DC Motors

🔌 Electric Machines Overview

1. **Definition**:
   Electric machines are devices that convert energy from one form to another — specifically between mechanical and electrical energy.
2. **Types**:
   - **Generator**: Converts **mechanical energy → electrical energy**.
   - **Motor**: Converts **electrical energy → mechanical energy**.
3. **Working Principle**:
   To understand motors or generators, one must understand how a **current-carrying conductor** behaves in a **magnetic field**.

🧲 Force on Current-Carrying Conductor

1. **Basic Concept**:
   When a **current-carrying conductor** is placed in a magnetic field, it experiences a **mechanical force**. This is the basic principle behind how motors work.
2. **Experiment Setup**:
   - A **straight conductor** is placed between the poles of a **permanent magnet**.
   - When **current flows** through the conductor, it creates its own **magnetic field**.
3. **Magnetic Interaction**:
   - The magnetic field of the current-carrying conductor interacts with the field of the permanent magnet.
   - This causes a **force** to act on the conductor.
4. **Direction of Force**:
   - Determined using **Fleming's Left-Hand Rule**.

- The conductor moves in a direction perpendicular to both the current and the magnetic field.

Magnitude of Force on a Current-Carrying Conductor

The **magnitude of force** FFF experienced by a current-carrying conductor placed in a magnetic field is given by the formula:

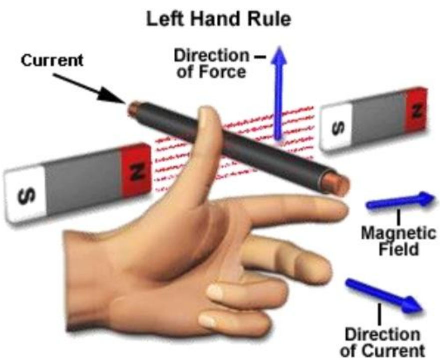
$$F = BILsin\theta$$

Where:

- F = Magnetic force (in newtons, N)
- B = Magnetic flux density (in tesla, T)
- I = Current flowing through the conductor (in amperes, A)
- L= Length of the conductor (in meters, m)
- θ = Angle between magnetic field and current direction

🧭 Direction of Force

- The **direction of rotation** of a conductor (such as in a motor) depends on:
  - The **direction of current** in the armature winding, and
  - The **direction of magnetic field**.
- The **direction of force** experienced by a current-carrying conductor in a magnetic field is given by **Fleming's Left-Hand Rule**.



✋ Fleming's Left-Hand Rule (Statement)

It states that:

If the **thumb**, **forefinger**, and **middle finger** of the **left hand** are held mutually **at right angles (90°)** to each other:

- The **Forefinger** indicates the **direction of the magnetic field** (from North to South).
- The **Middle finger** indicates the **direction of current** (from positive to negative).
- The **Thumb** gives the **direction of force** (or motion) acting on the conductor.

This rule is commonly used to determine the direction of motion in electric motors.

⚙️ Windings in DC Machines

- In **DC machines**, there are **two types of windings**:
    1. **Field Winding**
    2. **Armature Winding**
- Out of these:
    - The **field winding** is **stationary** — it does **not move**.
    - The **armature winding** is **mounted on a shaft** so that it can **rotate freely**.

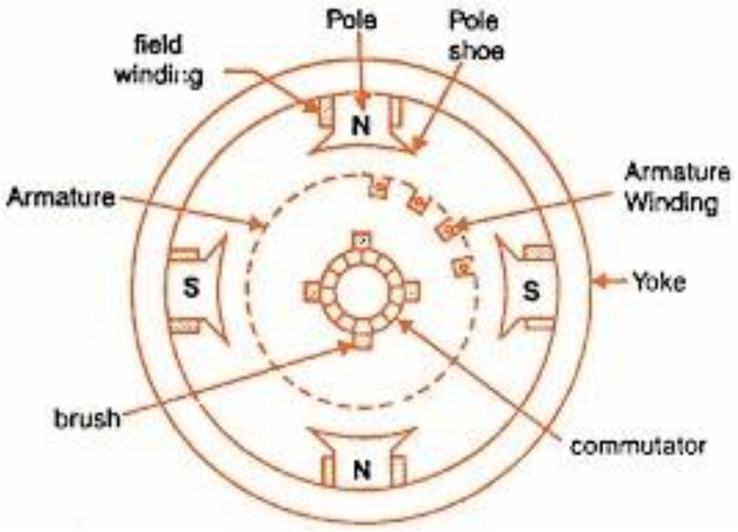
🔌 Connection of Windings for Motor Operation

