A t/f is a static electromagnetic a.c device that transfer an a.c. electric power from one ckt to another at the same freq but the voltage level is changed. T/f only serves a very important link b/w the generat^n of electrical energy and its utilization. The use of the t/f action is one of the major reason for commercial preference of a.c. for power use.

→ Two or more wdgs which link with common magnetic field. → alt. volt source → an alt. d/s is mod. whose amplit. depend on the voltage & no. of turns
$E_p = 4.44 f \phi_m T_p$

Electrical energy is mostly generated at remote places where large water head is available for hydro electric power station or thermal energy in the form of coal for thermal power station. This energy is transmitted to long distances for use at load centres. Therefore the transmission and distribution of electrical energy is become economically possible by extensive use of transformers. In this area of applications the transformer are termed as power t/f and Distribution t/fs

$E_s = 4.44 f \phi_m T_s \Rightarrow \frac{E_s}{E_p} = \frac{T_s}{T_p} \Rightarrow$ any desired value of E_s can be obtained

Distb^n t/fs:- up to size of about 200-250KVA used for stepping down the voltage to a standard service voltage. They are continuously in the ckt whether they are carrying any load or not. The core losses would occurs for all the times whereas copper losses only when they are loaded. Therefore designers have to give attention to reduce core losses compared to full load copper losses and coils also arranging in such a way to minimize the leakage reactance.

Power t/fs:- → Above 200-250KVA used in generating station or substat^n for transforming the voltage at each end of power transmsn line.

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they are put into operation during load hours and through off during light load hours. there t/fs are designed to have maximum efficiency at full load.

Some other types also like - instrument t/f for metering purposes, [they are named as CT & PT]

- In high voltage laboratory they are used to generate very high voltage for testing purpose termed as testing t/f.

* Transformer type :- Acc. to construction
ⓐ Core & ⓑ Shell type

Acc to service condition :-
↳ ⓐ Distbn t/f &
ⓑ Power t/f.

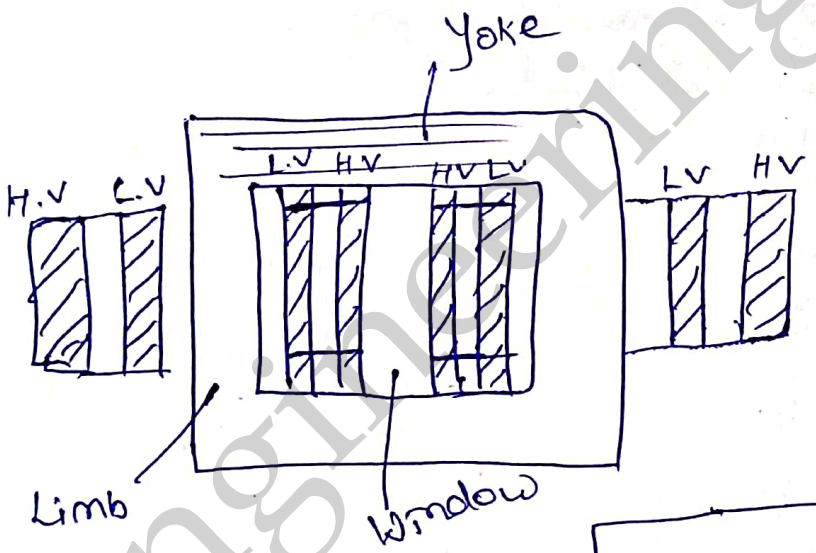
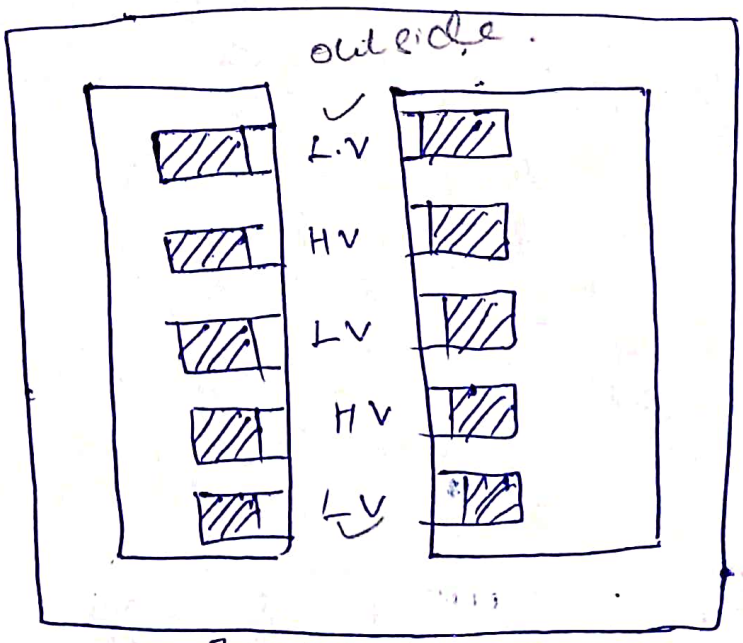


Fig-1 a Core type Concentric



shell type

Both LV & H.V windings are put around the central limb.

E-type.

