Syllabus: Synchronous Motor:

- Principle of Operation,
- Phasor Diagrams,
- Torque and Torque Angle,
- Blondal Diagram,
- Effect of Change in Load,
- Effect of Change in Excitation,
- V and Inverted V Curves.
- Synchronous Condenser,
- Hunting and Damping.
- Methods of Starting Synchronous Motors.

Principle of Operation,

- A 3-phase synchronous motor is a 3-phase synchronous machine which is operated as a motor i.e. converts electrical energy input into mechanical energy output.
- A synchronous motor has a unique feature that is it runs at a constant speed equal to the synchronous speed at all load provided that the load on the motor does not exceed the limiting value.

Principle of Operation,

- ✓A synchronous motor is a doubly-excited machine.
- ✓Its stator winding or armature winding is connected to the AC supply
- ✓The rotor winding or field winding is excited by a DC source.

Construction of Three-Phase Synchronous Motor

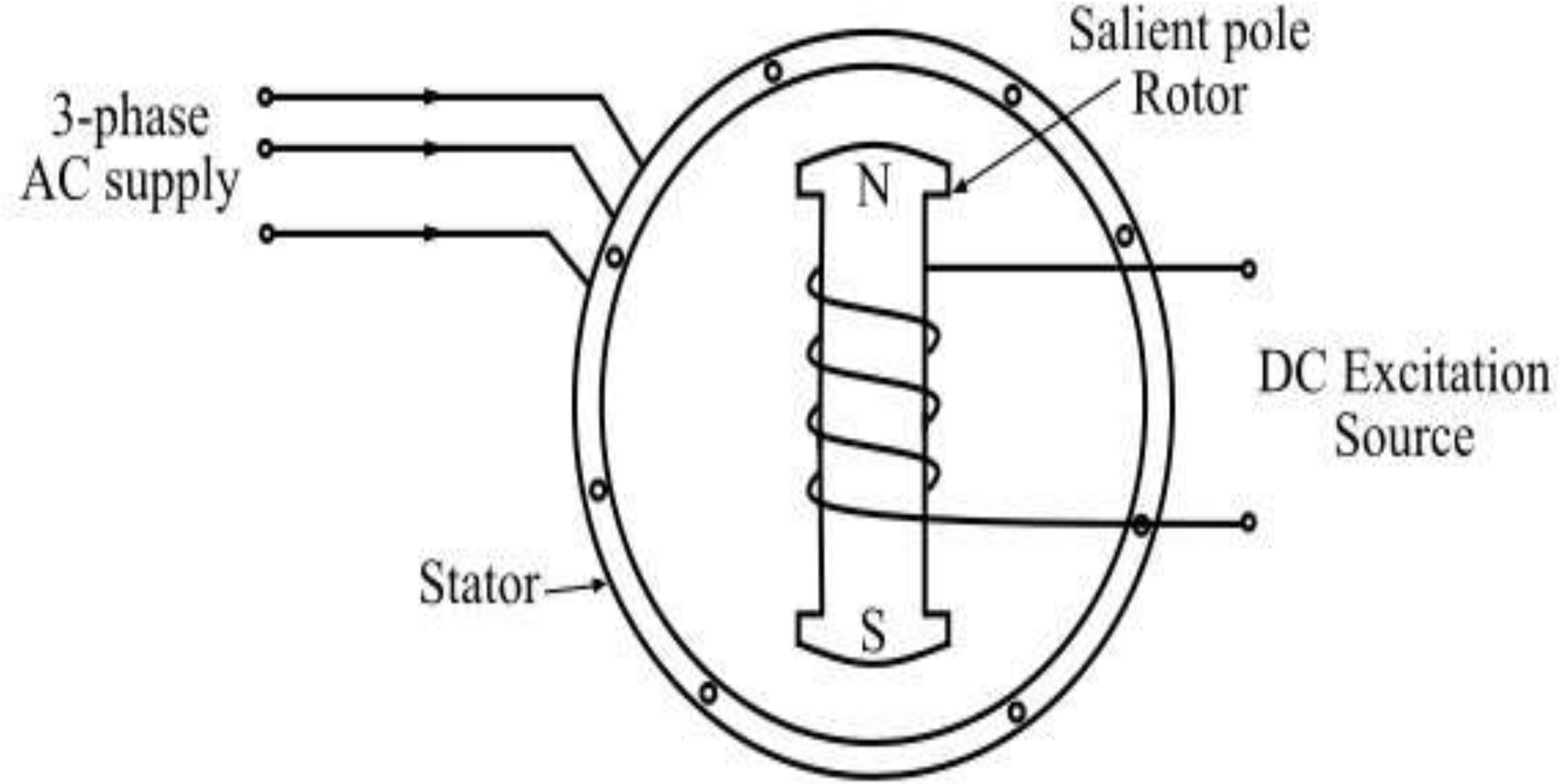


Figure-1

Construction of Three-Phase Synchronous Motor

Stator

- The stator is the stationary part of the machine and is built up of sheet steel laminations having slots on its inner periphery.
- A three-phase winding is placed in these slots which is called armature winding and receives power from a 3-phase supply.

Construction of Three-Phase Synchronous Motor

Rotor

- The rotor of the synchronous motor has set of salient poles carrying a field winding which is supplied with direct current through two slip-rings by a separate DC source to form alternate N and S poles.
- The DC source is generally a small DC shunt generator mounted on the shaft of the motor.

Working Principle of Synchronous Motor

- Consider a 3-phase, 2-pole synchronous motor having two rotor poles NR and SR as shown in Figure-2.
- The stator is also being wound for two poles NS and SS.
- A three-phase AC supply is connected to the stator winding and a DC voltage is applied to the rotor field winding.

Working Principle of Synchronous Motor

- The stator winding produces a rotating magnetic field which revolves around the stator at synchronous speed.
- The DC voltage applied to the rotor sets up a two-pole field which is stationary so long as the rotor is not running.
- Hence, under this condition, there exists a pair of revolving stator poles (NS-SS)and a pair of stationary rotor poles (NR-SR).

