CHAPTER – 10

SYNCHRONOUS GENERATOR

10.1 Introduction:

An *alternator* is an alternating current voltage generator. It is also called as a '*synchronous generator*'. We have learnt in chapter 7 about the D.C. generator in which the field system is stationary and the armature rotates. But in the case of an alternator, the field system is rotating and the armature is stationary. This is because, in the case of an alternator, having a stationary armature has several advantages. They are;

1. The generated voltage can be directly connected to the load, so that, the load current need not pass through brush contacts.
2. It is easy to insulate the stationary armature for high a.c. generated voltages, which may be as high as 11 kV to 33 kV.
3. The sliding contacts i.e. the slip rings are transferred to the low voltage, low power d.c. field circuit which can be easily insulated. The excitation voltage is only of the order of 110 V to 220 volts d.c.
4. The armature windings can be easily braced to prevent any deformation produced by large mechanical stresses set up due to short circuit currents and large centrifugal forces that might be set up.

10.2 Construction:

Basically an alternator consists of two parts viz (i) *Stator* and (ii) *Rotor*.

(i) Stator:

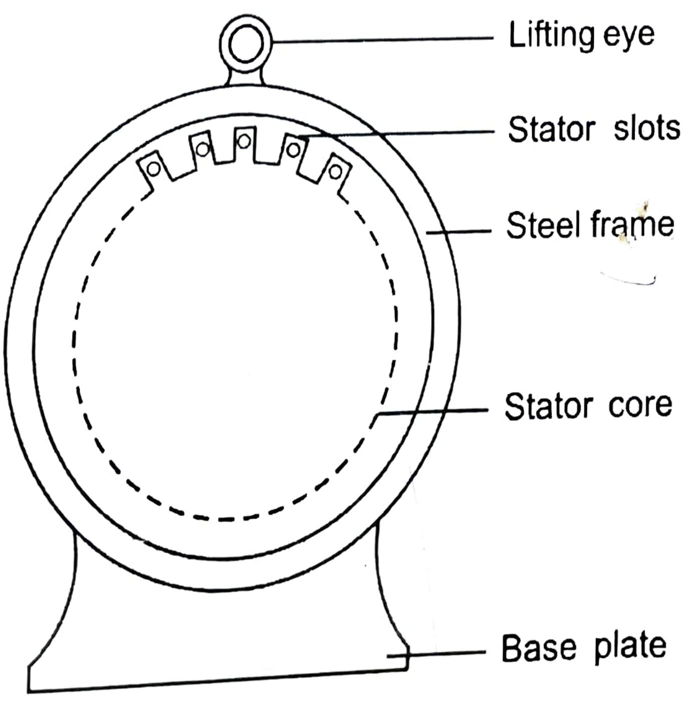


Fig.10.1

The stator of an alternator is similar in construction to the stator of a three phase induction motor. It consists of a stator frame made of mild steel plates, welded together to form a cylindrical drum. Inside this cylindrical drum, cylindrical stator laminations made of a special steel alloy are fixed. The stator core laminations are insulated from one another and pressed together to form the core. On the inner periphery of the stator core, uniform slots are cut to house the stator conductors. There are holes cast in the stator frame and radial ventilating spaces in the laminations which circulate free air and help in the cooling of the alternator. For small alternators, the laminations are in one section and for large alternators, each lamination is made up of several segments.

(ii) Rotor:

There are two types of rotors (a) *salient pole type* and (b) *smooth cylindrical type*. The alternator with salient pole type rotor is called as salient pole alternator and the alternator with a smooth cylindrical type rotor is called as non-salient pole alternator or turbo-alternator.

non-salient pole generator.

(a) Salient Pole Type of Rotor:

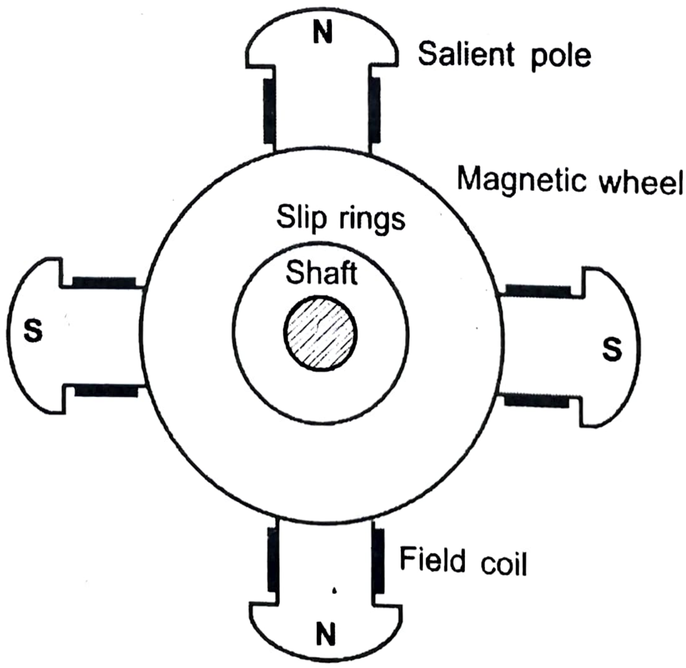


Fig.10.2

This type of rotor shown in Fig.10.2 is used in low and medium speed alternators (300 to 600 r.p.m.). This type of rotor has a large number of projecting poles having their cores bolted to a heavy magnetic wheel of cast iron or steel. Such rotors have large diameter and short axial length. The poles are laminated to reduce eddy current losses. Coils are wound on these poles and when a D.C. supply is given to these coils, the poles become electromagnets. The D.C. voltage required to excite the pole coils is obtained from a pilot exciter (D.C. generator), which is fixed on the shaft of the alternator itself. The D.C. voltage is fed to the field coils through two carbon brushes, which slide on two slip rings fixed to the shaft of the alternator. The alternators with this type of rotors are usually engine driven and rotate on a horizontal axis.

(b) Smooth Cylindrical Type Rotor:

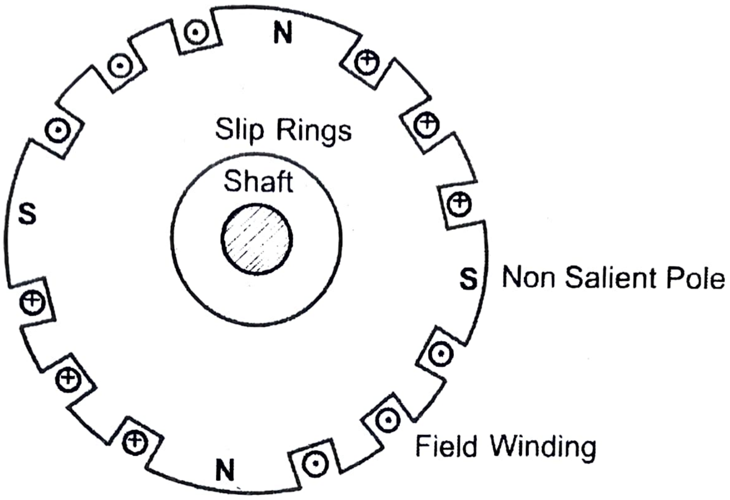


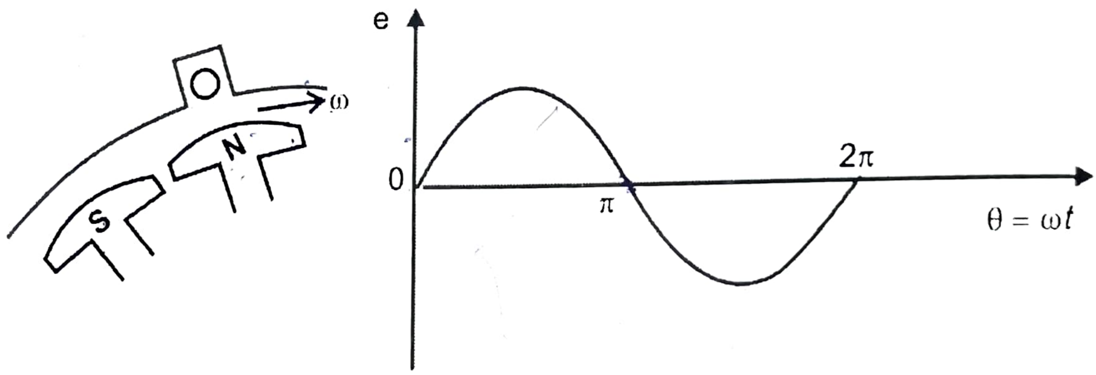
Fig.10.3

This type of rotor shown in Fig.10.3 is usually driven by a turbine and rotates at very high speed (1500 or 3000 r.p.m.). The rotor consists of steel laminations which are insulated from each other and pressed together to form a cylindrical core having a number of slots on its outer periphery, for accommodating the field winding. Such a rotor is designed to have two or four poles. It usually rotates on a vertical axis and is characterized by small diameter and large axial length. Two or four regions corresponding to the central polar areas are left unslotted and these areas are surrounded by the field windings placed in the slots. The field coils are so arranged around these polar areas, such that, the flux density is maximum on the polar central line. This type of rotor construction gives better balance and quieter operation and windage losses will be less.