Fig 1b Sandwitched

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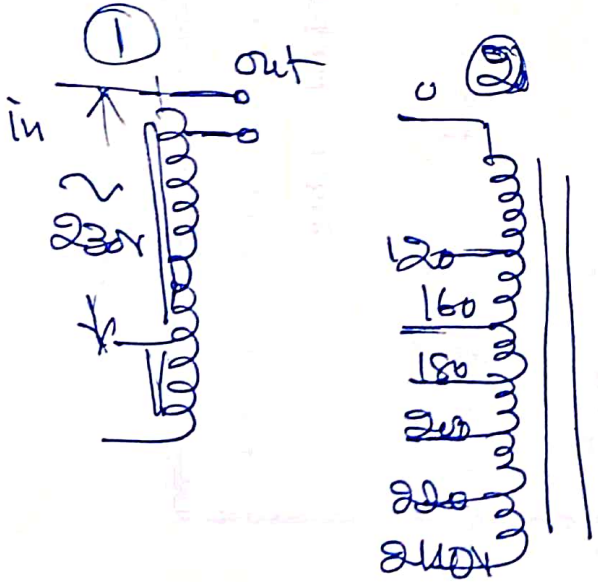
(92)

TYPES OF TRANSFORMERS

- Conventional type (with two wdgs Pr. & Se.)
  - Transmission type / power T/F
    - E.H.V Type — Above 66 kV
    - HV type — upto 66 kV
  - Distribution type — 200 – 250 kVA
    - Medium voltage — 11 kV / 0.4 kV
    - High Voltage Testing transformer — for checking Insul^n / Appliance upto 5000 V.
    - High Current Testing transformer — upto 200 – 400 A
    - Instrument Transformer
      - CT (Current) — 100/5A, 200/5A, 500/5A, 1000/5
      - PT (Potential) — 11kV/110V, 33kV/110V, 66kV/110V
- Auto transformers (with one wdg.)
  - (1) With Continuous Variation of V — 230V/0 to 270V (Variac)
  - (2) Variation in steps (used as stabilizer)



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Constructional Parts:→ fig page No-26

Static electric Device having no rotating part.

1. Magnetic ckt:- Limb, yoke, and clamping structure
2. Electric ~~Structure~~ ckt:→ Different windings (primary, 2ndary (and tertiary, if any) formers insulations.
3. Terminals:- Leads and tappings, bushing, terminal insulators.
4. Cooling circuit:- tank, oil, conservator, breath & auxiliary apparatus.

T/F used in p.s applications are mainly single phase and 3-phase core type. Rarely used shell type (3-ph) Here we also will most dealing & Discuss with single phase core & shell type but 3-ph only core type. (no any 3-ph shell type)

* Windings:→ circular and rectangular

mostly used circular bcz rectangular wdg involves wastage of space and under short ckt condition it get deformed. Hence it may be employed only for very very small capacity T/F.

Now further circular are classified:— (a) Concentric (b) Sandwitch

(a) (b)

fig 1.a & 1.b

The concentric ~~cylindrical~~ circular wdg is further classified as:→

(a) cylindrical (b) Helical wdg
(c) Crossover wdg (d) Continuous Disc wdg.

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DESIGN.

* **Specifications:→**

1. Capacity i.e, rating in KVA.
2. Voltage rating, kV of primary & 2ndary sides
3. No. of phases, 1-ph or 3-ph.
4. freq. in Hz
5. Connections Y or Δ for 3-ph. tfr
6. Type - Core or shell (Constructional) pt. of view
7. Type - power or Distribution → (Apph " " ")
8. Type of cooling 9. Temperature rise, depending upon type of insulation. 10. Voltage regulation
11. No Load current, 12 Efficiency 13. p.f.

* **Output Equation:→** The o/p of tfr in KVA is to be related with its main dimension. (Ai, Aw) is called as o/p equation.

Let Q = output, kVA

ϕ_m = Main flux, wb first fig page No-26

B_m = Max. flux density A/m^2

A_i = Net cross section area of iron core, m^2, Net core area

A_{gi} = Gross (iron) core section, m^2, gross core area

A_w = Net window area, m^2 [$A_i = k_s A_{gi}$] (including stacking factor)

stacking factor 0.85–0.9

D = Dist. b/w core centres, m

d = Diam of circumscribing circle around core, m

K_w = Window space factor, f = freq, Hz

E_t, E.m.f per turn, volt

T_1, T_2 = No. of 1° & 2° turns, I_1, I_2 = 1° & 2° current

V_1, V_2 = Primary (and of) & 2ndary phase voltage, volt.

a_1, a_2 = primary & 2ndary conductor sections, m^2 (area of 1° & 2ndary conductor wdg Des 12)

L_i = mean length of flux path in iron, m

L_{mt} = Length of mean turn of wdg, m.

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G_i = Weight of active part of iron, kg
G_c = " " copper, kg
P_i = specific core losses, W per kg
P_c = " copper " " —.

output Eqn For
* 1-phase core type T/F :→
E.M.f. induced in H/F wdg as
$E = 4.44 f \phi_m T$
The e.m.f per turn
$E_t = \frac{E}{T} = 4.44 f \phi_m$ ... (1)
Wheather the primary & 2ndary turn is the part of that it link with flux ϕ_m.
The window space factor K_W is defined as ratio of copper area in window to total window area. ie,

$$K_W = \frac{\text{Copper area in Window}}{\text{Total window area } (= A_W)}$$

Hence copper area in window $= K_W A_W$ — (2)
→ The copper area can also be found out by the no. of turns of the primary and 2ndary winding and the conductor sections. The window here contains only one primary and one 2ndary wdg. (both L.V. near limb) Here we are considering one 1" & one 2"
Copper area in window $= T_1 a_1 + T_2 a_2$

$$= T_1 \frac{I_1}{\delta} + T_2 \frac{I_2}{\delta}$$ [Assuming that the current density δ is same for both the wdg. $a_1, a_2 \rightarrow$ 1" & 2" cond sect^n]

$$= \frac{1}{\delta}(T_1 I_1 + T_2 I_2)$$

$$= \frac{2IT}{\delta} \quad \text{— (3)}$$ [$I_1 T_1 \cong I_2 T_2 = IT$ If we neglect magnetising AT/mmf.]

