4
UNIT

Electrical Machines

PART-1

DC Machines : Principle and Construction, Types, EMF Equation of Generator and Torque Equation of Motor, Applications of DC Motor (Simple Numerical Problems).

CONCEPT OUTLINE : PART-1

- DC machine is an alternating current machine, furnished with a special device called the commutator, which under certain condition converts into DC and vice versa.
- **Types of DC generator :**
  1. Series generator
  2. Shunt generator
- **Types of DC motor :**
  1. DC series motor
  2. DC shunt motor
  3. Cumulatively compounded motor
  4. Differentially compounded motor

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. **Explain the principle of working of DC generator.**

Answer

1. DC generator works on the principle of Faraday's law of electromagnetic induction.
2. Consider elementary generator as shown in Fig. 4.1.1.
3. When the mechanical input *i.e.*, $P_m = T\omega$ (Torque × Angular speed) is given to generator, armature conductors start rotating. These armature conductors cut the magnetic field set up by the field poles electromagnetically.
4. Hence an emf is induced in armature whose direction is decided by Lenz's law, *i. e.*, to oppose the cause producing it.
5. This emf is known as generated emf in case of generator. To create the flux electromagnetically, poles are wound with field coils. When field current flows through these field coils, flux ϕ is set up whose magnitude is directly proportional to field current I_f.

$\phi \propto I_f$

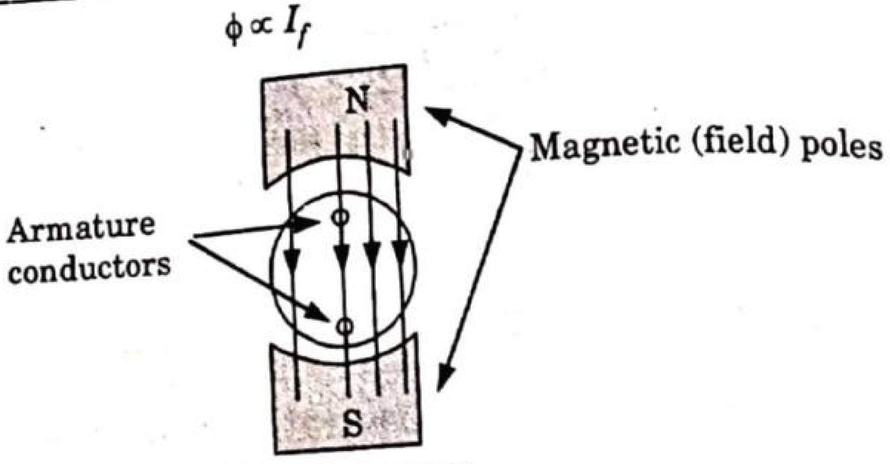

Fig. 4.1.1.

6. Thus in armature, alternating emf is generated which will be converted into direct current (DC) with the help of commutator and brushes.

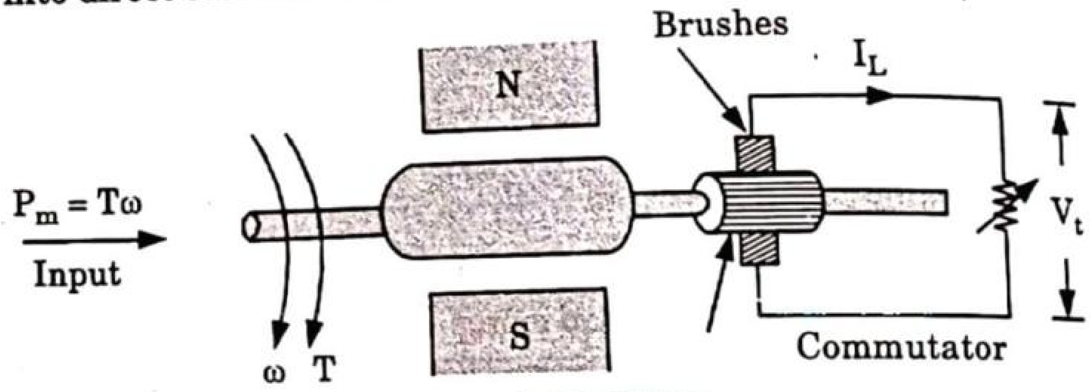

Fig. 4.1.2.

Que 4.2. **Explain the working principle of DC motor.**

Answer

1. DC motor has two basic coils namely field coil and armature coil as shown in Fig. 4.2.1.

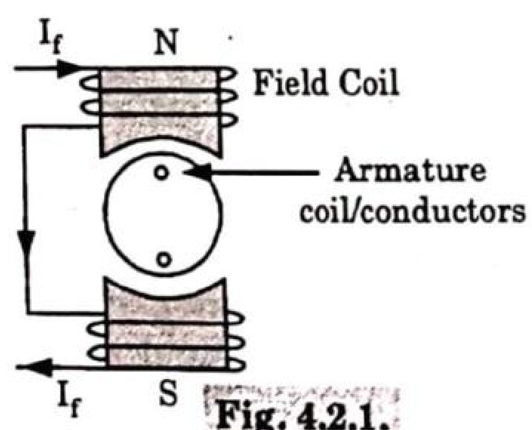

Fig. 4.2.1.

2. When the DC supply is given to motor, current flows through field coil as well as armature coil. Due to this field, poles are magnetised and flux sets up.
3. Due to interaction of this field flux and armature current, torque is generated (T_a). The direction of torque is given by Fleming's left hand rule.

4. Since armature current is of alternating nature, due to commutation unidirectional torque (T_a) is generated whose magnitude is directly proportional to ϕ and I_a.
5. Thus electrical input P_e is converted into mechanical output P_m in DC motor.

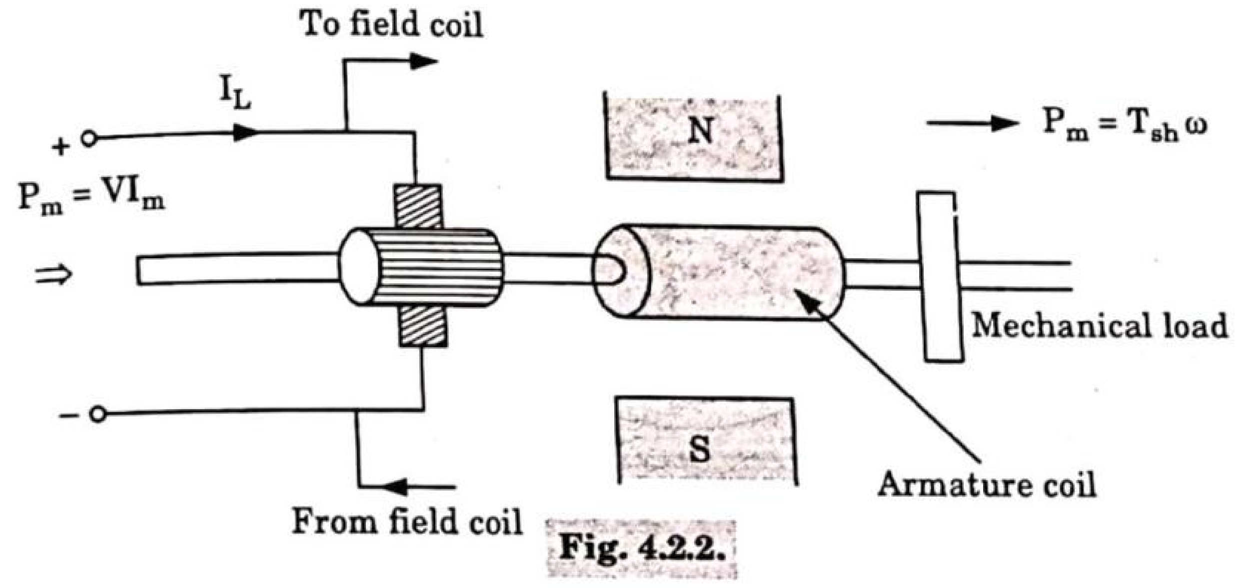

Fig. 4.2.2.

Que 4.3. **Give the construction and principle of DC machine.**

Answer

A. Construction of DC machine :

a. Stator

1. Yoke (or frame) is made of unlaminated ferromagnetic material. Yoke is made up of cast iron for small machines and of fabricated steel for larger machines (for higher permeability).
2. Salient field poles bolted to the inner periphery of the yoke, and bearings, brush-rigging carrying brush holders, end covers etc.
3. Field poles are made up of stacks of steel plates, riveted together. The pole core where the field winding is wound, is usually of smaller cross-section than the pole shoe, so as to :
   a. Reduce amount of copper used for field winding.
   b. Reduce air gap reluctance.
   c. Provide mechanical strength and support to field winding.
4. When the field winding is excited with DC, north and south poles are produced. Both armature core and yoke, carries half of flux per pole.
5. The brush-rigging as shown in Fig. 4.3.1 consists of a group of brush holders and their attachment to the yoke or end cover.

6. Stationary carbon brushes are housed in the brush holders and are kept pressed on to the commutator surface by means of tension controlled springs.

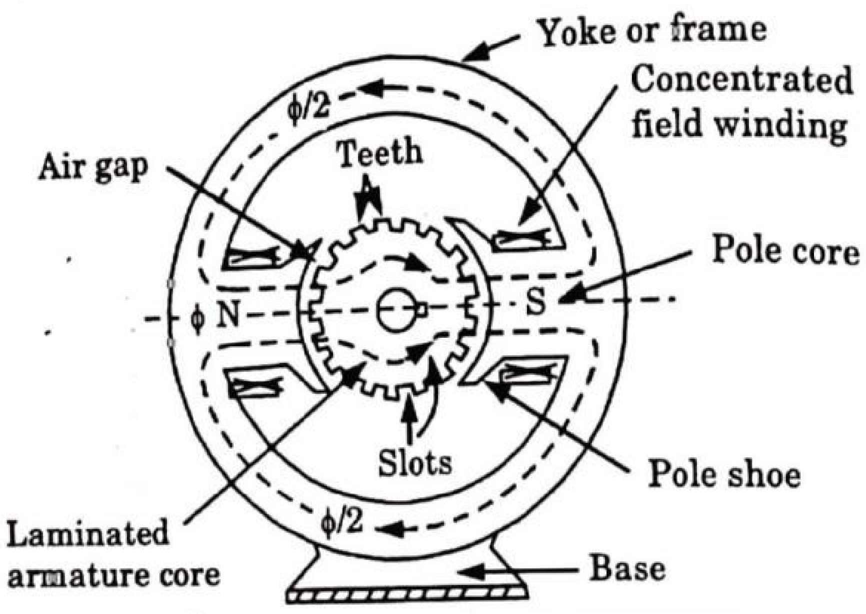

Fig. 4.3.1. Constructional features of a 2-pole DC machine.

b. **Rotor :**

1. Rotor is the rotating part also called armature.
2. The insulated conductors are put in the slot of the armature core. Armature core consists of a stack of circular steel laminations, about 0.4 to 0.6 mm thick, insulated from each other to avoid eddy current losses.

B. **Principle of operation of DC motor :** Refer Q. 4.2, Page 4–3D, Unit-5.

Que 4.4. What are the different types of DC machine ? Also write the applications of each.

OR

Draw and discuss the construction and principle of operation of a DC motor and also give some of its applications.

AKTU 2017-18(Sem-1), Marks 07

Answer

A. **Construction :** Refer Q. 4.3, Page 4–4D, Unit-4.

B. **Principle :** Refer Q. 4.2, Page 4–3D, Unit-4.

C. **Types of DC machine :** Depending on methods of excitation the DC machines are classified into two groups :

1. **Separately excited DC machine (generator/motor)**

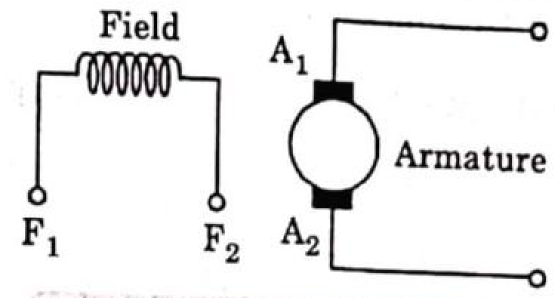

Fig. 4.4.1. Separate excitation.

2. **Self excited DC machine :**

a. **Shunt excitation of DC shunt machine :** If field winding and armature winding is connected in parallel, the machine is known as DC shunt machine.

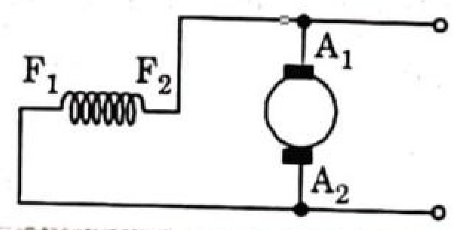

Fig. 4.4.2. DC shunt machine.

b. **Series excitation of DC series machine :** If field winding is connected in series with the armature winding, the DC machine is known as DC series machine.

