DC MACHINE

Text Book: Electric Machinery Fundamentals

(Stephen J. Chapman)

Reference Book: A Textbook of Electrical Technology

(B.L. Theraja & A.K Theraja)

DC MOTOR

1. 5 major types of DC motor:

(i) Separately excited

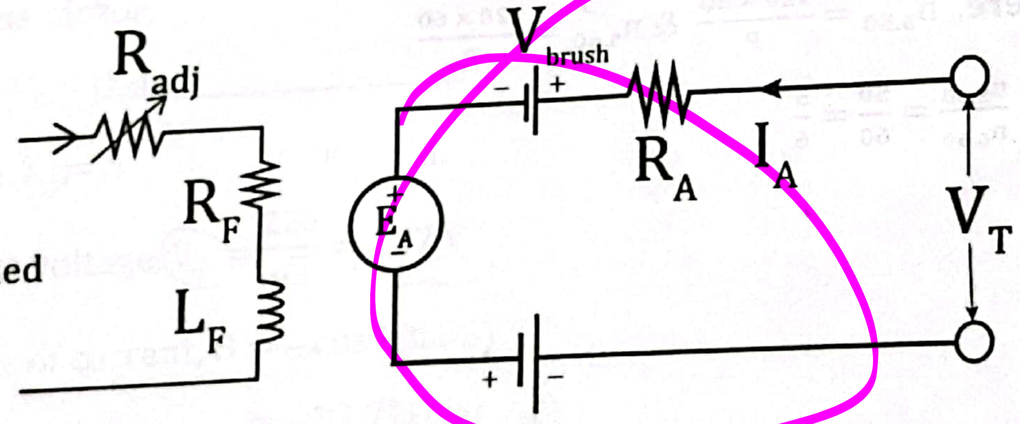
(ii) Shunt DC motor

(iii) Permanent magnet DC motor

(iv) Series DC motor

(v) Compounded DC motor

2. Separately Excited DC Motor :

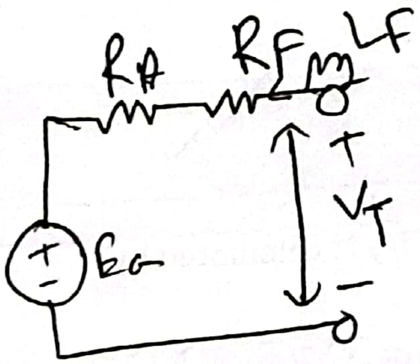


$V_T = I_A R_A + 2V_b + E_A$, Considering brush Voltage Drop

ω_m= Mechanical speed

No Load Condition ↵ Armature Current Zero ($I_A = 0$). So, No Load Condition ↵
$V_T = E_A$

3. Compound DC motor:



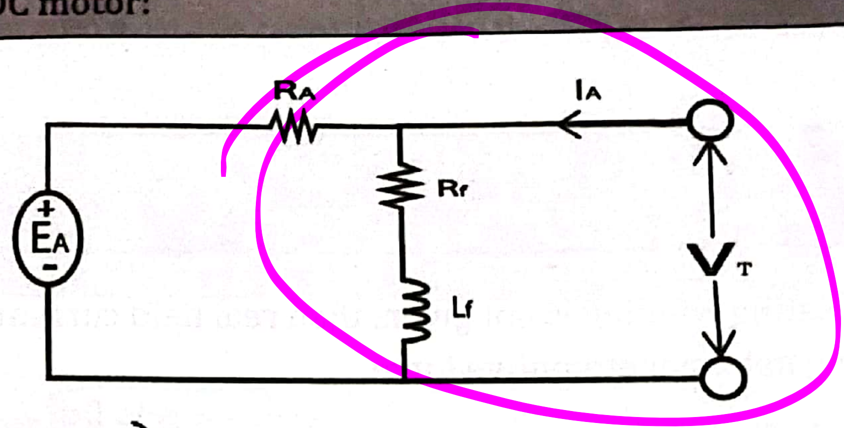
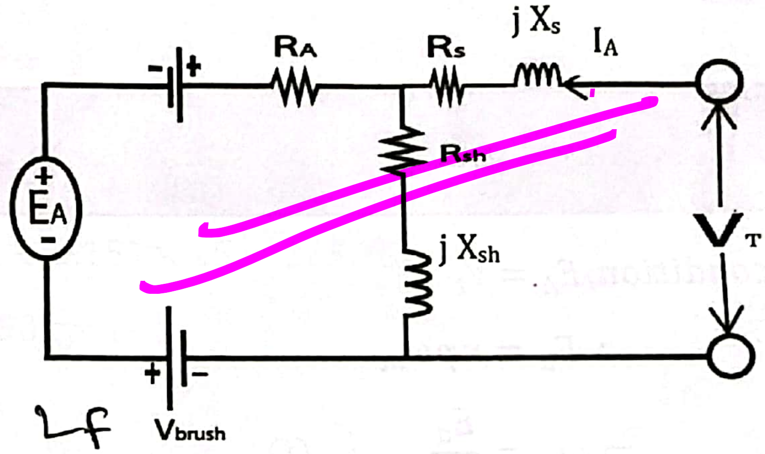


