UNIT 3

D.C GENERATOR AND D.C MOTOR

Marketed by:
SIA GROUP

PART-A

SHORT QUESTIONS WITH SOLUTIONS

Q1. Write the principle of working of a D.C generator.

Ans:

D.C generator works on the principle of Faraday's laws of electromagnetic induction i.e., whenever a moving conductor is placed in a magnetic field, dynamically induced e.m.f is produced in the conductor or whenever a conductor cuts the magnetic flux dynamically, e.m.f is produced. As a result, this e.m.f causes a current to flow in the conductor if the conductor circuit is closed.

Q2. State the purpose of magnetic yoke in a D.C machine.

Model Paper-II, Q6

Ans:

The purpose of magnetic yoke are as follows,

(i) The magnetic yoke or the frame is the outermost metal structure, which provides mechanical strength to the whole machine and acts as a protective cover.

(ii) The field poles are held firmly on the inner side of yoke.

(iii) The yoke offers low reluctance path for the magnetic flux produced by the main poles.

(iv) The internal parts such as rotor, armature winding etc., are protected from external damage by this magnetic yoke.

Q3. What is the function of armature coils?

Ans:

The following are the functions of armature coils.

(i) Armature coils carry the armature current.

(ii) It is responsible for the generation of e.m.f in armature of a D.C machine.

(iii) For D.C generators, armature coil supplies the current to the load, whereas for D.C motors the armature coil draws current from the supply.

Q4. What are the advantages and disadvantages of carbon brushes?

Ans:

Brushes are made up of different materials. Carbon brushes are mostly used in D.C machine because carbon lubricates and polishes the commutator.

Advantages of Carbon Brushes

(i) It is a good electric conductor which improves the conductivity and insulates the voltage induced in conductors confining current to them.

(ii) It has negative temperature coefficient of resistance and can slide on the commutator with the rotation of brush gears.

(iii) Carbon brushes are used in lower circuit machine and are self lubricating materials.

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Disadvantages of Carbon Brushes

(i) Carbon brushes can only work at a current density of about 40-50 A/cm² as compared to 150-200 for copper brushes. This necessitates a large commutator.

(ii) Brush contact resistance decreases with increase in current density. Variation of brush contact resistance results in non-linear variation of current in a coil going commutation.

Q5. Distinguish between lap and wave windings.

Ans:

	Lap Winding		Wave Winding
1.	In this winding, all the pole groups of the coils generating e.m.f in the same direction at any instant of time are connected in parallel by the brushes.	1.	In this winding, all the coils carrying current in the same direction are connected in series i.e., coils carrying current in one direction are connected in one series circuit and coils carrying current in opposite direction are connected in other series circuit.
2.	Lap winding is also known as parallel windings.	2.	Wave winding is also known as series winding.
3.	The number of parallel path is equal to the number of poles i.e., A = P.	3.	The number of parallel paths is always equal to 2, i.e., A = 2.
4.	The number of brushes required is equal to the number of poles.	4.	The number of brushes required is equal to 2.

Q6. Show the power stages in a D.C generator.

Ans:

The various power stages present in a D.C generator are shown in figure below.

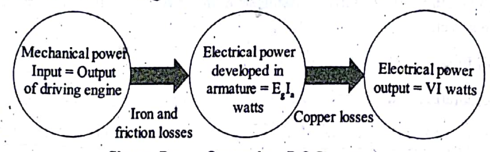


Figure: Power Stages in a D.C Generator

In case of D.C generator, mechanical power is given as input. Iron and friction losses takes place before the conversion of mechanical form to electrical form, whereas copper loss takes place after the conversion of mechanical form to electrical form.

Q7. Classify D.C generators based on their field excitations.

Ans:

D.C generators are classified into two types based on their field excitation. They are,

1. Separately excited D.C generator
2. Self excited D.C generator.

1. Separately Excited D.C Generator

In separately excited D.C generator, separate D.C source is used to excite the field of the generator.

2. Self Excited D.C Generator

In self excited D.C generator, there is no need of any external D.C source to excite the field but in these generators the field is excited by current produced by the generator itself. Self excited D.C generators are further classified as follows,

(a) D.C series generators

(b) D.C shunt generators

(c) D.C compound generators.

D.C compound generators are classified as,

(i) D.C long shunt compound generator

(ii) D.C short shunt compound generator.

Q8. What is armature reaction? List the different effects of it.

Model Paper-I, Q5

Ans:

Armature Reaction: The effect of magnetic field set up by the armature current on the distribution of flux under the main poles of a D.C generator or a D.C motor is known as armature reaction.

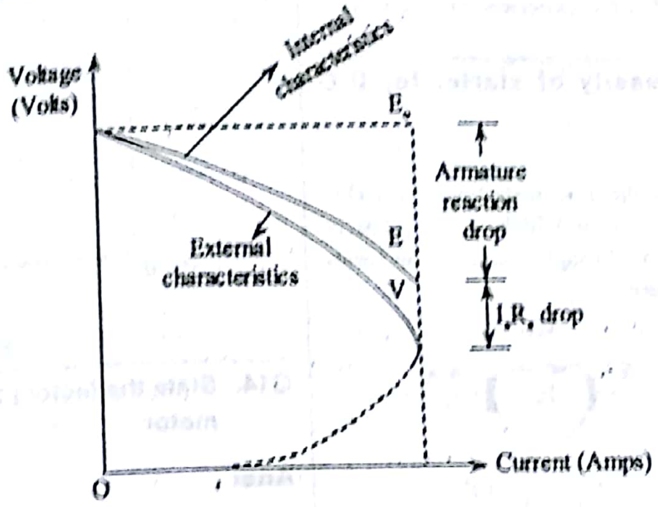
Effects: The armature magnetic flux produces two undesirable effects on the main field. They are,

1. Distortion of the main field flux wave along the airgap periphery i.e., cross magnetization.
2. Net reduction in the main field flux per pole i.e., demagnetization.

Q9. Draw the external and internal characteristics of a D.C shunt generator.

Ans:

The internal and external characteristics of D.C shunt generator are shown in figure.



Figure

Q10. List different losses that occur in a D.C machine.

Ans:

The different losses occurring in D.C machines are shown below with the help of a neat diagram.

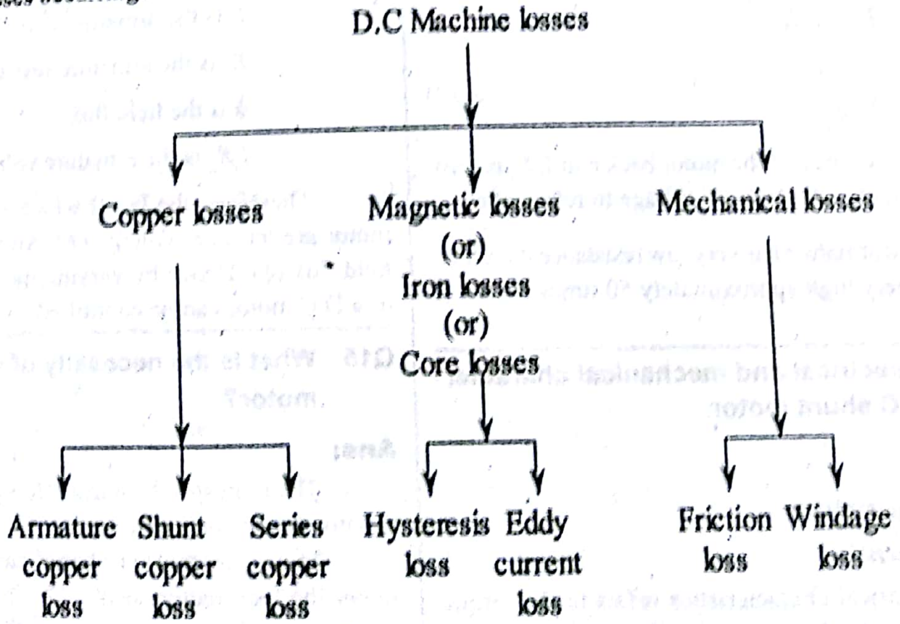


Figure: Losses in a D.C Machine

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Q11. State the working principle of D.C motor.

Ans: *Model Paper-II, Q5*

D.C motor works on the principle of Faraday's Laws of electromagnetic induction i.e, whenever a current carrying conductor is placed in a magnetic field. It experience a mechanical force.

The magnitude of the mechanical force experienced is given as,

$$F = BIl \text{ newton}$$

Where,

B is the flux density (Wb/m² or Tesla)

I is the current flowing through the conductor (Ampere)

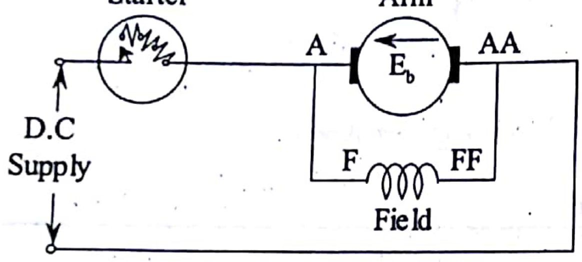
l is the length of the conductor (Meters).

Also the direction of force experienced is given by Flemings left hand rule.

Q12. What is the necessity of starter for D.C motors?

Ans:

A starter is necessary at the time of starting of any D.C motor. Starter is nothing but a resistor, which has the property that opposes the current to flow through it and it is in series with armature as shown in figure.



Figure

From voltage equation of a D.C machine at steady state operating conditions, armature current can be written as,

$$V = E_b + I_a R_a \quad \text{... (1)}$$

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

At stand still position of the motor back e.m.f, E_b is zero. Then armature current is the ratio of voltage to resistance.

We know that armature has very low resistance therefore, starting current is very high approximately 50 times to that of rated current.

Q13. Draw the electrical and mechanical characteristics of D.C shunt motor.

Ans:

Shunt Motor Characteristics

Electrical Characteristics

The term electrical characteristics refers to the torque and armature current (T_a/I_a) characteristics. The electrical characteristics of a D.C shunt motor is shown in figure (1).

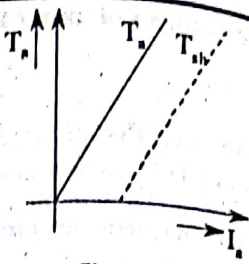


Figure (1)

Mechanical Characteristics

The term mechanical characteristics refers to the speed and torque (N/T_a) characteristics. The mechanical characteristics of D.C shunt motor is shown in figure (2).

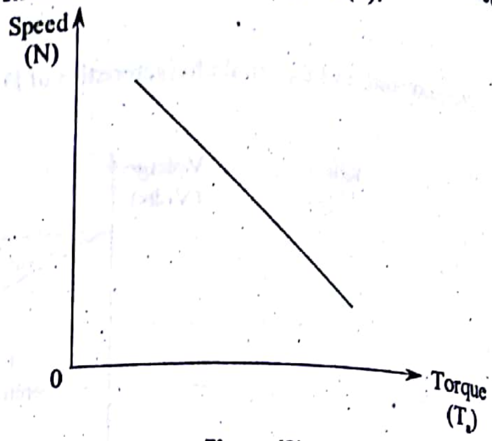


Figure (2)

Q14. State the factors that effect the speed of a D.C motor.

Ans:

$$\text{Speed, } N \propto \frac{(V - I_a R_a)}{\phi}$$

Where,

N is the speed of the D.C motor

V is the terminal voltage

I_a is the armature current

R_a is the armature resistance

ϕ is the field flux

$I_a R_a$ is the armature voltage drop.

Therefore, the factor which effects the speed of a D.C motor are terminal voltage (V), Armature resistance (R_a) and field flux (ϕ). Hence by varying these three factors the speed of a D.C motor can be controlled.

Q15. What is the necessity of speed control of D.C motor?

Ans: *Model Paper-I, Q5*

The term speed control refers to the change of speed of a motor as per our requirement.

Motors are said to be beneficial when the motors operate as per the load requirements. For loads that require variable speed operations, it necessary for the motor to be used with varying speeds,

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Therefore the necessity of speed control of D.C motor arises. The other reasons for preferring speed control of D.C motors are,

1. In D.C motors, the speed can be very easily controlled.
2. The speed control achieved in D.C motor is very smooth and such smooth speed control is not possible in A.C motors.
3. In D.C motors, speed can be controlled over a wide range.

Q16. Write the applications of shunt and compound D.C motors.

Ans:

Applications

D.C Shunt Motor

1. Shunt motors are applicable in industry where wide range of speed control required, like, lathes, centrifugal pumps, fans, blowers, conveyers, wood working machines, spinning and weaving machines etc.,
2. Shunt motors are also applicable to steel and aluminium rolling mills.
3. Shunt motors are used in Ward leonard system of speed control when its field winding is separately excited.