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from eqn (2) & (3)

$$K_W A_W = \frac{2IT}{\delta} \Rightarrow IT = \frac{K_W A_W \delta}{2}$$

Now rating of 1-ph T/F is $Q = E \times I \times 10^{-3}$ → (4)

$$Q = V_{ph} I_{ph} \times 10^{-3} \cong E_{ph} I_{ph} \times 10^{-3}$$

[As V_{ph} is Approx Equal to E_{ph}]

$$= (4.44 f \phi_m T) I \times 10^{-3}$$

$$= 4.44 f \phi_m (IT) \times 10^{-3}$$

$$= 4.44 f \phi_m \left[\frac{K_W A_W \delta}{2}\right] \times 10^{-3}$$ [from eqn (4)]

$$= 2.22 f \phi_m K_W A_W \delta \times 10^{-3}$$

$A_i = \frac{\phi_m}{B_m}$

$$\boxed{Q = 2.22 f B_m A_i A_W K_W \delta \times 10^{-3} \text{ KVA}}$$

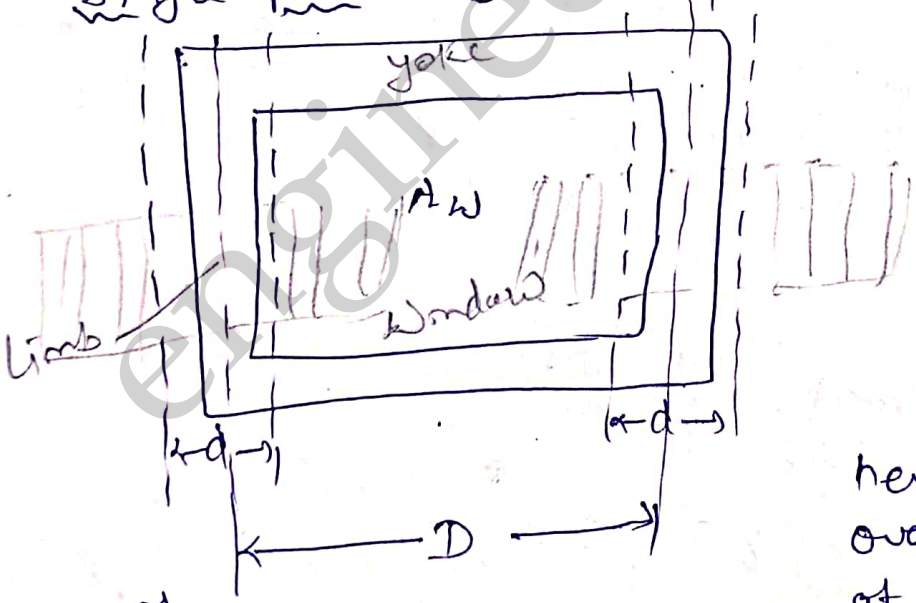
$B_m = \frac{\phi}{A}$

As [$\phi_m = B_m A_i$]

B_m → Max. Flux density Wb/m²

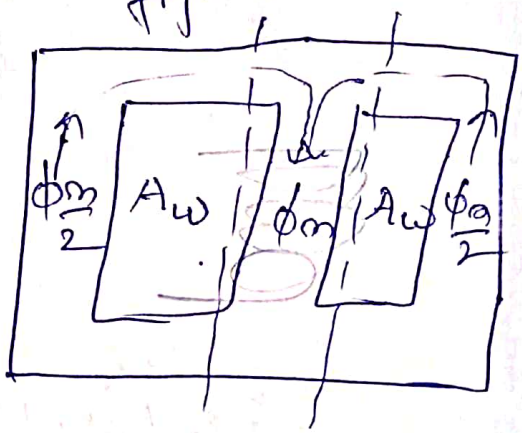
A_i → Net cross section area, m.

Single phase shell type T/F :→



1-ph shell type

fig



here both wedgs are wound over the central limb. Each of window contains all the 1ry & 2ndary turns

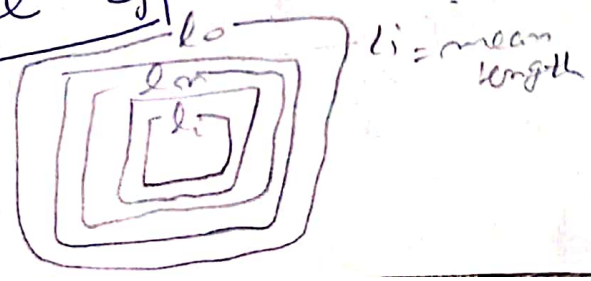
Copper area in window

$$= T_1 a_1 + T_2 a_2 = \frac{2IT}{\delta}$$

$$= K_W A_W \quad \text{same}$$

1-ph core type

fig



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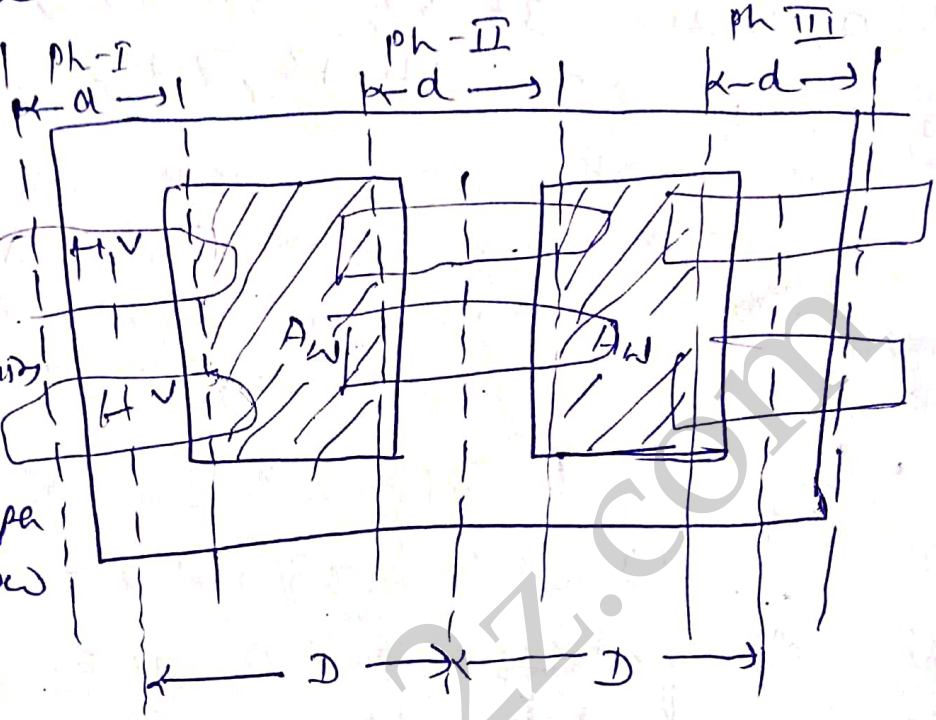
Three phase T/F :→ (Core-type)