Fig : DC shunt motor

$V_T = E_a + I_A(R_A + R_F)$

Fig1 DC series motor

In case of motor,



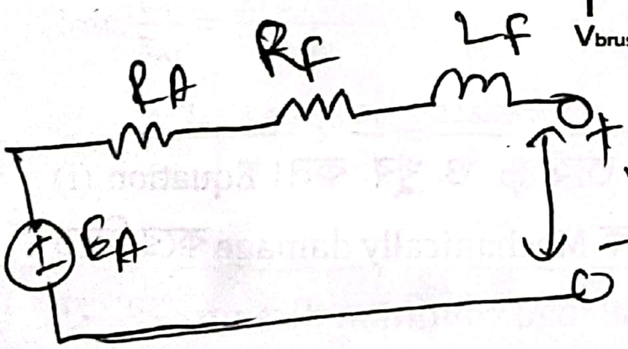
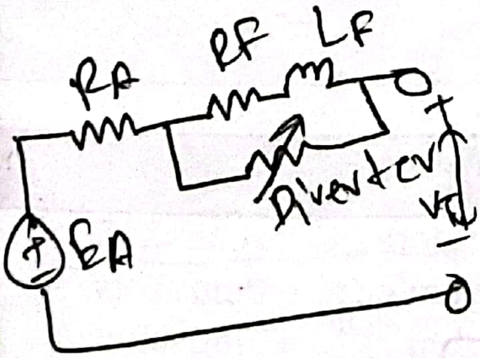


Fig : Short shunt compound DC motor



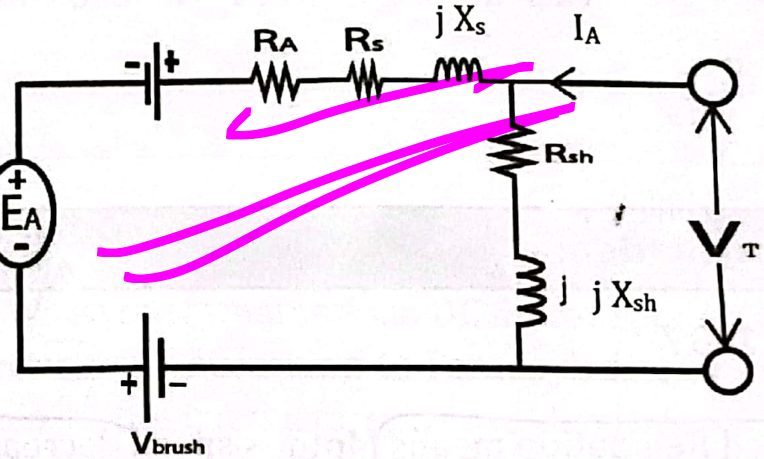


Fig : Long shunt compound DC motor

4. Power:

$$P_{conv} = T_{ind}\omega_m = E_A I_A$$

Question: How Real field current is calculated if compensated winding is not given?

If compensating winding is not given, then real field current (I_f) is calculated by considering net magnetomotive force.

$$F_{net} = N_F I_F - F_{AR}$$

$$\Rightarrow I_f^* N_F = I_F N_F - F_{AR}$$

$$\Rightarrow \quad I_f^* = I_f - \frac{F_{AR}}{N_F}$$

Question :-Why is DC series motor always started with a load?

$\Rightarrow$ *At no load condition,* $E_A = V_t$

$$\therefore E_a = \kappa\varphi\omega_m$$

$$\Rightarrow \omega_m = \frac{E_a}{\kappa\varphi} \ldots\ldots\ldots (i)$$

$\varphi \propto I_A$ যেহেতু I_A কম (Approximately zero), তাই φ ও খুব কম। Equation (i) অনুযায়ী ω বা Speed অনেক বেশী হয়। যা Motor কে Mechanically damage করে দিতে পারে। এই কারণে DC series motor কে কখনো No load condition এ start করা হয় না।

5. Speed regulation:

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

$\Rightarrow$ Positive Speed Regulation means Motor's speed decreases with increasing load.

