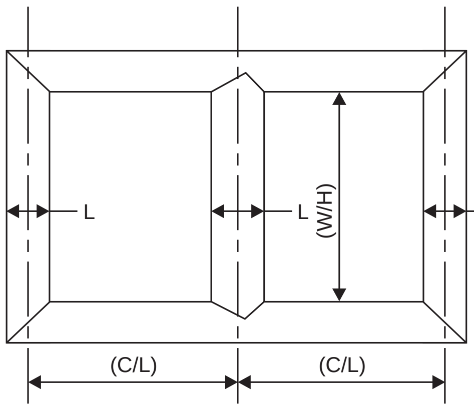


Fig. 38.15. View of a fully mitre cut core assembly

Example: A 100 kVA, 11/0.433 kV aluminium-wound transformer has the following assumed parameters:

Window height of core (*W*/*H*)	: 49 cm
Limb centre of core (*C*/*L*)	: 26.5 cm
Width of first step (*L*) (maximum width of core)	: 11 cm

Gross sectional area of core (A_g) : 95.942 sq.cm
specific gravity of core material (D) : 7.65 g/cc
Therefore, approximate weight of complete assembled core is:

$$= [(3 \times 49 + 4 \times 26.5) + 2 \times 11 \times 0.86)] \times 95.942 \times 7.65 \times 0.97 \times 10$$
$$= 193.6 \text{ kg}$$

The weight of core calculated by the above formula is fairly correct and is within ± 1 % of the actual designed weight.

38.9 CALCULATION OF WINDING RESISTANCE AND LOAD LOSS

While designing a transformer, we need to calculate the winding resistance as well as load loss. Since these are performance parameters of a transformer and are often required to be figured in the technical data sheet, it is necessary to see that these figures are calculated with fine accuracy.

Example 1: Let us calculate the resistance and load loss of a 100 kVA, 11/0.433 kV, aluminium-wound, Delta/Star connected transformer having following parameters:

LV coil ($ID \times OD$) : 120 × 162 mm (mean dia. 141 mm)
HV coil ($ID \times OD$) : 182 × 252 mm (mean dia. 217 mm)
Size of LV strip, bare (A) : 11 × 4.5 mm × 2 nos. in parallel (net area 97.28 sq.mm)
Size of HV wire, bare (A) : 1.7 mm dia. (net area 2.27 sq.mm)
LV turns per phase : 76 T
HV turns per phase : 3344 T
Resistivity of aluminium *(L)* : 0.0345 ohm mm^2/m at 75°C.

Calculation

Table 38.2

Particular	*LV coil*	*HV coil*
Mean length turn (*Mlt*) (π × mean dia.)	π × 141 = 443 mm	π × 217 = 682 mm
Length of conductor (*K*) (*Mlt* × turns)	443 × 76 = 33668 mm	682 × 3344 = 2280608 mm
Resistance per phase at 75°C	$\frac{0.0345 \times 33668 \times 10^{-3}}{97.28}$	$\frac{0.0345 \times 2280608 \times 10^{-3}}{2.27}$
$R = \frac{L \times K \times 10^{-3}}{A}$	= 0.012 Ohm	= 34.67 Ohm
Current per phase (I)	$\frac{100}{\sqrt{3 \times 0.433}}$ = 133.34 A	$\frac{100}{3 \times 11}$ = 3.03 A
$3 \times I^2 R$ at 75°C	$3 \times 133.34^2 \times 0.012$ = 3 × 214 = 642 W	$3 \times 3.03^2 \times 34.67$ = 3 × 319 = 957 W

Contd.

Total I^2 R(LV + HV) Approx. stray loss for 100 kVA aluminium-wound transformer Load loss at rated load and at 75°C	(642 + 957) = 1599 W 100 Watt (assumed) (1599 + 100) = 1699 Watt	

Example 2: Let us establish one more example for calculating resistance and load loss of a 630 kVA, 11/0.433 kV copper-wound, Delta/Star connected transformer having following parameters:

LV coil (*ID* × *OD*) : 210 × 256 mm (mean dia. 233 mm)
HV coil (*ID* × *OD*) : 280 × 360 mm (mean dia. 320 mm)
Size of LV strip, bare (*A*) : 11 × 5 mm × 6 nos.in parallel. (net area 324.84 sq. mm)
Size of HV wire, bare (*A*) : 3.1 mm dia. (net area 7.547 sq. mm)
LV turns/phase : 24 T
HV turns/phase : 1056 T
Resistivity of copper (*L*) : 0.021 ohm mm^2/m at 75°C

Table 38.3

Particular	*LV coil*	*HV coil*
Mean length turn *(Mlt)* (π × mean dia.)	π × 233 =732 mm	π × 320 =1006 mm
Length of conductor (*K*) (*Mlt* × turns)	732 × 24 =17568 mm	1006 × 1056 = 1062336 mm
Resistance per phase at 75°C	$\frac{0.021 \times 17568 \times 10^{-3}}{324.84}$	$\frac{0.021 \times 1062336 \times 10^{-3}}{7.547}$
$R = \frac{L \times K \times 10^{-3}}{A}$	= 0.001136 ohm	= 2.96 ohm
Current per phase (*I*) 3 × I^2 R at 75°C	$\frac{630}{\sqrt{3 \times 0.433}} = 840$ A 3 × 840^2 × 0.001136 = 3 × 802 = 2406 W	$\frac{630}{3 \times 11} = 19.1$ A 3 × 19.1^2 × 2.96 = 3 × 1080 = 3240 W
Total I^2 R (LV + HV) Approx. stray loss for 630 kVA copper-wound transformer (15% of I^2R loss) Load loss at rated load and at 75°C	(2406 + 3240) = 5646 W (5646 × 0.15) = 847 W (5646 + 847) = 6493 W	

38.10 CALCULATION OF NO-LOAD LOSS FROM BASIC PARAMETERS

Magnetic characteristics in terms of loss per kg are available for various grades of materials. Considering the desired no-load loss, we need to select first the grade of lamination. Once the grade is decided, loss per kg for the particular grade can easily be found out from the available characteristic curve at the designed flux density. Calculated core weight as illustrated under Section 38.8 multiplied by loss per kg available from characteristic curve is the no-load loss (W_o).

Further on account of slitting, shearing, notching, air gaps, human error during assembly etc. the core loss tends to increase by approximately 30% (for small transformers) from that of the specified value. This is commonly known as handling factor.

Therefore, effective core loss including handling factor is (W_o × 1.3). However, the designer should ascertain correctly the handling factor at the designed flux density based on the workmanship as well as the grade of material used.

30% handling factor is assumed for small distribution transformers. It may vary widely between 20 to 45% on the basis of the rating of transformer, quality of material, processing and workmanship. The readers should select appropriate value of handling factor based on their experience.

Example: A 100 kVA, 11/0.433 kV aluminium-wound transformer has the following parameters:

Weight of core	: 193.6 kg
Designed flux density	: 1.6T
Grade of core	: 27-M4
Lose per kg at 1.6 T for 27-M4 Grade material	: 1.0 W/kg
Handling factor (assumed)	: 30%
Calculated no-load loss (W_o)	: 193.6 × 1.0 × 1.3 × = 251.68 W.

38.11 NO-LOAD CURRENT

No-load current is equivalent to the vectorial sum of magnetising current (1_m) and hysteresis and eddy current $I\ (h + e)$. $I\ (h + e)$ is in phase, where as 'I_m' is perpendicular to voltage vector-V. Since cos 90° is zero, magnetising component of no-load current does not add any wattage to the no-load loss. However, $I\ (h + e)$ is responsible for adding no-load loss to the magnetic circuit. That is why, we always look for magnetic materials with low hysteresis and eddy current losses.

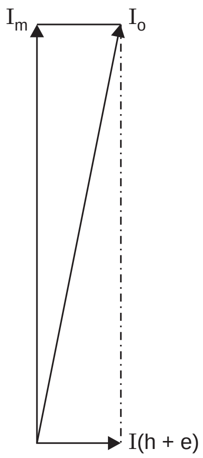


Fig. 38.16. Vector diagram of components of no-load current

Magnetising component of no-load current is many times higher than hysteresis and eddy current component and for that reason, we are required to keep magnetising component as low as possible to make the transformer functioning even at over voltage. Since the transformer has to perform satisfactorily at over voltage also, we should be familiar with the calculation of no-load current at rated voltage as well as at 112.5% voltage.

Example: A 100 kVA, 11/0.433 kV aluminium-wound, Delta/Star connected transformer has the following parameters:

Weight of core	: 193.6 kg
Grade of lamination	: 27 MOH
Flux density at rated condition	: 1.6 T
VA/kg at 1.6 T(rated) (available from the characteristics curve)	: 1.7 VA/kg
VA/kg at 1.8 T(112.5%) (available from the characteristics curve)	: 7.0 VA/kg
No-load loss at rated voltage	: 252 W
No-load loss at 112.5% voltage	: 460 W

Since the measurement of no-load loss and currents are done at low voltage, we shall establish the relation by referring to secondary voltage.

(*a*) No-Load Current at Rated Voltage

(*i*) *Magnetising component of no-load current (I_m)*

Magnetising VA/kg at rated voltage (1.6 T) : 1.7 VA/kg

where, V is the phase voltage (V_p) : $\dfrac{433}{\sqrt{3}} = 250$ V

and weight of complete set of core : 193.6 kg

Per phase magnetising current : $\dfrac{1.7 \times 193.6}{3 \times 250} = 0.44$ A

Add 300% towards handling factor for stress developed during slitting, shearing, notching, thickness variation and human error.

Therefore, per phase magnetising current (I_m) : 0.44 + 3 × 0.44 = 1.76 A

(*ii*) *Hysteresis and Eddy current component of no-load current I(h + e)*

$$I(h + e) = \frac{\text{No-load loss at rated voltage}}{3 \times V_p}$$

$$= \frac{252}{3 \times 250} = 0.336 \text{ A}$$

(*iii*) *No-load current at rated voltage (I_o)*

$$I_o = \sqrt{I_m^2 + I(h+e)^2} = \sqrt{1.76^2 + 0.336^2} = 1.8 \text{ A}$$

No-load current at rated voltage as percentage of full load current = $\dfrac{1.8 \times 100}{133.4} = 1.35\%$

(*b*) No-Load Current at 112.5% Voltage

(*i*) *Magnetising component of no-load current (I_m)*

Magnetising VA/kg at 112.5% voltage (1.8 T) : 7 VA/kg

where, V is phase voltage at 112.5% (V_p) : 250 × 1.125
= 281.25 V

and weight of complete set of core = 193.6 kg

Per phase magnetising current = $\dfrac{7 \times 193.6}{3 \times 281.25} = 1.606$

Add 300% towards handling factor,

Therefore, per phase magnetising current (I_m) : 1.606 + 3 × 1.606 = 6.424 A

(*ii*) *Hysteresis and Eddy current component of no-load current I* (*h + e*)

$$I(h + e) = \frac{\text{No-load loss at 112.5\% voltage}}{3 \times V_p}$$

$$= \frac{460}{3 \times 281.25} = 0.545 \text{ A.}$$

(*iii*) *No-load current at* 112.5% *voltage* (I_o)

$$I_o = \sqrt{I_m^2 + I(n+e)^2} = \sqrt{6.424^2 + 0.545^2} = 6.45\text{A}$$

No-load current at 112.5% voltage as percentage of full load current = $\dfrac{6.45 \times 100}{133.4}$ = 4.84%.

While establishing the no-load current, we have estimated handling factor as 300%, which may vary widely on the basis of the quality of CRGO laminations and workmanship.

The readers may assume a handling factor between 100% to 400% based on the circumstance, experience, grade of CRGO steel, human skill, quality of processing etc.

38.12 EFFICIENCY

Efficiency is defined as output divided by input and is expressed as percentage.

Therefore, efficiency is written as $\dfrac{\text{Output}}{\text{Input}} \times 100\%$

The above expression may be rewritten as = $\dfrac{\text{Output}}{(\text{Output + Losses})}$ × 100% ...(10)

where, output is the rated kVA of the transformer and losses is the sum total of no-load and load loss in kW.

Example: Let us calculate the efficiency of a 100 kVA, 11/0.433 kV transformer with the following parameters:

Rating	: 100 kVA (output)
No-load loss	: 0.260 kW
Load loss at rated load	: 1.76 kW

(*i*) Efficiency at rated load and UPF $= \dfrac{\text{Output}}{(\text{Output + Losses})} \times 100\%$

$$= \frac{100}{(100 + 0.26 + 1.76)} = 98.02\%.$$

(*ii*) Efficiency at 125% load and at UPF $= \dfrac{(100 \times 1.25)}{(100 \times 1.25) + 0.26 + (1.25^2 \times 1.76)} \times 100\%$

= 97.65%.

(*iii*) Efficiency at 75% load and at UPF $= \dfrac{(100 \times 0.75)}{(100 \times 0.75) + 0.26 + (0.75^2 \times 1.76)} \times 100\%$

$= 98.36\%.$

(*iv*) Efficiency at 50% load and at UPF $= \dfrac{(100 \times 0.5)}{(100 \times 0.5) + 0.26 + (0.5^2 \times 1.76)} \times 100\%$

$= 98.62\%.$

(*v*) Efficiency at 25% load and at UPF $= \dfrac{(100 \times 0.25)}{(100 \times 0.25) + 0.26 + (0.25^2 \times 1.76)} \times 100\%$

$= 98.54\%.$

(*vi*) Efficiency at any percentage of load (*n*%) and at UPF

$$= \frac{(100 \times n)}{(100 \times n) + 0.26 + (n^2 + 1.76)} \times 100\%$$

(*vii*) Efficiency at rated load and at 0.8 PF

$$= \frac{(100 \times 0.8)}{(100 \times 0.8) + 0.26 + 1.76} \times 100\%$$

$= 97.54\%.$

(*viii*) Efficiency at 125% load and at 0.8 PF

$$= \frac{(100 \times 0.8 \times 1.25)}{(100 \times 0.8 \times 1.25) + 0.26 + (1.26^2 \times 1.76)}$$

$= 97.08\%.$

(*ix*) Efficiency at 75% load and at 0.8 PF $= \dfrac{(100 \times 0.8 \times 0.75)}{(100 \times 0.8 \times 0.75) + 0.26 + (0.75^2 \times 1.76)} \times 100\%$

$= 97.96\%.$

(*x*) Efficiency at 50% load and at 0.8 PF $= \dfrac{(100 \times 0.8 \times 0.5)}{(100 \times 0.8 \times 0.5) + 0.26 + (0.5^2 \times 1.76)} \times 100\%$

$= 98.28\%.$

(*xi*) Efficiency at 25% load and at 0.8 PF

$$= \frac{(100 \times 0.8 \times 0.25)}{(100 \times 0.8 \times 0.25) + 0.26 + (0.25^2 \times 1.76)} \times 100\%$$

$= 98.18\%.$

(*xii*) Efficiency at any % load and at any PF

$$= \frac{(100 \times n \times PF)}{(100 \times n \times PF) + 0.26 + (n^2 \times 1.76)} \times 100\%$$

Efficiency calculated at different loads and at 0.8 power factors are tabulated on next page:

Table 38.4

Percentage load	*Efficiency at UPF*	*Efficiency at 0.8 PF*
125%	97.65%	97.08%
100%	98.02%	97.54%
75%	98.36%	97.96%
50%	98.62%	98.28%
25%	98.54%	98.18%

A closer look at the table above indicates that the efficiency increases with the decrease of load but up to a load of 50%. At lower percentage of load this relation does not hold good. It could be seen that the efficiency at 25% load is lower than that of 50% load. We shall now take up the procedure of calculating the maximum efficiency with some numerical values.

Maximum Efficiency

No-load loss of a transformer is constant and does not change with the variation of load. However, load loss changes with respect to the loading pattern. Transformer will yield maximum efficiency at a load when the no-load loss and load loss are equal and may be represented as

Load at which maximum efficiency will occur = K

$$K = \sqrt{\frac{\text{No-load loss}}{\text{Load loss}}} \qquad \ldots(11)$$

and maximum efficiency
$$= \frac{(KVA \times K)}{(KVA \times K) + NLL + (K^2 \times LL)} \times 100\% \qquad \ldots(12)$$

where, K is the percentage load
NLL is the no-load loss in kW
LL is the load loss in kW.

Example: A 100 kVA transformer has the following parameters:

Rating : 100 kVA
NLL : 0.26 kW
LL : 1.76 kW

Calculation

Load at which maximum efficiency will occur = K

$$K = \sqrt{\frac{0.26}{1.76}} = 0.3844; \textit{ i.e.}, \text{ at } 38.44\% \text{ load}$$

and maximum efficiency
$$= \frac{(100 \times 0.3844)}{(100 \times 0.3844) + 0.26 + (0.3844^2 \times 1.76)} \times 100\%$$

$$= \frac{38.44}{(38.44 + 0.26 + 0.26)} \times 100\%$$

$$= 98.67\%.$$

38.13 REGULATION

Voltage ratio of a transformer is generally specified at no-load. During loading, the load voltage drops down on the basis of percentage reactance and percentage resistance. For any assumed load *(n)* other than rated load and at any power factor, the percentage regulation is approximately equal to

$$(nE_r\% \cos\varphi + nE_x\% \sin\varphi) + \frac{(nE_x\% \cos\varphi - nE_r\% \sin\varphi)^2}{200} \qquad \ldots(13)$$

where 'n' is the percentage of loading and '$E_r\%$' and '$E_x\%$' are the percentage resistance and percentage reactance respectively.

Example: A 100 kVA transformer has the following parameters:

Percentage resistance $(E_r\%)$ = 1.76%

Percentage reactance $(E_x\%)$ = 4.14%.

Calculation

(*i*) *Regulation at rated load and at unity power factor*

$$n = 1.0$$
$$E_r = 1.76\%$$
$$E_x = 4.41\%$$
$$\cos\varphi = 1.0$$
$$\sin\varphi = \text{Zero}$$

Therefore, regulation at rated load and at

$$\text{UPF} = \frac{(1\times 1.76\times 1 + 1\times 4.14\times 0) + (1\times 4.14\times 1\times 1.76\times 0)^2}{200}$$

$$= (1.76 + 0) + \frac{(4.14 - 0)^2}{200}$$

$$= 1.76 + \frac{4.14^2}{200}$$

$$= 1.85\%.$$

(*ii*) *Regulation at rated load and at 0.8 PF*

$$n = 1.0$$
$$E_r = 1.76\%$$
$$E_x = 4.14\%$$
$$\cos\varphi = 0.8\ (\varphi = 36.87°)$$
$$\sin\varphi = \sin 36.87° = 0.6$$

Therefore, regulation at rated load and at 0.8 PF

$$= \frac{(1\times 1.76\times 0.8 + 1\times 4.14\times 0.6) + (1\times 4.14\times 0.8 - 1\times 1.76\times 0.6)^2}{200}$$

$$= (1.408 + 2.484) + \frac{(3.312 - 1.056)^2}{200}$$

$$= 3.892 + \frac{2.256^2}{200}$$

$= 3.917\%.$

(*iii*) ***Regulation at rated load and at 0.9 PF***

$$n = 1.0$$
$$E_r = 1.76\%$$
$$E_x = 4.4\%$$
$$\cos \varphi = 0.9\ (\varphi = 25.84°)$$
$$\sin \varphi = \sin 25.84° = 0.436$$

Therefore, regulation at rated load and at 0.9 PF

$$= (1 \times 1.76 \times 0.9 + 1 \times 4.14 \times 0.436) + \frac{(1 \times 4.14 \times 0.9 - 1 \times 1.76 \times 0.436)^2}{200}$$

$$= (1.584 + 1.805) + \frac{(3.726 - 0.77)^2}{200} = 3.389 + 0.044$$

$$= 3.433\%.$$

38.14 CALCULATION OF LOAD LOSS AND IMPEDANCE FROM TEST PARAMETERS

Unless otherwise specified, the impedance voltage and load loss should be measured at principal tappings and at rated frequency by applying an approximate sinusoidal supply to one winding, with other winding short-circuited.

The measurement may be made at any current between 25 to 100 per cent, but preferably not less than 50 per cent of the rated load current. Each measurement should be performed within the shortest possible time and the interval between them should be long enough to ensure that the temperature rise of the windings do not cause significant error.

The measured value of the load loss should be corrected by multiplying it with square of the current ratio of rated current and test current. The value so derived should be corrected for reference temperature (75°C) taking I^2R loss (R = DC resistance) as varying directly with temperature and other losses (stray) as varying inversely with temperature.

The measured value of impedance voltage should be corrected by increasing it in the ratio of rated current to the test current. The value of the impedance voltage so derived should be further corrected by the ratio of rated frequency to test frequency. Finally, it is to be corrected for reference temperature (75°C).

Sample Calculation of Load Loss Measured at Reduced Current

Example 1: 100 kVA, 11/0.433 kV aluminium-wound transformer, connected in Delta/Star with rated current (HV/LV): 5.25/133.3 A.

Test condition: Low voltage terminals with neutral are shorted with a copper bus bar of section 50 × 6 mm, (or equivalent); voltage is applied from 12 kV side.

