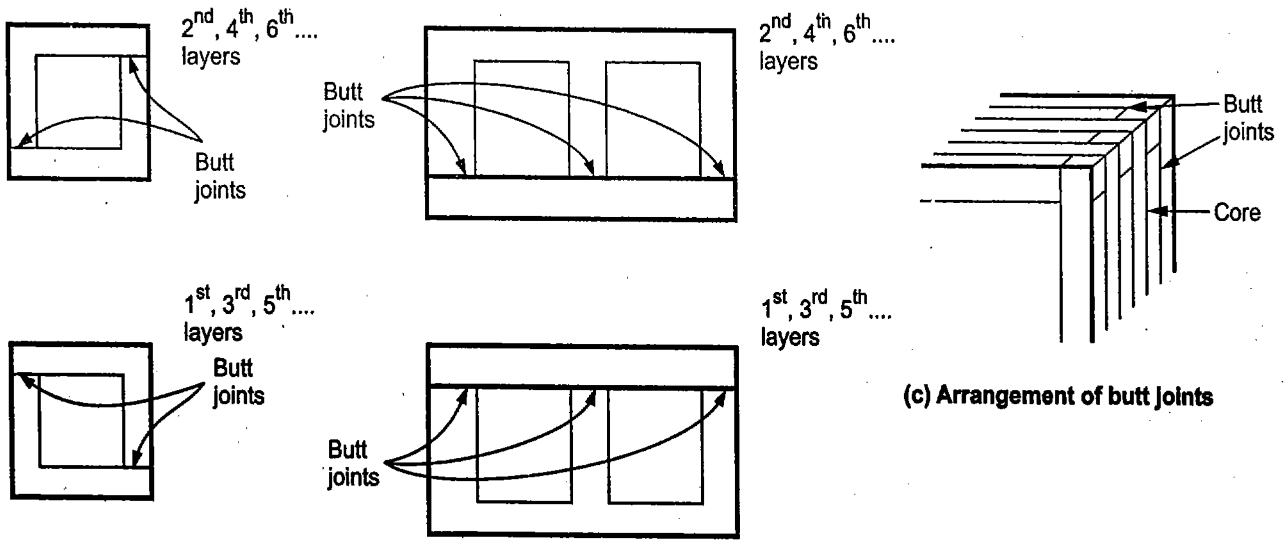


(a) Core type (b) Shell type

Fig. 4.3.3 Staggering in transformer

The **advantages of staggering** in transformer are,

1. It avoids continuous air gap.
2. The reluctance of magnetic circuit gets reduced.
3. The continuous air gap reduces the mechanical strength of the core. The staggering helps to increase the mechanical strength of the core.

In large transformers, the core is corrugated. The tank walls are corrugated means having folds and ridges. It has following advantages.

1. It allows changes in the effective volume of the oil with temperature. It helps in accomodating expansion and contraction of oil.
2. It helps to dissipate the losses effectively, by increasing the surface area of the tank. It provides large heat radiation area.

4.3.2 Types of Windings

The coils used are wound on the limbs and are insulated from each other. In the basic transformer shown in the Fig. 4.2.1, the two windings wound are shown on two different limbs i.e. primary on one limb while secondary on other limb. But due to this leakage flux increases which affects the transformer

