DC MACHINES

Basic Overview :

DC machines are electromechanical devices that convert energy between mechanical and electrical forms, utilizing direct current (DC) for their operation. They are broadly classified as DC generators and DC motors, each performing opposite energy conversions. DC generators convert mechanical energy (like from a rotating shaft) into DC electrical power, while DC motors convert DC electrical power into mechanical energy (like rotation).

Key Aspects of DC Machines:

- **Energy Conversion:**

DC machines are fundamental for converting energy between mechanical and electrical forms, with generators converting mechanical to electrical and motors converting electrical to mechanical.

- **Two Main Types:**

The two primary types are DC generators (converting mechanical energy to electricity) and DC motors (converting electrical energy to mechanical energy).

- **DC Power:**

They utilize direct current, which is a steady, unidirectional electrical current.

- **Construction:**

DC machines have a similar construction, generally including a stationary field structure (stator), a rotating armature, and a commutator/brushes for DC conversion.

- **Working Principle:**

The working principle of DC generators is based on Faraday's law of electromagnetic induction, where a conductor moving in a magnetic field generates an electromotive force (EMF). Conversely, the DC motor operates on the principle that a current-carrying conductor in a magnetic field experiences a force, causing rotation.

- **Reversibility:**

In principle, a DC machine can be used as either a generator or a motor, with the direction of energy flow being reversed.

- **Applications:**

DC machines find applications in various fields, including electric motors, generators, and other electromechanical systems where DC power is required

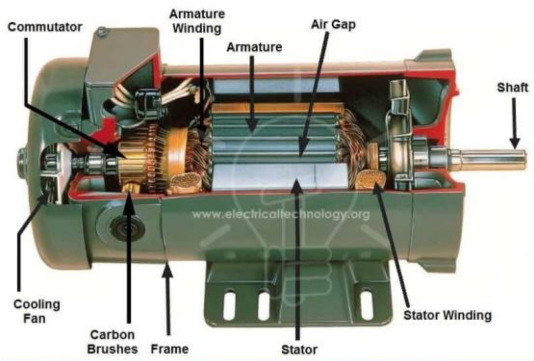
Let us dive into the topic to develop an in-depth understanding :

SECTION 1. CONSTRUCTION AND BASIC COMPONENTS

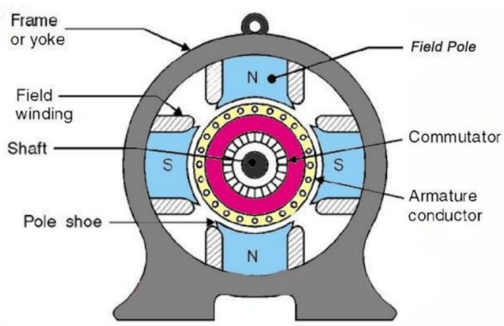
1. What are the basic parts of a DC machine?

Ans:

- **Stationary parts**:
    - **Yoke (Frame):** Provides mechanical support and forms the magnetic return path.
    - **Main Poles:** Produce the main magnetic field using field coils.
    - **Field Coils (Field Windings):** Carry DC current to excite the main poles.
    - **Interpoles (Commutating Poles):** Small auxiliary poles placed between main poles to improve commutation.
    - **Compensating Windings:** Placed in slots on pole faces to counteract armature reaction effects.
- **Rotating parts**:
    - **Armature Core:** Laminated to minimize eddy current losses; provides a path for magnetic flux.
    - **Armature Windings:** Conductors where emf is induced (generator) or through which current flows (motor).
    - **Commutator:** Mechanical rectifier converting AC induced in armature to DC at output.
    - **Shaft:** Transmits mechanical power and supports rotating parts.



Construction of DC Machine



Construction of DC Machine

2. Name the parts of a DC machine that control the magnetic circuit.

Ans:

- **Poles:** Produce the required magnetic field.
- **Air-gap:** Gap between armature and poles, where the rotating action occurs.
- **Armature Core:** Provides a path for flux from one pole to another.
- **Yoke:** Acts as a magnetic return path and supports poles.

