### Methods of starting a synchronous motor

1 By using a pony motor
2 By using damper windings
3 By synchronisation

### 1 By using a pony motor

A three-phase current is fed to the stator winding of three-phase synchronous machine and its rotor is started by a pony (starting) motor, having same number of poles as that of synchronous motor. The small induction motor coupled to the synchronous machine for starting purpose is called the pony motor. The pony motor brings the motor very close to the synchronous speed, then the DC is supplied to the field and the switch of the pony motor is switched 'off'. Then the motor pulls itself to the synchronous speed.

### 2 By using damper windings

The damper winding is just like squirrel cage winding consisting of copper embedded in the pole shoe and short circuited at both sides.

### Action of damper winding at start

While starting a synchronous motor set up a rotating magnetic field that cuts the cage (damper) winding on the field system (rotor) and induces current in it. A torque is developed and the motor runs to a speed a little less than that of synchronous speed as an induction motor. The DC excitation is then switched on and definite poles on the rotor are set up. Now the two sets of poles suddenly lock each other by which the motor pulls into synchronous speed.

While starting a synchronous motor provided with damper windings, first the main field windings is short circuited and AC supply is switched on to stator terminals through suitable starter. The motor starts up and when a steady speed is reached DC excitation is applied after removing the short on the field winding. If the excitation is sufficient the machine will be pulled into synchronism.

### 3 By synchronisation

Initially the synchronisation motor is run as an alternator and it is synchronised with the main supply bus by following one of the synchronisation methods. After synchronisation the prime mover is disconnected. Now the alternator, ie the synchronous motor continues to run at synchronous speed by drawing power from supply mains.

**Comparision of Synchronous and Induction motor**

| | Aspects | Synchronous motor | Induction motor |
|---|---|---|---|
| 1 | Speed | Synchronous speed constant is independent of load condition. | Less than synchronous speed. Decreases with increasing load. |
| 2 | Power factor | Operates at all power factors whether lagging or leading. | Operates at only lagging power factor. |
| 3 | Efficiency | Very good | Good |
| 4 | Cost | Costlier | Cheaper |
| 5 | Starting | Not self-starting | Self-starting |
| 6 | Speed control | No question | Can be controlled to small units. |
| 7 | Application | Used for mechanical load and also to improve power factor as synchronous condenser. | Limited to supply of mechanical load. |

### Application

Synchronous motors are employed exclusively as power factor correction devices, they are termed as synchronous condenser, because the effect on the power system is the same as that of a static capacitor which also produces a leading current.

1 Induction motors of all types particularly when they are underloaded
2 Power transformers and voltage regulators
3 Arc welders
4 Induction furnaces and heating coils
5 Choke coils and magnetic systems and
6 Fluorescent and discharge lamps, neon signs, etc.

### Causes of low power factor

**The principle cause of a low power factor is due to the reactive power flowing in the circuit. The reactive power depends on the inductance and capacitance of the apparatus.**

### The disadvantages of low power factor are as follows

1 Overloading of cables and transformer
2 Decreased line voltage at point of application
3 Inefficient operation of plant and

4 Penal power rates

**The advantages of high power factor are as follows**

1 Reduction in the current
2 Reduction in power cost
3 Reduced losses in the transformers and cables
4 Lower loading of transformers, switch gears, cables etc.
5 Increased capability of the Power system (additional load can be met without additional equipment)
6 Improvement in voltage conditions and apparatus performance and
7 Reduction in voltage dips caused by welding and similar equipment

### Power factor control

If the rotor excitation is varied when the motor is running on load, the load angle and stator current will change, but the speed, load (and hence input power) remain the same.

The power factor of the motor can therefore be adjusted by means of the excitation. Unity power factor operation is possible over a wide range of loads and by using a high rotor excitation the motor can operate at leading power factor. This is particularly valuable with a large synchronous motor, which can be used to compensate for the lagging power factor of other induction motors on the same site.