Test parameters

Current fed through primary : 5 A

Load loss measured at 5 A current : 1390 W

Ambient temperature : 35°C
Test frequency : 49 Hz
Cold HV resistance at 35° C measured across delta line terminals

1 U–1 V : 20.8 ohm
1 V–1 W : 20.7 ohm
1 W–1 U : 20.9 ohm

Cold LV resistance at 35°C measured across line terminals of star connected windings

2 U–2 V : 21.6 m. ohm
2 V–2 W : 21.82 m. ohm
2 W–2 U : 21.56 m. ohm.

Calculation

Table 38.5

1.	Load loss corrected to rated current at 35°C	$\left(\frac{5.25}{5}\right)^2 \times 1390 = 1532$ W at 35°C
2.	Average HV winding resistance between line terminals of delta connected winding at 35°C	$\frac{(20.8 + 20.7 + 20.9)}{3} = 20.8$ ohm at 35°C
3.	Per phase HV resistance at 35°C (being delta connected)	20.8 × 1.5 = 31.2 ohm at 35°C 4.
Average	LV resistance between line terminals of a star connected winding at 35°C	$\frac{(21.6 + 21.82 + 21.56)}{3} = 21.66$ m.ohm
5.	Per phase LV resistance at 35°C (being star connected)	$\frac{21.66}{2} = 10.83$ m.ohm
6.	HV-3 × I^2R loss at 35°C	$3 \times \left[\frac{5.25}{\sqrt{3}}\right]^2 \times 31.2 = 860$ W at 35°C
7.	LV-3 I^2R loss at 35°C	$3 \times 133.33^2 \times 10.83 \times 10^{-3}$ = 578 W at 35°C
8.	Total I^2R (HV + LV) at 35°C	(860 + 578) = 1438 W
9.	Stray loss at 35°C (1-8)	(1532 – 1438) = 94 W 10.
T o t a l	I^2R (HV + LV) at 75°C (being aluminium winding)	$1438 \times \left(\frac{225 + 75}{225 + 35}\right) = 1660$ W
11.	Stray loss at 75° C	$94 \times \left(\frac{225 + 35}{225 + 75}\right) = 82$ W
12.	Load loss at rated load and at 75°C (10 + 11)	(1660 + 82) = 1742 W

In the case of copper winding transformer, the procedure for calculating load loss is same except for the absolute temperature which is 235°C for copper winding (225°C for aluminium-winding).

Impedance calculation

Test parameters: Impedance voltage measured across 11 kV side between the line terminals.

1 U – 1 V = 446 V
1 V – 1 W = 472 V
1 W – 1 V = 470 V

Test frequency = 49 Hz.

Table 38.6

1.	Average impedance voltage at 5 A and at 35°C with 49 Hz	$= \dfrac{(466 + 472 + 470)}{3} = 469.33$ V
2.	Average impedance voltage at rated current and at 35°C corrected to 49 Hz	$\left(\dfrac{5.25}{5}\right) \times 469.33 = 493$ V
3.	Average impedance voltage at rated current and at 35°C corrected at 50 Hz	$\left(\dfrac{50}{49}\right) \times 493 = 503$ V
4.	Percentage impedance at 35°C	$\dfrac{503}{11{,}000} \times 100 = 4.57\%$
5.	Percentage resistance at 35°C	$\dfrac{1532}{100 \times 10^3} \times 100 = 1.532\%$
6.	Percentage reactance	$\sqrt{(4.57^2 - 1.532)} = 4.31\%$
7.	Percantage resistance at 75°C	$\dfrac{1742}{100 \times 10^3} \times 100 = 1.742\%$
8.	Percantage impedance at 75°C	$\sqrt{(4.31^2 - 1.742^2)} = 4.65\%$

Example 2: 630 kVA, 11/0.433 kV copper-wound transformer, connected in Delta/Star with rated current (HV/LV) 33/840 A.

***Test condition*:** Low voltage terminals with neutral are shorted with a copper bus bar of section 75 × 10 mm (or equivalent), voltage is applied from 11 kV side.

Test parameters

Current fed through primary	:	30 A
Load loss measured at 30 A current	:	4720 W
Ambient temperature	:	35°C
Test frequency	:	51 Hz

Cold HV resistance at 35°C measured across delta line terminals

1 U–1 V	:	1.71 ohm
1 V–1 W	:	1.708 ohm
1 W–I U	:	1.706 ohm

Cold LV resistance at 35°C measured across line terminals of star connected windings

2 U–2 V	:	2.04 m. ohm
2 V–2 W	:	2.06 m. ohm
2 W–2 U	:	2.06 m. ohm.

Calculation

Table 38.7

1.	Load loss corrected to rated current at 35°C	$\left(\frac{33}{30}\right)^2 \times 4720 = 5711$ W
2.	Average HV winding resistance between line terminals of delta connected winding at 35°C	$\frac{(1.71 + 1.708 + 1.706)}{3} = 20.8$ ohm at 35°C
3.	Per phase HV resistance at 35°C (being delta connected)	$1.708 \times 1.5 = 2.562$ ohm at 35°C
4.	Average LV resistance between line terminals of a star connected winding at 35°C	$\frac{(2.04 + 2.06 + 2.06)}{3} = 2.05333$ m. ohm
5.	Per phase LV resistance at 35°C (being star connected)	$\frac{2.05333}{2} = 1.0266$ m. ohm
6.	HV-3 x I^2R loss at 35°C	$\left(\frac{3 \times 33}{\sqrt{3}}\right) \times 2.562 = 2790$ W at 35°C
7.	LV-3 I^2R loss at 35°C	$3 \times 840^2 \times 1.0266 \times 10^{-3} = 2173$ W
8.	Total I^2R (HV + LV) at 35°C	(2790 + 2173) = 4963 W
9.	Stray loss at 35°C(1-8)	(5711 – 4963) = 748 W
10.	Total I^2R (HV + LV) at 75°C (being copper winding)	$4963 \times \left(\frac{235 + 75}{235 + 35}\right) = 5698$ W
11.	Stray loss at 75° C	$748 \times \left(\frac{235 + 25}{235 + 75}\right) = 652$ W
12.	Load loss at rated load and at 75°C (10 + 11)	(5698 + 652) = 6350 W

Impedance Calculation

Impedance voltage measured across 11 kV side between the line terminals

1 U–1V = 485 V
l V–1 W = 492 V
1 W–1 V = 488 V
Test frequency = 51 Hz.

Table 38.8

1.	Average impedance voltage at 30 A and at 35°C with 51 Hz	$= \dfrac{(485+492+488)}{3} = 488.33$ V
2.	Average impedance voltage at rated current and at 35°C corrected at 51 Hz	$\left(\dfrac{33}{30}\right) \times 488.33 = 537.163$ V
3.	Average impedance voltage at rated current and at 35°C corrected at 50 Hz	$\left(\dfrac{50}{51}\right) \times 537.163$ V $= 526.63$ V
4.	Percentage impedance at 35°C	$\dfrac{526.63}{11{,}000} \times 100 = 4.79\%$
5.	Percentage resistance at 35°C	$\dfrac{5711}{630 \times 10^3} \times 100 = 0.907\%$
6.	Percentage reactance	$\sqrt{(4.79^2 - 0.907^2)} = 4.703\%$
7.	Percentage resistance at 75°C	$\dfrac{6350}{630 \times 10^3} \times 100 = 1.0\%$
8.	Percentage impedance at 75°C	$\sqrt{(4.703^2 - 1.0^2)} = 4.81\%$

38.15 CALCULATION OF RADIAL FORCES AND STRENGTH DURING DYNAMIC SHORT CIRCUIT

In order for the transformer to survive an external short circuit, the windings must have sufficient mechanical strength to withstand without damage the electromagnetic forces produced by the current. At the same time the materials used in the construction, for both conductor and insulation, must be able to withstand without significant deterioration due to the high temperature produced by the fault current. It is necessary for the designer to know the characteristics of fault current and the forces and temperature produced by the fault current. Further, it is also essential that the designer is able to calculate the mechanical strength of the various parts of the transformer to resist these forces.

The detailed calculations with empirical formulas of various short circuit forces (radial and axial in nature) are highlighted by M. Water in his book "The short circuit strength of power transformers." This is a book which can be taken as a reference for the calculation of short circuit forces as well as the methods of determining the strength of the windings. The author has suggested various means of construction of the windings to resist such forces successfully.

Radial Forces and Stress on Outer Winding

The mean hoop stress in the outer winding is calculated as if for a cylindrical boiler shell as illustrated in Fig. 38.17. The transverse force 'P_w' on two opposite halves of the winding is equivalent to the pressure upon a diameter and is expressed as

$$P_w = \frac{2(ni)^2 \, \pi D_w}{h \times 10^{11}} \text{ Ton} \qquad \ldots(14)$$

where P_w = Radial forces in Ton;

ni = Peak asymmetrical ampere-turns;

D_w = Mean diameter of the coil in mm; and

h = Length of the coil in mm.

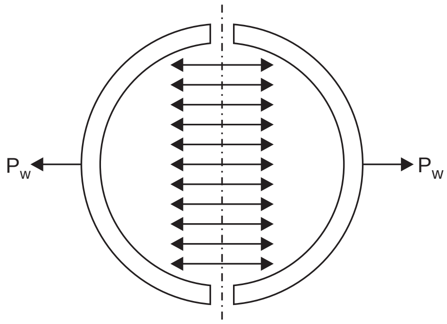


Fig. 38.17. Method of calculating mean hoop stress

Example: Let us select an orthodox type of concentric winding, core type, 5 MVA transformer with following details:

Type of coil	:	Continuous disc
No. of turns/phase (n)	:	1195 T (at normal tap)
Diameter of coil (ID/OD)	:	485/597 mm
Mean diameter of coil (D_w)	:	541 mm
Length of coil (h)	:	920 mm
Voltage rating of the outer winding (E)	:	33000 V
Per unit impedance (e_z)	:	0.0715

Peak asymmetrical current (i)

$$= \frac{1.8\sqrt{2} \times MVA \times 10^6}{\sqrt{3} \times E \times e_z}$$

$$= \frac{1.8\sqrt{2} \times 5 \times 10^6}{\sqrt{3} \times 33000 \times 0.0715}$$

$$= 3114.4 \text{ A}$$

Connection of the outer winding: Delta

Therefore, Peak asymmetrical current flowing through the winding $= \dfrac{3114.4}{\sqrt{3}}$

$= 1798$ A

Radial forces on the outer winding

$$P_w = \frac{2(ni)^2 \ \pi \ D_w}{h \times 10^{11}} \text{ Tons}$$

$$= \frac{2 \times (1195 \times 1798)^2 \times \pi \times 541}{920 \times 10^{11}} = 170.6 \text{ Tons.}$$

Calculation of Hoop Stress

The calculated radial forces of 170.6 Tons is applied to twice the copper area of the winding and may be calculated as follows:

$$\text{Hoop stress} = \frac{\text{Radial forces}}{2 \times n \times \text{conductor area}} \text{ Ton/sq.inch} \qquad \text{...(15)}$$

Conductor being used : 9 × 2.2 mm
Area of the conductor : 19.36 sq. mm (0.0301 sq. inch)

$$\text{Therefore, hoop stress} = \frac{170.6}{2 \times 1195 \times 0.0301}$$

= 2.37 Tons/sq. inch.

An alternative expression is also available to calculate the stress in Tons/sq.inch from the following formula:

$$\text{Hoop stress} = 0.0787 \times \frac{W_{cu}}{h}\left(\frac{1}{e_z}\right)^2 \text{ Ton/sq. inch}$$

where, W_{cu} = Per phase I^2R (DC) at 75°C of the winding, which is available as 5.57 kW
h = 920 mm (36.22 inch)
e_z = 0.0715

Therefore, hoop stress calculated from the alternative formula

$$= 0.0787 \times \frac{5.57}{36.22} \times \left(\frac{1}{0.0715}\right)^2$$

= 2.37 Tons/sq. inch

From the above, it is established that both the formulas are fairly correct and whichever is convenient may be used.

Radial Forces and Stresses on Inner Winding

Example:

Type of coil	:	Continuous disc
No. of turns/phase (n)	:	230 T
Diameter of coil (*ID/OD*)	:	353/437 mm
Mean diameter of coil (D_w)	:	395 mm
Length of coil (h)	:	920 mm
Voltage rating of the inner winding (E)	:	11000 V
Per unit impedance (e_z)	:	0.0715

Peak asymmetrical current (i) $= \dfrac{1.8\sqrt{2} \times MVA \times 10^6}{\sqrt{3} \times E \times e_z}$

$$= \frac{1.8\sqrt{2} \times 5 \times 10^6}{\sqrt{3} \times 11000 \times 0.0715}$$

= 9343.3 A

Connection of inner winding: Star

Therefore, peak asymmetrical current flowing through the winding: 9343.3 A

Radial forces on the outer winding using expression (14)

$$P_w = \frac{2 \times (ni)^2 \times \pi \times D_w}{h \times 10^{11}} \text{ Tons}$$

$$= \frac{2 \times (230 \times 9343.3)^2 \times \pi \times 395}{920 \times 10^{11}}$$

= 124.6 Tons.

Calculation of Hoop Stress

The calculated radial forces of 124.6 tons is applied to twice the copper area of the winding and may be calculated using expression (15).

$$\text{Hoop stress} = \frac{\text{Radial forces}}{2 \times n \times \text{Conductor area}} \text{ Tons/sq. inch}$$

Conductor being used : 11.5 × 5.2 mm × 2 nos. in parallel.

Area of conductor: 117.64 sq. mm (0.1823 sq. inch)

$$\text{Therefore, hoop stress} = \frac{124.6}{2 \times 230 \times 0.1823}$$

= 1.49 Ton/sq. inch

Using expression (16) we can cross check to verify the hoop stress calculation.

Alternative method of calculating hoop stress

$$= 0.0787 \times \frac{W_{cu}}{h} \times \left(\frac{1}{e_z}\right)^2 \text{ Ton/sq. inch}$$

where, W_{cu} = Per phase $I^2 R$ (DC) at 75°C of the winding which is available as 3.506 kW

h = 920 mm (36.22 inch)

e_z = 0.0715

Therefore, hoop stress calculated from the alternative formula.

$$= 0.0787 \times \frac{3.506}{36.22} \times \left(\frac{1}{0.0715}\right)^2$$

= 1.49 Tons/sq. inch

From the above, it is established that both the formulas are fairly correct and whichever is convenient may be used.

In case, we are required to calculate hoop stress from expression (15) for transformer with aluminium winding, the factor 0.0787 may be replaced with 0.0525.

38.16 CALCULATION OF WINDING TEMPERATURE GRADIENT

Winding temperature gradient is defined as the difference between maximum permissible winding temperature rise and average oil temperature calculated from top oil temperature rise and is represented as

$$\theta_g = \theta_w - \theta_o$$

where θ_g : Winding temperature gradient;
θ_w : Permissible maximum winding temperature rise; and
θ_o : Average oil temperature rise.

As per recommendation of IS: 2026, the maximum winding and oil temperature rise are limited to 55°C and 50°C respectively.

Average oil temperature is taken as 0.8 times the top oil temperature rise and is equal to

$$\theta_o = 0.8 \times 50 = 40°\text{C}$$

Therefore,

$$\theta_g = \theta_m - \theta_o$$
$$= 55 - 40$$
$$= 15°\text{C (which is the maximum limit of winding temperature gradient)}$$

The above calculations will help us to identify the requirement of winding temperature gradient from the available specified winding and oil temperature rise and is calculated as 15°C for a 50/55°C rtse. In case of 40/50°C rise, the gradient will be taken as 18°C.

Now, it is the responsibility of the designer to design the winding configurations in such a way that the designed winding temperature gradient remains below the gradient as calculated above from the available specified winding and oil temperature rise.

Example: Let us calculate the winding temperature gradient with various assumed numerical values taken from a design of 5 MVA, 33/11 kV, delta/star connected transformer.

The following figures are made available from the design output of a 5 MVA transformer:

Configuration of LV Coil

Inside diameter of coil	:	353 mm
Outside diameter of coil	:	437 mm
Mean diameter of coil	:	395 mm
Length of mean turn (Lmt)	:	1241 mm
No. of turns per phase	:	230 T
Size of bare conductor	:	11.0 × 4.7 mm × 2 nos.
Area of conductor	:	[(11.0 × 4.7) – 0.86] × 2 = 101.68sq. mm
No. of disc per phase	:	60 nos.
Radial build of coil	:	$\left(\frac{437 - 353}{2}\right) = 42$ mm

Type of coil	:	Continuous disc
No. of discs per coil (ND)	:	60 discs
No. of blocks per circle	:	12 nos.
Width of spacer between the discs	:	35 mm
Conductor covering	:	TPC/0.3 mm radially.

Calculation

$$\text{Winding resistance per phase } (R) = \frac{\rho \times L \times 10^{-3}}{A} \text{ ohms at } 75° \text{ C}$$

where, ρ = Resistivity of electrolytic grade copper
= 0.021 ohm mm^2/m at 75°C
L = Length of conductor
= Lmt × No. of turns
= 1241 × 230 mm
a = Cross sectional area of the conductor
= 101.68 sq.mm

Therefore,

$$\text{Winding resistance per phase } (R) = \frac{0.021 \times 1241 \times 230 \times 10^{-3}}{101.68}$$

= 0.059 ohm at 75°C

$$\text{LV current per phase} \quad (I) = \frac{5000}{\sqrt{3} \times 11} = 262.43 \text{ A}$$

Therefore, I^2R = 262.43^2 × 0.059
= 4064 W at 75°C

Considering stray loss as 15% of the calculated I^2R,

Load loss per phase = 4064 + 4064 × 0.15
= 4674 W at 75°C

For standard paper covered conductor of maximum covering thickness 0.3 mm radially, we can assume a dissipation of heat from the conductor surface as 60 W per m^2/°C.

Based on this assumption of dissipation of heat, we can calculate the winding temperature gradient (θ_g) as:

$$\theta_g = \frac{\text{Load loss per phase at } 75°\text{C}}{\text{Effective dissipation area of coil in sq.m} \times \text{Heat dissipation factor}}$$

where,

Load loss per phase (as calculated above) = 4674 W at 75°C
Heat dissipation factor = 60 W per m^2/°C
Effective dissipation area of coil = 2 ND × Lmt × ($h_b + h_c \times B$)

where,

ND = No. of disc = 60 nos.
Lmt = Length of mean turn = 124.1 cm (1.241 m)

h_b = Width of strip conductor = 1.15 cm (0.0115 m)
h_c = Radial build of coil = 4.2 cm (0.042 m)
b = Covering space factor of disc coil

$$= \frac{\text{Lmt} - (\text{No. of spacer per circle} \times \text{Width of spacer})}{\text{Lmt}}$$

$$= \frac{124.1 - (12 \times 3.5)}{124.1}$$

= 0.662

Therefore, effective dissipation area of coil

= 2 × 60 × 1.241 × (0.0115 + 0.042 × 0.662) = 5.8532 sq.m

Therefore, calculated winding temperature gradient,

$$\theta_g = \frac{4674}{5.8532 \times 60} = 13.3°\text{C}$$

The calculated winding temperature gradient of LV winding is 13.3°C. However, due to irregular flow of oil through the oil ducts, the estimated value of winding temperature gradient will tend to increase by approximately 10% than the calculated value. Taking this additional factor of 1 0% over the calculated value of 13.3°C, the maximum LV winding temperature gradient = 13.3 + 13.3 × 0.10 = 14.63°C.

We have earlier estimated that the specified winding temperature gradient is 15°C for a rise of 50/55°C, as against the calculated LV temperature gradient of 14.63°C, and hence within limit and may be considered as an acceptable design configuration.

Configuration of HV Coil

Inside diameter of coil	:	485 mm
Outside diameter of coil	:	597 mm
Mean diameter of coil	:	541 mm
Length of mean turn (Lmt)	:	1700 mm
No. of turns per phase	:	1196 T
Size of bare conductor	:	9 × 2.2 mm
Area of conductor	:	[(9 × 2.2) – 0.25] [9.55 sq. mm]
No. of disc per phase	:	68 nos.
Radial build of coil	:	$\left(\frac{597 - 485}{2}\right)$ = 56 mm
Type of coil	:	Continuous disc
No. of disc per coil (ND)	:	68 disc
No. of block per circle	:	12 nos.
Width of spacer between the disc	:	35 mm
Conductor covering	:	TPC/0.3 mm radially.

Calculation

Winding resistance per phase $(R) = \dfrac{\rho \times L \times 10^{-3}}{A}$ ohm at 75°C

where, ρ = 0.021 ohm mm^2/m at 75°C
L = Length of conductor
= Lmt × No. of turns
= 1700 × 1196 mm
a = Cross sectional area of the conductor
= 19.55 sq.mm

Therefore, winding resistance per phase

$$(R) = \frac{0.021 \times 1700 \times 1196 \times 10^{-3}}{19.55}$$

= 2.184 ohm at 75°C

LV current per phase $(I) = \dfrac{5000}{3 \times 33}$

= 50.5A

Therefore, $I^2R = 50.5^2 \times 2.184$
= 5570 W at 75°C

Considering stray loss as 15% of the calculated I^2R,

Load loss per phase = 5570 + 5570 × 0.15
= 6406 W at 75°C

Winding temperature gradient (θ_g) as:

$$\theta_g = \frac{\text{Load loss per phase at 75°C}}{\text{Effective dissipation area of coil in sq.m} \times \text{Heat dissipation factor}}$$

where,

Load loss per phase (as calculated above)	= 6406 W at 75°C
Heat dissipation factor	= 60W per m^2/°C
Effective dissipation area of coil	= 2 ND × Lmt × (h_b × h_c × B)
where, ND = No. of disc	= 68 nos.
Lmt = Length of mean turn	= 170 cm (1.7 m)
H_b = Width of strip conductor	= 0.9 cm (0.009 m)
H_c = Radial build of coil	= 5.6 cm (0.056 m)

β = Covering space factor of disc coil

$$= \frac{\text{Lmt} - (\text{No. of spacer circle} \times \text{Width of spacer})}{\text{Lmt}}$$

$$= \frac{170 - (12 \times 3.5)}{170}$$

= 0.753

Therefore, effective dissipation area of coil

= 2 × 68 × 1.7 × (0.009 + 0.056 × 0.753) = 11.83 sq. m

Therefore, calculated winding temperature gradient,

$$\theta_g \text{ (HV)} = \frac{6406}{11.83 \times 60}$$

$$= 9.03°\text{C}.$$

The calculated winding temperature gradient of HV winding is 9.03°C. However, due to irregular flow of oil through the oil ducts, the estimated value of winding temperature gradient will tend to increase by approximately 10% than the calculated value. Taking this additional factor of I 0% over the calculated value of 9.03°C, the maximum HV winding temperature gradient = 9.03 + 9.03 × 0.10 = 10°C.