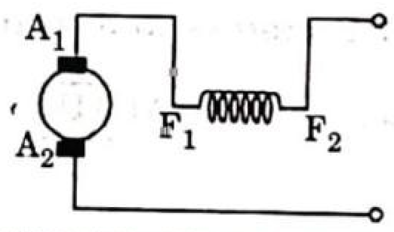

Fig. 4.4.3. DC series machine.

c. **Compound excitation or DC compound machine :** If both series and shunt field windings are present, along with the armature winding, the machine is known as DC compound machine.

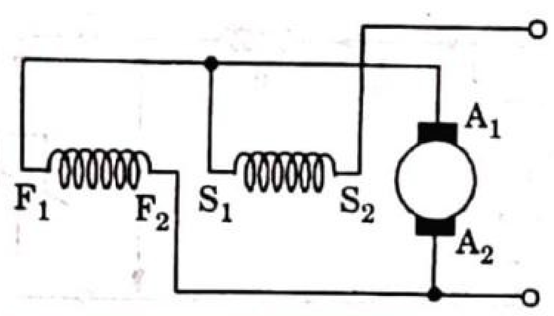

Fig. 4.4.4. DC compound machine.

D. Applications of DC machines :

S. No.	Types of DC Machines	Applications
1.	DC shunt generator	For electroplating, Battery charging, excitation of alternators.
2.	Series generators	Used as boosters, for supply to arc lamps.
3.	Compound generator	To supply power DC welding machines, for offices, hostels and lodges, to compensate the voltage drop in feeders.
4.	Separately excited generator	For the testing purposes.
5.	DC shunt motors	In Lathes, Drills, Boring mills, Shapers, and weaving machines.
6.	DC series motor	In Electric traction, Cranes, Elevators, Air compressor, Vacuum cleaner, Hair dryer.
7.	DC compound motor	In Presses shears, Reciprocating machine.

Que 4.5. **Classify DC motors and write current and voltage equation for each type.** **AKTU 2014-15(Sem-2), Marks 05**

Answer

A. Classification : Refer Q. 4.4, Page 4–5D, Unit-4.

B. Current and voltage equations :

i. Equations for series generators :

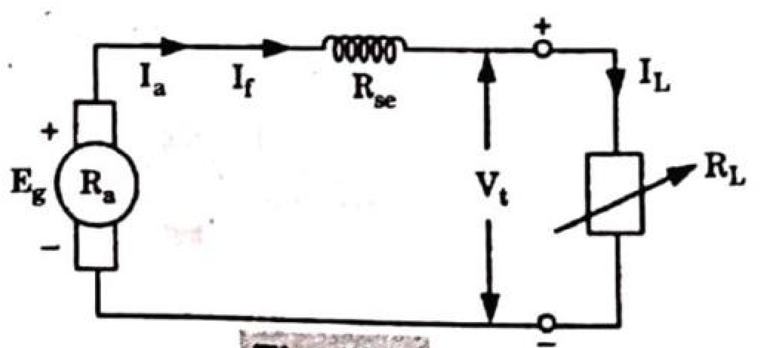

Fig. 4.5.1.

i. $$I_a = I_f = I_L$$

ii. $$E_g - V_{drop} = I_a R_a + I_a R_{se} + V_t$$

$\therefore$ $$E_g = V_t + I_a (R_a + R_{se}) + V_{drop}$$

iii. Load power, $$P_L = V_t I_L$$

ii. Equations for shunt generators :

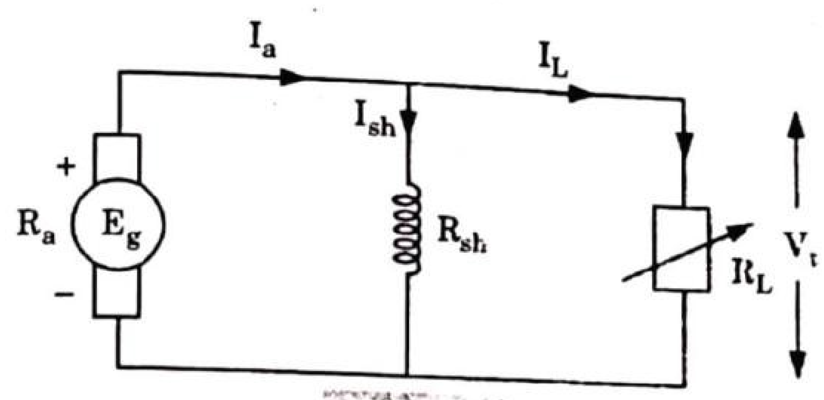

Fig. 4.5.2.

i. $$V_t = I_{sh} R_{sh}$$

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

iii. $$E_g = V_t + I_a R_a + V_{drop}$$

iv. $$P_L = V_t I_L$$

Que 4.6. **Derive the expression for generated emf in DC machine. Explain the term back emf when applied to DC motor. Briefly explain what role back emf plays in starting and running of motor ?** **AKTU 2015-16(Sem-1), Marks 10**

Answer

A. Derivation :

1. Let

P = Number of poles
ϕ = Flux per pole
N = Speed of rotation
Z = Number of conductors around the armature
A = Number of parallel paths

2. The time taken by the armature for one revolution

$$= \frac{1}{N} \text{ min} = \frac{60}{N} \text{ sec}$$

3. Hence, time taken by each armature conductor to move through one pole pitch

$$t = \frac{60}{N} \times \frac{1}{P} \text{ sec}$$

4. During this period, the conductor cuts all the flux ϕ, produced by the pole and the average emf induced per conductor

$$= \phi \times \frac{NP}{60} = \frac{\phi NP}{60} \text{ volts/conductor}$$

5. The emf of a DC generator
E = (emf induced per conductor) × (number of conductors per parallel path)

$$= \frac{\phi NP}{60}\left(\frac{Z}{A}\right)$$

$$E = \frac{\phi ZNP}{A \times 60}$$

$$E = \frac{\phi ZPn}{A} \text{ volts}$$

where n is rps.

6. For a given DC generator P, Z and A are fixed and hence E is proportional to ϕ and n (*i.e.*, $E \propto \phi n$).
7. In case of motor, this emf is known as back emf E_b

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

B. Role of back emf : The presence of back emf makes the DC motor a self regulating machine, *i.e.*, it makes the DC motor to draw as much armature current as is just sufficient to develop the required load torque.

Que 4.7. **Find torque equation of a DC Motor.**

AKTU 2014-15(Sem-2), Marks 05

OR

Write the expression for the induced emf and torque of a DC machine. What is the value of the constant relating ω and *n* ?

AKTU 2014-15(Sem-1), Marks 10

OR

Derive emf equation of DC machine. Also deduce the expression for torque of a dc machine.

AKTU 2016-17(Sem-2), Marks 07

Answer

A. Emf equation : Refer Q. 4.6, Page 4–8D, Unit-4.

B. Torque equation :

1. Voltage equation of a DC motor is $V = E + I_aR_a$
Multiplying both sides by I_a

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

where, VI_a = Electrical power input to rotor

$I_a^2R_a$ = Copper loss in armature.

2. We know, Input = Output + Losses
3. Mechanical power developed by the armature,

$$P_m = \omega\tau_{av} = 2\pi n\tau_{av}$$
$$P_m = EI_a = \omega\tau_{av} = 2\pi n\tau_{av}$$

EI_a = Electrical equivalent of gross mechanical power developed by the armature

τ_{av} = Average electromagnetic torque developed by the armature in Newton metres (N-m)

4. Also, $E = \dfrac{nP\phi Z}{A}$

Therefore, $\dfrac{nP\phi Z}{A} I_a = 2\pi n\tau_{av}$ ∴ $\tau_{av} = \dfrac{PZ}{2\pi A}\phi I_a$

C. As $\omega = \dfrac{2\pi N}{60}$, the constant relating to ω and N is $\dfrac{2\pi}{60}$ (= 0.10472).

Que 4.8. **Draw and explain the operating characteristics of DC series motor.**

Answer

A. Speed-armature current (N-I_a) characteristics :

1. In case of DC motors, $N \propto \dfrac{E_b}{\phi}$ ...(4.8.1)

where, N = Speed in rpm
E_b = Back emf,
ϕ = Flux / pole.

2. Also $\phi \propto I_a$ (Since $I_f = I_a$) ...(4.8.2)
And $E_b = V - I_a(R_a + R_{se})$ ...(4.8.3)

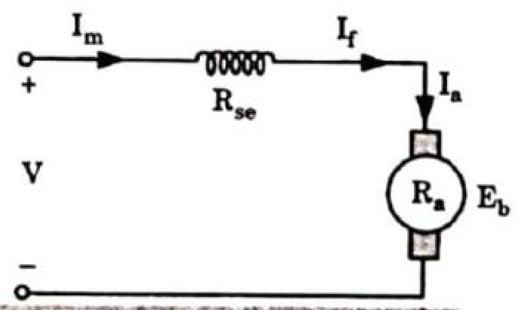

Fig. 4.8.1. DC series motor.

3. At low values of I_a, flux will be very small. Hence the speed will be very high, as per eq. (4.8.1) and (4.8.2).
4. As I_a increases, the flux increases and hence the speed decreases as shown by curve I in Fig. 4.8.2.

5. As I_a increases, I_a $(R_a + R_{se})$ drop increases, thus E_b decreases and speed also decreases as per eq. (4.8.1) and (4.8.3). This decrease in speed due to ohmic drop is shown by curve II in Fig. 4.8.2.

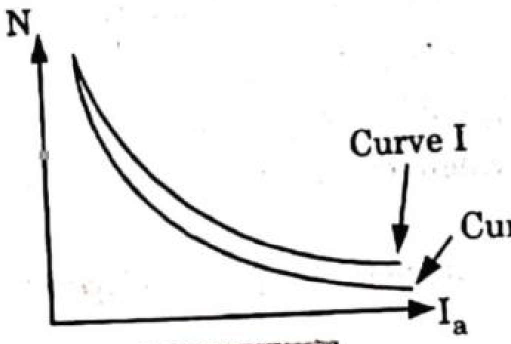

Fig. 4.8.2.

B. Torque-current ($T - I_a$) characteristics :

In case of DC motor $T \propto \phi I_a$ ...(4.8.4)

In Fig. 4.8.3,

i. Before saturation :

$$\phi \propto I_f \;\; i.e., \phi \propto I_a \qquad ...(4.8.5)$$

From eq. (4.8.4) and (4.8.5)

$$T \propto I_a^2 \qquad ...(4.8.6)$$

$\therefore$ The curve will be parabolic in nature.

ii. After saturation : ϕ is constant.

$\therefore$ $T \propto I_a$

Hence the characteristics will be a straight line.

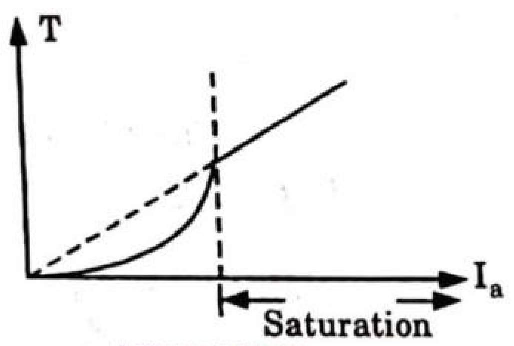

Fig. 4.8.3.

C. Speed-Torque (N–T) characteristics :

1. As I_a increases, torque increases as per eq. (4.8.4). This will decrease the speed as discussed in $N–I_a$ characteristics.
2. The further development is exactly similar to $N–I_a$ characteristics.

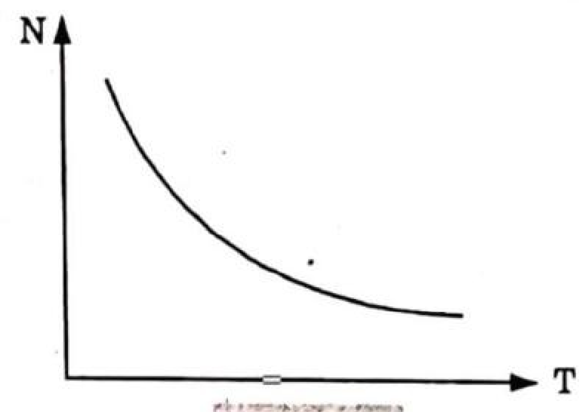

Fig. 4.8.4.