Working Principle of Synchronous Motor

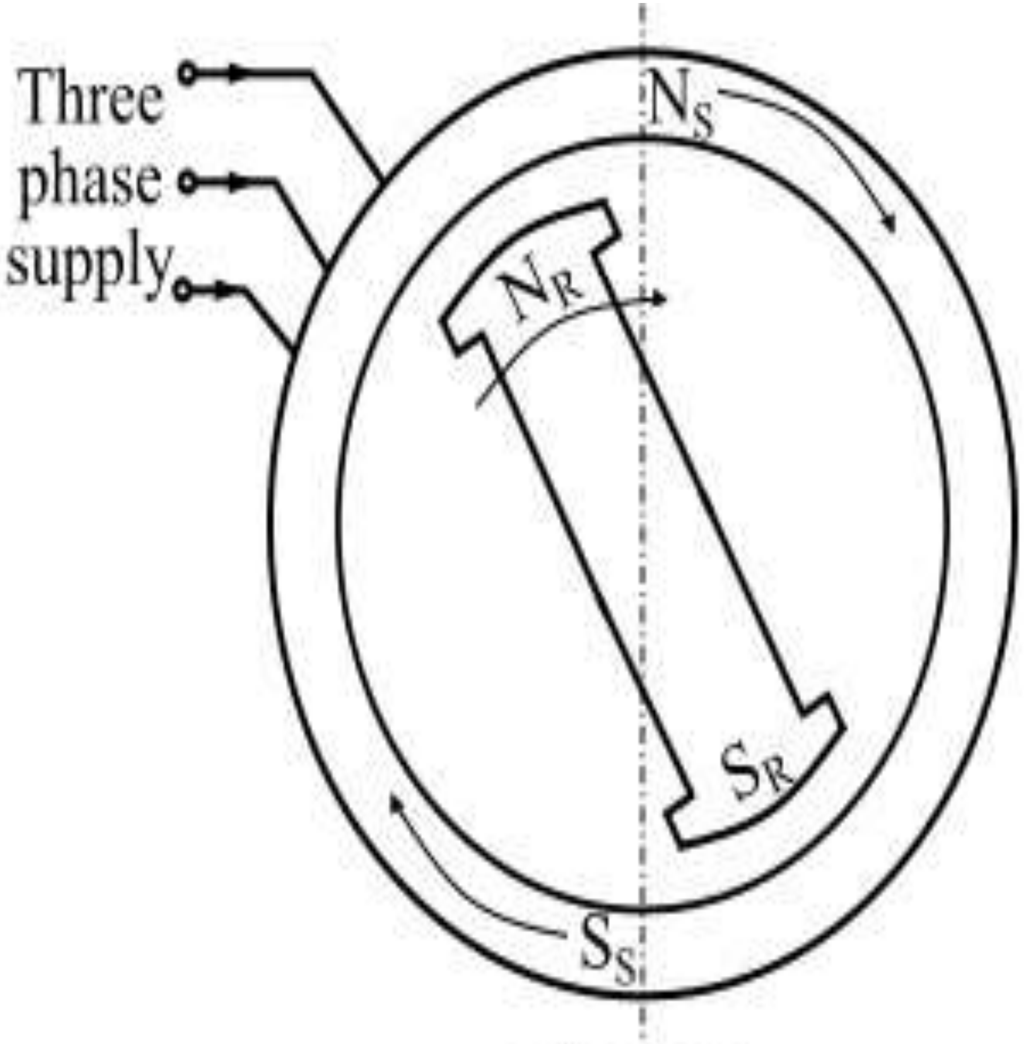


Figure-2

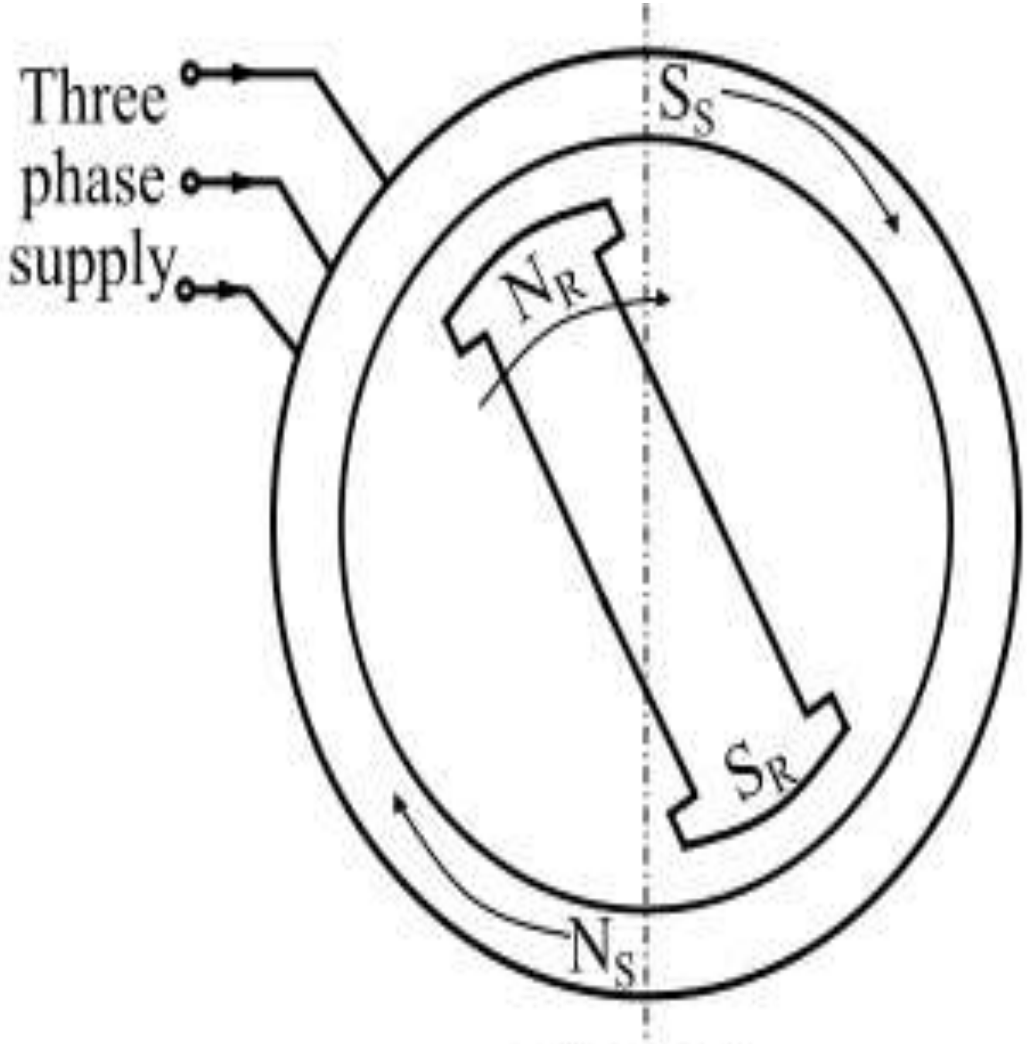


Figure-3

Working Principle of Synchronous Motor

- Now, suppose at any instant, the stator poles are at positions as shown in Figure-2. From Figure-2, it is clear that poles NS and NR repel each other and also at SS and SR.

