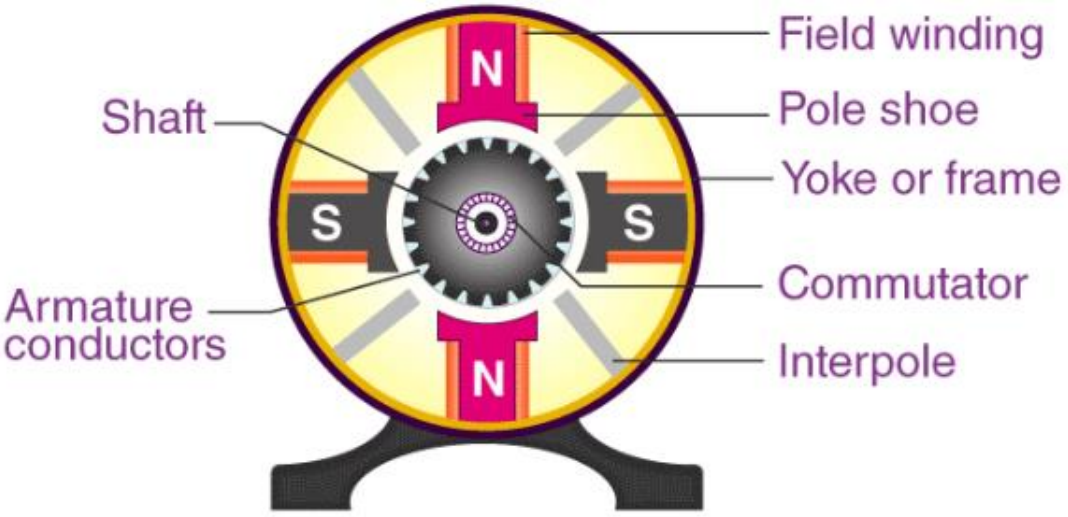
D.C. MOTOR

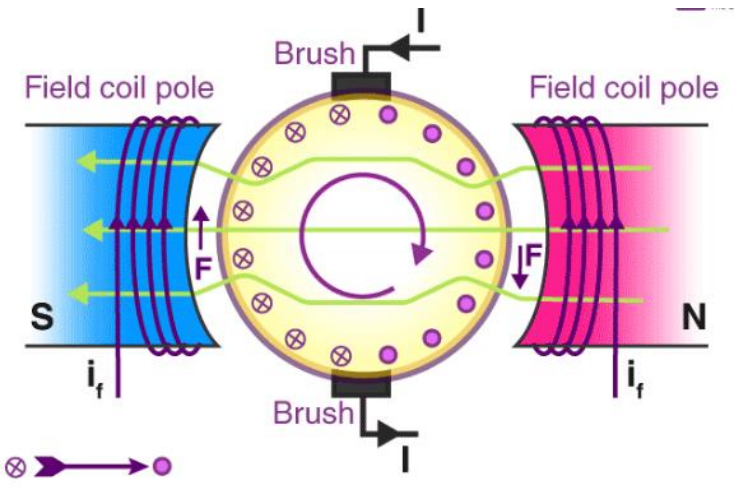
A DC motor is an electrical machine that converts electrical energy into mechanical energy. In a DC motor, the input electrical energy is the direct current which is transformed into the mechanical rotation.

DC Motor Diagram



DC motor construction parts

A magnetic field arises in the air gap when the field coil of the DC motor is energised. The created magnetic field is in the direction of the radii of the armature. The magnetic field enters the armature from the North pole side of the field coil and "exits" the armature from the field coil's South .pole side



Production of torque in a DC motor

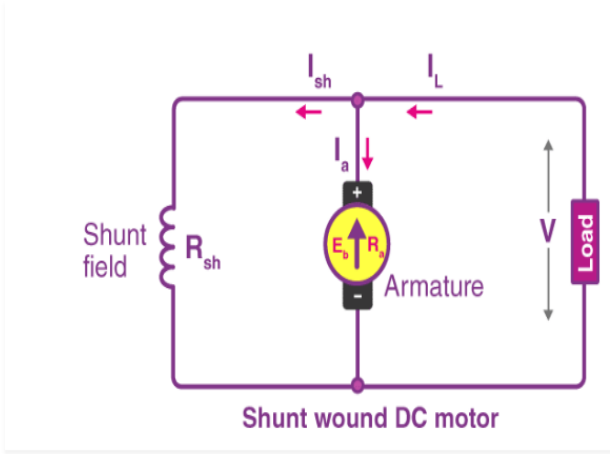
Types of DC motor

DC motors have a wide range of applications ranging from electric shavers to automobiles. To cater to this wide range of applications, they are classified into different types based on the field winding connections :to the armature as:

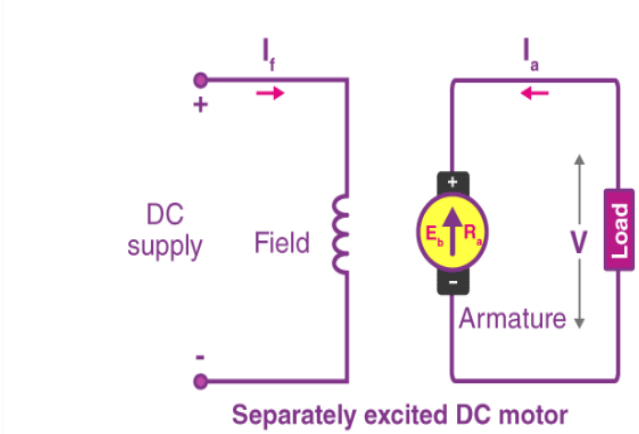
Self-Excited DC Motor

Separately Excited DC Motor

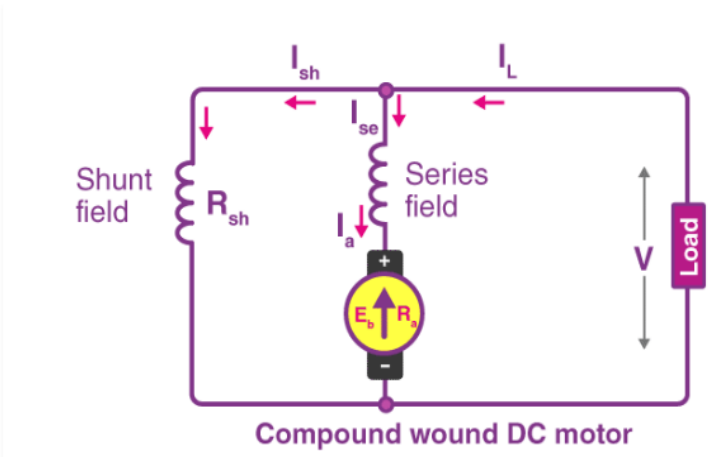
Shunt wound DC motor



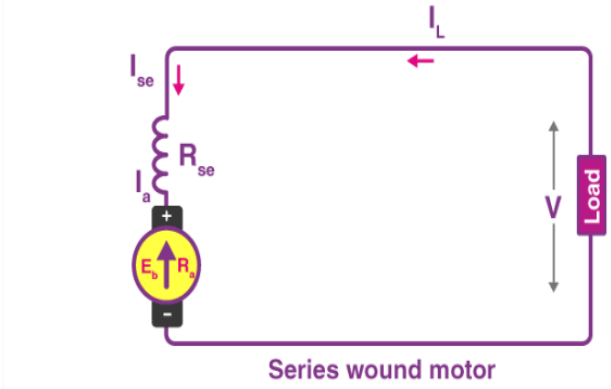
Separately Excited DC Motor



Compound wound DC motor



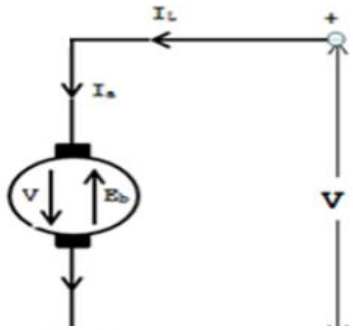
Series wound DC motor



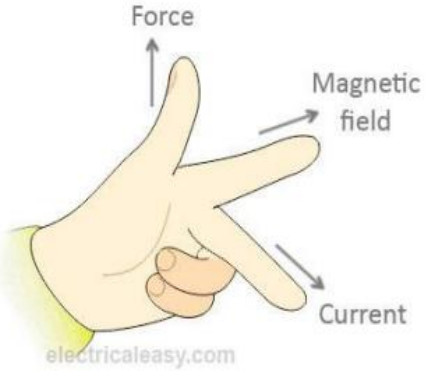
1. Applied Voltage, $V = I_a R_a + E_b$

This is known as voltage equation of DC Motor

$$I_a = \frac{V - E_b}{R_a}$$



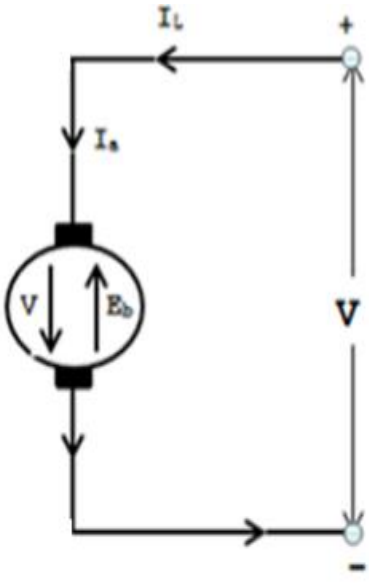
- **When a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.**
- The direction of this force is given by **Flemings Left Hand Rule**



