EEE/ETI 3105
ELECTRICAL MACHINES I

LECTURE 8: DC MOTORS

Introduction

- A machine that converts d.c. power into mechanical power is known as a d.c. motor.
- D.C. motors are rarely used in ordinary applications because many electric utility companies supply alternating current.
- However, for special applications such as in steel mills, mines and electric trains, it is advantageous to convert alternating current into direct current in order to use d.c. motors.
- The reason is that speed/torque characteristics of d.c. motors are much more superior to that of a.c. motors.
- Therefore, it is not surprising to note that for industrial drives, d.c. motors are as popular as 3-phase induction motors.
- Like d.c. generators, d.c. motors are also of three types viz.,
  - series-wound,
  - shunt-wound
  - compound wound.
- The use of a particular motor depends upon the mechanical load it has to drive.

Working of D.C. Motor

- DC motor 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;

$$F = BIl \quad \textit{Newton}$$

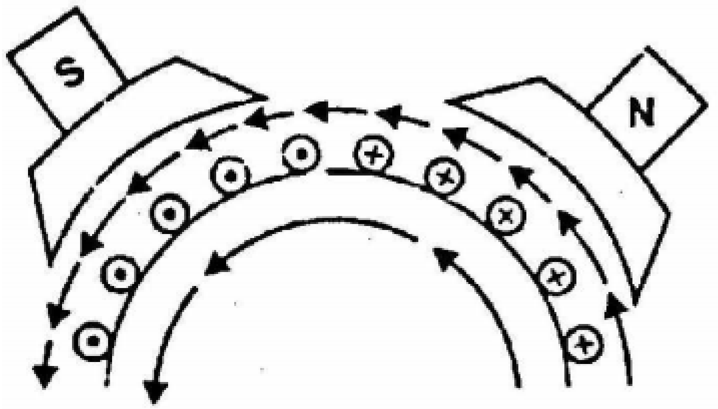
- Basically, there is no constructional difference between a d.c. motor and a d.c. generator.
- The same d.c. machine can be run as a generator or motor.

Working of D.C. Motor

- The principle of operation of a d.c. motor can be stated in a single statement as “ when a current carrying conductor is placed in a magnetic field; it experiences a mechanical force.
- In practical d.c. motor, field winding produces a required magnetic field while armature conductors play a role of a current carrying conductors and hence armature conductors experience a force.
- As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductors acts as a twisting or turning force on the armature which is called a torque.

Working of D.C. Motor

- Consider a part of a multipolar d.c. motor as shown below.

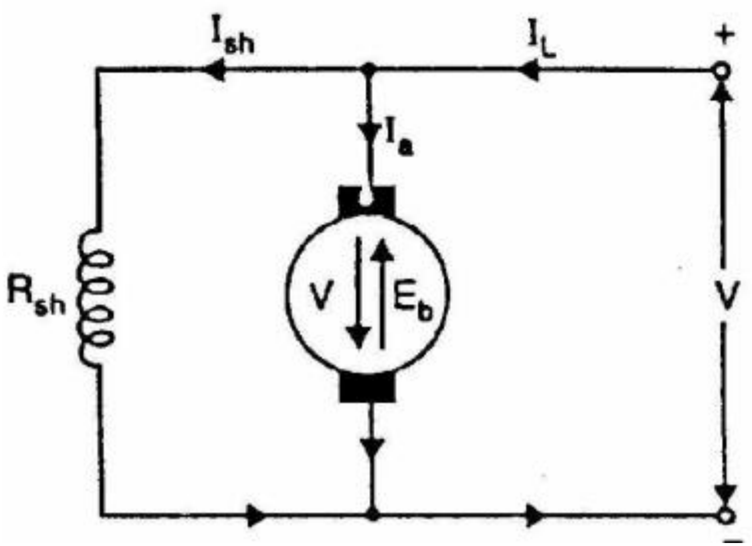


- When the terminals of the motor are connected to an external source of d.c. supply:
    i. the field magnets are excited developing alternate N and S poles;
    ii. the armature conductors carry currents. All conductors under N-pole carry currents in one direction while all the conductors under S-pole carry currents in the opposite direction.
- Suppose the conductors under N-pole carry currents into the plane of the paper and those under S-pole carry currents out of the plane of the paper as shown above.

- Since each armature conductor is carrying current and is placed in the magnetic field, mechanical force acts on it.
- Referring to the figure and applying Fleming’s left hand rule, the force on each conductor is tending to rotate the armature in anticlockwise direction.
- All these forces add together to produce a driving torque which sets the armature rotating.
- When the conductor moves from one side of a brush to the other, the current in that conductor is reversed and at the same time it comes under the influence of next pole which is of opposite polarity.
- Consequently, the direction of force on the conductor remains the same.

Back or Counter E.M.F.

- When the armature of a d.c. 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(Lenz's law) and in known as back or counter e.m.f. E_b.
- The back e.m.f. E_b (= PΦZN/60A) is always less than the applied voltage V, although this difference is small when the motor is running under normal conditions.
- Consider a shunt wound motor shown in Fig. below
- When d.c. voltage **V** is applied across the motor terminals, the field magnets are excited and armature conductors are supplied with current.
- Therefore, driving torque acts on the armature which begins to rotate.
- As the armature rotates, back e.m.f. E_b is induced which opposes the applied voltage V.