3. What is the function of a commutator?

Ans:

- Converts the alternating current induced in the armature winding into unidirectional current for external use.
- Enables current collection from rotating armature without reversing direction every half cycle.

4. What is the function of brushes in a DC machine?

Ans:

- They are carbon blocks that maintain electrical contact with the rotating commutator.
- Transfer current between stationary external circuit and rotating armature.

5. What is the purpose of the yoke in a DC machine?

Ans:

- Provides mechanical protection and support for the entire machine structure.
- Forms the outer magnetic circuit and carries the return magnetic flux from the poles.

6. Why are carbon brushes preferred in DC machines?

Ans:

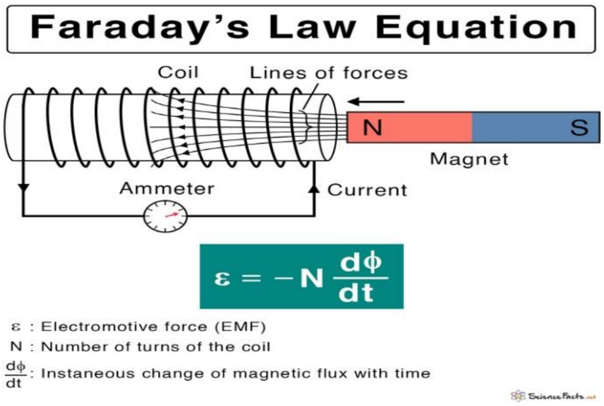
- Carbon has good lubricating properties, reducing wear and tear.
- It provides high contact resistance, aiding in smooth commutation and reducing sparking.

SECTION 2. DC GENERATOR – PRINCIPLES AND TYPES

7. What is the working principle of a DC generator?

Ans:

- It operates on **Faraday's Law of Electromagnetic Induction**: when a conductor cuts through magnetic flux, an emf is induced in it.



8. How is voltage generated in rotating machines?

Ans:

- Either conductors rotate in a magnetic field, or the magnetic field rotates around conductors.
- Relative motion between the conductor and magnetic field is essential.

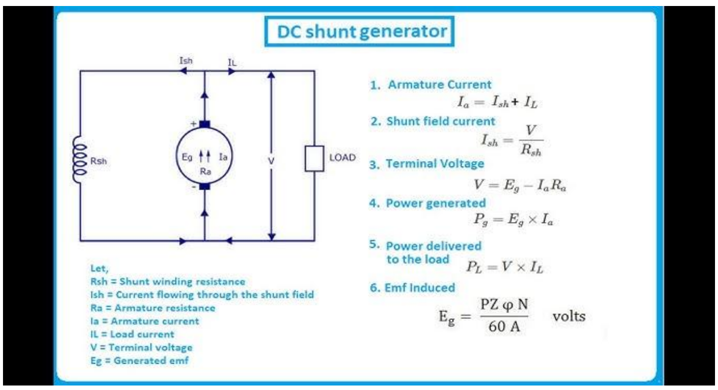
9. Define the EMF equation of a DC generator.

Ans:

E= [ΦZNP/60A] Volts

Where:

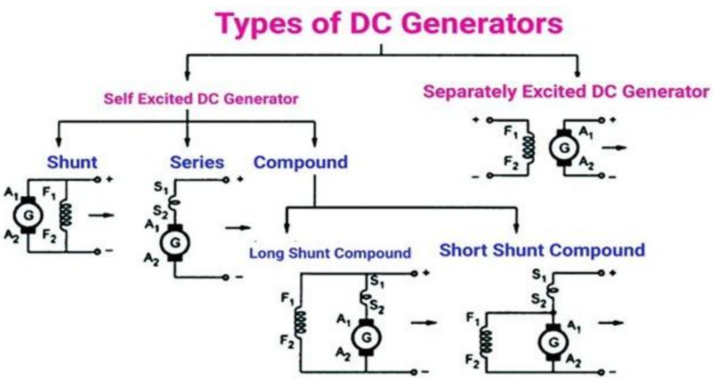
- Φ = Flux per pole (Weber)
- Z = Total number of armature conductors
- N = Armature speed in RPM
- P = Number of poles
- A = Number of parallel paths (depends on winding type)