Que 4.9. **Draw and explain the characteristics of DC shunt motor.**

Answer

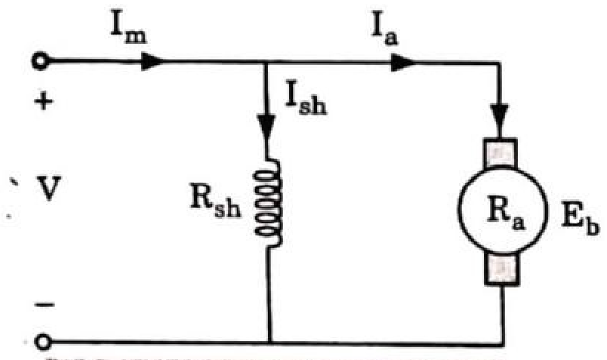

Fig. 4.9.1. DC shunt motor.

1. For DC shunt motor

$$I_m = I_a + I_{sh} \qquad ...(4.9.1)$$

$$E_b = V - I_a R_a \qquad ...(4.9.2)$$

$$\phi \propto I_{sh} \text{ and } I_{sh} = \frac{V}{R_{sh}} \qquad ...(4.9.3)$$

$$N \propto \frac{E_b}{\phi} \qquad ...(4.9.4)$$

2. Since supply voltage V and shunt field resistance R_{sh} is constant, I_{sh} and hence flux is practically constant.
3. As I_a increases, ohmic drop $I_a R_a$ increases, which will decrease E_b. Thus speed N will decrease as armature current I_a increases.

A. Torque-current ($T–I_a$) or speed-current ($N–I_a$) characteristics of DC shunt motor :

1. In case of DC shunt motor, since I_{sh} is constant so flux ϕ is practically constant.

$\therefore$ $T \propto \phi I_a$

If ϕ = Constant, then $T \propto I_a$, *i.e.*, as armature current increases, torque will also increase.

2. At starting upto small value of armature current I_{a0}, torque of shaft will be zero. After I_{a0}, as current increases, torque will increase linearly. This is shown by curve I in Fig. 4.9.2.

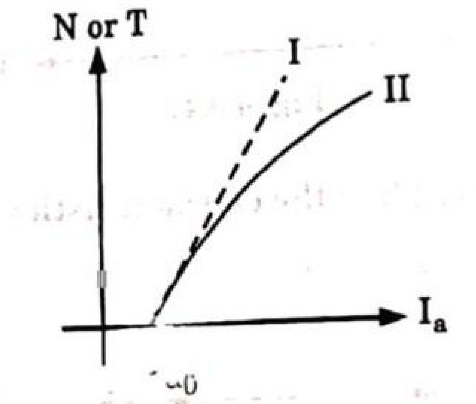

Fig. 4.9.2.

3. As armature current I_a increases, armature reaction will also increase. This will decrease the total flux ϕ.

$\therefore$ Actual characteristics will be as shown in curve II in Fig. 4.9.2

B. Speed torque (*N–T*) characteristics of DC shunt motor :

1. At $I_a = I_{sh}$, *i.e.*, at small values of torque, the speed N will be of rated value.
2. As I_a increases, *i.e.*, as torque increases, since E_b decreases due to I_aR_a drop, speed will slightly decrease.

Fig. 4.9.3.

Que 4.10. **Draw and explain the characteristics of DC compound motor.**

Answer

A. *N–I_a* characteristics :

1. Consider $N–I_a$ characteristics of shunt motor as shown in Fig. 4.10.2 by curve I.
2. As I_a increases, series flux ϕ_{se} increases whereas shunt flux ϕ_{sh} remains practically constant.

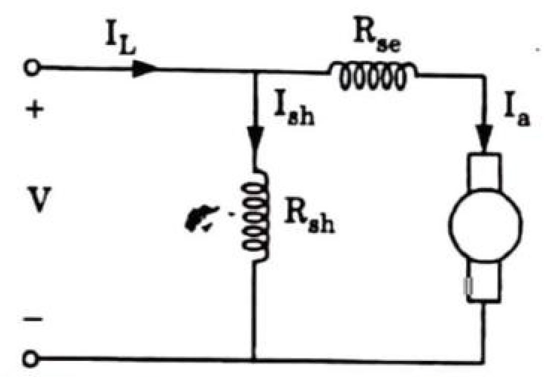

Fig. 4.10.1. Long shunt compound connections.

3. For cumulatively compounded motor, total flux ϕ_T increases as I_a increases.

Since $\phi_T = \phi_{sh} + \phi_{se}$

$\therefore$ Speed N decreases as $N \propto \dfrac{1}{\phi_T}$. This is shown in characteristics by curve II in Fig. 4.10.2.

4. For differentially compounded motor total flux $\phi_T = \phi_{sh} - \phi_{se}$

$\therefore$ As I_a increases, ϕ_{se} increases which decreases the total flux ϕ_T

$\therefore$ Speed N will increase, sir ases. This is shown by curve III in Fig. 4.10.2.

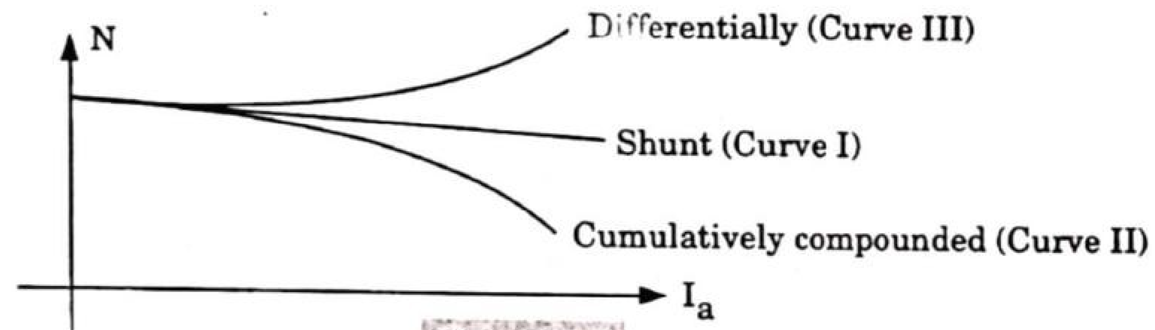

Fig. 4.10.2.

B. *T–I_a* characteristics :

1. Consider $T–I_a$ characteristics of DC shunt motor. If effect of series winding flux is added to motor, the characteristics will belong to DC compound motor.
2. As I_a increases, series flux ϕ_{se} increases.
3. For cumulatively compounded motor, the total flux ϕ_T increases since $\phi_T = \phi_{sh} + \phi_{se}$

   This increases the torque since $T \propto I_a \phi$.

   The increase in torque is shown by curve II in Fig. 4.10.3 in case of cumulatively compounded motor.
4. In case of differentially compounded motor, the total flux ϕ_T decreases with the increase in armature current I_a. This is due to $\phi_T = \phi_{sh} - \phi_{se}$ and ϕ_{se} increases as I_a increases.

∴ Torque will be less as compared to shunt motor, as shown by curve III in Fig. 4.10.3.

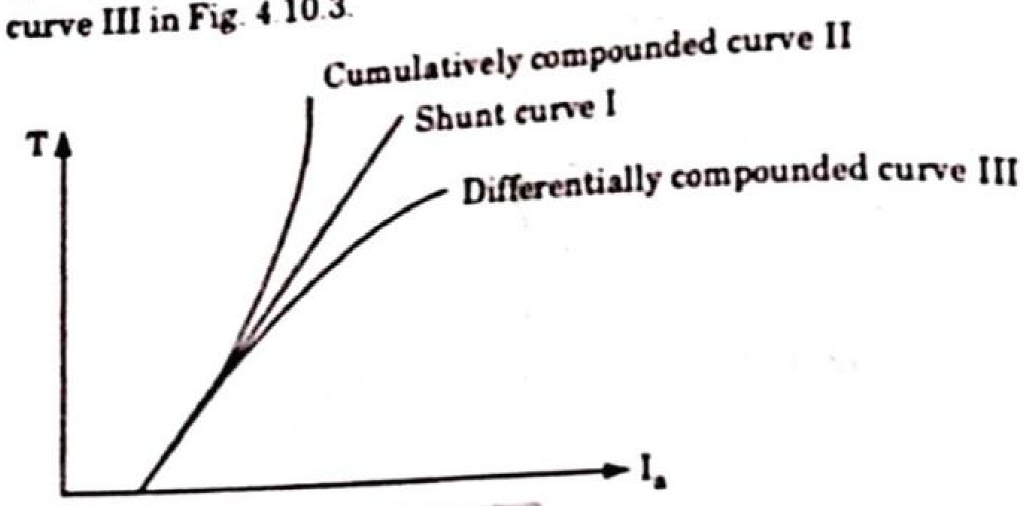

Fig. 4.10.3.

C. ***N-T* characteristics of DC compound motor :** The *N–T* characteristics are exactly similar to the $N–I_a$ characteristics of DC compound generator.

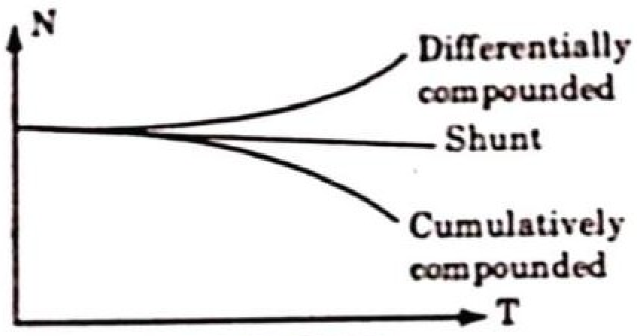

Fig. 4.10.4.

Que 4.11. **How can the speed of DC motor be varied ? Explain the method by which you can vary speed above and below the base speed.**

AKTU 2013-14(Sem-2), Marks 10

Answer

Speed of motor can be varied by varying field flux and armature resistance.

A. **Field flux control method :**

1. Since the flux is produced by the field current, control of speed by this method is obtained by control of the field current.
2. In the shunt motor, this is done by connecting a variable resistor R_c in series with the shunt field winding as shown in Fig. 3.11.1. The resistor R_c is shunt field regulator.
3. The shunt field current is given by $I_{sh} = \dfrac{V}{R_{sh} + R_c}$.

4. The connection of R_c in the field reduces the field current and hence the flux ϕ is also reduced.
5. The reduction in flux will result in an increase in the speed.
6. Consequently, the motor runs at a speed higher than normal speed.

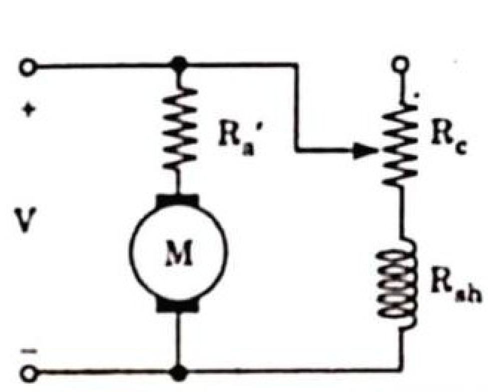

Fig. 3.11.1. Speed-control of a DC shunt motor by variation of field flux.

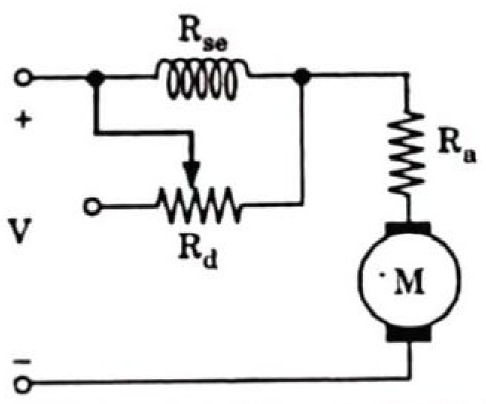

Fig. 3.11.2. Diverter in parallel with the series of DC motor.

7. For this reason, this method of speed-control is used to give motor speeds above normal or to correct for a fall in speed due to load.
8. The variation of field current in a series motor is done by a variable resistance R_d is connected in parallel with the series field windings as shown in Fig. 3.11.2. The parallel resistor is called the diverter. A portion of the main current is diverted through R_d.

   Thus, the diverter reduces the current flowing through the field winding. This reduces the flux and increases the speed.
9. Fig. 3.11.3(*a*) and 3.11.3(*b*) shows the typical speed/torque curves for shunt and series motors respectively, whose speed are controlled by the variation of the field flux.

