2.7 COMPUTER PROGRAM TO DESIGN TRANSFORMER MAIN DIMENSIONS

Aim:

To design the Transformer core using MATLAB coding.

Problem:

Calculate approximate overall dimension for a 200kVA, 6600/440 V , 50Hz, 3 – phase core type transformer.The following data is provided: emf per turn = 10V; maximum flux density = 1.3Wb/m2; current density = 2.5A/mm2;window space factor = .3 overall height = overall width; stacking factor = .9; 3 stepped core used. width of largest stamping = .9d and net iron area = .6d2 where obviously d is diameter of circumscribing circle.

Solution:

Net iron area Ai = Et/(4.44fBm) = 10/(4.44x50x1.3) = .0347m2

as given net iron area = .6d2 therefore d = √Ai/.6 = .24m

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So as we have d so we also got

width of largest stamping a= .9 x .24 = .216m

As core type transformer therefopre Dy = Hy = a = .216m

Now in 3 phase equation

Q = 3.33fBmKwJAwAi x 10-3

Aw is unknown so finding Aw we get

Aw = Q/(3.33fBmKwJAi x 10-3) = .0355m2

As Aw = Hw x Ww = .0355m2

H = Hw + 2Hy = Hw + .432

Now W = 2D + a = 2(Ww + a) + a = 2Ww + .648

Given H = W we have

Hw + .432 = 2Ww + .648

substituting Hw = .0355/Ww

.0355 = 2Ww2 + .214Ww

or

2Ww2 + .214Ww – .0355 = 0

solving the quadratic equation we get

Ww = .083m

and Hw = .0355/.083 = .428m

Thus dimension of core H = Hw + 2Hy = .8m

W = 2(Ww + a) + a = .8m

So in the end we do get overall height = overall length

Program:

```
function determining_dimension_of_3_phasse_mesh_star_coreType( )
% Detailed explanation goes here
 % rating given Vrate is in kva
Vrate = 200;
% ratio 6600/400 V
f = 50;
max_flux_density = 1.3;
J = 2.5;
% given overall heigh = overall width
 % H = W
 % Aw = .25 Acore
 % overall dimesion of core needs to be found
 % 3 step core
 % width of largest core = .90
 % Ai = .6*(d^2);
 % for 3 phase
 % Q = 3.33*f*max_flux_density*Kw*J*Ai*Aw;
 % deriving Q = 3.33*f*max_flux_density*Kw*Ai*Ai*1.25;
 % Q = 3.33*f*max_flux_density*Kw*J*Ai*Ai*1.25;
Q = Vrate;
Kw = .3;
Ai = sqrt((Q*1000*(10^-6))/(3.33*f*max_flux_density*J*Kw*1.25));
```

