DEE 3143 BASIC ELECTRICAL MACHINE & POWER SYSTEMS

CHAPTER 3
DIRECT CURRENT MOTOR

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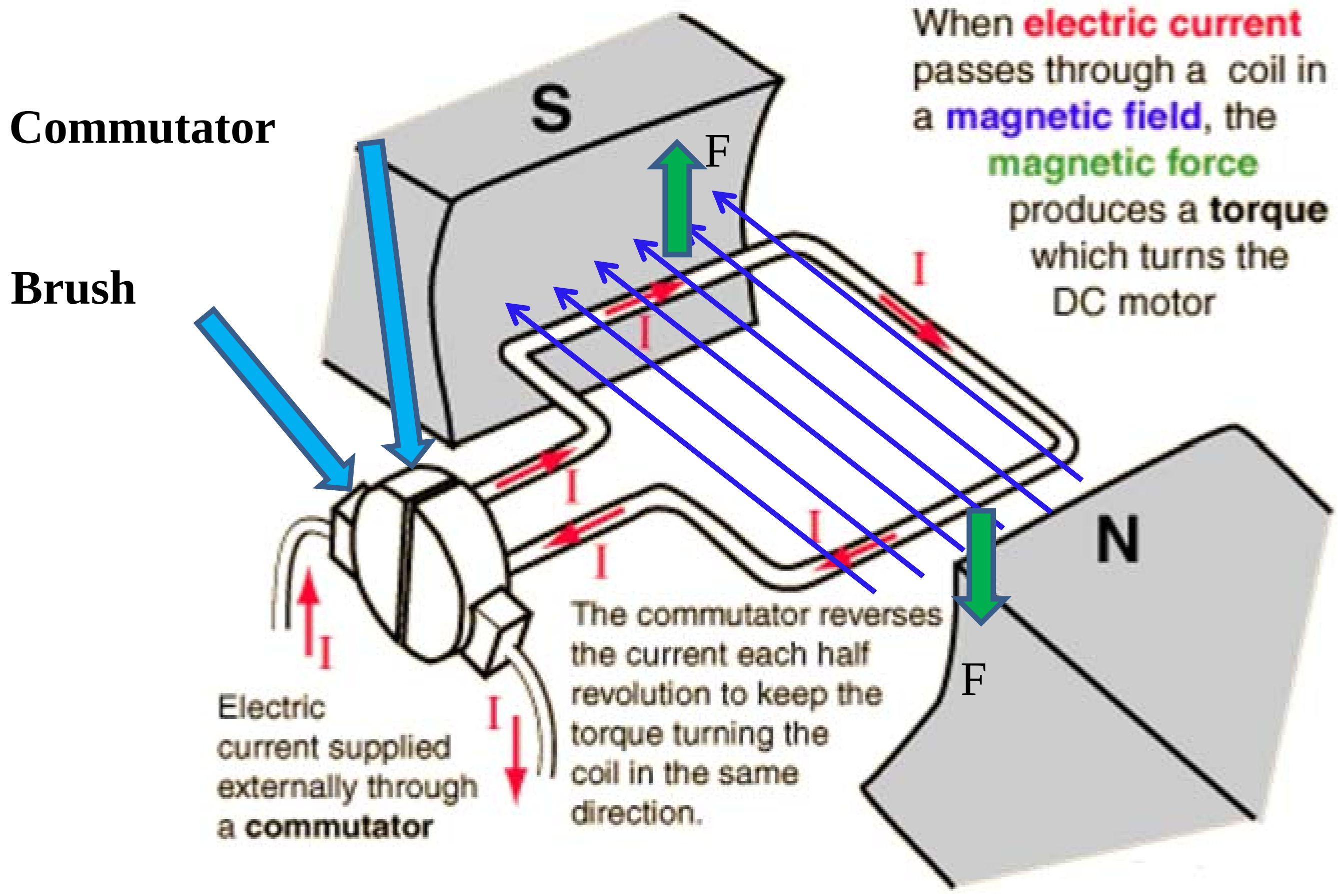
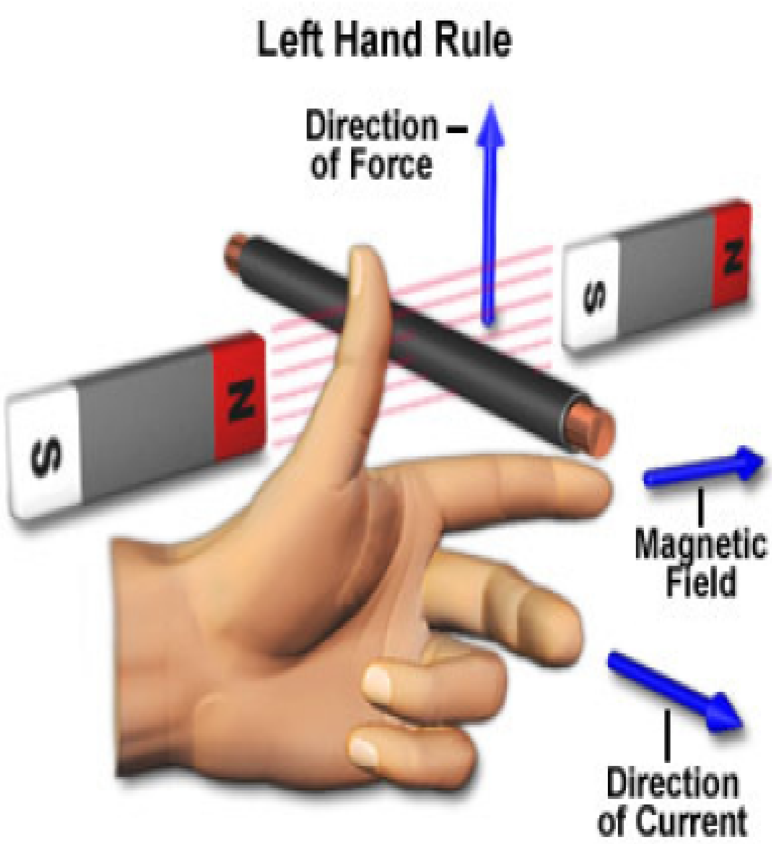
2.3 PRINCIPLES OF OPERATION