D.C Compound Motor

D.C compound motors are used for high torque intermittent loads like punches, shears, elevators, conveyors, rolling mill etc.

Q17. Write down the similarities between motors and generators.

Ans:

	D.C Motor		D.C Generator
1.	Both induced e.m.f and mechanical forces are developed in a D.C motor.	1.	Both induced e.m.f and mechanical forces are developed in a D.C generator.
2.	The construction of a D.C motor is identical with a D.C generator.	2.	The construction of a D.C generator is identical with a D.C motor.
3.	Any machine operated as a D.C motor can also be operated as a D.C generator.	3.	Any machine operated as a D.C generator can also be operated as a D.C motor.

Q18. A 4-pole D.C generator having a wave wound armature conductors has 51 slots with each slot containing 20 conductors. Find the e.m.f generated when the machine is driven at 1500 r.p.m assuming flux per pole 60 mWb.

Ans:

Given that,

Wave wound D.C generator

Number of poles, $P = 4$

Number of slots = 51

Conductors per slot = 20

Speed, $N = 1500$ r.p.m

Flux per pole, $\phi = 60 \text{ mWb} = 60 \times 10^{-3}$ Wb

Generated e.m.f, $E = ?$

Total number of armature conductors,

Z = Number of slots × Conductors per slot

$= 51 \times 20$

$= 1020$

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∴ The expression for e.m.f generated is given as,

$$E = \frac{\phi ZN}{60} \times \frac{P}{A} \quad [\because \text{For wave winding, } A = 2]$$

$$= \frac{(60 \times 10^{-3}) \times (1020) \times (1500)}{60} \times \frac{4}{2}$$

$$= 3060 \text{ Volts}$$

Q19. A 6-pole wave wound D.C generator running at a speed of 300 r.p.m generates an e.m.f 535 V. Calculate the flux per pole if it has 650 conductors.

Ans:

Given that,

Number of poles, $P = 6$

Speed, $N = 300$ r.p.m

Induced e.m.f, $E = 535$ V

Number of conductors, $Z = 650$

Flux per pole, $\phi = ?$

We know that, the e.m.f induced in a generator is given by,

$$E = \frac{\phi ZN}{60} \times \frac{P}{A}$$

$$= \frac{\phi Z N}{60} \times \frac{P}{2} \quad (\because \text{Wave wound, } A = 2)$$

$$= \frac{\phi Z N P}{120}$$

∴ Flux per pole, $\phi = \dfrac{120 \times E}{Z N P}$

$$= \frac{120 \times 535}{650 \times 300 \times 6}$$

$$= 0.05487 \text{ Wb}$$

$$= 54.87 \text{ mWb}$$

$$\boxed{\therefore \phi = 54.87 \text{ mWb}}$$

Q20. A D.C series motor working on 200 V supply draws a current of 50 A, its armature and series field resistance are 0.03 Ω and 0.02 Ω respectively. Calculate the back e.m.f.

Ans:

Given that,

Terminal voltage, $V = 200$ V

Line current, $I_L = 50$ A

Series field resistance, $R_{se} = 0.02\ \Omega$

Armature resistance, $R_a = 0.03\ \Omega$

Back e.m.f, $E_b = ?$

For series motor, $I_a = I_{se} = I_L = 50$ A

Back e.m.f,

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

$$= 200 - 50 \times 0.03 - 50 \times 0.02$$

$$= 200 - 1.5 - 1$$

$$= 197.5 \text{ V}$$

Q21. In a 4 pole lap wound D.C compound develops back e.m.f of 200 V. The field pro a flux of 0.025 Wb and the armature co 400 conductor. Calculate the speed deve

Ans:

Given that,

Number of poles, $P = 4$

Back e.m.f, $E_b = 200$ V

Flux, $\phi = 0.025$ Wb

Number of conductors, $Z = 400$

Speed, $N = ?$

We know that,

Back e.m.f,

$$E_b = \frac{\phi PNZ}{60\,A}$$

$$N = \frac{60\,AE_b}{\phi PZ}$$

For lap winding, $A = P = 4$

$$N = \frac{60 \times 4 \times 200}{0.025 \times 4 \times 400}$$

$$= \frac{48000}{40}$$

$$= 1200 \text{ r.p.m}$$

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PART-B

ESSAY QUESTIONS WITH SOLUTIONS

3.1 D.C GENERATOR

3.1.1 Principle of Operation, Constructional Details, E.M.F Equation

Q22. What is D.C generator? And explain the basic principle of a D.C generator.

Ans:

D.C Generator

A D.C generator is a device that transforms mechanical energy as input to electrical energy as output on the basis of dynamically induced e.m.f.

Working Principle of a D.C Generator

Production of dynamically induced e.m.f is the operating principle of D.C generator. This can be achieved by placing a conductor in a magnetic field.

According to Faraday's second law, its magnitude is proportional to rate of change of flux linkages.

Hence, the D.C generator must possess the magnetic field, a conductor and motion of the conductor relative to the field for the production of dynamically induced e.m.f. Figure shows that the flux lines of magnet (either permanent or electromagnet type) are perpendicular to the plane of the rectangular coil. Rectangular coil is made of copper and whose sides are 12, 22', 2'1', 11'.

Say coil rotates in clockwise direction from its initial position 0°.

At initial position (i.e., 0°), the induced e.m.f of coil is zero even though flux linkage is maximum.

This is because of minimum rate of change of flux linkage which results from the sliding of the coil along the flux lines.

As soon as the coil starts its rotation, the rate of change of flux linkage starts increasing and reaches its maximum value at position $\frac{\pi^\circ}{2}$.

Therefore, at this instant, induced e.m.f is maximum, though the coil has minimum flux linkage.

Similarly, at further position like π° and $\frac{3\pi^\circ}{2}$, the induced e.m.f of coil has minimum and maximum values respectively.

Here, induced e.m.f's of coil sides 12 and 1'2' are considered, as they aid each other but not of the coil sides 11' and 22'. Because coil sides 11' and 22' moves in same direction under the same flux therefore, their magnitude of induced e.m.f's are equal but opposite in direction which results in zero resultant e.m.f.

The induced e.m.f of coil side 12 is in one direction (say positive) up to position π°, and then it is reversed for period of another π° (i.e., negative).

The same effect takes place in reverse order for coil side 1' 2'.

Hence, induced e.m.f's, thereby currents of coil reverses its direction after every π° rotation. Such a periodic reversal of coil current is known as alternating current. But the D.C generator output is not alternating in nature.

In order to obtain the D.C output, the two coil ends are connected to two split rings, *a* and *b* on which brushes (carbon or copper type) *A* and *B* are arranged as shown in figure.

The two split rings are insulated from each other and also from armature shaft on which it is mounted. The two split rings are collectively known as commutator.

As we know for first π rotation of the coil, the induced e.m.f of coil side 12 thereby its current is positive, at this instant the current flowing path is 12*aABb*2'1'.

Thus, brush, *A* acts as positive output terminal and *B* as negative one as shown in figure.

For further π rotation of the coil also, the brushes have same polarity though the coil and split rings changes its polarity.

Thus, the induced e.m.f's are alternating in nature but the D.C generators output is unidirectional because of rectifying action of split rings.

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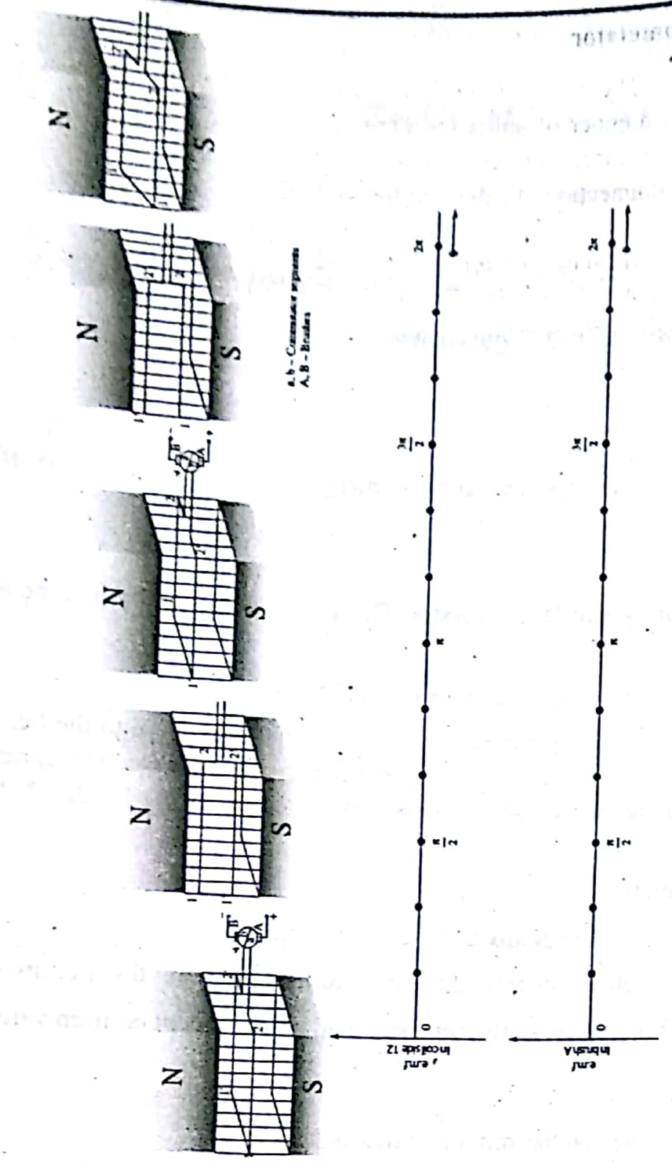

Figure: Simple D.C Generator with Two Segments Commutator

Q23. Describe the construction of a D.C generator and write the functions of each part with neat sketch.

Ans: Model Paper-I, Q13(a)

A D.C machine consists of stator and rotor. Stator is the assembly of main parts like yoke, main poles, pole shoe, inter pole windings etc., and the rotor is the assembly of armature, armature winding, commutator fan etc.

D.C. Machine

- Stator
  - Yoke
  - Pole core and Pole shoe
  - Interpoles
  - Field windings
  - Brush and brush holders
- Rotor
  - Armature
  - Armature winding
  - Commutator

Yoke

Yoke is the outer cover of the machine supporting and protecting the internal parts. It is made of low reluctance material like silicon steel or cast iron. It provides the close path for the flux produced through the poles.

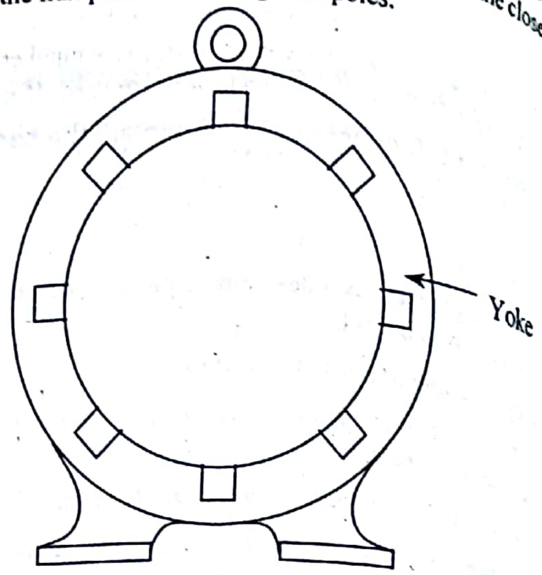

Figure (1): Yoke

Pole Core and Pole Shoe

Pole core is generally a solid material and pole shoe has laminated construction in small machines. The purpose of the pole core is to provide flux and to support the field windings, whereas the pole shoe is stretched so as to provide uniform air gap along the armature core and also to provide uniform flux distribution in the airgap.