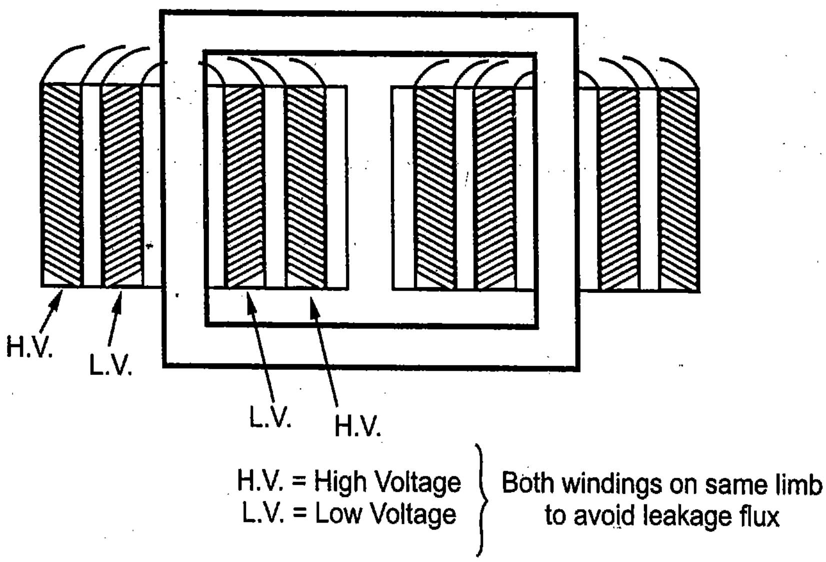


Fig. 4.3.4 (a) Cylindrical concentric coils

performance badly. Similarly it is necessary that the windings should be very close to each other to have high mutual inductance. To achieve this, the two windings are split into number of coils and are wound adjacent to each other on the same limb. A very common arrangement is cylindrical concentric coils as shown in the Fig. 4.3.4 (a).

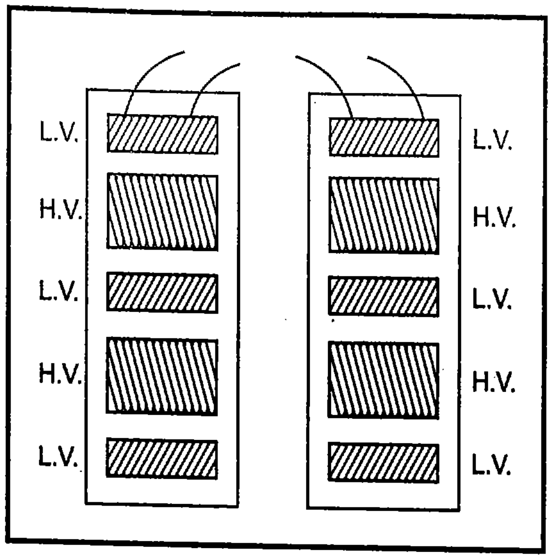


Fig. 4.3.4 (b) Sandwich coils

Such cylindrical coils are used in the core type transformer. These coils are mechanically strong. These are wound in the helical layers. The different layers are insulated from each other by paper, cloth or mica. The low voltage winding is placed near the core from ease of insulating it from the core. The high voltage is placed after it.

The other type of coils which is very commonly used for the shell type of transformer is **sandwich coils.** Each high voltage portion lies between the two low voltage portion sandwiching the high voltage portion. Such subdivision of windings into small portions reduces the leakage flux. Higher the degree of subdivision, smaller is the reactance. The **sandwich coil** is shown in the Fig. 4.3.4 (b). The top and bottom coils are low voltage coils. All the portions are insulated from each other by paper.

Review Questions

1. *Discuss the constructional features of transformers. Draw neat diagrams.*

   JNTU : May-03, 04, 05, Nov.-03, 05, Dec.-04, March-06, Marks 8

2. *What are the different parts of a transformer and explain their functions clearly.*