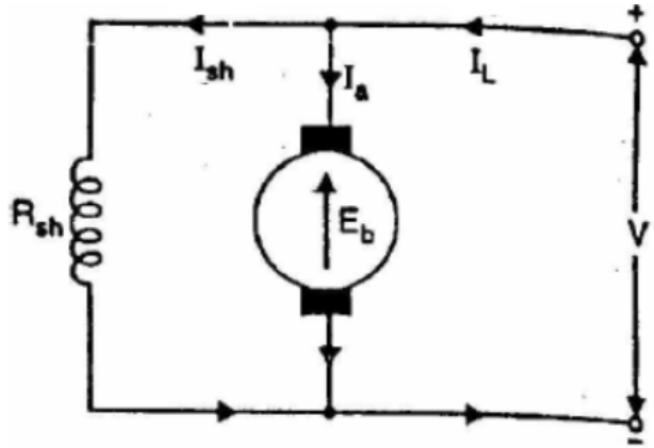


- The applied voltage V has to force current through the armature against the back e.m.f. E_b.
- The electric work done in overcoming and causing the current to flow against E_b is converted into mechanical energy developed in the armature.
- It follows, therefore, that energy conversion in a d.c. motor is only possible due to the production of back e.m.f. E_b.
- Net Voltage across the armature circuit = $V - E_b$

- If Ra is the armature circuit resistance, then, $I_a = \frac{V - E_b}{R_a}$
- Since V and R_a are usually fixed, the value of E_b will determine the current drawn by the motor.
- If the speed of the motor is high, then back e.m.f. $E_b \left(= \frac{P\Phi ZN}{60A}\right)$ is large and hence the motor will draw less armature current and vice versa.
- *NOTE: Back e.m.f. in a d.c. motor regulates the flow of armature current i.e., it automatically changes the armature current to meet the load requirement*

Voltage Equation of D.C. Motor

- Consider the d.c motor shown below



- Let V = applied voltage, E_b = Back emf, R_a = armature resistance and I_a = armature current.
- Since back e.m.f. E_b acts in opposition to the applied voltage V, the net voltage across the armature circuit is $V - E_b$.
- The armature current Ia is given by;

$$I_a = \frac{V - E_b}{R_a} \quad \text{or } V = E_b + I_a R_a ......(i)$$

- This is known as voltage equation of the d.c. motor.

Power Equation of D.C. Motor

- If Eq.(i) above is multiplied by I_a throughout, we get,

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

- This is known as power equation of the d.c. motor.

$$\begin{aligned} VI_a &= \text{ electric power supplied to armature (armature input)} \\ E_b I_a &= \text{ power developed by armature (armature output)} \\ I_a^2 R_a &= \text{ electric power wasted in armature (armature Cu loss)} \end{aligned}$$

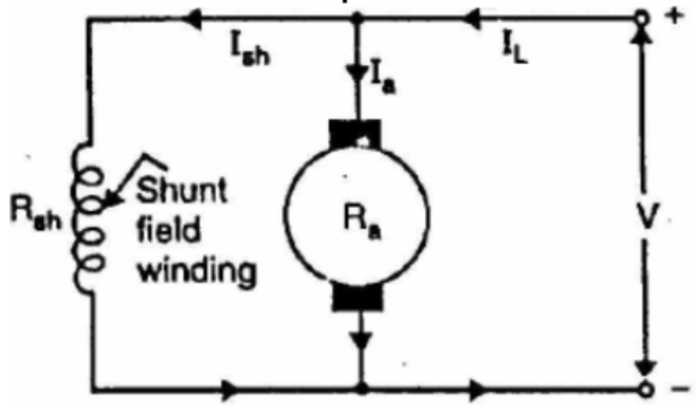
- Thus out of the armature input, a small portion (about 5%) is wasted as $I_a^2 R_a$ and the remaining portion $E_b I_a$ is converted into mechanical power within the armature.

Types of D.C. Motors

- Like generators, there are three types of d.c. motors characterized by the connections of field winding in relation to the armature.

Shunt-wound D.C. motor

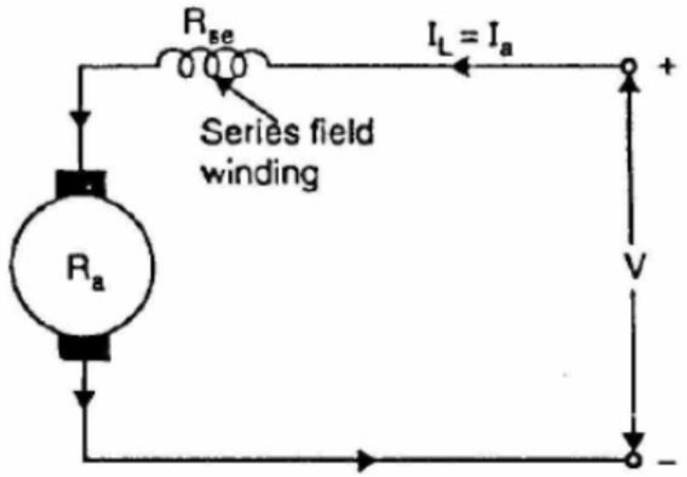
- The field winding is connected in parallel with the armature.



- The current through the shunt field winding is not the same as the armature current.
- Shunt field windings are designed to produce the necessary m.m.f. by means of a relatively large number of turns of wire having high resistance.
- Therefore, shunt field current is relatively small compared with the armature current.