DC Motor Operation



Source: http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/motdc.html

Fleming left hand rule



Magnitude of force in motor:

$$F = Bl I \text{ (N)}$$

B = flux density due to the flux produced by the field winding

l = length of the conductor

I = magnitude of the current passing through conductor

Source: https://www.electrical4u.com/fleming-left-hand-rule-and-fleming-right-hand-rule/

Back EMF

- An EMF induced due rotational of coil within magnetic field, which the flux field changes at different positions
- The EMF induced in several coils:

$$E_a = \frac{\phi ZNP}{60a} = V - I_a R_a$$

Ø	Flux per pole
Z	no of conductors in the armature
P	no of poles
a	no of parallel paths
N	speed of the motor
V	supply voltage
Ia	Armature current
Ra	Armature resistance

Developed torque

- The force acting on the rotor: $F = il \times B$
- The rotor rotates at a speed of N rpm, so the angular speed of the rotor:

$$\omega_m = \frac{2\pi N}{60} rad/\sec$$

- Current in a single conductor is:

$$I_{cond} = \frac{I_a}{a}$$

- The total induced torque is:

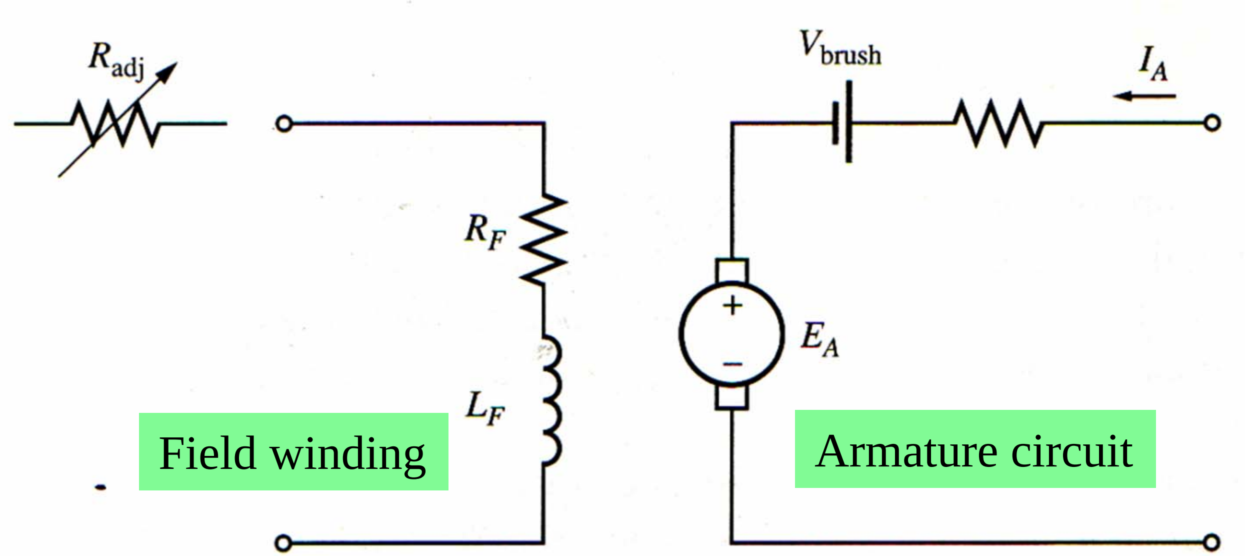
$$\tau_{ind} = \frac{ZP\phi I_a}{2\pi a} = K\phi I_a \quad where\ K = \frac{ZP}{2\pi a}$$

- The mechanical power generated is:

$$P_{dev} = E_a I_a = \tau\omega_m$$

2.4 TYPES OF DC MOTOR

DC Motor (Equivalent circuit)

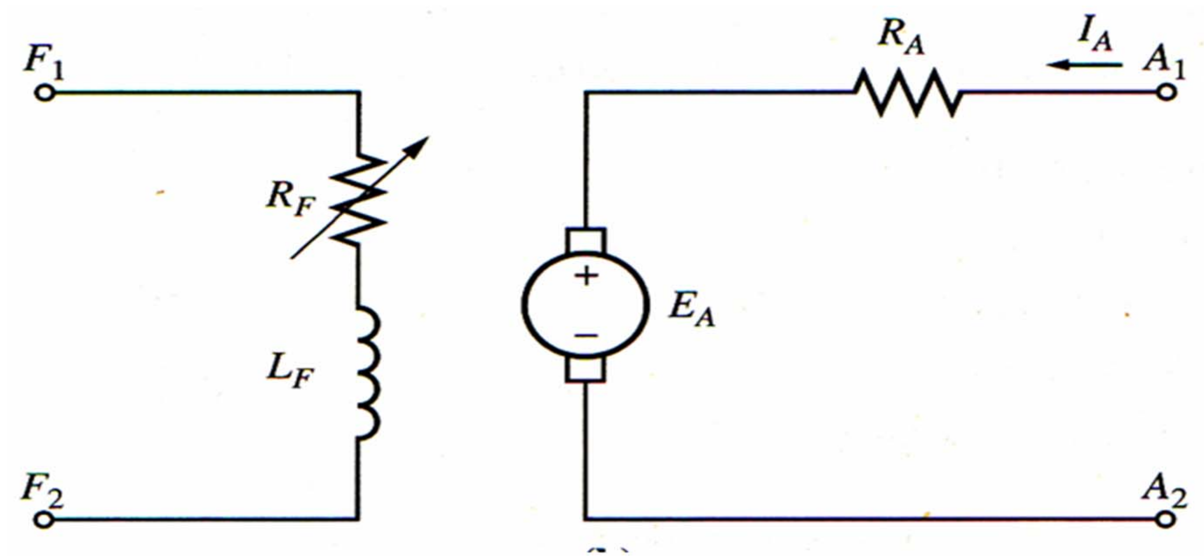


Source: https://amornsak.co/diagrams/permanent-magnet-dc-motor-equivalent-circuit-diagram.