   JNTU : Nov.-06, Marks 16

4.4 Construction of Single Phase Transformers

JNTU : Nov.-05, 08

The various constructions used for the single phase transformers are,

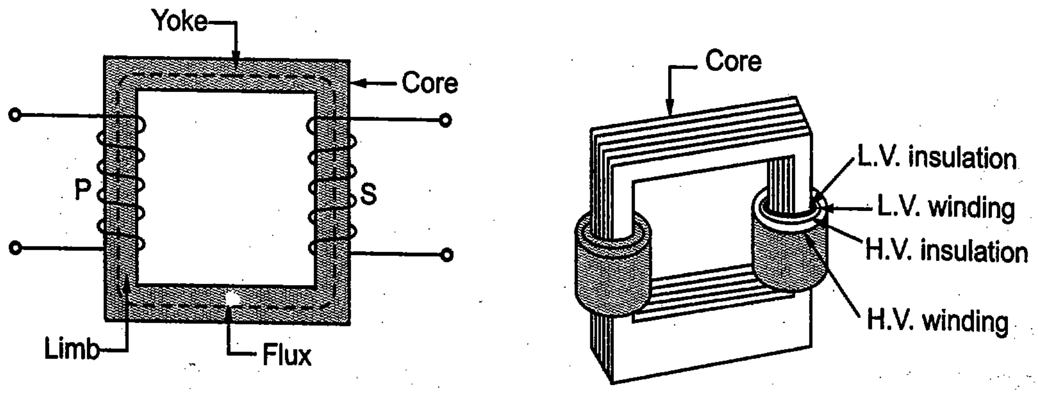
1. Core type 2. Shell type and 3. Berry type

4.4.1 Core Type Transformer

It has a single magnetic circuit. The core is rectangular having two limbs. The winding encircles the core. The coils used are of cylindrical type. As mentioned earlier, the coils are wound in helical layers with different layers insulated from each other by paper or mica. Both the coils are placed on both the limbs. The low voltage coil is placed inside near the core while high voltage coil surrounds the low voltage coil. Core is made up of large number of thin laminations.

As the windings are uniformly distributed over the two limbs, the natural cooling is more effective. The coils can be easily removed by removing the laminations of the top yoke, for maintenance.

The Fig. 4.4.1 (a) shows the schematic representation of the core type transformer while the Fig. 4.4.1 (b) shows the view of actual construction of the core type transformer.



(a) Representation

(b) Construction

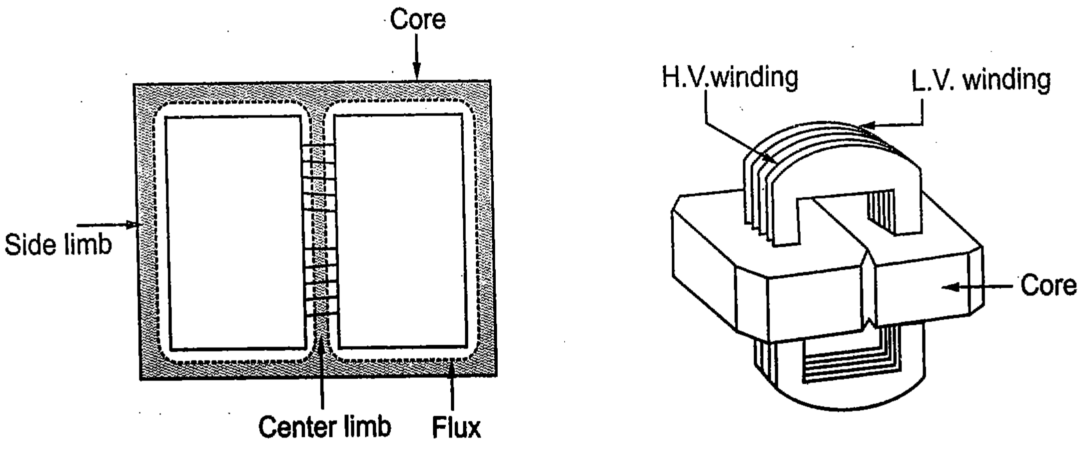
Fig. 4.4.1 Core type transformer

4.4.2 Shell Type Transformer

It has a double magnetic circuit. The core has three limbs. Both the windings are placed on the central limb. The core encircles most part of the windings. The coils used are generally multilayer disc type or sandwich coils. As mentioned earlier, each high voltage coil is in between two low voltage coils and low voltage coils are nearest to top and bottom of the yokes.