10. What are the different types of DC generators?

Ans:

- **Separately Excited** Generator
- **Self-Excited** Generators:
    - Series
    - Shunt
    - Compound:
        - Long-shunt
        - Short-shunt



11. Define separately and self-excited generators.

Ans:

- **Separately Excited Generator:** The field winding is powered by an external DC source.
- **Self-Excited Generator:** The field winding is energized by the generator's own induced emf.

12. What is residual flux and its importance in generators?

Ans:

- Residual magnetism is the small magnetic field remaining in the poles even when the machine is off.
- It is crucial for initiating the emf buildup during starting.

13. Why may a DC generator fail to build up voltage?

Ans:

- Absence of residual magnetism
- Field winding incorrectly connected
- Field circuit resistance is too high
- Reversed polarity of field connection

14. Define critical field resistance.

Ans:

- It is the maximum field circuit resistance at which a shunt generator will just build up voltage.

15. Define critical speed in a DC generator.

Ans:

- Minimum speed below which a DC generator fails to build up the required emf for a given field resistance.

SECTION 3. DC MOTOR – PRINCIPLES AND PERFORMANCE

16. What is the operating principle of a DC motor?

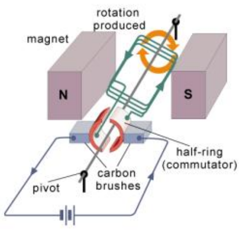
Ans:

- Based on **Lorentz Force**: When a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force.

17. What is back EMF in DC motors?

Ans:

- It is the emf induced in the armature due to its rotation in the magnetic field, which opposes the applied voltage (Lenz's Law).



18. Give the condition for maximum mechanical power in a DC motor.

Ans:

- Mechanical power is maximum when back emf $E_b = V/2$ and $I_a = V/2R_a$

Where:

- E_b = Back EMF
- V = Applied voltage
- I_a = Armature current
- R_a = Armature resistance

19. Define speed regulation.

Ans:

%Speed Regulation = [(Nno_load−Nfull_load) / (Nfull_load)]×100%

Where:

- Nno_load = No-load speed
- Nfull_load = Full-load speed

Indicates how much speed drops from no-load to full-load.

20. Why can't a series motor run without a load?

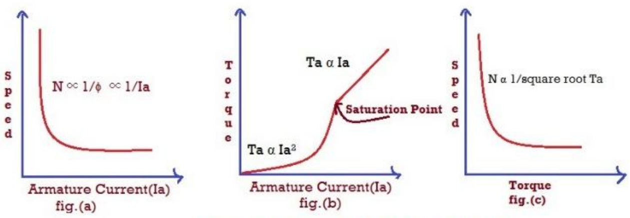
Ans:

- Flux (Φ) becomes small at no load due to low current, increasing speed dangerously as

$N \propto 1/\Phi$

Where:

- N = Speed of motor
- Φ = Magnetic flux per pole



Characteristics of DC Series Motor

21. Why is a DC shunt motor called a constant speed motor?

Ans:

- Field current is almost constant → constant flux → speed remains nearly unchanged with varying load.

22. What happens if current direction is reversed at motor terminals?

Ans:

- If both armature and field currents are reversed, direction of rotation remains unchanged.