1. Applied Voltage, $V = I_a R_a + E_b$

This is known as voltage equation of DC Motor

$$I_a = \frac{V - E_b}{R_a}$$



Back EMF of DC motor controls the armature current.

2. Multiplying voltage equation with Ia

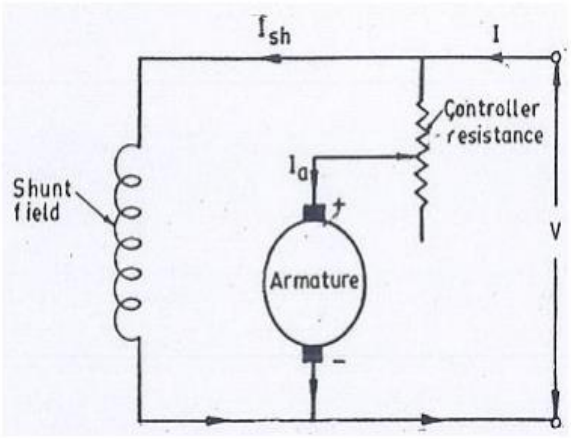
$$VI_a = I_a^2 R_a + E_b I_a$$

Power $E_b I_a$ is converted to mechanical energy and transmitted through shaft.

DC Motor – Necessity of Motor Starter

- Applied Voltage, $V = I_a R_a + E_b$

$$I_a = \frac{V - E_b}{R_a}$$



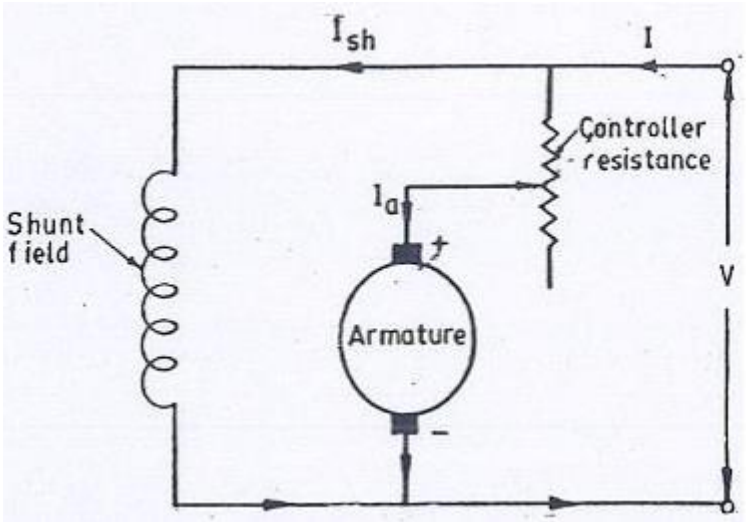
- Back EMF, $E_b = \frac{\phi Z N}{60} \frac{P}{A}$

- At starting motor is stationary N=0, Eb = 0, Ia = V/Ra is very high.