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```
fprintf('\nDersign of 3 phase Mesh star core type transformer'); fprintf('\n————————
——————————————————————');
fprintf('\nTherfore Area of iron core Ai = ');
disp(Ai);
fprintf('\nTherfore diameter of circumscribing circle d = ');
d = sqrt(Ai/.6);
disp(d);
% a = .9d
Aw = 1.25*Ai;
% Ww = Aw/Hw;
 % H = Hw + 2Hy
a = .9*d;
Hy = a;
Dy = a;
% Hw^2 – (1.1d)Hw – 2Aw;
a1 = 1;
b = 1.1*d;
c = 2*Aw;
Hw = (b + sqrt((b^2)+ (4*a1*c)))/2;
fprintf('\nHieght of Window Hw = ');
disp(Hw);
Hwmod = abs(Hw);
fprintf('\nHieght of Window Hw = ');
disp(Hwmod);
W = ((2*Aw)/Hwmod) + (2*d) + (.9*d);
fprintf('\nOverall width of window W = ');
disp(W);
H = Hwmod + (2*Hy);
fprintf('\nOverall height of window H = ');
disp(H);
end
```

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Output:

Therfore Area of iron core Ai = 0.0314

Therfore diameter of circumscribing circle d = 0.2287

Hieght of Window Hw = 0.4329

Hieght of Window Hw = 0.4329

Overall width of window W = 0.8447

Overall height of window H = 0.8447

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TRANSFORMER CONSTRUCTION

- A transformer consists of two windings coupled through a magnetic medium.
- The two windings work at different voltage level.
- The two windings of the transformer are called High voltage winding and Low voltage winding.
- Both the windings are wound on a common core.
- One of the winding is connected to ac supply and it is called primary.
- The other winding is connected to load and it is called secondary.
- The transformer is used to transfer electrical energy from high voltage winding to low voltage winding or vice-versa through magnetic field.
- The construction of transformers varies greatly, depending on their applications, winding voltage and current ratings and operating frequencies.
- The two major types of construction of transformers (used in transmission and distribution of electrical energy) are core type and shell type.
- Depending on the application, these transformers can be classified as distribution transformers and power transformers.
- The transformer is extremely important as a component in many different types of electric circuits, from small-signal electronic circuits to high voltage power transmission systems.
- The most important function performed by transformers are,
    - ✓ Changing voltage and current level in an electric system.
    - ✓ Matching source and load impedances for maximum power transfer in electronic and control circuitry.
    - ✓ Electrical isolation.

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CORE TYPE TRANSFORMER

- In core type transformer, the magnetic core is built of laminations to form a rectangular frame and the windings are arranged concentrically with each other around the legs or limbs.
- The top and bottom horizontal portion of the core are called yoke.
- The yokes connect the two limbs and have a cross sectional area equal to or greater than that of limbs.
- Each limb carries one half of primary and secondary.
- The two windings are closely coupled together to reduce the leakage reactance.
- The low voltage winding is wound near the core and high voltage winding is wound over low voltage winding away from core in order to reduce the amount of insulating materials required.

SHELL TYPE TRANSFORMER

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- In shell type transformers the windings are put around the central limb and the flux path is completed through two side limbs.
- The central limb carries total mutual flux while the side limbs forming a part of a parallel magnetic circuit carry half the total flux.
- The cross sectional area of the central limb is twice that of each side limbs

DISTRIBUTION TRANSFORMER

- Transformers up to 200kVA are used to step down distribution voltage to a standard service voltage or from transmission voltage to distribution voltage are known as distribution transformers.
- They are kept in operation all the 24 hours a day whether they are carrying any load or not.
- The load on the distribution transformer varies from time to time and the transformer will be on no-load most of the time.
- Hence in distribution transformer the copper loss (which depends on load) will be more when compared to core loss (which occurs as long as

transformer is in operation).