23. What happens if a DC motor is connected to AC supply?

Ans:

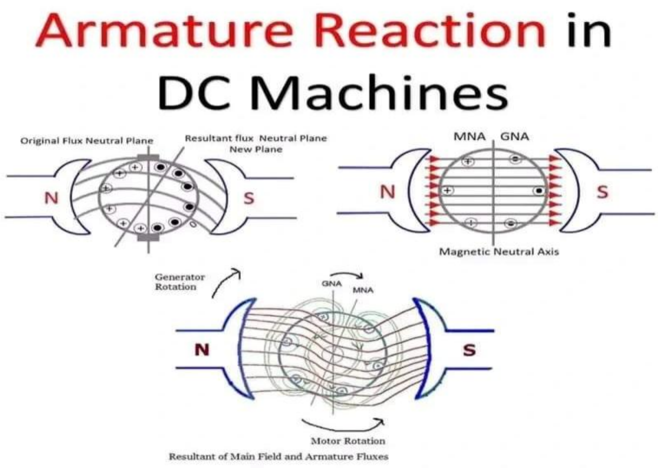
- Severe sparking, heating due to eddy currents, vibration, and poor performance – not suitable.

SECTION 4. ARMATURE REACTION AND COMMUTATION

24. What is armature reaction?

Ans:

- The distortion and weakening of the main field flux due to the magnetic field of armature current.



25. What are the effects of armature reaction?

Ans:

- **Demagnetizing effect:** Reduces the effective flux.
- **Cross-magnetizing effect:** Distorts the flux distribution.
- **Brush sparking:** Due to shifted neutral plane.

26. What are compensation windings?

Ans:

- Conductors embedded in the pole faces.
- Carry armature current in opposite direction to cancel the cross-magnetizing effect.
- Used in large or fluctuating load motors to stabilize performance and minimize commutation problems.

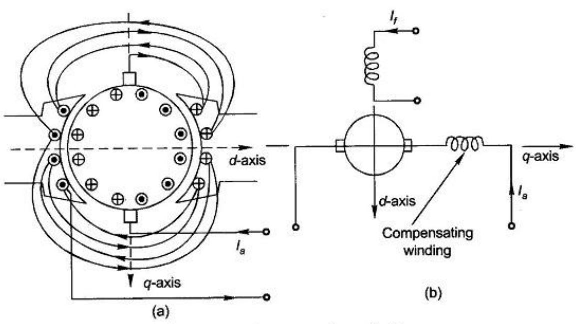
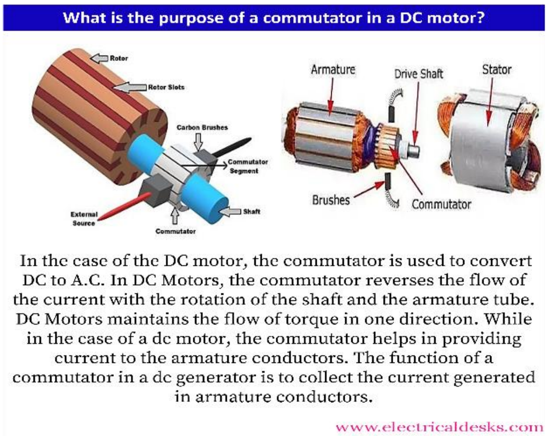


Fig. 7.13 *Compensating winding*

27. What is commutation in DC machines?

Ans:

- The process of current reversal in armature conductors under the influence of brush contact.



28. How to improve commutation?

Ans:

- **Resistance Commutation:** Using carbon brushes to increase resistance.
- **EMF Commutation:** Using interpoles with commutating polarity to neutralize reactance emf.

SECTION 5. SPEED CONTROL OF DC MOTORS

29. What are the different methods of speed control of DC motors?

Ans:

DC motor speed is given by:

$$N \propto (V - I_a R_a) / \Phi$$

So, speed can be varied by changing:

1. **Armature Voltage (V):** Affects numerator → controls speed directly.
2. **Field Flux (Φ):** Inversely affects speed.
3. **Armature Circuit Resistance (R_a):** Alters voltage drop across the armature.