Working Principle of Synchronous Motor

- **After a period of half-cycle of the AC supply, the polarities of the stator poles are reversed but the polarities of the rotor poles remain the same as shown in Figure-3**. in the anticlockwise direction
- Under this condition, the poles SS and NR attract each other and so do the poles NS and SR. Due to this, the rotor tends to move in the clockwise direction.

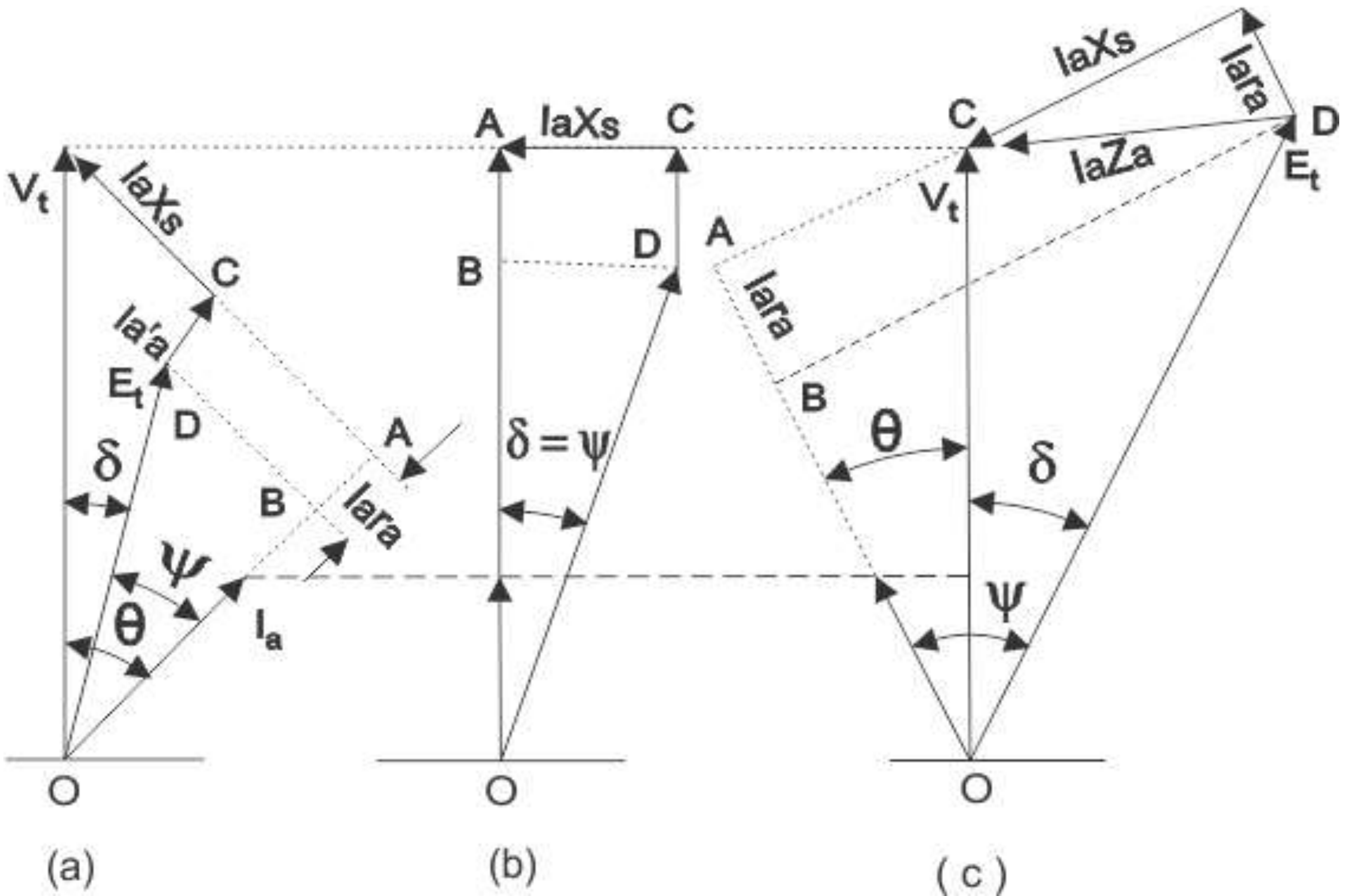
Why synchronous motor not self starting?

- Since the stator poles change their polarities rapidly, they tend to pull the rotor first in one direction and then after a period of half cycle in the other direction.
- But the rotor has high inertia, consequently, the rotor does not move and we say that the starting torque is zero.
- In other words, a synchronous motor is not self starting.

Phasor diagram of synchronous motor

(a) Motoring operation at lagging power factor,(b) Motoring operation at unity power factor

c) Motoring operation at leading power factor.



Torque and torque angle

- **The torque angle** of the synchronous motor is defined by the angle between the air gap flux line and the rotor flux lines. The maximum value of torque angle in a synchronous motor is 90 degrees electrical.

Effect of change in load

When the load on a synchronous motor is increased, then

- The motor continues to run at synchronous speed
- The torque angle (δ) increases.
- The magnitude of the excitation voltage (Ef) remains constant
- The armature current (Ia) drawn from the supply increases.

When the load on a synchronous motor is decreased, then

- The motor continues to run at synchronous speed.
- The torque angle (Ia) decreases.
- The magnitude of the excitation voltage (Ef) remains constant.
- The armature current (Ia) drawn from the supply decreases.