- E_A = voltage source of armature circuit
- R_A = resistor for armature circuit
- V_{brush} = brush voltage drop
- L_F = inductor of field winding
- R_F = resistor of field winding
- R_{adj}=external variable resistor

Simplified Equivalent circuit of dc motor

- Some variation and simplifications can be made:
  - V_{brush} may be left out ($V_{brush} << E_A$) or included in R_A
  - The total of R_F and R_{adj} is called variable resistor, R_F



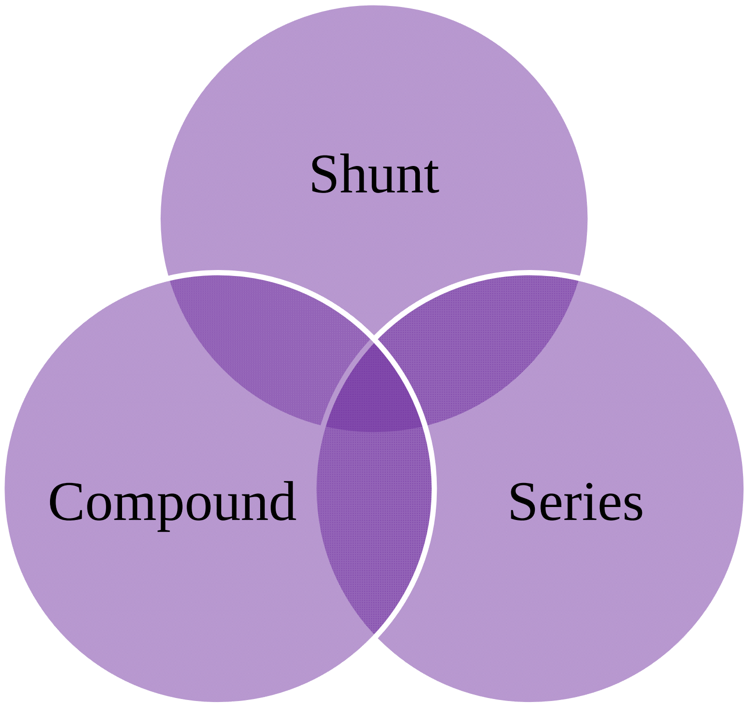
$$\text{internal voltage}: E_A = K\phi\omega$$

$$\text{induced torque}: \tau_{ind} = K\phi I_A$$

Source: https://amornsak.co/diagrams/ permanent-magnet-dc-motor-equivalent-circuit-diagram.php

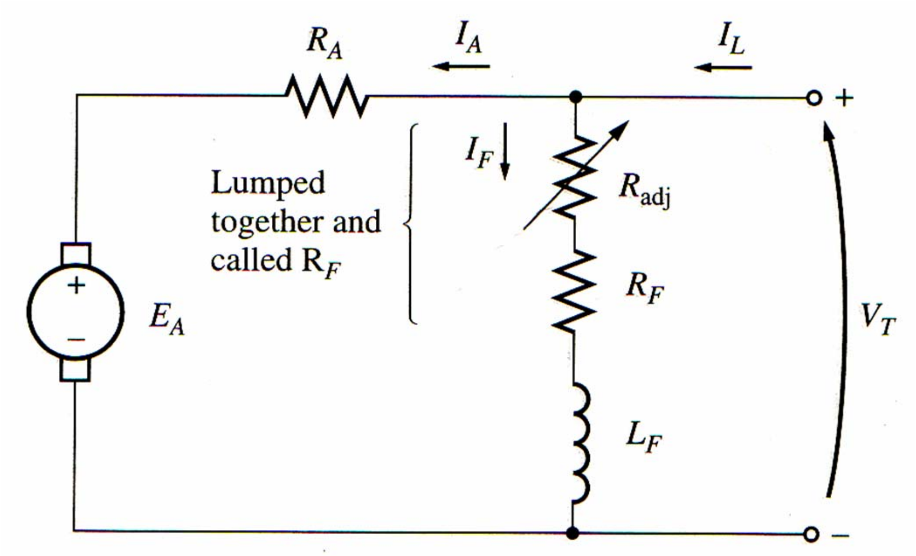
Types of DC Motor

- DC motor can be classified according to the electrical connections of the armature winding and the field windings.
- There are three major types of dc motor in general use:



Shunt DC Motor

- The armature and field winding are modelled in **parallel** configuration.



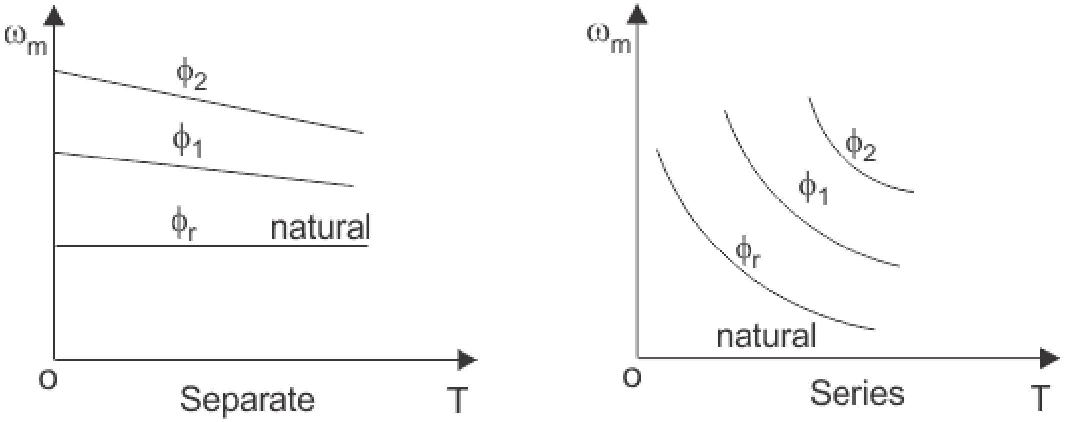
$$I_F = \frac{V_T}{R_F}$$

$$I_L = I_A + I_F$$

$$V_T = E_A + I_A R_A$$

Source: https://www.quora.com/How-does-a-DC-shunt-motor-work-and-what-causes-it-to-decrease-the-voltage-when-load-is-increased