We have estimated earlier that the specified winding temperature gradient is 15°C for a rise of 50/55°C. The calculated HV temperature gradient is 10°C, and hence within limit and may be considered as an acceptable design configuration.

The following points may be kept in mind while undertaking the calculation of temperature gradient of windings:

(*a*) The calculation is fairly correct for conductor covering up to 0.3 mm radial. Beyond 0.3 mm, elaborate procedures considering thermal resistivity of paper—pressboard, size and location of oil ducts etc. are to be taken in to account while calculating winding temperature gradient.

(*b*) In case the calculated winding temperature gradient is more than the reference value, the cooling radiators should be increased proportionately to make the transformer run successfully on load. If the calculated gradient is 16°C as against required 15°C, the design of radiators should be done for an effective top oil temperature rise of 50 – (16 – 15) = 49°C.

(*c*) Winding temperature gradient gives a fair idea on the sustainability of the transformer under continuous over load. In a design with concentric coils, since the HV windings are placed around LV, it is seen that the effective dissipation area of HV coils become almost 2 times that of LV coils, whereas I^2R loss of HV coils is approximately 1.5 times the LV I^2R loss. As such, the temperature gradient of HV coils is always less than LV coils for a common current density. Taking this factor in to account, HV current density can be proportionately increased compared to LV current density to design a successful cost effective transformer.

Section V

CHAPTER 39

Scope of Inspection and Quality Assurance

FOOD FOR THOUGHT

In competitive business environment, it is not enough for a company to be doing well. The performance has to be seen in comparison with its best competitors. A company growing at the rate of 10% in an industry with an average growth rate of 15% is in fact losing market shares slowly but surely to its competition. In such a situation, 10% growth is not enough. However, the same growth rate may be considered very good in another industry which grows at an average rate of 3% and where the best competitor is growing at the rate of 5%. Thus, it is necessary to have a point of reference to knowhow well one is doing. The need for keeping a constant watch on the competition is necessary for achieving and maintaining leadership position. This is well illustrated in a long distance race. The leader keeps looking how ahead he is of the next competitor. If he sees him closing in, he steps up his pace to retain or even increase his lead. The runner in the second position may have a strategy to keep within the striking distance of the leader with a plan to shoot ahead towards the end of the race. He ensures that the lead remains up to a predetermined level which he can make up in the final burst.

In a dynamic business environment where customer expectations are changing fast, it is not enough to meet current expectations of the customers. Competition is constantly trying to improve its products and services to lure one's customers away. A company in the lead, like the leader in a race, has to keep a watch on its competitors, to maintain its lead. Constant vigilance and an attitude of continuous improvement are extremely essential to do well in such an environment. Bench marking which helps an organization to do just that, is therefore a very useful tool in the hands of the management of a company that desires to be more competitive. Bench marking is a process of comparing company performance continuously against those recognised as best with a view to improve. Bench marking is necessary for companies to retaining their competitive edge. It is even more useful for companies who are yet to achieve leadership position in their industry.

39.1 INTRODUCTION

Inspection is defined as to examine carefully especially for flaws or to review officially. Inspection and quality go hand in hand. One inspects an item to assess the expected quality. Since customer expectations are always going to be there, inspection will never cease to be in existence. Inspection means evaluating the quality of some characteristic in relation to a reference value.

Inspection will always be there. No matter, how sophisticated the world gets or how automated the system is, has to inspect to assure that everything is in order. One may say it an audit. Inspection, audit, assessment, test measurement and comparison all describe the same phenomena of examining carefully to some established criteria. Product audit, which is a subset of system audit, is an inspection activity.

Heavy emphasis is placed on inspection under the current environment of global market and keen competition. Inspection is not cheap. It is considered as non-value function even though it protects customers.

Inspection is an essential part of quality assurance.

It falls into four main categories:

(*a*) Visual (appearance, surface characteristics, size, shape, colour etc.)

(*b*) Physical (dimensional measurements)

(*c*) Testing (electrical properties and strength)

(*d*) Sensory (touch, smell, taste).

Factors such as human judgement, environment, sample size etc. can influence the results of inspection. Visual inspection can be subjective without a standard for reference. It can be performed with naked eyes or can be with the aid of a magnifier.

Physical or dimensional measurements can be performed using tools, such as micrometer, vernier, scale and similar measuring devices.

Testing involves electrical, mechanical, and other characteristic measurements.

Sensory testing involves smelling or tasting as in the case of wine or tea.

Why do we inspect?

The main object of inspection is to ensure that the customer requirements are met. The objective of in-process inspection is to prevent defective products flowing down the successive operations and thus prevent loss of yield. In many cases, only a few of the characteristics can be inspected at the intermediate or sub assembly stage.

When should we inspect?

Inspection should be done at a process stage when it is economical to detect defects.

What should be inspected?

Inspection should be performed according to the established criteria and specification, and it should be recorded.

Who should inspect?

Only well trained and competent persons should be authorized to inspect. Inspection requirements must be understood by all concerned.

As was said earlier both the manufacturers and the users should join hands for the common cause, *i.e.*, ***quality assurance***. Organizing preshipment inspection at the manufacturer's premises before accepting any material is one of the prime responsibilities of the buyer. It is, however the duty of the inspectors to prepare themselves thoroughly before undertaking any inspection.

Inspectors should be prepared with the following documents:

(*a*) Contract documents together with technical specifications

(*b*) Basic guideline regarding the scope of inspection

(*c*) Approved drawings and reference standards (ISS/IEC/BS etc.)

(*d*) Previous inspection reports of transformers of similar rating (if available)

(*e*) Type test certificates (if already conducted).

Once these documents are available, it is suggested that the inspector read the documents carefully and prepare a check list prior to start of inspection. The check list should include the verification of electrical parameters as well as various mechanical dimensions and constructional details.

Engaging qualified inspectors for inspecting a particular type of engineering product is the responsibility of the buyers. The buyers may be required to buy various categories of engineering products relating to electrical, mechanical, chemical, electronic etc. and depending upon the characteristics and nature of the product to be inspected, it is again the responsibility of the buyer to engage inspectors who have the expertise to handle the product in question.

39.2 STAGE INSPECTION

Though it is not mandatory to organize stage inspection by the buyer on every batch of production, it is recommended to keep a provisional clause in the contract for carrying out inspection at the manufacturing stages. The basic need of stage inspection by the buyer is to ensure the quantity and equality of the materials used in the transformers.

General workmanship, internal clearances, manufacturing processes etc. are the key areas the inspectors should concentrate on during stage inspection. Flux density of core material and current density of winding wire and strip can easily be verified during stage inspection. Provision of stage inspection in the contract will compel the manufacturer to go for the verification of such parameters and in case, any of the parameters is found to be not acceptable, enough scope is there to apply correction to rectify the short comings. Moreover such verifications also help in developing quality awareness among the working personnel. The stage inspection clause in the contract will make the manufacturer alert and self-motivated.

Stage inspection is quite a popular activity in RSEB, MPEB, UPPCL (for 8 MVA onward) etc.

More SEBs are planning to make stage inspection mandatory. It is often seen that due to the delay in conducting stage inspection by the buyer within the scheduled time frame, the production gets held up resulting in loss of time and money. The contract should be clear enough to arrest such inadvertent delay. It is suggested that at least 10 clear days from the date of receipt of inspection call should be given to the buyer to organize stage inspection. In case the buyer fails to organize inspection within the stipulated 10 days, the manufacturers may be allowed to proceed with the work on the transformers without waiting to receive any further official communication from the buyers.

A sample format as shown on next page may be used for carrying out stage inspection.

Table 39.1. Proforma for stage inspection of transformers

Order no./date	*5344 dated 12.03.1999*
Name of the firm	Transformer Industries Limited
Rating/kV	100 kVA, 11/0.433 kV
Quantity ordered	1000 nos.
Quantity already supplied	300 nos.
Quantity under process	200 nos.
Inspected by	Er. V.K. Kaushik, XEN, SEB
Date of inspection	05.06.1999

Particulars	*Offered*	*Observed*	*Deviation/Remarks*
A. Inspection of core			
1. Core material, grade and thickness	M4/0.27 mm		
2. Physical look of core lamination (rust/smooth etc.)	Rustless/smooth		
3. Core diameter	114 mm		
4. Window height	490 mm		
5. Limb centre	265 mm		
6. No. of steps	9 steps		
7. Step width (L_1, L_2, L_3, ...)	110, 105, 100, 90, 80, 70, 60, 50, 40 mm		
8. Step stack (K_1, K_2, K_3, ...)	29.93, 14.46, 10.34, 15.24, 11.24, 8.76, 6.96, 5.52, 4.3 mm		
9. Gross core area	9594.2 sq.mm		
10. Voltage per turn	250/76 = 3.289		
11. Flux density	1.592 T		
12. Core channel size/painting	75 × 40 mm/zinc chromate		
13. Core bolt no. and size	4 nos. × 12 mm dia.		
14. Tie rod no. and size	4 nos. × 12 mm dia.		
15. Foot channel size/painting	75 × 40 mm/zinc chromate		
16. Weight of core	193.6 kg		

Contd.

Particulars	*Offered*	*Observed*	*Deviation/Remarks*
B. Inspection of LV coil			
1. Size of LV conductor /covering	11 × 4.5 mm × 2 nos. (bare)		
2. Area of LV conductor	97.28 sq.mm		
3. Current density	1.37 A/sq.mm		
4. No. of turns per coil	76 turns		
5. No. of layers	2 layers		
6. Coil inside diameter	120 mm		
7. Coil outside diameter	162 mm		
8. Coil length	470 mm		
9. Inter-layer insulation	4 mil × 2 nos.		
10. Transposition (Yes/No)	Yes		
11. Weight of coil per set	27.5 kg		
C. Inspection of HV coil			
1. Size of HV conductor/covering	1.7 mm dia. (bare) 1.95 mm dia. (covered)		
2. Area of HV conductor	2.27 sq.mm		
3. Current density	1.33 A/sq.mm		
4. No. of HV coils per phase	4 nos.		
5. Coil inside diameter	182 mm		
6. Coil outside diameter	252 mm		
7. Coil length	104 mm		
8. Inter-layer insulation	2 × 2 mil		
9. Weight of coil per set	46 kg		
D. Inspection of coil assembly			
1. Gap between HV and LV coil to yoke	25/10 mm		
2. Gap between HV plain coils	8 mm		
3. Gap between HV tap coils	NA		
4. Gap between HV limbs between the phases	10 mm		
5. Insulating cylinder between core to LV coil	1.0 mm thick		
6. Insulating cylinder between LV and HV coil	1.5 mm thick		
7. Oil duct between LV coil and cylinder	3 mm		
8. Oil duct between cylinder and HV	4 mm		

Contd.

Particulars	*Offered*	*Observed*	*Deviation/Remarks*
9. No. of space block per circle	8 nos.		
10. Phase barrier	2 × 1 mm		
11. Core channel separator	1.5 mm		
12. Material/size of delta and line leads	Copper/2.9 mm dia.		
13. Material/size of tapping leads	Copper/ 1.7 mm dia.		
14. π- support frame	Bakelite/6 mm		
15. Core earthing strip	34 swg tinned copper foil		
16. Weight of core-coil assembly	310 kg		
E. Inspection of tank			
1. Tank (length × breadth × height)	835 × 335 × 905 mm		
2. Sheet thickness (side/bottom/top)	3.15/5/5 mm		
3. Radiator (*a*) Elliptical tube (*b*) Pressed steel	Two radiators each having 16 tubes × 590 mm tube length NA		
4. Size of conservator	230φ × 500 mm long		
5. Size and length of base channel	75 × 40 × 460 mm		
6. Size and no. of stiffener	40 × 6 mm × 2 nos.		
7. Thickness of lifting hook	10 mm		
8. Location of HV bushing	On tank side		
9. Shape of tank	Rectangular		
10. HV bushing on conical pocket or not	Yes		
11. Weight of tank and fittings	190 kg		
F. Inspection of boxed up transformer			
1. Clearance between tank and coil on (*a*) Bushing side (*b*) Non-bushing side	 40 mm 25 mm		
2. Clearance between core yoke and tank cover	150 mm		
3. Projection of HV bushing in the tank	50 mm		
4. HV phase clearance (with connectors fitted)	255 mm		
5. LV phase clearance (with connectors fitted)	75 mm		
6. Tank pressure test at 0.8 kg/cm^2 and vacuum test at (–) 0.7 kg/sq cm	Yes		
7. Oil quantity in litres (oil drained)	190 litres		

Contd.

Particulars	*Offered*	*Observed*	*Deviation/Remarks*
8. Complete weight of transformer with all fittings	660 kg		
9. Explosion vent material	44 swg brass/copper foil		
10. Size of tank cover gasket	40 × 6 mm		
11. Size of locking bolt and number	½″ dia. × 2 nos. on each side		
12. Size of tank cover bolt and spacing between two consecutive bolts	½″ dia. × 93 mm		
13. Silicagel breather	500 g		
14. Location of thermometer pocket	At the centre of tank cover		
15. Painting of lank inside	Zinc chromate paint		
G. Inspection on complete transformer			
1. Overall dimension ($L \times B \times HT$)	1382 × 592 × 1410 mm		
2. Famish (painting)	Dark Grey		
3. Availability of all fittings as per contract	Yes		
4. Special comments, if any	Nil		
5. External phase clearances with connector fitted (*a*) HV side (*b*) LV side	 255/140 mm 75/40 mm		

The stage inspection format shown above is an illustrative example only. The buyers may draft their own formats based on the specifications and technical requirements.

In case of any dispute on the quality of a particular material during stage inspection, the buyer at his option may collect samples for getting them tested at any independent test laboratory at the buyer's cost. In the event the material is found defective, the test charge should be borne by the manufacturer. Still the buyer is not sure if the same lot of transformers which were stage inspected have been offered for final inspection.

The buyer has valid reasons to be suspicious and in fact, they are absolutely dependent on the honesty of the manufacturers. The solution lies in the buyer and the manufacturer joining together for quality improvement.

39.3 SAMPLING PLAN

Different SEBs follow different plans in sampling. PSEB select 30% of the quantity being offered as samples for inspection. However, most of the SEBs follow the simple rule of 10% of the offered quantity as samples. However, sampling plan of Assam State Electricity Board is quite different than the other SEBS. The di-electric tests with respect to separate source and induced over voltage test are conducted on 100% offered quantity. All other routine tests are conducted on 10% sample transformers.

WBSEB follow norms which are entirely different from the other boards. They select one sample out of each batch of 10 transformers, and if a sample fails in the routine test, the particular batch of 10 transformers from which the defective sample was drawn, is rejected. However, the entire lot (not the batch of 10 only) is rejected in the event the sample transformer fails to satisfy the requirement of the temperature rise test.

The sampling plan discussed above relates to the distribution transformers only. However, in the case of power transformers and special transformers 100% of transformers are generally subjected to verification.

The sampling plan of Rajasthan State Electricity Board, as shown below, appears to be more logical, than those of other SEBS and power utilities.

Table 39.2

Size of lot	***No. of samples***
Up to 20 nos.	5 nos.
From 21 up to 40 nos.	5 nos. plus 20% of the quantity exceeding 20 nos.
From 41 up to 80 nos.	9 nos. plus 15% of the quantity exceeding 40 nos.
From 81 and above	15 nos. plus 10% of the quantity exceeding 80 nos.

It is further stated in RSEB contract that all routine tests shall be repeated by the inspecting officers on the selected samples. The lot shall be accepted or rejected on the basis of results of the manufacturer's routine test certificates and the tests conducted on the selected samples.

For selection of sample for conducting temperature rise test, most of the SEBs select one sample out of the offered lot. However, few SEBs opt one sample out of each lot of 100 transformers, *i.e.*, in case the lot size is 140 nos. two samples are selected for temperature rise test.

39.4 VERIFICATION OF DOCUMENTS AT THE MANUFACTURER'S PREMISES PRIOR TO START OF INSPECTION

Inspection is somewhat similar to auditing. Auditing is done on the basis of a few selected sample cases. In ISO:9000 auditing, the auditor picks up few sample cases and verify all the documents relating to the activities both down stream and up stream.

An example of the auditing activities is given below:

If the auditor spots a coil affixed with a red tag, which indicates that it is a rejected coil, lying in the quarantine area, the auditor asks the manufacturer to establish justification with documents the reason for rejection and proposed corrective measures to curb the occurrence of rejection in future.

Downstream Verification (↓)

(*i*) ***Identification and traceability*****:** The manufacturer is asked to establish the name of the operator who had made the coil, customer for whom the coil was made, date of manufacture, rating and kV, Job no./work order no. etc.

The following information marked on the foundation ring of the coil is verified:

Operator : Shivram Yadav (code-92)
Customer/w.o. no. : CPWD /608

Rating/kV : 500 kVA/11 kV

Date : 3.3.1999.

(*ii*) ***Inspection report*:** The auditor questions the reason for rejection. Justification for rejection should be recorded in the inspection report. For example, outside diameter of the coil is more by 3 mm than the design value, whereas the acceptable norm is ±1 mm. Hence, the coil is rejected

(*iii*) ***Verification of non-conformance record*:** The next step is to show evidence of corrective action taken by the manufacturer to curb occurrence of similar non-conformance in future.

This is done by the manufacturer through non-conformance analysis up to final disposition.

The rejection is recorded in a non-conformance register indicating the following:

(*a*) *Nature of non-conformance*: Coil outside diameter is beyond permissible limit by more than 3 mm.

(*b*) *Analysis*: Diameter of the insulated winding wire is recorded as 2.98 mm as against acceptable limit of 2.9 mm ± 0.03 mm.

(*c*) *Corrective action proposed*: It is decided to reject the coil and store in the quarantine area till further inspection by the concerned vendor. However, fresh coil is made with correct size of wire and the transformer is completed.

(*d*) *Disposition*: The material is returned to store wide Material Return Slip (MRS) no.: 033/4.3.99.

Here the verification towards the down stream activities are completed. However with the material return slip, the auditor starts his verification of upstream activities.

Upstream Activities (↑)

(*i*) ***Verification of material return slip*:** While verifying documents in the stores, the auditor examines the material return slip; for example, slip no: 033 with a remark as rejection of 43 kg of 2.6/2.9 mm TPC copper wire.

Vendor: Conductor and Cable, Meerut, U.P.

(*ii*) ***Corrective action taken*:** There should be a register for receiving the conductor with details of types of material, supplier, date of receipt etc. During verification, it is established that 729 kg of 2.6/2.9 mm TPC copper wire was received from M/S conductor and cable on 26.2.99, vide invoice no. 2335, out of which 43 kg of conductor was rejected because of over insulated diameter. The copy of MRS along with a brief report on the cause of rejection is sent to the purchase department for taking up the issue with the vendor.

(*iii*) ***Follow up action*:** It is further verified in the purchase department that a letter was sent to the vendor enclosing a copy of the non-conformance report and MRN with a remark to inspect the material at the store and to submit a report within 7 days indicating the reason for supplying poor quality of material. A debit note equivalent to 43 kg of material was also sent to the vendor. Poor performance was recorded in the name of the vendor.

(*iv*) ***Vendor's inspection report*:** Vendor inspects the material and gives a report revealing that the over diameter of the insulated wire is due to the thickness variation of the insulated kraft paper.

It may be further mentioned in the report that the vendor will remain more cautious during future supplies.

Here the verification towards up stream activities are completed.

The purpose of quoting such an example of auditing the function of process control is to highlight the nature of verification needed at the workshop level together with relevant supporting documents which are necessary to justify that the manufacturer is keen to establish quality by eliminating the root cause of occurring non-conformance.

Prior to the inspection of transformer, the manufacturer may be asked to submit the following documents:

(*i*) Routine test certificate of the entire lot of transformers.
(*ii*) Factory test result register (very important document).
(*iii*) List of instruments being used and calibration status.
(*iv*) Test certificates of the vital raw materials and components.
(*v*) Approved drawings and copy of the specification.
(*vi*) Latest reference standards.

It is of prime importance to verify the results of routine test certificates with respect to the date-wise test records available in the factory test result register. It is suggested that the test results of all transformers be recorded first in a register on a regular basis and on completion of the lot, the results may be compiled in the form of a routine test certificate. It is essential to understand that the factory test results register is the first-hand information, on the basis of which the test certificates are made. In other words, test certificates cannot be made without the test results, so test results register must be available during inspection. The manufacturer should keep the test results register in a presentable condition.

