DC Motor :

→ A machine that converts dc power into mechanical power is known as a d.c. motor.

DC motor Principle :-

→ Its operation is based on the principle that 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 Fleming's left hand rule and magnitude is given by;

$$F = BIl \text{ Newtons.}$$

F = force in Newton
B = flux density in tesla
I = Current in ampere
l = conductor length in metre

Fleming's Left hand Rule :-

Thumb — Direction of force
first finger — magnetic field
Middle finger — Direction of Current

→ Applying Fleming's left hand rule, it is clear that force on each conductor is tending to rotate the armature. All these forces add together to produce a driving torque which sets the armature rotating.

Back or Counter EMF :-

When the armature of a dc motor rotates under the Influence of the driving torque, the armature Conductors move through the magnetic field and hence e.m.f is Induced in them as in a generator. The Induced e.m.f acts in opposite direction to the applied Voltage V and is Known as back or Counter e.m.f. E_b.

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

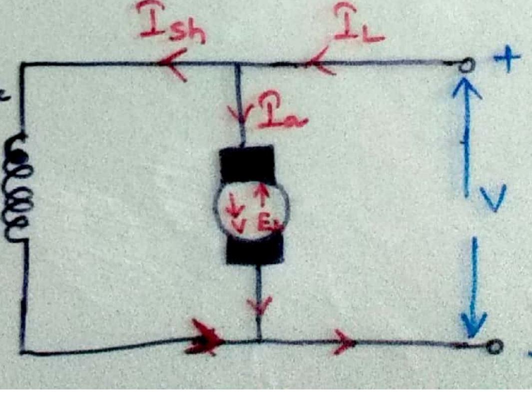
The applied Voltage V has to force Current through the armature against the back Emf. E_b. The Electric work done in over-Coming and Causing the Current to flow against E_b is Converted into Mechanical Energy developed in the armature. It follows, therefore that energy Conversion in a d.c. motor is only possible due to the production of back emf. E_b.

Considering a shunt wound motor,

Net Voltage across armature circuit $= V - E_b$.

if R_a is the armature circuit resistance

then, $I_a = \frac{V - E_b}{R_a}$.



Significance of Back e.m.f :-

The presence of back e.m.f makes the d.c motor a self-regulating machine. i.e., it makes the motor to draw as much armature current as is just sufficient to develop the torque required by the load.

Armature Current, $I_a = \frac{V - E_b}{R_a}$; $E_b = \frac{\phi Z N P}{60 \times A}$.

(i) When the motor is loaded, Armature slows down,

$\therefore$ speed at which armature conductors rotates ↓

$\therefore$ $E_b \downarrow$ $\therefore$ $I_a \uparrow$ $\Rightarrow$ driving torque ↑.

The motor continues to ~~rotate~~ till $T_{em} = T_L$. and steady state conditions are obtained.

(ii) when ~~motor is~~ load on motor ↓, Armature accelerates,

$\therefore N \uparrow \Rightarrow E_b \uparrow \Rightarrow I_a \downarrow \Rightarrow$ driving torque ↓.

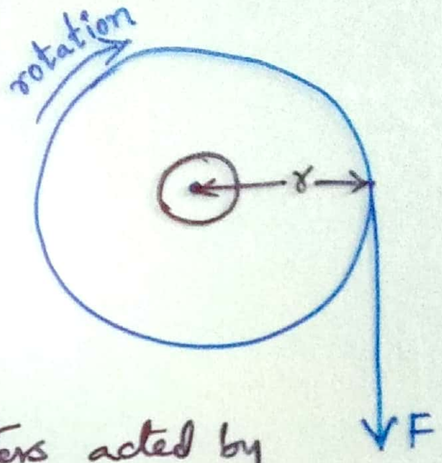
steady state condition obtain when $T_{em} = T_L$.

⇒ Thus it is evident that back emf E_b acts like a governer i.e., it makes a motor self regulating so that it draws as much current as just required

Torque :-

The measure of causing the rotation of a wheel or the turning or twisting moment of a force about the axis is called the torque.

Torque is measured by the product of force and the radius at which this force acts.



Consider a wheel of radius r meters acted by a circumferential force F newtons, as shown in figure.

Let the force F cause the wheel to rotate at n rps.

$$\text{Torque, } T = F \times r \text{ newton-metres.}$$

Work done per revolution = F × distance travelled in one Revolution

$= F \times 2\pi r$ joules.

P = Work done per second $= F \times 2\pi r \times N/60$

$= \dfrac{F \times 2\pi R}{\text{Time for 1 revolution}}$ $\quad = F \times r \times 2\pi N/60$ joules/sec or watts

⇒ Work done per second $= T \times \omega$ $\quad (\because T = F \times r,\ \omega = 2\pi n)$

and power developed, $P = T\omega$

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

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

Armature torque :-

Let T_e be the electromagnetic torque developed in newton-metres by the motor running at n rps.

Power developed = Work done per second

$= T_e \cdot \omega$

$= T_e \cdot 2\pi n$ watts. ——— (1)

Electrical equivalent of Mechanical Power developed by the armature is given as

$$P_m = E_b \cdot I_a \quad \text{——— (2)}$$

Comparing equations (1) & (2)

$$T_e \cdot 2\pi n = E_b \cdot I_a$$

$$T_e = \frac{E_b \cdot I_a}{2\pi \cdot n} = \frac{E_b \cdot I_a}{2\pi \cdot \frac{N}{60}}$$

$$T_e = \frac{\frac{\phi Z N P}{60 \times A} \cdot I_a}{2\pi \cdot \frac{N}{60}} = 0.159 \phi Z P \cdot \frac{I_a}{A}$$

* $$\boxed{T_e = 0.159 \phi Z \cdot P \cdot \frac{I_a}{A}}$$

* $$\boxed{T_e \propto \phi I_a}$$ ← for shunt motor

* $$\boxed{T_e \propto I_a^2}$$ ← for series motor.

