# SYNCHRONOUS GENERATOR

## Basic Principle

A.C. generators or Alternators (as they are usually called) operate on the same fundamental principles of electromagnetic induction as D.C. generators. They also consist of an armature winding and a magnetic field. But there is one important difference between the two. Whereas in D.C. generators, the armature rotates .And the field system is stationary, the arrangement in alternators is just the reverse of it. In their case, standard construction consists of armature winding mounted on a stationary element called stator and field windings on a rotating element called rotor.

## Constructional Details :

### Stator:

The stator is a stationary armature. This consists of a core and the slots to hold the armature winding similar to the armature of a d.c. generator. The stator core uses a laminated construction. It is built up of special steel stampings insulated from each other with varnish or paper. The laminated construction is basically to keep down eddy current losses. Generally choice of material is steel to keep down hysteresis losses.

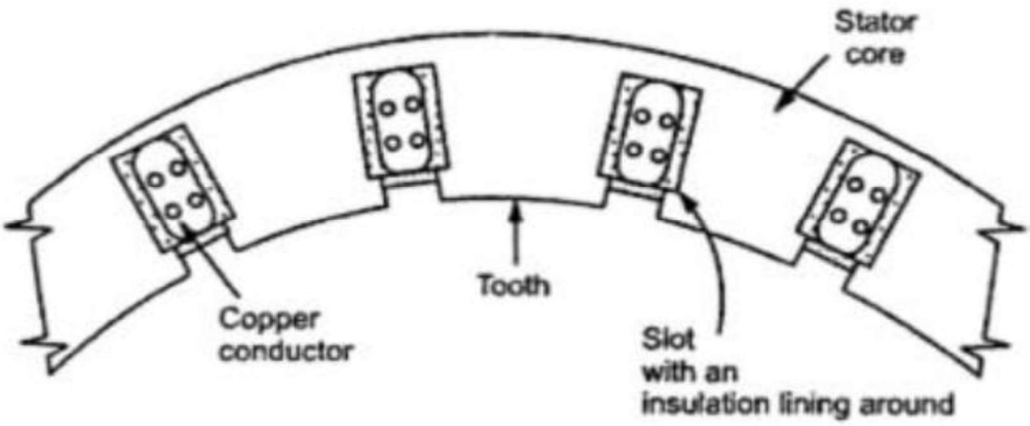


**Figure 1.1 Section of an alternator stator**

The entire core is fabricated in a frame made of steel plates. The core has slots on its periphery for housing the armature conductors. Frame does not carry any flux and serves as the support to the core. Ventilation is maintained with the help of holes cast in the frame. The section of an alternators stator is shown in the Figure 1.1

### Rotor

There are two types of rotors used in alternators,

1) Salient pole type, and
2) Smooth cylindrical type.

### Salient Pole Type

This is also called projected pole type as all the poles are projected out from the surface of the rotor. The poles are built up of thick steel laminations. The poles are bolted to the rotor as shown in the Figure.1.2. The pole face has been given a specific shape. The field winding is provided on the pole shoe. These rotors have large diameter and small axial length. The limiting factor fore the size of the rotor is the centrifugal force acting on the rotating member of the machine. As mechanical strength of salient pole type is less, this is preferred for low speed alternators ranging from 125 r.p.m. to 500 r.p.m. The prime movers used to drive such rotor are generally water turbines and I.C. engines.

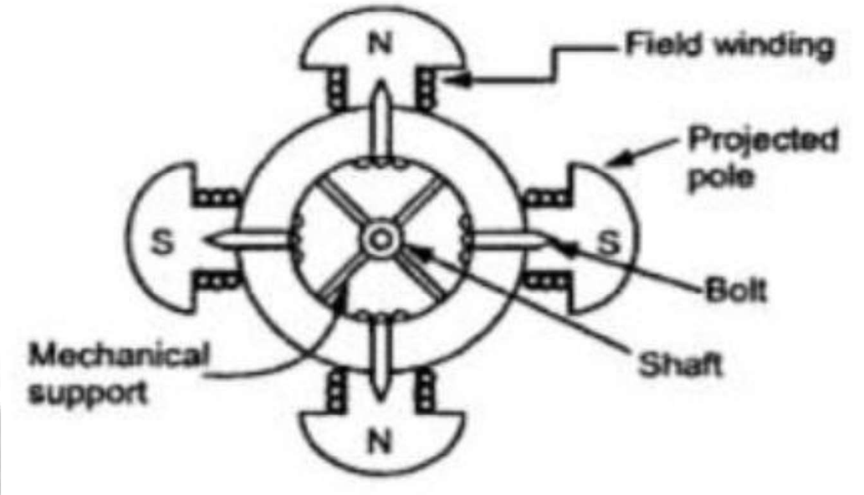


**Figure 1.2 Salient pole type rotor**

**Smooth Cylindrical Type**

This is also called non-salient type or non-projected pole type or round rotor construction. The Figure. 1.3 shows smooth cylindrical type of rotor.