Upon satisfactory verification of the first two documents (*i.e.* test certificate and test result register), the next important aspect to look into, is the list of instruments, their class of accuracies, date of calibration, sealing of instruments, colour of stickers etc. Accuracy class and valid calibration certificates must be as per the requirement of contract. Sealing of instrument is again a vital aspect which may be ensured. Instrument with tampered seal may not be used. Coloured stickers on the top of the instrument will provide clear information on the status of calibration.

Green sticker : Accuracy found within specified limits.
Yellow sticker : In some of the scales or ranges, the accuracy is beyond limit.
Red sticker : Functioning of the instrument is erratic.

Green sticker instruments are safe and are always recommended for use. Yellow sticker instruments may also be considered for use, avoiding scales where the accuracies are beyond limit or else, using a correction factor as per the calibration chart. Red sticker instruments are not recommended for use at all.

As was discussed earlier, the quality of finished products depend on the quality of basic inputs. It is, therefore essential to ensure that the basic materials like core, copper/aluminium, oil, bushing, insulating paper/press board etc. are purchased from quality vendors and conform to the relevant standards. It is one of the responsibilities of the manufacturer to produce before the inspecting officer the documents containing the list of approved vendors and test certificates of the materials being used as per relevant ISS/IEC/BS standards. It is the job of the inspector to review such test certificates for compliance. The manufacturer should also ensure that all standards of current status are available.

All the above documents including a copy of the approved drawings, technical specification, guaranteed particulars, latest reference standards etc. may be kept in a folder for presentation to the inspecting officer.

39.5 SCOPE OF FINAL INSPECTION

As discussed above, verification of documents is the initial activity under the scope of inspection. Upon satisfactory verification of documents, final inspection can start.

Verification of Quantity

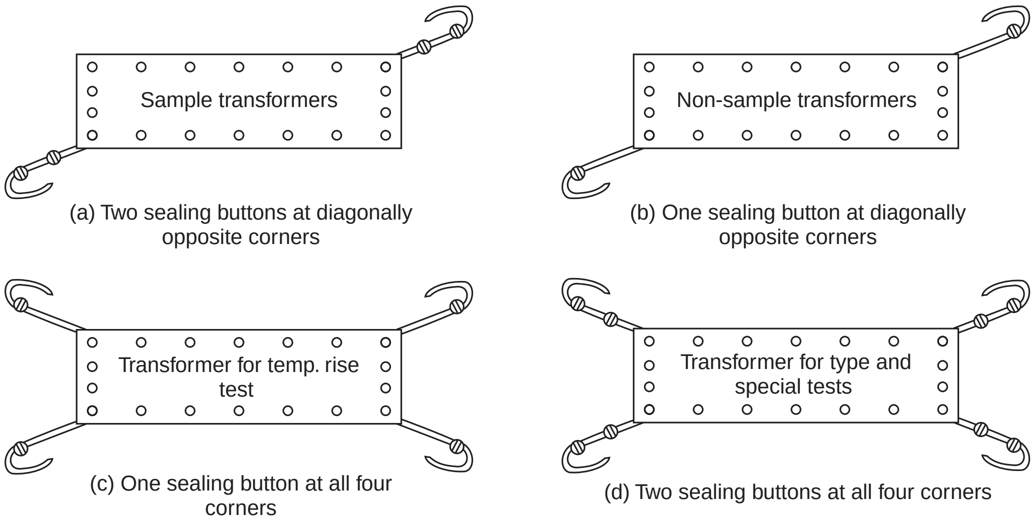
It is advisable to keep the offered transformers in a row with sufficient space in-between and serial number of each marked on the conservator (or any other convenient location) for easy identification.

Say, a lot of 100 transformers have been offered for inspection with Sl. no. 1, 2, 3, 4 ... 97, 98, 99, 100. The inspector should ensure first the availability of all transformers along with the name plate fixed at the right location. In case the name plates are not fixed on the transformers, it is difficult for the inspector to identify and to trace a particular transformer and is, therefore recommended not to proceed further till the name plates are fixed.

Sampling

Upon successful verification of quantity, selection of sample transformers are done as per the guidelines of the respective SEBs. The samples should be drawn by the inspector himself. After the sampling is done, the transformers should be sealed at two diagonally opposite corners.

Sealing plan of WBSEB seems to be more practical. As per their practice, all the samples are sealed at two corners, diagonally opposite, with two lead buttons at each corner. Balance transformers in the lot are sealed at diagonally opposite corners, with one lead button at each corner. It is the easiest way to identify the samples from the other transformers. Transformer selected for temperature rise test is sealed at four corners with one lead button at each corner. Selected samples for type and special tests are sealed at four corners with two buttons at each corner.



(a) Two sealing buttons at diagonally opposite corners

(b) One sealing button at diagonally opposite corners

(c) One sealing button at all four corners

(d) Two sealing buttons at all four corners

Fig. 39.1. Model for transformer sealing

Sample transformers	:	Two buttons each a diagonally opposite corners [Fig 39.1 (*a*)]
Non-sample transformers	:	One button each at diagonally opposite corners [Fig 39.1 (*d*)]
Transformer for temperature rise test	:	One button each at all the four corners [Fig 39.1 (*c*)]
Transformer for type and special tests	:	Two buttons each at all the four corners [Fig 39.1 (*d*)]

Sampling and sealing plan as described earlier is a simple illustration of the activities followed by one of the SEBs. Buyers may adopt their own norms as per their convenience and practice. However, sampling plan of RSEB and sealing plan of WBSEB are more practical which the other SEBs may think of adopting (with some modifications, if necessary).

Verification on the Health Status of Instruments Used

Though only calibrated instruments with valid certification are used, occasionally they behave erratically.

It is suggested that the health of these instruments be checked before using them for measurements.

Resistance bridge should be checked with standard resistances available in the market.

Wattmeter, ammeter and voltmeter are calibrated against a standard load of resistive bulb which must satisfy the equation $VI = W$

where, V is the voltage impressed against load
I is the current drawn by the load
W is the reading of the wattmeter.

However, such verifications may be subjected to a tolerance of ± 1 %.

Digital frequency meter is recommended for use. Motorised megger instead of hand driven megger is preferred.

Verification of Electrical Parameters and Dielectric Test

The procedure for various tests and measurements were covered in Chapter-7, Section-II. However, some of the important aspects are discussed below:

(*i*) Measurement of leakage current during separate source power frequency test on HV side will ensure the status of dryness of insulation and dielectric strength of insulating oil. Hence this test may be introduced while carrying out HV separate source test. Procedure of measurement of leakage current is discussed in Chapter-8, Section-III. This is a routine practice of WBSEB while carrying out inspection at the manufacturer's premises.

(*ii*) Frequency correction as suggested in Chapter-8, Section-III may be applied while measuring no-load loss at any frequency other than rated frequency, but within ± 3% of rated frequency.

(*iii*) Connection of voltmeter and frequency meter at the supply end may be more logical for correct measurement of no-load loss for a 3-phase load.

(*iv*) No-load current at overvoltage (*i.e*. 112.5% of V) should be the maximum current drawn by any of the phases. Average of phase currents as the no-load current at over voltage is not recommended.

(*v*) In case of a transformer with tap switch on HV side, the HV resistance at all taps for all the three phases are to be measured. It is further recommended to measure the HV resistance twice at all taps, once during clockwise rotation and another during anticlockwise rotation. However, the resistances measured at both the occasions for a particular tap position should be more or less same.

Table 39.3

Tap position	***Resistance measured during clockwise rotation***	***Resistance measured during anti- clockwise rotation***	***Remark***
1.	Value should be recorded	Value should be recorded	No change
2.	-do-	-do-	-do-
3.	-do-	-do-	-do-
4.	-do-	-do-	-do-
5.	-do-	-do-	-do-

In the case of a tap switch with weak roller contact, the value of resistances measured on two occasions for a particular tap position are bound to differ. In case the difference in the resistances is above ± 1 %, the manufacturer should be able to identity the cause for such variations and take corrective action. This is a routine practice of WBSEB while carrying out inspection at the manufacturer's premises.

(*vi*) Before commencing separate source power frequency test on sample transformers, it· is recommended to check the source high voltage transformer along with the control panel and tripping mechanism, for its proper working.

Turns ratio bridge may be employed to check the turns ratio the of HV source transformer which should be the same as that of calibration ratio of the kV meter of the control panel. In case the turns ratio and calibration ratio are found to be almost same (within ±2%), the separate source test may be conducted, keeping an additional voltmeter connected at the input side of the source transformer for cross verification.

For example, the source transformer has a ratio of 250 V /40 kV and we are required to carry out 28 kV separate source test on 11 kV transformer. During the application of 28 kV, the additional voltmeter connected across the primary side of the source transformer should read $(28/40) \times 250 = 175$ V.

After successfully carrying out the separate source test for 60 seconds, the earth lead may be brought closer to the wire carrying high voltage using an earth discharge rod with utmost care and safety. When the gap between the earth lead and the high voltage source becomes closer, an arc with cracking sound will be established in the gap, resulting in instantaneous tripping of the control panel. This check will ensure the right application of high voltage on the primary windings as well as correct functioning of the test panel. This is a routine practice of PSEB while carrying out inspection at the manufacturer's premises.

IS-2026 recommends 3 kV separate source test on secondary side of the distribution transformer rated for about 433 V. Since 3 kV can be measured directly with 'motwane' type multimeter, it is suggested to make use of such meters for cross verification and health of the test set. However, before proceeding further, the tripping mechanism of the test set must be checked for proper functioning.

(*vii*) As per the recommendation of IS-2026, the induced over voltage test shall be carried out at double the rated voltage and the measurement of voltage shall be done on high voltage side. For example, a 11/0.433 kV transformer shall be tested at 22/0.866 kV with increased frequency (100 Hz or more). But the voltage measurement shall be done on 22 kV side. To measure such high voltage, low burden (VA) potential transformer is needed which is not generally available to most of the small transformer manufacturers in India. As a result, the voltage is usually measured on the low voltage side which is not correct according to the recommendation of ISS. The inspector conducting the DVDF test should ensure the availability of appropriate instrument for high voltage measurement. Even if it is measured on the low voltage side, the measurement should be done with a voltmeter connected directly across the low voltage terminals of the transformer under test.

(*viii*) During temperature rise test, three thermometers are used for measuring ambient temperature and one thermometer is used for measuring top oil temperature. Before starting the test, all four thermometers should be kept in a pot containing insulating oil at room temperature. It is essential that all the four thermometers read the same.

(*ix*) During temperature rise test, ambient temperature should be measured by keeping the thermometers in a specially built oil cup as recommended in IS-2026-1962. Figure 39.2 shows the dimensions and the construction of a fixed time constant oil cup.

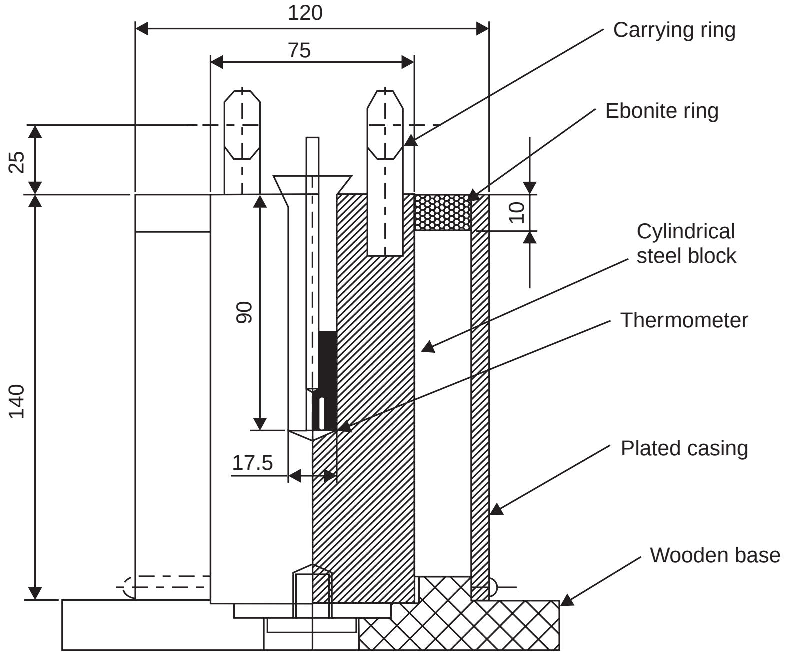


Fig. 39.2. Fixed time constant oil cup dimensions

(*x*) Long leads for making connections to the meters as well as outgoing leads to the transformer, may add error to the measurement. It is advisable to use short thick leads for current carrying circuits and comparatively thin leads for voltage circuits. Use of crocodile clips for meter connections should be encouraged.

(*xi*) Oil sample shall be drawn only from the bottom valve after cleaning the outlet orifice thoroughly. After successful cleaning, at least 2 to 3 litres of oil should be drained off before drawing sample for test.

(*xii*) It is recommended to compare the test results of the sample transformers with the routine test certificates submitted by the manufacturer before concluding the inspection. It is needless to say that the results of tests taken earlier by the manufacturer and later by the inspector for the same transformer should match, especially those of insulation resistance, turns ratio, resistance of the windings etc. In all these cases, the results are the output of a single test meter, where we do not expect much human error. Too much deviation in the test results taken before and after for the same transformer, is not expected.

In the event, there is too much deviation in the test results, the manufacturer may be asked to explain the reasons for deviations which may also be recorded in the inspection reports as a critical observation. It is, therefore essential to prepare routine test certificate out of the results taken during shop floor testing only. Otherwise such deviations may sometimes call for withdrawal of inspection.

(*xiii*) The function of explosion vent is to burst in the event of excessive pressure inside the transformer. The manufacturers sometimes use thick aluminium or brass foil as vent material which does not burst even at 2 kg/sq.cm. Occasionally even 5 mm thick cork gasket and 3 mm perspex sheet are also used as vent material. It is suggested that the specifications should state the bursting pressure of vent (which may be around 0.9 to 1.1 kg/sq.cm). The manufacturer may be asked to demonstrate the bursting of explosion vent during inspection.

(*xiv*) Breather is usually provided with a PVC adhesive tape at the bottom plug to prevent ingress of moisture during storage. This tape should be removed while fixing the breather in the transformer during temperature rise test. Moreover, the construction of breather, especially the oil cup inside the breather container, may be checked. Content of silicagel may also be checked with ± 10% accuracy.

(*xv*) HT and LT bushing fittings are available in the market as per IS-3347. It is suggested to check the weight of the complete fittings and verify the same with the weight of the proto-type sample done previously. The difference in weight should not be more than ± 5%. This is a routine practice of PSEB while carrying out inspection in the manufacturer's premises.

Verification of Physical Parameters and Constructional Details

Upon successful completion of the electrical tests, the inspection may continue further for verification of physical parameters and checking of constructional details including various internal gaps and clearances.

A check list to record such physical parameters is made in advance and the verifications are done in line with the check list and recorded. The contract should have clear guidelines about the scope of physical verification necessary during inspection and the manufacturer should extend all possible assistance to satisfy the requirements of the inspector. The inspector should also see that with minimum labour and investment, the physically opened transformer can be completed. The manufacturer may be allowed to despatch the opened transformer without further inspection as it is the routine practice of UPPCL, HPSEB, RSEB etc.

39.6 SELECTION OF TRANSFORMER FOR TYPE AND SPECIAL TESTS

Method of selection of transformers for type and special tests are different for different state electricity boards. MPEB, UPPCL etc. allow the manufacturers to undertake mass production only after the proto type sample is successfully type and special tested under the supervision of the departmental engineer. On the other hand PSEB, HPSEB, RSEB, BSEB, WBSEB etc. select a sample transformer out of an offered pilot lot for getting it tested in any of the approved test laboratories in India. Upon successful type (impulse) test and special (short circuit) test on the sample transformer, mass production is permitted.

With this, the formalities imposed by the buyers for carrying out type and special tests are over for most of the SEBs, except WBSEB who preserve the transformer at the manufacturer's premises with special sealing at four corners. As per WBSEB practice, the manufacturers are supposed to make further transformers identical to the short circuit design with similar type of construction, lead supports, framework, core guide, fixing of tap switch, connection layout etc. It is often seen that while undertaking bulk production, the manufacturers, of course use identical design for core, winding and tank, but follow a simpler and easier method of construction for quicker production. This is a deviation from the requirements of type tested design.

To avoid this problem, while carrying out inspection on the rest of the transformers at the manufacturer's premises, it is customary for WBSEB to detank the type tested transformer along with one of the transformers from the new lot for overall comparison of design as well as construction. Minor discrepancies are generally overlooked. If any major constructional flaw is noticed, which could have weakened the transformer in its short circuit and impulse performances, the entire lot is recommended for rejection.

There was an instance when a whole batch was rejected by WBSEB inspector as the coils of the transformer from the new lot were not varnished, whereas the same were found varnished for the type tested transformer.

After the inspection is over, the type tested transformer is again boxed up and sealed at four corners by WBSEB for making further references at subsequent inspections. The type tested transformer is, however, allowed to be despatched as the last transformer against the contract for which it was tested.

The procedure of verification of construction of transformer by WBSEB is quite encouraging and is recommended for other SEBs to follow.

39.7 PREPARATION OF INSPECTION REPORT

Preparation of inspection report is the concluding part of inspection. Every inspection agency has its own style of preparation of inspection report. However, since it is a quality document, we must ensure that all relevant information and enclosures are made available along with the report. The inspection report has mainly three parts:

(*i*) The first part contains details of equipment, quantity offered, sampling, observation noted during inspection, remark on test results etc.

(*ii*) The second part contains reports on physical verification. This report has three columns as below:

Table 39.4

Particulars	*Guaranteed*	*Physically verified*
Weight of complete set of core	99.5 kg	100.2 kg
Flux density	1.6 T	1.587 T
HV conductor size	1.2 mm dia.	1.203 mm dia.
LV conductor size	9 × 4 mm	9.03 × 3.98 mm
Other similar parameters		

(*iii*) The third part of the report contains the routine test results of the inspected transformers, temperature rise test results, if carried-out, and few demonstrative sample calculations.

It is further stressed that the inspection reports should be completed with the following enclosures:

(*a*) Manufacturer's routine test certificates of the entire lot.

(*b*) List of instruments used with their calibration date and status (like green, yellow, red).

(*c*) Test certificates of the vital raw materials and components.

39.8 CONCLUSION

The need for discussing the scope of inspection is to highlight some of the functionings which the young inspector must be aware of. The purpose of inspection is to ensure that the buyer is getting right equipments as have been specified in the contract. It has been observed on few occasions that the inspectors find themselves helpless due to some vital information missing in the contract. It is suggested to include all such requirements in the contract which will facilitate the inspector to check during inspection (for example, bursting pressure for explosion vent, weight of bushing fittings, tolerance on thickness of MS sheet etc.). An action plan should be made available to the inspector from the buyer's end. Based on the action plan, the inspector should prepare a check list which should include all the activities along with document verification, final inspection up to preparation of inspection reports etc. Manufacturers may also find this chapter useful and may prepare themselves in advance with all such documents which are needed during inspection. Manufactures should also see the availability of the register containing shop floor test results and must ensure that the actual results are being reflected in test certificates.

Responsibility of the inspectors is immense as they are the first hand representative from the buyer's end to judge the quality of the products.

In case of any compromise in assessing the quality or ignoring any vital requirement which may cause problem during functioning, we cannot expect trouble free service of the transformer.

Hence, it is essential that the buyer should identify and recommend good equipments only. That is why it has been said many times in this book that quality can only be assured when the buyers and manufacturers both join hands together for the common cause *i.e.* quality assurance.

It has been seen recently that some of the SEBs get the transformers inspected by third party inspection agencies, like RITES, DGS and D, BBMB, Utility, Lloyds, NPC etc. They are neither manufacturers nor users. This decision does not look to be sound towards quality implementation. It is preferred that the engineers from the department, either from maintenance or from any other user's department should be entrusted such responsibilities for carrying out inspection. Under such arrangements, the field engineers will get the scope of enhancing their knowledge on the products and can exchange their views with the manufacturers for quality improvement. This is a routine practice of RSEB which other boards may also follow.

Section V

CHAPTER 40

Role of the Quality Assurance Engineer

FOOD FOR THOUGHT

Quality, excellence, zero-defect, error-free—all these words convey but one message: The customer is supreme, and it has to be made sure that the customer is getting what he is paying for.

40.1 INTRODUCTION

Confomance to resquirements is critical for existence in a highly competitive environment. Supplier's goal should have to be satisfying the needs of the customer, both specified and implied, at the lowest possible cost. This requires dedication to quality. By anticipating and verifying customer's needs, we shall be able to serve them well.

Inspection is the main tool for the quality assurance engineer to maintain quality in the finished products. However, inspection by itself cannot build quality products. Inspection can only lead to the segregation of good from the bad.

To build quality into products, the active participation of the entire working team contributing to the manufacturing processes under the strong leadership of the quality assurance engineer is needed. Role of the quality assurance engineer is to create quality awareness among all the working people within the organization. Quality is one thing which cannot be achieved overnight. It is a culture which has to penetrate into the mind of everybody.

Quality is not a one-man job, it is the output of a team and the quality assurance engineer should be the leader of the team. It is the duty of the quality assurance engineer to organize quality checks at all stages of production and review the outcome of such checks with respect to requirements.