Shaft Torque (T_{sh}) :-

The torque which is available at the motor shaft for doing useful work is known as shaft torque (T_{sh}).

→ The electromagnetic torque developed in armature of a motor is not available at the shaft as a part of it is lost in overcoming the iron and frictional losses in the motor. Therefore $T_{sh} < T_e$

The difference $T_e - T_{sh}$ is known as lost torque.

$$T_{sh} = 9.55 \times \frac{output}{N} = \frac{9.55 \times E_b I_a}{N} \text{ Nm.}$$

Losses in a DC motor :-

Same as in a dc generator.

efficiency of a DC Motor :-

$$\eta = \frac{output}{Input} \times 100 = \frac{Output}{output + losses} \times 100.$$

As in a DC generator, efficiency of a dc motor will be maximum when :

Variables = Constant losses

Speed Equation :-

we know, the Expression for back emf developed in the armature of a dc motor are given as

$$E_b = \frac{\phi Z N \times P}{60 \times A} \text{ Volts} \quad \text{--- (1)}$$

$$E_b = V - I_a R_a \quad \text{--- (2)}$$

Comparing equations (1) & (2)

$$\frac{\phi Z N P}{60 \times A} = V - I_a R_a$$

$$N = \frac{V - I_a R_a}{\phi \cdot Z} \times \frac{60 A}{P}$$

$$= K \cdot \frac{V - I_a R_a}{\phi}$$

(Since Z, A, P are constant for a particular machine)

$$* \quad \boxed{N = K \cdot \frac{E_b}{\phi}}$$

Brake Horse Power (BHP):- In case of electric motors the mechanical power available at the shaft in horse power is known as brake horse power (bhp).

if T_{sh} is the shaft torque in newton metres and N is speed in rpm then

$$\boxed{\text{output in bhp} = \frac{2\pi N T_{sh}}{60 \times 746}}$$

DC Motor characteristics :-

The performance of a dc motor can be judged from its characteristics curves known as motor characteristics.

(i) Torque and Armature current characteristic (T/I_a)

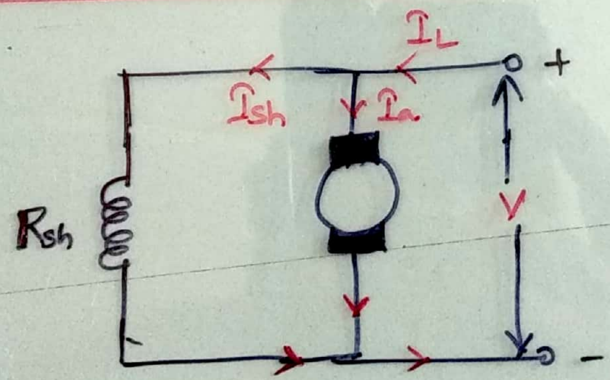
(ii) Speed and Armature current characteristic (N/I_a)

(iii) Speed and torque characteristics. (N/T).

⇒ The Important relations to be kept in mind while discussing motor characteristics are :

(i) $I_a = \frac{V - E_b}{R_a}$ (ii) $N \propto \frac{E_b}{\phi}$ and (iii) $T \propto \phi I_a$.

Characteristics of Shunt Motors :-

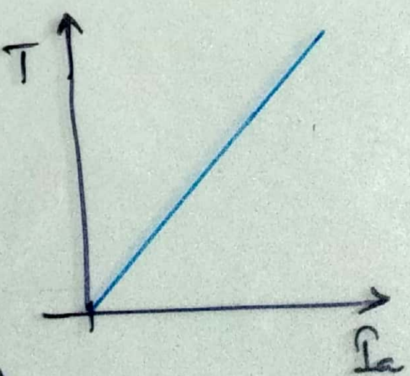


(i) T/I_a characteristic :-

We know that in a dc motor,

$$T \propto \phi I_a$$

$$\boxed{T \propto I_a}$$ ($\because \phi$ is constant in DC shunt motor)

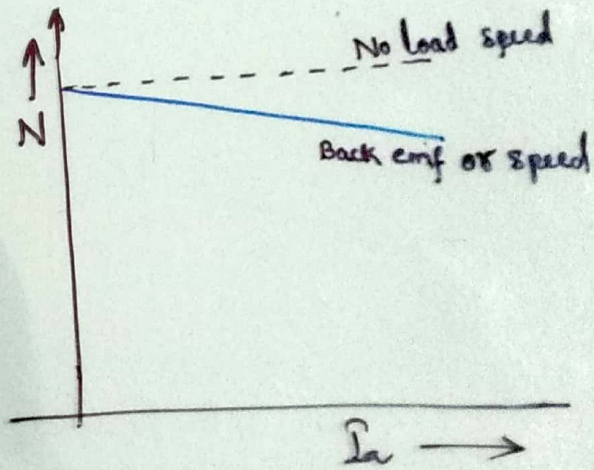


(ii) N/I_a characteristic :- $N \propto \frac{E_b}{\phi}$ (15) (9)

if applied Voltage V is kept constant, the field current will remain Constant, hence flux is Constant.

But as load is Increased, E_b $(= V - I_a R_a)$ and ϕ decrease due to the armature reaction and armature resistance drop respectively.

→ with the Increase in Armature Current the speed slightly falls due to Increase in Voltage drop in armature



(iii) N/T characteristic :-

$T \propto \phi I_a$

$T \propto I_a$. ($\because \phi$ Const in shunt motor)