10.3 Working Principle:

The field windings of the rotor are supplied with a D.C. voltage of 110 or 220 volts, generated by the pilot exciter, through the two brushes which are set to slide on two slip rings fixed to the shaft of the alternator. The rotor is rotated by a prime mover and the flux produced by the rotor poles sweeps across the stator conductors and hence the e.m.f. is induced in them.

10.4 Frequency of the Induced e.m.f.:



(a) (b)

Fig.10.4

Consider a single conductor placed in the slot of the stator as shown in Fig10.4 (a). Let the rotor with alternate north and south poles N and S, rotate with an angular velocity ω in the clockwise direction. Positive half cycle of e.m.f. is induced in the conductor, when the north pole N sweeps across the conductor. Negative half cycle of e.m.f. is induced in the conductor when the south pole S sweeps across It and hence, one cycle of e.m.f. is induced in the conductor, when one pair of poles N and S sweep across it as shown in fig. 10.4 (b).

No of cycles/revolution

∴ Number of cycles of e.m.f. induced in one revolution = $\frac{P}{2}$

No of revolution/sec

Number of revolutions per second = $\frac{N}{60}$

Where, N is the speed in r.p.m

Therefore, the frequency of the induced e.m.f., which is nothing but the number of cycles per second is given by,

f = Number of cycles of e.m.f. induced per revolution x Number of revolutions per second.

$$= \frac{P}{2} \times \frac{N}{60} = \frac{PN}{120} \text{ Hz} \qquad (10.1)$$

f = No of cycles/revolution x No of revolution/sec

$f = \frac{P}{2} \times \frac{N}{60} = \frac{PN}{120}$ Hz.

10.5 E.M.F. Equation of an Alternator:

Let Z = Number of stator conductors per phase. (Z = 2T, T → turns/phase)

P = Number of poles.

f = Frequency of the induced e.m.f. in Hz

N → Rotation speed of motor in R.P.M

ϕ = Flux per pole in webers.

The flux cut by the conductor in one revolution = Pϕ = dϕ

The time taken for one revolution = $\frac{60}{N}$ sec = dt

$\therefore$ The average e.m.f. induced in one conductor = $\frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{\phi PN}{60}$ volts

$f = \frac{PN}{120} \Rightarrow N = \frac{120f}{P}$

Average e.m.f. induced per phase = $\frac{\phi PN}{60}$ x Z = $\frac{\phi PZ}{60} \times \frac{120f}{P} \left[\because N = \frac{120f}{P}\right]$

$= 2\, f\, \phi\, Z$ volts

K_f, form factor

For a sinusoidal wave, $\frac{E_{r.m.s.}}{E_{av}} = 1.11$

$\therefore$ r.m.s. value of the e.m.f. induced per phase

$= 1.11 \times 2\, f\, \phi\, Z = 2.22\, f\, \phi\, Z$ volts

$\therefore$ The e.m.f. equation of an alternator is

$E_{ph} = 2.22\, f\, \phi\, Z$ volts

$= 4.44\, f\, \phi\, T$ volts $\quad 2.22 \times 2 f \phi T$ (10.2)

$\because$ T = number of turns = $\frac{Z}{2}$ (10.3)

The e.m.f. equation (10.2) is derived assuming that the stator winding is full pitched and the e.m.f.s induced in the various conductors are equal in magnitude and does not have any phase difference. It is also assumed that all the conductors per pole per phase are concentrated in a single slot. But in practice, the coils are short pitched. The conductors are uniformly distributed in all the slots of the stator. Due to these two facts, the e.m.f. induced in the alternator gets reduced by a small quantity. The equation for the e.m.f. induced is modified as, (10.4)

$E_{ph} = 2.22\, K_p\, K_d\, f\, \phi\, Z$ volts

Where, K_p = pitch factor and
K_d = distribution factor