Each limb is wound with both primary and secondary wdgs of respective phases. Each window contains two primaries and two secondaries. i.e. Copper area in each window



$= 2(T_1 a_1 + T_2 a_2)$

$$= 2\left[T_1 \frac{I_1}{\delta} + T_2 \frac{I_2}{\delta}\right] = \frac{2}{\delta}\left[I_1 T_1 + I_2 T_2\right]$$

$$= \frac{4IT}{\delta} \quad [I_1 T_1 \cong I_2 T_2 = IT]$$

[If we neglect magnetising AT/mmf]

(IT)

Also copper area in each window $= K_W A_W$

$$\therefore \quad K_W A_W = \frac{4IT}{\delta}$$

$$IT = \frac{K_W A_W \delta}{4} \quad \text{— (6)}$$

Now output of 3-ph T/F is ratings of 1-ph T/F is

$[Q = 3EI \times 10^{-3}$

$$Q = 3 E_{ph} I_{ph} \times 10^{-3} = 3(4.44 f \phi_m T_{ph}) I_{ph} \times 10^{-3}$$

$$= 3(4.44 f \phi_m)\left(\frac{K_W A_W \delta}{4}\right) \times 10^{-3} \quad \text{from (6)}$$

$$\boxed{Q = 3.33 f B_m A_i A_W K_W \delta \times 10^{-3}} \text{ KVA} \quad [\phi_m = B_m \times A_i$$

$$B_m = \frac{\phi_m}{A_i}$$

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Volt/per turn OR

Output Equation :- E.m.f per turn of wdg :-

$E_t = K\sqrt{Q}$

We have to relate the output kVA of T/F to e.m.f per turn that is the ~~deciding~~ design factor for T/F. ~~take~~ from where a const value (K) we will obtained.

$\phi = \frac{mmf}{Rel}$ at/IT

O/P) Rating for a 1-ph. T/F

Rating of 1-ph T/F - OR O/P of 1-ph T/F -

$$Q = E \times I \times 10^{-3}$$

$$= 4.44 f \phi_m T \times I \times 10^{-3} \quad \text{—(1)}$$

Any no. of Design should satisfy this Eqn. The flux (ϕ_m) is roughly a measure of the cross section of a core and (IT, mmf) IT gives the cross section of the winding. Therefore the ratio of ϕ_m / IT will be a const.

Let $\frac{\phi_m}{IT} = r$

mmf = flux × reluct

emf = I × Res. r'

$\frac{1}{rel} = \frac{\phi_m}{mmf} = \frac{\phi_m}{IT}$

$= r = \frac{1}{rel} \quad \frac{\phi_m}{IT}$

$\frac{1}{reluct} = \underset{\text{permeance}}{\lambda} = r$

(1) ⇒

$\therefore Q = 4.44 f \phi_m (IT) \times 10^{-3}$

$= 4.44 f \frac{\phi_m^2}{r} \times 10^{-3} \quad \left[IT = \frac{\phi_m}{r}\right]$

$\phi_m^2 = \frac{r \times 10^3}{4.44 f} \cdot Q$

$\phi_m = \sqrt{\frac{r \times 10^3}{4.44 f}} \cdot \sqrt{Q}$

put this value in emf/turn $E = 4.44 f \phi_m T$

$E = E_t = 4.44 f \phi_m$

$= 4.44 f \left[\sqrt{\frac{r \times 10^3}{4.44 f}} \sqrt{Q}\right]$

$E_t = \sqrt{4.44 f r \times 10^3} \sqrt{Q}$

i.e. $\boxed{E_t = K\sqrt{Q}}$ —(5)

where $K = \sqrt{4.44 f r \times 10^3}$

This K is a const and depends upon type, service condition and construction.

Table : P.T.O.

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DESIGN OF CORE: →

Mainly the core used in the t/f are of rectangular and squared.

→ for very small size of t/f - simple rectangular core section are used having circular or rectangular coils.

→ As size of t/f are increased, we use generally the squared shape core and these squared core are - TWO STEPPED, THREE STEPPED and FOUR stepped core sect^n.

