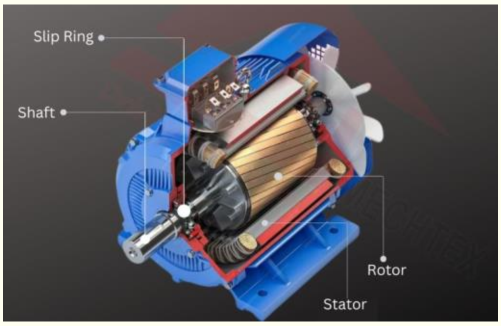
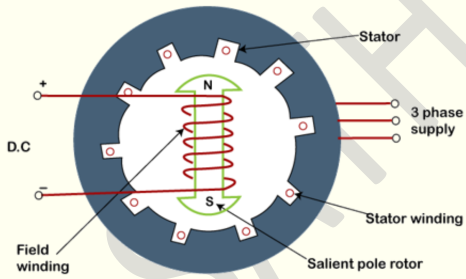
SYNCHRONOUS MACHINES

Basic Overview:

Synchronous machines are AC electrical machines where the rotor rotates at the same speed as the rotating magnetic field, which is also known as the synchronous speed. These machines are primarily used as generators (also called alternators) to produce electrical power, but can also be used as motors or reactive power compensators.





Key Characteristics and Applications:

- **Synchronous Speed:**

The rotor's speed is directly related to the frequency of the AC supply and the number of poles in the machine.

- **Generators:**

Synchronous generators are the primary devices for converting mechanical energy into electrical energy.

- **Motors:**

Synchronous motors are used where a constant speed is required and can operate efficiently.

- **Reactive Power Control:**

They can be used to improve the power factor in power systems.

Construction:

- **Rotor:** Can be either cylindrical (for high-speed applications) or salient pole (for lower speeds).
- **Stator:** Contains the armature winding, where the AC voltage is generated.
- **Excitation System:** Provides the DC power to excite the field windings on the rotor, creating the magnetic field.

Working Principle:

- The rotating magnetic field generated by the stator windings induces an EMF (electromotive force) in the armature winding.
- The interaction between the rotating field and the rotor's magnetic field causes the rotor to rotate at the synchronous speed.

Advantages and Disadvantages:

- **Advantages:** High efficiency, constant speed, can provide power factor correction.
- **Disadvantages:** May not be self-starting (requires assistance to get started), more complex construction than induction machines.

Applications:

- **Power Generation:** Used in large-scale power plants to generate electricity.
- **Pumps, Compressors, and HVAC Systems:** Provide precise speed control and high torque.
- **Industrial Machinery:** Used in applications requiring constant and accurate speed control.
- **Power Systems:** Used as reactive power compensators to improve power factor.

Let us dive deep into the topic to develop an in-depth understanding:

SECTION 1: FUNDAMENTALS OF SYNCHRONOUS MOTORS

1. **What is a synchronous motor, & how is it different from other types?**
   A synchronous motor is an AC motor that operates at a constant speed determined by the frequency of the supply and the number of poles. Unlike induction motors, it runs at synchronous speed without slip.
2. **How is synchronous speed calculated?**
   Synchronous Speed (RPM) = $120 \times f/P$
   Where:

- f = Frequency of AC supply
- P = Number of poles

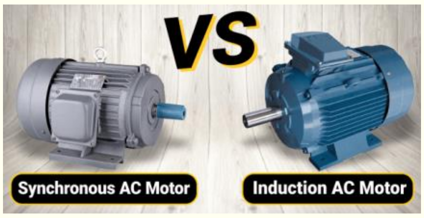
3. **What factors influence synchronous motor speed?**
   Speed depends on supply frequency and the number of poles. It remains constant under varying loads.

4. **Can synchronous motors operate above synchronous speed?**
No, they cannot function as motors beyond synchronous speed; however, they can act as generators if driven above synchronous speed.

5. **Can synchronous motors run on single-phase supply?**
No, they require a three-phase supply to produce the rotating magnetic field necessary for operation.