- Hence distribution transformers are designed with less iron loss and designed to have the maximum efficiency at a load much lesser than full load.
- Also it should have good regulation to maintain the variation of supply voltage with in limits and so it is designed with small value of leakage reactance.

POWER TRANSFORMER

- The transformers used in sub-stations and generating stations are called power transformers.
- They have ratings above 200kVA. Usually a substation will have number of transformers working in parallel.
- During heavy load periods all the transformers are put in operation and during light load periods some transformers are disconnected.
- Therefore the power transformers should be designed to have maximum efficiency at or near full load.
- Power transformers are designed to have considerably greater leakage reactance that is permissible in distribution transformers in order to limit the fault current.
- In the case of power transformers inherent voltage regulation is less important than the current limiting effect of higher leakage reactance.

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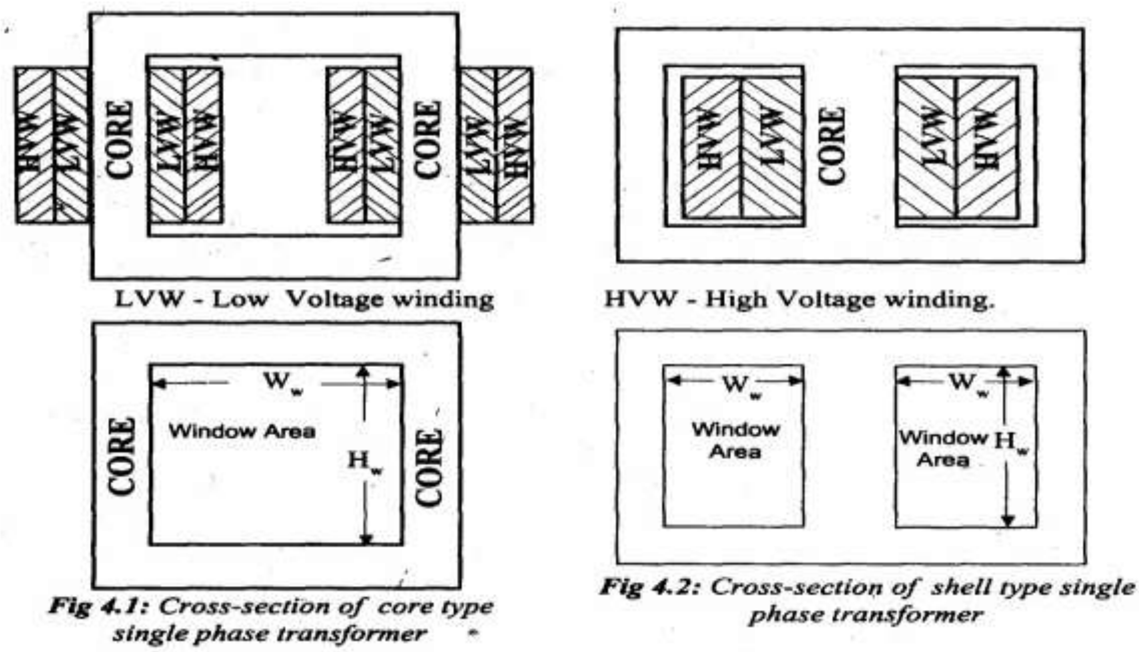

Figure 2.1.1 Core and shell type transformer

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.4]

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2.4 DESIGN OF CORES

- For core type transformer the cross-section may be rectangular, square or stepped.
- When circular coils are required for distribution and power transformers, the square and stepped cores are used.
- For shell type transformer the cross-section may be rectangular.
- When rectangular cores are used the coils are also rectangular in shape.
- The rectangular core is suitable for small and low voltage transformers.
- In core type transformer with rectangular cores, the ratio of depth to width of the core is 1.4 to 2.
- In shell type transformers with rectangular cores the width of the central limb is 2 to 3 times the depth of the core.
- The figure shows the cross-section of transformer cores.

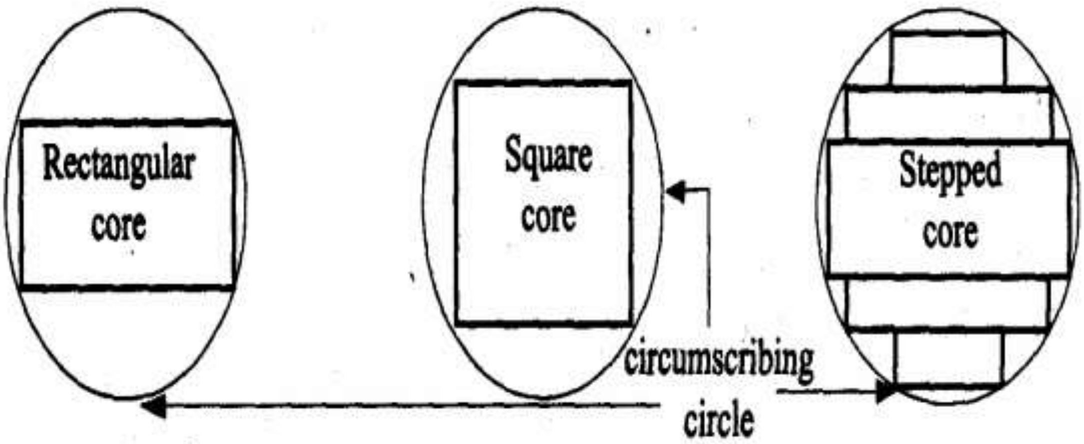

Figure 2.4.1 Cross-sectional core of transformer

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.56]

- In square cores the diameter of the circumscribing circle is larger than the diameter of stepped cores of same area of cross-section.
- Thus when stepped cores are used the length of mean turn of winding is reduced with consequent reduction in both cost of copper and copper loss.
- However, with larger number of steps a large number of different sizes of laminations have to be used.

- This results in higher labor charges for shearing and assembling different types of laminations.

SQUARE CORES

- Let d = diameter of circumscribing circle
- Also, d = diagonal of the square core and a = side of square
- Diameter of circumscribing circle,

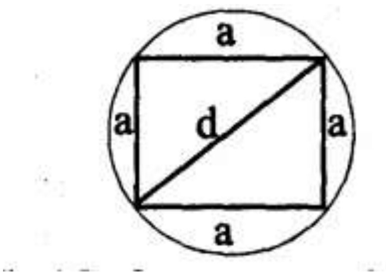

Figure 2.4.2 Cross-sectional view of square core

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.55]

$$d = \sqrt{2}a$$

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- Therefore Side of square,

$$a = d/\sqrt{2}$$

- Gross core area, A_{gj} = area of square = a^2

$$a^2 = 0.5d^2$$

- Let stacking factor, $S_f = 0.9$
- Net core area, A_i = Stacking factor x Gross core area

$$= 0.9 \times 0.5\, d^2 = 0.45\, d^2$$

- Area of circumscribing circle,

$$= \frac{\pi}{4} d^2$$

$$\frac{Net\ core Area}{Area\ of\ curcumscribing\ circle} = 0.58$$

$$\frac{Gross\ core\ Area}{Area\ of\ curcumscribing\ circle} = 0.64$$

- Another useful ratio for the design of transformer core is core area factor.
- It is the ratio of net core area and square of the circumscribing circle

$$\frac{Net\ core\ Area}{Square\ of\ curcumscribing\ circle} = 0.45$$

TWO STEPPED CORE FOR CRUCIFORM CORE

- In stepped cores the dimensions of the steps should be chosen, such as to occupy maximum area within a circle. The dimensions of the two step to give maximum area for the core in the given area of circle are determined as follows.
- Let, a = Length of the rectangle

  b = Breadth of the rectangle

  d = Diameter of the circumscribing circle

  Also, d= Diagonal of the rectangle

  Θ = Angle between the diagonal and length of the rectangle.

- The cross-section of two stepped core is shown in figure.