(i) SQUARE SECTION: → Refering fig-1

Gross core section

Gross area of core, $A_{gi} = a^2$

where, a = side of square and d = diam of circumscribing circle

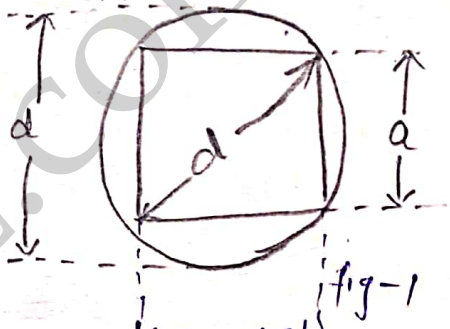


fig-1

$$a = d/\sqrt{2} = 0.707\,d = 0.71\,d$$

$d^2 = a^2 + a^2$

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

$d = \sqrt{2}\,a \Rightarrow a = \frac{d}{\sqrt{2}}$

$$\therefore \quad A_{gi} = (0.71\,d)^2 = 0.5d^2$$

Net iron /core area/ $= A_i = K_s A_{gi} = 0.9 \times 0.5d^2 = 0.45d^2$

Net core section

Area of circle $= \pi r^2 = \pi\left(\frac{d}{2}\right)^2 = \frac{\pi}{4}d^2$

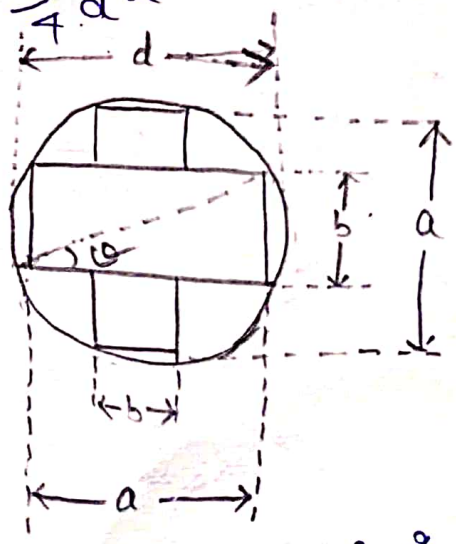
$$\text{Ratio} = \frac{\text{Net core area}}{\text{area of circumscribing circle}} = \frac{0.45d^2}{\pi/4\, d^2} = 0.58$$

circumcircle

$$\text{Ratio} = \frac{\text{Gross core area}}{\text{area of circumscribing circle}} = \frac{0.5d^2}{\pi/4\, d^2} = 0.64$$

2. STEPPED CORES: →

fig-2 shows a two stepped or cruciform core. The dimension of the two steps to give maximum area for a given diameter are determined as below



Gross core area $A_{gi} = ab + b(a-b)$

$= ab + ab - b^2 = 2ab - b^2$

Now, $a = d\cos\theta$ and $b = d\sin\theta$

$A_{gi} = 2(d\cos\theta \cdot d\sin\theta) - d^2\sin^2\theta = 2d^2\sin\theta\cos\theta - d^2\sin^2\theta$

$[2\sin\theta\cos\theta = \sin 2\theta]$

$= d^2(\sin 2\theta - \sin^2\theta)$

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Differentiating Eqn (2) w.r.t. θ

$$d^2(2\cos 2\theta - 2\sin\theta\cos\theta)$$

$$\frac{dA_{gi}}{d\theta} = d^2(2\cos 2\theta - \sin 2\theta)$$

Equating $\frac{dA_{gi}}{d\theta} = 0 \Rightarrow \tan 2\theta = 2 \Rightarrow \theta = 31°45'$

Therefore $a = d\cos 31°45' = 0.85d$ $\quad b = d\sin 31°45 = 0.53d$

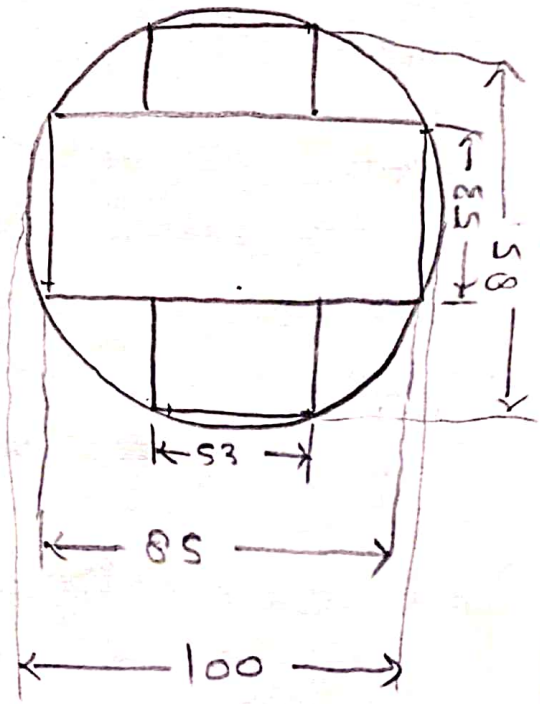
$\therefore$ Gross core area, $A_{gi} = 2ab - b^2 = 2(0.85d \cdot 0.53d) - (0.53d)^2$

$= 0.618d^2$

Net core area, $A_i = K_s A_{gi} = 0.9 \times 0.618d^2 = 0.56d^2$

$$\text{Ratio} = \frac{\text{Net core area}}{\text{area of circumscribing circle}} = \frac{0.56d^2}{(\pi/4)d^2} = 0.71$$

and $$\frac{\text{Gross core area}}{\text{area of circumscribing circle}} = \frac{0.618d^2}{(\pi/4)d^2} = 0.79$$



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Selection of Design Constants:→

Much of the design depends upon proper selection of design constants, flux density B_m, current density δ, and window space factor K_w.

* **Choice of flux density, B_m:→** $\frac{1}{A_i} \propto B_m$

from voltage equation as well as output equation [$Q = 2.22 f B_m A_i A_w K_w \delta \times 10^{-3}$] indicates that, if we choose higher value of flux density B_m, the core area reduces. This will reduces the diameter of circumcircle thereby reducing the length of mean turn. Therefore there is a saving in cost of iron and copper. Also higher value of flux density increases the iron losses which will require the elaborate / more cooling arrangement. $P_i = B_m n^{1.6}$ Losses ⇒ Heat ⇒ Cooling.

