2.3 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.

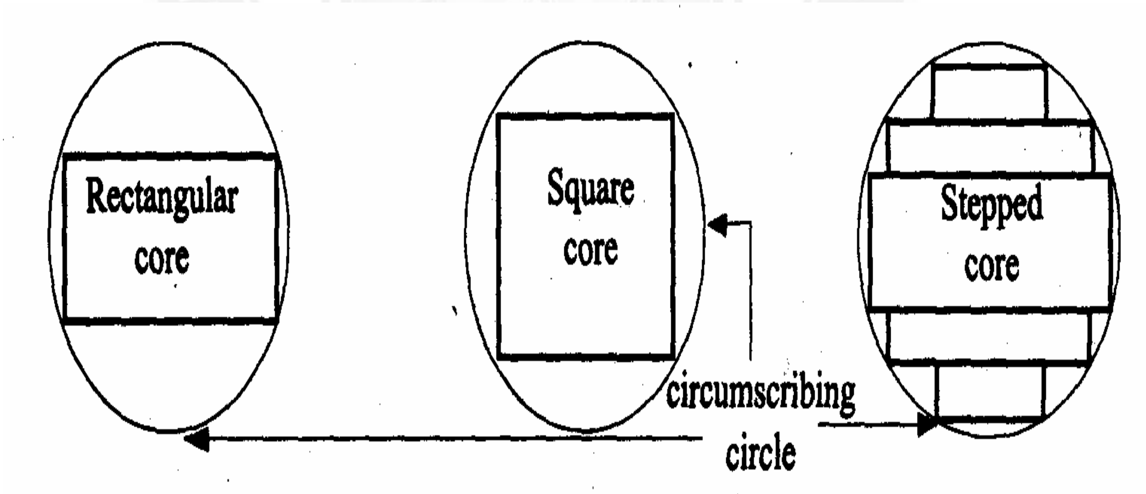

Figure 2.4.1 Cross-sectional core of transformer

[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,

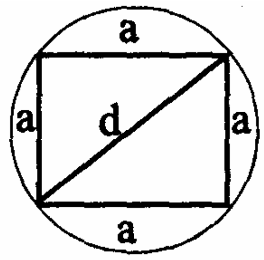

Figure 2.4.2 Cross-sectional view of square core

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

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

- 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.

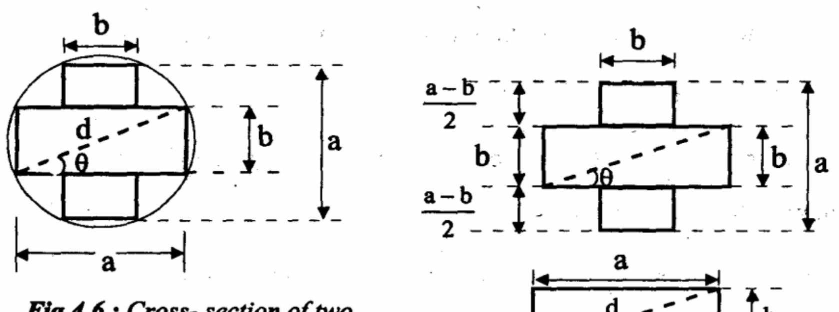

Fig 4.6 : Cross- section of two stepped core

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 Ɵ is maximum value.
- Hence differentiate A_{gi} with respect to Ɵ and equate to zero to solve for maximum value of Ɵ.
- 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,

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

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

Ɵ=31.72

- When Ɵ =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,

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

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

= 0.9 x 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.

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

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.