Thus, the main methods are:

- **Field Control (Flux Control):**
    - Vary field current using a rheostat in series with the shunt field.
    - $N \propto 1/\Phi$ → Decreasing flux increases speed.
    - Only provides speeds **above** the rated value.

- **Armature Resistance Control:**
    - Add variable resistance in series with armature.
    - Voltage across armature reduces → speed decreases.
    - Used for speeds **below** rated value.
    - Poor efficiency due to power loss in added resistance.
- **Voltage Control Method:**
    - Vary the armature terminal voltage (used in modern methods with power electronics).
    - Provides **smooth and wide** range control.

30. What are the advantages of flux control method?

Ans:

- Simple and economical.
- No power loss as in resistance control.
- Allows speed control over a wide range **above** rated speed.
- Easy to implement using a field rheostat.

31. What are the disadvantages of armature resistance control?

Ans:

- **I^2R losses** in the external resistor → poor efficiency.
- Poor speed regulation (speed varies with load).
- Requires large resistors that dissipate heat.
- Effective only for **short-term** or **intermittent** applications.

32. What is Ward Leonard system of speed control?

Ans:

- A method of **variable voltage control** for DC motors.
- Components:
    - Motor-generator set (AC motor drives a DC generator).
    - DC motor is supplied by the output of the DC generator.
- Speed of DC motor controlled by varying field excitation of the generator.
- Allows **smooth and wide-range** speed control in both directions.
- Used in lifts, rolling mills, traction.

SECTION 6. STARTING AND PROTECTION

33. Why is a starter needed for DC motors?

Ans:

- At start, back EMF Eb=0 , so:

$$Ia = V/Ra$$

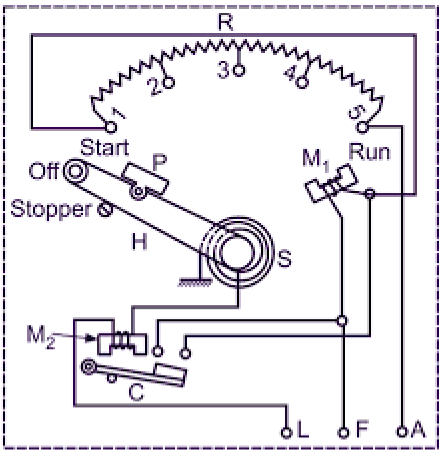
where Ra is very small → excessive current can damage the motor.

- A **starter limits starting current** by inserting resistance in series with armature.

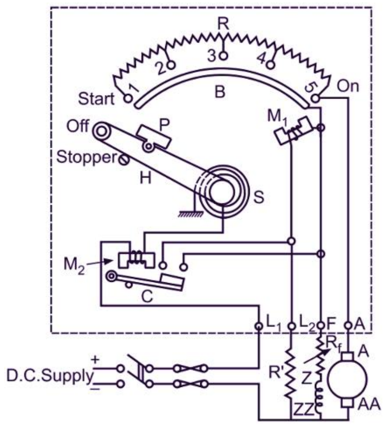
34. Name different types of DC motor starters.

Ans:

- **3-point starter:**
  - For **shunt** or **compound** motors.
  - Three terminals: L (Line), A (Armature), F (Field).
  - Provides overload protection and under-voltage protection.
- **4-point starter:**
  - Similar to 3-point, but field coil is connected separately to line.
  - Independent field circuit → better speed control, especially for field weakening method.



3 point starter



4 point starter

35. What is the role of the No-volt coil (NVC)?

Ans:

- Prevents motor from restarting automatically after power failure.
- If supply fails, the starter handle is pulled back to 'OFF' position by a spring.

36. What is the function of an overload release coil?

Ans:

- Protects the motor from excessive current (overload).
- Trips the starter handle when armature current exceeds a preset limit.