The permissible value of flux densities are

Distbn tfr 1.1 to 1.4 Wb/m² (1.3)

Power tfr 1.2 to 1.5 Wb/m² (1.4)

* **Choice of current Density, δ:→**

A higher value of current density will affect heating and efficiency. A higher value of current density will produce excessive temperature rise and insulation may be damaged due to intense local heating. The choice of current density affect the I^2R loss and efficiency hence also the load at which maximum efficiency occurs. The permissible value of current density are:-

Ind^n m/c - 3-5 A/m²

① for stdard Distbn & small Power tfr

$\delta = 1.5$ to 2.6 A/mm²

② for med. & large power tfr

$\delta = 2.4$ to 3.1 A/mm²

for Large P.T

$\delta = 5.4$ to 6.3 A/mm²

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* Choice of window space factor :- K_W

The window space factor, K_W is the ratio of copper area in window to the total window area. As the total window area include the copper area, the insulation, and air or oil spaces. The ammount of copper and insulation used depend upon the KVA capacity and voltage rating resp. The choice of K_W depends upon KVA capacity and voltage rating. The follow. empirical relation :- for K_W

(ii) $K_W = \frac{10}{30+KV}$ b/w 50 - 200 KVA

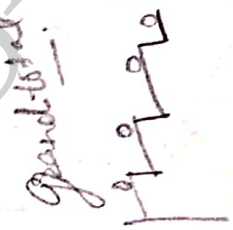
(iii) $K_W = \frac{12}{30+KV}$ for about 1000 KVA

(i) $K_W = \frac{8}{30+KV}$ for abt 10 KVA

(0.3 to 0.4)

where KV is voltage in KV (kilo-volt of high voltage wdg.

eg. Designing a 250 KVA, 2000/400V, 50 Hz, 1-ph core type



Choice of Window Dimensions :→

The window area A_W, composed of two dimensions window hight h_W and window width W_W. $A_W = h_W \times W_W$

→ Too narrow a window – gives increased hight of wind. making wdgs long and thin. In this case the dist. b/w adjac. Limb / wdgs is less, the leakage reactance also reduces.

→ On the other hand if we choose lower hight – window width (W_W) rises giving ↑ed dist b/w adjac. Limb/wdgs. This will leads to increased leakage reactance.

Depending upon the suitability of window and desirability of leakage reactance, the hight and width of window can be adjusted: the ratio generally lies b/w

$\frac{h_W}{W_W} = 2$ to 4 the most usual value is 3.

and $A_W = h_W \times W_W$ thus h_W and W_W can be calculated.

17 Dec 2020

* **Yoke Dimension / Design of Yoke :→** $\frac{1}{A_i} \propto B_m \downarrow$

No windings comes over the yoke portion, therefore there is possibility of reducing the iron loss by increasing the cross section area of yoke – how → reducing the flux density of yoke portion. Generally yoke area is taken as 15 to 25 percent higher than that of limb section.

The yoke section is most normally rectangular but it may be two stepped also. Considering the yoke section to be rectangular

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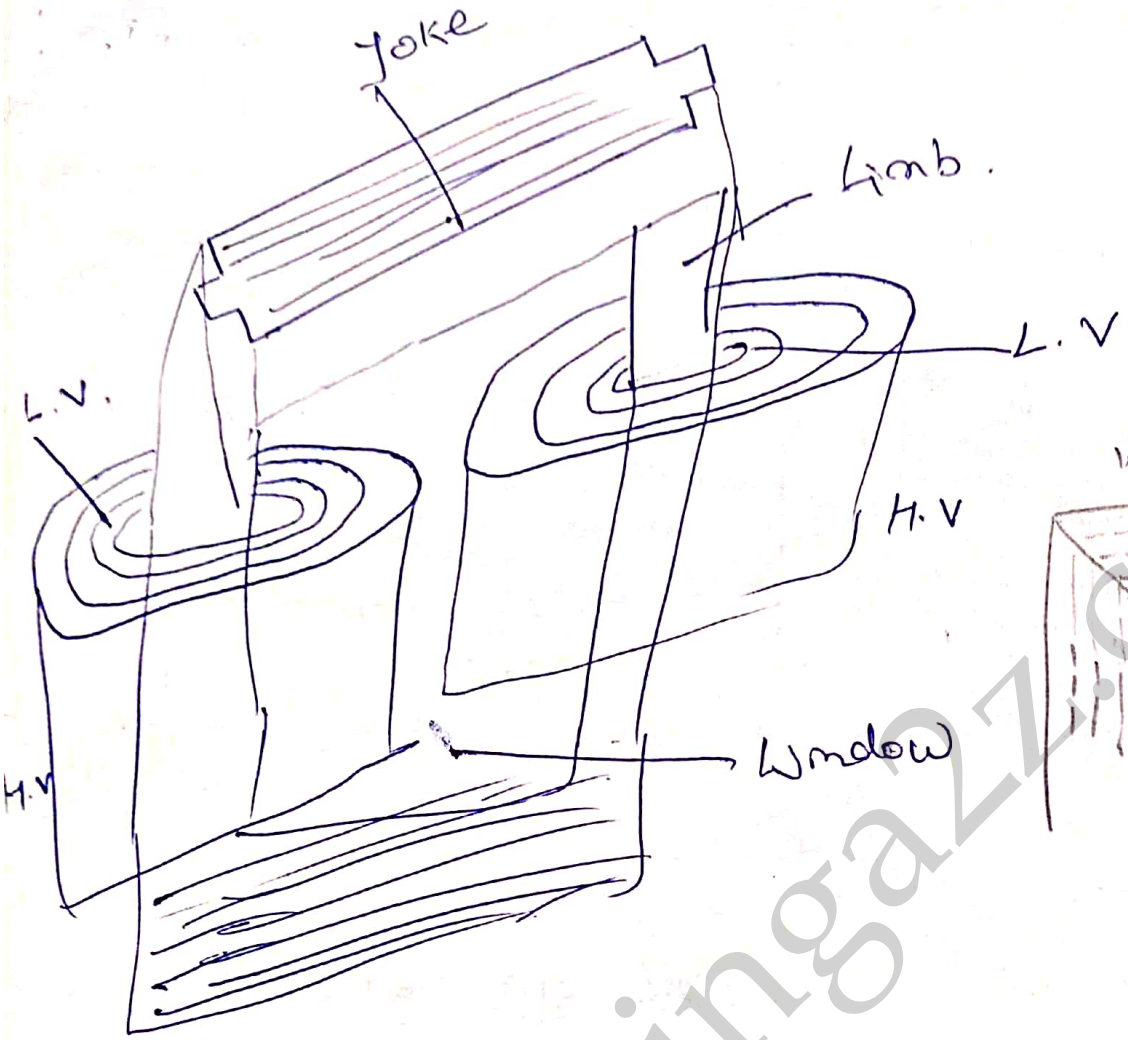