In case the review indicates that the results of a unit or a batch are not within the acceptable quality norms, the quality assurance engineer should find out the causes of failures and suggest corrective measures at all stages to curb occurrence of such non-conformities in future. The function of the quality assurance engineer is not to identify good and bad pieces, but to create a quality environment, where only good pieces are produced.

40.2 DESIGN REVIEW

In transformer manufacturing industry, the very first responsibility of the quality assurance engineer is to review the design output in line with the requirements of the customer's specifications as well as the reference standards. The review is done by a group of engineers from the design department, purchase, marketing, production etc. The quality assurance engineer should be the convenor of such review meetings. He should organize the meeting with regard to the place and time, make the details of design available, decide on the review team members etc. He should be aware of the formalities of reviewing a design. The parameters which affect the performance of a transformer are generally discussed and reviewed in the meeting. While reviewing the design of a special type transformer, being made for the first time, it is essential to discuss whether the available infrastructure and manpower are enough to undertake manufacturing of such transformers. Delivery is one aspect which is also discussed in the review meeting. Sometimes during review, the designer is advised to change the design to make it more friendly to manufacture and to ensure timely delivery.

However, these revisions are done without the cost of quality. Records of reviews including the remarks of the individuals are kept in a register, commonly known as **'design review register'**. After successful review, with the consent of all review members, the design is passed on to the works for taking up production of the prototype (sample) transformer.

In the event the design is not found suitable to yield quality output and requires further modification, the designer is advised to redesign (modify) taking into consideration the suggestions of the members of the review committee. In such cases, the quality assurance engineer will organize further meetings to review the outcome of the amended design. However, the outcome of both the review meetings are recorded. The outcome of design review meeting is recorded under a review code number and date with all remarks of the individual participants and clear instruction to the works to organize manufacture of the prototype transformer.

To organize review meetings successfully and with authority, the quality assurance engineer is required to familiarize himself in advance, with the customer specifications, reference standards and design.

A checklist may be prepared by the quality assurance engineer indicating the requirements of various parameters as per customer's specification vis-a-vis design output. This will help to identify deviations, if any, and apply immediate corrective measures.

40.3 DESIGN VALIDATION

During the manufacturing of the prototype transformer, it is the responsibility of the quality assurance engineer to monitor the outcome of each stage of production up to final assembly and testing. The physical parameters should be checked and recorded in a format indicating design values and observed values. Functioning of independent items like winding, core assembly, coil assembly, tank fabrication, box up etc. are checked and recorded. In-process checks on the prototype transformer, with respect to ratio, resistance, *IR* values etc. are done at this stage. All routine and type tests as per customer's specification and standards are done on the finished transformer and recorded.

It is prime responsibility of the quality assurance engineer to see that the prototype transformer is made truly as per design and closely monitor the outcome of each stage. The test results on the prototype is again placed before a committee for design validation. Organizing design validation meeting is again the responsibility of the quality assurance engineer.

Members of the design validation team review the results of the prototype transformer with respect to the design outputs/specifications/standards. If impulse and short circuit tests were conducted on the prototype transformer, the results of such tests are also reviewed by the committee members.

In the event the parameters and results of hte prototype transformer are found to be within workable tolerance limits of design output/specification/standards, the quality assurance engineer organizes to release instruction for mass production. The outcome of all the meetings includilng the remark of the individuals, are recorded in a register commonly known as **'design validation register'**.

The procedure described above is an ideal case of design validation. In case any of the quality parameters is found beyond acceptable norms, the quality assurance engineer takes up the matter with the members of the committee to discuss and review the probability of accepting the design as it is or with further revision.

Through review and validation, a design is approved and accepted for mass production. The quality assurance engineer is responsible to keep the records of review meetings. Prototype result sheet is a quality record and is required to be maintained properly.

40.4 SPECIFICATIONS OF MATERIALS AND COMPONENTS

Incomplete specification in the purchase order is most often the reason for the supply of poor quality materials by the subcontractors or vendors. It is one of the responsibilities of the quality assurance engineer to ensure that the purchase order is made complete with required specifications incorporating working tolerances. In case reference Indian standards are available for materials (say, IS-335 for insulating oil) and components (say IS-3347 for bushing), the same should be clearly mentioned in the purchase order. If it is required to buy components as per drawing (for example tank, CRGO laminations, ratio switch etc.), the purchase order should be completed clearly indicating the drawing number, title of the drawing along with working tolerances etc. Appropriate methods should be developed to ensure that the requirements for supplies are clearly defined, communicated and most importantly completely understood by the subcontractors or vendors. The quality assurance engineer, in consultation with the design department, should prepare the technical specifications of all the purchased materials and components and also ensure that the technical information is rightly mentioned in the purchase order.

Examples:

(*a*) *Technical Specification of the Purchase Order for DPC Aluminium-Windings Wire*

- Aluminium wire should be made out of electolytic grade hard drawn aluminium rod as per IS-5484.
- Diameter of bare wire 1.7 mm with tolerance as per IS-6162 (*i.e.* ± 0.07 mm).
- Double paper covering with overall covered wire diameter 1.95 mm and working tolerance as per IS-6162 (*i.e.* ± 5%).
- 1.5 mil thick kraft paper of Tribeni Tissue Limited make should be used for covering.
- Overlapping during paper covering should be about 60 per cent.
- The direction of rotation of the papers should be opposite for DPC covering, *i.e.*, if one paper rotates in clockwise direction, the other should rotate in anti-clockwise direction.

- The finished material should be soft annealed.
- The weight of each spool containing the DPC aluminium wire should not be more than 10 kg including tare (approximate).
- Information relating to vendor's name, order number, gross and net weight, bare and covered wire size etc. should be affixed on each spool.
- Each spool should be polythene wrapped to prevent seepage of rain water during transport.
- Customer hold point (chp) for inspection is the verification of diameter of bare wire. Hence the vendor must get the bare wire inspected by the purchaser before proceeding further for paper covering.

(*b*) *Technical Specification of the Purchase Order for RGO Lamination*

- Drawing no. PMF 2965 dated 03.05.1999 should be followed for weight, dimensions and grade of material
- Dimensional tolerance on width:

Up to 100 mm	:	± 0.15 mm
101 mm to 230 mm	:	± 0.2 mm
231 mm to 380 mm	:	± 0.25 mm
381 mm to 580 mm	:	± 0.4 mm
Above 580 mm	:	± 0.5 mm

- Dimensional tolerance on length:

Up to 300 mm	:	± 0.5 mm
301 mm to 700 mm	:	± 0.75 mm
701 mm to 1100 mm	:	± 1.0 mm
1101 mm to 1500 mm	:	± 1.25 mm
Above 1500 mm	:	± 1.5 mm

- Tolerance on thickness: ± 0.0125 mm.
- Tolerance on cutting angle: ± 0.5°.
- Tolerance on out of square (cut length):
  The deviation of an edge from a straight line placed at right angle to the side touching one corner and extending to the other side shall not exceed 2 mm over 150 mm width or fraction thereoff.
- Surface condition:
  Free from surface defects, such as hole, scab, blister, silver spot, dent, rust and from other harmful defects, such as non-uniform insulating surface coating on either side of the lamination.
- Finished workmanship and appearance:
  Free from sharp and short waves, buckles etc. maximum burrs not to exceed 40 microns on the slit and cut edges.
- Camber should be appreciably low.

(*c*) *Technical Specifications in the Purchase Order for Transformer Tank Fabricated by Outside Fabricator*

- Drawing no. PKL, dated 01.9.1999 shall be followed for verification of dimensions.
- Outline general arrangement drawing no PKL 1329, dated 19.9.1999 shall be followed to verify the location of fittings and accessories.
- Tolerance on sheet, flat, angle, channel etc. are in accordance with IS-1852.

- Tolerance on tank dimensions:
  (–) zero and (+) 2 mm
- Tolerance on overall dimensions:
  (–) zero and (+) 10 mm.

The above examples are provided as references for preparing technical specifications to be included in the purchase order. It is always preferred to mention in the purchase order the relevant Indian standards for the particular material and component. The purchase order for insulating oil should mention that the oil should conform to IS-335. Similarly bushings or bushing fittings should conform to IS-3347, Parts I and II etc.

Even though filling up correct technical information in the purchase order is one of the responsibilities of the quality assurance engineer, he will need the assistance of the design department for the standardization of specifications of various materials and components.

Once the specifications with working tolerances of all the purchased items are made ready by the design department, the quality assurance engineer will draft out the technical portion of the purchase order incorporating the specifications of the material. The requirement of inspection at the vendor's premises is again a pre-determined clause in the purchase order, The quality assurance engineer must review the requirement of such inspection. In case the quality assurance engineer desires the inspection to be carried out on a particular hold point, the same should also be clearly mentioned in the purchase order. Vendors should also know the meaning of customer hold point (chp) and should not proceed beyond hold point without written permission from the purchaser.

40.5 INSPECTION OF INCOMING MATERIALS AND COMPONENTS

The purpose of incorporating detailed technical specification in the purchase order is to facilitate the vendors to check the quality requirements before the materials are despatched. Here the quality assurance engineer can perform a vital role towards quality implementation. He should keep in close touch with the vendors while the materials are being processed and extend necessary guidance to the vendors on the type and nature of checks that are necessary to upgrade the quality and reduce rejection. Frequent visits to the vendor's premises will encourage the vendors to review the quality requirements on a regular basis. Providing training to the vendors at frequent intervals will help them to be more organized in quality implementation. It is suggested that the quality assurance engineer should stress more on reviewing quality records at the vendor's premises instead of verifying the quality of the materials using instruments.

In case of any doubt on any of the quality records, the particular area may be physically/electrically checked for compliance. He should also ensure the availability of test instruments as well as their calibration status. Sometimes the vendors issue test certificates on the basis of earlier documents, without actually conducting any quality checks. This practice should not be encouraged. It is the duty of the quality assurance engineer to inspire the vendors to check the quality parameters before issuing test certificates.

The very first quality document is the test certificate issued by the vendors for various materials and components. Aluminium/copper rod, insulating oil, bushing, paper and pressboard are received on the basis of manufacturer's test certificates. The quality assurance engineer should review the test certificates thoroughly inline with the requirements of latest ISS. Acceptance of such materials without the test certificates should be discouraged. In case of any doubt, samples of materials may be sent to the government approved test laboratory for quality verification without the knowledge of the vendors. Such surprise checks will definitely help to improve the quality of the basic inputs. Though it is customary to accept materials and components on the basis of manufacturer's test certificates, it is mandatory to organize incoming inspection on the materials at the works before the materials are approved to be used.

It is the duty of the quality assurance engineer to organize collectively the inspection of the incoming materials. The inspection may be done by the engineers of the user departments, but the inspection reports are necessarily certified by the quality assurance engineer before the materials are issued for production. Responsibility for various activities of the production engineers may be allotted as below:

Table 40.1

Sl. No.	*Responsibility*	*Item to be inspected*
1.	Winding department	Winding wire and strip
2.	Core assembly department	CRGO lamination
3.	Coil assembly department	Insulating paper and pressboard, tapping switch, SRBP tube etc.
4.	Fabrication department	MS sheet, angle, channel, tube, radiator, welding electrode etc.
5.	Box up department	Bushing and bushing fitting, OTI, WTI, MOG, buchholz relay, gasket etc.
6.	Painting and finishing department	Paint and thinner, breather, connector etc.
7.	Testing department	Insulating oil, name plate etc.

In case a production engineer is in-charge of more than one department, then he should be entrusted with verification of quality of all the materials concerning those departments. However, a checklist should be made in advance on the nature of verification for all the incoming materials. Acceptable quality norms for various materials and components are available in the relevant ISS. The quality assurance engineer should prepare quality acceptance norms in consultation with the design department and also in accordance with the customer specifications and ISS. The standard quality norms are circulated to the working engineers for reference during verification. It is desired that the working engineers measure the quality parameters and compare the same with the design values and fill up the remark column indicating the extent of deviation from the acceptable value. Based on the remarks, the quality assurance engineer will certify acceptance or rejection of the materials. Most of the checks, done at the incoming stages, are physical in nature. Verification of dimensions and comparing the same with the design values are the prime activities. However, there are a few materials where electrical checks are also recommended, like insulating oil, loss per kg of CRGO laminations etc.

The quality assurance engineer should stress more on quality improvement and not on quality checking. Quality checking is, of course, the measuring unit of quality improvement, but the main aim of quality assurance engineer is to see that the entire organization including the vendors and subcontractors are working as a team towards quality assurance.

We have so for discussed the role of the quality assurance engineer in monitoring the quality aspect of design, up to the successful development of prototype transformer. We have also discussed on how the quality assurance engineer can be made useful for preparation of technical specifications of the purchased materials. Vendors and subcontractors should be trained in self-motivation to check the quality aspects of the products. Frequent visits to the vendors premises may encourage the vendors to be quality conscious. Checking of test certificate, supplied by the vendors for various raw materials and components, is again a step towards quality implementation. Further, it is recommended that the quality assurance engineer should organize routine checks on the incoming materials for quality assurance.

The next step is mass production with the validated design and quality raw materials.

40.6 INPROCESS INSPECTION

It was said previously that inspection is the measuring unit of quality, but inspection cannot by itself improve the quality of the products. It is, therefore essential for the quality assurance engineer to identify the weak areas in the manufacturing processes and strengthen them through training and technical guidance. To identify such weak areas, it is advisable that the quality assurance engineer formulate some stage inspection schemes for effective control on quality assurance.

So far we have discussed the function of the quality assurance engineer in the standardization of design and checking the basic input materials. There are some essential responsibilities the quality assurance engineer has, while checking transformer during inprocess manufacturing stages.

The manufacturing process of transformer may be broadly divided in to six independent functions. They are:

(*a*) Coil winding

(*b*) Core assembly

(*c*) Coil assembly

(*d*) Fabrication of tank and core frame

(*e*) Box up or tanking

(*f*) Painting and finishing.

The output of each department should undergo some predetermined checks to verify the quality status as well as to identify the weak areas for applying corrective action and to curb production of non-conforming items. Various checks have been suggested in Chapter-4 of Section-II, which may be referred to while carrying out in-process inspection.

The quality assurance engineer is expected to identify the responsibilities of the individuals towards maintenance of quality. Routine quality checks are done by the production engineers or testing engineers.

The outcome of the checking are recorded. Normally these reports are reviewed by the quality assurance engineer before allowing further processing.

In case any of the inprocess components are found defective or the quality parameters are found beyond acceptable norms, the quality assurance engineer should identify the cause of defects through analysis of non-conformities and suggest corrective measures to curb the occurrence of such defects in future. For example, in a manufacturing organization, about 80% of the in-process components cross the quality requirements and 20% remain below the acceptable quality norms. Then it is the prime responsibility of the quality assurance engineer to identify the weak areas and strengthen them through (*a*) training, (*b*) maintenance of machines and (*c*) quality improvement of basic inputs. Continuous monitoring of the weak areas in the manufacturing activities will ultimately convert the weaknesses into strengths.

So far, we have discussed how quality assurance engineer can be effective in implementing quatity in design, incoming materials and in-process components up to box up and finishing. Now we shall discuss the contribution of the quality assurance engineer in maintaining quality of the finished products.

40.7 QUALITY CONTROL ON FINISHED PRODUCTS

It is a routine responsibility of the testing engineers to carry out tests on finished products. The function of the quality assurance engineer is to review the test results before declaring the equipment fit for despatch. Many a time, transformers fail in the dielectric tests or the performance parameters are beyond acceptable limits. It is again the responsibility of the quality assurance engineer to analyse the performance to identify the root cause of the failure and organize remedial measures to prevent failures in future.

Procedure of each test has been clearly described in ISS. To make it more simple and understandable, it is recommended that the quality assurance engineer prepare a booklet describing the test procedures along with connection diagrams. In some cases, the quality assurance engineer is advised to take the help of sample calculations for making the procedure more understandable. Load loss and impedance at 75°C may be a good example to demonstrate by calculation.

Record keeping of the test results of finished transformer is again a skillful job. Generally, the records are kept by the testing department. Since the records of the test result are a part of the quality documents, the quality assurance engineer is advised to institute a system so that the test engineers keep the documents readily available in presentable condition—even after 5 years.

Formulating the work instructions of various processes for controlling the quality of the finished products is again the responsibility of the quality assurance engineer. Various process instructions in bold letter and understandable language may be made and displayed at appropriate locations to enable the engineers as well as the operators to follow the procedures in a better way.

40.8 CALIBRATION

Arranging calibrated meters and gauges for measuring the performance parameters of transformers, is again the prime responsibility of the quality assurance engineer. All instruments, meters, gauges etc. which are used directly or indirectly for testing should be calibrated. The frequency of calibration depends upon the type and use of the instruments. Indicating instruments are to be calibrated once in a year. The rotary instruments lime megger are recommended for calibration once in six months. Static equipements like CT, PT etc. are recommended for calibration once in 5 years. It is essential that the calibrations are done only in government approved test houses. High voltage source transformer may be calibrated inhouse using turns ratio bridge.

Apart from organizing calibration of instruments and meters for checking of finished products, the quality assurance engineer should look into the inhouse calibration of meters which are used for stage inspection and stage testing. Further, as per ISO : 9001 quality procedure, all gauges, scale, vernier, micrometer, thermometer etc. which are used for quality checks, should also be covered under regular calibration.

One set of such instruments which are known as 'master set' are calibrated in the government approved test laboratories. These calibrated master instruments are used only to calibrate other similar instruments and gauges which are issued to different departments for checking the in-process components.

The master set instruments are not used for regular measurements.

So far we have discussed that the quality assurance engineer should share the responsibility of calibration of instruments, meters, gauges etc. from (*a*) outside agencies, (*b*) inhouse calibration and (*c*) maintenance of master set. This is done to ensure that the calibrated instruments are available to all departments on a regular basis. This is quite a difficult task unless the calibration activities are properly planned in advance.

The purpose of calibration plan is to organize the calibration activities well in advance in such a way that one set of calibrated instruments are always available to all the departments including finished product testing. Wrong calibration plan leads to non-availability of calibrated meters for testing. Breakage and/or non-functioning of instruments should also be taken into account while preparing calibration plan. In fact, if the manufacturer can afford to spend a little more on the infrastructure, the ideal condition would have been as follows:

- One set of calibrated instruments is available for testing of finished transformer.
- One set of instruments having inhouse calibration status is available for in-process inspection.
- One set of instruments is available as spares which may come into use only on emergency in case of non-functioning of any of the above instruments.
- One set may remain with the repairing house and/or calibration agency.

With this kind of arrangements, the manufacturer will never feel the absence of calibrated meters. Moreover, the calibration plan should also indicate, in advance, the movement of all such meters. All instruments, meters, gauges etc. which come under the calibration plan should be codified. The code number along with the date of expiry of calibration should appear at a visible position on the instrument. Instruments under inhouse calibration, master set, scale, vernier, micrometer, thermometer, gauges, weighing bridge etc. should come under codification. The working engineers should be trained not to use any instrument, the calibration status of which has expired.

The quality assurance engineer should impart training to the working engineers for condition monitoring of the meters. Proper trolley or test table or test panel, based on the type of instruments and their uses, are to be employed. Ratio meter, resistance bridge etc. are generally kept on a trolley. Loose instruments, like megger, multimeter etc. are kept on test tables. Wattmeter, voltmeter, ammeter etc. are kept on test panels. Instruments should always be kept away from dust. After use, suitable measures should be taken to cover the instruments to prevent penetration of dust and moisture.

40.9 MAINTENANCE PLAN FOR MACHINES

The basic responsibility of the quality assurance engineer is to create a healthy working environment and to inspire everybody in the organization to perform with a team spirit. He should remain as a bridge connecting all the quality activities in the team. The quality assurance engineer should see first that the entire production team is working under a defined quality system. The second objective is to find out the reason for non-conformities and the third objective is to offer corrective measures to curb recurrence in future.

It was discussed earlier that we need good healthy machines to manufacturer quality products without interruption.

It is one of the responsibilities of the quality assurance engineer to see that the machines used for production are properly maintained and suitable for continuous operation. In medium and big industries, a separate group of mechanics headed by an engineer generally take charge of the maintenance work of the machines. But in the case of small manufacturing units. Even the quality assurance engineer sometimes becomes the head of the maintenance department. Whether it is a small, medium or big industry, the maintenance work is classified into two categories:

(*a*) Preventive maintenance

(*b*) Breakdown maintenance

Preventive maintenance of a machine is essential to reduce the chance of reoccurrence of breakdown during operation. Depending upon the nature of the machine and its use, the frequency of maintenance is fixed. Rotory machines like motor, generator, EOT crane etc. require frequent attention. Maintenance mechanics should have enough skill to judge the requirement of preventive maintenance. Based on the experience, judgement and detailed study of the equipment, essential spares which are needed for frequent replacement should be listed out in advance and the availability of such spares should be monitored.

Whether the quality assurance engineer is directly involved in the maintenance work (for small organization) or indirectly associated with the maintenance work (for medium and big organization), preparation of maintenance plan is the duty of the quality assurance engineer. Schedule of preventive maintenance is done on annual basis. The master plan of maintenance containing the entire plant and machineries should indicate the proposed date of preventive maintenance. Date of last maintenance, whether preventive or breakdown in nature, should also appear in the master plan. The maintenance schedule is done in such a way that the productivity of that particular machine is not disturbed. Maintenance is done either on weekly-off day or after working hours. In case of machines scheduled for continuous operation round the clock (like electric oven), maintenance schedule should be done judiciously to effect minimum loss of production. If spare capacity of such machines are made, the loss of production can be minimized.