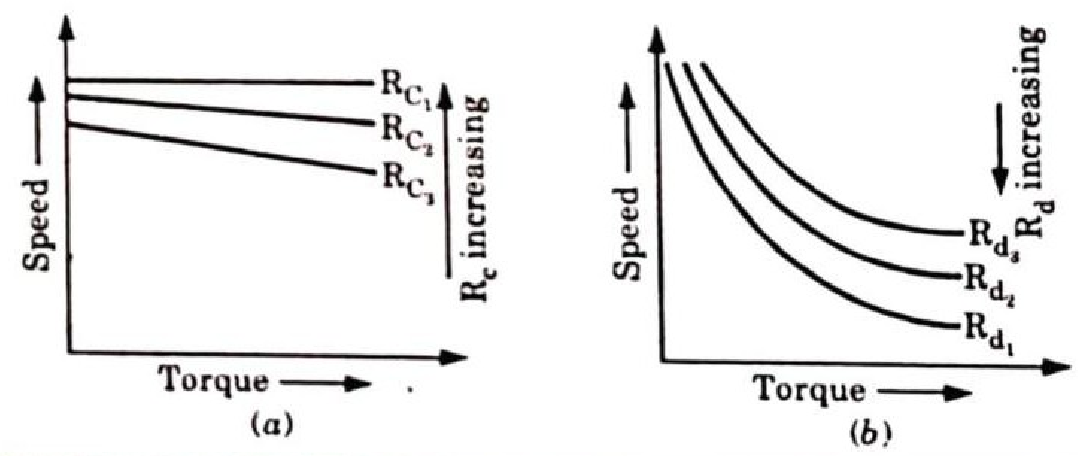

Fig. 3.11.3. Typical speed-torque curves (a) shunt motor (b) series motor.

B. **Armature resistance control method :**

1. In this method a variable series resistor R_e is put in the armature circuit.
2. In this case, the field is directly connected across the supply and therefore the flux ϕ is not affected by variation of R_e.

3. Fig. 3.11.5 shows the method of connection of external resistance R_e in the armature circuit of a DC series motor.
4. In this case the current and hence the flux are affected by the variation of the armature circuit resistance.
5. The voltage drop in R_e reduces the voltage applied to the armature and therefore the speed is reduced.
6. Fig. 3.11.6(*a*) and 3.11.6(*b*) shows typical speed-current characteristics for shunt and series motors respectively.

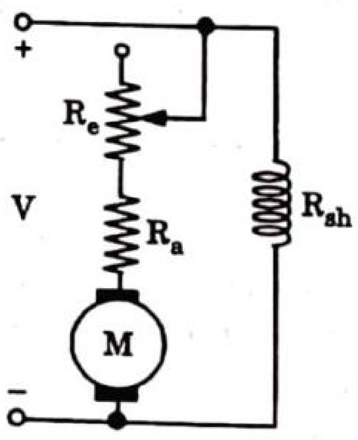

Fig. 3.11.4. Speed-control of a DC shunt motor by armature resistance control.

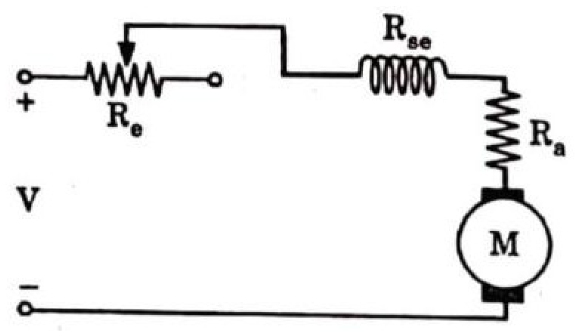

Fig. 3.11.5. Speed-control of a DC series motor by armature resistance control.

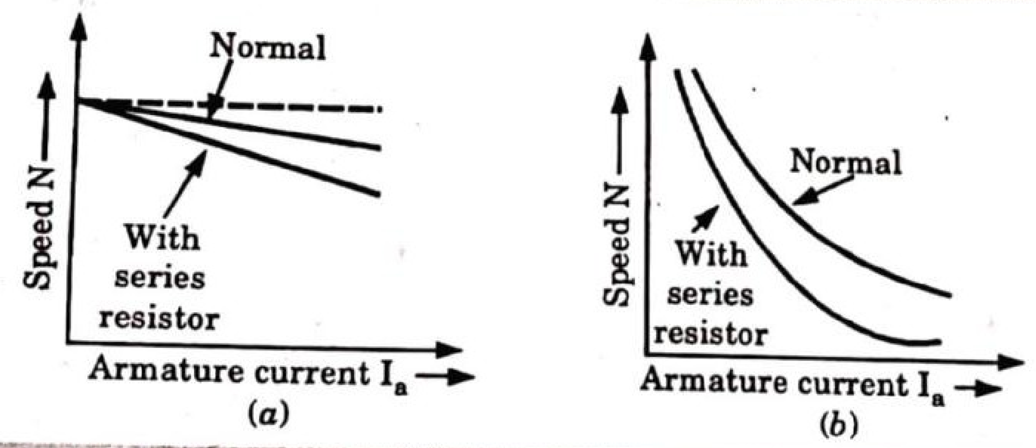

Fig. 3.11.6. Speed-current characteristics (a) shunt motor (b) series motor.

7. In both the cases the motor runs at a lower speed as the value of R_e is increased.
8. Since R_e carries full armature current, it must be designed to carry continuously the full armature current.

Que 4.12. **A 4-pole DC generator with wave connected armature has 41 slots and 12 conductors/ slots. Armature resistance and shunt field resistance are 0.5 Ω and 200 Ω. Flux per pole is 125 mWb. Speed N = 1000 rpm, calculate the voltage drop across terminals. The load resistance is 10 Ω.**

AKTU 2013-14(Sem-1), Marks 05

Answer

Given : No. of slots = 41, Conductor/slots = 12, $P = 4$, $R_a = 0.5\ \Omega$, $R_{sh} = 200\ \Omega$, N = 1000 rpm, ϕ/pole = 125 mWb, $R_L = 10\ \Omega$

To Find : Voltage drop, V_d.

1. Generated emf, $E_g = \dfrac{\phi NZ}{60} \times \dfrac{P}{A} = \dfrac{125 \times 10^{-3} \times 1000 \times 41 \times 12}{60} \times \dfrac{4}{2}$
$= 2050$ V
2. Let the voltage across 10 Ω load resistance be V volts.

Load current, $I_L = \dfrac{V_d}{10}$

Shunt field current, $I_{sh} = \dfrac{V_d}{R_{sh}} = \dfrac{V_d}{200}$

3. Armature current $I_a = I_L + I_{sh} = \dfrac{V_d}{10} + \dfrac{V_d}{200} = \dfrac{21\,V_d}{200}$
4. As generated $E_g = V_d + I_a R_a$, neglecting voltage drop

$$2050 = V_d + \frac{21V_d}{200} \times 0.5 = \frac{421}{400}V_d$$

Voltage drop, $V_d = \dfrac{2050 \times 400}{421} = 1947.7$ V

Que 4.13. **A 230 V DC series motor is taking 50 A. Resistance of armature and series field winding is 0.2 Ω and 0.1 Ω respectively. Calculate :**

i. **Brush voltage**
ii. **Back emf.**

AKTU 2013-14(Sem-2), Marks 05

Answer

Given : V = 230 V, R_a = 0.2 Ω, R_{se} = 0.1 Ω, $I = I_a = I_{se}$ = 50 A

To Find : Brush voltage and back emf.

1. For series motor, $V = E_b + I\,(R_a + R_{se}) + V_b$
2. Let brush contact drop = 1 V/ brush

i. **Brush voltage,** $V_b = 2 \times 1 = 2$ V

ii. **Back emf,** $E_b = V - I\,(R_a + R_{se}) - V_b$
$= 230 - 50\,(0.2 + 0.1) - 2 = 213$ V

Que 4.14. **A 6-pole lap wound DC shunt motor has 250 armature conductors, a flux of 0.04 wb/pole and runs at 1200 rpm. The armature**

and field winding resistances are 1 ohm and 220 ohm respectively. It is connected to a 220 V DC supply. Determine

i. **Induced emf in the motor**
ii. **Armature current**
iii. **Input supply current**
iv. **Mechanical power developed in the motor**
v. **Torque developed.**

AKTU 2015-16(Sem-2), Marks 10

Answer

Given : $\phi = 0.04$ wb/pole, $P = A$, $Z = 250$, $N = 1200$ rpm, $R_a = 1\ \Omega$
$R_{sh} = 220\ \Omega$, $V = 220$ V
To Find : E_a, I_a, I, P and T.

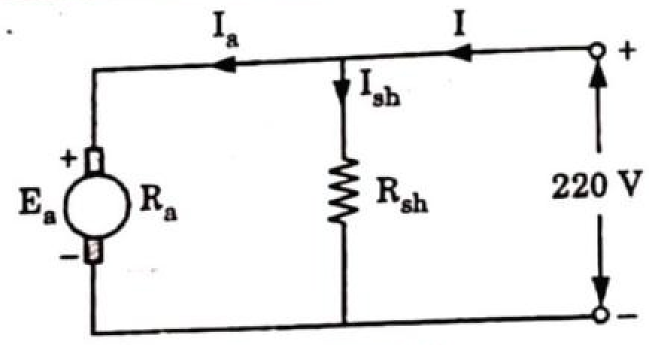

Fig. 4.14.1.

1. $\because \quad E = \dfrac{NP\phi Z}{60\,A}$

$$E_a = \frac{1200 \times 0.04 \times 250}{60}$$

Induced emf, $E_a = 200$ V

2. $\because \quad V = E_a + I_a R_a$

$$I_a = \frac{V - E_a}{R_a} = \frac{220 - 200}{1}$$

Armature current, $I_a = 20$ A

3. $$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{220} = 1\text{ A}$$

Input current, $I = I_{sh} + I_a = 21$ A

4. **Mechanical power,**

$$P = E_a I_a = 200 \times 20 = 4\text{ kW}$$

5. **Torque,** $$T = \frac{P}{\omega} = \frac{P}{\frac{2\pi N}{60}} = \frac{60 \times 4000}{2 \times 3.14 \times 1200} = 31.83\text{ N-m}$$

Que 4.15. **A 120 V DC shunt motor having an armature circuit resistance of 0.2 Ω and field circuit resistance of 60 Ω, draw line current of 40 A at full load. The brush voltage drop is 3 V and rated full load speed is 1800 rpm. Calculate**

i. **The speed at half load**
ii. **The speed at 125 % of full load.**

AKTU 2016-17(Sem-1), Marks 07

Answer

Given : $V_t = 120$V, $R_a = 0.2\ \Omega$, $R_f = 60\ \Omega$, $I_L = 40$ A (at full load)
$V_{brush} = 3$ V, full load speed, $N_1 = 1800$ rpm
To Find : Speed at half load, N_2; Speed at 125 % of full load, N_3.

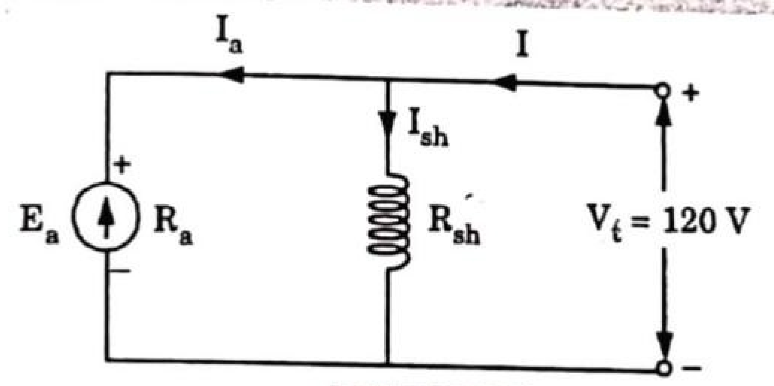

Fig. 4.15.1.

1. $$I_{sh} = \frac{V_t}{I_{sh}} = \frac{120}{60} = 2\text{ A}$$

2. $$I_{a1} = I_L - I_{sh} = 40 - 2 = 38\text{ A}$$

3. $$E_{a1} = V_t - I_{a1}R_a - \text{voltage drop}$$
$$= 120 - (38 \times 0.2) - 3 = 109.4\text{ V}$$

4. At half load, $$I_{L1} = \frac{40}{2} = 20\text{ A}$$
$$I_{a2} = 20 - 2 = 18\text{ A}$$
$$E_{a2} = V_t - I_{a2}R_a - \text{voltage drop}$$
$$= 120 - (18 \times 0.2) - 3 = 113.4\text{ V}$$

5. **Speed at half load,**

$$N_2 = \frac{E_{a2}}{E_{a1}} \times N_1$$
$$= \frac{113.4}{109.4} \times 1800 = 1865.8 \approx 1866\text{ rpm}$$

6. **Speed at 125 % of full load,** N_3

$$I_{L3} = 40 \times 1.25 = 50\text{ A}$$
$$I_{a3} = I_{L3} - I_{sh}$$
$$= 50 - 2 = 48\text{ A}$$

$$E_{a3} = V_t - (I_{a3}R_a) - \text{voltage drop}$$
$$= 120 - (48 \times 0.2) - 3 = 107.4 \text{ V}$$

7. $$N_3 = \frac{E_{a3}}{E_{a1}} \times N_1$$
$$= \frac{107.4}{109.4} \times 1800 = 1767.09 \approx 1767 \text{ rpm}$$

Que 4.16. **A DC shunt generator delivers 50 kW at 250 V when running at 500 rpm. The armature and field resistances are 0.05 Ω and 125 Ω respectively. Calculate the speed of the same machine and developed torque when running as a shunt motor and taking 50 kW at 250 V.**

AKTU 2016-17(Sem-2), Marks 07

Answer

Given : $R_a = 0.05\ \Omega$, $R_{sh} = 125\ \Omega$ As generator, $N_g = 500$ rpm, Output power, $P_g = 50$ kW, $V = 250$ V As motor, Input power, $P_m = 50$ kW, $V = 250$ V

To Find : Speed of motor, N_m and Torque developed, τ_d.