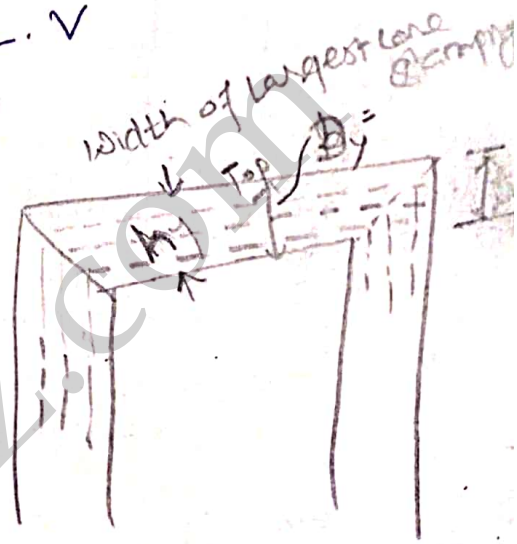

Let A_y = Area of yoke, D_y = Depth of yoke
h_y = hight of yoke

$$A_y = D_y \times h_y \quad \text{— (1)}$$

Now, ~~width~~ depth of yoke has to be same as the depth of core (as already obtained while designing the core section)

i.e. depth of yoke = Depth of core
= Width of largest core stamping $= D_y = a$

and $$A_y = (1.15 \text{ to } 1.25)\, A_{gi} \quad \text{— (2)}$$

(1) ⇒ $A_y = D_y \times h_y$ ⇒ $h_y = A_y / D_y$ (from Depth of core)

↳ Thus h_y could be calculated.

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OVERALL CORE DIMENSIONS:→

After Designing the core & yoke section and also the window dimension, the overall dimensions can be calculated.

① for 1-phase (core) type 1/7:→

$D = W_W + d$

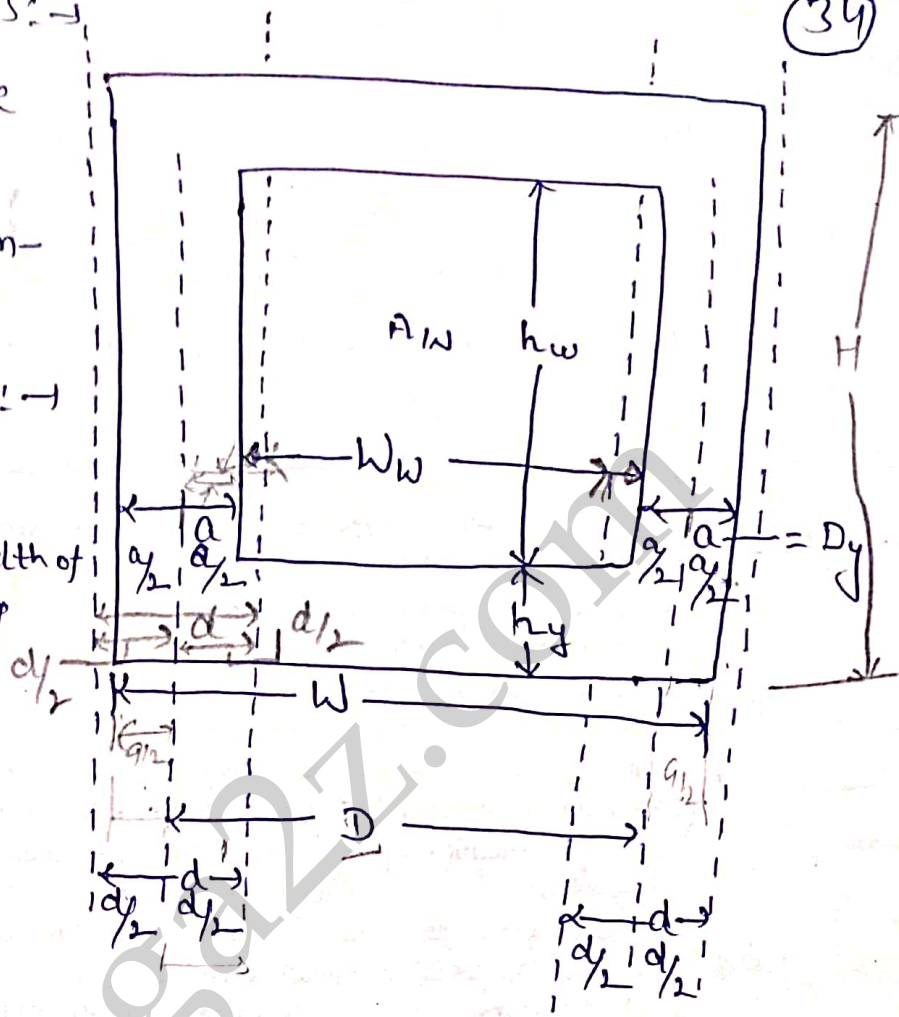
$D_y = a$ = Depth of yoke = width of largest core stamping