We cannot overrule the possibility of *breakdown maintenance*, even if the preventive maintenance is done to full satisfaction. In case, breakdown occurs during the operation of a machine, it should be attended to by skilled mechanics on priority. Cause of breakdown along with the parts replaced should be recorded in the histroy card. Moreover, the operator should also be trained to handle routine maintenance in case of emergency.

If routine maintenance, as per the master maintenance plan, could not be done on a particular machine, it is a case of non-conformance and the same should be recorded in a register along with the reason for non-conformance, code number of the machine and final disposition.

40.10 CORRECTION AND PREVENTIVE ACTION

As was seen in earlier chapters, any activity or operating system which deviates from the specified standard operating conditions for a variety of reasons will result in non-conformity. ISO standards on quality system requires the supplier to have an institutionalized quality system for monitoring manufacturing activities or processes. When non-conformities are observed, prompt corrective and preventive action must be taken to bring the operating system back to the standard or normal condition.

Corrective action through analysis of non-conforming products was already discussed in Chapter-9, Section-III. Correcting the manufacturing process to ensure that all subsequent products conform to the specification is far more important. It calls for a systematic analysis of non-conformities and trends for non-conformities in the process. Some process variations or deviations are bound to occur because of inherent unavoidable reasons. However, major deviations, abnormalities or adverse trends in a process indicate problems that can and must be traced. When investigating defects or non-conformities, the quality assurance engineer must bear in mind that not all defects are attributable to machines or the shop -floor.

In fact, the root cause of the majority of defects can often be traced to some deficiency or lapse in functional areas, such as design, process engineering, purchase etc. Some causes may be apparent from the very nature of the defect and the frequency of its occurrence. In most cases, however, defect investigation is a complex exercise involving the analysis of inspection records and test data on materials as well as the examination of tooling and the process capability of manufacturing equipment. A number of statistical techniques can also be used.

While analysing causes, the quality assurance engineer should be on the lookout for the typical causes of non-conformity. These are listed below:

(a) Design and Specifications

- Vague or insufficient manufacturing particulars or illegible drawing or overwriting of numerical values
- Impracticable design or incompatible components and assembly tolerances
- The use of obsolete drawings

(b) Machinery and Equipment

- Inadequate process capability
- Incorrectly designed tooling
- Worn tools, jigs or dies
- Non-availability of gauges or measuring equipments
- Poor maintenance of machines
- Equipment affected by environmental conditions such as temperature, humidity etc.

(c) Material

- Use of untested materials.
- Use of materials of same look but having different specification (example: CRGO lamination)
- Substandard materials accepted under concession on account of emergency

(d) Operating and Supervisory Staff

- Operator does not possess adequate skill in the operating process and in using the equipments
- Operator does not understand the manufacturing drawings or instructions related to the process
- Machine setter does not know how to set the machine correctly (*Example:* Setting of the blade of shearing machine while cutting CRGO lamination. Wrong setting will lead to generation of excessive burrs)

- Careless operators and inadequate supervision
- Undue haste of the operator to achieve targets

(e) Process Control and Inspection

- Inadequate process control
- Non-availability of proper test equipment
- Test equipment out of calibration
- Vague inspection/testing instructions
- Inspectors do not posses the necessary skills

If the analysis of a defect causing process is carried out in sufficient depth, the cause will itself suggest the remedy. Some remedies (*e.g*. replacement of an obsolete drawing or a test equipment with calibration overdue) may be quite simple and can be applied straight away.

Other remedial measures may require considerably more planning. For instance, it may not be feasible to replace a machine that is found to be incapable of processing to the specified tolerance. Other measures may, therefore, have to be considered before a final decision is made. The possible measures include:

- Alternative method of manufacture
- Selective assembly
- 100% inspection of the affected components
- Redesign of the component to provide for wider tolerances etc.

During this stage, the quality assurance engineer should consult all departments concerned to obtain their views on various methods of preventing defects. The decision on the remedial measures to be adopted will depend on a comparison of the practicability and economics of the various alternatives.

Once corrective measures are applied, the product must be carefully monitored to see if the non-conformity is eliminated or minimized. During this stage, further changes in the process or its controls may be called for. This process of readjusting and applying remedial measures and reviewing their effects must be continued until the objectives of the study are fully achieved.

40.11 CUSTOMER COMPLAINTS AND FEEDBACK

The basic objective of the quality assurance engineer is to monitor the quality aspects in manufacturing and in other functions to produce quality products and to earn customer satisfaction. The purpose of this paragraph is to see how to analyse customer complaints and apply proper corrective measures to improve upon the quality in future supplies.

Data bank of each failed transformer should be prepared. A team of engineers from each of the departments of design, production, testing etc. headed by the quality assurance engineer should critically analyse the cause of failure and offer remedial measures. In case failure is attributed to the users, the same should be brought to the notice of the users without fear. The causes, like continuous overloading, low oil level, loose connection, running without breather etc. may be termed as failure due to the negligence of the users. It is seen that the customers do not want to share the responsibility of failures in almost 90% of cases (which is not a healthy practice). It is suggested that the users constitute a task force to monitor the performance of the transformers at regular intervals, as indicated in Chapter-3, Section-I. This will definitely enhance the life span of transformer to a great extent.

However, on failure analysis, if it is established that the failure is because of the mistake at the manufacturer's end, then the following corrective measures should be taken for quality upgradation in future supplies:

(*a*) If the failure is due to weak construction, the designer should be made responsible to study and correct the design.

(*b*) If it is proved that the failure is due to bad materials or components, the vendors should be invited to see the specific instances of such failures which will enable them to understand the cause of failure and to offer necessary corrections in the future supplies.

(*c*) In case it is established that the failure is due to human error, the concerned workman should be explained how his mistake has caused the failure of transformer in service.

It is seen that the causes of failures are numerous, but in most of the cases the effect is burning of windings. So failure analysis and correctly identifying the root cause of failure is a very skillful job. It is suggested that failure analysis should be done by a group of expert engineers within the organization headed by the quality assurance engineer who is responsible for preparing a data bank. Documentation relating to the failure analysis and communication to the different departments including users are also a part of the responsibilities of the quality assurance engineer.

In case, it is proved that the failure is due to the repeated mistake by a particular operator or vendor, he should be debarred from handling such activities in future.

40.12 TRAINING/MOTIVATION

The purpose of training is to develop the skill in the individuals so that they perform effectively to produce better quality products. The process of manufacturing a transformer is mostly manual in nature where the individual's skill plays a vital role in the quality of the finished product. It is recommended to identify the weak areas of the personnel and strengthen them through training.

The quality assurance engineer is the key person in identifying the needs of training for the production supervisors and workers. The basic work elements in all functional areas are carried out by the workers under the guidance of the supervisors. Their skill and competence have a decisive effect on the quality of the end products. These workers and the supervisors should be thoroughly trained in the skills required for their tasks. They need to know how to operate machines, tools and instruments. They should be able to read and understand specifications, drawings and other documents of the quality related activities. The persons to undertake special processes, such as winding, welding, oil filtration, shot blasting, brazing etc. need to be certified after proper assessment. Some training in elementary statistics is also desirable to create awareness of quality in their working style and to raise their confidence in producing quality jobs. Training may be provided for individuals or groups (departmentwise) as per requirement.

Requirement for training is generally identified through performance appraisal. In case a workman is slow in acquiring a desired skill, he may be put through frequent training either on-the-job or through demonstration of the same operation done by a skilled operator who is known for his product quality. In case a specific need for training has emerged from the customer complaints, the same should also be done.

The quality assurance engineer is responsible for organizing training to the supervisors and workers. Scheme for imparting training is made in such a way that the personnel of all departments are covered. Frequency of training depends upon the type of jobs they are handling, but not less than once in every alternate month.

Whatever may be the nature of training, it is to be documented. The documents should cover the training materials, record of interaction and the name of the participants. Every departmental head, concerned for quality, should be asked to assess the training need as well as the scope and the level of training required for the personnel working under him.

Departmental heads should identify the personnel to be trained. On the basis of the above information, the quality assurance engineer should identify the trainers as well as organize trainees and arrange sessions/classes in a systematic manner so that the persons concerned can be trained within a definite time frame. Particular attention should be paid to the training of newly recruited workers and supervisors.

Some training can be imparted in the form of organized courses, but much of it will be on-the-job, with employees working as understudies to their seniors. A full record of persons trained, the scope and duration of training and qualifications attained should be documented centrally. These records should be made available to various departments so that the persons can be deployed for some specific work on the basis of their qualifications.

Motivation

Although ISO:9001 does not cover motivation as a part of it, motivation is very important for the effective implementation of quality system. A well organized quality management system will fail, if the management is unable to create enthusiasm for the system among the personnel and secure their full co-operation.

The meaning of motivation is different for different groups of personnel in an organization. Some may work for money. Others may work for security of jobs, for them money may not be the motivation. The motivation of the middle management may be advancement in their carrier through promotions. The top executives generally look for fame.

Involving personnel at various levels when activities in their areas are reviewed, will lead them to identify with the new system. No attempt should be made to impose a new system or procedure on a department without offering sufficient training. In the early stages of system development, the floor shop engineers of all concerned departments, should be encouraged to analyse their existing activities, come up with suggestions for improving standard operating procedures and instructions and propose mechanisms for monitoring and control. However such suggestions should be critically reviewed before implementation. This mechanism of exchanging thoughts will encourage the middle management personnel and give them a sense of participation in the management programme.

The quality assurance engineer is the key person for engaging workers in quality management. Involving workers in the quality management is the most effective means of stimulating their interest in performing to achieve the quality standards. Genuine participation can be expected only if they are given full opportunity to express constructive criticism and suggest methods of improvement. Workers should be encouraged to make suggestions and these should be given serious consideration.

If found practicable, these suggestions should be implemented immediately and the author should be acknowledged publicly. If the suggestion is not found useful, its drawbacks should be discussed with the workers and the difficulties in implementation should be explained. The author or some other worker may be able to make further suggestions to solve the problem presented. In no case, should a suggestion be brushed aside at first glance. In fact workers should be encouraged to offer any solution which come to their mind without fear of being ridiculed.

The above approach can be given a practical shape by constituting a shop quality committee which could meet periodically to review the implementation of quality programme. One workman from each functional department headed by the quality assurance engineer may form the shop quality committee (sometimes it is called quality circle). The meeting to review the quality implementation, if properly conducted, will draw upon experiences and ideas of actual operators and will be invaluable in highlighting areas of weaknesses and a source of possible solutions. This mechanism of joint consultation will give the workers a sense of participation and generate enthusiasm for quality programme.

40.13 QUALIFICATION CRITERIA OF THE OPERATORS

It is one of the responsibilities of the quality assurance engineer to ensure that only qualified operators are engaged in production activities.

The qualification criteria of each activity (say winding, assembling, tanking, painting, fabrication etc.) are prepared in advance and the operators are screened based on the qualification requirements before declaring them as qualified operators. It is essential that a qualified operator must be able to read and understand the work instructions, design and data sheets, quality guidelines, acceptable tolerance limits etc. Apart from these academic knowledge, their product outputs must be of acceptable quality. Productivity may also be taken as one of the qualification criteria. Moreover, they should be able to use correctly the scale, vernier, micrometer etc. On the whole, the qualification criteria both theoretical and practical, should be set for each activity and the operator should be aware of the qualification requirements in advance so that he can prepare himself before the screening test.

The above are some of the qualification requirements for general operators who undertake normal production jobs. There are other manufacturing processes in transformer industry which are directly linked with the quality of the ultimate products. These processes are termed as ‘special processes’. Welding, leak testing, brazing, operation of oven for demoisturisation, oil filtration etc. are some of them. The qualification criteria for such special processes are quite different from that of normal production jobs. The details of each of the above processes were discussed earlier in Chapter-5, Section-III.

Based on the outcome of the screening test, a list of qualified operators, department-wise, should be made and the QA engineer should ensure the availability of this list to all production supervisors who are responsible for delivering quality outputs. It is the duty of the production engineers to see that only such qualified operators are engaged for manufacturing transformers. In case some of the workmen fail to prove themselves qualified in the screening test, the reason for disqualification should be identified first and the same should be brought to the knowledge of the failed operators, so that they can know their weaknesses and can prepare themselves for future tests. If the quality assurance engineer finds it necessary to organize training to improve the skills of the disqualified operators, the same should be arranged in a phased manner.

The frequency of screening test to update the list of qualified operators (say once is six months) should be predetermined.

Sometimes the production supervisors may not be able to arrange enough qualified operators to undertake a targeted production output. On such occasions, the quality assurance engineer may allow unqualified operators on merit basis to take part in production activities. However such outputs are critically examined and tested both at in-process stages as well as on finished transformers. If possible, field performance of these transformers should be critically watched.

40.14 CONCLUSION

Inspection is the best mechanism to identify the weak areas in a manufacturing organization. Once the weak areas are identified, it is the responsibility of the quality assurance engineer to bring out the root cause of the problem through analysis of non-conformity. Based on the outcome of such analysis, the quality assurance engineer will suggest necessary corrective and preventive measures to strengthen the weaknesses and to stop occurrence of mistakes in the future activities. Continuous efforts to reduce the gap between the 'quality targeted and quality achieved' is quality improvement.

We have discussed in this chapter various means to assure quality. The activities covered are design, purchase, in-process checks, final testing, training etc. Role of the quality assurance engineer can be concluded with a brief table as shown below covering all major activities and responsibilities of the quality assurance engineer.

Table 40.2 Activities and responsibilities of the quality assurance engineer

Scope of work	*Activities and responsibilities*
l. Design review	(*a*) Organize design review committee meeting as and when required to review the design output vis-a-vis customer's specifications and reference ISS/IEC/BS standards. (*b*) Release the working design to shop floor for making a prototype transformer.
2. Design validation	(*a*) Organize the manufacturing of the prototype transformer strictly as per design and record the outcome of each stage of production. (*b*) Organize meeting of the design validation committee to discuss and review the results of the prototype transformer. (*c*) Approve the design for mass production if the prototype test results and performance parameters are found within acceptable tolerance limits.
3. Specification of incoming materials and components	Prepare, in consultation with the design department, the technical specifications of all purchased materials and components as well as ensure that the technical information is correctly mentioned in the purchase order.
4. Review of inspection report of incoming materials and components	(*a*) Organize inspection of materials and components at the vendor's end as well as at the receiving stores. (*b*) Review the test certificates submitted by the vendors for the materials and the components (*e.g.* insulating oil, bushing etc.) before acceptance/ rejection. (*c*) Review the materials inspection reports and release for production. (*d*) Conduct frequent visits to the vendor's premises to encourage the vendors in checking the quality requirements of the purchased items before delivery. (*e*) Once the non-conforming materials or components are identified, analyse the cause for non-conformance and take action to prevent its occurrence in future.

Contd.

Scope of work	*Activities and responsibilities*
5. Inprocess inspection	(*a*) Identify the responsibilities of the individuals towards maintenance of quality. Routine checks are done by the production engineers and testing engineers and the results are recorded. Review these records before allowing for further processing. (*b*) Once non-conforming products are identified during in-process inspection. analyse the cause of non-conformance and take action to prevent its occurrence in future. (*c*) Prepare quality acceptability norms in consultation with the design department and in accordance with the customer's requirement and ISS. These standard quality norms are circulated to the working engineers for reference during verification. It is customary that the working engineers should measure the quality parameters and compare the same with the design values and fill up the remarks column with deviation from the acceptable values. Based on the remarks, the quality assurance engineer certify for acceptance or rejection.
6. Control on finished products	(*a*) Review the test results of finished products before they are declared fit for dispatch. (*b*) Review and analyse the non-conforming products, to know the cause of failure and organize remedial measures to curb the occurrence of such premature failure. (*c*) Prepare a booklet containing the test procedures along with connection diagrams and sample calculations to make it more understandable.
7. Calibration	(*a*) Organize calibration of instruments. (*b*) Ensure the availability of calibrated meters of desired class of accuracy for testing. (*c*) Organize calibration of meters and instruments from outside agencies. (*d*) Organize inhouse calibration and issues test certificates of meters and instruments. (*e*) Store master instruments, like scale, vernier, micrometer, thermometer, pressure and vacuum gauges etc. in safe custody for 5 years. (*f*) Organize inhouse calibration and issue certificates for scale, micrometer, vernier, gauges etc. (*g*) Prepare calibration plan and implement/monitor the same. (*h*) Organize the repair and maintenance of meters and instruments. (*i*) Provide stickers on all the instruments, meters, gauges etc. indicating the code number, calibration status, calibration due etc. (*j*) Keep checks on the distribution of instruments, meters, gauges in various departments. (*k*) Condition monitoring of instruments, meters, gauges etc.
8. Check on maintenance of plant and machinaries	(*a*) Prepare a maintenance plan on annual basis. (*b*) Codify plant and machinary for easy identification. (*c*) Organize the availability of good healthy machines to effect uninterrupted manufacturing of quality products.

Contd.

Scope of work	Activities and responsibilities
9. Corrective and preventive action	Corrective and preventive action in the following items through analysis of typical non-conforming products (*a*) Design and specifications (*b*) Machinary and equipment (*c*) Materials (*d*) Operating and supervisory staff (*e*) Process control and inspection
10. Customer complaints and feed back	(*a*) Identify the root cause of customer complaints and offer corrective measures to improve upon the quality in future supplies (*b*) Prepare a data bank of causes of failure and their analysis
11. Training and motivation	(*a*) Identify the training needs of operators and supervisors (*b*) Prepare training plan (*c*) Organize training course (*d*) Keep full records of persons trained, scope and duration of training, qualification attained (*e*) Motivate all personnel to produce quality products (*f*) Organize the meeting of quality committee and review and implement the decisions taken in the meeting
12. Qualification criteria of the operators	(*a*) Ensure that only qualified operators are engaged to participate in production activities (*b*) Set qualification criteria for each activity and process (*c*) Organize qualification tests for workmen (*d*) If unqualified operators are used in un-avoidable circumstances, critically examine their outputs (in-process as well as final)

Quality assurance and quality verification are two different entities. Quality verification is the measuring unit of quality assurance. Strict quality verification will help to establish assured quality, but cannot itself improve the quality.

Quality verification can only identify the bad pieces (poor quality) from an offered lot and approve the good pieces for onward processing.

In small scale industries in India, it is seen that the test engineers are often given the dual charges of quality verification as well as quality assurance. But these two activities are to be handled by two different people. Testing engineer is considered to be a part of the production group who is also responsible for achieving targeted output. Quality assurance engineer should always be kept away from the production activities. He should be responsible only for activities concerning quality assurance.

Section V

CHAPTER 41

Thoughts for Progress

41.1 INTRODUCTION

Quality has many definitions and the true definition is valid at a point of time from customer's perspective. There are many aspects of quality and they fall into categories, such as customer view point of quality, procedure view point of quality, personal quality, behavioural quality, quality practices etc. Reliability, education, training, team work, communication and other such topics are always included in quality discussion. Quality is the key tool to beat the competition and thrive in the world market.

History of quality is not too old. Quality movement started with Shewhart Control charts in 1940's. But quality was always present in our historical monuments, art work, literature etc. Quality awareness increased in the past two decades with opening up of global business and competition in the international market. Interests in the Quality Circle, National Quality Awards and ISO standards activities started from this awareness.

Sharing information, training, and education increases the quality awareness. The purpose of this book is to stimulate thinking in the quality direction, promote product excellence, and help 'Made in India' product known world-wide for its excellence in quality.

41.2 CORRECTIVE AND PREVENTIVE ACTION

"An ounce of prevention is worth a pound of cure" is truly applicable in the business world as well as physical well being. Generally, corrective action means 'short-term' action and preventive action means 'long-term' permanent solution. How can one be healthy? The answer lies in the preventive action.

In the case of kitchen fire, extinguishing the fire immediately is the corrective action. Keeping a fire extinguisher readily available is a preventive action.

Corrective action means implementation of effective action to eliminate problems identified in products, services, or processes. Preventive action means avoiding problems through planned activities. Generally corrective action follows detection of problem or non-conformance. Both corrective and preventive actions can be applied when the problem is detected. Corrective actions will take care of immediate problem and preventive actions will take care of the recurrence of the problem.

Corrective and preventive action, after problem detection, involve problem definition and analysis, root cause analysis, an effective action plan, implementation and verification activities etc.

Audit and inspection provide some assurance on the product quality and help to prevent products of bad quality from reaching the customer.

But audit and inspection detect the problem after its occurrence. The damage has already been done. Audit and inspection are useless if effective actions are not taken to prevent defects from happening again. Calibration, certification, training, supplier surveys, planning and process control are some of the activities used in the prevention process.

Prevention means not letting failures to occur. Warranty and associated failure costs are avoided with preventive action. Customer satisfaction is earned and an excellent product image is set in the mind of the customer. Disaster and potential non-conformities are eliminated when preventive action is taken.

A quote from Price Pritchett who is known internationally as a leading authority on the dynamics of change will illustrate clearly the difference in the application of corrective and preventive actions.

"I was in the drug stores the other day, trying to get a cold medication ...

Not easy.

There's an entire wall of products that you need. You stand there going,

"well, this is quick acting,

but this is long lasting ...