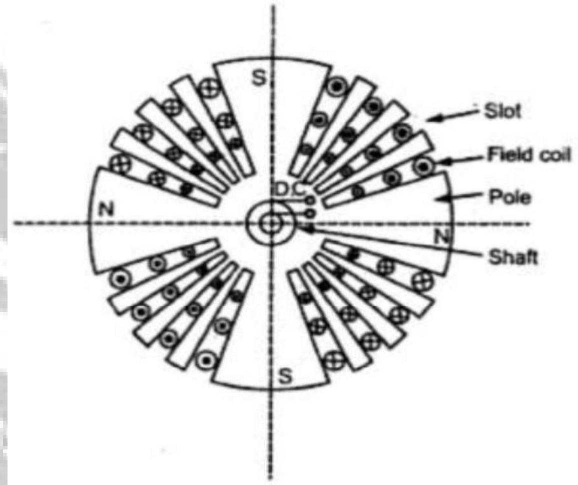


**Figure 1.3 Smooth cylindrical rotor**

The rotor consists of small solid steel cylinder, having number of slots to accommodate the field coil. The slots are covered at the top with the help of steel or manganese wedges. The unslotted portions of the cylinder itself act as the poles. The poles are not projecting out and the surface of the rotor is smooth which maintains uniform air gap between stator and the rotor. These rotors have small diameters and large axial lengths. This is to keep peripheral speed within limits. The main advantage of this type is that these are mechanically very strong and thus preferred for high speed alternators ranging between 1500 to 3000 r.p.m. Such high speed alternators are called 'turbo alternators'. The prime movers used to drive such type of rotors are generally steam turbines, electric motors.

**Working Principle of Synchronous Generator**

The alternators work on the principle of electromagnetic induction. When is a relative motion between the conductors and the flux, e.m.f. gets induced in the conductors. The d.c. generators also work on the same principle. The only difference in practical alternator and a d.c. generator is that in an alternator the conductors are stationary and field is rotating. But for understanding purpose we can always consider relative motion of conductors with respect to the flux produced by the field winding. Consider a relative motion of a single conductor under the magnetic field produced by two stationary poles. The magnetic axis of the two poles produced by field is vertical, shown dotted in the Figure 1.4.

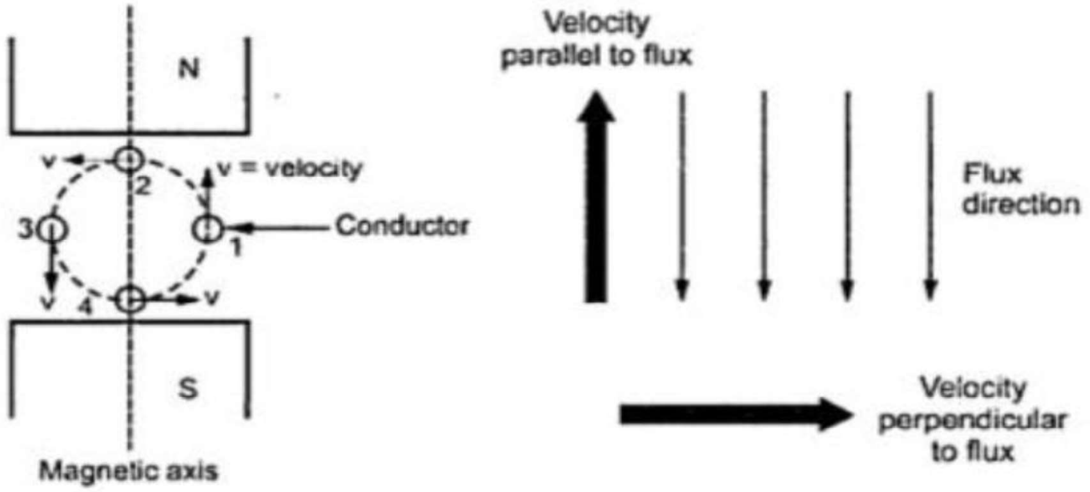


**Figure 1.4 Two pole Alternator**

Let conductor starts rotating from position 1. At this instant, the entire velocity component is parallel to the flux lines. Hence there is no cutting of flux lines by the conductor. So $d\Phi/dt$ at this instant is zero and hence induced e.m.f. in the conductor is also zero.

As the conductor moves from position 1 towards position 2, the part of the velocity component becomes perpendicular to the flux lines and proportional to that,
e.m.f. gets induced in the conductor. The magnitude of such an induced e.m.f. increases as the conductor moves from position 1 towards 2.