SOLVED PROBLEMS

1. A DC series motor operates at 800 rpm with a line current of 100A from 230V mains. Its armature circuit resistance is 0.15Ω and its field resistance 0.1Ω. Find the speed at which the motor runs at a line current of 25A, assuming that the flux at this current is 45% of the flux at 100A.

[BADB-20, BUET]

Solution:

We know, For DC motor, $\boxed{E_A = K' \emptyset \omega}$

Now, let at first flux is $\emptyset_1$ and after reduction in line current, it is $\emptyset_2$

$\therefore \emptyset_2 = 0.45\ \emptyset_1$

$\Rightarrow \frac{\emptyset_1}{\emptyset_2} = \frac{1}{0.45} = \frac{20}{9}$

$\frac{E_{A1}}{E_{A2}} \sim \frac{\emptyset_1 \omega_1}{\emptyset_2 \omega_2}$

$\therefore$ At first case, $E_{A1} = V_T - (R_A + R_F) \times I_{A1} = 230 - (0.15 + 0.1) \times 100 = 205$ V

When, line current reduces to 25 A,

Then, $E_{A2} = 230 - (0.1 + 0.15) \times 25 = 223.75$

At first speed, $\omega_1 = 800$ rpm

$-V_T + I_A(R_A + R_F) + E_A$

$E_A = V_T - I_A(R_A$

Now, $\frac{E_{A2}}{E_{A1}} = \frac{K' \emptyset_2 \omega_2}{K' \emptyset_1 \omega_1}$

$\Rightarrow \omega_2 = \frac{E_{A2} \times \omega_1}{E_{A1}} \times \frac{\emptyset_1}{\emptyset_2} = \frac{223.75 \times 800}{205} \times \frac{20}{9} = 1940.38$ rpm

2. What is back EMF of DC motor?

[BS&EC-18, Tejgaon Govt]

Solution:

Back EMF of DC motor: When the armature of a DC motor rotates, the conductors also rotate in the magnetic field. According to Faraday's law of electromagnetic induction, emf is induced in the conductors, whose direction is found by right hand rule, is in opposite to the applied voltage. This is called back EMF of DC motor.

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3. *A 220V DC series motor has armature resistance 0.15Ω and field resistance 0.1Ω. It draws 30A at 1000 rpm speed. Now a diverter is added across the field having e resistance of 0.2Ω. Find steady state current and rpm if load torque is constant.* [BWDB-18, BUET]

Solution:

For series motor, field current, I_F and armature current, I_A are same.

$\therefore$ At first, $I_{A1} = I_{F1} = 30$ A

$\therefore E_{A1} = V_T - (R\, I_{A1})$

$= 200 - (R_A + R_F) \times I_A$

$= 220 - (0.1 + 0.15) \times 30$

$= 212.5$ V

We know, torque, $\tau = K \, \emptyset \, I_A$

Now, τ_{load} = constant

$\therefore K I_{A1} \emptyset_1 = K I_{A2} \emptyset_2$ [$\because \emptyset \propto$ Field current]

$\Rightarrow I_{A1} I_{F1} = I_{A2} I_{F2}$ ....(i)

Here, $I_{F2} \neq I_{A2}$, because a diverter is added to reduce field current.

$E_A = K\phi\omega$

$E_A = V_T - I_A(R_A + R_F)$

$= 220 - 30(0.15 + 0.1)$

$= 212.5$ V

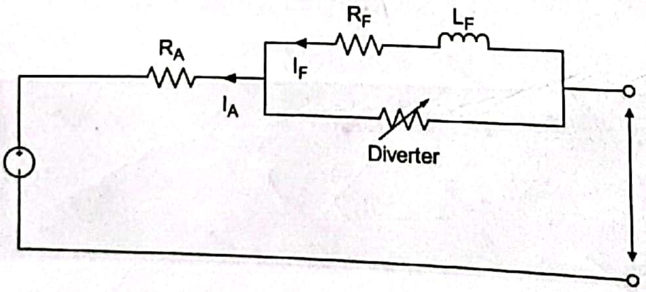
$= 220 = 212.5 + I_A(0.3 + 0.15)$

V_F 220

$I_A = 16.67$

$\phi_1\omega_1 = \phi_2\omega_2$

$\omega_2 = \dfrac{\phi_1\omega_1}{\phi_2}$



$\therefore I_{F2} = I_{A2} \times \dfrac{0.2}{0.2 + 0.1}$

$\therefore$ From (i) $\Rightarrow I_{A1} \times I_{A1} = I_{A2} \times I_{A2} \times \dfrac{0.2}{0.3}$