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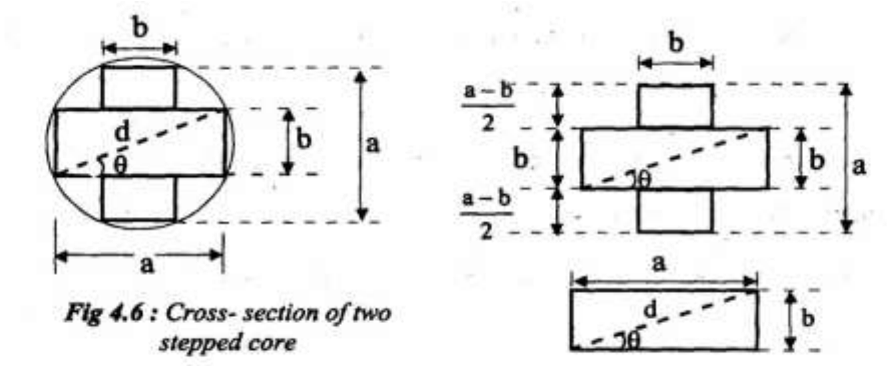

Figure 2.4.3 Cross-sectional view of two stepped core

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.56]

- The maximum core area for a given d is obtained when Θ is maximum value.
- Hence differentiate A_{gi} with respect to Θ and equate to zero to solve for maximum value of Θ.
- From figure we get,

$$a = d\cos\theta$$

$$b = d\sin\theta$$

- The two stepped core can be divided into three rectangles. The area of three rectangles gives the gross core area. With reference to figure, we can write,

$$A_{gi} = 2ab - b^2$$

- On substituting for a and b in above equation we get,

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$$A_{gi} = d^2 \sin 2\theta - d^2 \sin^2 \theta$$

- To get maximum value of Θ, differentiate A_{gi} with respect to Θ, and equate to zero,

$$\Theta = 31.72$$

- When Θ =31 .72° the dimensions of the core (a & b) will give the maximum area for core for a specified ' d'.

$$a = 0.85d, \ b = 0.53d$$

- On substituting the above values of a & b we get,

$$A_{gi} = 0.618 \ d^2$$

- Let stacking factor, $S_f = 0.9$
- Net core-area, A_i = Stacking factor x Gross core area

$$= 0.9 \times 0.6\,18 \ d = 0.56 \ d$$

$$\frac{Net\ core Area}{Area\ of\ curcumscribing\ circle}=0.71$$

$$\frac{Gross\ core\ Area}{Area\ of\ curcumscribing\ circle}=0.79$$

- Another useful ratio for the design of transformer core is core area factor.
- It is the ratio of net core area and square of the circumscribing circle

$$\frac{Net\ core\ Area}{Square\ of\ curcumscribing\ circle}=0.56$$

MULTI-STEPPED CORES

- We can prove that the area of circumscribing circle is more effectively utilized by increasing the number of steps.
- The most economical dimensions of various steps for a multi-stepped core can be calculated as shown for cruciform (or two stepped) core. The results are tabulated in table.

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Ratio	square core	cruciform core	3-stepped core	4-stepped core
$\frac{A_{gi}}{\text{Area of circumscribing circle}}$	0.64	0.79	0.84	0.87
$\frac{A_i}{\text{Area of circumscribing circle}}$	0.58	0.71	0.75	0.78
Core area factor, $K_c=A_i/d^2$	0.45	0.56	0.6	0.62

CHOICE OF FLUX DENSITY IN THE CORE

- The flux density decides the area of cross-section of core and core loss.
- Higher values of flux density results in smaller core area, lesser cost, reduction in length of mean turn of winding, higher iron loss and large magnetizing current.
- The choice of flux density depends on the service condition (i.e.,

distribution or transmission) and the material used for laminations of the core.

- The laminations made with cold rolled silicon steel can work with higher flux densities than the laminations made with hot rolled silicon steel.
- Usually the distribution transformers will have low flux density to achieve lesser iron loss.
- When hot routed silicon steel is used for laminations the following values can be used for maximum flux density (Bm)
  - ✓ Bm = 1.1 to, 1.4 Wb/m^2 - For distribution transformers
  - ✓ Bm = 1.2 to 1.5 Wb/m^2 - For power transformers
- When cold rolled silicon steel is used for laminations, the following values can be used for maximum flux density (Bm)
  - ✓ Bm = 1.55 Wb/m - For transformers with voltage rating upto 132 kV
  - ✓ Bm= 1.6 Wb/m - For transformers with voltage rating 132 kV to 275 kY
  - ✓ Bm = 1.7 Wb/m - For transformers with voltage rating 275 kV to 400 Kv

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OVERALL DIMENSIONS OF THE TRRNSFORMER

- The main dimensions of the transformer are Height of window (Hw) and Width of window (Ww).
- The other important dimensions of the transformer are width of largest stamping (a), diameter of circumscribing circle (d), and distance between core centres (D), height of yoke (Hy), depth of yoke (Dy), overall height of transformer frame (H) and overall width of transformer frame (W).
- These dimensions for various types of transformers are shown in figures.

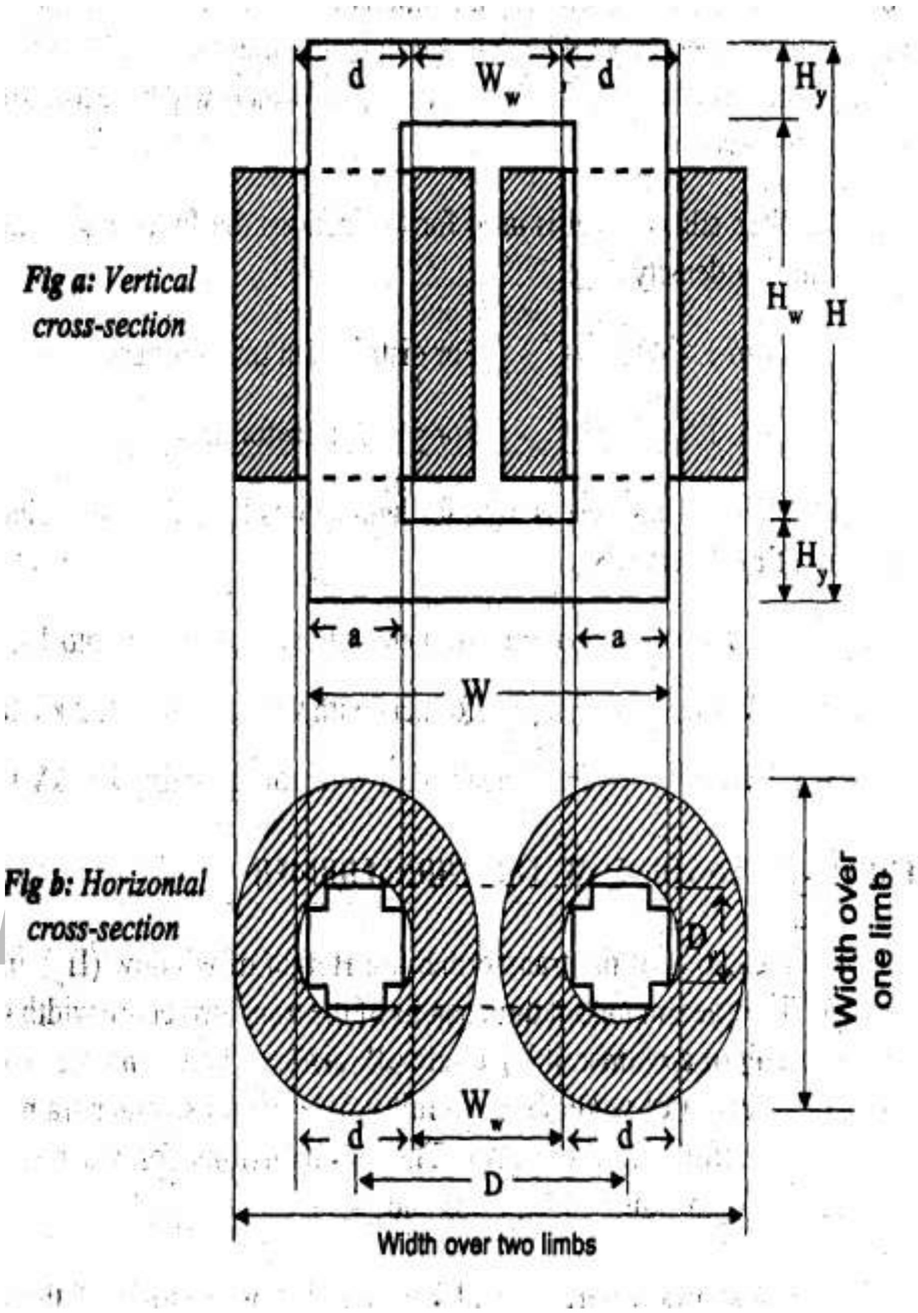

Figure 2.4.4 Single phase core type transformer

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.73]

- The above figure shows a vertical and horizontal cross-section of the core and winding assembly of a core type single phase transformer.