Speed-torque Characteristic



Filed flux control ϕ_r (rated) > ϕ_1 > ϕ_2

Source: https://www.electrical4u.com/dc-motor-drives/

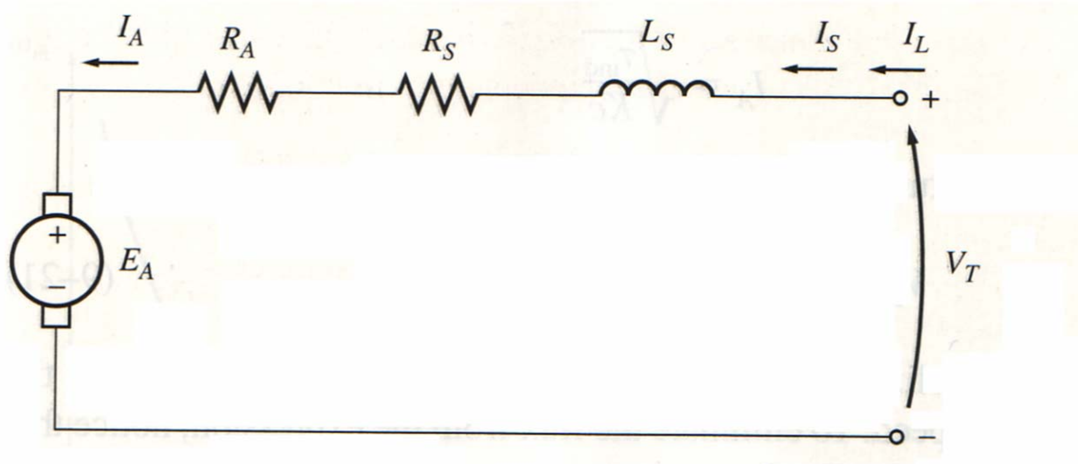
From derivation of induced voltage and torque equations, motor speed is:

$$\omega = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2}\tau_{ind}$$

- As the *load torque increases the speed falls somewhat*, but the machine *may be regarded as an approximately constant speed motor*

DC Motor Series

- Armature winding and field winding are modelled in **series configuration**.
- Current in field winding and armature winding are the same.



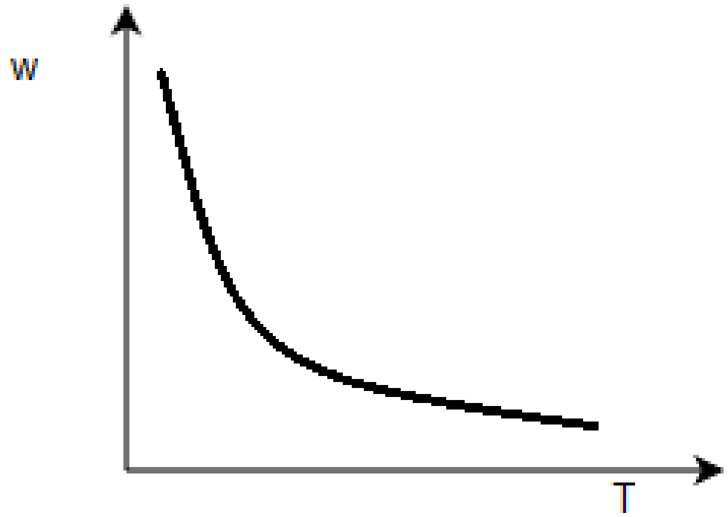
$$V_T = E_A + I_A(R_A + R_s)$$

$$I_L = I_A = I_S$$

Source: http://aliveandbloggin.com/dc-series-motor-wiring-diagram.html

Speed-torque Characteristic

Source: http://www.sanfoundry.com/electrical-machines-questions-answers-operating-characteristics-dc-motor/



- As *the load torque increases the speed falls rapidly*.
- For *no load connected* to the motor, it can *seriously damages the motor (due to high speed)*

- Different from shunt motor: Flux in series motor is directly proportional to the armature current.

- Induced torque is:

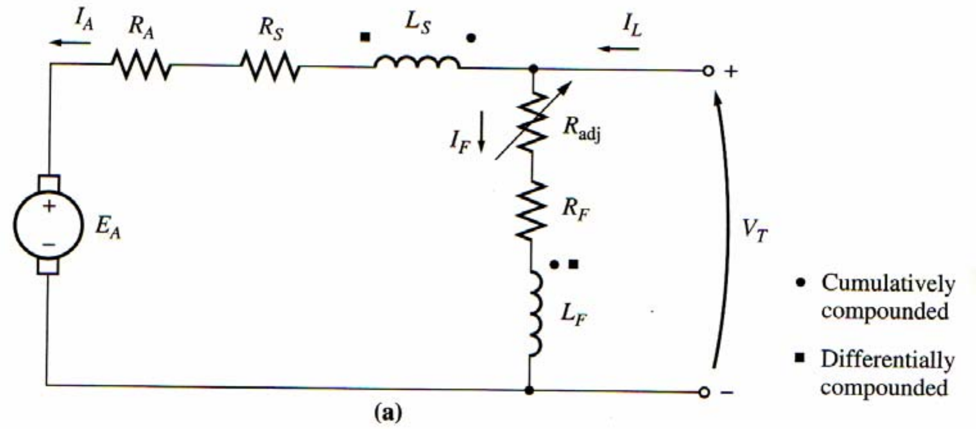
$$\tau_{ind} = K\phi I_a = KcI_a^{\,2}$$

- From derivation of induced voltage and torque equations, motor speed is :

$$\omega = \frac{V_T}{Kc}\frac{1}{\sqrt{\tau_{ind}}} - \frac{R_A + R_S}{Kc}\tau_{ind}$$

DC Motor Compound

- Compounded DC motor consist of motor with a shunt and a series field.
- Two types of arrangements in compound motors.
  - Cumulative compound - Magnetic fluxes produced by series and shunt field windings are in the same direction.
  - Differential compound - two fluxes are in opposition direction.