Series-wound D.C. Motor

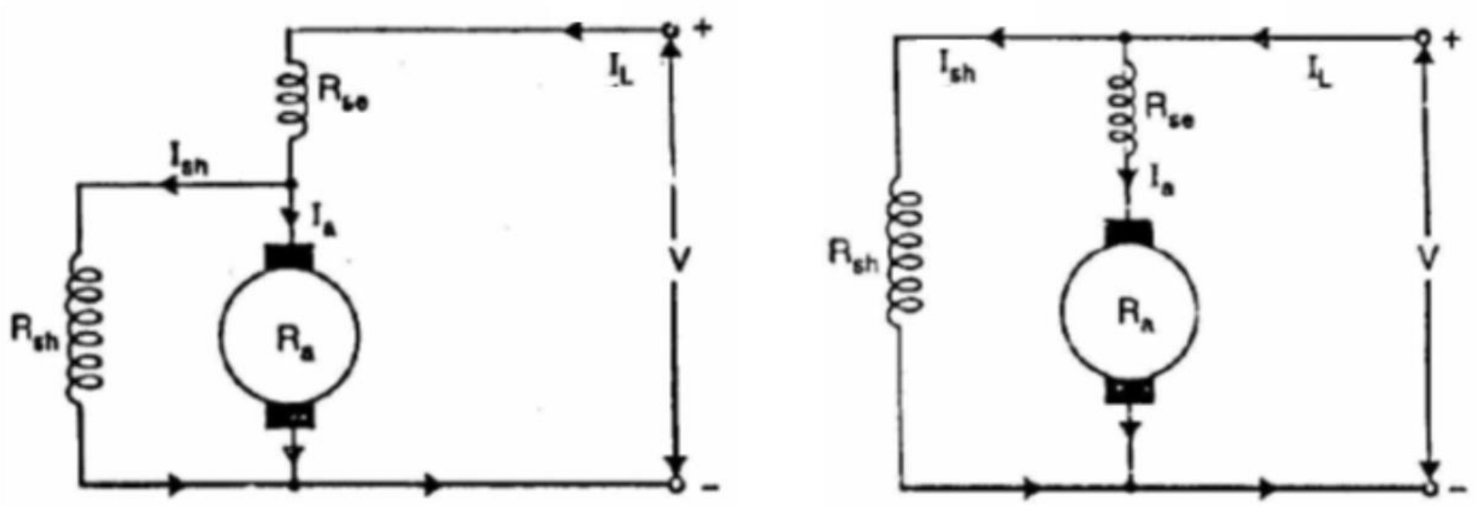
- Here the field winding is connected in series with the armature.
- Therefore, series field winding carries the armature current.



- Since the current passing through a series field winding is the same as the armature current, series field windings must be designed with much fewer turns than shunt field windings for the same m.m.f.
- Therefore, a series field winding has a relatively small number of turns of thick wire and, therefore, will possess a low resistance.

Compound-wound D.C. Motor

- Two field windings; one connected in parallel with the armature and the other in series with it just like in generators.



(a) Short Shunt (b) Long Shunt

- The compound machines (generators or motors) are always designed so that the flux produced by shunt field winding is considerably larger than the flux produced by the series field winding.
- Therefore, shunt field in compound machines is the basic dominant factor in the production of the magnetic field in the machine.

Practice Questions

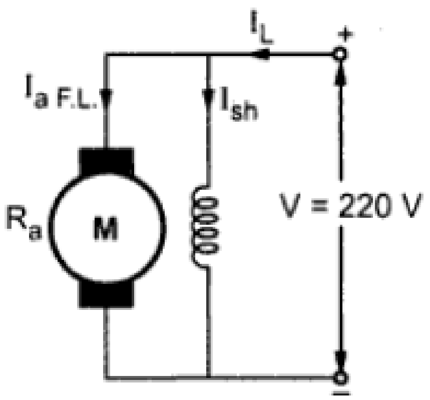
- **Qn 1:** A d.c shunt motor runs at a speed of 1000rpm on no load taking a current of 6 A from the supply, when connected to 220V d.c. supply. Its full load current is 50A. Calculate its speed on full load. Assume Ra = 0.3Ω and Rsh = 110 Ω
- **Qn 2:** A 4 pole, 250 V, d.c. series motor has a wave connected armature with 200 conductors. The flux per pole is 25mWb when motor is drawing 60 A from the supply. Armature resistance is 0.15 Ω while series field winding is 0.2 Ω. Calculate the speed under these conditions.
- **Qn 3:** A short shunt compound d.c generator supplies a current of 75A at a voltage of 225V. Calculate the generated voltage if the resistance of armature, shunt field and series field windings are 0.04Ω, 90Ω and 0.02Ω respectively.

Solution Q1

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

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

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



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

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

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

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

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

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

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

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

$$I_L = I_{aF.L.} + I_{sh}$$

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

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

Contin…Solution Q1

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

$$\therefore \quad 220 = E_{bF.L.} + 48 \times 0.3$$

$$\therefore \quad E_{bF.L.} = 205.6 \text{ V}$$

From the speed equation, $N \propto \frac{E_b}{\phi}$

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

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

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

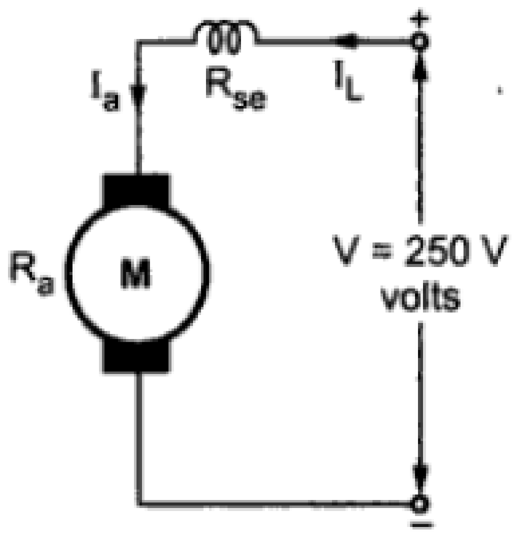
Solution Q2

$P = 4,\ Z = 200 \qquad A = 2,\ \phi = 25 \times 10^{-3}$ Wb $\qquad I_a = I_L = 60$ A