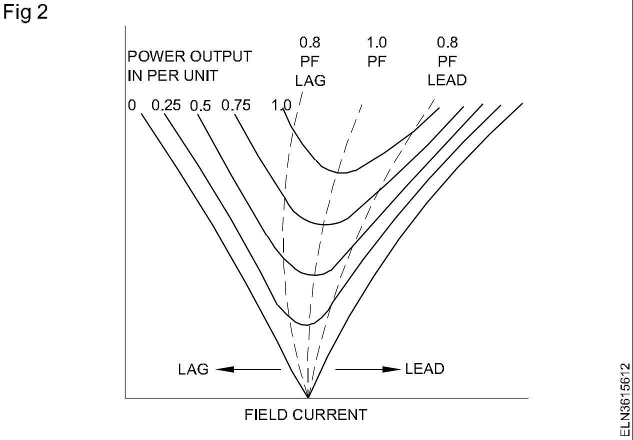
### Instant speed application

As the efficiency of a synchronous motor is high, these motors are well suited for loads where constant speed is required.

### V Curves of synchronouos machines

V-Curve of a synchronous machine shows the relation between the armature current and excitation current, when the load and input voltage to the machine is constant. At a constant load, if excitation is changed the power factor of the machine changes, i.e. when the field current is small (machine is under-excited) the P.F. is low and as the excitation is increased the P.F. improves so that for a certain field current the P.F. will be unity and machine draws minimum armature current. This is known as normal exciation. If the excitation is further increased the machine will become over-excited and it will draw more line current and P.F. becomes leading and decreases. Therefore, if the field current is changed keeping load and input voltage constant, the armature current changes to make VIcos$\theta$ constant. Variation of armature current with excitation are called 'V' curves (Fig 2).

Fig 2



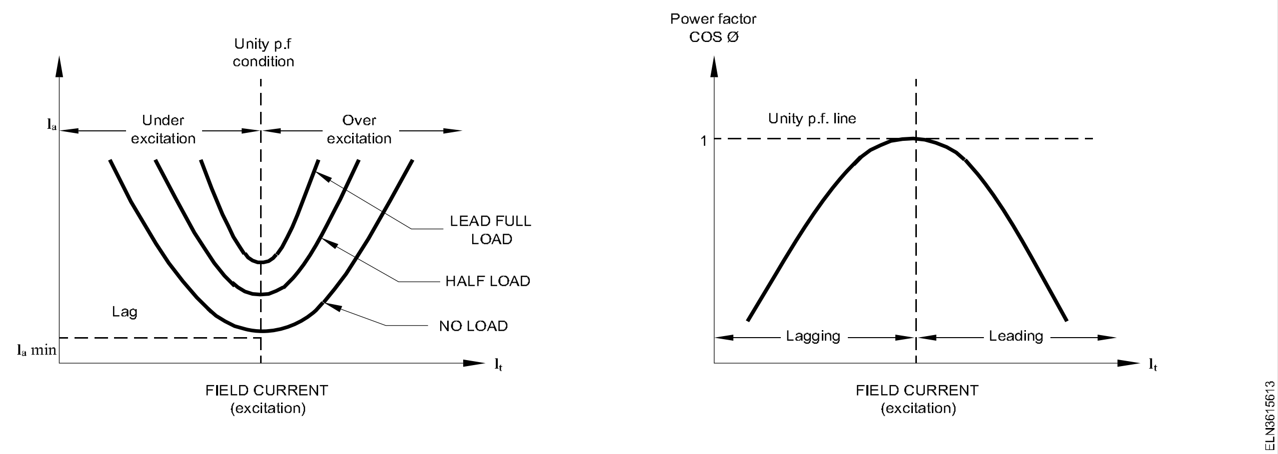
The Fig 3 shows V and inverse V curves of synchronous motor.

### Effect of Changing Excitation on Constant load

As shown in Fig. (4a), suppose a synchronous motor is operating with normal excitation ($E_b = V$) at unity p.f. with a given load. If $R_a$ is negligible as compared to $X_S$, then $I_a$ lags $E_R$ by 90° and is in phase with V because p.f. is unity. The armature is drawing a power of $V.I_a$ per phase which is enough to meet the mechanical load on the motor. Now, let us discuss the effect of decreasing or increasing the field excitation when the load applied to the motor remains constant

Fig 3

V and inverse V curve of Synchronous Motor



### a) Excitiation Decreased

As shown in Fig (4b), suppose due to decrease in excitation, back e.m.f. is reduced to $E_{b1}$ at the same load angle $\alpha_1$. The resultant voltage $E_{R1}$ causes a lagging armature current $I_{a1}$ to flow. Even though $I_{a1}$ is larger than $I_a$ in magnitude it is capable of producing necessary power $V.I_a$ for carrying the constant load because $I_{a1}$ cos $\phi_1$ component is less than $I_a$ so that $V.Ia_1 \cos \phi_1 < V.I_a$.

