Synchronous Motors

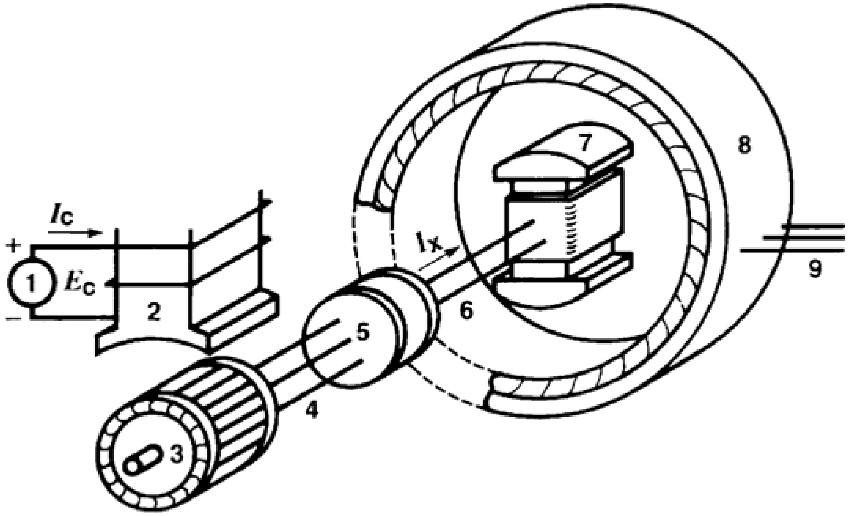
Synchronous Motors

- A synchronous motor is the same physical machine as a generator, except that the direction of real power flow is reversed.
- When operating as motors (by connecting them to a 3-phase source), they are called *synchronous motors*.
- Synchronous motors are used to convert AC electric power to mechanical power at constant speed called as Synchronous Speed.
- Synchronous motors run in synchronism with the revolving field.
- The speed of rotation is tied to the frequency of the source.
- The motor speed stays constant, irrespective of the load or voltage of the 3-phase line and it does not depend on the torque acting on it.
- So it has a constant-speed torque characteristic.
- The efficiency of synchronous motor is around 90%–93%.

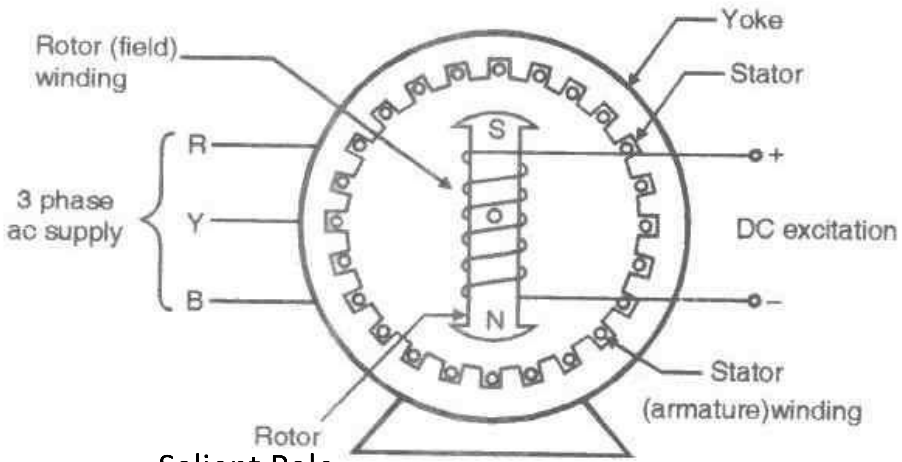
- It is a doubly excited machine i.e. three-phase power is given to the stator while the rotor is fed from a DC source for excitation of the field winding.
- The air gap flux is therefore the resultant of the flux due to both rotor current and stator current.
- Synchronous motors are used not so much because they run at constant speed.
- They possess some unique electrical properties.
- Most synchronous motors are rated between 150 kW (200 hp) and 15 MW (20,000 hp) and turn at speed ranging from 150 to 1800 rev/min.
- Consequently, these machines are used in heavy industry.
- At the other end of the power spectrum, we find tiny single-phase synchronous motors used in control devices and electric clocks.
- *Synchronous motors* are built in large units compare to induction motors (Induction motors are cheaper for smaller ratings) and used for constant speed industrial drives.

Construction

- The construction of 3-Phase Synchronous motors are identical to AC synchronous generators.
- **The *Stator:***
  - The stator has a laminated core with slots to hold the three-phase armature windings and are wound for the same number of poles as the rotor.
  - It is composed of a slotted magnetic core, which carries a lap winding which is also identical to a 3-phase induction motor.