$R_a = 0.15\ \Omega \qquad R_{se} = 0.2\ \Omega$

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

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



$$\therefore \qquad E_b = 229\text{V}$$

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

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

$$\therefore \qquad \mathbf{N = 1374\ r.p.m.}$$

Practice Questions

- **Qn 1:** A 25-kW, 250-V, d.c. shunt generator has armature and field resistances of 0.06 Ω and 100 Ω respectively. Determine the total armature power developed when working:

  (i) as a generator delivering 25 kW output and

  (ii) as a motor taking 25 kW input. [Ans., 26.3kW & 23.8kW]

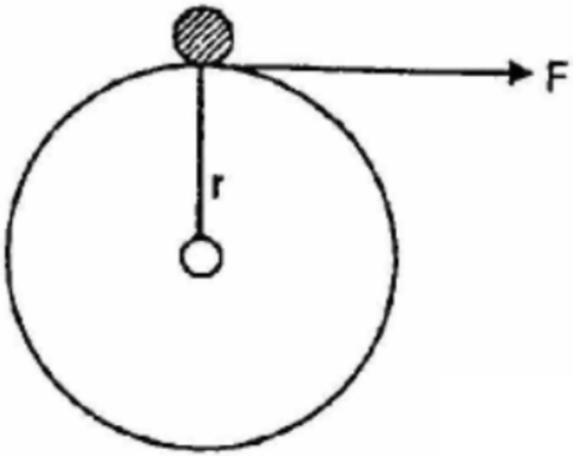
- **Qn 2:** A 4 pole, 32 conductor, lap-wound d.c. shunt generator with terminal voltage of 200 V delivering 12 A to the load has Ra = 2 Ω and field circuit resistance of 200 Ω. It is driven at 1000 r.p.m. Calculate the flux per pole in the machine. If the machine has to be run as a motor with the same terminal voltage and drawing 5 A from the mains, maintaining the same magnetic field, find the speed of the machine. [Ans., **Φ** = 0.424Wb, N = 850 r.p.m.]

Armature Torque of a DC Motor

- Torque is measured by the product of force (F) and radius (r) at right angle to which the force acts.
- In a d.c. motor, each conductor is acted upon by a circumferential force F at a distance r, the radius of the armature.
- Each conductor exerts a torque, tending to rotate the armature and their sum is known as gross or armature torque (Ta).

- Let in a dc motor:

  $r=$ Armature radius in m
  $\ell=$ length of each conductor in m
  $Z=$ No of conductors
  $A=$ Number of parallel paths
  $B=$ Armature flux density in Wb/m^2
  $\Phi=$ Flux per pole in Wb
  $P=$ number of poles



Armature (Gross) Torque of a DC Motor

- Force on each conductor, $F = Bi\ell$
- Torque due to one conductor $= F \times r = Bi\ell r$, N-m
- Total Armature torque $= Z \times Bi\ell r = ZBi\ell r$ N-m
- Now $i = I_a/A$, $B = \Phi/a$ where a is the cross-sectional area of flux path per pole at radius r i.e., $a = 2\pi r\ell/P$

$$\therefore T_a = Z \times \frac{\Phi}{2\pi r\ell/P} \times \frac{I_a}{A} \times \ell \times r = \frac{Z\Phi I_a P}{2\pi A} = 0.159 Z\Phi I_a(\frac{P}{A}) \text{ N-m}$$

- Since Z, P and A are fixed for a given machine, then $T_a \propto \Phi I_a$
- Hence torque in a d.c. motor is directly proportional to flux per pole and armature current.

Alternatively:

$$\because E_b = \frac{P\Phi ZN}{60A} \qquad \therefore \frac{P\Phi Z}{A} = \frac{60 \times E_b}{N}$$

$$T_a = 0.159(\frac{60 \times E_b}{N}) \times I_a$$

$$\boxed{T_a = 9.55 \times \frac{E_b I_a}{N} \quad \text{(Nm)}}$$

Shaft Torque of a DC Motor

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

$$T_a - T_{sh} = 9.55 \times \frac{\text{Iron and Frictional loss}}{N}$$

- It is the shaft torque that produces the useful output
- if the speed of the motor is N r.p.m., then:

$$\text{Output in watts} = \frac{2\pi N T_{sh}}{60}$$

$$\text{or } T_{sh} = \frac{\text{Output in watts}}{2\pi N/60} = 9.55 \times \frac{\text{Output in watts}}{N} \text{ N-m}$$

Brake Horse Power (B.H.P.)