Let H = overall height

W = " width

$$\boxed{H = h_W + 2h_y}$$

$$\boxed{W = D + a}$$



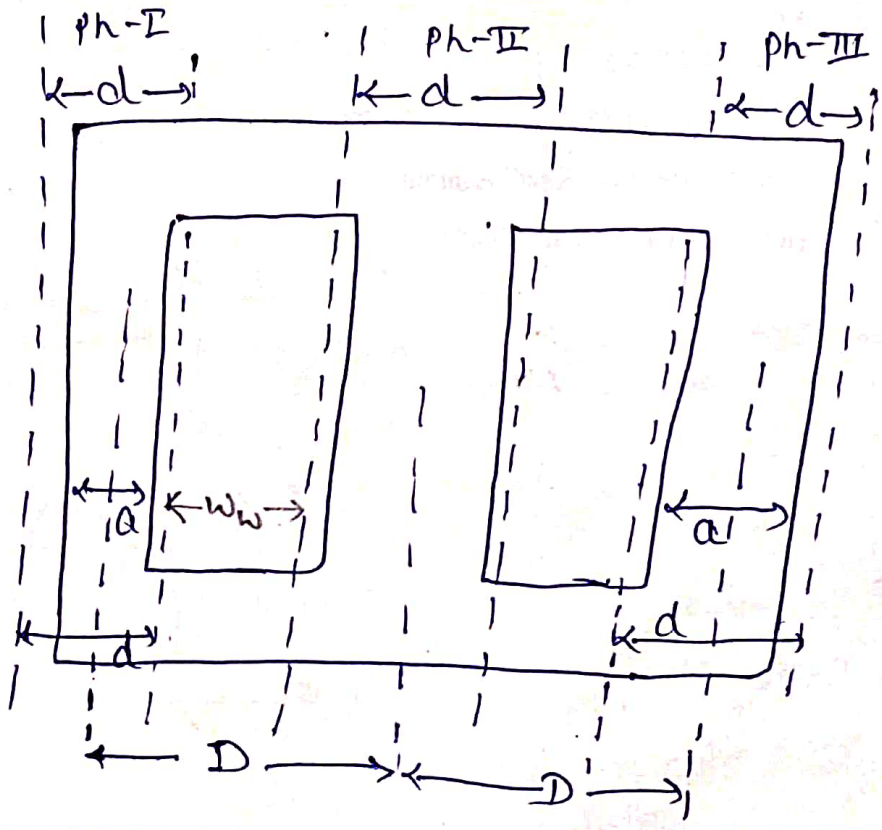
for 3-phase (core) type 1/7:→

$D = W_W + d$

$D_y = a$

$$\boxed{H = h_W + 2h_y}$$

$$\boxed{W = 2D + a}$$



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Sol^n:- ① CORE

A_i, d, a

a = Width of Largest core stamping = Depth of yoke

d = diam. of circumcircle around the core

$A_w = ?$ $h_w \times W_w$

$Q = 2.22 f B_m A_i A_w K_w S \times 10^{-3}$

I II

Voltage per turn

$\frac{E}{T} = E_t = 4.44 f \phi_m = 4.44 f B_m A_i$

I $A_i = \frac{15}{4.44 \times 50 \times 1.25} = 0.05405 \, m^2$

II $A_w = \frac{250}{2.22 \times 50 \times 1.25 \times 0.05405 \times 0.3 \times 2.75 \times 10^6 \times 10^{-3}}$ ↓ output Eq^n

$A_w = 0.04040 \, m^2$

$A_w = h_w \times W_w = 0.04040 \, m^2$

$\frac{h_w}{W_w} = 3 \Rightarrow$ $h_w = 3W_w$

$h_w \times W_w = 0.04040$

$3W_w^2 = 0.04040$

$W_w = \sqrt{\frac{0.04040}{3}} = 0.116$

$W_w = 0.116 \, m$

$h_w = 0.348 \, m$

② yoke

Assumming 3-stepped section of yoke

Hight of yoke, $h_y = a$ = Depth of yoke, $D_y = a$

overall hight

$H = h_w + 2h_y$

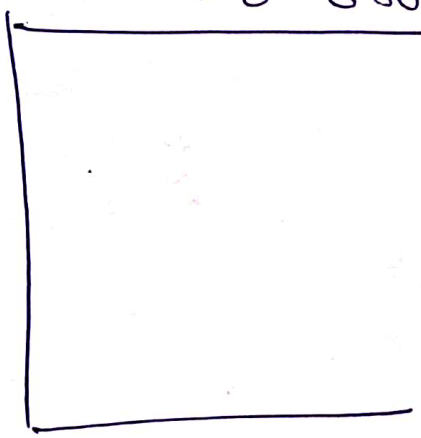
$= 0.348 + 2(0.27) = 0.888 \, m$

overall width $W = D + a$

$\Rightarrow = W_w + d + a$

$= 0.116 + 0.3 + 0.27$

$= 0.686 \, m$



II Assumming 3-stepped core section

$A_i = 0.6 d^2$

$0.05405 = 0.6 d^2 \Rightarrow d = 0.30 \, m$

Now a = Width of Largest stamping

$a = 0.9 d = 0.27 \, m$

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Example:- ~ std and. 3-stepped

Design a 250 KVA, 2000/400 V, 50 Hz, 1-phase, core type oil immersed, self cooled, power t/f with foll. data 3-stepped core section.

Induced emf per turn = 15 V, current den = 2.75 A/mm²

Max. flux den in core = 1.25 Wb/m², window space factor (k_w) = 0.3

Window proportion $\frac{\text{Height}}{\text{Width}} = 3$

Determine the main dimension of core and yoke

Soln:- [$\phi_m = B_m A_i$]

Voltage per turn $= \frac{E}{T} = E_t = 4.44 f \phi_m = 4.44 f B_m A_i$

$$A_i = \frac{E_t}{4.44 f B_m} = \frac{15}{4.44 \times 50 \times 1.25} = 0.05405 \, m^2$$

Assumming a 3-stepped core section

$\boxed{A_i = 0.6 d^2}$ ⇒ $0.05405 = 0.6 d^2$ ⇒ $d = 0.30 \, m$

The width of largest stamping, $\boxed{a = 0.9 d}$

Also depth of yoke

$= 0.9 \times 0.30 = 0.27 \, m$

$= 0.27 \, m$

KVA o/p of 1-ph t/f is

$$Q = 2.22 f B_m A_i K_w A_w \delta \times 10^{-3}$$

$$250 = 2.22 \times 50 \times 1.25 \times 0.05405 \times A_w \times 0.3 \times 2.75 \times 10^6 \times 10^{-3}$$

$$A_w = 0.04040 \, m^2$$

Now $\frac{h_w}{W_w} = 3$, $h_w \times W_w = 0.04040 \, m^2$

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