6. **Can the speed of a synchronous motor be varied?**
Only using external controllers like Variable Frequency Drives (VFDs), as speed is otherwise fixed.

7. **What is the difference between synchronous and induction motors?**

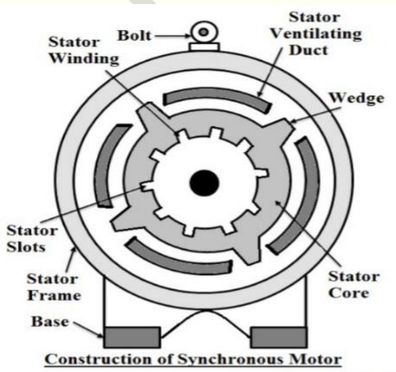


- Synchronous motors have constant speed; induction motors have slip.
- Synchronous motors require an external starting mechanism.
- Induction motors are self-starting; synchronous motors are not.

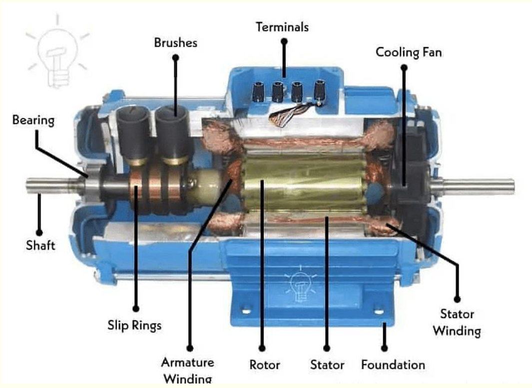
SECTION 2: CONSTRUCTION AND WORKING PRINCIPLE

8. **What are the main parts of a synchronous motor?**

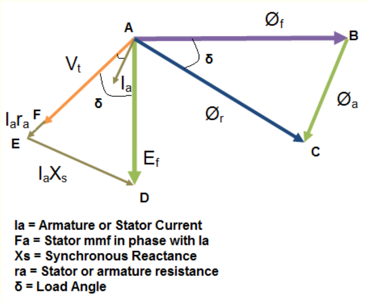
- **Stator** (3-phase winding)
- **Rotor** (with field winding or permanent magnets)
- **Excitation system**
- **Damper winding** (optional)



Construction of Synchronous Motor



9. **How does a synchronous motor maintain synchronism?**
   The rotor locks with the rotating magnetic field of the stator and rotates at the same speed.
10. **What happens if synchronism is lost?**
    The motor stops delivering torque and may need to be resynchronized.
11. **What is load angle in a synchronous motor?**
    It's the angle between rotor and stator magnetic fields. It affects torque and motor



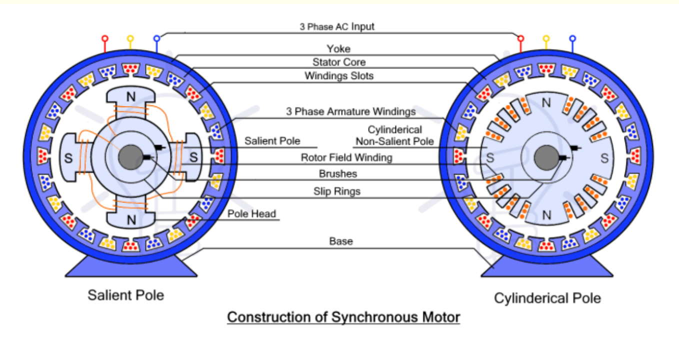
stability.