Which is more important, the present or the future."

41.3 EDUCATION AND TRAINING

There is a huge difference between education and training. Education is the knowledge obtained through learning basic principles. Education is a formal process of learning by attending classes, seminars and so forth. Education does not have any value if it is not applied appropriately. Training means becoming proficient through special instructions and drills. Training also means growing, thus achieving desired goals or results. It is teaching someone else how to avoid making the same mistake that we made. Training provides very specific skills intended to close the gap between current and desired abilities. Education and training require practice. Practice makes it perfect. Mastery is achieved after education and training have been put into practice. Education provides understanding 'Why' and training provides knowing 'How to'. Understanding and knowing the underlying concepts allow instant and intelligent course correction.

Education can be general or specific, but training is only in a specific field. Training can be in a classroom, one-to-one, or on-the-job. Learning through experience is also a form of training.

Occasionally, business condition or environment, demand training in a specific field. For example, clerks and secretaries used to be the only individuals who required training in typing.

These days, anyone who uses a computer, must learn to type. Not knowing how to type is a handicap and results in low productivity.

Similarly, driving is a necessity if one lives in an urban area. Mobility is limited if one does not know how to drive. Excellent communication and presentation skills are emphasized heavily in the business world. Technical persons should acquire presentation and communication skills.

Training cannot be avoided in specific situations. Acquiring new skills, becomes a necessity and these are acquired through training.

Education and training aim at expanding knowledge and improving skills. There should be continuous learning regardless of position or age. Training must be incorporated into a company's strategic business plan and directed towards achieving business objectives.

Today's world has no pity on the person who is lazy to learn. If we do not take personal responsibility for continuing our education, we end up without the knowledge we need to protect our career.

Lifelong learning is the only way to remain competitive in the job market. We should invest in our own growth, development, and self-renewal. We should do this the way a company invests in research and development, and come up with "new and better products or services."

So let us forget the thought that we have finished our education. We must defend our career by updating our knowledge and skills.

41.4 UNITED WE STAND

'*United we stand, divided we fall*' is a familiar slogan. It could also mean team approach, team spirit, team work, working unity or working together. Teaming within an organization or teaming with other organization is not new but it is a requirement for survival and growth. Teaming with other organization is called alliance or partnership. The main objective is to pull together collective skills and talents in order to survive and grow.

Internal fights and politics will not allow an organization to achieve its goals and objectives, but will make it fall apart. Employees have to support the mission of an organization and its objectives in order to compete in the global market.

Each single strand in a rope is weak, but when wound together, they can pull a heavy load. Similarly, additional strength is obtained by working together as a team. Living and working in unity is essential for individuals as well as organizations. Standing united makes business sense and makes everyone stronger.

Not everyone has every skill or talent, but collectively a lot can be accomplished. This makes it possible for people having different but complementary knowledge and skills to contribute to the development of a strategy or solution to a problem important to the country or company.

Organizations should break down barriers. People should be able to work together for the betterment of human kind. Working together can eliminate their disputes and can unite them to form a stronger organization with a common goal. Quality professionals can work as the catalysts. As quality professional, our objectives must be to work together, not against each other. It is one of the lessons all individuals and organizations must learn.

41.5 CAREER PATH

Superhighways have entrance ramps and multiple lanes for slow drivers and fast drivers. There are some rest stops also. Then there are toll booths. Finally, there are exit ramps. Occasionally, road blocks, road construction, natural disasters, bumps, rough road surfaces etc. can cause delay in the journey.

Is there not a similarity between a career path and super highway?

The same elements are present in a career path. Drivers on the career path control their destiny just like on the superhighway. Entrance bumps are for the people entering into the job market.

Quick learners with initiative move faster while procrastinators stay behind. People move according to their ability, desire and the available opportunity.

Either people run away from problems, or ignore them, suppress them, or resolve them. The first three ways do not get us anywhere, the last way is the best way to deal with the problems or obstacles.

To succeed in the career path and to move forward, one should keep ahead of technology and new developments in the field. Skills need to be sharpened by retraining and reeducation. Enhance application-based knowledge and skills. Stay ahead of the game by increasing learning power. Life in the slow lane gets boring and skills become obsolete and rusty.

Alice Wonderland quotes:

"If you don't know where you are going, then it does not matter where you end up."

We live in an impatient world, with fierce competition and fleeting opportunities. Organizations that are lean, agile, and quick to respond clearly have the edge.

But organizations can't go fast if their employees go slow.

So we need to operate with a strong sense of urgency. We must accelerate in all aspects of our work, even if it means living with a few more ragged edges.

41.6 ROLE OF CUSTOMER AND SUPPLIER

Who is our customer? Everyone has a customer. The customer may be our parents, brothers, sisters, other relatives, teachers, our boss, organization, spouse, children, neighbours, local community or government. Anyone accepting the output from a person is a customer. Hence the customer is everywhere.

Everyone plays a dual role. Sometimes as a supplier and sometimes as a customer. At home, at work, in the community, in a professional society, and in every phase of life. Dual roles of customers and suppliers become evident.

On many occasions, it is easy to think as a customer and forget about being a supplier. Take for example a fire fighting crew. A bucket of water is passed on from one person to the next person. The main objective of each member of the crew is to extinguish the fire as quickly and as efficiently as possible. Each one is a customer for one second and then becomes a supplier to the next person in line. It is a team work.

The person in the middle does not know the location of the water source and is unaware of where it is actually used. But each one knows that water is used to extinguish the fire. All are synchronized to their roles and make sure that there is no delay. This is a classic example of customer and supplier roles being played by the same person.

Similarly, a person in the factory wonders how the ultimate customer is satisfied by his/her role. An operator takes work from a previous operation and hands it over to the person in-charge of the next operation. No one knows the ultimate customer. Each one has to first satisfy his/her immediate customer, then the next higher level and so on, and ultimately the final customer.

The point is that everyone acts as a customer and supplier at different points in time. The person to take the output is always the customer, while the source of the output is always the supplier.

It is obvious that if a process is good, the results are bound to be favourable. One aims at better results through more capable processes. This belief naturally leads one to the importance of improving one's processes. Another fact of process improvement is orientation towards the process rather than people. Quality gurus have long been saying that 85% of quality problems are system related and are under management control and only 15% are people (employee) related. Dr. Deming put the figures for management controllable problems at 94%. It should, therefore be obvious that to reduce quality problems or to improve quality level, one must concentrate on improving the processes.

A process is defined as a series of activities or tasks performed to produce a desired result. The process, through a series of operations, converts available inputs into desired output.

The essential features of a process are inputs of various types used to produce an output or outputs by a series of value adding activities.

The inputs are provided by the suppliers and the output goes to customers. There has to be an agreement between the processor and his customers about the requirements that the output must meet. Similarly, there has to be an agreement between the processor and his supplier about the requirements that the inputs must meet.

Every company, however small it may be, carries out large number of processes. These processes are connected to one another by linkages between internal customers and internal suppliers. The output of one process becomes the input of the next process.

41.7 DO MORE WITH LESS

"*Do more with less*" means be efficient and productive.

In the competitive world of technology, we must cut corners to save money and reduce costs to survive. Income and expenses must be balanced. But how can we reduce the cost without compromising on quality?

Perhaps some or all of the following will help:

- Plan ahead.
- Be thrifty (economical management of resources).
- Increase productivity.
- Reduce manpower.

Some important things to do everyday:

- Learn the job well.
- Communicate skillfully and precisely.
- Plan ahead.

A well developed plan is a window to the bright future. Planning ahead means responding to expected future changes. A rigid plan is sometimes an unworkable plan.

Increase productivity by discarding inefficient operations. Discard all unnecessary things that are lying around. Concentrate only on the essentials. Doing more with less will essentially improve the efficiency and reduce cost. With the advent of computers, manual work can be reduced substantially. Effective processes that eliminate unnecessary work are the key to our success.

41.8 OUR STRENGTH

White is made of seven different colours (Violet, Indigo, Blue, Green, Yellow, Orange and Red—VIBGYOR) mixed together. We can't see all seven different colours separately in white colour, only one colour is observed. Similarly, our strength lies in unity.

Eating different kind or different colour of food makes our blood red. When different hands are joined together in work, it can bring out the desired results. Our strength lies in being one, not in fighting with each other. Work environment is like a funnel, where diverse groups of people merge in a disciplined way.

The power of diversity provide real value to an individual and to an organization. The collective power of diversity can be leveraged to compete effectively and efficiently in the market place. The sum of individual strengths makes real strength for achieving desired output.

Team spirit plays an important role in the success of any organizational activity. With team spirit, a lot can be achieved and difficult tasks can be made easier. Nothing seems impossible in an environment where team spirit is present. But team spirit is achieved only when sensitivity towards others is maintained. The feelings of others should not be hurt and ego should not play any part in dealing with other members. Respect for the individuals should not be forgotten. We should treat all team members the way we would like to be treated.

The purpose of constructive criticism is to help find a solution to deliver defect free products or services. We should be pleased when problems are identified and we are giving an opportunity to correct them. We can learn from our errors. If we know the cause of error, future errors are avoidable. The challenge, then, is to help others to pinpoint their deficiencies without hurting them.

If we don't tell them about a problem, we are not doing them a favour. But, if we tell them in an insensitive way, there is a possibility we may lose a good team member.

Our objective is to work together, not against each other. It should not be 'you or us or them,' but 'we'.

41.9 WORK CULTURE

Our real crisis is our poor work ethics, as few, really want to work. Nothing makes our people more happy than getting something far doing nothing. A handful of people are indeed guided by their sense of values and principles and no one has to tell them to do what they are expected to do nor do they need any supervision. But the majority of our people are adverse to working, leave alone, working hard. We accept mediocrity or performance at a level less than the best or optimum level saying "Sab kuch chalta hai" (anything is ok). There is a widespread attitude that if the other guy is not working hard, then why should I, —if I work hard, I am the one who is given more work—the chap who does not work, gets away with it. All these reflect lack of ethics. It also shows lack of consideration for others and lack of pride in doing things well, in short, of not being motivated to do as much as we can and as best as we can.

The more holidays there are, the more happy people are. They do not take their work seriously, always wondering what more they can get for themselves as emoluments. Lethargy and greed result in poor work culture.

In a class of middle level executives from the Government department undergoing training, the question was how to increase people's motivation. One of them was asked what his goal in life was, and his answer was that he wanted to sail through his career and retire comfortably. He was asked how he could achieve his goal. His reply was that he would never write or recommend anything in the file. All he would do was to seek the order from the higher authority. For, taking a particular stand or recommending a decision was risky. One could get into trouble. Ultimately, since such a person never commits anything, he is left alone and he has no fears about being hauled up for wrong decisions.

One more instance to show the work culture of most of the management personnel in India is narrated below. A police officer was specially rewarded for his excellent performance in maintaining Law and Order situation under control in his area. During an informal chat, he disclosed to his friends and relatives the fact behind his excellent performance. The truth was whenever a victim made a complaint to him (theft, robbery, rape ...) he refused to record such cases in the official register. The clean register had misguided the higher officials to take a wrong decision for rewarding the worthless police officer.

Performance, in fact, is usually misjudged. A good performance appraisal system has to be drawn up. A person should be able to improve his work on the basis of constructive suggestions in the performance appraisal. It should be made a tool for improving people, not damaging their careers. which also sometimes happens at the highest levels. Superior officers need to look at people's work objectively, rather than exercising an authoritarian or hierarchical approach.

It is seen that daily wage workers will work well until they are regularized. Somehow, the motivation holds only until the purpose of getting into a regular job is achieved.

One would imagine that with so many people and so few jobs, it would not be difficult for the management to get rid of such indifferent employees. In reality, it is not so.

In Japan, where there is security of service, work ethics is just the opposite of what we have here. The workers take security of service very seriously and would dedicate their lives for the organization and the country. It is these ethics which govern the work culture in that country. In Britain, many of the old time permanent posts at the higher levels are now contractual and the employees are expected to complete the jobs assigned to them in the specified time frame.

The real problem seems to be that people do not find challenges in whatever they do. A good leader or supervisor can do a lot to inject enthusiasm into the workers and make the climate in the office congenial and pleasant. We need 'vision', 'long-term goals', 'short-term objectives', 'well-defined work that is measurable', and 'assessment of performance'. The question one should ask is "not what your organization can give you, but what you can give to it."

41.10 HUMAN RELATIONS

	1	2	3	4	5	6	7
The seven most important words	"I	don't	know:	I	will	find	out"
(Willingness to learn more)							
The six most important words	"I	admit	I	made	a	mistake"	
(Admit mistake)							
The five most important words	"You	did	a	good	job"		
(Appreciate others for good work)							
The four most important words	"What	is	your	opinion ?"			
(Encourage taking joint decision)							
The three most important words	"If	you	please"				

Contd.

(Encourage others)		
The two most important words	"Thank	you"
(Show respect to individuals)		
The one most important word	"We"	
(Team efforts)		
The least important word	"I"	
(Discourage 'I', encourage 'We')		

41.11 QUALITY GURUS

Name	*Definition of quality*	*Main emphasis*	*Dominant factor*
W.E. Deming	Customer-led	Process	Control of variation
J.M. Juran	Customer-led	People	Fitness for purpose/use
Philip. B.Crosby	Supply-led	Performance	Conformance, requirement, zero defects
A.V. Feigenbaum	Customer-led	Process	Total quality control
J.M. Grosscock	Value-led	Process	Chain of conformance
K. Ishikawa	Value-led	People	Company wide quality control/quality circle
G. Taguchi	Supply-led value to society	Process/design	Quality loss function
Shiv-Khera	Human relation	People	Human Resource Development (HRD)

41.12 SUMMARY

Organizations will be required to cope with a host of challenges at any given time. Some of the challenges can be met with pre-planning. Employee education and training should be given prime importance. Top management commitment, support and dedication are also essential for success. A systematic process to utilize customer survey and feedback on service and processes should be established. Assessment against ISO: 9000 standards will help to identify weaknesses and strengths in coping with challenges.

Emphasis must be on the prevention of defects, not on inspection, audit or rework. Quality improvement should be emphasized at all levels. Quality must be viewed as not just a programme, but a process, and not an instant cure. Quality must be an organization-wide activity. Excellence as a way of life in every activity must be a guiding factor. Strategy for improving performance should be made through on-going training and system changes.

Programmes that are well managed tend to show a higher degree of success. ISO: 9000 is vital to the future success of a company. ISO: 9000 should become the religion, organizing logic and culture of the organization. Lastly ISO: 9000 is not a destination, it is a journey.

Difference between Management and Administration

Management is an executive function involving the direction of human effort towards the realisation of the basic objectives of the organization.

On the other hand, administration is a determinative function concerned with laying down of basic objectives of the organization.

In practice, the two terms are used interchangeably, because both involve the same principles and functions. Management is more popular in business enterprises where economic performance is of primary importance and administration is preferred in government departments, hospitals and other non-business organizations.

To resolve the terminological conflict between the two, management is classified into administrative management, *i.e.* determination of objectives and policies and operative management *i.e.* execution of plans.

In simple words, administration is a thinking function concerned with the determination of policies, done mainly as a top level function which is influenced by outside forces and public opinion.

In contrast, management is a doing function concerned with the effective implementation of policies, and is influenced by the objectives of the organization. In short:

Management $\rightarrow$ you order yourself
Administration $\rightarrow$ you order others

41.13 KEY TO SUCCESS

A systematic approach to search for excellence is the key for continual improvement. As quality professionals, our objectives must be to work together, not against each other. It is one of the lessons all individuals and organizations must learn.

The following 20 elements are some of the **key activities** for the individuals to remain successful in their professional career:

- Control the process, not people
- Measure the process, not people
- Replace fear with trust, openness and integrity
- View problems as opportunities
- Focus on what is strong, not who is strong
- Value people for their thinking and work
- Replace problem-solving with problem-presentation
- Show respect for individuals
- Serve customer with excellence
- Treat suppliers as your business partners
- Emphasize customer service

- Welcome all ideas, suggestions, recommendations, as well as criticism
- Create an environment for team spirit
- Encourage to continually improve
- Make it right the first time and every time
- Satisfy customer needs first
- Train the people
- Pay attention to details
- Focus on long terms goals
- Plan ahead.

Everybody has the ability to achieve success. And yet, one can see people wasting their abilities because they lack direction. Further, the most important element in the development of a management style for any nation is its culture. Self-motivated people like reasonable challenges. The possibility of failure excites them to put in more efforts. But people lacking passion prefer an easy way to ensure success. Otherwise, they take high risk tasks, which can become an excuse for failure. Smile, listen, offer sincere appreciation since these are some of the key activities for success. Do not make the other person feel like a loser. As stated by Arindam Choudhary, the management Guru,

"It is said that if you can be sure of being right only 55 per cent of the time, you go to Wall Street and make a million dollars a day. If you can't be sure of being right even 55 per cent of the time, why tell other people they are wrong? And yes, whenever at fault, admit it quickly."

The following pages show collections of few motivating and inspiring thoughts of eminent personalities which may assist in developing a positive attitude. A rewarding and fulfilling life begins with a positive attitude.

1. ***"A hundred times everyday I remind myself that my inner and outer life depended on the labours of other men, living and dead, and that I must exert myself in order to give in the same measure as I have received and am still receiving."***

   — Albert Einstein

2. ***"Pay attention to your enemies, for they are the first to discover your mistakes."***

   — Antis thenes

3. ***"The only good luck many great men ever had was being born with the ability and determination to overcome bad luck."***

   — Channing Pollock

4. ***"We come across, very often, organizations which know what they are supposed to achieve, but don't know the 'how' of it and the path that must be followed."***
5. ***"Quality is an usually slippery concept,***
   Easy to visualize, but difficult to define
   And yet more difficult to practice."

6. ***"95% of the success comes from examining the 5% of the failures."***

Contd.

7. ***"We live in an 'Age of uncertainty.' Companies that master change will be in charge of their own destinities. They have the 'power' to become the best of the best. They are aware that***
   - ***Unless some things change, nothing will***
   - ***From change, comes momentum***
   - ***From momentum, comes progress.***

   These elements when focussed towards a singular goal, ultimately mean success for the organization."

   — CII, Quality Summit '94

8. ***"A lie has speed, but truth has endurance."***

   — Edgar Mohn

9. ***"Sow a thought, and you reap an act;***
   sow an act, and you reap a habit;
   sow a habit, and you reap a character,
   sow a character, and you reap a destiny."

   — G.D. Board man

10. ***"Don't be afraid of opposition. Remember, a kite rises against, not with, the wind."***

    — Hamilton Wright Mable

11. ***"In the long run men hit only what they aim at."***

    — Henry David Thoreay

12. ***"A man is literally what he thinks he is."***

    — James Allen

13. ***"Things that matter most must never be at the mercy of things that matter least."***

    — Johann Wolfgang Von Goethe

14. ***"Gardening requires lots of water—most of it in the form of perspiration."***

    — Lou Erickson in Atlanta Journal and Constitution

15. ***"Getting ready" often gives a person the feeling of progress, but it's usually a delaying tactic that gets in the way of growth. "Getting-going" is what puts you further down the road. The main growth strategy is the willingness to move."***

    — Mark Hanan, Author of Fast-Growth Management

16. ***"One needs to be slow to form convictions, but once formed, they must be defended against the heaviest odds."***

    — Mohandas K. Gandhi

Contd.

17. ***"The initial quality training begins with questions that are basic to the business process:***
What is my mission?
What is my product or services?
Who are my customers?
Who are my supplier?
What do I need to get the job done, to satisfy my customers?
Then you map your progress—break down operations into steps and tasks, chart the flow of work, spot tasks that are prone to error, and measure the cycle time. The shorter the cycle time, the more you learn, and higher the quality."

— Motorola Company, UK (Quality Summit '94)

18. ***"The starting point of all achievements is desire. Keep this constantly in mind. Weak desires bring weak results, just as a small amount of fire makes a small amount of heat."***

— Napolean

19. ***"Professionals are people who know their chosen speciality so well that they know which of its rules can be broken—and when, under what circumstances, and with what results."***

20. ***"In the past few years, we have seen more stories, seminars, and conferences tossing around words, like Quality, Productivity, Motivation, Employee participation, Quality-circle, Education and training.***
There is a message hidden in all these words.
The main message is information exchange, sharing and implementation."

21. ***Creativity is one of the many attributes of quality which manifests itself in different forms and styles. The artist displays his creativity on a canvas with paint and brush; the poet in words; the musician with harmonious and rhythmic sounds; and the engineer in the form of a product that performs useful work more efficiently for less cost with greater reliability."***

22. ***"Quality is that elusive entity that everyone is talking about.***
Customers want it!
The media promote it!
Manufacturers, developers, suppliers etc. seek it!
Unfortunately, quality is like a ghost, which
Everyone talks about, and few have seen."

23. ***Stumbling blocks to attain quality:***
- ***Lack of commitment from upper management***
- ***Authoritarian behaviour, hierarchical thinking***
- ***Fuzzy vision and mission***

Contd.