The core is laminated. While arranging the laminations of the core, the care is taken that all the joints at alternate layers are staggered. This is done to avoid narrow air gap at the joint, right through the cross-section of the core. Such joints are called over lapped or imbricated joints. Generally for very high voltage transformers, the shell type construction is preferred. As the windings are surrounded by the core, the natural cooling does not exist. For removing any winding for maintenance, large number of laminations are required to be removed.

The Fig. 4.4.2 (a) shows the schematic representation while the Fig. 4.4.2 (b) shows the outaway view of the construction of the shell type transformer.



(a) Representation (b) Construction

Fig. 4.4.2 Shell type transformer

4.4.3 Berry Type Transformer

This has distributed magnetic circuit. The number of independent magnetic circuits are more than 2. Its core construction is like spokes of a wheel. Otherwise it is symmetrical to that of shell type.

Diagramatically it can be shown as in the Fig. 4.4.3.

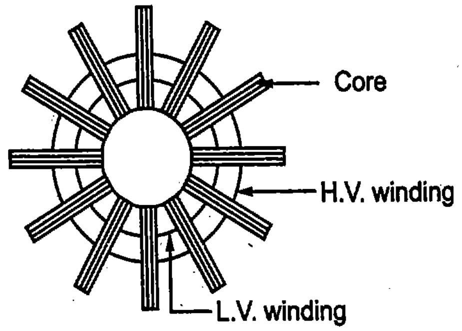


Fig. 4.4.3 Berry type transformer

Review Question

1. *Explain the constructional details of core and shell type transformers.* **JNTU : Nov.-05, 08, Marks 8**

4.5 Comparison of Core and Shell Type Transformers

JNTU : Nov.-04, 07, May-05

The comparison of core type and shell type transformers is given in the Table 4.5.1.

Sr. No.	Core type	Shell type
1.	The winding encircles the core.	The core encircles most part of the windings.
2.	The cylindrical type of coils are used.	Generally, multilayer disc type or sandwich coils are used.
3.	As windings are distributed, the natural cooling is more effective.	As windings are surrounded by the core, the natural cooling does not exist.
4.	The coils can be easily removed from maintenance point of view.	For removing any winding for the maintenance, large number of laminations are required to be removed. This is difficult.
5.	The construction is preferred for low voltage transformers.	The construction is used for very high voltage transformers.

6.	It has a single magnetic circuit.	It has a double magnetic circuit.
7.	In a single phase type, the core has two limbs.	In a single phase type, the core has three limbs.

Table 4.5.1

Review Question

1. *Distinguish between core type and shell type transformers.*

JNTU : Nov.-04, 07, May-05, Marks 6

4.6 E.M.F. Equation of a Transformer

JNTU : May-05, 08, 13, Dec.-03, Nov.-04, 05, 08, 12, March-05, 06

When the primary winding is excited by an alternating voltage V_1, it circulates alternating current, producing an alternating flux ϕ. The primary winding has N_1 number of turns. The alternating flux ϕ linking with the primary winding itself induces an e.m.f. in it denoted as E_1. The flux links with secondary winding through the common magnetic core. It produces induced e.m.f. E_2 in the secondary winding. This is mutually induced e.m.f. Let us derive the equations for E_1 and E_2.