- To avoid starting current, a variable resistance known as starting resistance is inserted in series with armature circuit as shown in figure. The resistance is gradually reduced as motor gains speed and is cut out completely after motor attains full speed.

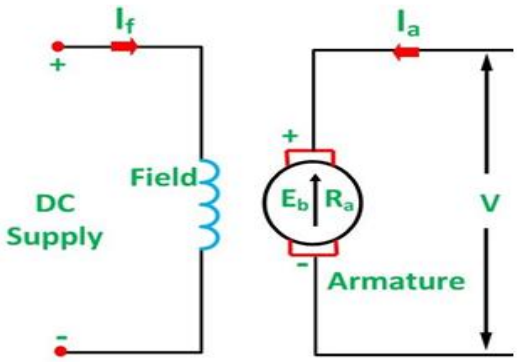
- High starting current causes:

1. Burning of armature due to excessive heating
2. Damage of commutator & brushes
3. Excessive voltage drop in line to which motor is connected.



Seperately Excited DC Motor

- Field winding is supplied from an independent external source



Armature Current, $I_a = I_L$ (line current)

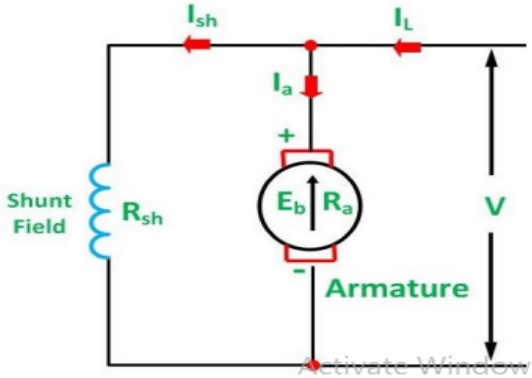
Terminal Voltage, $V = E_b + I_a R_a$

Electrical Power Developed = $E_b I_a$

Power Delivered to Load = $V I_L$

Shunt Wound DC Motor

- Field winding is connected in parallel with armature winding.
- Shunt field winding is generally made of large no. of turns of fine wire having high resistance.



Armature Current, $I_a = I_L - I_{sh}$

Activate Windows

Armature Current, $I_a = I_L - I_{sh}$

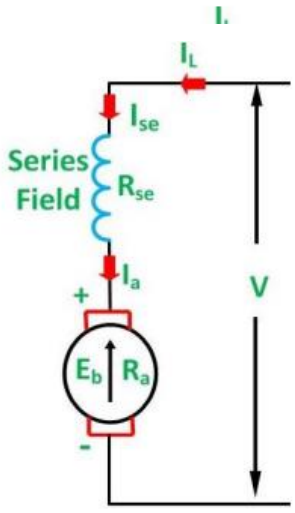
Field Current, $I_{sh} = V/R_{sh}$

Terminal Voltage, $V = E_b + I_a R_a$

Electrical Power Developed = $E_b I_a$

Series Wound DC Motor

- Field winding is connected in series with armature winding.
- Shunt field winding is generally made of few turns of wire with large cross-sectional area.



Armature Current, $I_a = I_{se} = I_L$

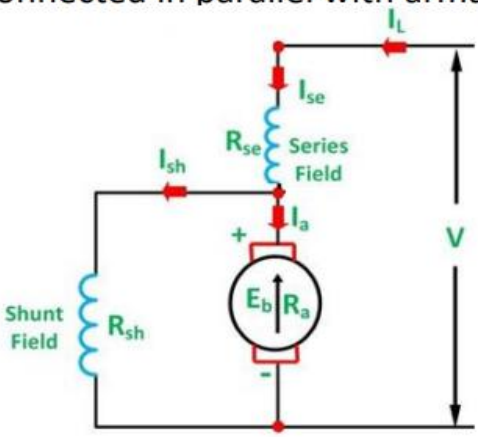
Terminal Voltage, $V = E_b + I_a R_a + I_{se} R_{se}$

Electrical Power Developed = $E_b I_a$

Power Delivered to Load = $V I_L$

Compound Wound DC Motor – Short Shunt

- Shunt field winding is connected in parallel with armature winding only.