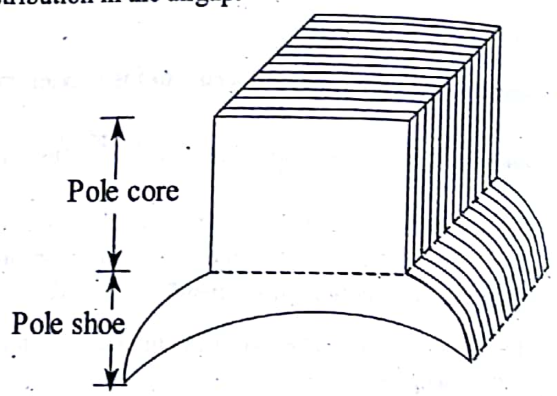

Figure (2): Pole Core and Pole Shoe

Brush and Brush Holders

Brushes are the structures placed on the rotating commutator through which the unidirectional current is to be collected. Generally, it is made of carbon, which can gives smooth surface at the contacts so as to reduce the spark and wear and tear of the commutator bars. These are fixed to the stator core (yoke) by means of brush holders

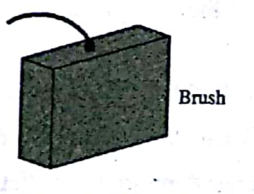

Figure (3): Brush

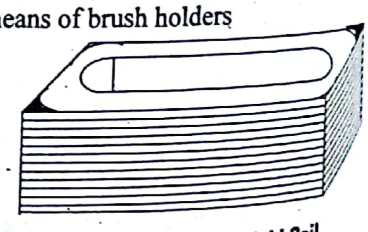

Figure (4): Wounded Field Coil

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Field Windings

The field windings are wound initially on a wooden former and then installed into the pole core. These are generally made of low resistivity materials like copper or aluminum. There are two ways of connecting the field winding to the armature in case of self-excited machine. They can be connected in series or shunt. If it is connected in series less numbered turns with larger cross-sectional conductors are used. If it is connected in shunt, the winding would be of large turns, whose cross-section is less, so as to withstand for whole supply voltage.

Interpoles

These are the pole structures generally smaller than main poles and are placed in between the main poles. The windings of the interpoles are of less turns since it is connected in series with armature windings. The main purpose of these interpoles is to reduce the armature reaction, thereby reducing the sparks at the brush contacts. The polarity of the interpole is made same as that of the main pole ahead of it in the direction of rotation.

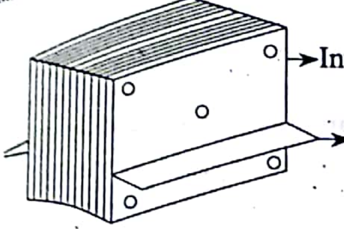

Figure (5): Interpole and Support to Coil

Rotor

The rotor is generally rotating part which carries the armature, armature windings and the commutator on the same shaft. The armature core is made of laminated silicon steel. The main purpose is to hold the armature windings and to provide the low reluctance path for the flux.

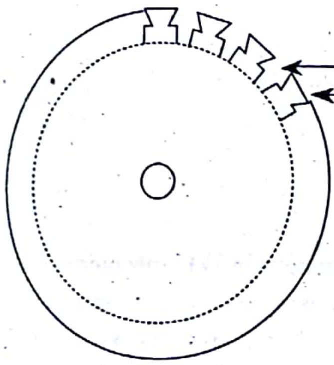

Figure (6): Armature Core (End View)

Armature Windings

The windings placed in the armature are called the armature windings and are generally connected in two ways,

(i) Lap windings

(ii) Wave windings.

Lap windings are preferred for higher currents and low voltage and wave windings are preferred for higher voltages and lower currents.

Commutator

The commutator is a split ring of larger size with large number of splits (commutator segments). It is called a mechanical rectifier in generator and an inverter in motor. The connections to the commutator depends upon the type of armature windings. These are made of hard copper so as to withstand the brush forces which are placed upon the commutator segments. The position of the brushes is generally based on the winding. Commutator consists of number of segments or bars insulated from each other and are combined together tightly to form a cylinder as shown in figure (7), and fitted on the insulated shaft of the armature. This is known as commutator.

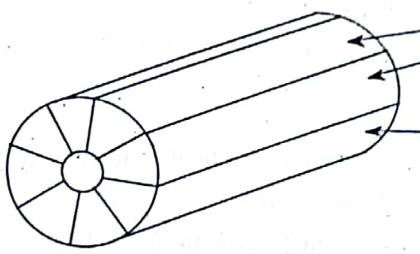

Figure (7)

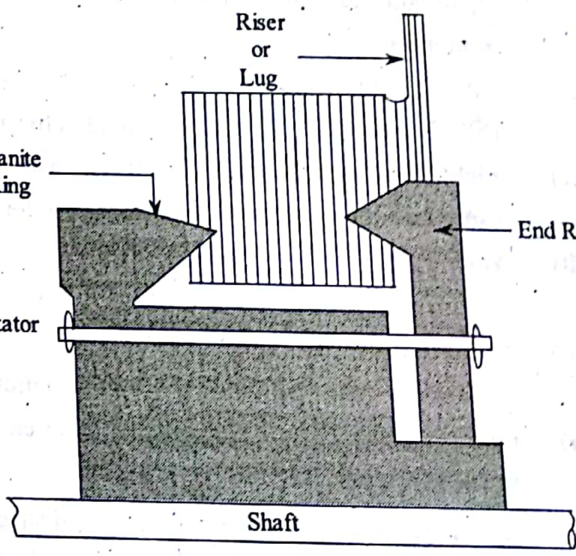

Figure (8): Sectional View of Commutator

Importance of Commutator in a D.C Machine

1. As the voltage build up in the armature conductors is A.C voltage, to convert it into D.C voltage commutator is used in the external circuit in generator operation.

2. It facilitates the collection of current from armature.

3. It helps in connecting the armature with the external circuit.

4. It converts alternating quantity into a direct quantity (i.e., voltage or current) and vice-versa.

5. It keeps rotor or armature m.m.f stationary in space even though the armature is rotating.

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Q24. Give the materials and functions of the following parts of a D.C machine.

(i) Field poles

(ii) Yoke

(iii) Commutator

(iv) Commutating poles

(v) Armature.

Ans:

(i) **Field Poles:** They establish the magnetic field necessary for the operation of a D.C machine. They consist of three parts,

(a) Pole core

(b) Pole shoe

(c) Field windings.

(a) **Pole Core: Material Used:** In older design, it is made up of cast iron or steel, whereas in modern design it is made up of laminated annealed steel.

Functions

(a) It provides housing for the field windings.

(b) It supports the pole shoe.

(c) It provides low reluctance path for the flux.

(b) **Pole Shoe: Material Used:** In older design it is made up of laminated steel or iron, whereas in modern design it is made up of laminated annealed steel.

Functions

(a) It supports field winding.

(b) It establishes the magnetic field in the airgap by spreading out the flux uniformly.

(c) **Field Windings: Material Used:** It is made up of highly conducting material like copper.

Function: It carries the current necessary for the establishment of the magnetic flux in the D.C machine.

(ii) **Yoke**

For answer refer Unit-III, Q23, Topic: Yoke.

(iii) **Commutator**

For answer refer Unit-III, Q23, Topic: Commutator.

(iv) **Commutating Poles:** Commutating poles consists of pole shoe and pole windings.

Material Used

(a) Pole shoes are made up of laminated sheets of steel.

(b) Pole windings are made up of good conducting material like copper.

Function: The main function of commutating poles is to improve the commutation in D.C machines. They are kept in between the main poles and its windings connected in series with the armature windings so that they carry currents proportional to the armature currents and produces flux in order to improve the commutation process and avoid the damage to the brushes and commutator. Commutating poles are also used to minimize the effect of cross magnetization.

(v) **Armature:** Armature is the major part in the D.C machine. It houses armature slots and armature windings. So it has two parts,

(a) Armature core

(b) Armature windings.

(a) **Armature Core: Material Used:** The armature core is made up of magnetic material like cast iron or steel in order to provide a path of low reluctance. The body of the core is made up of thin sheets/laminations of steel in order to reduce eddy current loss.

Functions

(a) It houses armature coils i.e., armature conductors or windings.

(b) It provides a path of low reluctance to the magnetic flux generated by the field poles.

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(b) **Armature Windings: Material Used:** Armature windings are made up of very good conducting material like copper as they carry the entire load current.

Functions

- To carry current, in case of generator they supply current to the load and for motor takes current from the supply.
- The e.m.f in the generators is induced in these conductors.

Q25. Derive the e.m.f equation of a D.C generator.

Ans:

Let,

ϕ = Flux per pole in Webers

Z = Total number of armature conductors

= Number of slots × Number of conductors per slot

P = Number of poles

A = Number of parallel paths in armature

N = Armature rotation in r.p.m

E = e.m.f induced in any parallel path armature.

As per Faraday's law of electromagnetic induction, we have,

$$\boxed{\therefore \text{Average e.m.f generated per conductor} = \frac{d\phi}{dt} \text{ Volts } (\because n = 1)} \quad \dots (1)$$

During one revolution of armature in a P pole generator, each armature conductor cuts the magnetic flux P times so that flux cut per conductor in one revolution is,

$$\boxed{\therefore d\phi = \phi P \text{ Weber}} \quad \dots (2)$$

Armature revolves $\frac{60}{N}$ times in one second. Therefore, the time required by it for one revolution is dt.

i.e., $$\boxed{\therefore dt = \frac{60}{N} \text{ seconds}} \quad \dots (3)$$

Substituting equations (2) and (3) in equation (1), we get,

i.e., e.m.f generated/conductor $= \frac{d\phi}{dt} = \frac{\phi P}{\frac{60}{N}} = \frac{\phi PN}{60}$ Volts

The total number of armature conductors per parallel path $= \frac{Z}{A}$

$\therefore$ Total e.m.f generated/path $= \frac{\phi PN}{60} \times \frac{Z}{A}$

$\therefore \frac{\phi PNZ}{60\,A}$ Volts

Where,

Number of parallel paths,

$A = 2$ for simplex wave winding and

$A = P$ for simplex lap winding.

Q26. An eight pole D.C generator has 960 armature conductors and a flux per pole of 20 m-Wb calculate the e.m.f generated when running at 500 r.p.m. If the armature is,

(i) Lap connected

(ii) Wave connected.

Ans:

Given that,

D.C generator,

Number of poles, $P = 8$

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Armature conductors, $Z = 960$

Flux per pole, $\phi = 20$ m-Wb

Speed, $N = 500$ r.p.m

(i) E.m.f generated when the armature is lap connected, $E_g = ?$

(ii) E.m.f generated when the armature is wave connect, $E_g = ?$

We know that,

E.M.F generated, $E_g = \frac{\phi ZN}{60} \times \frac{P}{A}$

(i) Lap Connected

In case of lap wound armature, we have,

Number of parallel paths, (A) = Number of poles (P)

$$A = 8$$

$\therefore$ e.m.f generated, $E_g = \frac{\phi ZN}{60} \times \frac{P}{A}$

$$= \frac{(20\times10^{-3})\times960\times500}{60}\times\frac{8}{8}$$

$$= 160 \text{ Volts}$$

(ii) Wave Connected

In case of wave wound armature, we have,

Number of parallel paths = 2

i.e., $A = 2$

$\therefore$ e.m.f generated, $E_g = \frac{\phi ZN}{60} \times \frac{P}{A}$

$$= \frac{(20\times10^{-3})\times960\times500}{60}\times\frac{8}{2}$$

$$= 640 \text{ Volts}$$

Q27. A 4-pole machine running at 1000 r.p.m has an armature with 80 slots having 8 conductors per slot. The flux per pole is 6 × 10⁻² Wb. Determine the induced e.m.f as a D.C generator, if the coils are lap connected. If the current per conductor is 50 amperes, determine the electrical power output of the machine.

Ans:

Given that,

Number of poles, $P = 4$

Speed, $N = 1000$ r.p.m

Number of slots = 80

Number of conductors per slot = 8

Flux per pole, $\phi = 6 \times 10^{-2}$ Wb

Induced e.m.f, $E_g = ?$

$P_0 = ?$

Electrical power output, when the current per conductor is 50 Amps.

Total number of conductors, Z = Number of slots × Conductors per slot

$= 80 \times 8$

$= 640$

The e.m.f induced in a generator is given as,

$$E_g = \frac{\phi ZN}{60} \times \frac{P}{A}$$

$$= \frac{6\times10^{-2}\times640\times1000}{60}\times\frac{4}{4}$$

[$\because$ Lap winding, $A = P$]

$$= \frac{6\times10^{-2}\times640\times1000}{60}\times 1$$

$$= 640 \text{ V}$$

The total current in a conductor is given as,

I_a = Number of parallel paths × Current per parallel path

$= 4 \times 50$

$= 200$ Amps

The electrical power output is given as,

$$P_0 = E_g \times I_a$$

$= 640 \times 200$

$= 128000$

$= 128$ kW

$$\boxed{\therefore P = 128 \text{ kW}}$$

3.1.2 Types of Generators, Armature Reaction

Q28. Classify the generators based on excitation. Draw the figure and write the current, voltage equation for each configuration.