1. Shunt field current, $I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125} = 2$ A
2. **As generator :**

   Load current, $I_L = \frac{50 \times 10^3}{250} = 200$ A

   Armature current, $I = I_L + I_{sh} = 200 + 2 = 202$ A

   Generated emf, $E_g = V + I_{ag}R_a = 250 + (202 \times 0.05) = 260.1$ V
3. **As motor :**

   Line current, $I_L = \frac{50 \times 10^3}{250} = 200$ A

   Armature current, $I_{am} = I_L - I_{sh} = 200 - 2 = 198$ A

   Back emf developed, $E_b = V - I_{am}R_a = 250 - (198 \times 0.05) = 240.1$ V

i. **Speed of motor,** $N_m = \frac{E_b}{E_g} N_g = \frac{240.1}{260.1} \times 500 = 461.55$ rpm

ii. **Torque developed,** $\tau_d = \frac{E_b I_{am}}{\frac{2\pi N_m}{60}} = \frac{240.1 \times 198 \times 60}{2 \times \pi \times 461.55} = 983.58$ N-m

Que 4.17. **Give the EMF equation of a DC generator and draw the characteristics of a DC series motor. A 25 kW, 250 V, DC shunt generator has armature and field resistances of 0.06 ohm and 100 ohm respectively. Determine the total armature power developed.**

AKTU 2017-18(Sem-1), Marks 07

Answer

A. **EMF equation of a DC generator :** Refer Q.4.6, Page 4–8D, Unit-4.

B. **Characteristics of DC series motor :** Refer Q. 4.8, Page 4–10D, Unit-4.

C. **Numerical :**

Given : $P = 25$ kW, $R_{sh} = 100\ \Omega$, $R_a = 0.06\ \Omega$, $V = 250$ V

To Find : Power developed, P_g.

1. Load current, $I_L = \frac{P}{V} = \frac{25000}{250} = 100$ A
2. Shunt field current, $I_{sh} = \frac{V}{R_{sh}} = \frac{250}{100} = 2.5$ A
3. Armature current, $I_a = I_L + I_{sh} = 100 + 2.5 = 102.5$ A
4. Generated emf, $E_g = V + I_aR_a = 250 + 102.5 \times 0.06 = 256.15$ V
5. Power developed, $P_g = E_g \times I_a = 256.15 \times 102.5$
   $= 26.26$ kW

PART-2

Three Phase Induction Motor : Principle and Construction, Types, Slip-Torque Characteristics, Applications (Numerical Problems Related to Slip only).

CONCEPT OUTLINE : PART-2

- **3-ϕ Induction motors are of two types :**

  i. Squirrel-cage induction motor

  ii. Wound-rotor or slip-ring induction motor.

- **Slip :** $s = \frac{N_s - N_r}{N_s}$

  and $f_r = sf_s$

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.18. **Give the constructional details about three phase induction motor. Which types of rotors are used in 3ϕ induction motor ?**

Answer

A. Stator :

1. It is a stationary part of the motor. This part is made of silicon steel stampings (*i.e.*, thin sheets). The stampings are slotted.
2. When complete stator is assembled, the slots are formed on the inner side of the stator.
3. The slots may be open type, semi-open type or closed type. In these slots, a 3ϕ winding is accommodated. This winding may be star or delta connected.
4. The three ends of this winding are brought out into the terminal box where 3ϕ AC supply can be connected.
5. The stator windings, stator and the AC supply connected to the stator winding are shown in Fig. 4.18.1.

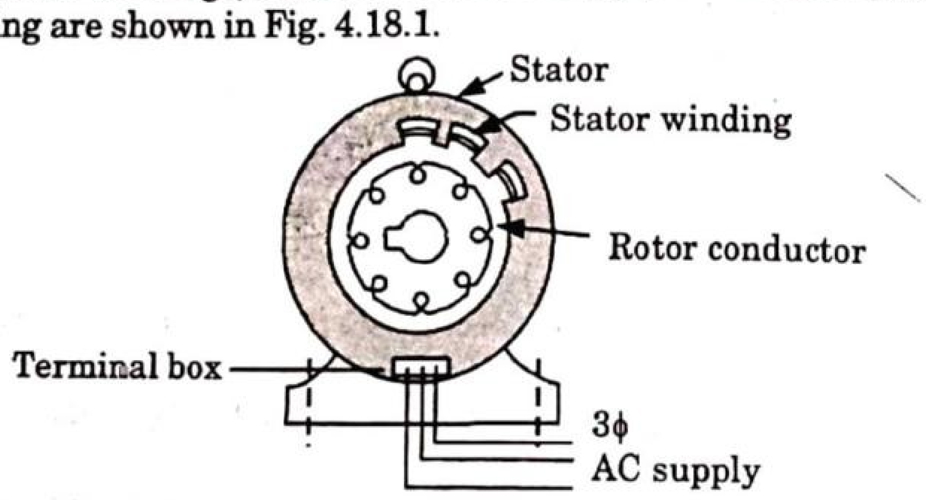

Fig. 4.18.1. Diagram of 3-phase induction motor.

B. Rotor : There are two types of induction motors depending upon the construction of the rotor :

a. Squirrel cage type rotor :

1. This is the simplest and most rugged construction. The rotor consists of a cylindrical laminated core with skewed rotor slots.

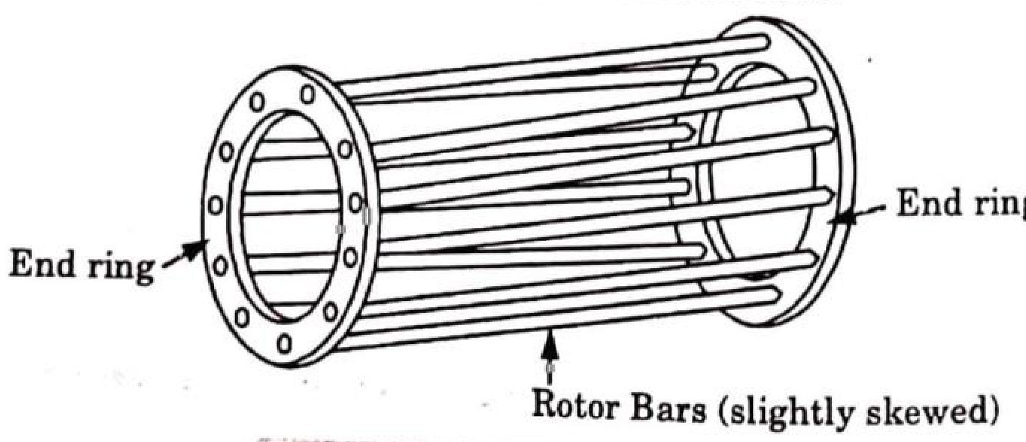

Fig. 4.18.2. Squirrel cage rotor.

2. The rotor conductors which are thick copper bars, are placed in these slots and are brazed or welded to end rings. Thus, the rotor conductors are permanently short-circuited. Therefore it is not possible to add any external resistance in the rotor circuit.

b. Wound type rotor with slip rings :

1. In this type of induction motor, the rotor is wound for the same number of poles as that on the stator.
2. The rotor is made up of laminations with slots on the outer periphery in which a 3ϕ rotor winding is placed.
3. The three phase are starred internally, the remaining three terminals are brought out and connected to the slip-rings mounted on the shaft.
4. The slip-rings are made up of copper or phosphor bronze and there are three brushes resting on them. External connections to additional resistances are done at the brushes.
5. When running under normal conditions, the slip-rings are short-circuited by a metal collar which is pushed along the shaft and the brushes are lifted from the slip-rings to reduce the frictional losses and wear.

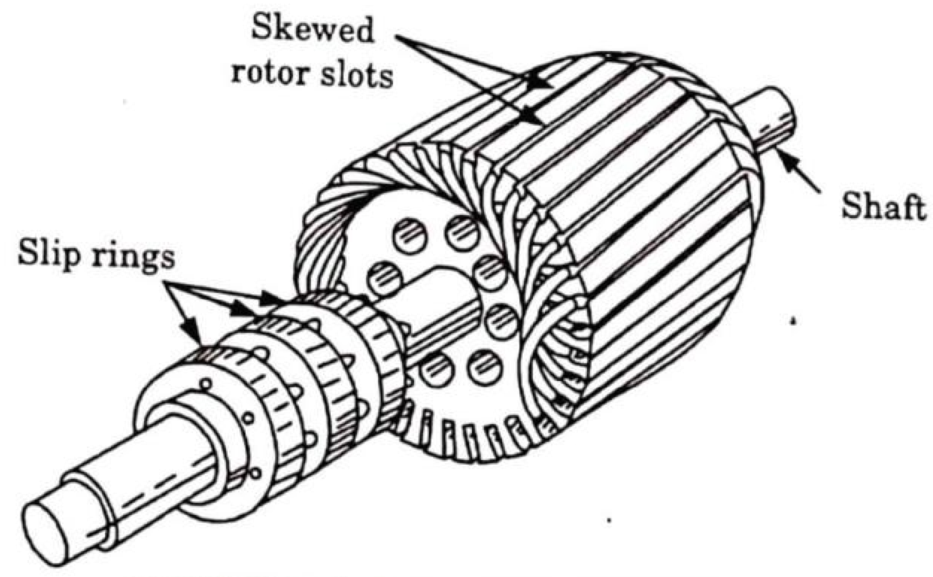

Fig. 4.18.3. Slip-ring type motor's rotor.

Que 4.19. **Explain the principle of operation of a 3-phase induction motor.**

Answer

1. Let us consider that the rotor is stationary and one conductor is on the rotor as shown in Fig. 4.19.1.

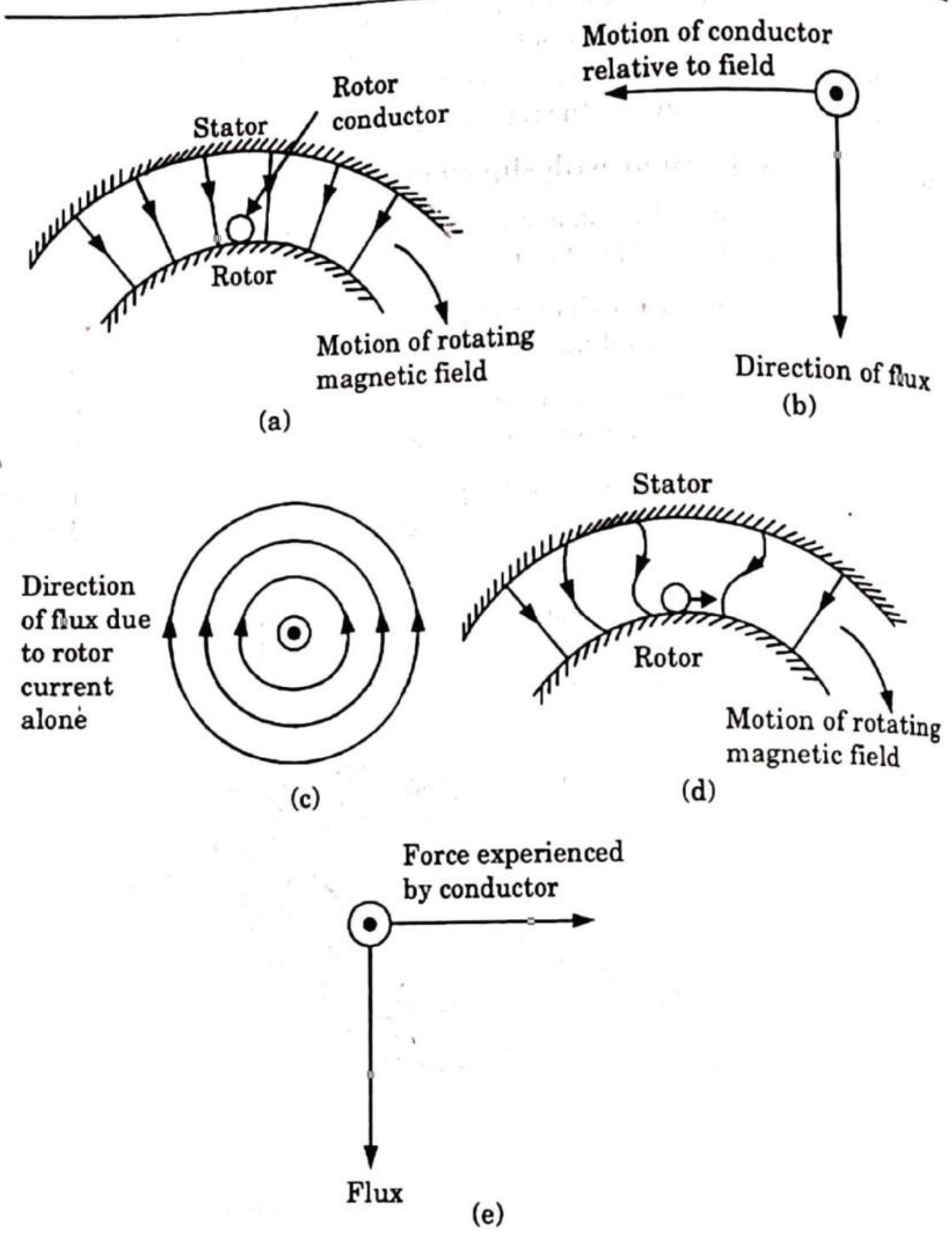

Fig. 4.19.1.