The horse power developed by the shaft torque is known as brake horsepower (B.H.P.). If the motor is running at N r.p.m. and the shaft torque is T_{sh} newton-metres, then,

W.D./revolution = force x distance moved in 1 revolution

$$= F \times 2\pi\, r = 2\pi \times T_{sh}\ J$$

$$\text{W.D./minute} = 2\pi\, N\, T_{sh}\ J$$

$$\text{W.D./sec.} = \frac{2\pi\, N\, T_{sh}}{60}\ Js^{-1} \text{ or watts} = \frac{2\pi\, N\, T_{sh}}{60 \times 746}\ \text{H.P.}$$

$$\therefore \quad \text{Useful output power} = \frac{2\pi\, N\, T_{sh}}{60 \times 746}\ \text{H.P.}$$

$$\text{B.H.P.} = \frac{2\pi\, N\, T_{sh}}{60 \times 746}$$

Practice Questions

- **Qn.1** A 6-pole, 440 V DC motor has 936 wave wound armature conductors. The useful flux per pole is 25 m Wb. The torque developed is 45.5 kg-m. Calculate the following, if armature resistance is 0.5 ohm; (i) Armature current (ii) Speed

- **Qn.2** A 4-pole, 540 conductor, 240V wave connected shunt motor gives 119kW when running at 1000 rpm and drawing armature and field currents of 50A and 1A respectively. Its resistance is 0.1Ω. Assuming a drop of 1 V per brush, calculate (a) total torque (b) useful toque (c) useful flux/pole (d) rotational losses (e) efficiency

- **Qn.3** Determine developed torque and shaft torque of 220-V, 4-pole series motor with 800 conductors wave-connected supplying a load of 8.2kW by taking 45 A from the mains. The flux per pole is 25 mWb and its armature circuit resistance is 0.6 Ω.

Solution Qn1

Here, $P = 6; Z = 936; \phi = 25 \text{ m Wb} = 25 \times 10^{-3} \text{ Wb}$

$A = 2$ (*wave wound armature*); $V = 440$ V; $R_a = 0{\cdot}5$ ohm;

Torque developed, $T = 45{\cdot}5 \text{ kg-m} = 45{\cdot}5 \times 9{\cdot}81 = 446{\cdot}35 \text{ Nm}$

(*i*) Using the relation, $T = \dfrac{PZ\phi I_a}{2\pi A}$

Armature current, $I_a = \dfrac{2\pi A \times T}{PZ\phi} = \dfrac{2\pi \times 2 \times 446 \cdot 35}{6 \times 936 \times 25 \times 10^{-3}}$ = **39·95 A** (*Ans.*)

(*ii*) Induced emf, $E = V - I_a R_a$ (motor action)

$= 440 - 39{\cdot}95 \times 0{\cdot}5 = 420$ V

Using the relation, $\omega T = EI_a$

or $\dfrac{2\pi N}{60} \times I = EI_a$

Speed $N = \dfrac{60 \times E\,I2}{\pi T} = \dfrac{60 \times 420 \times 39 \cdot 95}{2\pi \times 446 \cdot 35}$ = **359 rpm** (*Ans.*)

Speed control in DC Motors

- From the voltage equation:

$$E_b = V - I_a R_a \Longleftrightarrow \frac{P\Phi ZN}{60A} = V - I_a R_a$$

$$N = \frac{V - I_a R_a}{\Phi} \times \frac{60A}{PZ} = K\frac{V - I_a R_a}{\Phi}$$

- But $E_b = V - I_a R_a \quad \therefore N = \frac{KE_b}{\Phi}$ 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.
- There are three main methods of controlling the speed of a d.c. motor, namely:
    1. By varying the flux per pole (Φ). This is known as **flux control method**.
    2. By varying the resistance in the armature. This is known as **armature control method**.
    3. By varying the applied voltage V. This is known as **voltage control method**.

Torque and Speed of a D.C. Motor

- For any motor, the torque and speed are very important factors.
- When the torque increases, the speed increases and vice-versa.

$$\because N = K\frac{V - I_a R_a}{\Phi} = K\frac{E_b}{\Phi} \text{ and } T_a \propto \Phi I_a$$

- If the flux decreases, the speed increases but the torque decreases.
- This is not possible because the increase in motor speed must be the result of increased torque.
- Indeed, it is so in this case. When the flux decreases slightly, the armature current increases to a large value.
- As a result, in spite of the weakened field, the torque is momentarily increased to a high value and will exceed considerably the value corresponding to the load.
- The surplus torque available causes the motor to accelerate and back e.m.f. ($E_b = P\Phi ZN/60A$) to rise.
- Steady conditions of speed will ultimately be achieved when back e.m.f. has risen to such a value that armature current $[I_a = (V - E_a)/R_a]$ develops torque just sufficient to drive the load.

Illustrative Example

- Suppose a 400 V shunt motor is running at 600 r.p.m., taking an armature current of 50 A. The armature resistance is 0.28 Ω. Let us see the effect of sudden reduction of flux by 5% on the motor.
- Initially (prior to weakening of field), we have