Ans: *Model Paper-II, Q16(b)*

Based on the production of magnetic flux, D.C machines are classified as follows,

1. **Permanent Magnet Type Machines**

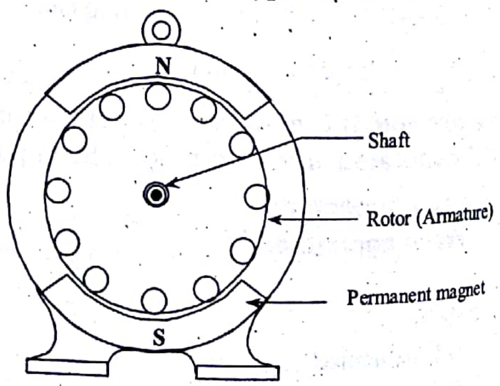

Figure (1): Permanent Magnet Type Machine

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This type of machines are of low rating and consists of the magnetic poles fixed in the inner periphery and the armature coils fed or being fed by the supply in case of generator and motor respectively.

2. Electromagnet Type Machines

(a) Separately Excited

The schematic diagram of separately excited D.C generator is shown in below figure.

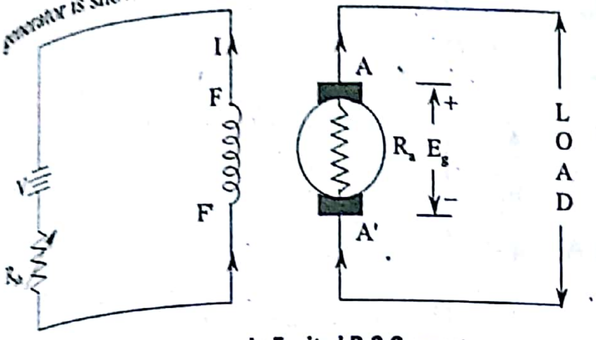

Figure (2): Separately Excited D.C Generator

The current and voltage equations are as follows,

Armature current (I_a) = Load current (I_L)

$$\therefore \quad I_a = I_L$$

Generated e.m.f, $E_g = V + I_a R_a$

(b) Self Excited: In case of self excited machines, the field windings are connected to the armature, so that the armature could feed the field coils. Let us consider, these conditions of connecting field winding in case of generators.

(i) Shunt Generator

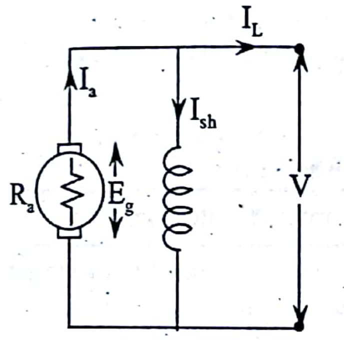

Figure (3)

$\therefore$ Line current = Armature current – Shunt field current

$$I_L = I_a - I_{sh} \quad \text{and}$$

$$E_g = V + I_a R_a = V_{sh}$$

Generated e.m.f = Terminal voltage + Armature resistance drop

$$\Rightarrow \quad E_g = V + I_a R_a$$

Where,

I_a is the armature current (line current) and R_a is the armature resistance.

(ii) Series Generator

The schematic diagram of D.C series generator is shown in below figure.

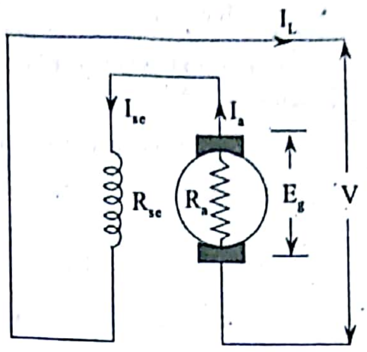

Figure (4): D.C Series Generator

The current and voltage equations are as follows,

Line current (I_L) = Series field current (I_{se})

= Armature current (I_a)

$$\therefore \quad I_L = I_{se} = I_a$$

Generated e.m.f, E_g = Terminal voltage + Voltage drop

$$= V + (I_a R_a + I_a R_{se})$$

$$= V + I_a(R_a + R_{se})$$

(iii) Compound Generator

The combination of two windings i.e., series winding and shunt field winding is considered as a compound generator. Based on the type of connection of the shunt field to the armature and series field it is classified as,

(a) Long shunt

(b) Short shunt.

(a) Long Shunt Machine

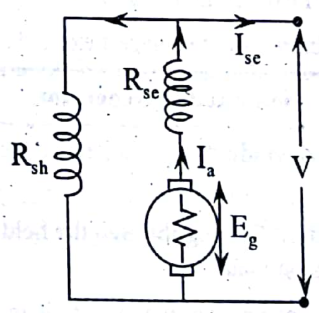

Figure (5)

$\therefore$ Series field current = Armature current

$$\therefore \quad I_a = I_{se} = I_L + I_{sh}$$

I_L = Load current

I_{sh} = Shunt field current

$$\text{and } V_L = V_{sh} = E_g - I_a R_a - I_{se} R_{se}$$

$$= E_g - I_a(R_a + R_{se})$$

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(b) **Short Shunt Machine**

The schematic diagram of D.C short shunt generator is shown in figure.

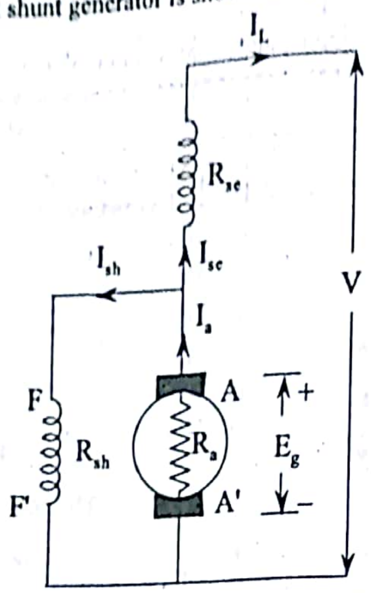

Figure (6): D.C Short Shunt Generator

The current and voltage equations are as follows,

Line current (I_L) = Series field current (I_{se})

$\therefore \quad I_L = I_{se}$

Armature current, $I_a = I_{sh} + I_L$

Voltage across shunt field, $V_{sh} = E_g - I_a R_a$

Generated e.m.f, $E_g = V + I_a R_a + I_{se} R_{se}$

Q29. Distinguish between self excited and separately excited D.C generators.

Ans:

The classification of the generators mainly depends on the way in which their fields are excited. There are mainly two broad categories. They are,

(i) Separately excited generators

(ii) Self excited generators.

The differences between self excited and separately excited generators are,

	Self Excited Generators		Separately Excited Generators
1.	The field windings are excited by the armature current.	1.	The field windings are excited by a separate D.C source.
2.	The current flowing through the field winding depends on load.	2.	The current flowing through the field winding is independent of load.
3.	Presence of residual magnetism is mandatory.	3.	Presence of residual magnetism is not essential.
4.	It does not require any external source or battery.	4.	It requires an external source or battery.
5.	There are chances that the self excited generator may fail to build up voltage.	5.	There are no chances of failure of voltage to build up.
6.	The field winding has lesser number of turns.	6.	The field winding has large number of turns of thin wire.
7.	The resistance of the field winding should be less than critical field resistance.	7.	The field circuit resistance should be high in order to limit the field current.
8.	D.C shunt generators are used in charging of batteries and lighting purposes.	8.	Used in Ward Leonard system of speed control to server as a control generator.

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Q30. How will you distinguish between series and shunt windings of a D.C compound machine?

Ans:

The distinguishing features between series winding and shunt winding of a D.C compound machine are listed below.

	Series Winding		Shunt Winding
1.	Series winding is connected in series with the armature.	1.	Shunt winding is connected in parallel with the terminals of armature.
2.	This winding consists of few number of turns.	2.	This winding consists of large number of turns.
3.	Series field winding provides a low resistance path for the current flowing through it.	3.	Shunt field winding provides a high resistance path for the current flowing through it.
4.	Large current flows through this winding.	4.	The current flowing through this winding is small.
5.	The direction of flux of series winding i.e., it is aiding or opposing shunt field flux decides whether the machine is cumulatively compound or differentially compound.	5.	The connection of shunt field winding in a D.C compound machine decides whether the machine is long shunt or short shunt compound machine.
6.	Series field winding is wound over the shunt field winding.	6.	Shunt field winding in a D.C compound machine is wound around the pole body.

Q31. Discuss about armature reaction and its effect on the performance of a D.C machine.

Ans:

The effect of magnetic field set up by the armature current on the distribution of flux under the main poles of a D.C generator or a D.C motor is known as armature reaction.

The armature m.m.f produces two undesirable effects on the main field flux. They are,

1. Distortion of the main field flux wave along the air gap periphery.
2. Net reduction in the main field flux per pole.

Reduction in main field flux per pole reduces the generated voltage and torque, whereas distortion of main field flux gives three harmful effects. They are increase in iron losses, poor commutation and sparking.

Consider a two-pole machine as shown in figure (1) at no-load i.e., having no armature currents. The main field flux is shown on a horizontal phasor OA which is produced by field m.m.f $(I_f N_f)$.

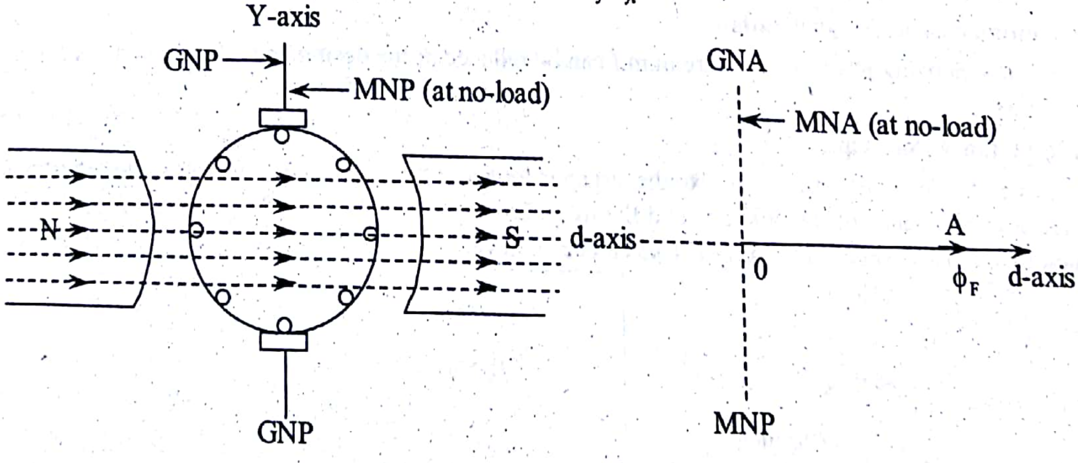

Figure (1)

The geometrical neutral plane and the magnetic neutral plane are coincident at no-load, i.e., magnetic lines of force intersect the MNP at right angles.

If D.C machine is loaded then the armature winding receives the current. These currents are shown in figure (2) by dots under south pole and by crosses under north pole. These currents setup armature flux. Armature flux ϕ_a is shown by a vertical phasor OB. ϕ_a is produced by armature m.m.f $I_a N_a$. If the D.C machine is working as generator, then its armature must be driven clockwise by prime mover and anti-clockwise for motoring operation.

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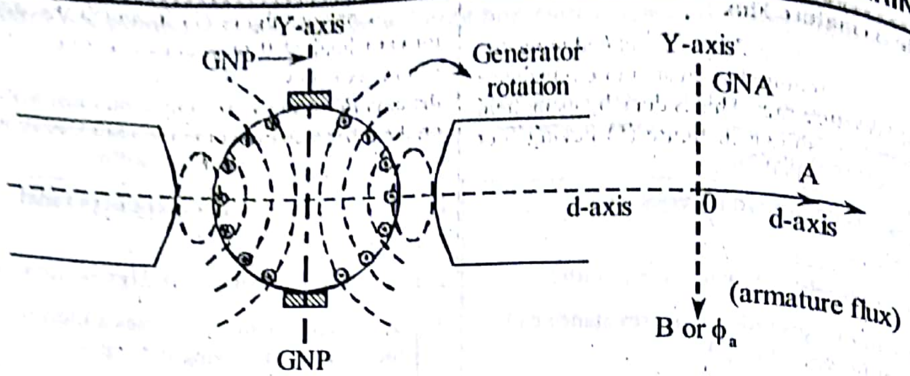

Figure (2)

From figure (2) it is seen that ϕ_a is perpendicular to ϕ_f i.e., the path of armature flux crosses the path of main field flux. This effect is known as cross magnetizing effect.