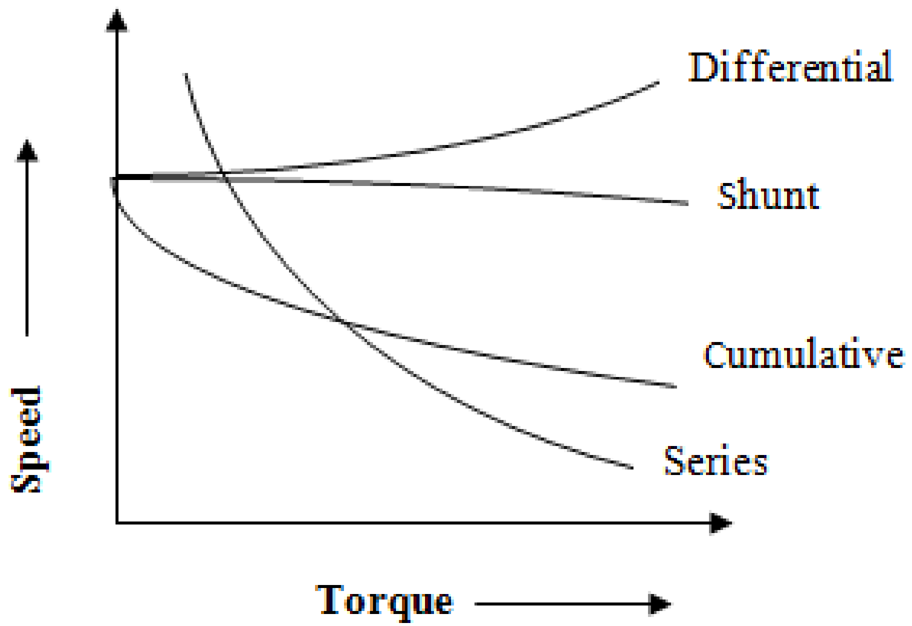
$$V_T = E_A + I_A(R_A + R_s)$$

$$I_A = I_L - I_S$$

$$I_F = \frac{V_T}{R_F}$$

Source: http://aliveandbloggin.com/dc-series-motor-wiring-diagram.html

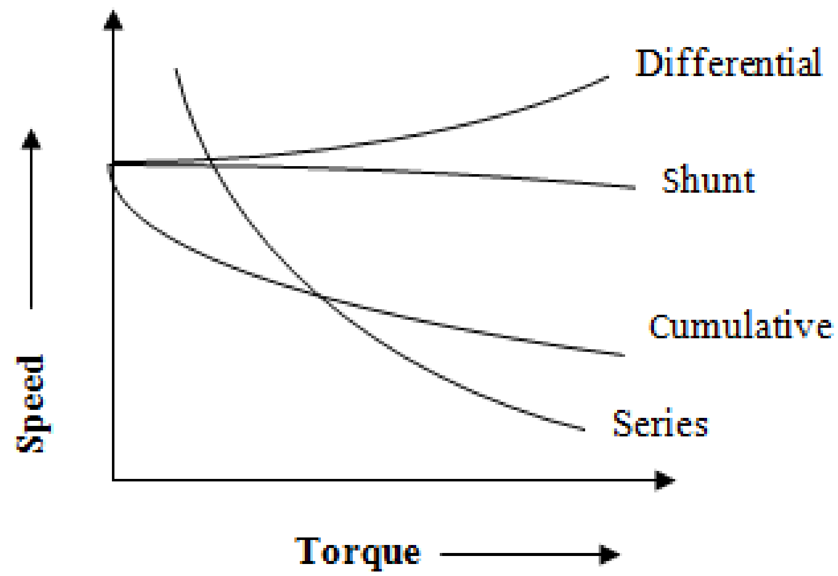
Speed-torque characteristic



Cumulative: The *speed falls appreciably as the torque increases* but on low torques the maximum speed is limited to a safe value.

Source: https://www.quora.com/What-will-be-the-torque-of-DC-motor-above-its-base-speed