- The following figure shows a vertical and horizontal cross-section of the core and winding assembly of a core type three phase transformer.

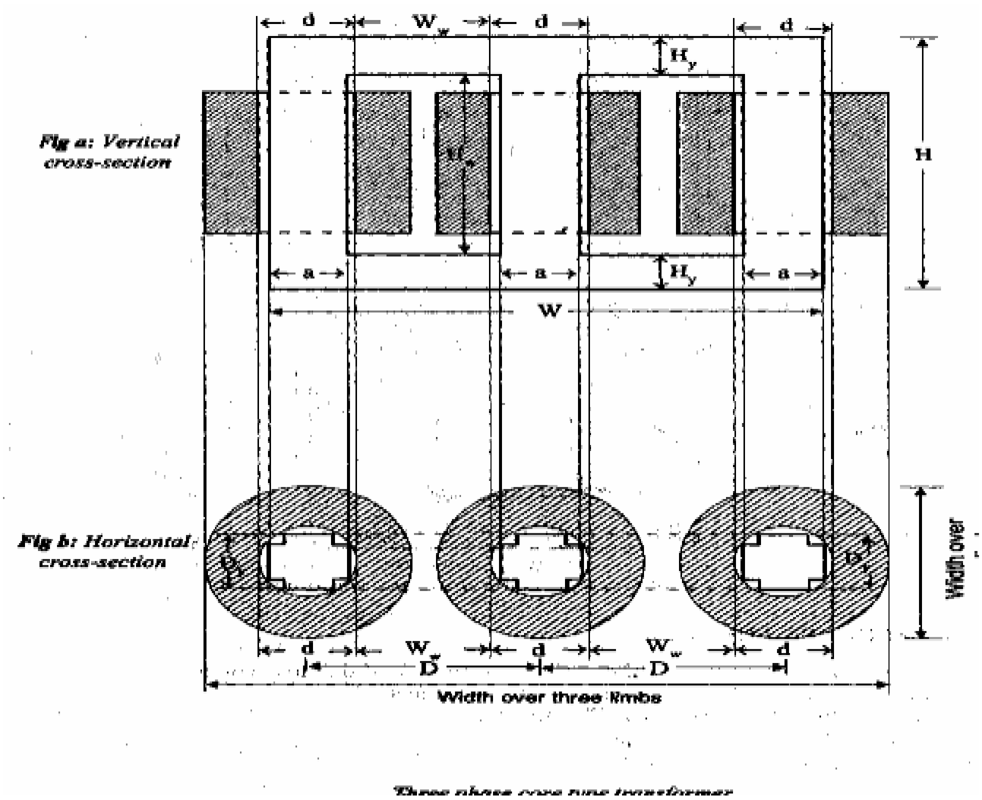

Figure 2.4.5 Three phase core type transformer

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.73]

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- The next figure shows a vertical and horizontal cross-section of a shell type single phase transformer.

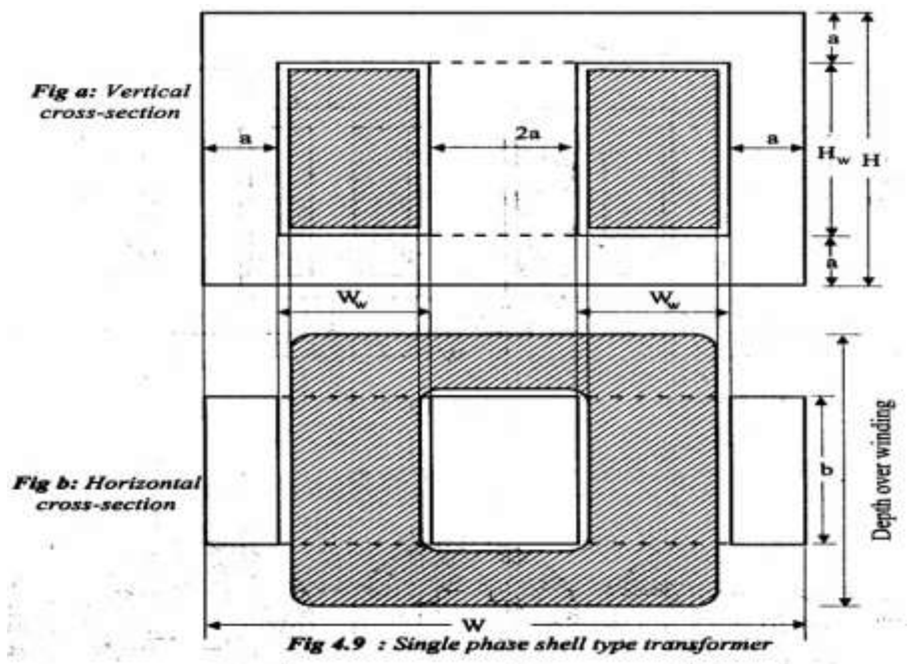

Figure 2.4.5 Single phase shell type transformer

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.73]

2.4 No load current

The phasor sum of the magnetizing current (Im) and the loss component of current (Il); Im is calculated using the MMF/m required for the core and yoke and their respective length of flux path. Il is determined using the iron loss curve of the material used for the core and yoke and the flux density employed and their weight.

The no-load current I0 is the vectorial sum of the magnetizing current Im and core loss or working component current Ic. [Function of Im is to produce flux φm in the magnetic circuit and the function of Ic is to satisfy the no load losses of the transformer].

Thus, No load input to the transformer = $V_1 I_0 \cos\varphi_0 = V_1 I_c$ = No load losses as the output is zero and input = output + losses.

Since the copper loss under no load condition is almost negligible, the no load losses can entirely be taken as due to core loss only. Thus the core loss component of the no load current

$$I_o = \sqrt{I_c^2 + I_m^2} \text{ ampere.}$$

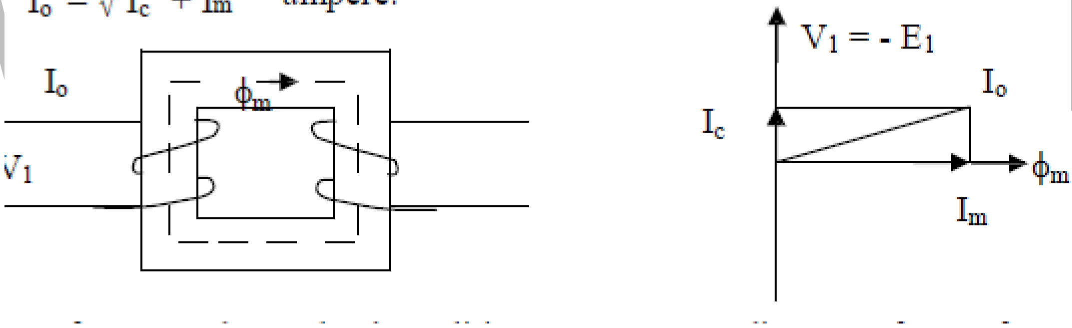

Figure 2.5.1 Transformer under no-load condition Vector diagram of Transformer under no-load condition

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.98]

2.2 OUTPUT EQUATION OF SINGLE PHASE TRANSFORMER

- The equation which relates the rated kVA output of a transformer to the area of core and window is called output equation.
- In transformers the output kVA depends on flux density and ampere-turns.
- The flux density is related to core area and the ampere-turns is related to window area.
- The simplified cross-section of core type and shell type single phase transformers are shown in figures (4-1) and (4-2).
- The low voltage winding is placed nearer to the core in order to reduce the insulation requirement.
- The space inside the core is called window and it is the space available for accommodating the primary and secondary winding.
- The window area is shared between the winding and their insulations.

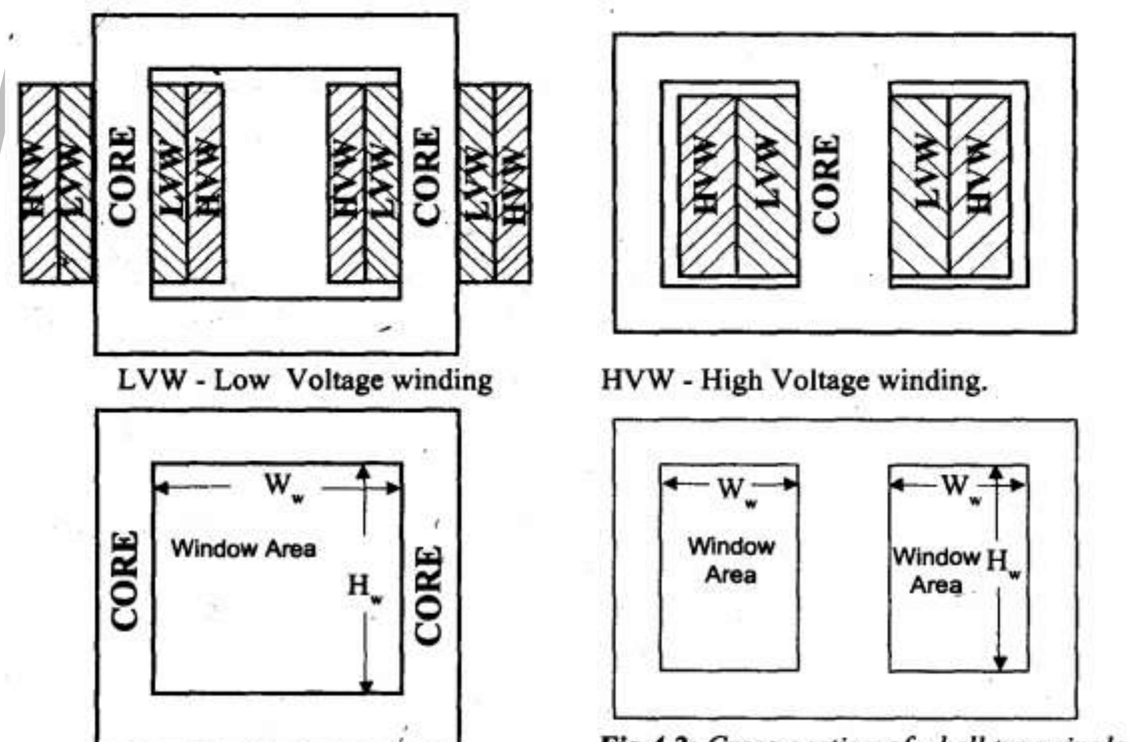

Fig 4.1: Cross-section of core type single phase transformer

Fig 4.2: Cross-section of shell type single phase transformer

Figure 2.2.1 Core and shell type transformer

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.4]

- The induced emf in a transformer,

$$E = 4 \cdot 44 f \phi_m \quad \text{Volts}$$

- Emf per turn,

$$E/T = 4 \cdot 44 f \phi \quad \text{Volts}$$

- The window in single phase transformer contains one primary and one secondary winding.
- The window space factor K_w is the ratio of conductor area in window to total area of window.

$$k_w = \frac{conductor\ area\ in\ window}{Total\ Area\ of\ window}$$

$$k_w = \frac{A_C}{A_w}$$

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- Conductor area in window,

$$A_C = k_W A_W$$

- The current density is same in both the windings. Therefore Current density,

$$\delta = \frac{I_p}{Ap} = \frac{I_S}{As}$$

- Area of cross - section of primary conductor,

$$A_P = \frac{I_P}{\delta}$$

- Area of cross - section of secondary conductor,

$$A_S = \frac{I_S}{\delta}$$

- If we neglect magnetizing mmf then primary ampere turns is equal to secondary ampere turns. Therefore, ampere turns,

$$AT = I_p T_p = I_S T_S$$

- Total copper area in window,

Ac = Copper area of primary winding + Copper area of secondary winding

= (Number of primary turns x area of cross-section of primary conductor) + (Number of secondary turns x area of cross - section of secondary conductor)

$$A_C = \frac{2AT}{\delta}$$

- On equating the above equations, we get,

$$K_W A_W = \frac{2AT}{\delta}$$

- Therefore, Ampere turns,

$$AT = \frac{1}{2} k_W A_w$$

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- The kVA rating of single phase transformer is given by,

$$Q = v_p I_p * 10^{-3}$$

$$Q = 2.22 f \phi_m k_w A_v \delta x 10^{-3}$$