If the current is flowing in both the windings, the resultant flux distribution is obtained by super imposing the two fluxes as shown in figure (3).

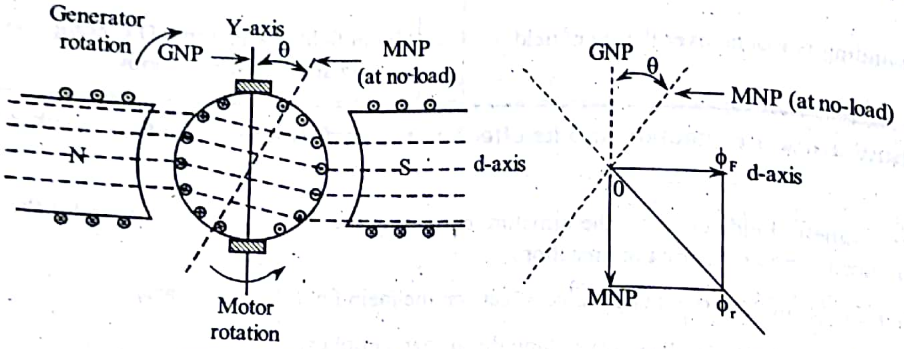

Figure (3): Resultant of Main Field and Armature Fluxes

From above, it is clear that armature flux aids the main field flux at upper end of north pole and at lower end of south pole. The D.C machine practically gets saturated and the strengthening effect is very low as compared with weakening effect and the resultant flux get decreased from its no-load value.

This effect on armature flux is called demagnetizing effect. This effect reduces the total flux/pole and found to be 1 to 5% from no-load to full-load.

Methods to Minimize Cross Magnetization

The cross magnetizing effect of armature m.m.f can be reduced at the design and construction stage of a D.C machine. They are as follows,

(a) High Reluctance Pole Tips

By flattening the pole faces slightly so that the airgap is longer at the pole tips rather than at the centre of the pole results in increase in reluctance of the pole tips and the magnitude of armature cross flux is reduced and the distortion of the resultant flux density wave is minimized. This can be achieved by using chamfered or eccentric pole face.

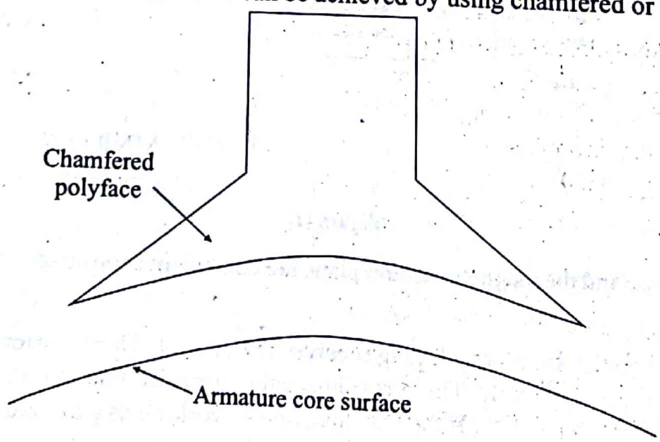

Figure (4)

(b) Reduction in Armature Flux

To reduce armature cross flux without reducing the main field flux, it is required to create more reluctance in the path of armature flux. This is done by using field pole laminations as shown in figure (5) having four rectangular poles punched.

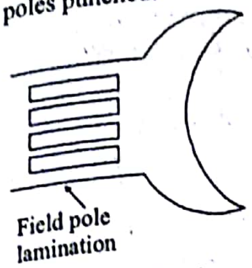

Figure (5)

The reluctance offered to armature flux is more pronounced due to four air gap openings introduced in the path of cross flux.

(c) Strong Main Field Flux

During the design of D.C machine, it should be ensured that main field m.m.f should be strong when compared to full load armature m.m.f. The distortion produced by armature cross flux can be minimized by increasing the ratio of main field m.m.f to the full load armature m.m.f.

(d) Interpoles

Interpoles are small poles placed in between the main poles. These are connected in series with armature, so that they carry armature current. The e.m.f induced by the interpoles neutralizes the effect of armature m.m.f in the interpolar region, thus making commutation sparkless.

(e) By Using Compensating Winding

A compensating winding is an auxiliary winding embedded in slots located in the faces of main poles. This winding is connected in series with armature in such a manner so that the direction of current flowing in this winding should be quite opposite to the direction of current flowing in the armature conductors. The m.m.f produced by the compensating winding should be equal to the m.m.f produced by the armature conductors. To maintain a uniform distribution of flux in the main poles and to neutralize the effect of armature reaction, compensating windings are provided. This winding adds cost of the machine and doubles the armature copper loss, but it makes the machine to withstand the most violent fluctuations of load that is applied to it.

Q32. How are demagnetizing and cross magnetizing ampere-turns/pole in a D.C machine calculated?

Ans:

When the brushes lie along the geometric neutral axis, then the entire armature reaction effect is cross magnetizing. But, if the brushes are shifted from the geometric neutral axis, then a part of the armature reaction becomes demagnetizing and the remaining armature reaction is cross magnetizing.

Consider figure (1) in which the brush axis is given forward load of θ mechanical degrees from the geometric neutral axis A-AA in the direction of rotation by an angle θ to the axis PQ. Consider another axis RS, symmetrical with PQ on the other side of geometric neutral axis such that the angle,

$\angle POR = 2\theta$

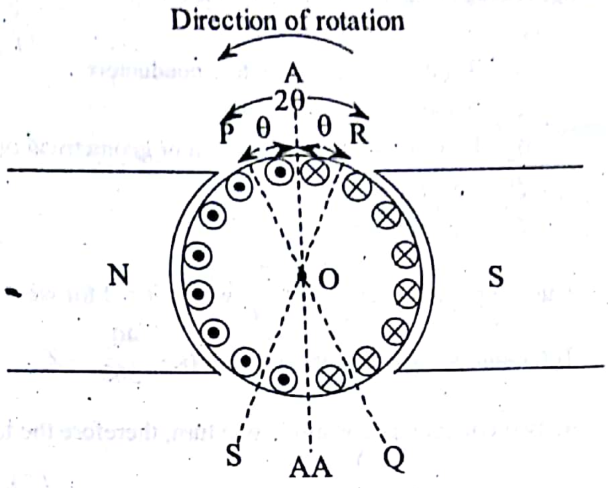

Figure (1)

If the armature is rotated in opposite direction (anti-clockwise) to that made by brush axis then it can be observed that all the conductors situated towards the left side of PQ will be carrying current towards the observer and are indicated by dotted marks. Those conductors which are situated towards the right side of PQ will be carrying current away from the observer and are indicated by cross marks. Therefore, the armature conductors carrying current can be grouped into two as shown in figures (2) and (3).

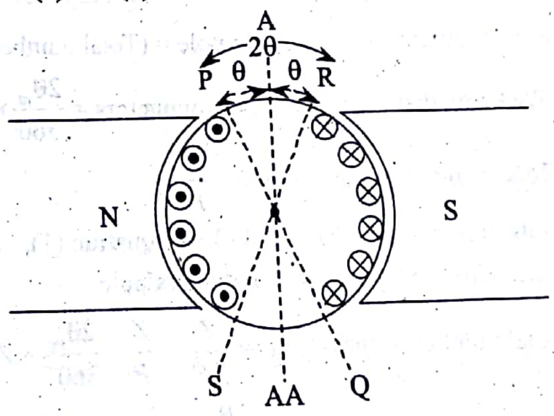

Figure (2)

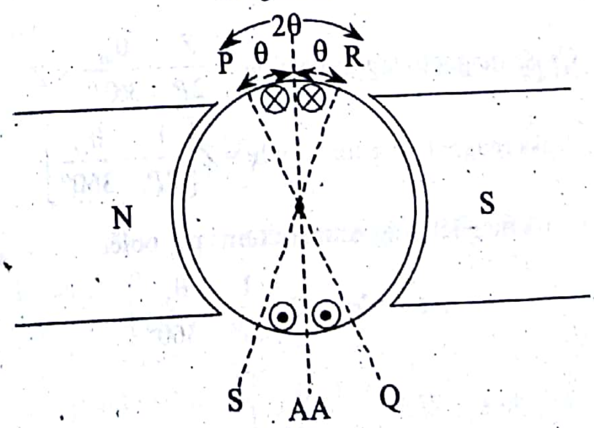

Figure (3)

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All the conductors lying between the angle $\angle POR$ and $\angle QOS$ establish flux in the armature which opposes main field flux. So these conductors cause demagnetizing effect and are known as demagnetizing armature turns. The demagnetizing ampere turns are shown in figure (2). The remaining conductors i.e., lying between angels $\angle POS$ and $\angle QOR$ produce flux which is at right angles to the main field flux, which results in distortion of main field flux so this conductors are called as cross magnetizing (distorting) conductors, cross magnetizing ampere turns are shown in figure (3).

Demagnetizing Ampere Turns Per Pole (AT_d)

Let,

Z = Total number of armature conductors

A = Number of parallel paths

θ_m = Forward lead in mechanical or geometrical or angular degrees.

P = Number of poles

I_a = Armature current

Current per conductor, $I_c = \dfrac{I_a}{A}$ where $A = 2$ for wave and $A = P$ for lap

Total number of armature conductots $= \dfrac{4\theta_m}{360} \times Z$

As two conductors constitute one turn, therefore the total number of turns in these angle $= \dfrac{2\theta_m}{360} \times Z$

Demagnetizing ampere turns per pair of poles $= \left(\dfrac{2\theta_m}{360} Z\right) \times I_c$

Demagnetizing Ampere Turns/pole = AT_d/pole

$$= \frac{\theta_m}{360} \times ZI_C$$

$$\boxed{\therefore\ AT_d\text{/pole} = ZI_c \times \frac{\theta_m}{360^\circ}}$$

Cross Magnetizing Ampere Turns Per Pole AT_c/Pole

Cross magnetizing conductor per pole = (Total number of conductors per pole) – (Demagnetizing conductors per pole) ...(

We know that demagnetizing conductors $= \dfrac{2\theta_m}{360} \times Z$

Total number of conductors $= \dfrac{Z}{P}$ ...(

Substitute equations (2) and (3) in equation (1),

i.e., Cross magnetizing conductors/pole

Total number of turns/pole $= \dfrac{Z}{2P} = \dfrac{Z}{P} - \dfrac{2\theta_m}{360^\circ} \times Z$

Demagnetizing turns/pole $= \dfrac{\theta_m}{360^\circ} \times Z$

$\therefore$ Cross magnetizing turns/pole $= \dfrac{Z}{2P} - \dfrac{\theta_m}{360^\circ} \times Z$

$\therefore$ Cross magnetizing turns/pole $= Z\left[\dfrac{1}{2P} - \dfrac{\theta_m}{360^\circ}\right]$

Cross magnetizing Ampere turns per pole,

$$= AT_c\text{/pole} = ZI_c\left[\frac{1}{2P} - \frac{\theta_m}{360^\circ}\right]$$

$$\boxed{\therefore\ AT_c\text{/pole} = ZI_c\left[\frac{1}{2P} - \frac{\theta_m}{360^\circ}\right]}$$

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Q33. A 75 kW, 4-pole wave wound D.C generator has 72 armature conductors. The brushes are given an actual lead of 9° at full-load. Calculate,

(i) Cross magnetizing AT/pole

(ii) Demagnetizing AT/pole and

(iii) Series turns required to neutralize the demagnetizing effect.

Ans:

Given that,

Power output = 75 kW

Number of poles, $P = 4$

Number of parallel paths, $A = 2$

Number of armature conductors, $Z = 72$

The advancement in brushes, $\theta_m = 9°$

Cross magnetizing ampere turns per pole, $AT_C = ?$

Demagnetizing ampere turns per pole, $AT_d = ?$

Series turns required to neutralize the demagnetizing effect = ?

Let, the terminal voltage of the generator be, $V = 230$ V.