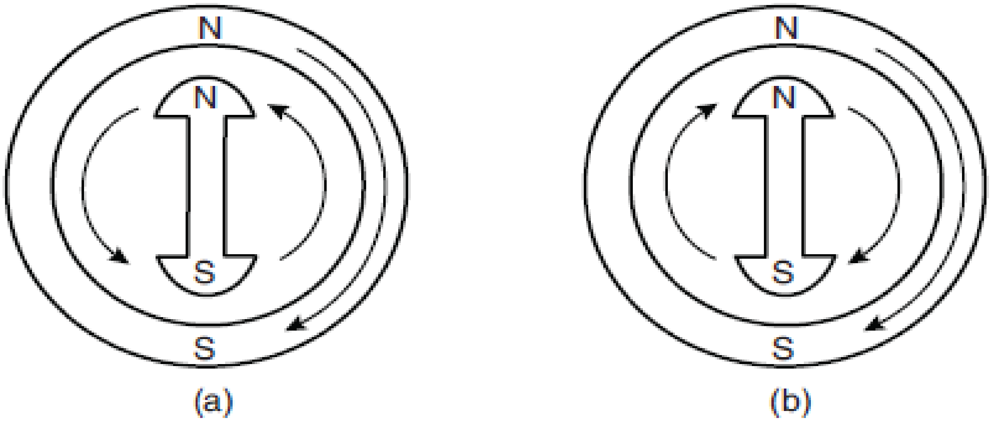
1 - dc control source
2 - stationary exciter poles
3 - alternator (3-phase exciter)
4 - 3-phase connection
5 - bridge rectifier
6 - dc line
7 - rotor of synchronous motor
8 - stator of synchronous motor
9 - 3-phase input to stator



Salient Pole Rotor

- **The *Rotor:***
  - Rotor holds the field winding.
  - The rotor can be of salient-pole type or cylindrical type.
  - Has a set of salient poles excited by a dc current using two slip-rings.
  - Synchronous motor is likely to hunt and so damper windings are mounted on the rotor in the slots located in the pole faces and parallel to the shaft.
  - It also carry a squirrel-cage winding similar to that in a 3-phase induction motor.
  - This *damper winding* serves to start the motor.
  - Damper winding also serve to increase the stability of the motor during load transient.
  - The ends of Copper (Cu) bars are short circuited in the same manner as the Cage Rotor of an Induction Motor.
- Modern synchronous motors often employ brushless excitation, similar to that used in synchronous generators.

Principle of Operation

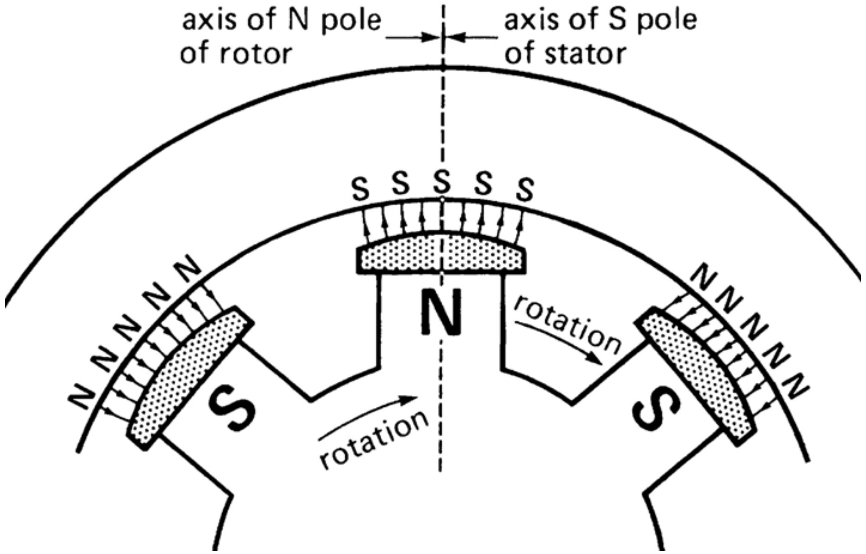


- The field current of a synchronous motor produces a steady-state magnetic field B_R
- A three-phase set of voltages is applied to the stator windings of the motor, which produces a three-phase current in the windings.
- This three-phase set of currents in the armature winding produces a uniform rotating magnetic field B_s in the air gap.
- The stator rotates at synchronous speed.
- DC supply on the rotor will also produce a flux of constant magnitude.
- Therefore, there are two magnetic fields present in the machine, and *the rotor field will tend to line up with the stator field*, just as two bar magnets will tend to line up if placed near each other.
- Since the stator magnetic field is rotating, the rotor magnetic field (and the rotor itself) will try to catch up with the rotating magnetic field of stator.