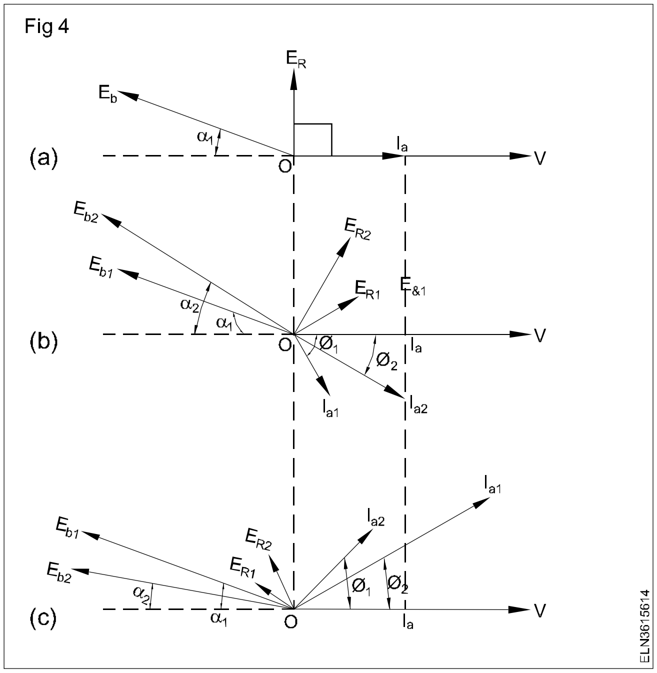
Hence, it becomes necessary for load angle to increase from $\alpha_1$ to $\alpha_2$. It increases back e.m.f. from $E_{b1}$ to $E_{b2}$ which, in turn, increases resultant voltage from $E_{R1}$ to $E_{R2}$. Consequently, armature current increases to $I_{a2}$ whose in-phase component produces enough power ($VI_{a2} \cos \phi_2$) to meet the constant load on the motor.

### b) Excitation Increased

The effect of increasing field excitation is shown in Fig 4c where increased $E_{b1}$ is shown at the original load angle $\alpha_1$. The resultant voltage $E_{R1}$ cause a leading current $I_{a1}$ whose in-phase component is larger than $I_a$. Hence, armature develops more power than the load on the motor. Accordingly, load angle decrease from $\alpha_1$ to $\alpha_2$ which decreases resultant voltage from $E_{R1}$ to $E_{R2}$. Consequently, armature current decreases from $I_{a1}$ to $I_{a2}$ whose in-phase component $I_{a2} \cos \phi_2 = I_a$. In that case, armature develops power sufficient to carry the constant load on the motor.

Hence, we find that variations in the excitation of a synchronous motor running with a given load produce variations in its load anlge only.

Fig 4



## Different Torques of a Synchronous Motor

Various torques associated with a synchronous motor are as follows:

1 starting torque

2 running torque

3 pull-in torque and

4 pull-out torque

### a) Starting Torque

It is the torque ( or turning effort) developed by the motor when full voltage is applied to its stator (armature) winding. It is also sometimes called breakaway torque. Its value may be as low as 10% as in case of centrifugal pumps and as high as 200 to 250% of full-load torque as in the case of loaded reciprocating two-cylinder compressors.

### b) Running Torque

As its name indicates, it is the torque developed by the motor under running conditions. It is the driven machine. The peak horsepower determine the maximum torque that would be required by the driven machine. The motor must have a break-down or a maximum running torque greater than this value in order to avoid stalling.

### c) Pull-in Torque

A synchronous motor is stated as induction motor till it runs 2 to 5% below the synchronous speed. Afterwards, excitation is switched on and the rotor pulls into step with the synchronously - rotating stator field. The amount of torque at which the motor will pull into step is called the pull-in torque.

### d) Pull-out- Torque

The maximum torque which the motor can develop without pulling out of step or synchronism is called the pull-out torque.

Normally, when load on the motor is increased, its rotor progressively tends to fall back in phase by some angle (called load angle) behind the synchronously-revolving stator magnetic field though it keeps running synchronously. Motor develops maximum torque when its rotor is retarded by an angle of 90° (or in other words, it has shifted backward by a distance equal to half the distance between adjacent poles). Any further increase in load will cause the motor to pull out of step (or synchronism) and stop.