At position 2, the entire velocity component is perpendicular to the flux lines. Hence there exists maximum cutting of the flux lines. And at this instant, the induced
e.m.f. in the conductor is at its maximum.

As the position of conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing and hence induced e.m.f. magnitude also starts decreasing.

At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced e.m.f. in the conductor is zero.

As the conductor moves from 3 towards 4, the velocity component perpendicular to the flux lines again starts increasing. But the direction of velocity component now is opposite to the direction of velocity component existing during the movement of the conductor from position 1 to 2. Hence an induced e.m.f. in the conductor increases but in the opposite direction.

At position 4, it achieves maxima in the opposite direction, as the entire velocity component becomes perpendicular to the flux lines.

Again from position 4 to 1, induced e.m.f. decreased and finally at position 1, again becomes zero. This cycle continues as conductor rotates at a certain speed.

So if we plot the magnitudes of the induced e.m.f. against the time, we get an alternating nature of the induced e.m.f. as shown in the Figure 1.5 This is the working principle of an alternator.

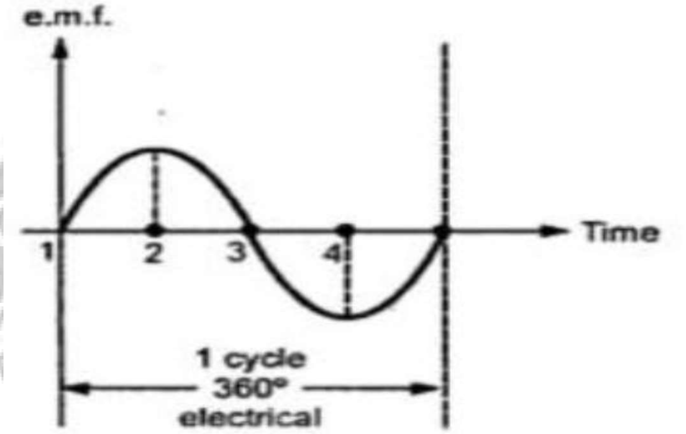


**Figure 1.5 Alternating nature of induced emf**

**Mechanical And Electrical Angle**

We have seen that for 2 pole alternator, one mechanical revolution corresponds to one electrical cycle of an induced e.m.f. Now consider 4 pole alternator i.e. the field winding is designed to produce 4 poles. Due to 4 poles, the magnetic axis exists diagonally shown dotted in the Figure. 1.6

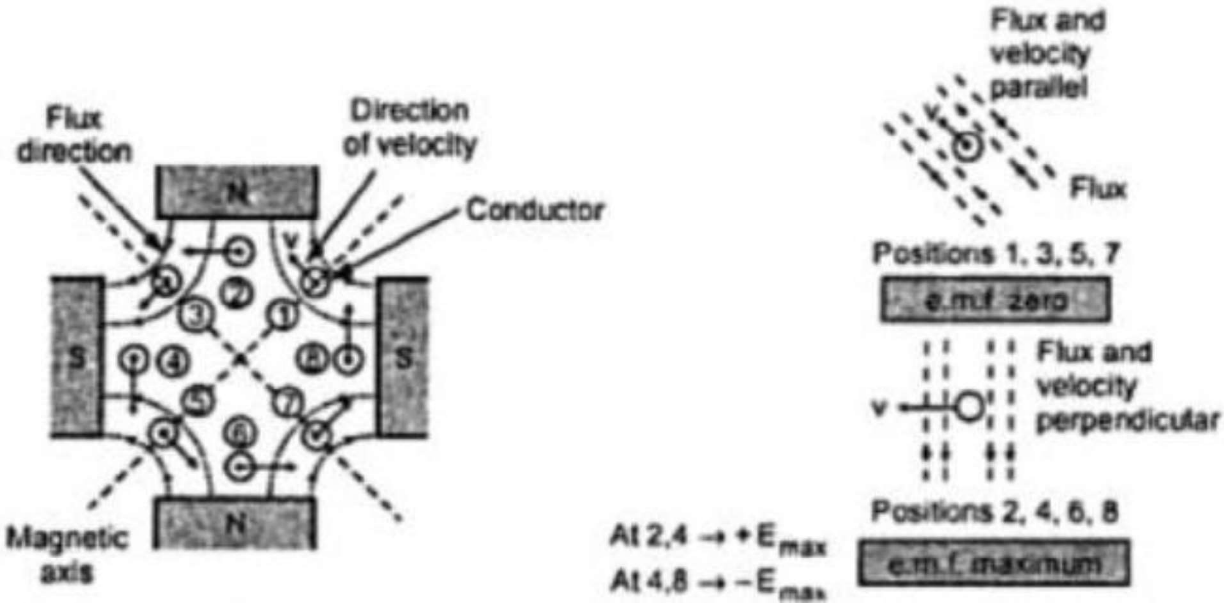


**Figure 1.6 Magnetic axis**

Now in position 1 of the conductor, the velocity component is parallel to the flux lines while in position 2, there is gathering of flux lines and entire velocity component is perpendicular to the flux lines. So at position 1, the induced e.m.f. in the conductors is zero while at position 2, it is maximum. Similarly as conductor rotates, the induced e.m.f. will be maximum at position 4, 6 and 8 and will be minimum at position 3, 5 and 7. So during one complete revolution of the conductor, induced e.m.f. will experience four times maxima, twice in either direction and four times zero. This is because of the distribution of flux lies due to existence of four poles.