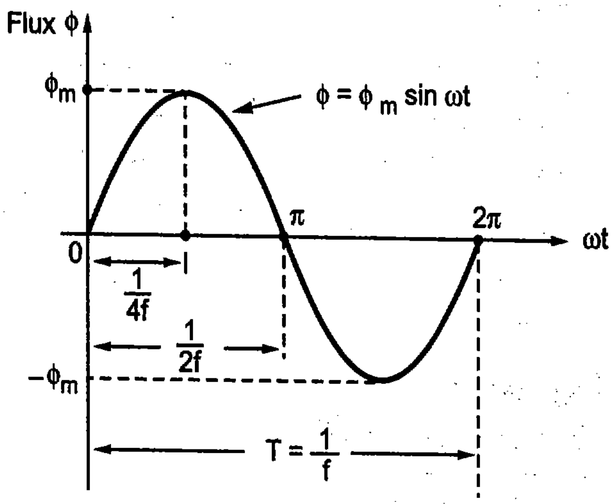


Fig. 4.6.1 Sinusoidal flux

The primary winding is excited by purely sinusoidal alternating voltage. Hence the flux produced is also sinusoidal in nature having maximum value of ϕ_m as shown in the Fig. 4.6.1.

The various quantities which affect the magnitude of the induced e.m.f. are :

ϕ = Flux, and ϕ_m = Maximum value of flux

N_1 = Number of primary winding turns, N_2 = Number of secondary winding turns

f = Frequency of the supply voltage

E_1 = R.M.S. value of the primary induced e.m.f.

E_2 = R.M.S. value of the secondary induced e.m.f.

From Faraday's law of electromagnetic induction the average e.m.f. induced in each turn is proportional to the average rate of change of flux.

$\therefore$ Average e.m.f. per turn = Average rate of change of flux

$$\therefore \quad \phi_m = B_m \times A = 6 \times 36 \times 10^{-4} = 0.0216 \text{ Wb}$$

$$E_1 = 4.44\, \phi_m f N_1 \quad \text{i.e.} \quad 2200 = 4.44 \times 0.0216 \times 50 \times N_1$$

$$\therefore \quad N_1 = 458.792 \approx \mathbf{459}$$

$$\frac{N_1}{N_2} = \frac{E_1}{E_2} \quad \text{i.e.} \quad N_2 = \frac{N_1 \times E_2}{E_1} = 52.13 \approx \mathbf{52}$$

Review Questions

1. *Derive the e.m.f. equation of a 1-phase transformer.*

   JNTU : May-05, 08, March-06, Nov.-04, 05, Marks 8

2. *What is an ideal transformer ?* **JNTU : Nov.-08, May-08, Marks 4**

3. *What is kVA rating of a transformer ?*

4. *A single phase transformer has 480 turns on primary and 90 turns on the secondary. The mean length of flux path in the core is 1.8 m and joints are equivalent to an air gap of 1 mm. The maximum value of the flux density is to be 1.1 T when a potential difference of 2200 volts at 50 Hz is applied to the primary. Assume value of magnetic field strength corresponding to the flux density of 1.1 T in the core to be 400 A/m.*

   Calculate

   i) The cross-section area of the core ii) Maximum value of the magnetizing current

   iii) Secondary voltage on no load. **[Ans. : i) 0.01876 m^2 ii) 1.500 A iii) 412.5 volts]**

5. *A single phase transformer has 350 primary and 1050 secondary turns. The primary is connected to 400 V, 50 Hz a.c. supply. If the net cross sectional area of the core is 50 cm^2, calculate i) The maximum value of the flux density in the core ii) The induced e.m.f. in the secondary winding.*

   [Ans. : B_m = 1.0296 Wb/m^2, E_2 = 1200 V]

6. *A single phase transformer has 500 turns on primary and 1000 turns on secondary. The voltage per turn in the primary winding is 0.2 volts. Calculate,*

   i) Voltage induced in the primary winding ii) Voltage induced in the secondary winding

   iii) The maximum value of the flux density if the cross section area of the core is 200 cm^2

   iv) kVA rating of the transformer if the current in primary at full load is 10 A, the frequency is 50 Hz. **[Ans. : i) E_1 = 100 volts, ii) E_2 = 200 volts, iii) ϕ_m = 9.009 × 10^{-4} Wb, iv) B_m = 0.045 web/m^2 or Tesla]**

4.7 Ideal Transformer on No Load

JNTU : Nov.-04, 05, 06, 08, 12, May-05, 08, 13, March-06

Consider an ideal transformer on no load as shown in the Fig. 4.7.1. The supply voltage is V_1 and as it is an no load the secondary current $I_2 = 0$.