$\Rightarrow 30 \times 30 = I_{A2}^2 \times \dfrac{2}{3}$

$\therefore I_{A2} = 36.74$ A

$\therefore I_{F2} = 36.74 \times \frac{0.2}{0.2 + 0.1} = 24.5$ A

Now back EMF, $E_{A2} = 220 - \{\frac{0.1 \times 0.2}{0.1 + 0.2} + 0.15\} \times 36.74 = 212$ V

At first, speed, $\omega_1 = 1000$ rpm

$\therefore \frac{E_{A1}}{E_{A2}} = \frac{\omega_1 \phi_1}{\omega_2 \phi_2}$

$\Rightarrow \omega_2 = \frac{E_{A2} \times \omega_1 \times \phi_1}{E_{A1} \times \phi_2} = \frac{212 \times 1000 \times I_{F1}}{212.5 \times I_{F2}} = \frac{212 \times 1000 \times 30}{212.5 \times 24.5} = 1221.6$ rpm

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4. A 250V shunt motor with armature resistance of 0.5Ω runs at 600 rpm on full load and takes an armature current of 20A. If resistance of 1Ω is placed in the armature circuit, find the speed at full load torque.

[RPCL-19, MIST]

Solution:

$\frac{E_{a2}}{E_{a1}} = \frac{\omega_2}{\omega_1} \times E_{a1}$

$\omega_2 = \frac{E_{a2}}{E_1} \times \omega_1$

At first, speed, $\omega_1 = 600$ rpm

$\therefore E_{A1} = V_T - I_{A1} R_A = 250 - (20 \times 0.5) = 240$ V

As field resistance is not changed, the field current and flux will remain constant.

$\therefore$ Torque, $\tau \propto I_A$

$\therefore$ Armature current will be same at full load torque.

20A

0.5

$\therefore I_{A1} = I_{A2} = 20$ A

$\therefore E_{A2} = 250 - (1 + 0.5) \times 20 = 220$ V

$\therefore$ As flux is constant, then $E_A \propto \omega$

$\therefore \frac{E_{A1}}{E_{A2}} = \frac{\omega_1}{\omega_2}$

$\frac{E_1}{E_2} = \frac{\phi_1 \omega_1}{\phi_2 \omega_2}$

$\therefore \omega_2 = \frac{600 \times 220}{240} = 550$ rpm

$E_a = V_T - I_A(0.5)$ R_a

$= 250 - 20 \times 0.5$

$= 240$ V

$250 - 1.5 \times 20$

INDUCTION MOTOR

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1) Slip calculation :

$$f_r = sf_e$$

$$n_{syn} = \frac{120 f_e}{P}$$

$$s = \frac{n_{syn} - n_R}{n_{syn}}$$

$$n_R = n_{syn}(1 - s)$$

f_e = Frequency of voltage

f_r = Frequency of the induced voltage

n_R = Rotor speed

n_m = Speed of the magnatic field

P = Number of poles

2) Different Powers in an Induction Motor :

$$P_{in} = P_{scl} + P_{core} + P_{ag}$$

$$P_{rcl} + P_{mech}$$

Wn-find

$$P_{fw} + P_{stray} + P_{out}$$

Wn-load

P_{in} = *Electrical input power*

P_{scl} = *Stator copper loss*

P_{rcl} = *Roton copper loss*

(i) $P_{rcl} = s\,P_{ag}$

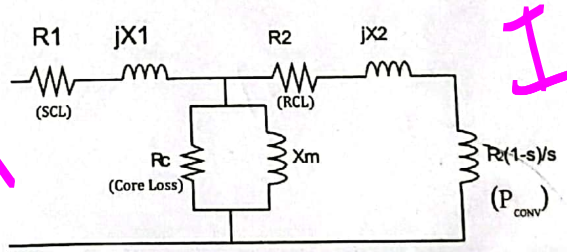
(ii) $P_{conv} = P_{mech}$

$$= P_{ag} - P_{rcl}$$

$$= P_{ag} - sP_{ag}$$

$$= P_{ag}(1 - s)$$

$$\therefore P_{conv} = P_{ag}(1 - s)$$



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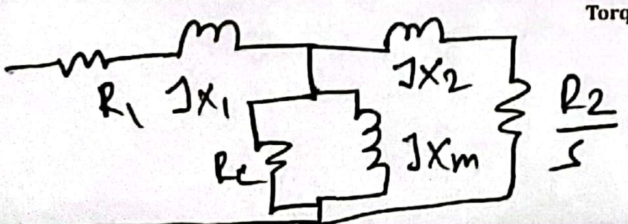
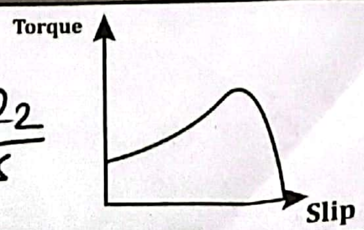
3) Torque Calculations :