So if we plot the nature of the induced e.m.f; for one revolution of the conductor, we get the two electrical cycles of the induced e.m.f., as shown in the Figure. 1.7.

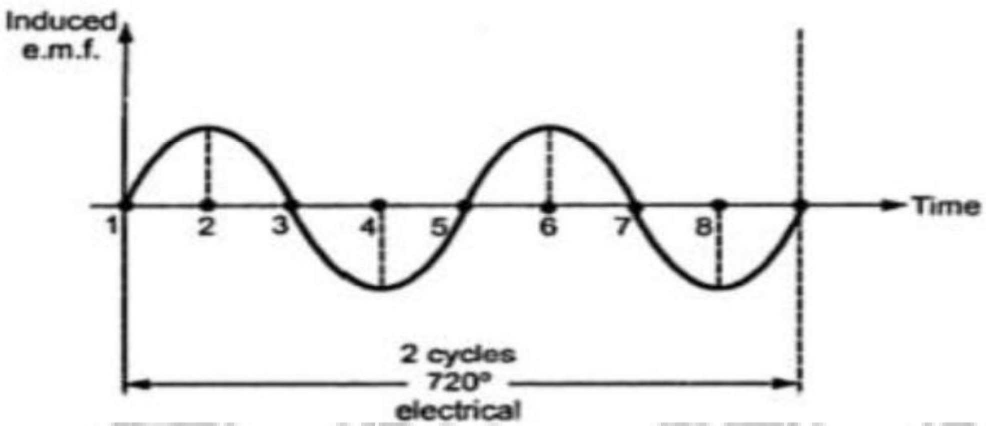


**Figure 1.7 Nature of induced emf**

Note : Thus the degrees electrical of the induced e.m.f. i.e. number of cycles of the induced e.m.f. depends on the number of poles of an alternator.So for a four pole alternator we can write,

$360_o$ mechanical = $720_o$ electrical From this we can establish the general relation between degrees mechanical and degrees electrical as, $360_o$ mechanical = $360_o$ x (p/2) electrical Where P = Number of poles

$$1^\circ \text{ mechanical} = \left(\frac{P}{2}\right)^\circ \text{ electrical.}$$

**Frequency of induced E.M.F.**

Let P = Number of poles N = Speed of the rotor in r.p.m. and f = Frequency of the induced e.m.f. From this discussion above in section 1.1, we can write, One mechanical revolution of rotor = P/2 cycles of e.m.f. electrically. Thus there are P/2 cycles per revolution. As speed is N r.p.m., in one second, rotor will complete (N/60) revolutions. But cycles/sec = frequency = f Frequency f = (No.of cycles per revolution) x (No.of revolution per second) ∴ f = (P/2) x (N/60)

$$f = \frac{PN}{120} \text{ Hz (cycles per sec).}$$

So there exists a fixed relationship between three quantities, the number of poles P, the speed of the rotor N in r.p.m. and f the frequency of an induced e.m.f. in Hz (Hertz).

Note : Such a machine bearing a fixed relationship between P, N and f is called synchronous machine and hence alternators are also called synchronous generators.

**Synchronous speed ($N_s$)**

From the above expression, it is clear that for fixed number of poles, alternator has to be rotated at a particular speed to keep the frequency of the generated e.m.f. constant at the required value. Such a speed is called synchronous speed of the alternator denoted as $N_s$.

$$N_s = \frac{120\,f}{P}$$

where f = Required frequency

In our nation, the frequency of an alternating e.m.f. is standard equal to 50 Hz. To get 50 Hz frequency, for different number of poles, alternator must be driven at different speeds called synchronous speeds. Following table gives the values of the synchronous speeds for the alternators having different number of poles.

| Number of poles P | 2 | 4 | 8 | 12 | 24 |
|---|---|---|---|---|---|
| Synchronous speed $N_s$ in r.p.m. | 3000 | 1500 | 750 | 500 | 250 |

From the table, it can be seen that minimum number of poles for an alternator can be two hence maximum value of synchronous speed possible in our nation i.e. for frequency of 50 Hz is 3000 r.p.m.