Armature Current, $I_a = I_L - I_{sh}$

Field Current, $I_{sh} = (V - I_{se} R_{se})/R_{sh}$

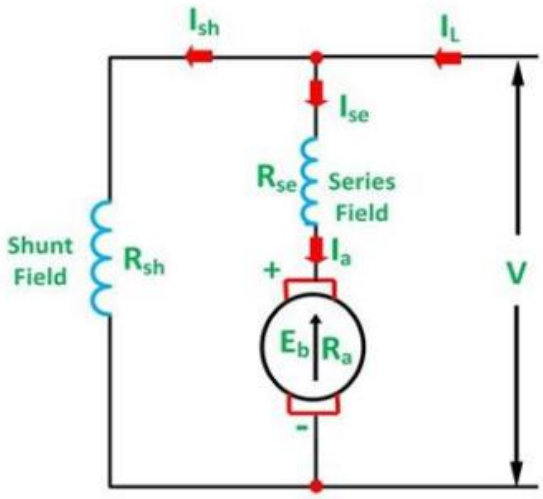
Terminal Voltage, $V = E_b + I_a R_{a+} + I_{se} R_{se} = I_{sh} R_{sh}$

Electrical Power Developed = $E_b I_a$

Power Delivered to Load = $V I_L$

Compound Wound DC Motor – Long Shunt

- Shunt field winding is connected in parallel with series field winding and armature winding.



Armature Current, $I_a = I_L - I_{sh} = I_{se}$

Field Current, $I_{sh} = V/R_{sh}$

Terminal Voltage, $V = E_b + I_a R_{a+} + I_{se} R_{se}$

Electrical Power Developed = $E_b I_a$

Power Delivered to Load = $V I_L$

Example 2.5 : *A 4 pole, 250 V, d.c. series motor has a wave connected armature with 200 conductors. The flux per pole is 25 mWb when motor is drawing 60 A from the supply. Armature resistance is 0.15 Ω while series field winding resistance is 0.2 Ω . Calculate the speed under this condition.*

Solution :

$P = 4, Z = 200$

$A = 2, \phi = 25 \times 10^{-3}$ Wb

$I_a = I_L = 60$ A

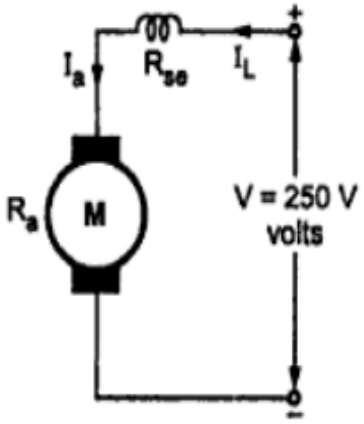
$R_a = 0.15\ \Omega$

$R_{se} = 0.2\ \Omega$

$V = E_b + I_a R_a + I_a R_{se}$

$\therefore \quad 250 = E_b + 60\ (0.15 + 0.2)$

$\therefore \quad E_b = 229$ V



Now $E_b = \dfrac{\phi P N Z}{60 A}$

$\therefore 229 = \dfrac{25 \times 10^{-3} \times 4N \times 200}{60 \times 2}$

$\therefore \quad N = 1374$ r.p.m.

Example 2.6 : *A 250 V, d.c. shunt motor takes a line current of 20 A. Resistance of shunt field winding is 200 Ω and resistance of the armature is 0.3 Ω. Find the armature current and the back e.m.f.*

Solution : $V = 250\ V,\ I_L = 20\ A$

$$R_a = 0.3\ \Omega,\quad R_{sh} = 200\ \Omega$$

$$I_L = I_a + I_{sh}$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{200} = 1.25\ A$$