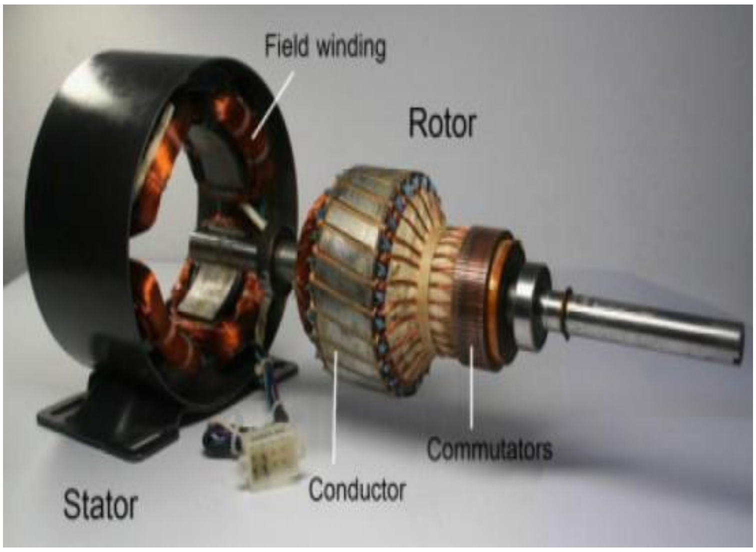
- To operate the DC machine as a **motor**, both the **field winding** and **armature winding** are connected across a **DC power supply**.

⚙️ Principle of Operation – DC Motor

- When **current-carrying conductors** are placed in a **magnetic field**, they experience a **force**.
- In the case of a **DC motor**, the magnetic field is developed due to the current (DC current) flowing in the **field winding** and **armature winding**.
- As a result, the **current-carrying conductors** of the **armature** experience a **force** and start **rotating**.

Construction of DC Motor





Parts of a DC Motor

1. Yoke

- Also called the **frame** of the motor.
- Made of cast iron or steel.
- Provides mechanical support and protection to the internal parts.
- Acts as the **magnetic path** for the flux.

2. Poles

- Bolted or welded to the yoke.
- Each pole has a **field winding** on it.
- Increases the magnetic field strength and helps in creating uniform flux distribution.

3. Field Winding

- Copper wire wound around the poles.
- When current flows, it produces a magnetic field.
- Controls the strength of the main field in the motor.
- Can be connected in different ways (shunt, series, compound).

4. Armature

- Rotating part of the motor.
- Consists of **armature core** (made of laminated steel) and **armature winding** (copper wire).
- Converts **electrical energy into mechanical energy** (or vice versa in generators).
- The rotation happens due to interaction with the magnetic field.

5. Commutator

- Cylindrical structure made of copper segments insulated from each other.
- Attached to the armature shaft.
- Converts the AC induced in the armature to **DC output**.
- Helps maintain unidirectional torque.

6. Brushes

- Usually made of carbon or graphite.
- Rest on the commutator.
- Conduct current between external circuit and rotating armature.
- Worn out brushes can cause sparking or poor contact.

7. Gear (if used)

- Not part of all DC motors, but used in geared DC motors.
- Helps **adjust the speed and torque**.
- Common in robotics, automation, and small electronic devices.

What is Back EMF in a DC Motor?

Back EMF (Electromotive Force) is the voltage **induced in the armature winding** of a DC motor due to its rotation in the magnetic field.

🔄 How it Works:

- When the **motor armature rotates**, it cuts through the magnetic field lines.
- According to **Faraday's Law of Electromagnetic Induction**, a voltage is induced in the armature.
- This induced voltage **opposes the applied voltage** (Lenz's Law), hence the name **"back EMF"**.

Formula:

$$Eb = \frac{P.\Phi.Z.N}{60.A}$$

Where:

- Eb = Back EMF (Volts).
- P = Number of poles.
- Φ = Flux per pole (Weber).
- Z = Total number of armature conductors.
- N = Speed of armature (RPM).
- A = Number of parallel paths in armature winding.