2. Let the rotation of the magnetic field be clockwise.
3. A magnetic field moving clockwise has the same effect as a conductor moving anti-clockwise in a stationary field.
4. By Faraday's law of electromagnetic induction, a voltage will be induced in the conductor. Due to this induced voltage, a current starts to flow in rotor conductor.
5. By right-hand rule the direction of induced current is downward as shown in Fig. 4.19.1(*b*).

6. Now the current in the rotor conductor produces its own magnetic field as shown in Fig. 4.19.1(*c*) due to this a force is produced on the rotor conductor.
7. By the left-hand rule the direction of force can be determined.
8. It is seen that the force acting on the conductor is in the same direction as the direction of the rotating magnetic field.
9. Since the rotor conductor is in a slot on the rotor, and the force acts in a tangential direction to the rotor and torque is developed. Similar torque is produced on all conductors in same direction.
10. Since the rotor is free to move, it starts rotating in the same direction. Thus it is noted that a 3ϕ induction motor is a self-starting motor.

Que 4.20. **Derive expression of slip speed, slip, percentage slip and frequency of rotor voltage and current.**

Answer

A. **Slip speed :** The slip speed expresses the speed of the rotor relative to the field.

If N_s = Synchronous speed in rpm

N_r = Actual rotor speed in rpm

$$\text{Slip speed} = N_s - N_r \text{ rpm}$$

B. **Slip :** The slip speed expressed as a fraction of the synchronous speed is called the per-unit slip or fractional slip. The per-unit slip is usually called the slip. It is denoted by *s*.

$$s = \frac{N_s - N_r}{N_s} \text{ per unit (p.u.)}$$

C. **Percentage slip :**

1. Let n_s = Synchronous speed in rps

n_r = Actual rotor speed in rps

then
$$s = \frac{n_s - n_r}{n_s} \text{ p.u.}$$

and percentage slip
$$= \frac{n_s - n_r}{n_s} \times 100$$

Also,
$$s = \frac{\omega_s - \omega_r}{\omega_s}$$

2. The slip at full load varies from about 5 % for small motors to about 2 % for large motors.

D. **Frequency of rotor :**

1. The frequency of current and voltage in the stator must be the same as the supply frequency given by

$$f = \frac{PN_s}{120} \qquad ...(4.20.1)$$

2. The frequency in the rotor windings is variable and depends on the difference between the synchronous speed and the rotor speed. Hence the rotor frequency depends upon the slip. The rotor frequency is given by

$$f_r = \frac{P(N_s - N_r)}{120} \qquad ...(4.20.2)$$

3. Division of eq. (4.20.2) by eq. (4.20.1) gives

$$\frac{f_r}{f} = \frac{N_s - N_r}{N_s}$$

$\therefore \quad f_r = sf$

Rotor frequency = Per unit slip × Supply frequency

Imp

Que 4.21. Derive the expression for developed torque for a 3ϕ induction motor and obtain the condition for maximum torque.

OR

Explain the working of 3-phase induction motor. What is meant by slip? Explain slip-torque characteristics of 3-phase induction motor.

AKTU 2015-16(Sem-1), Marks 15

OR

Explain working of 3-phase Induction Motor. Also draw torque-slip characteristics showing operating regions.

AKTU 2013-14(Sem-1), Marks 05

OR

Draw ~~and~~ explain the torque-slip characteristics of a three-phase induction motor.

AKTU 2014-15(Sem-2), Marks 05

Answer

A. Torque of an induction motor :

1. Electrical power generated in rotor

$$= 3E_{2s}I_{2s}\cos\phi_{2s}$$

$$= 3E_{2s}\frac{E_{2s}}{Z_{2s}}\frac{R_2}{Z_{2s}} = \frac{3E_{2s}^2R_2}{Z_{2s}^2} = \frac{3s^2E_{20}^2R_2}{R_2^2 + (sX_{20})^2}$$

2. All this power is dissipated as I^2R loss (copper loss) in the rotor circuit.
3. Input power to rotor = $2\pi n_s\tau_d$
4. s × Rotor input = Rotor copper loss

$$s \times 2\pi n_s\tau_d = \frac{3s^2E_{20}^2R_2}{R_2^2 + s^2X_{20}^2}$$

$$\tau_d = \frac{3E_{20}^2}{2\pi n_s}\frac{sR_2}{R_2^2 + s^2X_{20}^2}$$

$$\tau_d = \frac{KsE_{20}^2R_2}{R_2^2 + s^2X_{20}^2} \qquad ...(4.21.1)$$

where, $\quad K = \frac{3}{2\pi n_s} = \frac{3}{\omega_s}$ = Constant.

B. Condition for maximum torque :

1. Let $\quad KE_{20}^2 = K_1$ (Constant)

$$\therefore \quad \tau_d = \frac{K_1sR_2}{R_2^2 + s^2X_{20}^2}$$

$$\tau_d = \frac{K_1R_2}{\frac{R_2^2}{s} + sX_{20}^2} = \frac{K_1R_2}{\left(\frac{R_2}{\sqrt{s}} - X_{20}\sqrt{s}\right)^2 + 2R_2X_{20}} \qquad ...(4.21.2)$$

2. The developed torque τ_d will be maximum when the right-hand side of eq. (4.21.2) is maximum, which is possible only when

$$\frac{R_2}{\sqrt{s}} - X_{20}\sqrt{s} = 0$$

$$R_2 = sX_{20}$$

$$R_2 = X_{2s}$$

3. Maximum torque is obtained by putting $sX_{20} = R_0$ in eq. (4.21.1).

$$\therefore \quad \tau_{dmax} = \frac{KsR_2E_{20}^2}{R_2^2 + R_2^2} = \frac{KsE_{20}^2}{2R_2} = \frac{KsE_{20}^2}{2sX_{20}} = \frac{KE_{20}^2}{2X_{20}}$$

C. Torque-slip characteristics : The torque-slip characteristics are divided into three regions :

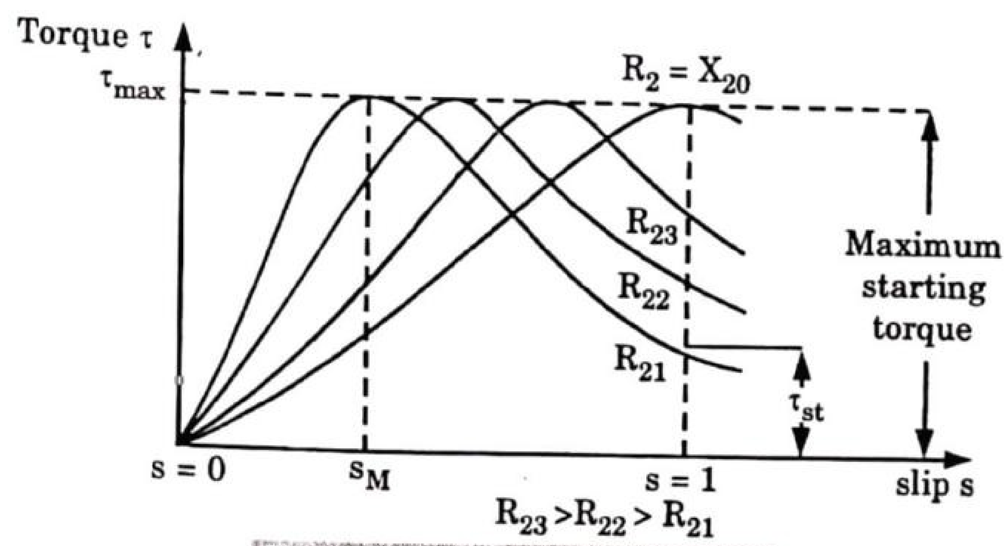

Fig. 4.21.1. Torque-slip curves.

a. **Low-slip region :** At synchronous speed $s = 0$, therefore, the torque is zero. When speed is near to synchronous speed, the slip is very low and $(sX_{20})^2$ is negligible in comparison with R_2. Therefore,

$$\tau = \frac{K_1 s}{R_2}$$

If R_2 is constant, $\tau = K_2 s$ $\left(\text{where, } K_2 = \frac{K_1}{R_2}\right)$

Relation shows that torque is proportional to slip. Hence, when slip is small, the torque-slip curve is straight line.

b. **Medium-slip region :** As slip increases, $(sX_{20})^2$ becomes large, so that R_2^2 may be neglected in comparison with $(sX_{20})^2$ and

$$\tau = \frac{K_3 R_2}{sX_{20}^2}$$

$\therefore$ $$\tau \propto \frac{1}{s}$$

The torque-slip characteristic is represented by a rectangular hyperbola.

c. **High-slip region :** The torque decreases beyond the point of maximum torque. The result is that the motor slows down and eventually stops. At this stage, the overload protection must immediately disconnect the motor from the supply to prevent damage due to overheating.

Que 4.22. **Discuss the applications of 3ϕ induction motor.**

Answer

A. **Squirrel cage induction motor :** This motor has the compact, simple and robust construction and is very cheap in cost. It runs almost constant at speed and has medium starting torque and high efficiency.
It is used extensively in industries for :

1. Lathe machine	2. Grinder
3. Compressor	4. Blowers
5. Printing machines	6. Textile mills
7. Wood work lathe	8. Washing machines etc.

B. **Wound rotor (slip-ring induction) motor :** This motor has higher starting torque and it can be further increased by adding external resistance in the rotor circuit. Its speed can be controlled smoothly. But its cost is more and maintenance cost is also higher. It is used in :

1. Electric Locomotives	2. Cranes
3. Hoists	4. Lifts
5. Compressors	6. Winding machines
7. Rolling mills	

Que 4.23. **A 3-phase 4 pole induction motor is supplied from 3-phase 50 Hz supply. Calculate :**

i. N_s
ii. Rotor speed when slip is 4 %
iii. Rotor frequency when rotor runs at 600 rpm.

AKTU 2013-14(Sem-2), Marks 05

Answer

i. $$N_s = \frac{120 f}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

ii. $$N = N_s (1 - s) = 1500 (1 - 0.04) = 1440 \text{ rpm}$$

iii. $$\text{Slip at 600 rpm} = \frac{1500 - 600}{1500} = 0.6$$

Rotor frequency, $f_r = s f = 0.6 \times 50 = 30$ Hz

Que 4.24. **A 6.6 kV, 20-poles, 50 Hz, 3-phase star-connected induction motor has rotor resistance of 0.12 Ω and a still reactance of 1.12 Ω. The motor has a speed of 292.5 rpm at full load. Calculate the slip at maximum torque.** **AKTU 2014-15(Sem-1), Marks 10**

Answer

$$s_{\max T} = \frac{\text{Rotor resistance}}{\text{Standstill reactance}}$$

$$= \frac{R_2}{X_2} = \frac{0.12}{1.12} = 0.1071$$

Que 4.25. **Draw torque-slip characteristics of 3 phase induction motor. A 12 pole alternator is coupled to an engine running at 500 rpm. It supplies a 3 phase induction motor having full-load speed at 1440 rpm. Find % slip and number of poles of the motor.**

AKTU 2017-18(Sem-1), Marks 07

Answer

A. **Torque-slip characteristics :** Refer Q. 4.21, Page 4–27D, Unit-4.

B. **Numerical :**

Given : $P_g = 12$; $N_m = 1440$ rpm; $N_g = 500$ rpm
To Find : Slip, s and number of poles of motor, P_m.