Speed-torque Characteristic



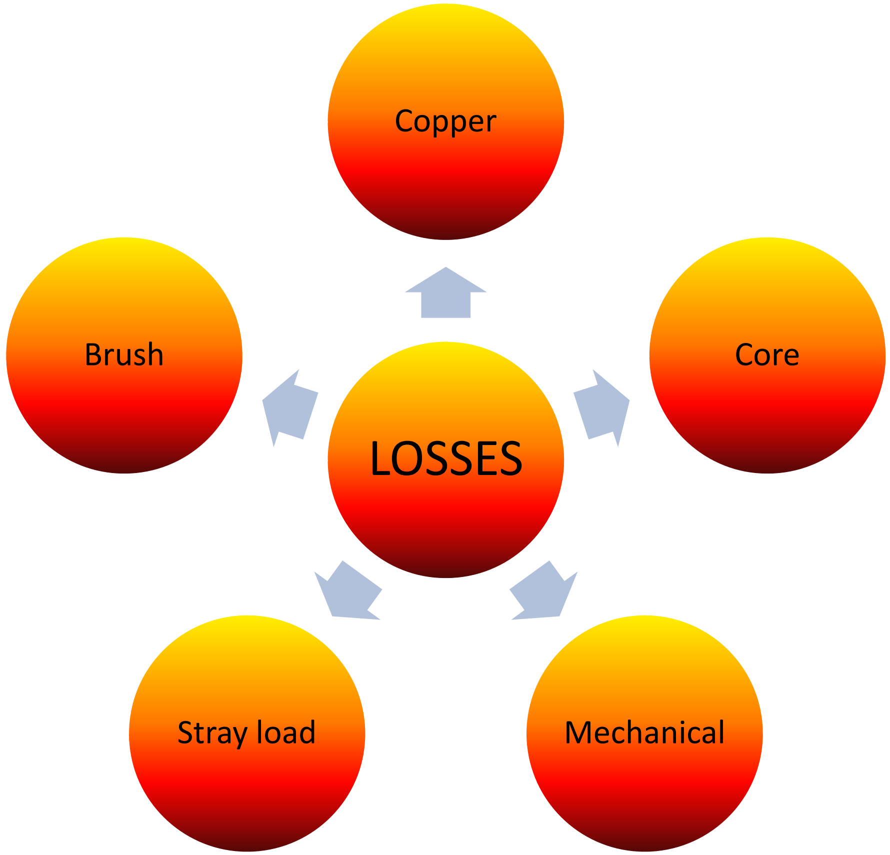
- **Differential**: The *speed at low torque is limited by the shunt winding* as in the cumulative compound machine.
- At high torques, the speed may be arranged to remain constant or with *stronger series field, the speed may rise with increasing load*.

Source: https://www.quora.com/What-will-be-the-torque-of-DC-motor-above-its-base-speed

2.5 POWER FLOW DIAGRAM

Losses in DC Motor

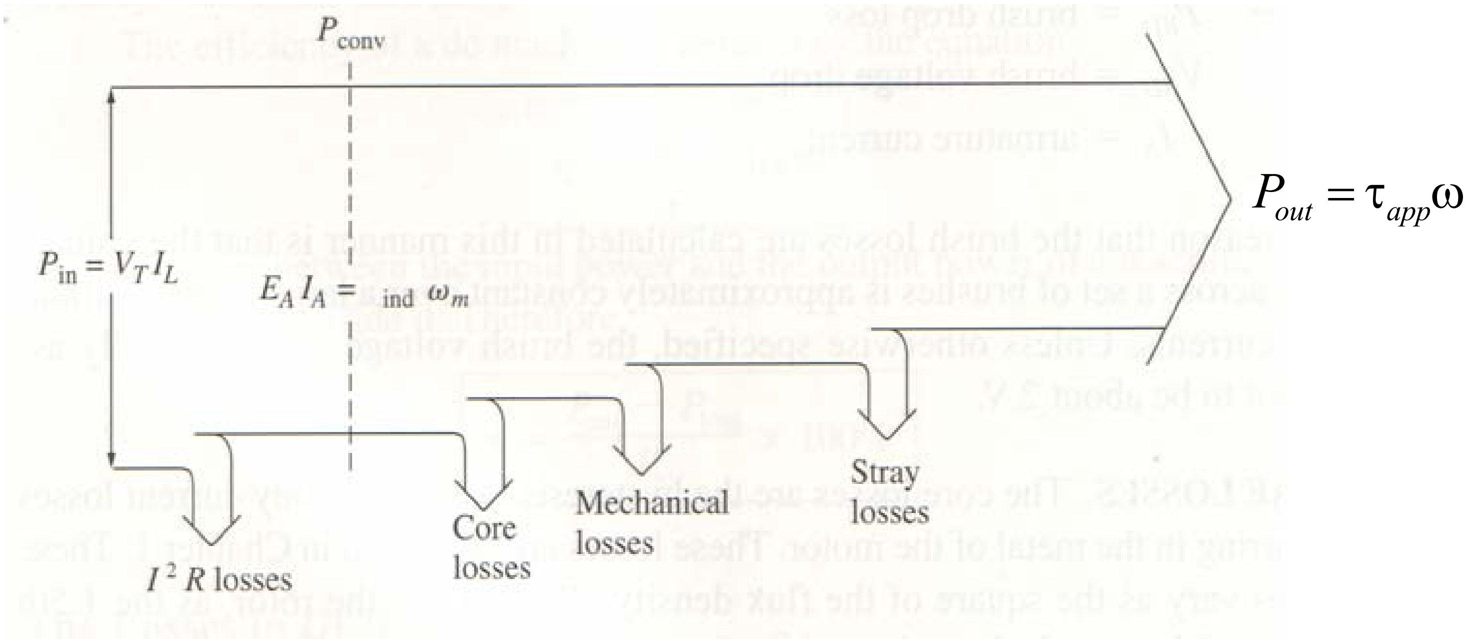
- 5 types of losses in DC motor:



Power losses

Core losses	• Consists of hysteresis and eddy current losses
Mechanical losses	• The losses that related with mechanical effects: friction & windage. Friction losses - friction of the bearings in the machine. Windage - friction between the moving parts of the machine and the air inside the motor casing's.
Stray (miscellaneous) losses	• Unknown categories.