🔍 Importance of Back EMF:

- **Limits armature current**: As speed increases, back EMF rises, reducing the net voltage and current.
- **Provides automatic speed regulation**: Acts as a self-governing mechanism.
- **Makes the motor more efficient**: Prevents excess current draw.

🔧 Practical Example:

- At startup: Armature is stationary → **Back EMF = 0** → **High current** (that's why a starter is used).
- At full speed: **Back EMF nearly equals applied voltage** → **Low current draw**.

✅ Why Back EMF Is Actually a Good Thing:

Aspect	**Explanation**
Self-regulating current	As motor speeds up, back EMF increases, reducing current and preventing overheating.
Energy efficiency	It helps avoid drawing unnecessary power once the motor is running.
Speed control	It makes the motor respond naturally to changes in load—when load increases, speed drops slightly, back EMF drops, and more current flows automatically.
Motor protection	At high speeds, it prevents excessive current draw, which protects windings and components.

Voltage Equation of a DC Motor:

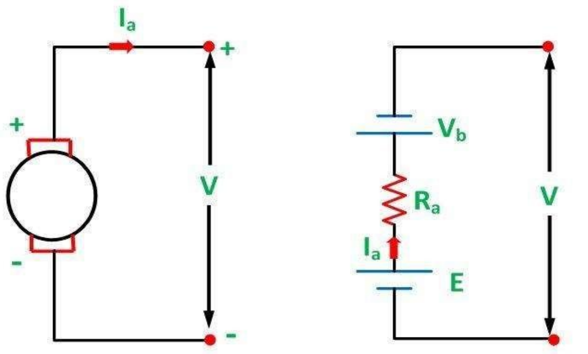


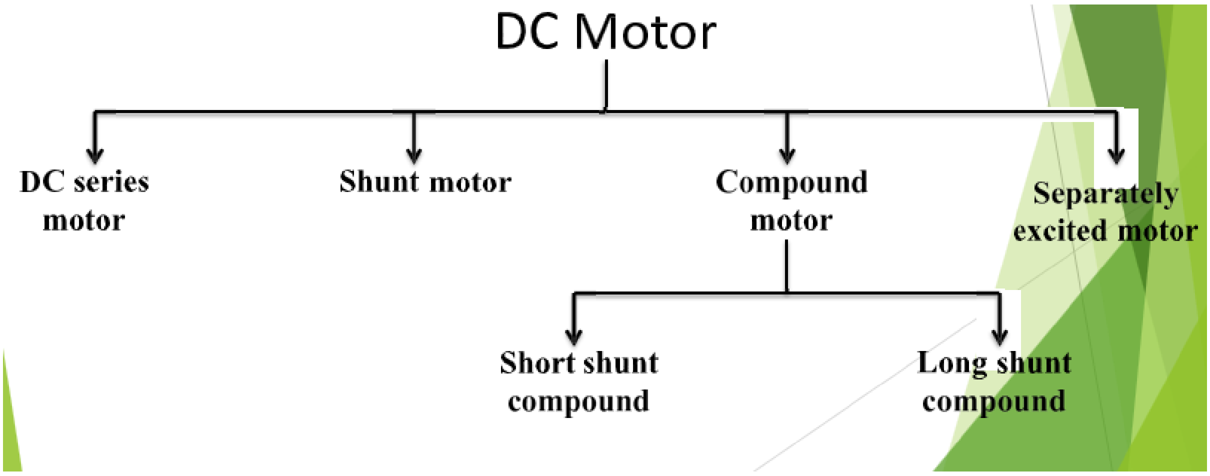
Fig.(1):Equivalent circuit of DC motor

$$V = Eb + IaRa$$

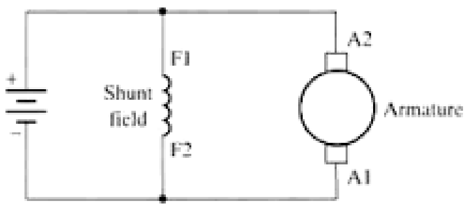
🔁 **Rearranged Form (to find Back EMF):**

$$Eb = V - IaRa$$

Types of DC Motors by Field and Armature Connection:



1. DC Shunt Motor



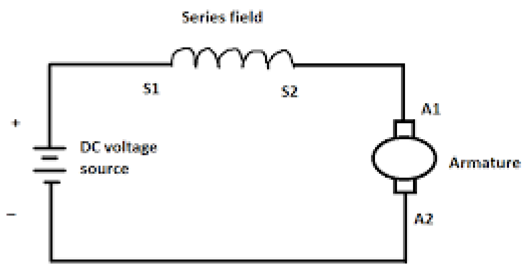
- **Connection**: Field winding is connected **in parallel** (shunt) with the armature.
- **Field Current**: Constant and independent of armature current.
- **Rsh** (Shunt Field Resistance is**)** typically **high,** **Ra** (Armature Resistance) is usually high.
- DC shunt motors have **constant flux** and relatively **constant speed**.
- **Features**:
  - Almost constant speed.
  - Good for applications needing **speed stability**.
- **Applications**: Lathes, fans, blowers, conveyors.
- Also known as constant flux motor.

2. DC Series Motor

- **Connection**: Field winding is connected **in series** with the armature.
- **Field Current**: Same as armature current.
- **Flux is proportional to field current, but here field current = armature current**. So:

  $$\Phi \propto Ia \ and \ \Phi \propto Is$$

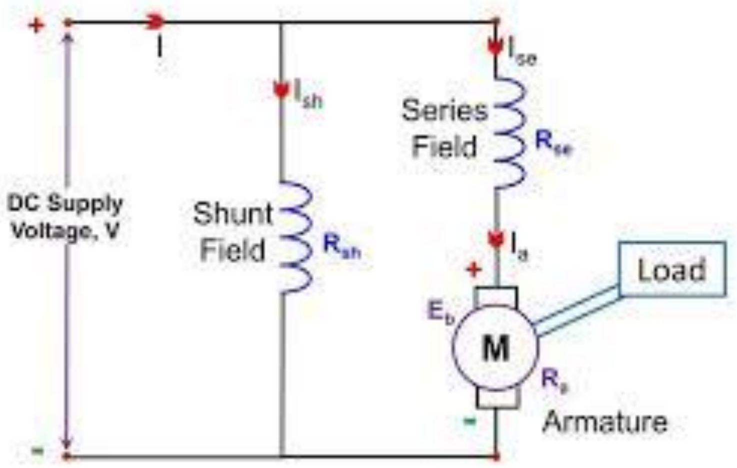
  Hence Flux is not constant
- **Features**:
  - High starting torque.
  - Speed varies greatly with load.
- **Applications**: Electric trains, cranes, elevators, traction systems.



3. DC Compound Motor

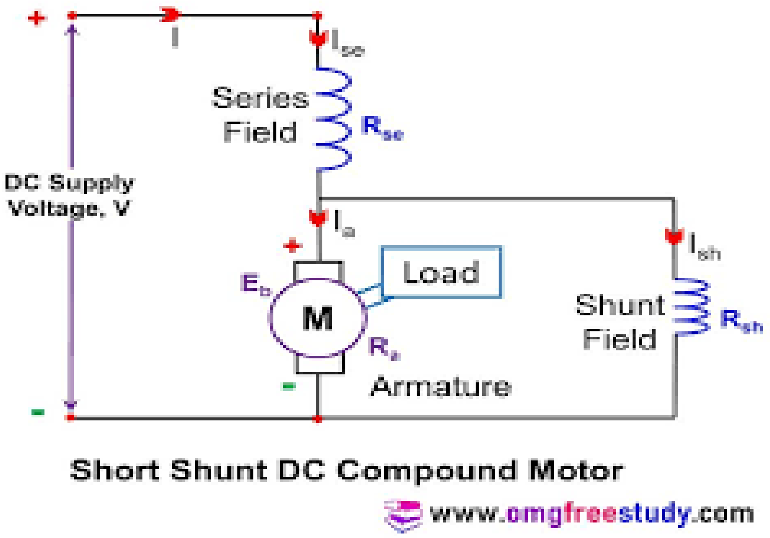
A DC compound motor combines the features of both **shunt** and **series** motors by having **two field windings.**

1. **Long Shunt Compound Motor**
   - **Connection**: The **shunt field** is connected in **parallel** with series combination of armature and series field.