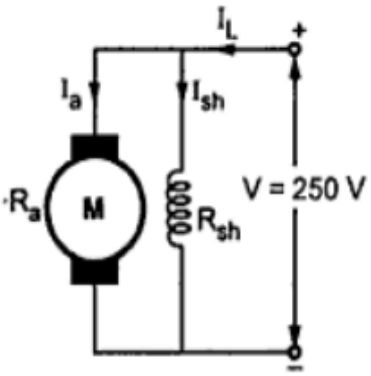


Fig. 2.21

$$\therefore \quad I_a = I_L - I_{sh}$$

$$= 20 - 1.25$$

$$= \mathbf{18.75\ A}$$

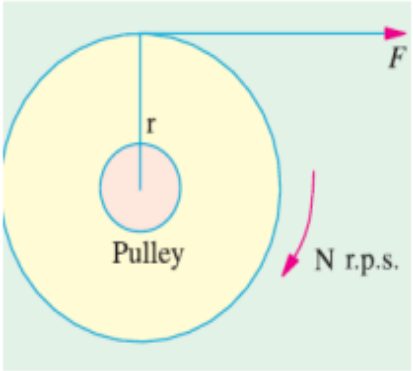
Now $\quad V = E_b + I_a R_a$

$$\therefore \quad E_b = V - I_a R_a$$

$$= 250 - 18.75 \times 0.3$$

$$= \mathbf{244.375\ V}$$

Torque



By the term torque is meant the turning or twisting moment of a force about an axis. It is measured by the product of the force and the radius at which this force acts. Consider a pulley of radius r meter acted upon by a circumferential force of F Newton which causes it to rotate at N r.p.m.

Then torque $T = F \times r$ (N - m)

Work done by this force in one revolution = Force × distance = $F \times 2\pi r$ Joule

Power developed = $F \times 2\pi r \times N$ Joule/second or Watt = $(F \times r) \times 2\pi N$ Watt

Now $2\pi N$ = Angular velocity ω in radian/second and $F \times r$ = Torque T

$\therefore$ Power developed = $T \times \omega$ watt or $P = T\omega$ Watt

Moreover, if N is in r.p.m., then

$\omega = 2\pi N/60$ rad/s

$$P = \frac{2\pi N}{60} \times T$$

Armature Torque of a Motor

Let Ta be the torque developed by the armature of a motor running at N r.p.s. If Ta is in N/M, then power developed

$$= T_a \times 2\pi N \quad \text{watt}$$

We also know that electrical power converted into mechanical power in the armature

$=E_bI_a$ watt

$$T_a = \frac{E_bI_a}{2\pi N} \text{ N.m , N in r.p.s}$$

$$T_a = 9.55\frac{E_bI_a}{N} \text{ N.m , N in r.p.m}$$

And

$$E_b = \frac{\phi ZNP}{A} \text{ , N in r.p.s}$$

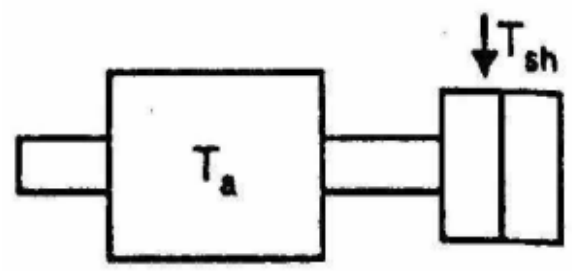
By substituting the three equations above we get,

$$T_a \times 2\pi N = \frac{\phi ZNP}{A}.Ia$$

$$T_a = 0.159\frac{\phi ZP}{A}.Ia \text{ N.m}$$

The torque which is available at the motor shaft for doing useful work is known as shaft torque. It is represented by T_{sh}. Figure below illustrates the concept of shaft torque. The total or gross torque T_a developed in the armature of a motor is not available at the shaft because a part of it is lost in overcoming the iron and frictional losses in the motor. Therefore, shaft torque T_{sh} is somewhat less than the armature torque T_a. The difference $T_a - T_{sh}$ is called lost torque

$$T_{sh} = 9.55\frac{\text{output}}{N} \text{ N.m , N in r.p.m}$$



Ex2: Determine developed torque and shaft torque of 220-V, 4-pole series motor with 800 conductors wave-connected supplying a load of 8.2 kW by taking 45 A from the mains. The flux per pole is 25 mWb and its armature circuit resistance is 0.6 Ω.