Power flow diagram



Source: https://www.slideshare.net/abhinaypotlabathini/chapter-4-dc-machine-autosaved

- Copper losses:

$$P_{cu} = P_{cu,A} + P_{cu,F}$$

$$P_{cu,A} = I_A^{\,2} R_A$$

$$P_{cu,F} = I_F^{\,2} R_F$$

Mechanical losses:

$$P_{mech} = P_{fric} + P_{windage}$$

Formulation of Performances

- Efficiency

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$P_{in} = V_T I_L$$

$$P_{out} = P_{in} - P_{loss}$$

$$P_{loss} = P_{cu} + P_{core} + P_{mech} + P_{stray}$$

- Induced torque

$$\tau_{ind} = \frac{P_{conv}}{\omega}$$

$$P_{conv} = E_A I_A, \quad E_A = K\phi\omega$$

$$P_{conv} = P_{in} - P_{cu}$$

Formulation of Performances

- Output torque or load torque

$$\tau_{out} = \tau_{load} = \frac{P_{out}}{\omega}$$

- Speed regulation

$$SR = \frac{\omega_{nl} - \omega_{fl}}{\omega_{fl}} \times 100\%$$

$$SR = \frac{n_{nl} - n_{fl}}{n_{fl}} \times 100\%$$

2.6 SPEED CONTROL

Speed control

- The techniques of controlling DC motor speed:

Shunt, compounded DC motors	Series DC motor
• Changing the field resistance • Changing the armature voltage • Adding a resistance in armature circuit (designed in series connection)	• Adjusting the armature voltage

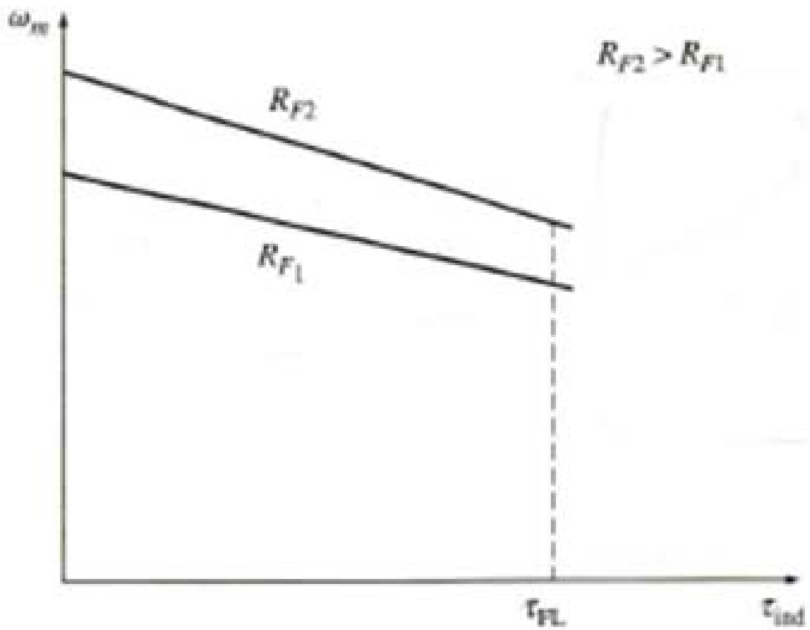
Speed control of Shunt DC motor

- *CHANGING FIELD RESISTANCE*:

Increasing R_F causes I_F to decrease	$I_F \downarrow = V_T / R_F \uparrow$
Decreasing I_F decrease ϕ	
Decreasing ϕ lowers E_A instantaneously	$E_A \downarrow = K\phi \downarrow \omega$
Decreasing E_A causes I_A to increase	$I_A \uparrow = \left(V_T - E_A \downarrow\right)/R_A$
Increasing I_A , increase τ_{ind}	$\tau_{ind} = K\phi \downarrow I_A \Uparrow$
Increasing τ_{ind} causes $\tau_{ind} > \tau_{load}$ hence motor speeds up, ω	
Since ω increase, E_A increase again	$E_A \uparrow = K\phi\omega \uparrow$
Increasing E_A causes I_A to decrease	$I_A \downarrow = \left(V_T - E_A \uparrow\right)/R_A$
Decreasing I_A , causes τ_{ind} decrease until $\tau_{ind} = \tau_{load}$ at higher speed ω	$\tau_{ind} \downarrow = K\phi I_A \downarrow$

Speed control of Shunt dc motor

- *CHANGING THE FIELD RESISTANCE*:

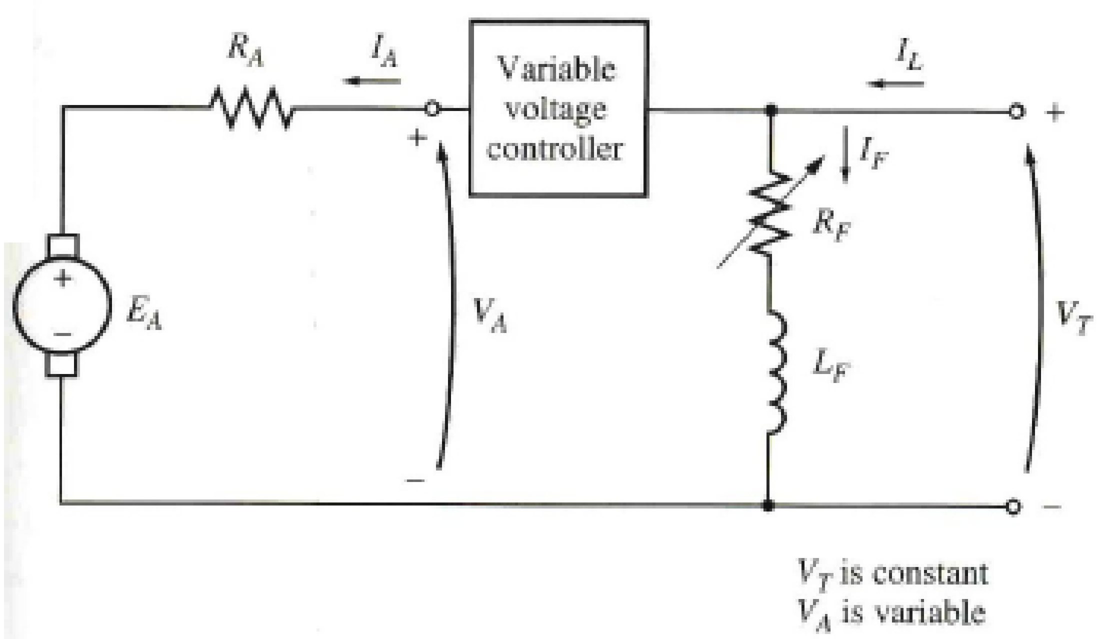


Source: http://slideplayer.com/slide/4773410/

Effect of field resistance speed control for a shunt motor's torque-speed characteristics

Speed control of shunt dc motor

- *CHANGING ARMATURE VOLTAGE*:
  - Involves changing the armature voltage (applied to the armature branch) ***without changing the voltage applied to the field circuit***.