We know that,

$$\text{Power} = \text{Voltage} \times \text{Current}$$

$$\therefore \quad \text{Current} = \frac{\text{Power}}{\text{Voltage}} \text{ and}$$

$$\text{Full load current, } I = \frac{\text{Full load power}}{\text{Voltage}}$$

$$= \frac{75 \times 1000}{230}$$

$$= 326.087 \text{ A}$$

Current per parallel path,

$$I_c = \frac{\text{Total current}}{\text{Number of parallel paths}} \quad [\because I_L = I_a]$$

$$= \frac{326.087}{2}$$

$$\therefore \quad I_c = 163.043 \text{ A}$$

(i) Cross Magnetizing Ampere Turns per Pole (AT_c/pole)

Cross magnetizing AT_c/pole is given by,

$$AT_c/\text{pole} = ZI_c\left[\frac{1}{2P} - \frac{\theta_m}{360°}\right]$$

$$AT_c/\text{pole} = 72 \times 163.043\left[\frac{1}{2\times4} - \frac{9}{360°}\right]$$

$$= 11739.096\left[\frac{1}{8} - \frac{1}{40}\right]$$

$$= 11739.096\left[\frac{1}{10}\right]$$

$$\therefore AT_c/\text{pole} = 1173.9096$$

(ii) Demagnetizing Ampere Turns per Pole (AT_d/pole)

Demagnetizing AT_d/pole is given by,

$$AT_d/\text{pole} = ZI_c\frac{\theta_m}{360°}$$

$$AT_d/\text{pole} = 72 \times 163.043 \times \frac{9}{360°}$$

$$= 11739.096 \times 0.025$$

$$\therefore \quad AT_d/\text{pole} = 293.477$$

(iii) Series Turns Required to Neutralize the Demagnetizing Effect

Series turns to neutralize demagnetizing effect,

$$= \frac{AT_d/\text{pole}}{\text{Full load current}(I)}$$

$$= \frac{293.477}{326.087}$$

$$= 0.899996 \simeq 1$$

$\therefore$ Number of series turns required = 1

3.1.3 No-Load and Load Characteristics

Q34. How do you determine the magnetization characteristics of a D.C generator?

Ans:

Open Circuit Characteristics: It is a curve plotted between the no-load generated e.m.f 'E_0' and field or exciting current 'I_f' at a given fixed speed. Its shape is practically the same for all generators and is just similar to the magnetization curve for the material of the electromagnets.

$$\text{As we know that, } \boxed{E_g = \frac{\phi ZNp}{60A}}$$

$$\therefore \quad E_g = k\phi N \qquad \left(\text{let } k = \frac{Zp}{60A}\right)$$

$$\Rightarrow \quad E_g \propto \phi N$$

$$\Rightarrow \quad E_g \propto \phi \qquad (\because \text{Speed is constant})$$

Now flux (ϕ) depends on m.m.f. (i.e., Number of turns × Current i.e., nI_f)

$$\Rightarrow \quad E_g \propto I_f \qquad (\because \text{Number of turns is constant})$$

$$\boxed{\therefore E_g \propto I_f}$$

Thus, the e.m.f generated and the field current should share a linear relationship, but it will not be true for all increasing values of the field current. That is to understand it, let us consider an experimental setup in which the field winding (of any machine) is first disconnected and is excited by a separate source as shown in figure (a) and armature is not loaded i.e., left open circuit.

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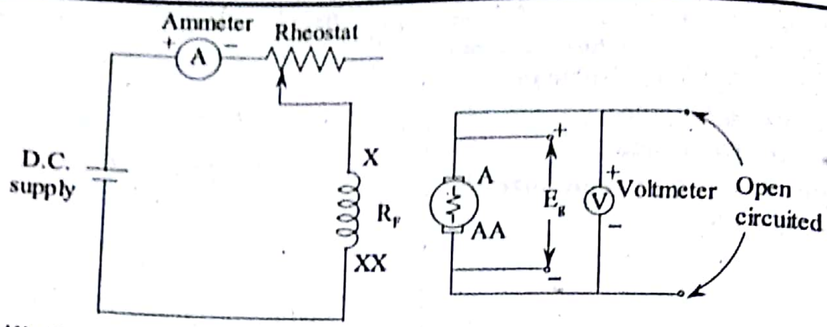

Figure (1): Circuit for Experimental Determination of Open Circuit Characteristics of D.C Generator

The field or exciting current is varied with the help of rheostat and is read from the ammeter connected in the field circuit and the voltmeter across armature terminals measures induced e.m.f (i.e., E_g). Keeping the speed constant, the readings of ammeter and voltmeter are noted for various positions of rheostat connected in the field circuit. When plotted the curve between E_0 (Voltmeter reading) and I_f (Ammeter reading), saturation curve is obtained as shown in figures (2) and (3).

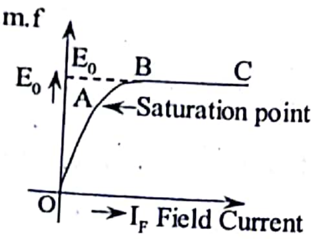

Figure (2): Theoretically Obtained O.C.C Curve

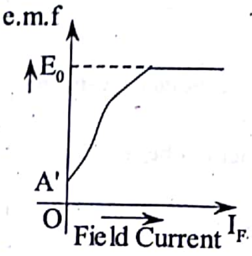

Figure (3): O.C.C Obtained Practically

O.C.C can be explained theoretically using figure (2), in which the portion '*OA*' explains the linear relationship between the no-load e.m.f and field current (i.e., $E_o \propto I_f$). But, beyond '*A*' point, as it was stated that it will not maintain linear relationship, the curve starts bending and reaches to point '*B*'. It indicates that the poles are said to be under saturation region. As it reaches '*B*', the poles get completely saturated and beyond which, the e.m.f E_0 remains constant for any increase in the field current.

Thus, the curve *OABC* in figure (2) is known as O.C.C curve of any D.C generator. But practically, the curve does not initiate from origin '*O*' as shown in figure (2). It originates from point *A'* as shown in figure (3). This is because, as we know that, before the generator gets started there is some residual magnetism present. Thus, rise at origin (*OA'* in figure (3)) gives the value of residual magnetism or flux.

Q35. Explain the external characteristics of D.C series generator. Why does the terminal voltage start decreasing after a certain value of load current?

Ans:

The connection diagram for obtaining the external characteristics of a series generator is as shown in figure (1).

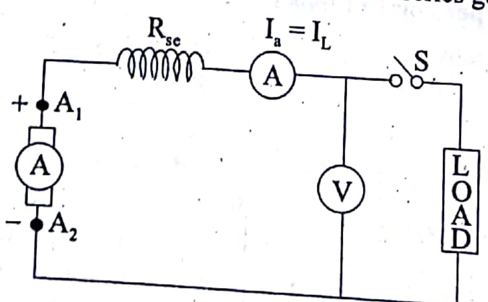

Figure (1): Connection Diagram of Series Generator

When the switch '*S*' is open, the voltmeter indicates the small voltage due to residual flux and when the switch is closed, field current equal to load current builds up and starts flowing. Note the readings of the load voltage and load current at different loads and plot the graph using those values. The curve so obtained will give the external characteristics as shown in figure (2).

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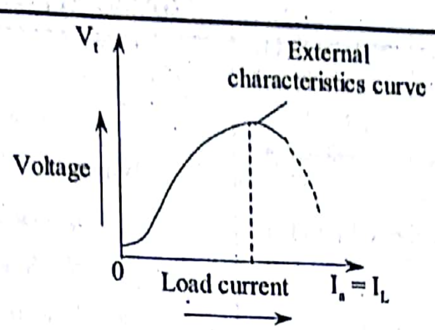

Figure (2): External Characteristics of Series Generators

The characteristic curve of a series generator illustrates that the terminal voltage increases with the increase in load current, reaches the maximum value and then starts decreasing. As the load current increases there is an increase in the terminal voltage. Further, increase in load current increases the terminal voltage up to a maximum value and after this the terminal voltage starts decreasing. This is due to more demagnetizing effect of armature reaction and finally reaches a zero value if the resistance in the load circuit is decreased.

In series generators, the terminal voltage is not constant. Therefore, it is never been used as a voltage source else can be used as boosters.

Q36. Draw and explain typical no-load and load characteristics of D.C series generator.

Ans:

When the armature of a D.C generator (series generator) is rotated by prime mover to rated speed, a small voltage is measured by voltmeter across it, with no field excitation and opened armature circuit. This is because of residual flux in the field winding.

If the flux produced by series field and its residual flux are in the same direction then voltage building process starts. Thereby, we can obtain no-load and load characteristics of series generator by varying field current and load current respectively as described below:

No-load Characteristics of Series Generator

At constant rated speed of D.C series generator, the graph itself which is drawn in between no-load generated e.m.f, E_0 and field current, I_f for zero armature current shows its no-load characteristics. But, the armature and field windings are in series for D.C series motor therefore armature current equals to field current.

To obtain zero armature currents i.e., no-load characteristics of D.C. series generator, the field has to be excited separately as shown in figure (1).

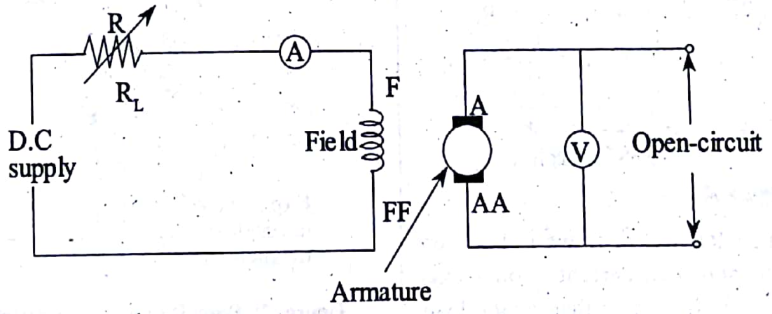

Figure (1)

The graph shown in figure (2) is obtained by noting the no-load generated e.m.f values for different field current values. Field current can be varied by varying the field rheostat first in ascending and then in descending order.

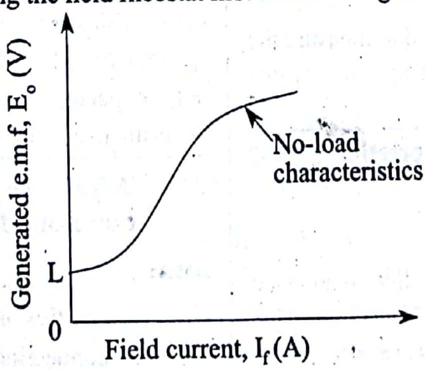

Figure (2)

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The noted values of E_o on y-axis and I_f on x-axis are the average values, obtained from values noted in ascending and descending order.

It is clear that from figure (2) that E_o value increases as the I_f value increases up to some value.

This is because at constant speed generated e.m.f, is proportional to flux i.e., $E_o \propto \phi$

But, $\phi \propto I_f$

$\therefore \quad E_o \propto I_f$

After that point, E_o is no longer proportional to field current, I_f.

Load Characteristics of D.C. Series Generator

It is as shown in figure (3) which are obtained with the help of circuit diagram as shown in figure (4).

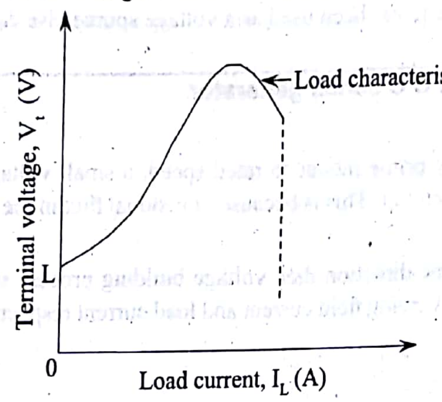

Figure (3)

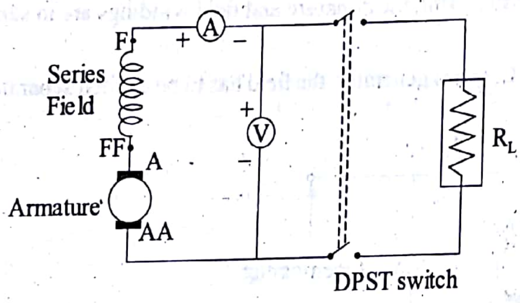

Figure (4)

The graph of load characteristics is drawn in between terminal voltage V_t on y-axis and load current I_L on x-axis at constant speed. It is clear from the graph that, as the load current, I_L increases and the terminal voltage, V_t also increases upto some value. After that, graph is nearly vertical and load current is constant.

From figure (4), DPST switch is opened to measure the residual voltage and then closed to plot the graph of terminal voltage for different values of load current.

Q37. Explain the magnetizing characteristics of D.C shunt generator.

Ans:

Open circuit characteristics are also called as no-load characteristics or magnetization curve or saturation curve. This characteristics gives the relationship between the airgap flux (ϕ) and the field winding m.m.f or field winding current (I_f).