Effect of change in load

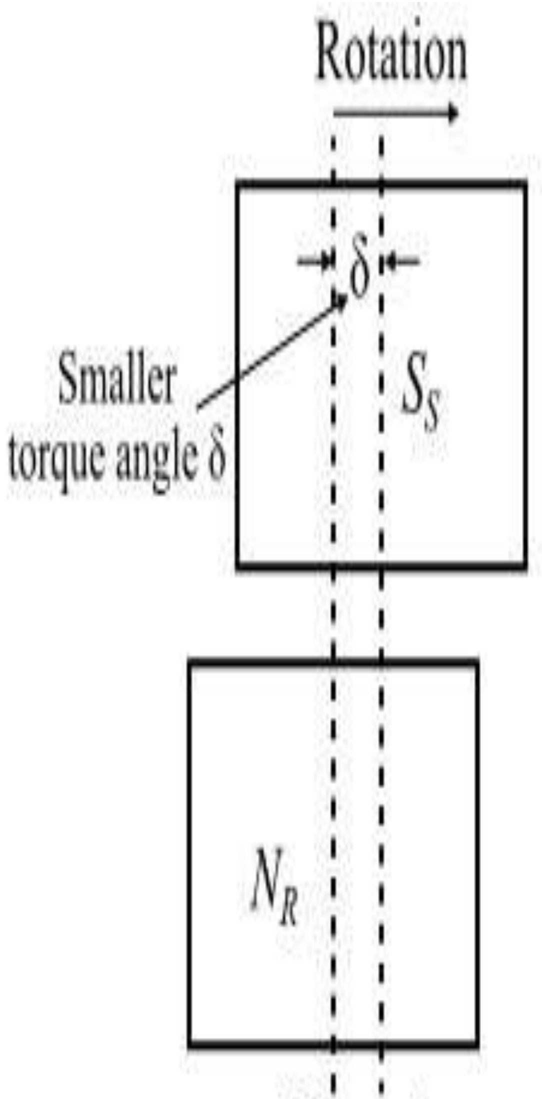


Figure-1

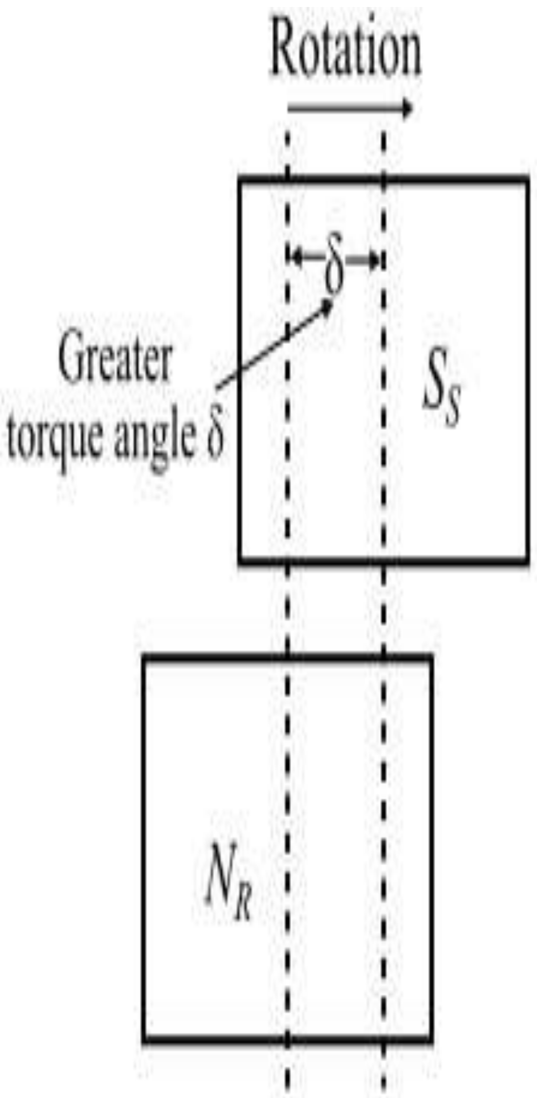


Figure-2

Effect of change in excitation

- As the excitation is increased, the power factor improves till it becomes unity at normal excitation. Under such conditions, the current drawn from the supply is minimum. If the excitation is further increased (i.e., over excitation), the motor power factor becomes leading.