$$Ea = V - IaRa = 400 - (50 \times 0.28) = 386 \text{ V}$$

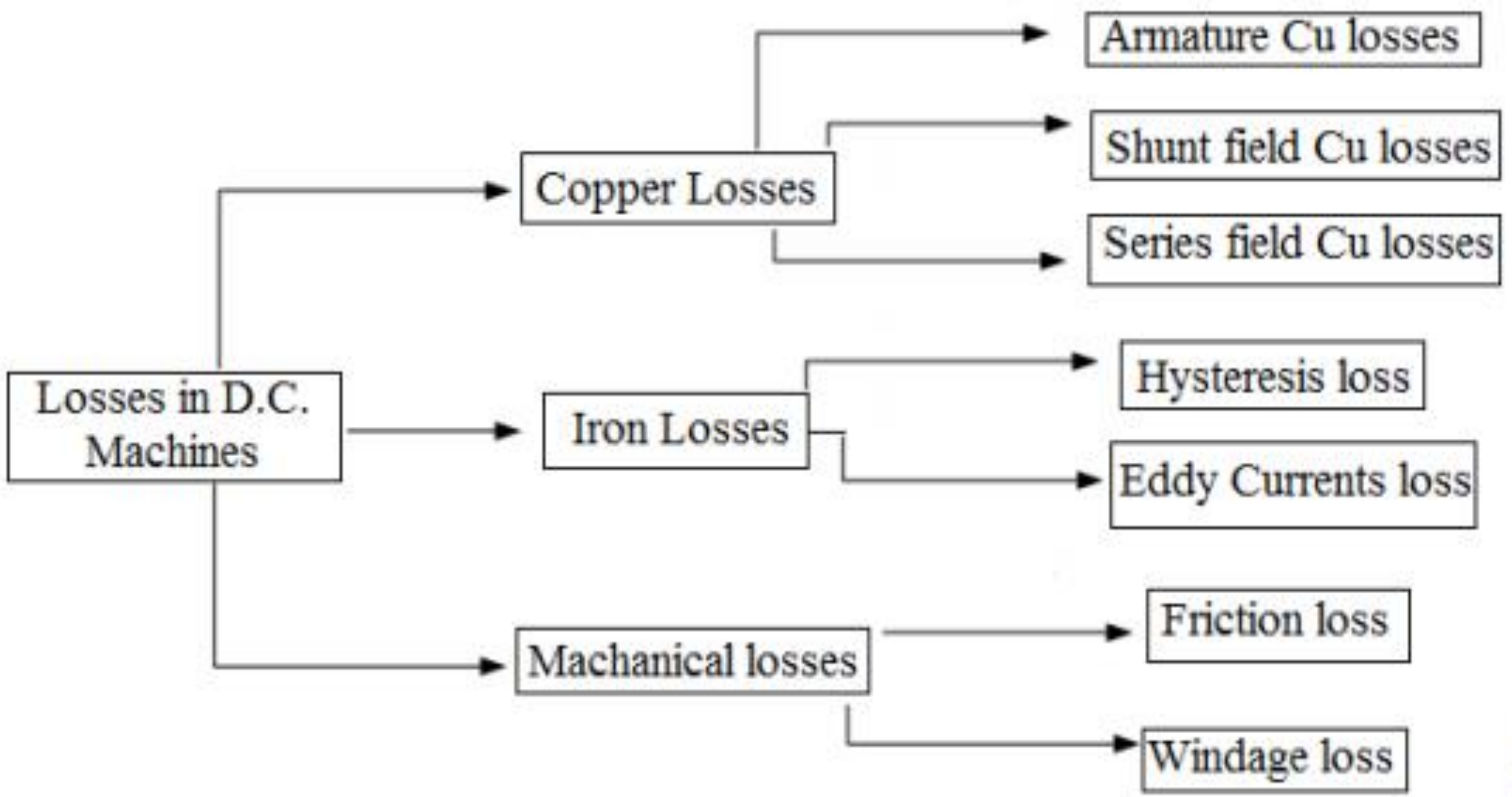
$$E'_b = 0.95 \times 386 = 366.7 \text{ V} \qquad E_b \propto \phi N$$

- Instantaneous armature current is

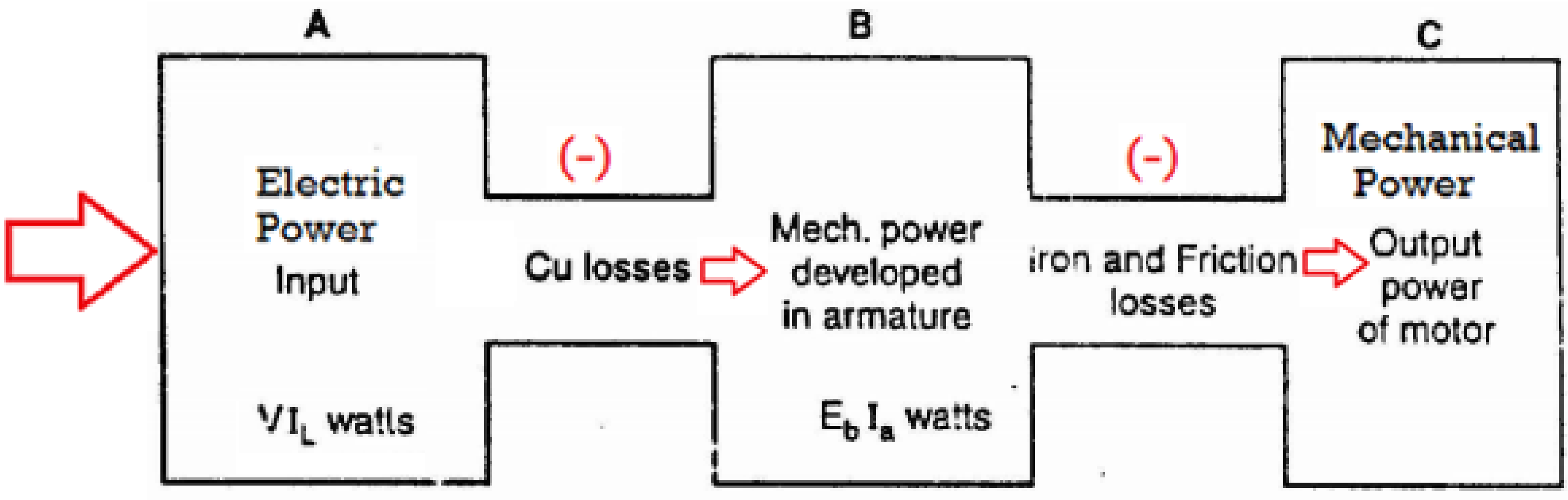
$$I'_a = \frac{V - E'_b}{R} = \frac{400 - 366.7}{0.28} = 118.9 \text{ A}$$

- Note that a sudden reduction of 5% in the flux has caused the armature current to increase about 2.5 times the initial value.
- This will result in the production of high value of torque. However, soon the steady conditions will prevail.
- This will depend on the system inertia; the more rapidly the motor can alter the speed, the sooner the e.m.f. rises and the armature current falls.