Long Shunt DC Compound Motor

2. **Short Shunt Compound Motor**
   - **Connection:** The shunt field is connected in parallel with the armature only, not with the series field.



Torque Equation of a DC Motor

$$T = k \cdot \Phi \cdot Ia$$

Where:

- T = Torque (Nm)
- k = Motor constant
- Φ = Magnetic flux per pole (Wb)
- Ia = Armature current (A)

Speed Equation of a DC Motor

- **Speed N:**

$$N = \frac{Eb}{k\Phi}$$

Where:

- N = Speed (RPM)

- Eb = Back EMF
- k = Motor constant
- Φ = Flux per pole

1. **DC Series Motor**
   - **Torque Equation**
     - Flux is **proportional to armature current** Φ∝Ia (until saturation).

$$T \propto \Phi \cdot Ia \Rightarrow T \propto Ia2$$

   - **Speed Equation**

$$\boldsymbol{N \propto \frac{V - IaRa}{\Phi} \Rightarrow N \propto \frac{1}{Ia}}$$

2. DC Shunt Motor
   - Torque Equation
     - Flux is **constant** (since shunt field current is constant for a fixed voltage).

$$\boldsymbol{T \propto \Phi \cdot Ia \Rightarrow T \propto Ia}$$

   - Speed Equation:

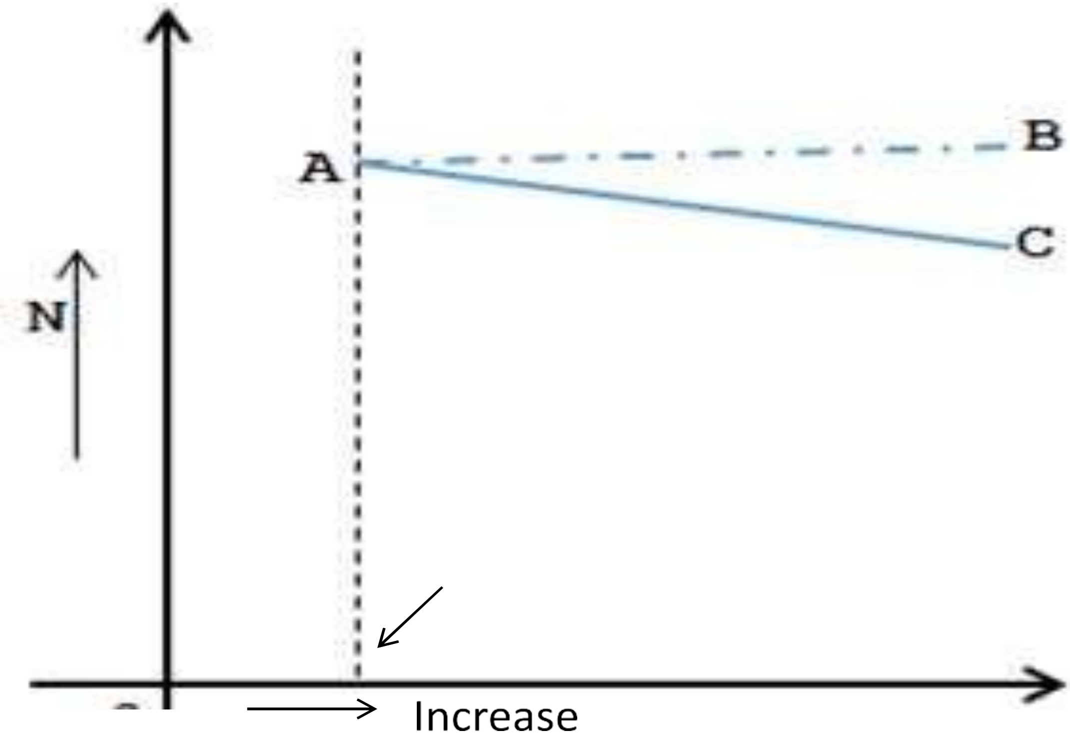
$$\boldsymbol{N \propto \frac{V - IaRa}{\Phi}}$$