Shaft torque, $T = \frac{P_{out}}{n_p(^{rad}/_s)}$

Induced torque, $T_{in} = \frac{P_{ag}}{n_{syn}}$

4) Torque-slip Charecteristics of Induction Motor:





Example 1 :

A 208-V, 10-hp, four-pole, 60 Hz, Y-connected induction motor has a full-load slip of 5 percent.

(a) What is the synchronous speed of this motor?
(b) What is the rotor speed of this motor at the rated load?
(c) What is the rotor frequency of this motor at the rated load?
(d) What is the shaft torque of this motor at the rated load?

Solution:

$$w_r = \frac{n_r \times 2\pi}{60}$$

a) $$n_{syn} = \frac{120 f_e}{P}$$

$$= \frac{120 \times 60}{4} = 1800\ rpm$$

b) $$n_r = n_{syn}(1 - s)$$

$$= 1800(1 - 0.05) = 1710\ rpm$$

c) $$f_r = s f_e$$

$$= 60 \times 0.05 = 3\ Hz$$

d) $$\tau_r = \frac{P}{\omega_r}$$

$$= \frac{10 \times 446}{1710 \times 2\pi / 60}$$

$$= 41.7\ Nm$$

Example 2:

A 480-V, 60-Hz, 50-hp three-phase induction motor is drawing 60 A at 0.85-PF lagging. The stator copper losses are 2 kW, and the rotor copper losses are 700 W. The friction and windage losses are 600 W, the core losses are 1800 W, and the stray losses are negligible. Find the following quantities:

(a) The air-gap power P_{ag}
(b) The power converted P_{conv}
(c) The output power P_{out}
(d) The efficiency of the motor.

Solution:

$P_{in} = P_{scl} + P_{core} + P_{ag}$

$$\boxed{P_{rcl} + P_{mech}}$$

Pag

$$\boxed{P_{fw} + P_{stray} + P_{out}}$$

a) $P_{ag} = P_{in} - P_{scl} - P_{cone}$

$= (\sqrt{3} \times 80 \times 60 \times 0.85) - (2 \times 10^3) - 1800$

$= 38600.6\ W$

b) $P_{conv} = P_{fw} + P_{stray} + P_{out}$ [$P_{conv} = P_{ag} - P_{rcl}$ দিয়েও Same answer আসবে]

$= 600 + 0 + (50 \times 746)$

$= 37900\ W$

c) $P_{out} = (50 \times 746) = 37.3\ kW$ 50 hp

d) $\eta = \dfrac{P_{out}}{P_{in}} \times 100\%$

$= \dfrac{50 \times 746}{\sqrt{3} \times 1480 \times 0.85} \times 100\% = 87.97\%$

Example 4 :

A two-pole, 50-Hz induction motor supplies 15 kW to a load at a speed of 2950 r/min.

(a) What is the motor's slip?
(b) What is the induced torque in the motor in N.m under these condition?
(c) What will the operating speed of the motor be if its torque is double?
(d) How much power will be supplied by the motor when the torque is doubled?

Solution:

a) $n_{sync} = \dfrac{120 \times 50}{2}$

$= 3000\ rpm$

$S = \dfrac{n_{sync} - n_r}{n_{syn}}$

$= \dfrac{3000-2950}{3000}$

$= 1.67\%$

$= 0.0167$

b) $\tau_{ind} = \dfrac{P_{conv}}{\omega_r}$

$= \dfrac{15\ k}{2950 \times \frac{2\pi}{60}}$

$= 48.6\ Nm$

c) *Induced torque* $\propto$ *slip*

সুতরাং Tongue double করলে Slip ও Double হবে।

$\therefore n_r = n_{syn}(1 - s)$

$= 3000(1 - 2 \times 0.0167)$

$= 2900\ rpm$

d) $P_{conv} = \tau_{ind} \times \omega_r$

$= (48.6 \times 2) \times (2900 \times \frac{2\pi}{60})$

$= 29.5\ k\omega$

[ans.]

$P_{conv} = \dfrac{15 \times 10^3}{295 \times \frac{2\pi}{60}}$