Losses in DC Machines



Power Stages in DC Motors



Mechanical efficiency, $\eta_m = C/B$

Electrical efficiency, $\eta_e = B/A$

Overall efficiency, $\eta_c = C/A$

Practice Question

- A 250V, d.c. shunt motor takes a full load current of 67 A. Its armature resistance is 15Ω and shunt field resistance is 166.67 Ω. When running on no load, the current drawn by the motor is 6.5 A and the speed as 1280 rpm. Determine:

  i). Full load speed

  ii) Speed regulation

  iii) h.p. rating of the machine

  iv). Full load efficiency.

Solution

$V = 250$ V, $R_a = 0.15\ \Omega$, $R_{sh} = 166.67\ \Omega$, $N_0 = 1280$ r.p.m.

I_{L1} = Current drawn on full load = 67 A

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{166.67} = 1.5\ \text{A} \quad \text{... as shunt motor}$$

$$I_{a1} = I_{L1} - I_{sh} = 67 - 1.5 = 65.5\ \text{A}$$

$$E_{b1} = V - I_{a1} R_a = 250 - 65.5 \times 0.15 = 240.175\ \text{V}$$

On no load, $I_{L0} = 6.5$ A

$I_{sh} = 1.5$ A ... remains same

$$I_{a0} = I_{L0} - I_{sh} = 6.5 - 1.5 = 5\text{A}$$

$$E_{b0} = V - I_{a0} R_a = 250 - 5 \times 0.15 = 249.25\ \text{V}$$

i) Use speed equation,

$$N \propto \frac{E_b}{\phi} \propto E_b \quad \text{... as } \phi \text{ is constant}$$

$$\therefore \quad \frac{N_1}{N_0} = \frac{E_{b1}}{E_{b0}} \qquad \frac{N_1}{1280} = \frac{240.175}{249.25}$$

$$\therefore \quad N_1 = \mathbf{1233.396\ r.p.m.}$$

ii) Speed regulation $= \dfrac{N_0 - N_1}{N_1} \times 100$

where N_0 = no load speed N_1 = full load speed

$$\therefore \text{ Speed regulation} = \frac{1280 - 1233.396}{1233.396} \times 100 = \mathbf{3.78\%}$$

Conti…Solution

iii) To calculate h.p. rating, calculate full load shaft output power

$$\text{F.L. shaft output} = \text{F.L. power developed} - \text{stray losses}$$

$$= E_{b1} I_{a1} - \text{stray losses}$$

Now $$\text{Stray losses} = \text{mechanical power developed on no load}$$

$$= E_{bo} I_{ao}$$

This is because on no load entire power developed is used to overcome stray losses.

$$\therefore \quad \text{F.L. shaft output} = E_{b1} I_{a1} - E_{bo} I_{a0}$$

$$= 240.175 \times 65.5 - 249.25 \times 5 = 14485.2125 \text{ watts}$$

$$\text{h.p. rating} = \frac{\text{F.L. Shaft output}}{746} = \mathbf{19.42\ h.p.}$$

iv) $$\text{Power input} = V I_{L1} \qquad \text{... full load}$$

$$= 250 \times 67 = 16750 \text{ watts}$$

$$\%\eta = \frac{P_{out} \text{ on full load}}{P_{in} \text{ on full load}} \times 100 = \frac{14485.2125}{16750} \times 100 = \mathbf{86.47\%}$$

Practice Questions

- **Qn 1.** A 25kW, 250V, d.c. shunt generator has armature and field resistances of 0.06Ω and 100Ω respectively. Determine the total armature power developed when working (i) as a generator delivering 25kW output and (ii) as a motor taking 25kW input.

- **Qn. 2.** A 230V series motor is taking 50A resistance of armature and series field is 0.2 Ω and 0.1 Ω respectively. Find i) brush voltage ii) back emf iii) power wasted in armature iv) mechanical power developed.

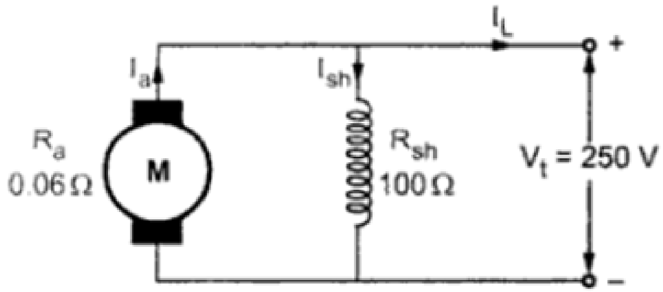
Solution Q1

i) As a generator

$$P_{out} = 25\text{ kW} = V_t I_L$$

$$\therefore \quad I_L = \frac{25\times10^3}{250} = 100\text{ A}$$

$$I_{sh} = \frac{V_t}{R_{sh}} = \frac{250}{100} = 2.5\text{ A}$$



$$\therefore \quad I_a = I_L + I_{sh} = 102.5\text{ A}$$

$$E_g = V_t + I_aR_a = 250 + 102.5\times0.06$$

$$= 256.15\text{ V}$$

$$\therefore P_{developed} = E_g\times I_a = 256.15\times102.5 = \mathbf{26.255\text{ kW}}$$

