Fundamentals Section

THREE-PHASE INDUCTION MOTOR

The three voltages of a three-phase supply system are displaced in time as shown in the diagram below, Fig. 1.

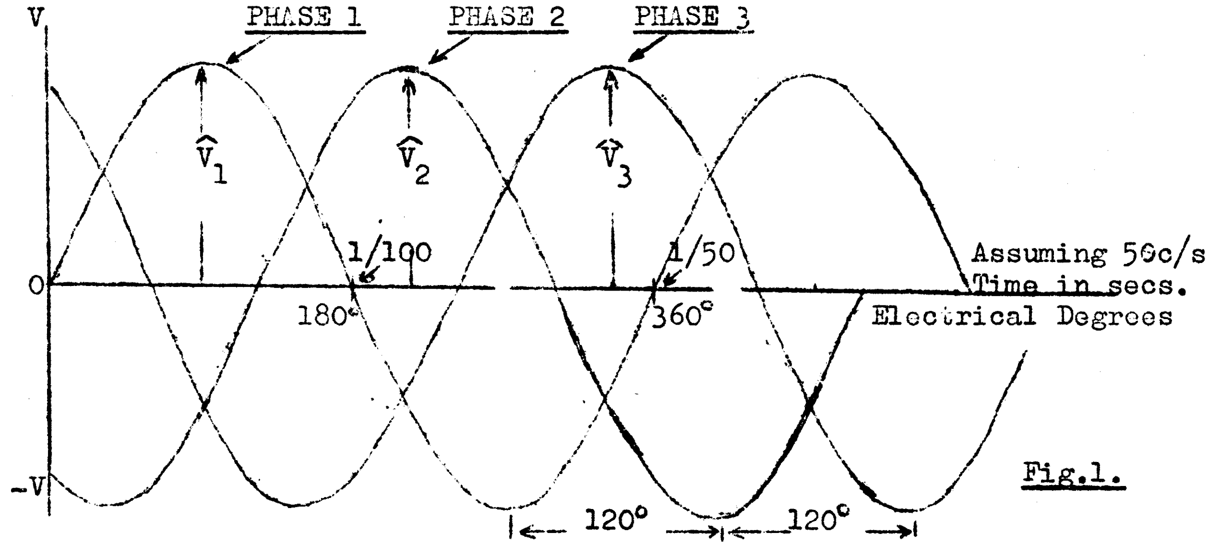
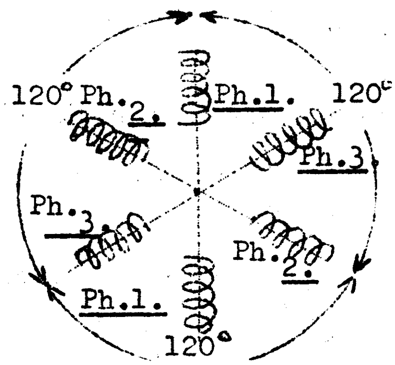


Fig.1.

If these voltages are applied to three identical loads (balanced loads), then the three currents which flow in the loads will have a similar relative displacement to each other in time as have the voltages above.

In a basic three-phase induction motor there are effectively three pairs of coils displaced mechanically from each other by 120°, and these constitute the three balanced loads across the three phase supply system.

Each pair of coils produce a resultant magnetic field passing through the diametric centre of the machine, as depicted in Fig. 2, and these three magnetic fields produce a resultant magnetic flux whose diametrical direction through the machine changes by 360 mechanical degrees in the period of one cycle of the supply frequency.



Each pair of coils of a given phase are connected to produce opposite polarity at their inner faces.

Fig.2.

The strength of this rotating magnetic flux is one and a half times that of each of the component fluxes.

Time for one rotation of the flux is given by $\frac{1}{f}$ secs., hence the number of revolutions per sec is given by

$$\frac{1}{\frac{1}{f}} = f$$

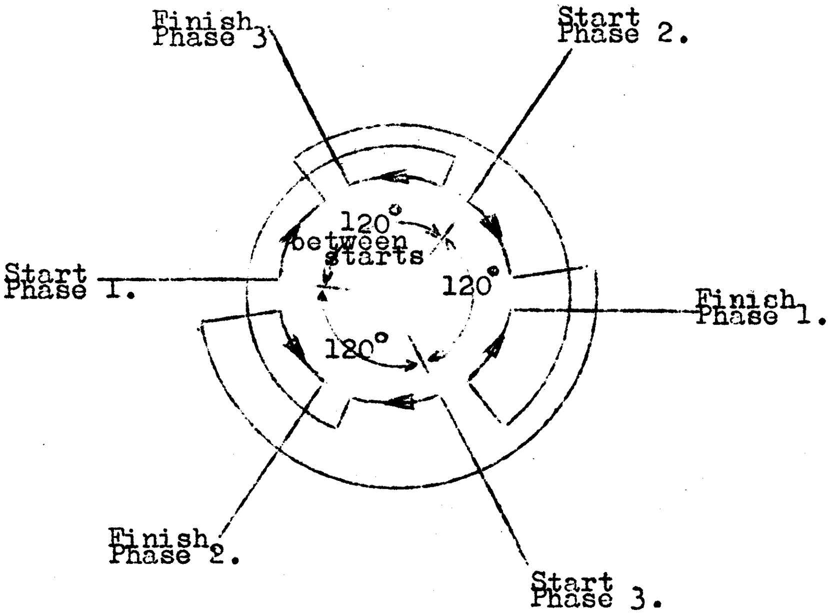
Hence if the supply frequency is 50c/s then

Speed of rotation = f revolutions per second
= f x 60 rev. per minute
= 3,000 r.p.m.