SECTION 7. APPLICATIONS OF DC MACHINES

37. Where are DC motors commonly used?

Ans:

- **DC Shunt Motor:**
  - Constant speed applications.
  - Lathes, fans, pumps, blowers, machine tools.
- **DC Series Motor:**
  - High starting torque applications.
  - Electric trains, cranes, hoists, elevators.
- **DC Compound Motor:**
  - Combination of high torque and relatively constant speed.
  - Presses, conveyors, rolling mills.

38. What are the applications of DC generators?

Ans:

- **Separately Excited DC Generators:**
  - Used in laboratory testing, electroplating, and excitation of alternators.
- **Shunt Generators:**
  - Battery charging, lighting, and low-load applications.
- **Series Generators:**
  - Rarely used; used in boosting low-voltage lines.
- **Compound Generators:**
  - Street lighting, heavy power loads where voltage regulation is essential.

39. Why is a DC series motor preferred for traction applications like electric trains or trams?

Ans:
DC series motors offer very high starting torque, which is essential for heavy traction loads. Their torque is proportional to the square of armature current (T∝Ia2T \propto I_a^2T∝Ia2), making them ideal for pulling heavy loads from rest.

40. Why are DC shunt motors used in lathes and machine tools?

Ans:
DC shunt motors have almost constant speed characteristics regardless of load, making them suitable for applications like lathes, where precise and stable speed is essential for machining accuracy.

41. What type of DC motor is used in cranes and hoists, and why?

Ans:
DC series or compound motors are used in cranes and hoists because they provide high starting torque and can handle sudden load variations effectively.

42. Why are compound generators used for street lighting or arc welding?

Ans:
Compound generators offer better voltage regulation compared to shunt or series generators. They maintain a relatively constant terminal voltage even under varying loads, which is crucial for consistent lighting and welding performance.

43. Can a DC motor be used for regenerative braking? If yes, how?

Ans:
Yes. In regenerative braking, the DC motor acts as a generator during deceleration. The kinetic energy of the load is converted into electrical energy, which can be fed back to the supply or dissipated. This method is commonly used in electric vehicles and elevators.

44. Why is a separately excited DC generator preferred for lab testing?

Ans:
It allows independent control of field excitation and hence, the output voltage. This makes it ideal for experimentation and testing where precise and variable voltage control is required.

45. Why are DC motors still used in electric traction even though AC machines are available?

Ans:
DC motors, especially series types, offer better torque-speed characteristics for traction, simple speed control, and reliable performance under variable load conditions. Even though AC motors are now replacing them, DC motors still find use in legacy systems and certain specialized applications.

46. In which applications would you prefer a DC compound motor over other types?

Ans:
DC compound motors are preferred where a **compromise between high starting torque and good speed regulation** is needed—such as in rolling mills, presses, and conveyors

SECTION 8. LOSSES AND EFFICIENCY

47. What are the different types of losses in a DC machine?

Ans:

- **Copper Losses (Variable Losses):**

- Armature copper loss: $I_a^{2}R_a$
- Field copper loss: I_f ^2R_f
- Brush contact loss (minor)

- **Iron or Core Losses (Constant Losses):**
  - **Hysteresis loss**: Due to reversal of magnetism in armature core.

$$P_h \propto (B_{max}^{1.6})*f$$

  - **Eddy current loss**: Induced currents in core.

$$P_e \propto B_{max}^2 f^2 t^2$$

- **Mechanical Losses (Constant Losses):**
  - Bearing friction
  - Windage (air resistance)

48. How is the efficiency of a DC machine defined?

Ans:

$$\eta = [\text{Output Power}/ \text{Input Power}] \times 100$$

- For generator:

$$\eta = [VI_L / VI_L + \text{Losses}] \times 100$$

- For motor:

$$\eta = [\text{Mechanical Output} / \text{Electrical Input}] \times 100$$

49. How can efficiency of a DC machine be improved?

Ans:

- Reduce copper losses by using low-resistance windings.
- Use laminated cores to reduce eddy current losses.
- Choose better magnetic materials to reduce hysteresis loss.
- Use high-quality bearings and maintain proper lubrication to reduce mechanical losses.