The primary draws a current I_1 which is just necessary to produce flux in the core. As it is magnetising the core, it is called **magnetising current** denoted as I_m. As the transformer is ideal, the winding resistance is zero and it is purely inductive in nature. The magnetising current I_m is very small and lags V_1 by 30° as the winding is purely inductive. This I_m produces an alternating flux ϕ which is in phase with I_m.

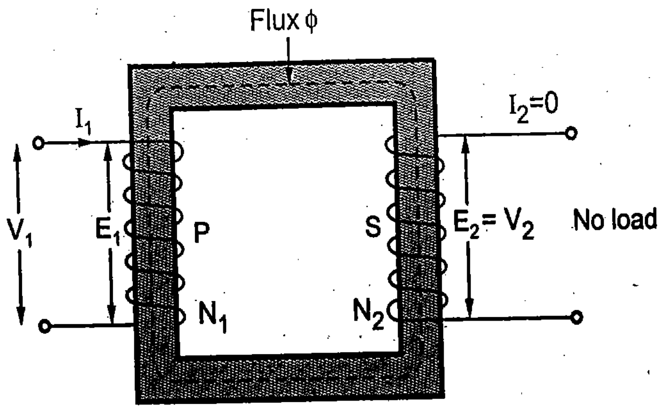


Fig. 4.7.1 Ideal transformer on no load

The flux links with both the winding producing the induced e.m.f.s E_1 and E_2, in the primary and secondary windings respectively. According to Lenz's law, the induced e.m.f. opposes the cause producing it which is supply voltage V_1. Hence E_1 is in antiphase with V_1 but equal in magnitude. The induced E_2 also opposes V_1 hence in antiphase with V_1 but its magnitude depends on N_2. Thus E_1 and E_2 are in phase.

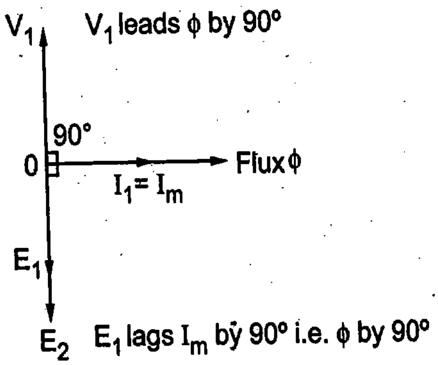


Fig. 4.7.2 Phasor diagram for ideal transformer on no load

The phasor diagram for the ideal transformer on no load is shown in the Fig. 4.7.2.

It can be seen that flux ϕ is reference. I_m produces ϕ hence in phase with ϕ. V_1 leads I_m by 90° as winding is purely inductive so current has to lag voltage by 90°.

E_1 and E_2 are in phase and both opposing supply voltage V_1.

The power input to the transformer is $V_1 I_1 \cos (V_1 \wedge I_1)$ i.e. $V_1 I_m \cos (90°)$ i.e. zero. This is because on no load output power is zero and for ideal transformer there are no losses hence input power is also zero. Ideal no load p.f. of transformer is zero lagging.

4.7.1 Practical Transformer on No Load

Actually in practical transformer iron core causes hysteresis and eddy current losses as it is subjected to alternating flux. While designing the transformer the efforts are made to keep these losses minimum by,

1. Using high grade material as silicon steel to reduce hysteresis loss.
2. Manufacturing core in the form of laminations or stacks of thin laminations to reduce eddy current loss.

Apart from this there are iron losses in the practical transformer. Practically primary winding has certain resistance hence there are small primary copper loss present.

Thus the primary current under no load condition has to supply the iron losses i.e. hysteresis loss and eddy current loss and a small amount of primary copper loss. This current is denoted as I_0.