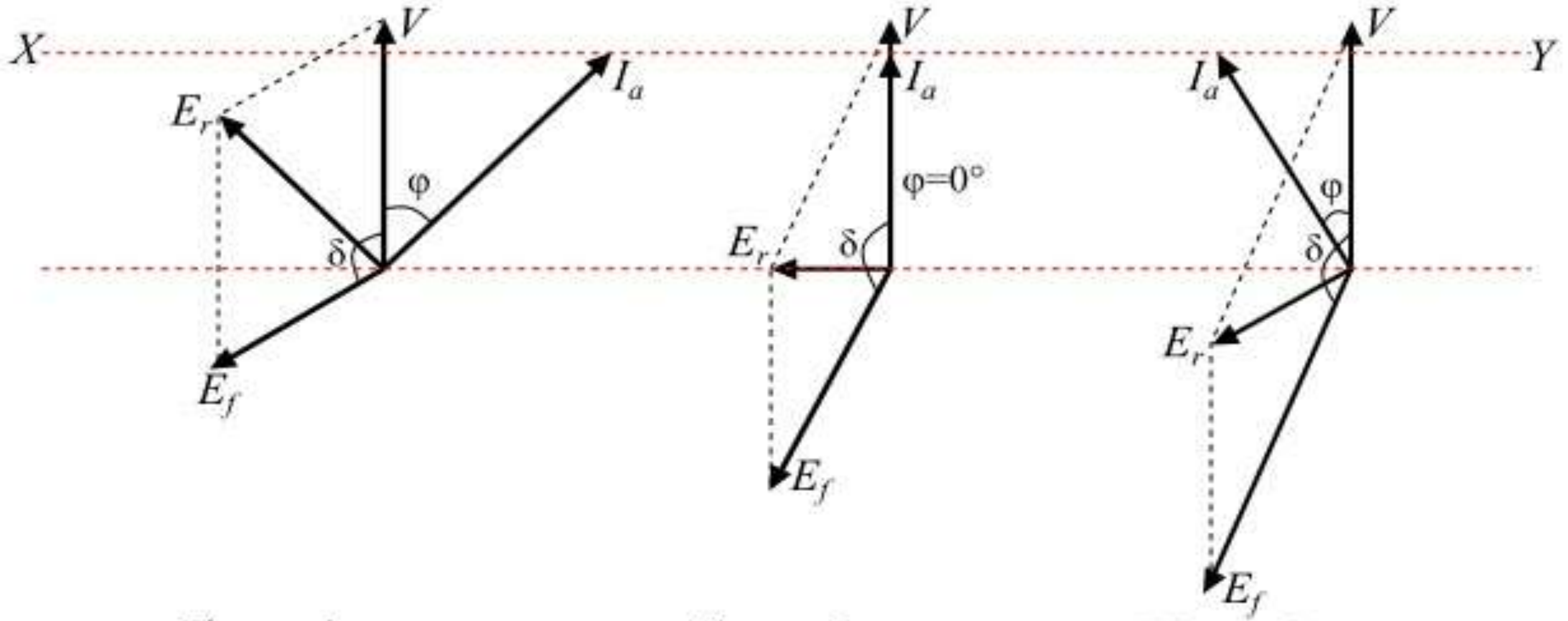
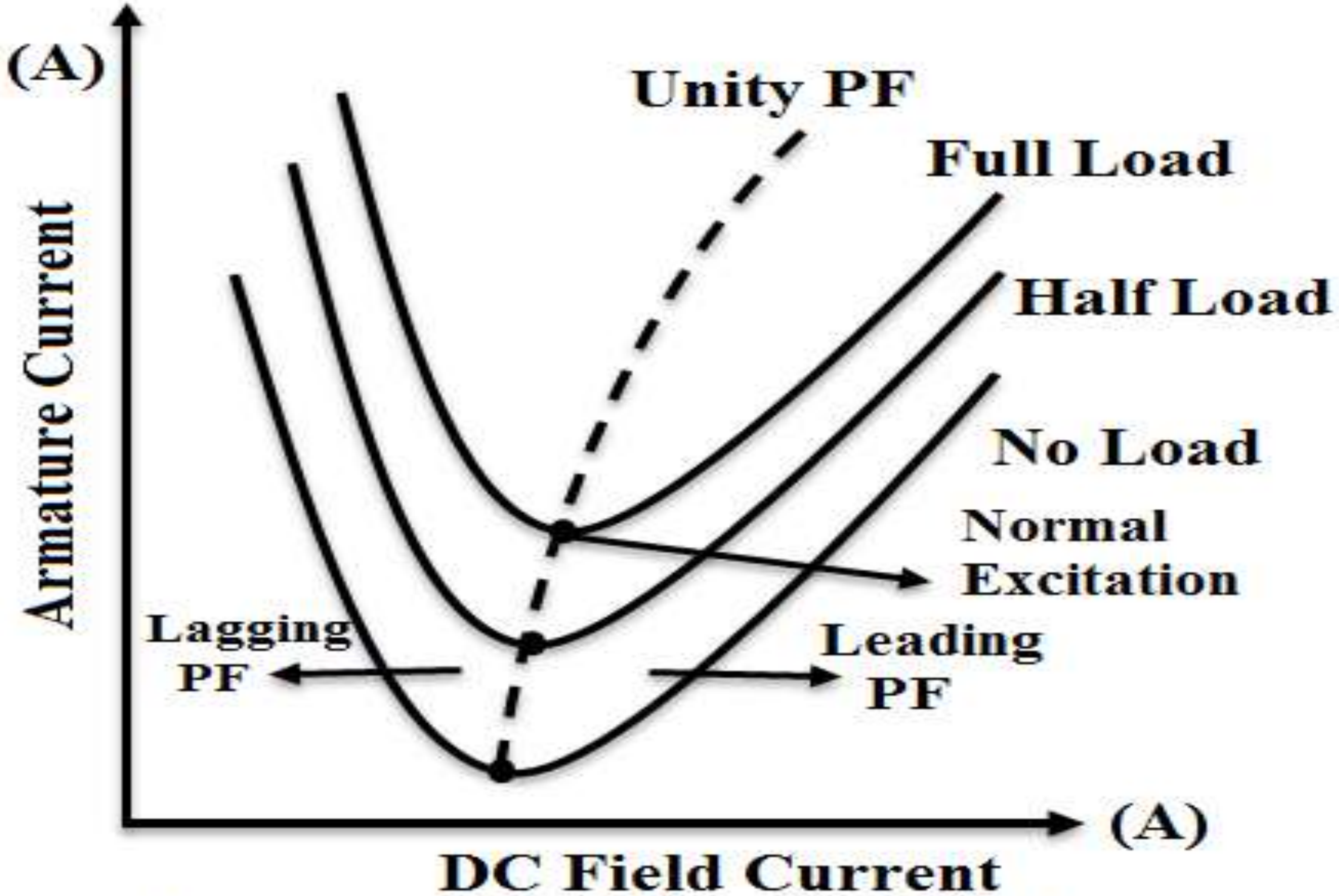


Figure-1 Under-Excitation

Figure-2 Normal-Excitation

Figure-3 Over-Excitation

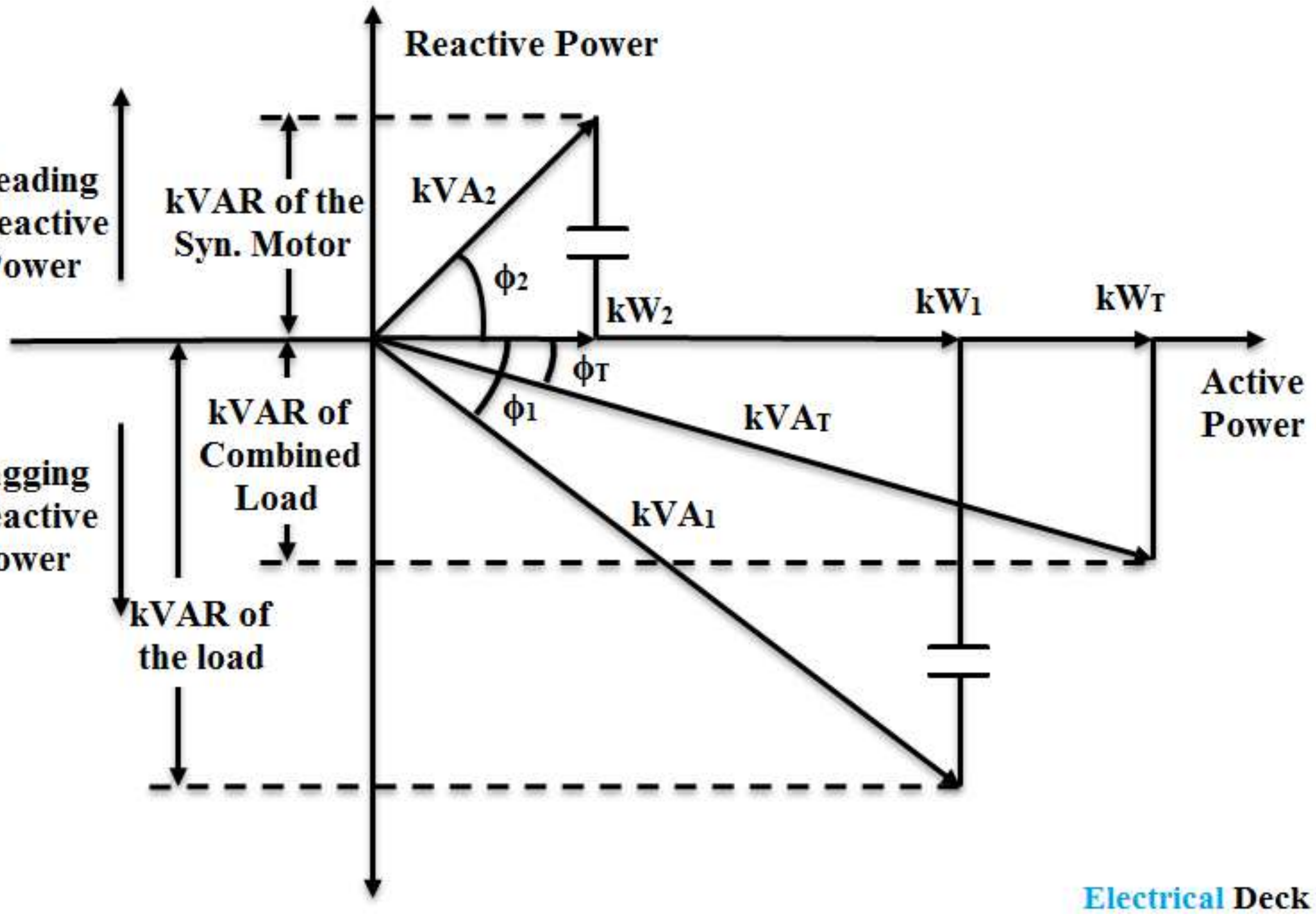
V and Inverted V Curves.