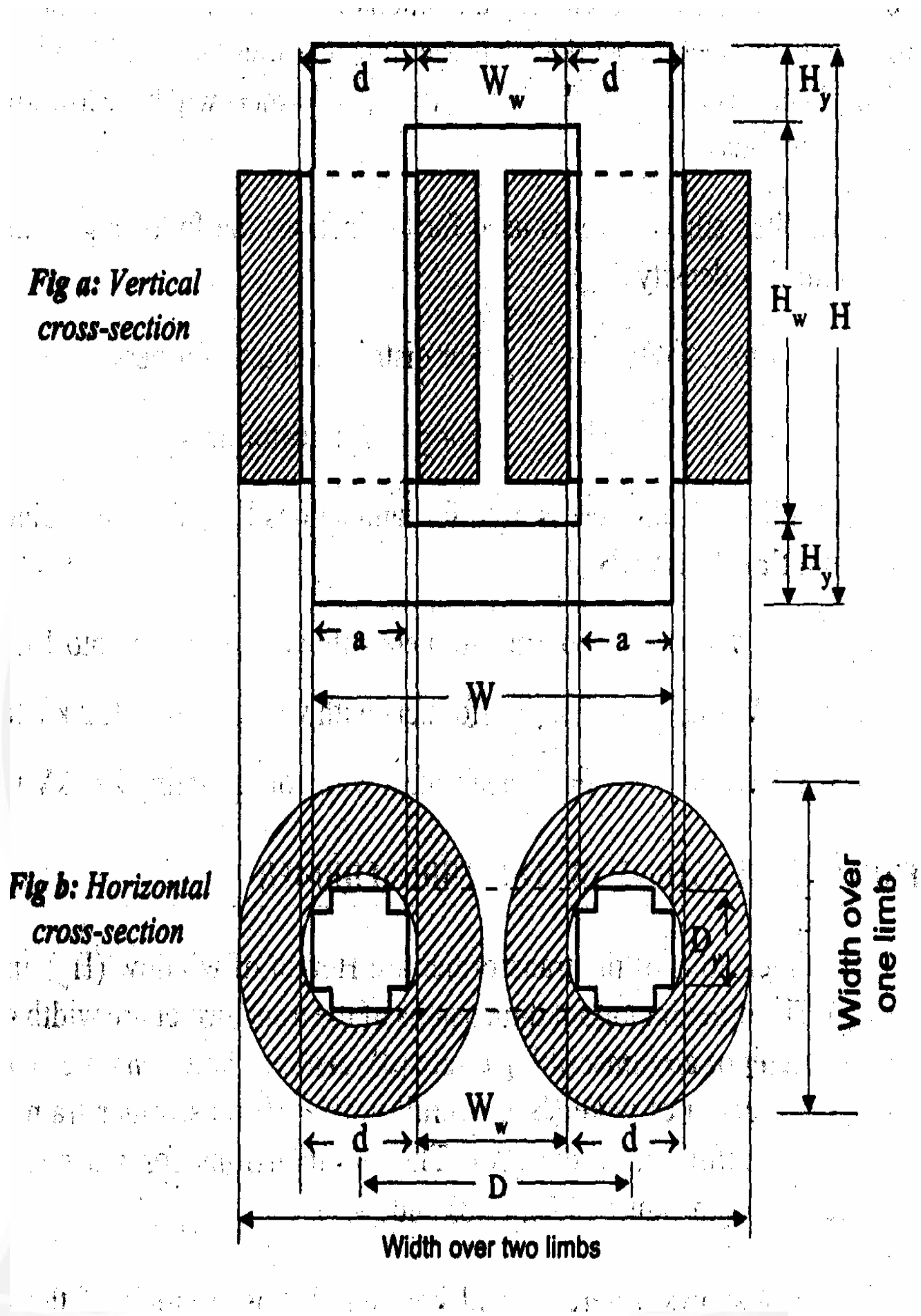

Figure 2.4.4 Single phase core type transformer

[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.