The above equation is the output equation of single phasetransformer.

2.2 OUTPUT EQUATION OF THREE PHASE TRANSFORMER

- The equation which relates the rated kVA output of a transformer to the area of core and window is called output equation.
- In transformers the output kVA depends on flux density and ampere-turns.
- The flux density is related to core area and the ampere-turns is related to window area.
- The simplified cross-section of core type three phase transformer is shown in figure.
- The cross-section has three limbs and two windows.
- Each limb carries the low voltage and high voltage winding of a phase.

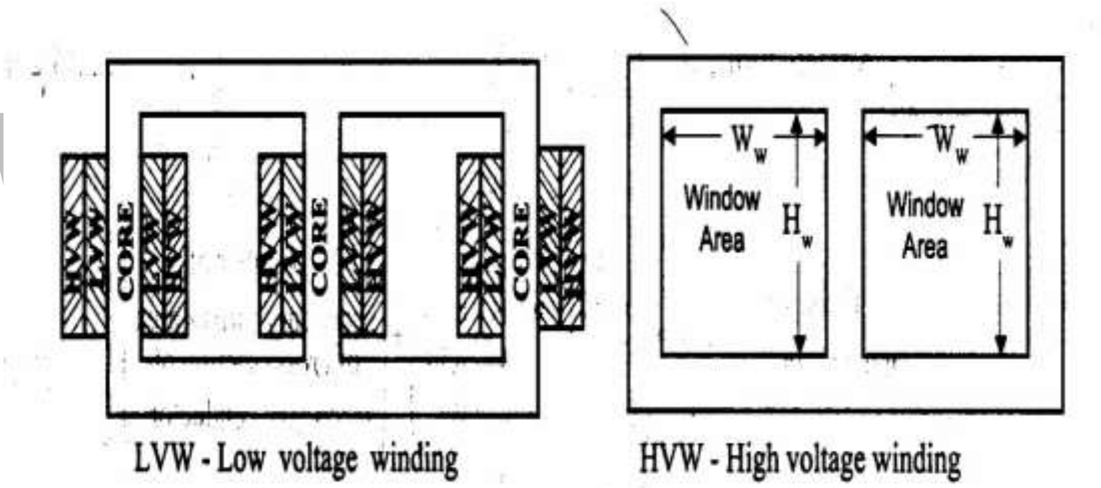

Figure 2.2.1 Core type three phase transformer

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.5]

- The induced emf in a transformer,

$$E = 4.44 f \Phi_m \quad \text{Volts}$$

- Emf per turn,

$$E/T = 4.44 f \Phi \quad \text{Volts}$$

- The window space factor K_w is the ratio of conductor area in window to total area of window.

$$k_w = \frac{\text{conductor area in window}}{\text{Total Area of window}}$$

$$k_w = \frac{A_C}{A_w}$$

- Conductor area in window,

$$A_C = k_W A_W$$

- The current density is same in both the windings. Therefore Current density,

$$\delta = \frac{I_p}{Ap} = \frac{I_S}{As}$$

- Area of cross - section of primary conductor,

$$A_P = \frac{I_P}{\delta}$$

- Area of cross - section of secondary conductor,

$$A_S = \frac{I_S}{\delta}$$

- If we neglect magnetizing mmf then primary ampere turns is equal to secondary ampere turns. Therefore, ampere turns,

$$AT = I_p T_p = I_S T_S$$

- Total copper area in window,

Ac = Copper area of primary winding + Copper area of secondary winding

= 2*(Number of primary turns x area of cross-section of primary conductor) + 2*(Number of secondary turns x area of cross - section of secondary conductor)

$$A_C = \frac{4AT}{\delta}$$

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- On equating the above equations, we get,

$$K_W A_W = \frac{4A\frac{T}{\delta}}{}$$

- Therefore, Ampere turns,

$$AT = \frac{1}{4} k_W A_w$$

- The kVA rating of three phase transformer is given by,

$$Q = 3 v_p I_p * 10^{-3}$$

$$Q = 3.33 f \phi_m k_w A_v \delta x 10^{-3}$$

The above equation is the output equation of three phasetransformer.

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2.5 Temperature rise in Transformers

Losses dissipated in transformers in the core and windings get converted into thermal energy and cause heating of the corresponding transformer parts. The heat dissipation occurs as follows: i) from the internal heated parts to the outer surface in contact with oil by conduction ii) from oil to the tank walls by convection and iii) from the walls of the tank to the atmosphere by radiation and convection.

Q = Power loss(heat produced), J/s or W

G = weight of the active material of the Machine, kg

h = specific heat, J/kg-◦C

S = cooling surface area, m2

λ = specific heat dissipation, W/ m2 -◦C

c = 1/ λ = cooling coefficient, m2 -◦C / W

θm = final steady temperature rise,◦C

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The temperature of the machine rises when it is supplying load. As the temperature rises, the heat is dissipated partly by conduction, partly by radiation and in most cases largely by air cooling. The temperature rise curve is exponential in nature. Assuming the theory of heating of homogeneous bodies,

Heat developed = heat stored + heat dissipated

Design of Tank

Because of the losses in the transformer core and coil, the temperature of the core and coil increases. In small capacity transformers the surrounding air will be in a position to cool the transformer effectively and keeps the temperature rise well with in the permissible limits. As the capacity of the transformer increases, the losses and the temperature rise increases. In order to keep the temperature rise with in limits, air may have to be blown over the transformer. This is not advisable as the atmospheric air containing moisture, oil particles etc., may affect the insulation. To overcome the problem of atmospheric hazards, the transformer is placed in a steel tank filled with oil. The oil conducts the heat from core and coil to the tank walls. From the tank walls the heat goes dissipated to surrounding atmosphere due to radiation and convection. Further as the capacity of the transformer increases, the increased loss demands a higher dissipating area of the tank or a bigger sized tank. These calls for more space, more volume of oil and increases the cost and transportation problems. To overcome these difficulties, the dissipating area is to be increased by artificial means without increasing the size of the tank. The dissipating area can be increased by