V curve of Synchronous Motor

Electrical Deck

Synchronous condenser



Hunting in synchronous machine

- Unloaded synchronous machine has zero degree load angle.
- On increasing the shaft load gradually load angle will increase.
- Let us consider that load P1 is applied suddenly to unloaded machine shaft so machine will slow down momentarily.
- Also load angle (δ) increases from zero degree and becomes δ1.
- During the first swing electrical power developed is equal to mechanical load P1.
- Equilibrium is not established so rotor swings further.
- Load angle exceeds δ1 and becomes δ2.
- Now electrical power generated is greater than the previous one.
- Rotor attains synchronous speed.
- But it does not stay in synchronous speed and it will continue to increase beyond synchronous speed.
- As a result of rotor acceleration above synchronous speed the load angle decreases.
- So once again no equilibrium is attained.
- Thus rotor swings or oscillates about new equilibrium position.
- This phenomenon is known as hunting or phase swinging.
- Hunting occurs not only in synchronous motors but also in synchronous generators upon abrupt change in load.

Damping in synchronous motor

- Damping is the phenomenon caused in synchronous machine due to the sudden change in load.

CONSTANT EXCITATION VARIABLE EXCITATION

As the **load on the motor is increase, the rotor progressively tends to fall back** ***in phase*** (but *not* in speed as in DC motors) by some angle (**Fig. 36.4**) *but it still continuous to run synchronously*.

Fig. 36.4

The value of this load angle or coupling angle (as it is called) depends on the amount of load to be met by the motor.

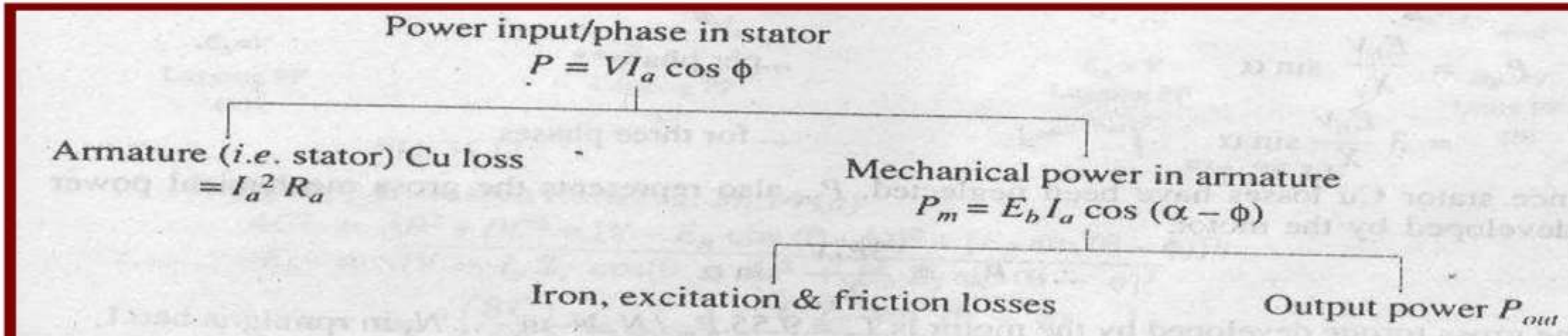
In other words, the torque developed by the motor depends on this angle, say, α.

This angle is referred as ***load angle*** **or** ***coupling angle*.**

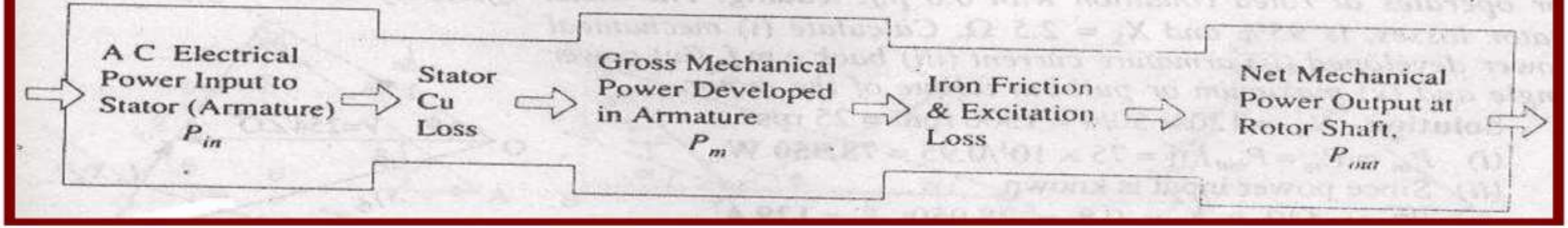
This is also the **angle between rotor and stator fields.**

LOSSESS IN SYNCHRONOUS MOTOR

The per phase power development in a synchronous machine is as under:



Different power stages in a synchronous motor are as under :