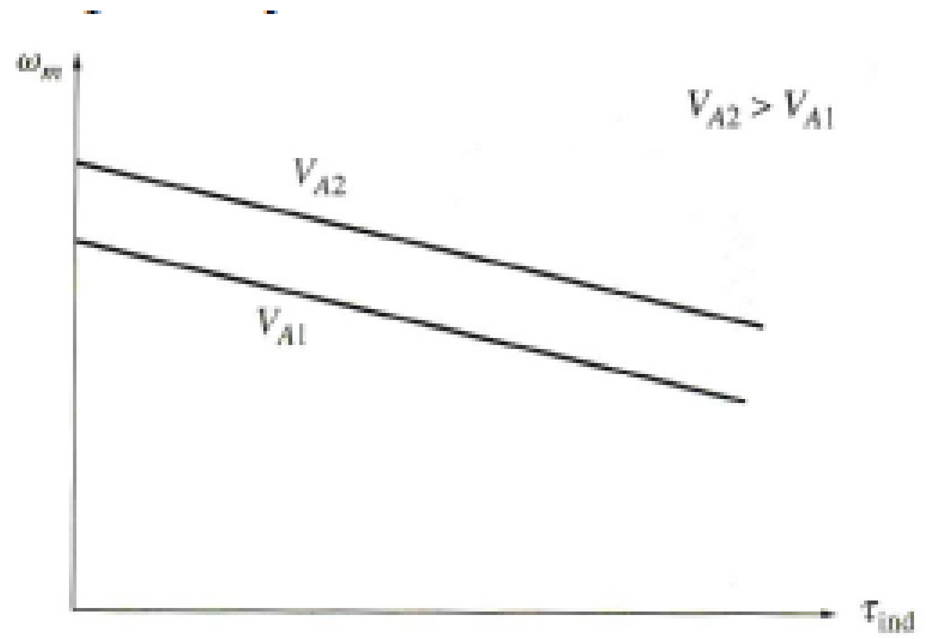
Speed control of Shunt dc motor

- *CHANGING ARMATURE VOLTAGE*:

Increasing V_A causes I_A to increase	$I_A \uparrow = (V_A \uparrow - E_A)/R_A$
Increasing I_A increase τ_{ind}	$\tau_{ind} \uparrow = K\phi I_A \uparrow$
Increasing τ_{ind} causes $\tau_{ind} > \tau_{load}$ hence motor speeds up, ω	
Since ω increase, E_A increase again	$E_A \uparrow = K\phi\omega \uparrow$
Increasing E_A causes I_A to decrease	$I_A \downarrow = (V_A - E_A \uparrow)/R_A$
Decreasing I_A, causes τ_{ind} decrease until $\tau_{ind} = \tau_{load}$ at higher speed ω	$\tau_{ind} \downarrow = K\phi I_A \downarrow$

Speed control of shunt dc motor

- *CHANGING THE ARMATURE VOLTAGE*:

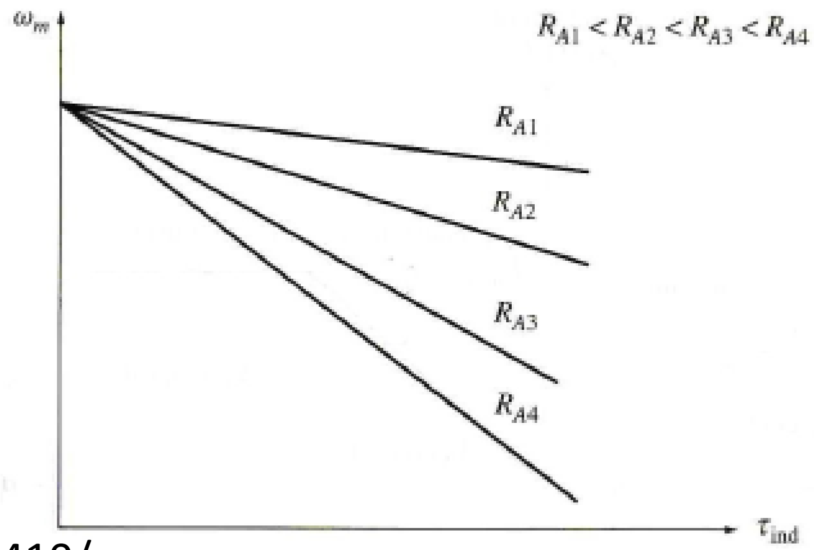


Source: http://slideplayer.com/slide/4773410/

Effect of armature voltage speed control for a shunt motor's torque-speed characteristics

Speed control of shunt dc motor

- *ADDING A RESISTOR IN ARMATURE CIRCUIT (SERIES CONNECTION)*:
  - By connecting resistor in series with armature circuit (R_A ↑*),* its escalate the slope of the motor's torque-speed characteristic, making it move/operate more slowly if loaded. – rarely used.



Effect of armature resistance speed control for a shunt motor's torque-speed characteristics

Source: http://slideplayer.com/slide/4773410/

Application Of DC Motors

TYPES OF DC MOTOR	CHARACTERISTICS	APPLICATIONS
Shunt	• Medium starting torque. • It is running in constant speed regardless the load.	Blower fans, centrifugal pumps, conveyers, elevators, woodworking and metalworking machinery.
Series	• High starting torque. • The speed varies automatically with the load. • No load condition is very dangerous.	Cranes, trolleys, gates, automobile starter, electric trains.
Cumulative compound	• High starting torque. • No load condition is allowed	Punch Presses, Shears, Bending Machines, Hoists, sudden temporary loads
Differential compound	• Speed increases as load increases	Not suitable for any practical applications.

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