1. fitting fins to the tank walls
2. fitting tubes to the tank and
3. using corrugated tank
4. using auxiliary radiator tanks

Since the fins are not effective in dissipating heat and corrugated tank involves constructional difficulties, they are not much used now a days. The tanks with tubes are much used in practice. Tubes in more number of rows are to be avoided as the screening of the tank and tube surfaces decreases the dissipation. Hence, when more number of tubes are to be provided, a radiator attached with the tank is considered. For much larger sizes forced cooling is adopted.

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Dimensions of the Tank

The dimensions of tank depends on the type and capacity of transformer, voltage rating and electrical clearance to be provided between the transformer and tank, clearance to accommodate the connections and taps, clearance for base and oil above the transformer etc.,. These clearances can assumed to be between

(30 and 60) cm in respect of tank height

(10 and 20) cm in respect of tank length and

(10 and 20) cm in respect of tank width or breadth.

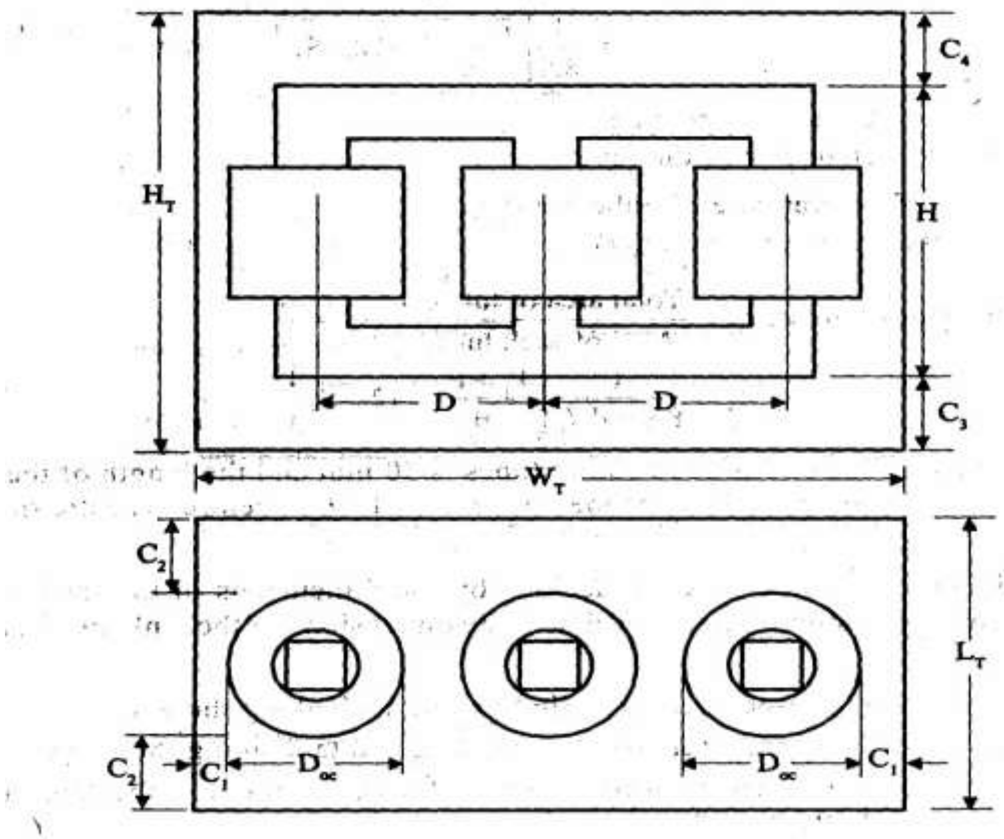

Figure 2.6.1 Dimensions of transformer tank

[Source: "A Course in Electrical Machine Design" by A.K.Sawhney, page-5.106]

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Tank height Ht = [Hw + 2Hy or 2a + clearance (30 to 60) cm] for single and three phase core, and single phase shell type transformers.

= [3(Hw + 2Hy or 2a) + clearance (30 to 60) cm] for a three phase shell type transformer.

Tank length Lt = [D + Dext + clearance (10 to 20) cm] for single phase core type transformer = [2D + Dext + clearance (10 to 20) cm] for three phase core type transformer = [4a + 2Ww + clearance (10 to 20) cm] for single and three phase shell type transformer

Width or breadth of tank Wt = [Dext + clearance (10 to 20) cm] for all types of transformers with a circular coil.

= [b + Ww + clearance (10 to 20) cm] for single and three phase core type transformers having rectangular coils.

= [b + 2Ww + clearance (10 to 20) cm] for single and three phase shell type transformers.

When the tank is placed on the ground, there will not be any heat dissipation from the bottom surface of the tank. Since the oil is not filled up to the brim of the tank, heat transfer from the oil to the top of the tank is less and heat dissipation from the top surface of the tank is almost negligible. Hence the effective surface area of the tank St from which heat is getting dissipated can assumed to be 2Ht (Lt + Wt) m^2.

Heat goes dissipated to the atmosphere from tank by radiation and convection. It has been found by experiment that 6.0W goes radiated per m^2 of plain surface per degree centigrade difference between tank and ambient air temperature and 6.5W goes dissipated by convection / m^2 of plain surface / degree centigrade difference in temperature between tank wall and ambient air. Thus a total of 12.5W/m^2/^{0}C goes dissipated to the surrounding. If is the temperature rise, then at final steady temperature condition, losses responsible for temperature rise is losses dissipated or transformer losses = 12.5 S_t .

Number and dimensions of tubes

If the temperature rise of the tank wall is beyond a permissible value of about 500C, then cooling tubes are to be added to reduce the temperature rise. Tubes can be arranged on all the sides in one or more number of rows. As number of rows increases, the dissipation will not proportionally increase. Hence the number of rows of tubes are to be limited. Generally the number of rows in practice will be less than four.

With the tubes connected to the tank, dissipation due to radiation from a part of the tank surface screened by the tubes is zero. However if the radiating surface of the tube, dissipating the heat is assumed to be equal to the screened surface of the tank, then tubes can assumed to be radiating no heat. Thus the full tank surface can assumed to be dissipating the heat due to both radiation and convection & can be taken as 12.5 S_t watts.