STARTING OF SYNCHRONOUS MOTOR

Synchronous Motor

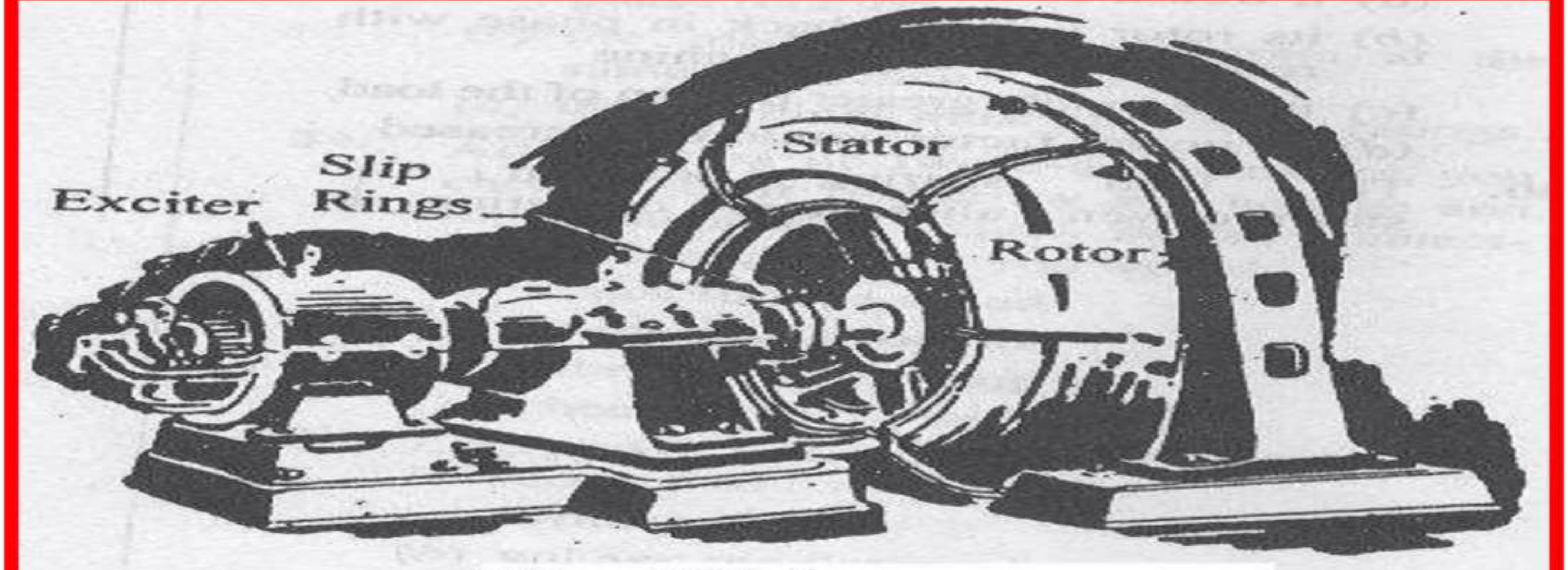


Fig. 36.1

Method of Starting

There are several methods to start the synchronous motor such as:

(a) Auxiliary drive (induction motor or dc motor),

(b) Induction start (using damper winding), etc

General Starting Procedure: The rotor (which is as yet unexcited) is **speeded up to synchronous or near synchronous speed** by some arrangement and then excited by the DC source.

The moment this (near) synchronously rotating rotor is excited, it is **magnetically locked into position with the stator** *i.e.* the rotor poles are engaged with the stator poles and both run synchronously in the same direction.

It is because of this inter-locking of stator and rotor poles that the motor has either to run synchronously or not at all.

However, it is important to understand that the arrangement between the stator and rotor poles is *not an absolutely rigid one*.