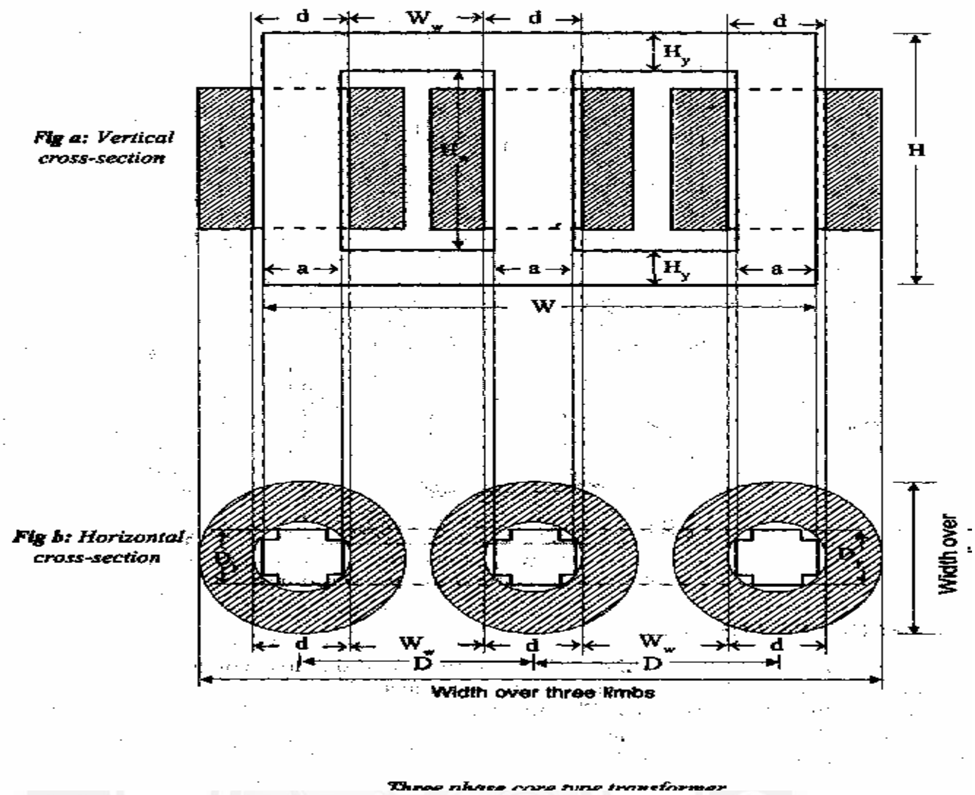

Figure 2.4.5 Three phase core type transformer

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

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

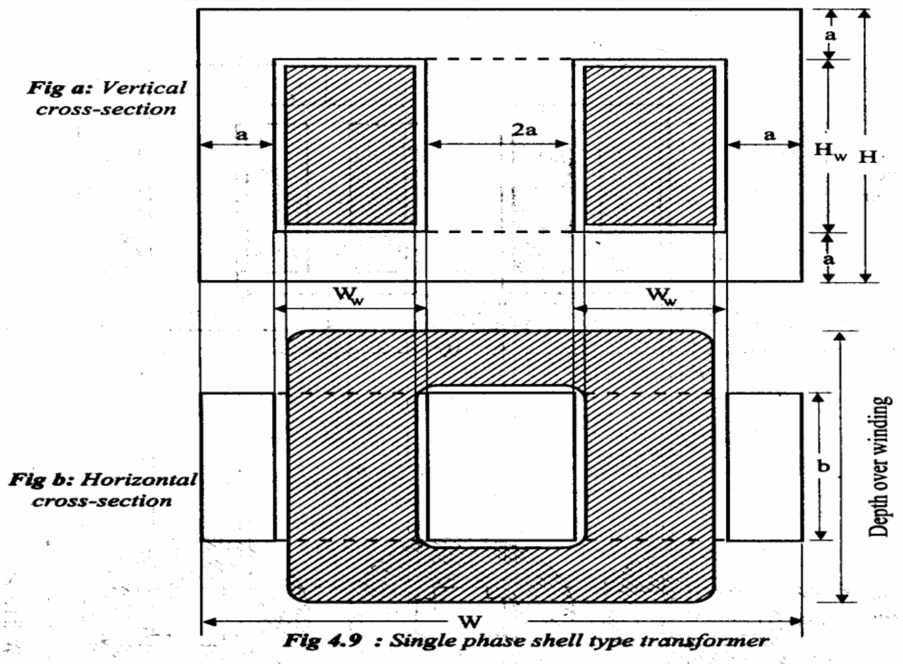

Figure 2.4.5 Single phase shell type transformer

[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

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

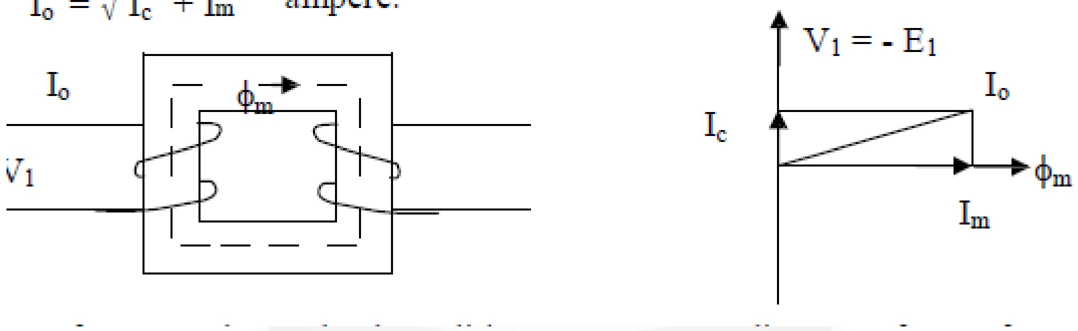

Figure 2.5.1 Transformer under no-load condition Vector diagram of Transformer under no-load condition

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