Because the oil when get heated up moves up and cold oil down, circulation of oil in the tubes will be more. Obviously, this circulation of oil increases the heat dissipation. Because of this siphoning action, it has been found that the convection from the tubes increase by about 35 to 40%.

Thus if the improvement is by 35%, then the dissipation in watts from all the tubes of area A_t = 1.35 x 6.5A_t = 8.78 A_t .

Thus in case of a tank with tubes, at final steady temperature rise condition, Losses = 12.5

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$S_t + 8.78\ A_t$

Round, rectangular or elliptical shaped tubes can be used. The mean length or height of the tubes is generally taken as about 90% of tank height.

In case of round tubes, 5 cm diameter tubes spaced at about 7.5cm (from centre to centre) are used. If dt is the diameter of the tube, then dissipating area of each tube at = pdt x $0.9H_t$. if n_t is the number of tubes, then $A_t = a_t n_t$.

Now a days rectangular tubes of different size spaced at convenient distances are being much used, as it provides a greater cooling surface for a smaller volume of oil. This is true in case of elliptical tubes also. The tubes can be arranged in any convenient way ensuring mechanical strength and aesthetic view.

COOLING OF TRANSFORMERS

- The losses developed in the transformer cores and windings are converted into thermal energy and cause heating of corresponding transformer parts.
- The heat dissipation in transformer occurs by Conduction, Convection and Radiation.
- The paths of heat flow in transformer are the following
    - ✓ From internal most heated spots of a given part (of core or winding) to their outer surface in contact with the oil.
    - ✓ From the outer surface of a transformer part to the oil that cools it.
    - ✓ From the oil to the walls of a cooler, eg. Wall of tank.
    - ✓ From the walls o the cooler to the cooling medium air or water.
- In the path 1 mentioned above heat is transferred by conduction. In the path 2 and 3 mentioned above heat is transferred by convection of the oil. In path 4 the heat is dissipated by both convection and radiation
- The various methods of cooling transformers are
    - ➢ Air natural
    - ➢ Forced circulation of oil
    - ➢ Air blast

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- Oil forced-air natural
- Oil natural
- Oil forced-air forced
- Oil natural-air forced
- Oil forced-water forced
- Oil natural-water forced

- The choice of cooling method depends upon the size, type of application and type of conditions obtaining at the site where the transformer in installed.
- Air natural is used for transformers up to 1.5 MVA. Since cooling by air is not so effective and proves insufficient for transformers of medium sizes, oil is used as a coolant.
- Oil is used for almost all transformers except for the transformers used for special applications.
- Both plain walled and corrugated walled tanks are used in oil cooled transformer.
- In oil natural-air forced method the oil circulating under natural head transfers heat to tank walls. The air is blown through the hollow space to cool the transformer.
- In oil natural-water forced method, copper cooling coils are mounted above the transformer core but below the surface of oil. Water is circulated through the cooling coils to cool the transformer.
- In oil forced-air natural method of cooling, oil is circulated through the transformer with the help of a pump and cooled in a heat exchanger by natural circulation of air.
- In oil forced-air forced method, oil is cooled in external heat exchanger using air blast produced by fans.
- In oil forced-water forced method, heated oil is cooled in a water heat exchanger. In this method pressure of oil is kept higher than that of water

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to avoid leakage of oil.

- Natural cooling is suitable up to 10 MVA. The forced oil and air circulation are employed for transformers of capacities 3Q MVA and upwards.
- The forced oil and water is used for transformers designed for power plants.

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