12. **What is the function of the excitation system?**
    It provides DC to rotor windings to generate the magnetic field required for synchronism.
13. **What are the types of excitation systems?**

- **DC excitation** (via slip rings or brushless exciters)
- **Permanent magnet excitation**

14. **Will synchronous motors work without excitation?**
    No. Excitation is essential to create the magnetic field for operation, unless using PMSMs.
15. **What are the types of rotor constructions?**

- **Salient pole** (projected poles – low-speed machines)
- **Cylindrical pole** (smooth – high-speed machines)
- **Interior Permanent Magnet (IPM)**



Construction of Synchronous Motor

SECTION 3: STARTING METHODS AND STABILITY

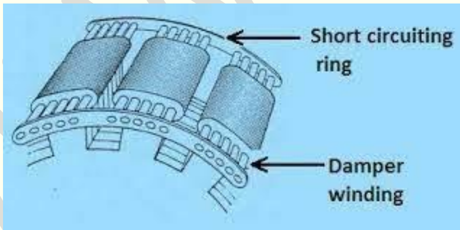
16. **How are synchronous motors started?**
Using:

- Damper windings (act like squirrel cage rotor)
- Separate starting motors
- VFDs

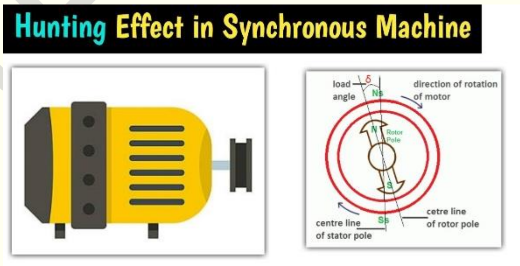
17. **Why do synchronous motors need external starting?**
Because the rotor cannot produce torque at standstill due to lack of relative motion.

18. **What is the role of damper windings?**

- Assist in starting
- Provide damping to prevent oscillations (hunting)



19. **What is hunting in synchronous motors?**
Oscillation of rotor due to load changes. It is reduced using damper windings and stabilizers.



• Reason of hunting in synchronous motor explained

20. **What steps reduce instability in synchronous motors?**

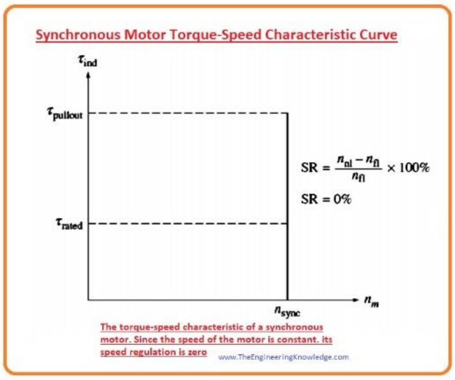
- Power System Stabilizers (PSS)
- Automatic Voltage Regulators (AVRs)
- Damper windings

SECTION 4: PERFORMANCE CHARACTERISTICS

21. **How is torque generated in synchronous motors?**
    Torque T=P/2πN, where P= power (watts), N = speed (RPM)

22. **What is the torque-speed characteristic of synchronous motors?**

- Flat at synchronous speed
- Zero torque below synchronous speed



23. **Are synchronous motors suitable for variable loads?**
    They are less suitable due to fixed speed. Load variation may cause synchronism loss.

24. **How does load angle affect performance?**
    A higher load angle increases torque, but too large an angle can cause loss of synchronism.

25. **How is efficiency affected by load changes?**
    Efficiency is highest at steady loads; frequent load fluctuations may reduce it.

SECTION 5: POWER FACTOR AND CONTROL

26. **How is power factor controlled in synchronous motors?**
    By adjusting excitation:

- **Under-excited** → Lagging PF
- **Over-excited** → Leading PF
- **Normal excitation** → Unity PF

27. **Why is power factor correction important?**
It improves system efficiency, reduces losses, and avoids penalties from utility companies.

28. **Can synchronous motors improve system power factor?**
Yes. When over-excited, they act as **synchronous condensers** and supply reactive power.

29. **How is power factor measured?**
Using power analyzers or meters connected to the motor's input lines.

SECTION 6: APPLICATIONS

30. **Where are synchronous motors commonly used?**

- Compressors, pumps
- Power factor correction
- Motion control
- Large-scale fans and mills

31. **Are they suitable for high-precision applications?**
Yes. Their fixed speed makes them ideal for CNC machines, robotics, and paper mills.

32. **Can they be used in regenerative braking?**
Yes. They can feed energy back into the grid when mechanically driven.

33. **Are they used in harsh environments?**
With proper protection and cooling, yes. They are used in steel, mining, and chemical plants.