For each phase there are two coils, giving opposite magnetic polarity at their inner faces, i.e. one pair of magnetic poles per phase.

Each coil associated with a magnetic pole may actually consist of a group of coils spread over a number of slots in the stator, and all connected to give the same polarity.

When drawing out a polyphase winding it is convenient to represent each pole group of coils by a straight line and to denote the polarity by the direction in which the current will pass along the line. A three-phase 2 pole stator drawn in this way is shown in Fig. 3.



Connections of 3-Phase, 2-pole stator.

Fig. 3.

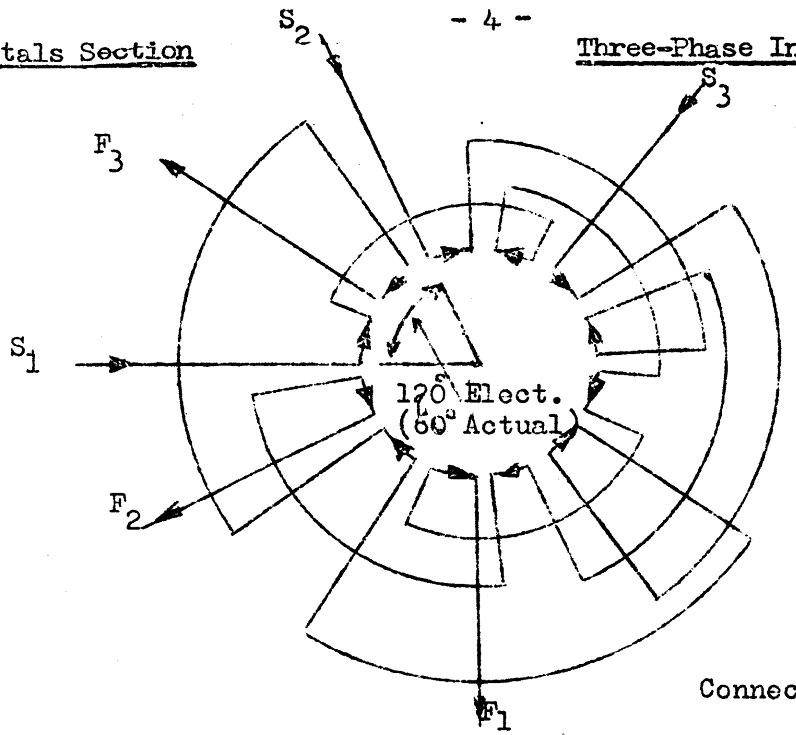
The total number of coils around the stator

= number of coils per pole group x no. of poles per phase

x no. of phases.

Machines are usually distinguished by the number of poles per phase, e.g. a two-pole machine has two poles per phase, where as a four-pole machine has four poles per phase.

The connections of a 3-phase, 4-pole machine are depicted in Fig. 4.



Connections of 3-phase, 4-pole stator.

Fig. 4.

By reference to this diagram it is seen that each pair of pole coil groups (one of each pair producing a N-pole and the other a S-pole at the inner faces) are displaced mechanically by 90° around the stator, but magnetically and electrically the displacement is 180°.

Similarly, the starting ends of each phase are mechanically displaced 60° but electrically the displacement is 120°; this may be referred to as a displacement of 60 mechanical degrees and 120 "electrical" degrees respectively.

The mechanical displacement being half the electrical displacement results in the magnetic field making only one half a revolution in the time of one cycle of the supply frequency, hence with a 50c/s supply the magnetic flux rotates at 1500 r.p.m.

Generally,

$$\text{r.p.m.} = \frac{\text{frequency of supply (c/s)} \times 60}{\text{pairs of poles per phase}}.$$

The stator is built up of iron laminations electrically insulated from one another and provided with slots to take the coil sides; the slots being lined with insulation before inserting the coil sides.

The rotor is built up of electrical sheet steel laminations pressed onto a shaft which runs in bearings housed in the machine casing. Tunnels run through the rotor laminations parallel to the shaft, and these may be filled with copper bars which at each end are welded to copper rings. This construction is referred to as a "squirrel-cage". Alternatively the rotor may be cast with aluminium so that the squirrel-cage becomes a homogeneous casting of aluminium, with blades formed at one end to create when running a fan action which circulates air through the machine.

For high efficiency the clearance between the rotor and stator should be as small as is practical, and this may necessitate very careful alignment of the bearings.

The polyphase currents in the stator coils create the rotating magnetic field, which cuts the copper or aluminium bars of the rotor inducing e.m.f.'s which set up circulating currents in the squirrel cage. These circulating currents create their own magnetic field which by interacting with the rotating magnetic field causes the rotor to rotate with it.

The theoretical maximum speed for the rotor is equal to the speed of rotation of the magnetic flux, hence a one pole pair per phase machine connected to a 50c/s supply has a theoretical maximum speed of 3000 r.p.m. However, the conductors of the rotor must be cut by the rotating flux to maintain the induced e.m.f.'s, which means that the rotor speed must be slightly less than that of the magnetic flux. Normally the rotor of a small machine rotates at about 95% of the flux speed, and the difference of 5% is called the "SLIP". The speed of rotation of the magnetic flux is termed the "SYNCHRONOUS SPEED", hence a machine with a synchronous speed of 3000 r.p.m. has a rotor speed of approximately 2850 r.p.m.

At the instant of starting the slip is 100% and the motor develops a starting torque 1·5 to 3 times the full load torque. Once having attained full speed there is little change in speed from no load to full load.

To reverse the direction of rotation of the motor it is only necessary to change over any two of the phase leads.

RDS/RAS
11.1.65.