However, as there is no direct relation between the field winding m.m.f and air gap flux (ϕ), we use the relation,

$$E \propto \phi N$$

Where,

E = Generated e.m.f

N = Speed of machine.

Therefore, the O.C.C of a D.C generator are plotted between the generated voltage (E) and field current (I_f) when speed N is constant.

O.C.C of Shunt Generator

In figure shown, the shunt generator has a variable resistance R_h in series with the shunt field F_1,F_2. An ammeter is employed to measure the field current which changes as R_h is varied. A voltmeter V is connected across the output of the armature and it measures the open circuit voltage E_{OC}.

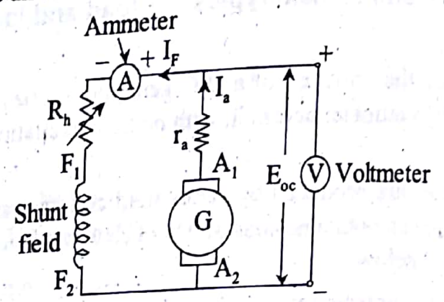

Figure (1): Shunt Generator

The armature of the generator is rotated with the help of a prime mover. E_{OC} is measured and plotted against different values of I_f by varying resistance R_h.

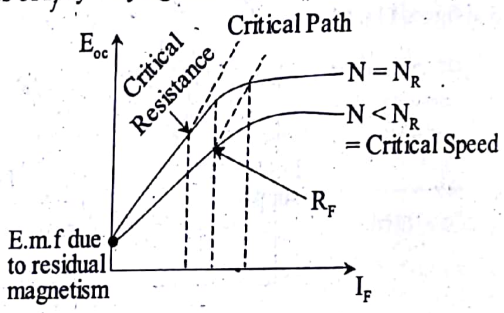

Figure (2): Open Circuit Characteristics of Shunt Generator

The O.C.C is a linear curve. However, as the magnetic saturation of the core occurs, the curve becomes non linear. R_f is the critical resistance in the field circuit. Above the critical resistance the field fails to excite. Similarly O.C.C can be plotted for speeds below the rated speed. It is observed that below the critical speed the generator fails to produce voltage.

Q38. What are the various characteristics of compound generators?

Ans:

Characteristics of Compound Generator: Compound generator connections (either short shunt or long shunt) consists of series field and shunt field windings.

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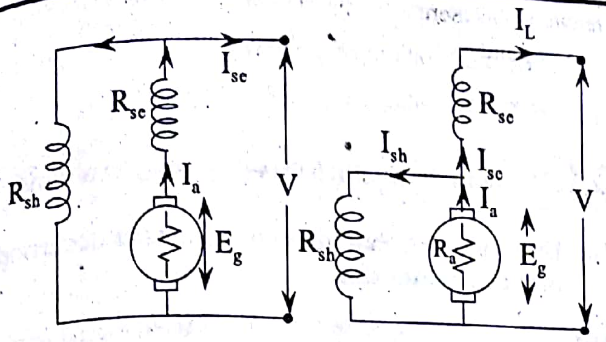

(i) Long Shunt Compound Generator (ii) Short Shunt Compound Generator

Figure (1)

Based on the current directions in series field and shunt field the compound generators can be classified as cumulative compound generator and differential compound generator.

1. **Cumulative Compound Generator:** When the flux due to series and shunt windings aids up ($\phi_T = \phi_{se} + \phi_{sh}$).

2. **Differential Compound Generator:** When the flux due to series and shunt windings opposes ($\phi_T = \phi_{se} - \phi_{sh}$).

Compound generator combines useful characteristics of series generator to produce magnetization with increase in load and useful characteristics of shunt generator to maintain constant voltage.

There are two types of compound generator characteristics. They are,

(a) No-load characteristic

(b) External characteristic.

(a) **No-load Characteristic:** When graph is plotted between no-load e.m.f., (E_o) and field current (I_f), it is known as no-load characteristic.

In short shunt compound generator, at no-load series field winding does not carry currents.

In long shunt compound generator at no-load, current through series field winding is neglected because series field turns are less than shunt field turns.

Therefore, no-load characteristic of short and long shunt compound generators is same as shunt generator no-load characteristic.

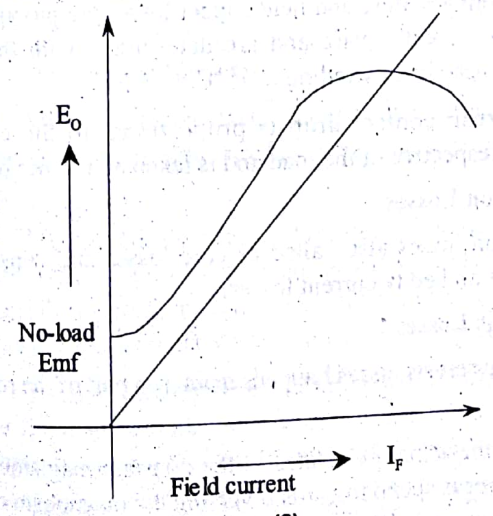

Figure (2)

(b) **External Characteristic:** When the graph is plotted between terminal voltage (V_t) and Load current (I_L), it is known as external characteristic.

(i) **External Characteristic of Cumulative Compound Generator:** Based on the number of series field turns, the terminal voltage of cumulative compound generator varies with load.

With increase in load when the terminal voltage falls, cumulative compound generator is known as under compounded.

With the increase in load when the terminal voltage remains constant, cumulative compound generator is known as flat compounded.

With the increase in load when the terminal voltage increase, cumulative compound generator is known as over compounded.

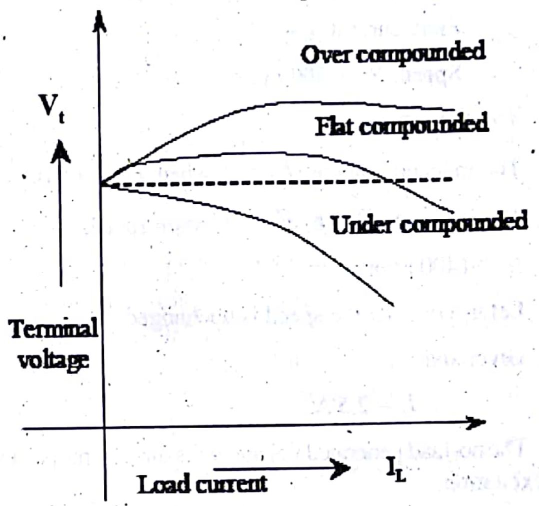

Figure (3): Cumulative Compound Generator External Characteristic

(ii) **External Characteristic of Differential Compound Generator:** In differential compound generator since series field opposes shunt field, with the increase in load current terminal voltage falls rapidly as shown in figure (4).

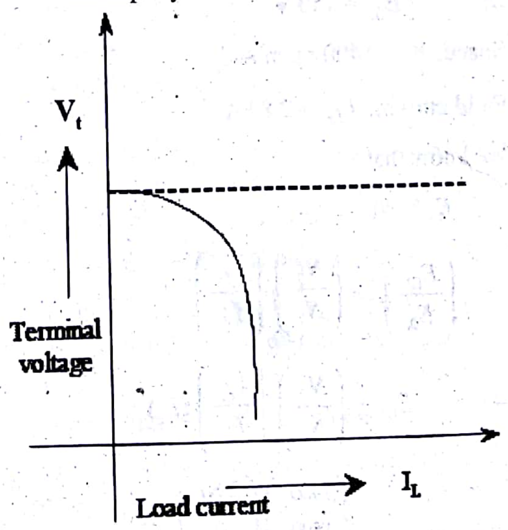

Figure (4): Differential Compound Generator External Characteristic

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Q39. A separately excited D.C generator has no-load voltage of 120 V at a field current of 2 A, when driven at 1500 r.p.m. Assuming that it is operating on the straight line portion of its saturation curve, calculate:

(i) The generated voltage when the field current is increased to 2.5

(ii) The generated voltage when the speed is reduced to 1400 r.p.m and the field current is increased to 2.84 A.

Ans:

Given that,

Separately excited D.C generator,

Induced voltage on no-load, $E_0 = 120$ V

Field current, $I_f = 2$ A

Speed, $N_1 = 1500$ r.p.m

To calculate,

(i) The induced voltage, $E_{01} = ?$, when $I_{f1} = 2.5$ A

(ii) The induced voltage, $E_{02} = ?$, when speed, $N_2 = 1400$ r.p.m, $I_{f_2} = 2.84$ A

(i) Let us consider the speed is unchanged.

Given that,

$$I_{f_1} = 2.5 \text{ A}$$

The no-load generated voltage, E_0 is directly proportional to its excitation.

$$E_0 \propto I_f$$

$$\Rightarrow \frac{E_{01}}{E_0} = \frac{I_{f_1}}{I_f}$$

$$\Rightarrow E_{01} = \left(\frac{I_{f_1}}{I_f}\right)(E_0) = \left(\frac{2.5}{2}\right)(120)$$

$$\Rightarrow E_{01} = 150 \text{ V}$$

(ii) Speed, $N_2 = 1400$ r.p.m and

Field current, $I_{f_2} = 2.84$ A

We know that,

$$E_0 \propto NI_f$$

$$\therefore \left(\frac{E_{02}}{E_0}\right) = \left(\frac{N_2}{N_1}\right)\left(\frac{I_{f_2}}{I_f}\right)$$

$$\Rightarrow E_{02} = \left(\frac{N_2}{N_1}\right)\left(\frac{I_{f_2}}{I_f}\right)(E_0)$$

$$= \left(\frac{1400}{1500}\right)\left(\frac{2.84}{2}\right)(120)$$

$$= 159.04 \text{ V}$$

Summary of Result

Generated voltage, $E_{01} = 150$ V

Generated voltage, $E_{02} = 159.04$ V

3.1.4 Losses and Efficiency, Applications

Q40. Describe in detail the various losses occurring in a D.C generator.

Ans: Model Paper-II, Q13(b)

Losses in a D.C Machine

Loss in a D.C machine is the difference between input power and output power, under steady state conditions.

The various D.C machine losses are,

(i) Copper losses

(ii) Iron losses

(iii) Mechanical losses

(iv) Stray load losses.

(i) Copper Losses

The amount of power utilized by the windings and connections for the flow of current against its resistance is called copper loss.

(a) Armature copper loss = $I_a^2 R_a$

Here,

I_a = Armature current in Amps.

These losses are accounts to 30% to 40% of the total full load losses.

(b) Field copper losses,

For shunt winding = $I_{sh}^2 R_{sh}$

For series winding = $I_{se}^2 R_{se}$

These losses are accounts to 20% to 30% of the total full load losses.

Both armature and field copper losses are proportional to current square and are determined with the D.C resistance of winding at 75°C.

(c) Brush contact drop is proportional to the current irrespective of the load and is taken as 1 V per brush.

(ii) Iron Losses

Iron losses also called as core losses and consists of hysteresis and eddy current losses.

Hysteresis Losses

Hysteresis losses happens in an iron part of the rotating armature.

If the armature rotates in the constant magnetic field, some power is spend towards reversing the magnetism of iron core after every half revolution.

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Power waste for magnetic reversal of iron core is called as "hysteresis loss" and is proportional to the speed.

Hysteresis loss in terms of 'f' and 'B_{max}' can be written as,

$$\boxed{\text{Hysteresis loss, } P_h = (B_{max})^{1.6} f.v \text{ Watts}} \quad ... (1)$$

Here,

h = Stainmetz hysteresis coefficient

v = Volume of core in m^3

B_{max} = Peak magnitude of flux density in magnetic cycles

f = Frequency of the magnetic cycle per second.

Hysteresis loss is reduced by using high permeability (low Steinmetz coefficient value) material as armature core like silicon steel.

Eddy Current Losses

Power loss due to the flow of eddy currents in an iron part of armature core is called "Eddy current loss".

Eddy currents are developed in the iron part of the core similar to the currents developed in core conductors.

That is, when the armature core rotates in magnetic field, e.m.fs are induced in core conductors as well as iron part of the core. Due to the closed path of the iron core e.m.fs are gives rise to currents which are called as Eddy currents.

In mathematical form,

$$\boxed{\text{Eddy current loss } P_e = k_e B_{max}^2 \ f^2 v t^2 \text{ Watts}} \quad ... (2)$$

It is clear that from equation (2) Eddy current losses depends upon,

(a) The range of variation of flux density, 'B_{max}'

(b) Frequency, 'f' of the varying flux

(c) Thickness, 't' of the iron laminations.

Eddy current losses are reduced by using thin laminations for armature core construction instead of solid iron core. [$\because P_e \propto t^2$]

Eddy current losses are proportional to the speed squared, iron losses are accounts to 20% to 30% of the total full load losses.