Solution

Developed torque or gross torque is the same thing as armature torque.

$$T_a = 0.159\frac{\phi ZP}{A}.I_a$$

$$T_a = 0.159\frac{0.025 \times 800 \times 4}{2} \times 45 = 286.2\ \text{N.m}$$

$$E_b = V - I_a R_a = 220 - 45 \times 0.6 = 193\ \text{V}$$

$$E_b = \frac{\phi\, P\, N}{60}\frac{Z}{A}$$

$$193 = \frac{0.025 \times 4 \times N}{60}\frac{800}{2} \rightarrow N = 289.5\ \text{r.p.m}$$

$$\text{Output} = 2\pi N T_{sh}$$

$$8200 = 2\pi \times \frac{289.5}{60} T_{sh} \rightarrow\rightarrow T_{sh} = 270.5\ \text{N.m}$$

Type of motor	Characteristics	Applications
Shunt	Approximately constant speed Medium starting torque (Up to 1.5 F.L. torque)	For driving constant speed line shafting Lathes Centrifugal pumps Machine tools Blowers and fans Reciprocating pumps
Series	Variable speed Adjustable varying speed High Starting torque	For traction work i.e. Electric locomotives Rapid transit systems Trolley, cars etc. Cranes and hoists Conveyors
Compound	Variable speed Adjustable varying speed High starting torque	For intermittent high torque loads For shears and punches Elevators Conveyors Heavy planers Heavy planers Rolling mills; Ice machines; Printing presses; Air compressors

Speed of a D.C. Motor

$$E_b = V - I_a R_a$$

But $$E_b = \frac{P\phi ZN}{60\ A}$$

$$\therefore \quad \frac{P\phi ZN}{60\ A} = V - I_a R_a$$

or $$N = \frac{(V - I_a R_a)}{\phi} \frac{60\ A}{PZ}$$

or $$N = K\frac{(V - I_a R_a)}{\phi} \qquad \text{where} \qquad K = \frac{60A}{PZ}$$

$$\therefore \quad N = K\frac{E_b}{\phi}$$

or $$N \propto \frac{E_b}{\phi}$$

Therefore, in a d.c. motor, speed is directly proportional to back e.m.f. E_b and inversely proportional to flux per pole ϕ.

Example : *A d.c. shunt motor runs at a speed of 1000 r.p.m. on no load taking a current of 6 A from the supply, when connected to 220 V d.c. supply. Its full load current is 50 A. Calculate its speed on full load. Assume* $R_a = 0.3\ \Omega$ *and* $R_{sh} = 110\ \Omega$.

Solution : Let no load, speed be N_0 = 1000 r.p.m.

I_{L0} = Line current on no load = 6 A

$I_{L0} = I_{a0} + I_{sh}$

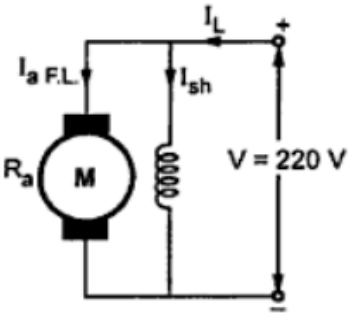


Fig.

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{110} = 2\ A$$

$$\therefore \quad I_{a0} = I_{L0} - I_{sh} = 6 - 2 = 4\ A$$

$\therefore$ Back e.m.f. on no load E_{b0} can be determined from the voltage equation.

$$V = E_{b0} + I_{a0} R_a$$

$$\therefore \quad 220 = E_{b0} + 4 \times 0.3$$

$$\therefore \quad E_{b0} = 218.8\ V$$

On full load condition, supply voltage is constant and hence,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{110} = 2\ A \quad \text{(remains same)}$$

Now $I_L = I_{a\ F.L.} + I_{sh}$

$\therefore \quad 50 = I_{a\ F.L.} + 2$

$\therefore \quad I_{a\ F.L.} = 48\ A$

and $V = E_{b\,F.L.} + I_{a\,F.L.} R_a$

$\therefore \quad 220 = E_{b\,F.L.} + 48 \times 0.3$

$\therefore \quad E_{b\,F.L.} = 205.6\ V$

From the speed equation,

$$N \propto \frac{E_b}{\phi}$$

But ϕ is constant as I_{sh} is constant for both the load conditions.

$$\therefore \quad \frac{N_0}{N_{F.L.}} = \frac{E_{b0}}{E_{bF.L.}}$$

$$\therefore \quad N_{F.L.} = N_0 \frac{E_{b\,F.L.}}{E_{b0}} = 1000 \times \frac{205.6}{218.8} = \mathbf{939.67\ r.p.m.}$$