- ***Un-attainable goals***
- ***Goals that don't solve core problems***
- ***Not listening to customers***
- ***Too many inefficient meetings***
- ***Skepticism, fear, resistance to change***
- ***Lack of meaningful measurements***
- ***Impatience***
- ***Obsession with the bottoom line, seeing quality as over head.***

24. ***The seven M's of quality:***
- ***Man (operator, training, skill, organization structure and culture, management dedication)***
- ***Machine (equipment, automation, age, maintenance)***
- ***Material (ingredients, purity level)***
- ***Method (process, technology, technique)***
- ***Media (environment, time)***
- ***Motivation (attitude, willingness)***
- ***Money (resources, investment, capital)***

25. ***"It costs five times to get a new customer than it does to keep a current customer."***

26. ***"More than 90% of unsatisfied customers don't complain, but they don't turnup to offer further business."***

— Navin Shyamji Dedhia

27. ***"In a restaurant, for instance, the menu is designed to meet the patron's taste and budget. Each item of the menu has a recipe for its preparation; each tool used in the preparation has its own requirements; those who serve the final product must know how to do it properly; and so it goes.***
The organization that creates the habit of meeting the requirement correctly the first time will have successful customers. As we learn, we improve the requirements. That is the source of the phrase continuous improvement."

28. ***Quality is not a game, or toy, to be tossed out to the crowd for their pleasure. It is a deadly serious business. In the coming years, quality will be expected as a given commodity. Customers will provide no additional rewards for companies who do what they said they were going to do. They will provide death for those who can't accomplish that simple task."***

29. ***"The policy of quality has to be a statement that cannot be misunderstood. It has to cover conformance requirements, time and money. The one I recommend is:***
We will deliver defect-free products and services to our customers and co-workers, on time, at agreed costs."

Contd.

30. ***"Experience in the west shows that one dissatisfied customer leads to loss of 23 potential clients. One satisfied client leads to addition of 7 potential clients."***

— Philip B. Crosby

31. ***"The entrance fee to this world economy is quality and quality is the engine of the economy."***

32. ***"The system of quality is prevention and not detection. We vaccinate our children in order to prevent them from contracting specific disease. We plan our expenditures in a way that does not cause us to spend more money than is available. We look both ways before attempting to cross the street. We have learned these things through experience."***

33. ***Today's slogan for the management:***
"We shall deliver defect free products and services to our customers and co-workers on time and every time at agreed cost."

34. ***"The goals for this century are:***
- ***Cause your employees to be successful.***
- ***Cause your suppliers to be successful.***
- ***Cause your customers to be successful.***

Together these will bring you and your organization success beyond your hopes."

35. ***"Quality is free, but it is not a gift."***

36. ***"Quality mast be achieved by prevention rather than detection. Think of vaccine instead of medicine."***

— Philip B.Crosby, Quality Summit '94

37. ***"The beginning is the most important part of the work."***

— Plato

38. ***"Time is one of your most precious resources, and you don't get a second chance to use it. Your first shot is your last one."***

39. ***"Are you making a good investment of your hours and minutes ? Or are you wasting these scarce resources***
spending time on staff that offers little return
fumbling the opportunity for fast growth."

40. ***"The slower you go in developing yourself today, the faster you'll need to move tomorrow. Today's world refuses to wait on anyone, we must learn to grow more rapidly, or we'll fall further and further behind. We need to accelerate our adaptability because changes keep picking up speed."***

Contd.

41. ***"Once upon a time, you could live in three tenses—the past, the present, and the future. There was time to consult history; there was time to plan for what lay ahead. The present tense was spent managing the transfer of the past into the future and imagining what that future might be. Today, under the pressure of accelerating change, the past and future have been fused into a single tense: the present."***

42. ***"If you develop yourself in the right direction, you can put a premium price tag on yourself and still be seen as a bargain. Contribute enough, and you'll create high demand for your work."***

43. ***"We don't discount the importance of integrity, character, attitude and such. We're not saying talent doesn't matter. But the reality is that employers don't really care how good you are per se (individual). What they truly care about is how good you will make them."***

44. ***"Plants aim themselves at sunlight, and they do it for a good reason. It helps them grow. Likewise, you need to 'align' with the Universe. Fast results come easier and count for more when you grow in the direction the world wants you to go."***

45. ***"Like it or not, everyone of us is at the mercy of the market. We'll be most successful at building our careers if we always remember to grow and sell what that market wants to buy."***

46. ***"The future behaves differently than it used to.***
It comes at us faster now,
And affects us more powerfully than before."

47. ***"Just as a 75 mile per hour wind isn't three times as forceful as a 25 mile per hour wind—but instead is nine times more powerful—the accelerating future will surprise us with the speed and impact that mark its arrival."***

48. ***"Mistakes guide you toward your goal, and you won't get far without making them. These bumps and bruises are very educational. They belong in the process."***

49. ***"The English word 'Career' comes from the French word*** 'Carrie're,' ***which originally meant 'a racing course'. As a verb, it means 'to move at speed.' In today's world careering comes down to a race against change......, a personal contest to see if we can grow as fast as the challenges we face in our work."***

50. ***"Start practicing the moves of the people you admire the most, and see what happens. Keep analyzing how they operate. Keep comparing it to the way you go about doing things. If their performance really does represent 'best practice', it's probably the result of several factors, including attitude and work habit as well as skills. That's all part of the performance package."***

Contd.

51. *"We believe the top performers are just blessed with more potential than we personally have to work with. But the people who set the standards—the highest achievers—aren't necessarily the brightest or the ones with the most pure talent. Sometimes they've just developed a better formula—they do things differently, and it delivers a lot better results."*

52. *"Resistance is a great con (control the steering of) artist. It tries to make you believe that sticking with your growth plans will be too painful. Too difficult. Not worth the struggle. It wants to sweet talk you into selling out your future for a little immediate comfort. But just like stretching out and continuing your physical exercise helps you work out muscle soreness, hanging in there with your fast growth programme pushes you past the resistance. Stretch yourself a bit more. Push for still faster growth."*

53. *William James, who's called 'The Father of American Psychology' said "There are three rules to follow if you want to change your life: (1) Start immediately; (2) Do it flamboyantly; (3) No exception. These recommendations produce a sense of urgency, an air of drama, and the level of commitment you'll need for fast growth."*

54. *"Start your growth programme with bold strokes, courageous acts. Your opening moves should be strong enough to overcome inertia, give you instant momentum and create excitement inside."*

55. *"Our strength is that we don't have any weakness, our weakness is that we don't have any real strength."*

56. *"Make a habit of taking the initiative in solution. First determine whom it makes sense to spend time with, and engineer those encounters. The idea is to create a circle of valuable contacts, people who have the potential to contribute to your personal growth. Reach out, connect quickly. Then cultivate the relationship—keep it alive by making it worthwhile and pleasing to the other person."*

57. *"Want more out of yourself? Is there some aspect you wish to change and improve ? Use it. Invest it. Spend it. Do something with it, otherwise it gradually diminishes. That's because you just can't put personal growth on hold. If you decide to wait, you have less to work with when you actually do begin. So the sooner you start, the better."*

58. *"In times past, the most common solution to problems was just to hire more employees. Spend more money. But companies can't afford that approach any more. Instead of simply throwing more people at problems, organizations now throw fewer. They have to do more faster and better with less. This calls for highly committed people."*

Contd.

59. ***"Using your talents to a greater degree doesn't use them up. In fact, personal resources actually multiply the more you put them to work. This is the physics of fast growth. You can look at it as law of increasing returns. The more you use your talent and personal resources, the more you have to use. To the extent that we fail to use our talents, energy, opportunity and such, the gods take them away. We lose what we don't use."***

60. ***"In today's world, career belongs to the committed, to those who work from the heart. Who invest themselves passionately in their jobs and who recommit quality when change reshapes their work.***
If you find you can't recommit rapidly when the company changes, you, probably should quit. Get out of there. Don't waste your energy resisting change, and don't kill precious time sitting on the fence. Either buy in, or be on your way, because that's best for both you and your employer."

61. ***"Bottom line: Commitment is a gift, you should give to yourself."***

62. ***"We live in an impatient world, with fierce competition and fleeting opportunities'. Organizations that are lean, agile, and quick to respond clearly have the edge. But organizations can't go fast if their employees go slow. So you need to operate with a strong sense of urgency. Accelerate in all aspects of your work, even if it means living with a few more ragged edges."***

63. ***"You should learn to create role clarity for yourself. Take personal responsibility for figuring out the top priority, then point yourself in that direction. Chase down the information you need. Fast. Show initiative in your efforts with the organization's large plan. Then give yourself permission to attack the job as best you understand it."***

64. ***"Your employer wants more than your body, more than just your arms and back and brain. Your employer wants you to act like an owner."***

65. ***"Today's world takes no pity on the person who gets lazy about learning. Either you take personal responsibility for continuing your education, or you end up without the knowledge you need to protect your career."***

66. ***"Lifelong learning is the only way to remain competitive in the job market. You should invest in your own growth, development and self-renewal. Do this the way a company invests in research and development, and come up with new and better products or services."***

67. ***"I tried ...***
I really worked hard ...
I did high quality work ... I did my part ...
All of those lines sound good on the surface, but they don't sell if the overall results aren't there."

Contd.

68. ***"Make sure you contribute more than you cost. Prove your worth to the organization. Make a difference. Add enough value, so everyone can see that something very important would be missing if you left."***

69. ***"You'll be better-off if you think in terms of being paid for performance—for the value you add rather than for your tenure, good intentions, or activity level."***

70. ***"It's your contribution that counts. Not hours (or years) you put in. Or how busy you are. We've all seen people who stay busy—who even work hard—without adding any real value. They make the mistake of thinking effort should earn them a pay-cheque. You can respect them for trying, but can't justify the cost of keeping them on board."***

71. ***"Our job security depends on how valuable we are to our customers. Customers are our only source of job security."***

72. ***"Keep in mind that there are both internal and external customers. You may deal directly with each type, but let's focus on whom you're supposed to serve inside the organization. It may be some other department, several people in your own functional area, or just your direct supervisor. May be you've always thought of them as co-workers, or as people you work with rather than for. But make no mistake—these are your clients and customers.***

Too often we don't stop and think about the full implications of this. We more or less take our jobs for granted. This means we're taking our customers for granted and that's a risky way to run a career."

73. ***"What is best for your career? Depersonalize the situation—accept it as the luck of the draw and harbour no resentment towards higher management. Ideally, you'll accept change as an exercise that, though sometimes painful, helps you build more emotional muscle."***

74. ***"The organization can't improve unless its people do. Continuous improvement—the Japanese call it Kaizen—offers some of the best insurance for both your career and the organization. Kaizen (pronounced Ky'izen) is the relentless quest for a better way, for higher quality relationship. Think of it as the daily pursuit of perfection."***

75. ***"Nobody can afford to rest on a reputation any more. Circumstances change too quickly. Competition gets tougher and more global all the time. What we consider 'good' today is seen "so-so" by tomorrow."***

76. ***"Every single employee should assume personal responsibility for upgrading his or her job performance. Your productivity, response time, quality, cost control, and consumer service should all show steady gains. And your skills should be in a state of constant renewal."***

Contd.

77. ***"Organizations need people who can take care of problems, not merely point them out. Too many employees get this confused. They seem to think complaining is a constructive act. They're keen on identifying all the problems—often in an accusing, blaming fashion—but contribute little towards improving things."***

78. ***"Instead of being a finger-pointer, and rather than trying to single out somebody to blame, assume ownership of problems. Let the solution start with you. You'll increase your odds of career success."***

79. ***"Organizations can't stop the world from changing. The best they can do is adopt. The smart ones change before they have to; the lucky ones manage to scramble and adjust when push comes to change. The rest are losers, and they become history."***

80. ***"People came to believe that, because of all the years of work they put in, the organization 'owed' them continued employment. Employees learn to expect regular pay increase and periodic promotions. Too often employees rested on their past achievements, instead of requiring themselves to constantly upgrade their skills. Obviously, it did not work.***
The market place is merciless, and it puts definite limits on how generous or protective an organization can be with its people.
This means you should reframe your relationship with the organization, just as it must reframe its relationship with customers and competitors. Don't fall into the trap of assuming that you're automatically entitled to pay increases and promotions etc."

81. ***"Guidelines for achieving job security and career success in this new 'employer-employee' relationship: it tells you how rapidly—***

'Align'	***Synchronize your efforts with your employer;***
'Adopt'	***Adjust to new challenges and develop the necessary competencies.***
'Add value'	***Contribute results that count the most.'***

— Price Pritchett

82. ***"I have often regretted my speech, never my silence."***

— Publilius Syrus

83. ***"A typical pattern will show that 80 per cent of outputs result from 20 per cent of inputs; that 80 per cent of consequences flow from 20 per cent of causes; or that 80 per cent of results come from 20 per cent of efforts.***
The few things that work fantastically well should be identified, cultivated, nurtured and multiplied. At the same time, the waste—the majority of things that will always prove to be low value to man and beast—should be abandoned or severely cut back. A few things are important, most are not."

— Ricjard Kach (The 80/20 principle)

Contd.

84. ***"Whatever is rightly done, however humble, is noble."***

85. ***"Quality is not a bolted-on afterthought or a take-it-or-leave-it option. Quality means recognizing that whoever we are and whatever we do we have a customer—somebody who depends on us, who has expectations and who expects satisfactory end results. Once we accept that principle, it must be built into our management strategy, our business objectives, our functional accountability and therefore become part of our everyday working life."***

— Rolls Royce Company UK (Quality Summit '99)

86. ***"Culture in any organization, community, country flows top down, not bottom up."***

— Shiv Khera

87. ***"Good quality is a stupid idea. The only thing that counts is your quality getting better at a more rapid rate than your principal competitors. It's real simple. If we're not getting more, better, faster, than they are getting more, better, faster—then we're getting less better or more worse."***

— Tom Peter

88. ***"Think like a wise man, but communicate in the language of the people."***

— Willian Butler Yeats

41.14 CONCLUSION

This book is written on the basis of the experiences that I have gathered during my 30 years of service in small scale industries. The main idea is to share my experiences with the readers, especially, with engineers who have just started their profession as transformer technocrats. The section 'Process control', containing sixteen chapters towards various checks and quality controls is dedicated mainly to the requirements of the transformer manufacturers.

As materials play a very vital role in the ultimate quality of the finished product, I thought it appropriate to share my experiences with the material processors and suppliers on some of the vital raw materials and components. Couple of chapters, *viz.* CRGO silicon steel, winding wires and strips, insulating pressboards, Insulating oil, Transformer tank body and radiators, porcelain bushings and fittings, off-circuit ratio switch, gaskets etc., are dedicated mainly to the requirements of the material processors.

Transformer users, mainly power utilities and SEBs, may also find the book useful. Couple of chapters, *viz.*, testing procedure, installation, erection and commissioning, maintenance and corrective actions, repair at site, user's contribution towards longer life span of transformers etc. are dedicated mainly to the users.

As was discussed earlier, to make a good transformer, we need a good cost effective type tested design. But only good design may not be sufficient to yield good transformers. Along with good design, we need good machines, good materials, and reasonably skilled workmen. We must ensure the availability of all these things before undertaking manufacturing activities. In fact, once all these four things are available, the percentage rework/rejection will be less which in turn will reduce the ultimate cost of the products. Good systematic process control with documented purchase procedure will also help in achieving good quality products.

Inspection is the first formal quality control mechanism. But inspection alone cannot build up the quality of a product. Most manufacturers still believe that the quality of products can be improved by strict inspection, which is not correct. Inspection has nothing to do with the ultimate quality of the products. It should be clearly understood that inspection can only lead to the segregation of good from the bad pieces. It cannot improve the quality of a manufacturcd product. Furthermore, recent studies have shown that 60 to 70 per cent of the defects detected at the shopfloor are directly or indirectly attributable to the lapses in areas such as design, purchase, process engineering etc.

Manufacturers of small scale industries are often blamed for the low quality of their products, on the lack of quality consciousness and poor work culture of their workers. A deeper analysis of this issue shows that the workers alone cannot be held responsible for poor quality of products. Honest appraisal of most of the manufacturing units in developing countries is likely to show that the management has failed to provide enough infrastructure and information in most of the workstations. Rather than finding scapegoats, companies need to examine weaknesses in their management system.

Motivation is again an area which is very important for the effective implementation of a quality system. A well organized quality management system will fail if the management is unable to create enthusiasm for the system among personnel and secure their full cooperation.

The meaning of motivation is different for different groups of personnel in an organization. Some may work for money. Others may work for reliability of job—for them money is not so important. The motivation of the middle management may be a promotion to the next level. The think-tank executives generally look for fame.

Involving workers in the quality management is the most effective means of stimulating their interest in performing to quality standards. Genuine participation can be expected only if they are given full opportunity to express constructive criticism and suggest methods of improvement.

Workers should be encouraged to make suggestions and these should be given serious consideration. If found practicable, the suggestions should be implemented immediately and the author should be acknowledged publicly. If the suggestion is not found useful, its drawbacks should be discussed with the workers and the difficulties in implementation should be explained. The author or some other workers may be able to make further suggestions to solve the problems presented. In no case should a suggestion be brushed aside at first glance. In fact, the workers should be encouraged to offer solutions which come to their mind without fear of being ridiculed. The above approach can be given a practical shape by constituting shop quality committees, which could meet periodically to review the implementation of quality programme. These meetings, if properly conducted, will draw upon the experiences and ideas of actual operators and will be invaluable in highlighting areas of weaknesses and will be a source of possible solutions. This mechanism of joint consultation will give workers a sense of participation in and generate enthusiasm for, quality programmes.

Quality assurance plan as shown below will give a basic idea on few of the manufacturing activities for improvement of quality.

The activities shown in the Quality Assurance Plan can be made available through ISO: 9000 Quality Procedure. It is strongly recommended that lSO: 9000 Quality System be adopted for the improvement of ultimate product quality.

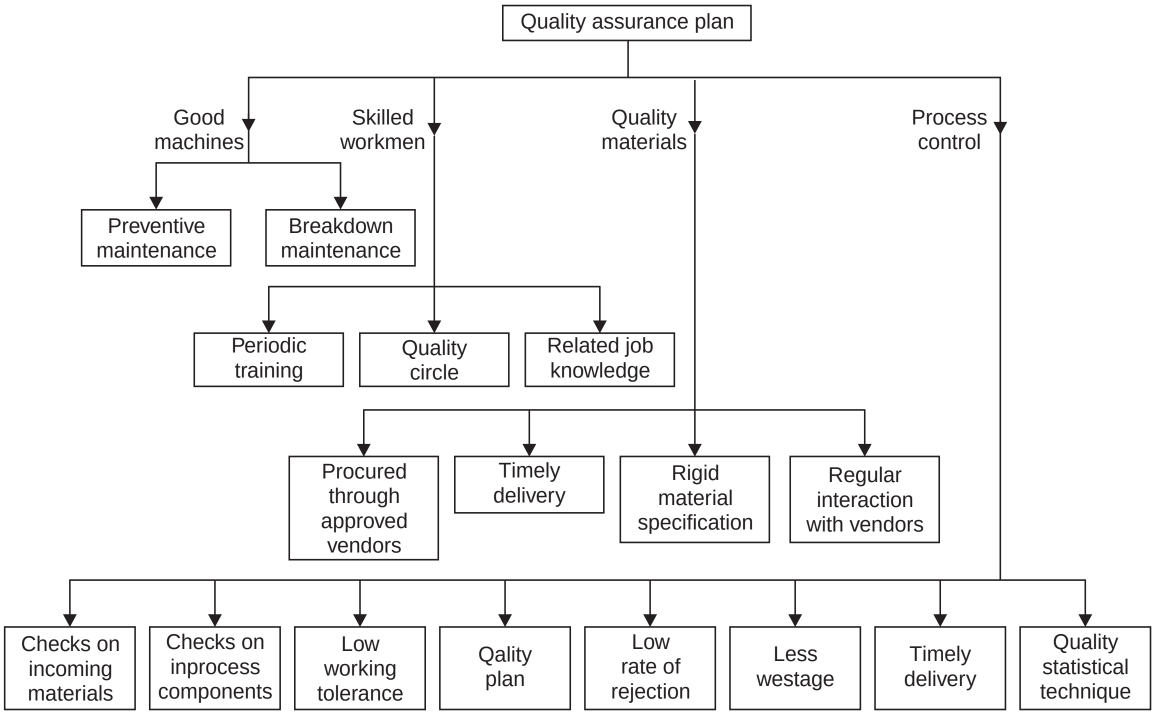


Fig. 41.1. *Various activities in the process of transfomer manufacturing*

All these days, the small scale industries have survived under the umbrella of the government policies. But the day is not far-off when we shall be required to compete with the multinationals in respect of quality and delivery. Look at the automobile and electronics industries, where all international giants are dominating the Indian market presently. It is high time for all of us to go for quality system which will enable us to play in a bigger field. ISO: 9000 certificate should not be used as a marketing tool, rather, the system should be religiously followed to improve upon quality.

To quote the great Quality Guru Philip B. Crosby, "**QUALITY IS FREE**." Quality reduces the cost of products by way of:

- Less wastage
- Less rework

- Less rejection
- Timely delivery

Our ‘**The National Anthem**’ and ‘**National Song**’

Composed by the all time great Kabi Guru Rabindra Nath Tagore, ‘*Jana Gana Mana*’ is the National Anthem of India. The song was first sang at the Calcutta session of the Indian National Congress on December 27, 1911. It was adopted by the constituent assembly of India on January 24, 1950 as India’s National Anthem.

Composed by Rishi Bankim Chandra Chatterjee; ‘*Vande Mataram*’ is the National Song of India. This song has been a source of inspiration to people in their struggle for freedom. It was first sang at the 1896 session of the Indian National Congress.

National Anthem is internationally accepted whereas National Song is nationally accepted.

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