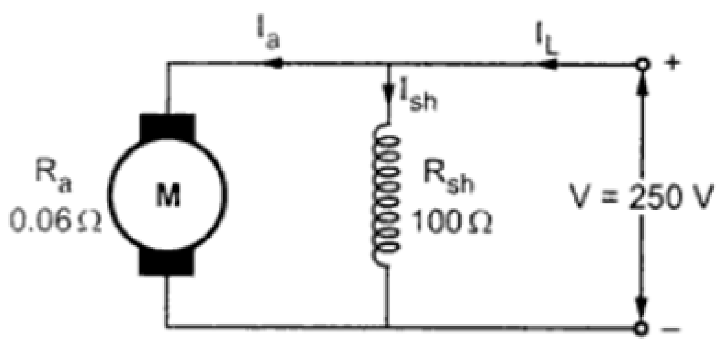
ii) As a motor

$$P_{in} = 25\text{ kW} = V\times I_L$$

$$I_L = \frac{25\times10^3}{250} = 100\text{ A}$$

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

$$I_{sh} = \frac{V}{R_{sh}} = \mathbf{2.5\text{ A}}$$



$$\therefore \quad I_a = 100 - 2.5 = 97.5\text{ A}$$

$$\therefore \quad E_b = V - I_aR_a$$

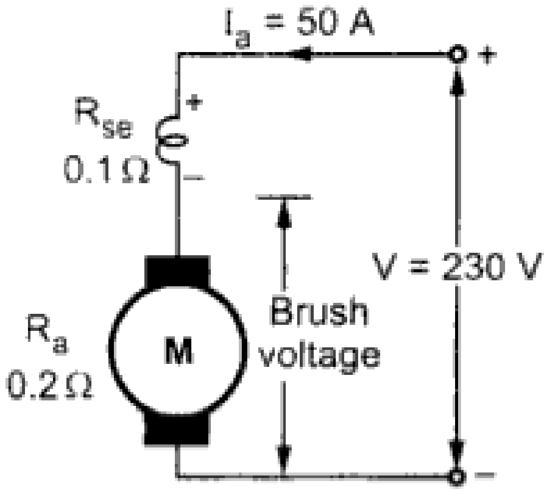
$$= 250 - 97.5\times0.06$$

$$= 244.15\text{ V}$$

$$\therefore P_{developed} = E_b\times I_a = 244.15\times97.5$$

$$= \mathbf{23.8\text{ kW}}$$

Solution Q2



i) Brush voltage $= V - I_a R_{se} = 230 - 50 \times 0.1$

$= \mathbf{225\ V}$

ii) $E_b = V - I_a R_{se} - I_a R_a$

$= 230 - 50 \times 0.1 - 50 \times 0.2$

$= \mathbf{215\ V}$

iii) Power wasted in armature $= I_a^2 R_a = (50)^2 \times 0.2 = \mathbf{500\ W}$

iv) Mechanical power developed $= E_b I_a = 215 \times 50 = \mathbf{10.75\ kW}$

Summary of Motor Application

Type of motor	Characteristics	Applications
Shunt	Speed is fairly constant and medium starting torque	1) Blowers and fans 2) Centrifugal and reciprocating pumps 3) Lathe machines 4) Machine tools 5) Milling machines 6) Drilling machines
Series	High starting torque. No load condition is dangerous. Variable speed	1) Cranes 2) Hoists, Elevators 3) Trolleys 4) Conveyors 5) Electric locomotives
Cumulative compound	High starting torque. No load condition is allowed.	1) Rolling mills 2) Punches 3) Shears 4) Heavy planers 5) Elevators
Differential compound	Speed increases as load increases	Not suitable for any practical application.

Troubles in D.C. Motors

Several troubles may arise in a d.c. motor and a few of them are discussed below:

1. **Failure to start** - This may be due to:
   - (i) ground fault
   - (ii) open or short-circuit fault
   - (iii) wrong connections
   - (iv) too low supply voltage
   - (v) frozen bearing or (vi) excessive load.
2. **Sparking at brushes**- This may be due to:
   - (i) Brush troubles which may arise due to insufficient contact surface, too short a brush, too little spring tension or wrong brush setting.
   - (ii) Commutator troubles which may be due to dirt on the commutator, high mica, rough surface or eccentricity.
   - (iii) Armature troubles may be due to an open armature coil. An open armature coil will cause sparking each time the open coil passes the brush. The location of this open coil is noticeable by a burnt line between segments connecting the coil.
   - (iv) excessive load.

Troubles in D.C. Motors

3. **Vibrations and pounding noises** - These maybe due to:
   i) worn bearings
   (ii) loose parts
   (iii) rotating parts hitting stationary parts
   (iv) armature unbalanced
   (v) misalignment of machine
   (vi) loose coupling etc.
4. **Overheating** - The overheating of motor may be due to:
   (i) overloads
   (ii) sparking at the brushes
   (iii) short-circuited armature or field coils
   (iv) too frequent starts or reversals poor ventilation
   (vi) incorrect voltage.

Self Assessment

- How does a DC motor differ from a DC generator in construction?
- Why the emf generated in the armature of a DC motor is called the back emf ?
- What will be the effect on direction of rotation of a DC series motor if the supply terminals are reversed?
- Identify suitable DC motors for the following applications:
- (a) Electric traction (b) Vacuum cleaners (c) Paper making (d) Shearing and punching.
- Name the methods used for speed control of DC motors
- A 250 V shunt motor runs at 1500 rpm at full load with an armature current of 15 A. The total resistance of the armature and brushes is 0.6Ω . If the speed is to be reduced to 1200 rpm with the same armature current, calculate the amount of resistance to be connected in series with the armature and power lost in this resistor. [R = 3.213Ω, P= 723 W (Ans.)]