1. Frequency of generated emf,

$$f = \frac{P_s \times N_s}{120} = \frac{12 \times 500}{120} = 50 \text{ Hz}$$

2. The number of poles even in number and to give a synchronous speed nearest than actual speed of motor that the motor must have is

$$P_m = \frac{120 f}{N_m} = \frac{120 \times 50}{1440} = 4.17 = 4$$

3. Synchronous speed of motor,

$$N_s = \frac{120 f}{P_m} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

4. Slip, $$s = \frac{N_s - N_m}{N_s} = \frac{1500 - 1440}{1500} = 0.04 \text{ or } 4\ \%$$

Que 4.26. **A 12-pole, 3-phase alternator is coupled to an engine running at 500 rpm. This alternator supplies an induction motor running at 1450 rpm. Find slip and number of poles of the induction motor.** **AKTU 2017-18(Sem-2), Marks 07**

Answer

The procedure is same as Q. 4.25, Page 4–30D, Unit-4.

(**Ans.** $P_m = 4$; $s = 3.33\ \%$)

Que 4.27. **The induced emf between the slip-ring terminals of 3-phase induction motor, when the rotor is stand still is 100 V. The rotor windings are star connected and have resistance and stand still reactance of 0.05 W and 0.1 W per phase respectively. Calculate the rotor current and phase difference between rotor voltage and current at 4 % slip.** **AKTU 2016-17(Sem-1), Marks 07**

Answer

Given : $E_2 = \frac{100}{\sqrt{3}}$ V, $R_2 = 0.05\ \Omega$, $X_2 = 0.1\ \Omega$, $s = 4\% = 0.04$

To Find : I_2 and phase difference between V and I.

i. **Rotor current :** $$I_2 = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}} = \frac{0.04 \times \frac{100}{\sqrt{3}}}{\sqrt{(0.05)^2 + (0.04 \times 0.1)^2}}$$

$$= 46.04 \text{ A}$$

ii. **Phase difference between V and I :**

$$\cos \phi = \frac{R_2}{Z_2} = \frac{0.05}{\sqrt{(0.05)^2 + [0.04 \times 0.1]^2}}$$

$$\cos \phi = 0.9968$$

$$\phi = \cos^{-1} 0.9968$$

$$= 4.574°$$

PART-3

Single Phase Induction Motor : Principle of Operation and Introduction to Methods of Starting, Applications.

CONCEPT OUTLINE : PART-3

- **Single-phase induction motor :**

1. A 1ϕ motor consists of a single-phase winding mounted on the stator and a cage winding on the rotor.
2. When a 1ϕ supply is connected to the stator winding a pulsating magnetic field is produced. By pulsating field we mean that the field builds up in one direction, falls to zero, and then builds up in the opposite direction.
3. Under these conditions, the rotor does not rotate due to inertia. Therefore, a 1ϕ induction motor is inherently not self-starting.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.28. **Using double-revolving field theory, explain the principle of operation of a single-phase induction motor.**

OR

Why single phase induction motor is not a self-starting machine ? Explain it. **AKTU 2014-15(Sem-2), Marks 05**

Answer

A. **Double-revolving field theory :**

1. It states that a stationary pulsating magnetic field can be resolved into two rotating magnetic fields, each of equal magnitude but rotating in opposite directions.

2. The induction motor responds to each magnetic field separately, and the net torque in the motor is equal to the sum of the torques due to each of the two magnetic fields.
3. The equation for an alternating magnetic field whose axis is fixed in space is given by

$$b(\alpha) = \beta_{max} \sin \omega t \cos \alpha \quad ...(4.28.1)$$

where β_{max} is the maximum value of the sinusoidally distributed air-gap flux density produced by a properly distributed stator winding carrying an alternating current of frequency ω and α is space-displacement angle measured from the axis of the stator winding.

4. Since $\sin A \cos B = \frac{1}{2} \sin (A - B) + \frac{1}{2} \sin (A + B)$,

eq. (4.28.1) can be written as

$$b(\alpha) = \frac{1}{2} \beta_{max} \sin (\omega t - \alpha) + \frac{1}{2} \beta_{max} \sin (\omega t + \alpha) \quad ...(4.28.2)$$

5. The first term on the right-hand side of eq. (4.28.2) represents the equation of a revolving field moving in the positive α direction. It has a maximum value equal to $\frac{1}{2} \beta_{max}$.
6. The second term on the right-hand side of eq. (4.28.2) represents the equation of a revolving field moving in the negative α direction. Its amplitude is also equal to $\frac{1}{2} \beta_{max}$.
7. The field moving in the positive α direction is called the forward rotating field. The field moving in the negative α direction is called the backward rotating field.
8. It is to be noted that both the fields rotate at synchronous speed $\omega_s (= 2\pi f)$ in opposite directions.
9. Thus, $\frac{1}{2} \beta_{max} \sin (\omega t - \alpha)$ is the forward field

and $\frac{1}{2} \beta_{max} \sin (\omega t - \alpha)$ is the backward field.

B. Reason (1 ϕ induction motor is not a self-starting machine) :

1. A 1ϕ motor consists of a single-phase winding mounted on the stator and a cage winding on the rotor.
2. When a 1ϕ supply is connected to the stator winding a pulsating magnetic field is produced. By pulsating field we mean that the field builds up in one direction, falls to zero, and then builds up in the opposite direction.
3. Under these conditions, the rotor does not rotate due to inertia. Therefore, a 1ϕ induction motor is inherently not self-starting.

Que 4.29. **Describe construction and working of a shaded-pole motor.**

Answer

A. Shaded-pole motor :

1. A shaded-pole motor is a simple type of self-starting 1ϕ induction motor. It consists of a stator and a cage-type rotor.
2. The stator is made up of salient poles. Each pole is slotted on side and a copper ring is fitted on the smaller part *a*. This part is called shaded pole. The ring is usually a single-turn coil and is known as shading coil.
3. When alternating current flows in the field winding, an alternating flux is produced in the field core. A portion of this flux links with shading coil, which behaves as a short-circuited secondary of transformer.
4. A voltage is induced in the shading coil and this voltage circulates a current in it. The induced current produces a flux which opposes the main core flux.
5. The shading coil, thus, causes the flux in the shaded portion to lag behind the flux in the unshaded portion of the pole.
6. At the same time, the main flux and the shaded pole flux are displaced in space. This space displacement is less than 90°.

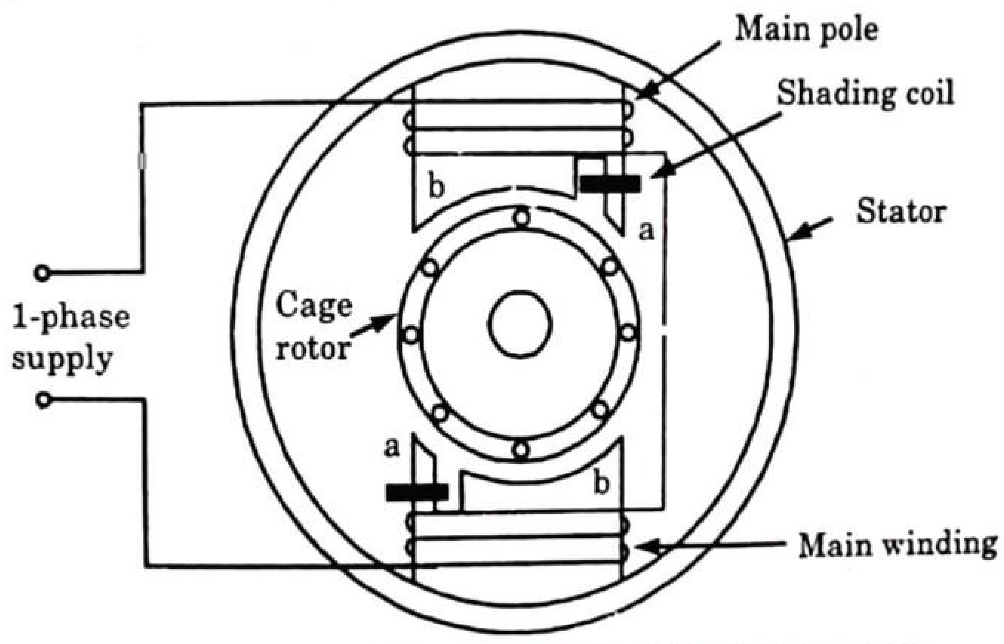

Fig. 4.29.1. Shaded-pole motor with two stator poles.

7. Since, there is time and space displacement between the two fluxes, conditions for setting up a rotating magnetic field are produced.
8. Under the action of the rotating flux a starting torque is developed on cage rotor. The direction of this rotating field (flux) is from the unshaded to shaded portion of the pole.
9. In a shaded-pole motor the reversal of direction of rotation is not possible.

B. Applications :

1. The most common applications are table fans, exhaust fans, hair driers, fans for refrigeration and air-conditioning equipments, electronic equipment, cooling fans etc.
2. They are also used in record players, tape recorders, slide projectors, photo copying machines, in starting electric clocks and other single-phase synchronous timing motors.

Que 4.30. **Using double revolving field theory explain why single phase induction motor is not self starting ? Describe capacitor-start capacitor-run method for starting single phase induction motor and give two applications of such motor.**

AKTU 2015-16(Sem-2), Marks 15

Answer

A. Double revolving field theory : Refer Q. 4.28, Page 4–32D, Unit-4.

B. Capacitor-start capacitor-run motor or two value capacitor motor :

1. Fig. 4.30.1 shows the schematic diagram of a two-value capacitor motor.
2. It has a cage rotor and its stator has two windings namely the main winding and the auxiliary winding.
3. The two windings are displaced 90° in space. The motor uses two capacitors C_S and C_R. The two capacitors are connected in parallel at starting.
4. The capacitor C_S is called the starting capacitor.

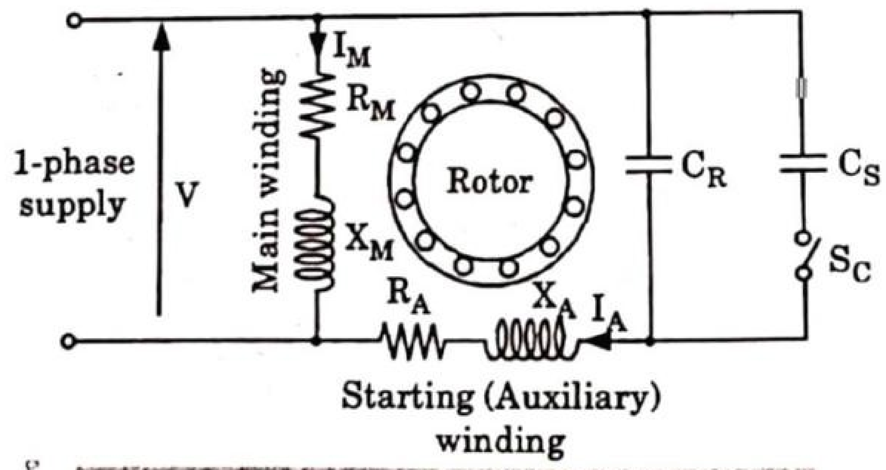

Fig. 4.30.1. Two-value capacitor motor or capacitor-start capacitor-run motor.

5. In order to obtain a high starting torque, a large current is required. For this purpose, the capacitive reactance X_A in the starting winding should be low. Since $X_A = 1/(2\pi fC_A)$, the value of C_s should be large.
6. During normal operation, the rated line current is smaller than the starting current. Hence the capacitive reactance should be large. Since $X_R = 1/(2\pi fC_R)$, the value of C_R should be small.

7. As the motor approaches synchronous speed, the capacitor C_S is disconnected by a centrifugal switch S_C. The capacitor C_R is permanently connected in the circuit. It is called the run-capacitor.
8. Since one capacitor C_S is used only at starting and the other C_R for continuous running, this motor is also called capacitor-start capacitor-run motor.

C. Applications : These are used for loads of higher inertia requiring frequent starts where the maximum pull-out torque and efficiency required. They are used in pumping equipment, refrigeration, air compressors etc.

Que 4.31. **Single-phase induction motor is not self-starting. Explain. Name various starting methods of single-phase induction motor and explain capacitor run motor.**

AKTU 2016-17(Sem-2), Marks 07

OR

Explain any one method of starting single-phase induction motor with neat diagram.