DIFFERENT METHODS OF STARTING SM

1. Using Auto transformer
2. Asynchronous motor
3. using small motor (induction motor or a dc motor)
4. Damper winding.

Methods of starting synchronous motor

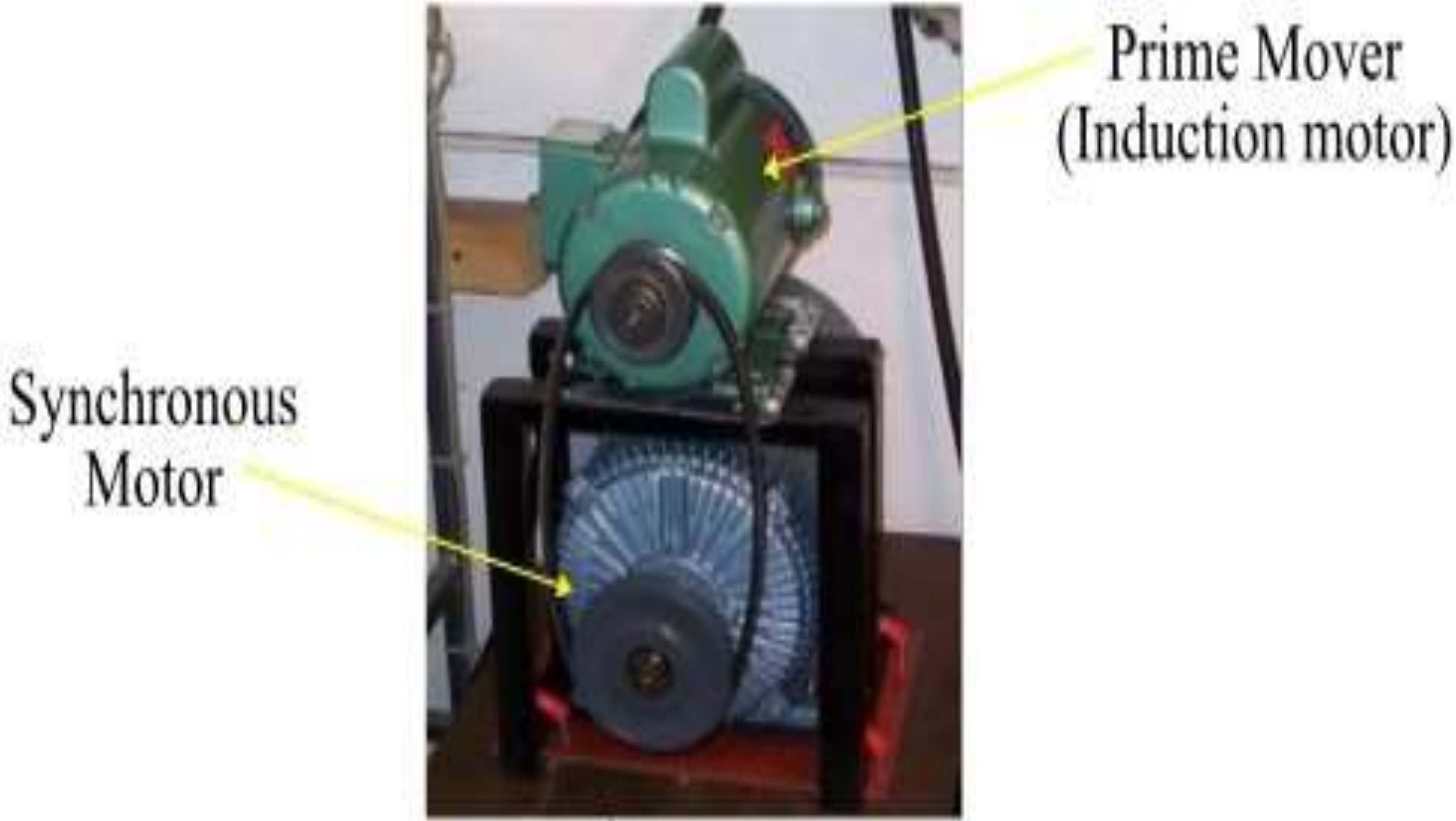


Figure-1

Using damper winding

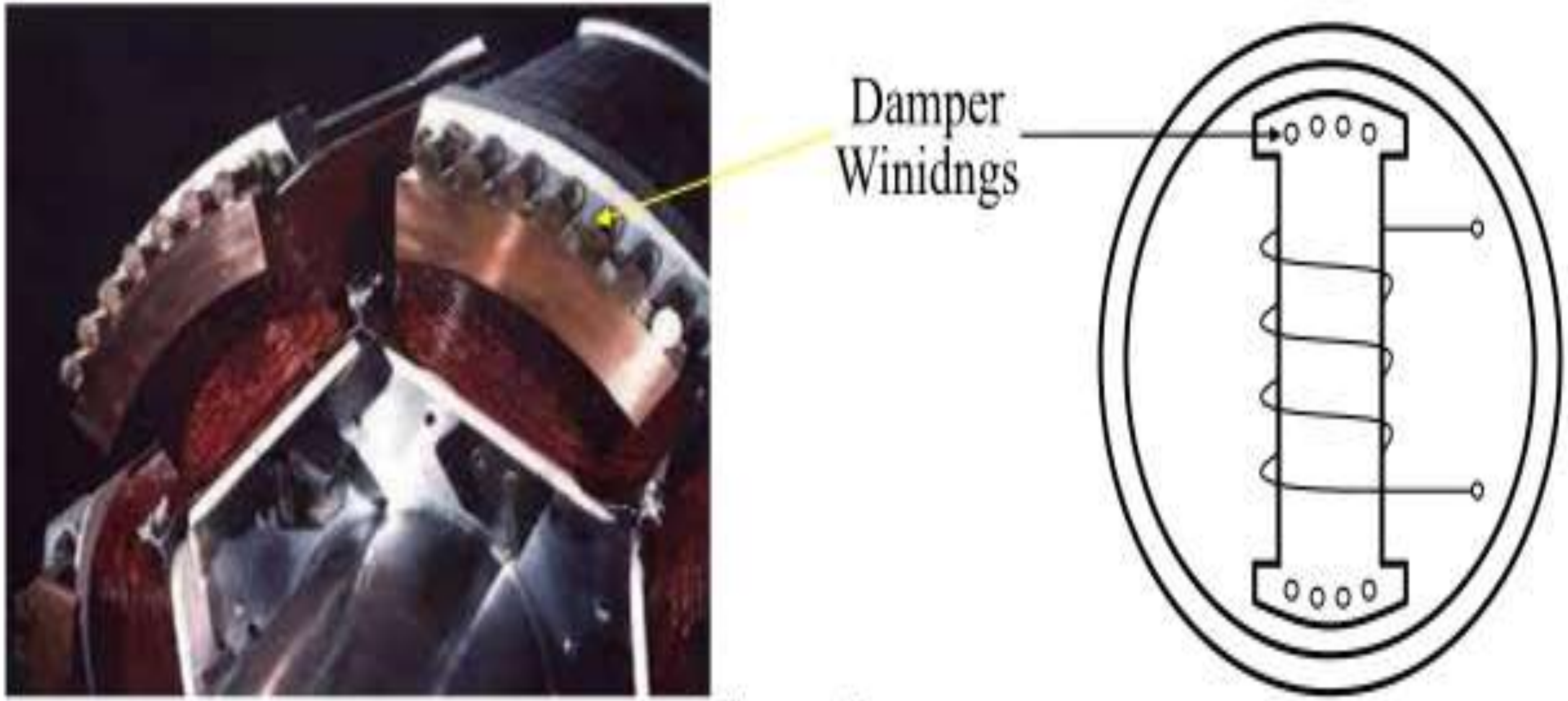


Figure-2

Procedure for Starting a Synchronous Motor Using the Damper Winding

While starting a modern synchronous motor provided with damper windings, following procedure is adopted.

1. First, **main field winding is short circuited**.
2. **Reduced voltage with the help of auto-transformers** is applied across stator terminals. The motor starts up.
3. When it reaches a steady state speed (as judge by its sound), a **weak DC excitation is applied by removing the short-circuit on the main field winding.** If excitation is sufficient, then the machine will be pulled into synchronism.
4. **Full supply voltage** is applied across stator terminals by cutting out the auto-transformers.
5. The **motor may be operated at any desired power factor by changing the DC excitation**.

Difference Between Synchronous and Asynchronous Motor are explained below in the tabulated form.

BASIS	SYNCHRONOUS MOTOR	ASYNCHRONOUS MOTOR
Definition	Synchronous motor is a machine whose rotor speed and the speed of the stator magnetic field is equal. $N = NS = 120f/P$	Asynchronous motor is a machine whose rotor rotates at the speed less than the synchronous speed. $N < NS$
Type	Brushless motor, Variable Reluctance Motor, Switched Reluctance Motor and Hysteresis motor are the synchronous motor.	AC Induction Motor is known as the Asynchronous Motor.
Slip	Does not have slip. The value of slip is zero.	Have slip therefore the value of slip is not equal to zero.

Additional power source	It requires an additional DC power source to initially rotate the rotor near to the synchronous speed.	It does not require any additional starting source.
Slip ring and brushes	Slip ring and brushes are required	Slip ring and brushes are not required.
Cost	Synchronous motor is costly as compared to Asynchronous motor	Less costly
Efficiency	Efficiency is greater than Asynchronous motor.	Less efficient
Power factor	By changing excitation the power factor can be adjusted accordingly as lagging, leading or unity.	Asynchronous motor runs only at a lagging power factor.
Current supply	Current is given to the rotor of the synchronous motor	The rotor of Asynchronous motor does not require any current.
Speed	The Speed of the motor does not depend on the variation in the load. It is constant.	The Speed of the Asynchronous motor decreases with the increasing load.
Self starting	Synchronous motor is not self starting	It is self starting
Affect in torque	Change in applied voltage does not affect the torque of the synchronous motor	Change in applied voltage does affect the torque of the Asynchronous motor

- **Operational speed**
- They operate smoothly and relatively good at low speed that is below 300 rpm.
- Above 600 rpm speed motor operation is excellent.
- **Applications**
- Synchronous motors are used in Power stations, manufacturing industries etc. it is also used as voltage controller.
- Used in Centrifugal pumps and fans, blowers, paper and textile mills, compressors and lifts. etc