✅ **Summary Table**

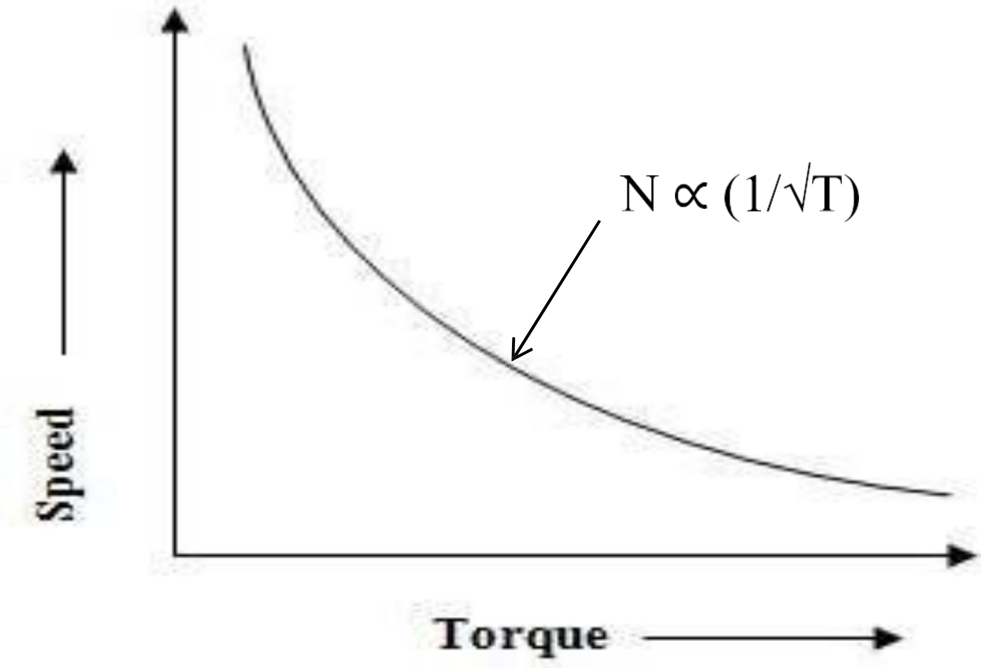
Feature	**Shunt Motor**	**Series Motor**
Flux (Φ)	Constant	Varies with Ia
Torque	$T \propto Ia$	$T \propto Ia^2$
Speed	Nearly constant	Varies widely (inversely with Ia)
Use Case	Constant speed applications	High torque needs (e.g. cranes)

Torque Speed Characteristics

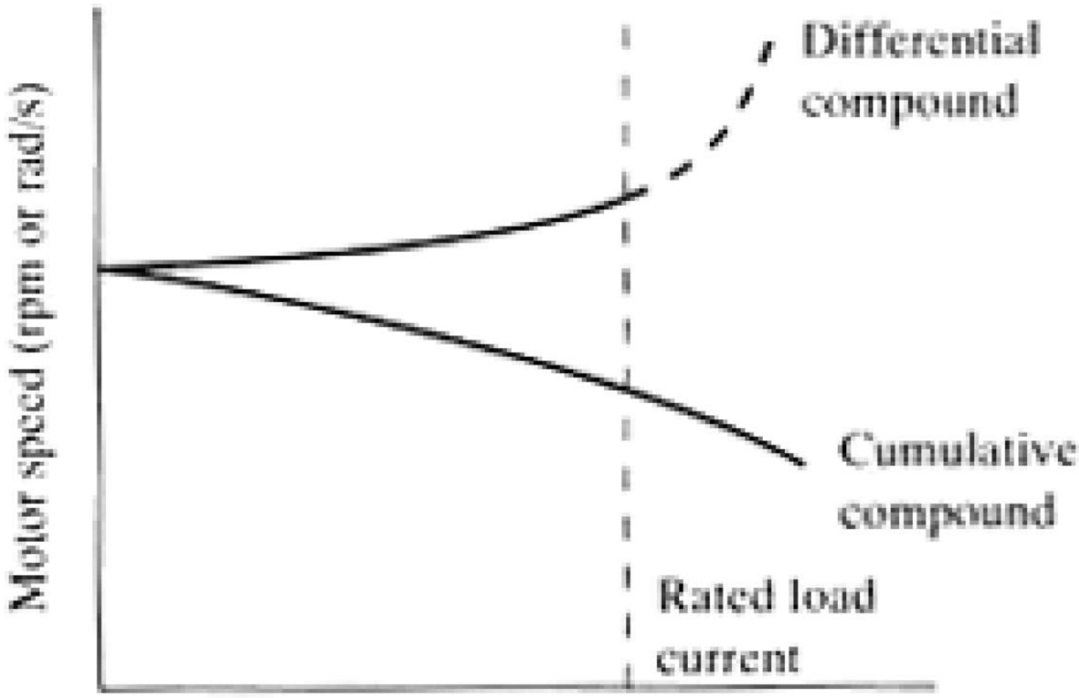
1. DC Shunt Motor:



2. DC Series Motor:



3. Compound Motor



Need for Starter in DC Motors ⚡

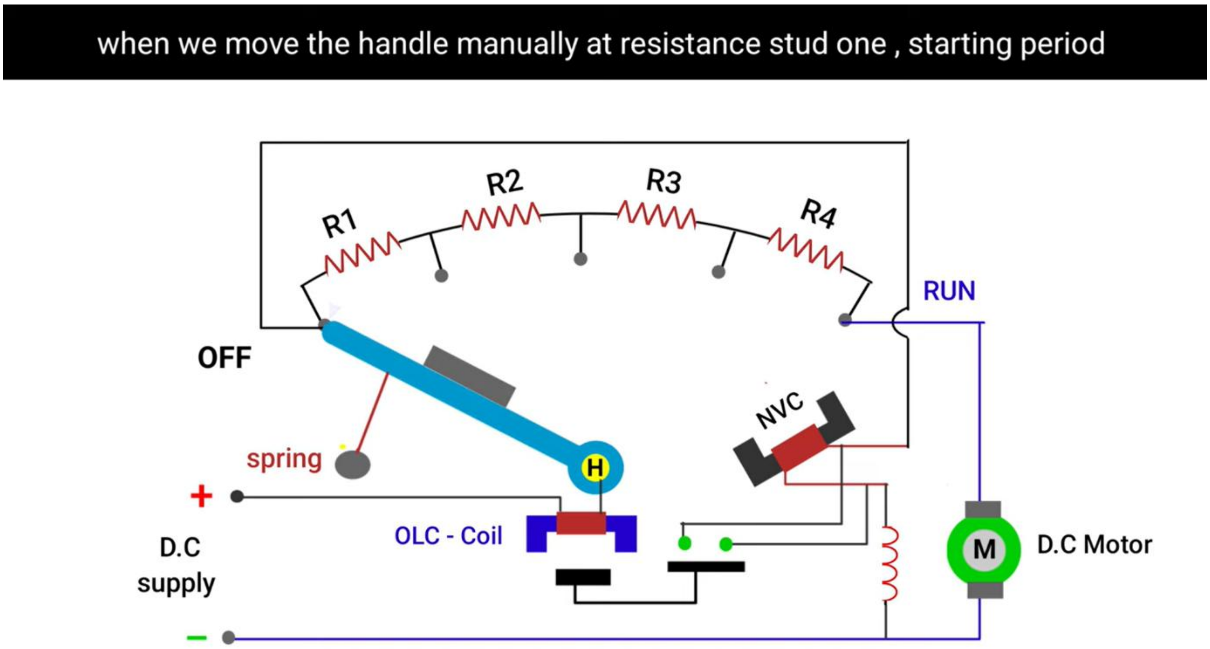
A **starter** is essential for **DC motors** (both **series** and **shunt**) to **safely initiate operation**. Here's **why it is needed**:

Function of Starter

A **starter** adds a **series resistance** to the armature circuit at startup, which:

- **Limits the initial current**
- Gradually **reduces resistance** as the motor picks up speed and back EMF builds up
- Ensures **smooth acceleration** and **prevents electrical/mechanical damage**

3-point starter



Three-Point Starter

Used for: 🟢 **DC Shunt Motor**

⚙️ **Connections:**

- **L** → Line
- **A** → Armature
- **F** → Field winding

🛠️ **Components:**

- **Starting resistance** (in series with armature)
- **No-Voltage Coil (NVC)** – pulls the handle to OFF if supply fails
- **Overload Relay (OLR)** – trips on overload
- **Spring-loaded handle** – returns to OFF on failure

✅ **Pros:**

- Protects motor from **overcurrent** and **supply loss**

❌ **Cons:**

- If field current is adjusted (e.g. for speed control), NVC might drop out unintentionally