- This is possible when the rotor also rotates at synchronous speed.
- The basic principle of operation of the synchronous motor is that the rotor chases the stator magnetic field.
- The stator rotating magnetic field tends to drag the rotor along, as if the north pole of the stator locks in with the south pole of the rotor.
- The larger the angle between the two magnetic fields (up to certain maximum), the greater the torque on the rotor of the machine
- A three phase synchronous motor is not self-starting.
- If the rotor of the synchronous motor is rotated by some external means at the start, there will be a continuous force of attraction between the stator and the rotor.
- This is called magnetic locking.
- Once this stage is reached, the rotor pole is dragged by the revolving stator field and thus the rotor will continue to rotate.

Pull-in torque

- As soon as the motor is running at close to synchronous speed, the rotor is excited with DC current. This produces N and S poles around the circumference of the rotor.
- If the poles on the rotor at the moment the exciting current is facing the poles of opposite polarity on the stator, a strong magnetic attraction is set up between them.
- The mutual attraction locks the rotor and stator poles together.
- The rotor is pulled with the revolving field. Torque develop at the moment is called *pull-in torque.*



- DC current must be applied at the right moment, otherwise a mechanical shock will be produced and the circuit breakers will trip.
- The starter detects the precise moment when to apply excitation.
- Once the motor turns at synchronous speed, no voltage is induced in the squirrel-cage winding and so it carries no current.
- The behavior of a synchronous motor is entirely different from that of an induction motor.

Features of Synchronous Motor

1. It runs either at synchronous speed or not at all, that means while running it maintains a constant speed which is independent of the load.

2. The only way to change its speed is to change its supply frequency. (As $N_s = 120f/P$).

3. Synchronous motors are inherently not self starting. They require some external means to bring their speed close to synchronous speed before they are synchronized to the supply.

4. The speed of operation of is in synchronism with the supply frequency.

5. This motor has the unique characteristics of operating under any electrical power factor (both lagging and leading). This makes it used in electrical for power factor improvement.

Starting a Synchronous Motor

- A synchronous motor can not start by itself.
- The different methods that are generally followed to start the synchronous motor are:
  - By using a pony motor (Small induction motor) (external prime mover)
  - By using a damper winding
  - By using DC motor
  - Starting as an induction motor
  - Finally, in some big installations the motor may be brought up to speed by a variable-frequency electronic source

By using a pony motor (Small induction motor):

- Very large synchronous motors (20 MW and more) are sometimes brought up to speed by an auxiliary motor, called a *pony motor.*
- It could be either 3 phase induction motor or DC shunt motor.
- In this method, the rotor of the synchronous motor is brought to its synchronous speed with the help of an external induction motor or DC motor.
- No DC excitation applied initially.
- It rotates at speed very close to its synchronous speed, and then we give the DC excitation.
- After some time when magnetic locking takes place supply to the external motor is cut off.
- Since the load is not connected to the synchronous motor before synchronizing, the starter motor has to overcome the inertia of synchronous motor at no load.
- The rating of the starter motor is much smaller than the rating of synchronous motor.
- At present most of the large synchronous motors are provided with brushless excitation system mounted on their shaft.
- These excitation systems are used as starting motor.

By using a damper winding:

- The motor is equipped with a squirrel case winding, to start it as an induction motor.
- The damper windings are provided on the pole face slots in the fields of rotor.
- These windings are short-circuited at both ends with the help of end rings, thus forming a squirrel-cage system.
- When the synchronous motor is started as a slip-ring induction motor, the three ends of the windings are connected to an external resistance in series through slip-rings.
- Initially, when the rotor is not rotating, the relative speed between damper winding and rotating air gap flux is large and an emf is induced in it which produces the required starting torque.
- Now, when a three-phase supply is given to the stator of a synchronous motor, it will start as a three-phase induction motor.
- The motor accelerates until it reaches slightly below synchronous speed.
- As the motor approaches synchronous speed, the DC excitation is applied to the field windings.
- As speed approaches synchronous speed, emf and torque are reduced and finally when magnetic locking takes place; torque also reduces to zero.
- Hence in this case synchronous motor first runs as three phase induction motor using additional winding and finally it is synchronized with the frequency.
- It is the most widely used method of starting.

Applications of Synchronous Motors

- Synchronous motors are usually used in large sizes because in small sizes they are costlier as compared with induction machines.
- The principal advantages of using synchronous machine are as follows:
  - Power factor of synchronous machine can be controlled very easily by controlling the field current.
  - It has very high operating efficiency and constant speed.
  - For operating speed less than about 500 rpm and for high-power requirements (above 600 KW) synchronous motor is cheaper than induction motor such as rolling mills, chippers, mixers, pumps, compressors etc.
- In view of these advantages, synchronous motors are preferred for driving the loads requiring high power at low speed; e.g.; reciprocating pumps and compressor, crushers, rolling mills, pulp grinders etc.
- Synchronous motor having no load connected to its shaft is used for power factor improvement.
- As synchronous motor is capable of operating under either leading or lagging power factor, it can be used for power factor improvement.
- A synchronous motor under no-load with leading power factor is connected in a power system where static capacitors cannot be used.