AKTU 2013-14(Sem-1), Marks 05

OR

Explain principle of operation of 1ϕ induction motor using two revolving field theory. List various methods of starting.

AKTU 2017-18(Sem-2), Marks 07

Answer

A. 1 ϕ I.M. is not self starting : Refer Q. 4.28, Page 4–32D, Unit-4.

B. Principle of operation of 1ϕ induction motor : Refer Q. 4.28, Page 4–32D, Unit-4.

C. Starting methods of 1ϕ induction motor (or Types of 1ϕ induction motor) :

a. Split-phase motor :

1. Fig. 4.31.1 shows a split-phase induction motor. It is also called a resistance-start motor.

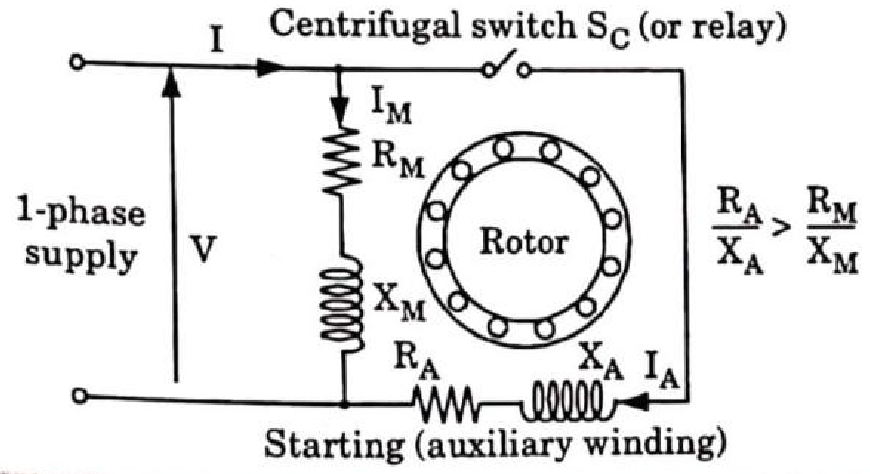

Fig. 4.31.1. Split-phase induction motor connections.

2. It has a single-cage rotor and its stator has two windings - a main winding and a starting (auxiliary) winding.
3. The main field winding and the starting winding are displaced 90° in space. The main winding has very low resistance and high inductive reactance.
4. Thus, the current I_M in the main winding lags behind the supply voltage V by nearly 90°.
5. The auxiliary winding has a resistor connected in series with it. It has a high resistance and low inductive reactance so that the current I_A in the auxiliary winding is nearly in phase with the line voltage.
6. Thus, there is time phase difference between the currents in the two windings. This phase difference is enough to producc a rotating magnetic field.

b. Capacitor-start motor :

1. Fig. 4.31.2 shows the connections of a capacitor-start motor. It has a cage rotor and its stator has two windings namely, the main winding and the auxiliary winding (starting winding).
2. The two windings are displaced 90° in space. A capacitor C_S is connected in series with the starting winding. A centrifugal switch S_C is also connected as shown in Fig. 4.31.2.
3. By choosing a capacitor of the proper rating the current I_M in the main winding may be made to lag the current I_A in the auxiliary winding by 90°.
4. Thus, a single-phase supply current is split into two phases to be applied to the stator windings. Thus the windings are displaced 90° apart in time phase.
5. Therefore the motor acts like a balanced two-phase motor. As the motor approaches its rated speed, the auxiliary winding and the starting capacitor C_S are disconnected automatically by the centrifugal switch S_C mounted on the shaft.

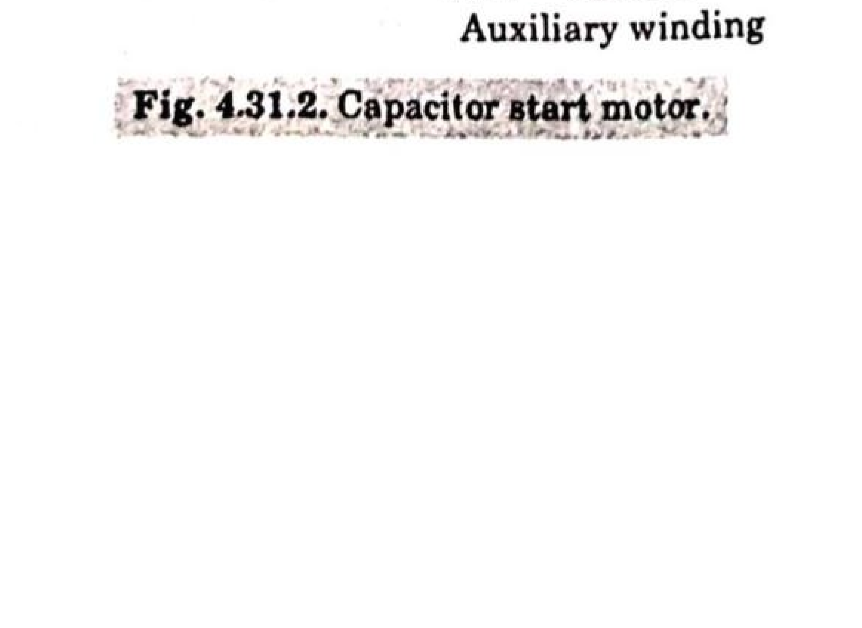

Fig. 4.31.2. Capacitor start motor.

c. Permanent capacitor-run motor :

1. A permanent-split capacitor (PSC) motor is shown in Fig. 4.31.3.
2. It has a cage rotor and its stator has two windings, namely, the main winding and the auxiliary winding.
3. This single-phase induction motor has only one capacitor C which is connected in series with the starting winding.
4. The capacitor C is permanently connected in the circuit both at starting and running conditions.

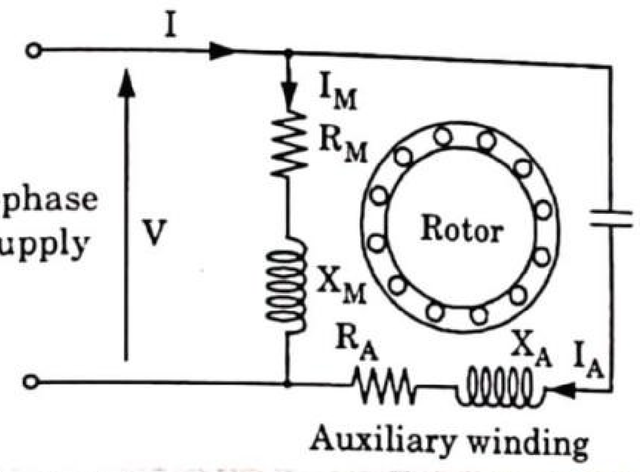

Fig. 4.31.3. Permanent-split capacitor motor.

5. A permanent-split capacitor motor is also called the single-value capacitor motor.
6. Since the capacitor C is always in the circuit, this type of motor has no starting switch.
7. The auxiliary winding is always in the circuit, and therefore this motor operates in the same way as a balanced two-phase motor.

d. Two value capacitor motor : Refer Q. 4.30, Page 4–35D, Unit-4.

e. Shaded-pole motor : Refer Q. 4.29, Page 4–34D, Unit-4.

PART-4

Three Phase Synchronous Machines : Principle of Operation of Alternator and Synchronous Motor and their Applications.

CONCEPT OUTLINE : PART-4

- Synchronous machine is an AC machine in which the rotor moves at a speed which bears a constant relationship to the frequency of currents in the armature winding.
- Synchronous machine provides constant speed industrial drives with possibility of low power factor correction.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.32. **Explain the principle of operation of an Alternator.**

AKTU 2014-15(Sem-2), Marks 05

Answer

1. Alternator means 3ϕ AC generator. Alternators operate on the electromagnetic induction principle, similar to DC generators.
2. 3ϕ windings are located at the hollow cylindrical stationary part known as stator and field system is rotated by prime mover.

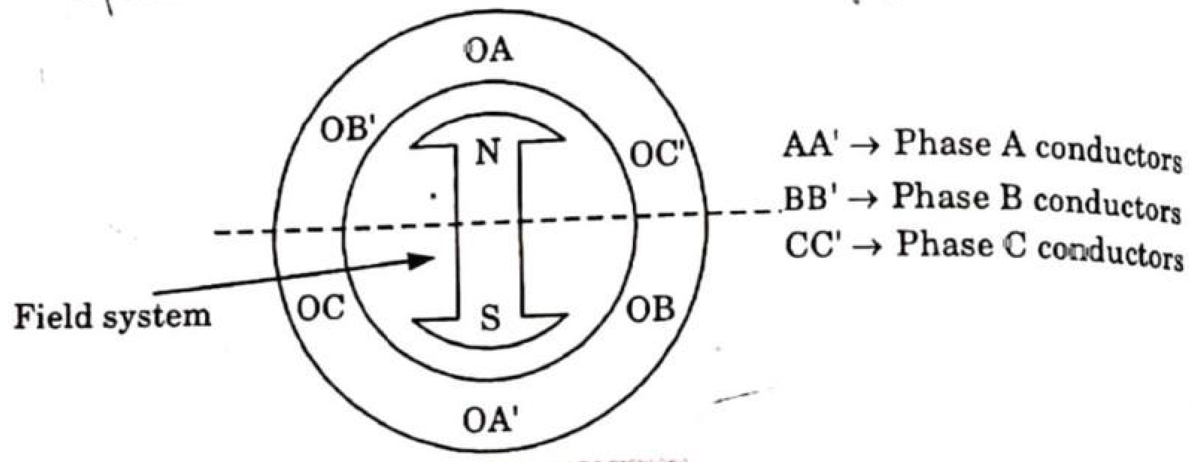

Fig. 4.32.1.

3. When the field system is rotated by a prime mover, the stator conductors are cut by magnetic flux and hence an emf is induced in the stator conductors which is given by

$$e = B\,l\,v$$

where, B = Flux density in Wb/m^2 or T

l = Length of stator conductors in meters

v = Speed of the conductor in m/s

4. Since induced emf e is directly proportional to flux density (if l and v is made constant, the emf wave will be identical to the flux density wave). If the flux density produced by the field winding is sinusoidal the emf induced in phase coils will be sinusoidal as shown in Fig. 4.32.2.

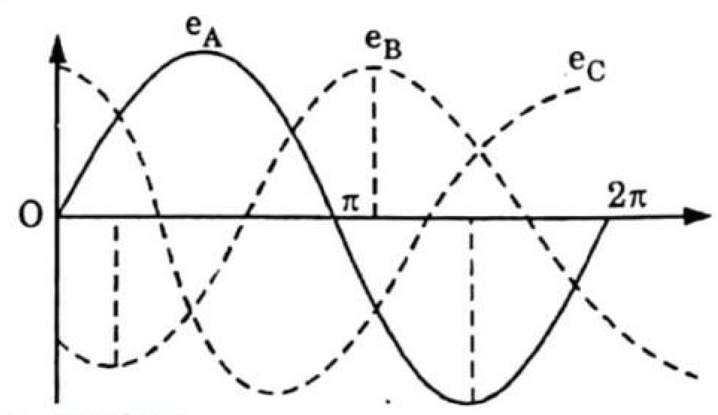

Fig. 4.32.2. Voltage wave shapes of 3ϕ alternator.

5. The frequency of the generated emf depends upon the number of poles P and the speed N at which the alternator is being run by prime mover,

$$\text{as } f = \frac{PN}{120} \text{ Hz.}$$

Que 4.33. **Discuss principle of operation of synchronous motor with diagram. Draw characteristics of DC series motor.**

AKTU 2013-14(Sem-1), Marks 10

OR

Illustrate the operating principle of synchronous motor with suitable figures.

AKTU 2014-15(Sem-1), Marks 10

OR

Explain working principle of synchronous motor and two applications.

AKTU 2014-15(Sem-2), Marks 05

OR

Explain :

a. **Explain the speed-torque characteristics of DC shunt and series motors.**

b. **Explain why a synchronous motor does not develop starting torque ?**

c. **Explain the working principle of three phase induction motor.**

AKTU 2016-17(Sem-1), Marks 07

OR

Explain principle of operation of 3-phase synchronous motor.

AKTU 2017-18(Sem-2), Marks 07

Answer

A. Principle of working of synchronous motor :

1. When the synchronous machine stator is supplied with three-phase balanced voltages and the rotor field is excited with DC current, then in the air gap there will be an mmf (magneto motive force) which is sinusoidally distributed and rotate at synchronous speed defined by the frequency of the applied voltage.
2. The rotor field is also sinusoidally distributed in the air gap due to the shaping of the poles and is stationary with respect to rotor. If the rotor is rotated at synchronous speed, then the rotor field also rotates at the same speed.
3. The interaction of stator mmf and the rotor flux generates unidirectional torque in the direction of motion of rotor. This is the principle of working