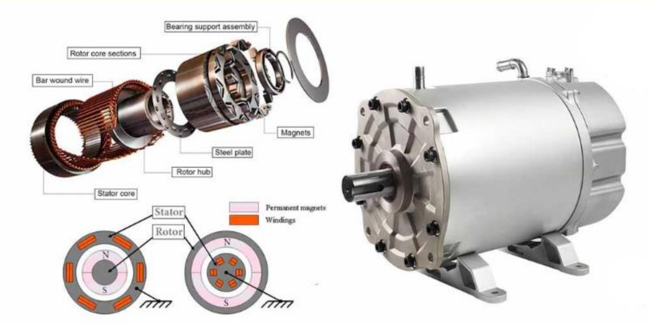
34. **Can synchronous motors operate in both motor and generator mode?**
Yes. They operate as motors below and at synchronous speed; above that, they generate power.

35. **What are typical low-speed high-torque applications?**
Applications like crushers or conveyors, usually with gear reduction systems.

36. **Why are PMSMs gaining popularity?**
They offer:

- High efficiency
- Better torque density

- Compact design



37. **Why are synchronous motors preferred in textile and paper industries over induction motors?**
    Answer:
    Synchronous motors provide constant speed regardless of load, which is crucial for applications like textile looms or paper mills where even slight speed variation can cause defects in the product. Induction motors may slip under varying load, making them less ideal in such cases.

38. **How are synchronous motors used in electric clocks and timers?**
    Answer:
    Synchronous motors are used in precision timing devices like electric clocks because they rotate at a speed strictly governed by the power supply frequency. This ensures accurate timekeeping as long as the supply frequency remains stable.

39. **Why are synchronous motors used in hydropower plants as generators?**
    Answer:
    Synchronous machines, when mechanically driven by turbines, act as generators. They are preferred in hydropower stations because they can be easily synchronized with the grid and maintain voltage and frequency control under varying load conditions.

40. **How does a synchronous motor act as a synchronous condenser in electrical substations?**
    Answer:
    When over-excited and run without mechanical load, synchronous motors can supply reactive power to the grid, improving power factor and voltage stability. This function is known as a synchronous condenser and is widely used in substations and power systems.

SECTION 7: COMPARISONS AND SPECIAL TOPICS

41. **Difference between synchronous and permanent magnet synchronous motors (PMSM)?**

- PMSM uses permanent magnets on rotor
- Conventional synchronous uses field winding
- PMSM is more efficient

42. **Difference between synchronous and synchronous reluctance motors?**

- Reluctance motors have no windings or magnets on rotor
- Use reluctance torque
- Simpler and more efficient in some applications

43. **What is the role of phase sequence?**
    Correct phase sequence ensures correct rotation direction and proper synchronism.
44. **Can multiple synchronous motors run in parallel?**
    Yes, if synchronized to same voltage, frequency, and phase.

SECTION 8: PROTECTION, MAINTENANCE, AND DESIGN CONSIDERATIONS

45. **Why is rotor design important?**
    It affects:

- Inertia
- Torque
- Mechanical strength
- Heat dissipation

46. **What protection features are used?**

- Overcurrent relays
- Thermal protection
- Vibration sensors
- Differential protection

47. **What factors to consider while selecting a synchronous motor?**

- Load torque and speed
- Duty cycle
- Power factor requirements
- Environmental conditions

48. **How are motors cooled?**

- Air cooling
- Liquid cooling
- Forced ventilation in large motors

49. **What are effects of over-excitation & under-excitation?**

- **Under-excitation**: lagging PF, overheating
- **Over-excitation**: leading PF, potential system instability

50. **What causes loss of synchronism?**

- Sudden load changes
- Faults in excitation system
- Improper voltage/frequency

51. **Can synchronous motors work with renewable sources?**
    Yes, especially with wind turbines or hydro plants acting as synchronous generators.

52. **How does excitation control impact performance?**
    It regulates:

- Power factor
- Reactive power
- Stability
- System voltage support