(iii) Mechanical Losses

Mechanical losses takes place just before, the mechanical power developed by armature becomes ready to available at the shaft.

Mechanical losses consists of power loss due to bearing friction and air friction or windage. Power waste to circulate air through the machine and ventilating ducts is called as windage loss and is approximately proportional to the speed squared.

Bearing friction losses are included in windage losses since these losses are small compared to windage losses. Friction losses are roughly proportional to speed.

Mechanical losses are accounts to 10% to 20% of the total full load losses.

(iv) Stray Load Losses

Stray load losses is the increment of core loss, when a machine is loaded. Core losses are increases, when ever the air gap flux distorted by the m.m.f, developed by the load current.

Usually stray load losses are proportional to the square of the load current and is taken as 1% of the rated output for rating above 150 kW.

Mechanical losses and magnetic losses are combinely termed as "no-load rotational" or stray losses as they are caused by rotor rotation.

Q41. State with reason the area of application of various D.C. generators used.

Ans:

Applications of D.C Generators

D.C generators have vast area of application and the choice of a D.C generator for a particular service depends upon its performance characteristics. The applications of various D.C generators are given below.

1. Separately Excited D.C Generators

Though being expensive, separately excited generators find their applications where self-excited generators would be relatively unsatisfactory. They are used where quick and definite response to control is important since quicker and more precise response to the changes in the resistance of the field circuit is obtained by separate excitation.

The principle applications of separately excited D.C generators are as follows,

(a) They are used in Ward-Leonard system of speed control to serve as a control generator.

(b) Used in power-generating station to serve as an excitation source for large alternators.

(c) Used to serve as auxiliary and emergency power supplies.

2. Series Wound D.C Generators

They are used in D.C locomotives for the purpose of supplying field current for regenerative braking. These type of generators also find use in series arc lighting. The most important use of series wound D.C generators is as a series booster. The drooping portion of the V-I characteristics enables them to be employed as a constant current source.

3. Shunt Wound D.C Generators

Its property to give constant output voltage makes their use in charging of batteries and also for lighting and power supply purpose.

4. Compound Wound D.C Generator

The property of it is to maintain constant voltage at the consumer terminals makes its use for lighting and power services.

They are referred as constant current generator and finds useful application as an arc welding generator

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Q42. In a D.C machine the total iron loss is 8 kW at its rated speed if the excitation remains the same, but speed is reduced by 25%, the total iron loss is found to be 5 kW. Calculate the hysteresis and Eddy current losses at,

(a) Full speed

(b) Half the rated speed.

Ans:

Given that,

At rated speed,

Total iron losses, $P_i = 8$ kW

At 75% rated speed,

Total iron losses, $P_i = 5$ kW

At full speed and half rated speed,

Hysteresis losses, $P_h = ?$

Eddy current losses, $P_e = ?$

$\therefore$ Hysteresis losses, $P_h = k_1 B_{max}^{1.6} f$

Eddy current losses, $P_e = k_2 B_{max}^2 f^2$

Frequency, f is directly proportional to speed i.e.,

$$f \propto N$$

Given that excitation remains same.

$\therefore$ Flux density B also constant,

Then,

$$P_h = k_1 N$$

$$P_e = k_2 N^2$$

At rated speed say, $N = 1$

Total iron losses, $P_i = P_h + P_e$

$$8 = k_1 + k_2 \quad \text{... (1)}$$

At 75% rated speed, $N = 0.75$

Total iron losses, $P_i = 0.75\, k_1 + (0.75)^2 k_2$

$$5 = 0.75\, k_1 + (0.75)^2\, k_2 \quad \text{... (2)}$$

Subtracting equation (2) from equation (1) × 0.75,

$$0.75\, k_1 + 0.75\, k_2 = 8(0.75) = 6$$

$$0.75\, k_1 + (0.75)^2\, k_2 = 5$$

$$- \quad - \quad -$$

$$0.1875\, k_2 = 1$$

$$k_2 = 5.33 \times 10^3$$

$$k_1 = 2.67 \times 10^3$$

At rated speed, $N = 1$

Hysteresis losses,

$$P_h = k_1(N) = 2.67(1)$$

$$= 2.67 \text{ kW}$$

Eddy current losses,

$$P_e = k_2 N^2 = 5.35\,(1)$$

$$= 5.33 \text{ kW}$$

At half rated speed, $N = \frac{1}{2}$

Hysteresis losses,

$$P_h = k_1\left(\frac{1}{2}\right) 2.67 \times \left(\frac{1}{2}\right) = 1.335 \text{ kW}$$

Eddy current loss,

$$P_e = k_2\left(\frac{1}{2}\right)^2 = 5.33 \times \left(\frac{1}{4}\right) = 1.337 \text{ kW}$$

Results

At full speed,

Hysteresis loss, $P_h = 2.67$ kW

Eddy current loss, $P_e = 5.35$ kW

At half of the rated speed,

Hysteresis loss, $P_h = 1.335$ kW

Eddy current loss, $P_e = 1.337$ kW

3.2 D.C MOTOR

3.2.1 Principle of Operation, Types of Motors

Q43. Explain D.C motor principle and its working.

Ans:

Principle of Operation of a D.C Motor

For answer refer Unit-III, Q15.

Working of a D.C Motor: The force on a current carrying conductor of length l meters and carrying current I amperes in a magnetic field of flux density B Wb/m² is,

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

When a D.C machine is connected to a voltage supply, the action of an armature with current carrying conductors under magnetic field flux is as shown in figure (1).

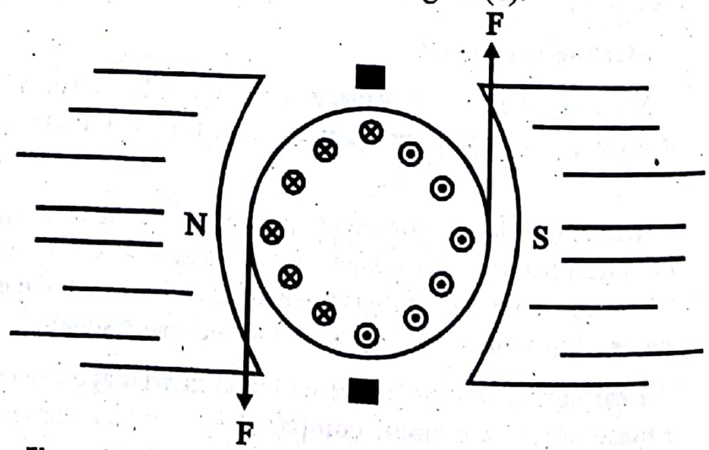

Figure (1): Armature Current with Stator Field of D.C Motor

Inward direction ← ⊗ and ⊙ → Outward directon

Figure (2): Directional Arrow of the Current

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Under the north pole, the direction of current carrying conductors is into the plane of this paper and is denoted by the crosses which are the ends of the directional arrows of the current. The current in the conductors under the south pole have a direction out of the plane of the paper and are denoted by dots which are the heads of the directional arrows of the current. The magnetic flux of the armature core is at right angles to the main field flux. By applying Fleming's left hand rule, the armature rotates in anti-clockwise direction.

The physical phenomenon is explained below,

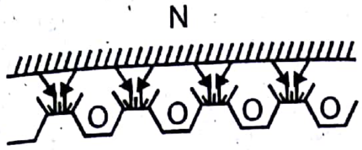

Figure (3): Field Flux without Armature Current

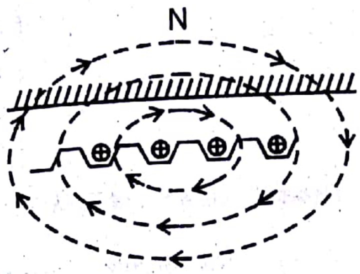

Figure (4): Armature Flux without Field Flux

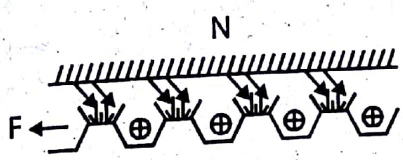

Figure (e): Resultant Field Flux with Armature Flux

1. When there is no armature current, the field flux converges symmetrically and enters the teeth of the armature core.
2. When there is no field flux, the armature flux is clockwise around the conductors in the armature core.
3. When the armature flux and field flux act together, the resultant flux is inclined to the teeth of the armature core.
4. The resultant flux tries to straighten itself by pulling the teeth of the armature core and causing the armature to move with a force F. The force F multiplied by the radius gives the torque and sum of all such torque is the total torque.

Q44. Explain the significance of back E.M.F.

Ans:

Back E.M.F or Counter E.M.F: When the motor armature rotates, the conductors also rotate due to motor action and cuts the flux and therefore inducing e.m.f in them in accordance with Faraday's law of electromagnetic induction. The direction of e.m.f as found by Fleming's right hand rule is found to be opposite to that of applied voltage. Since, due to applied voltage V, a current I is produced and hence the armature rotates which in turn results in the inducement of back e.m.f. In accordance with Lenz's law every induced quantity opposes the very cause producing it. Here the main cause is voltage applied i.e., 'V'. Hence back e.m.f 'E_b' opposes the applied voltage and thus it is also called as counter e.m.f.

The equivalent circuit of a motor is shown in figure.

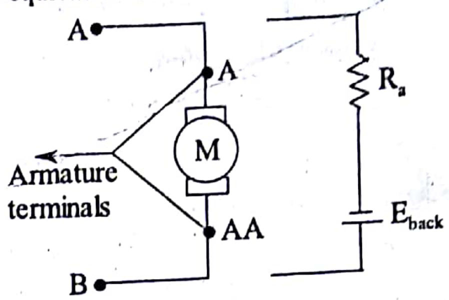

Figure: Motor

The armature circuit, which is equivalent to a source of e.m.f E_b in series with a resistance 'R_a', put across the D.C supply mains of 'V' volts. The applied voltage 'V' must be large enough to balance both the voltage drop in armature resistance and back e.m.f at all times i.e.,

$$V = E_b + I_a R_a$$

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

Where,

V – Applied voltage

E_b – Back e.m.f

I_a – Armature current

R_a – Armature resistance.

Q45. Give the power, voltage and current equations for different types of D.C motors.

Ans:

Based on the type of field excitation mainly D.C motors are of two types. They are,

1. Separately excited D.C motors
2. Self excited D.C motors.

1. **Separately Excited D.C Motors**

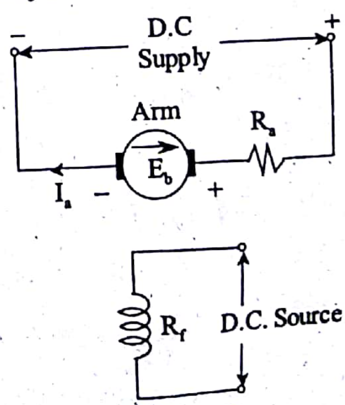

Figure (1)

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Terminal voltage, $V_t = E_b + I_a R_a + V_{bd}$

$$\therefore \; E_b = V_t - I_a R_a - V_{bd}$$

Here,

E_b = Back e.m.f

R_a = Armature resistance

I_a = Armature current

V_{bd} = Voltage drop across brushes.

Input power, $P_i = VI_a$

Mechanical power developed,

$$P_m = P_i - P_a$$

$$= V_t I_a - I_a^2 R_a$$

$$= I_a(V_t - I_a R_a)$$

$$= E_b I_a$$

2. Self Excited D.C Motors

(a) Shunt Motor

Input power, $P_i = VI_L$

Terminal voltage, $V_t = E_b + I_a R_a + V_{bd}$

$$\therefore \; E_b = V_t - I_a R_a - V_{bd}$$

$$I_a = I_L - I_{sh} \qquad \boxed{\because I_{sh} = \frac{V_t}{R_{sh}}}$$

Output power, $P_o = E_b I_a$

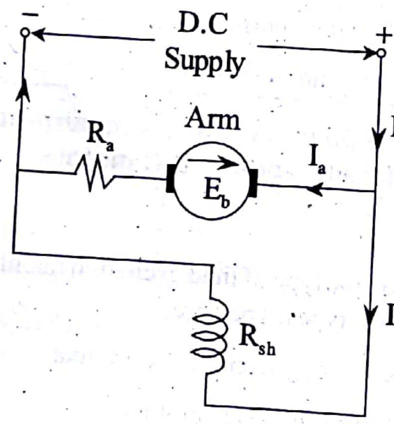

Figure (2)

(b) Series Motor

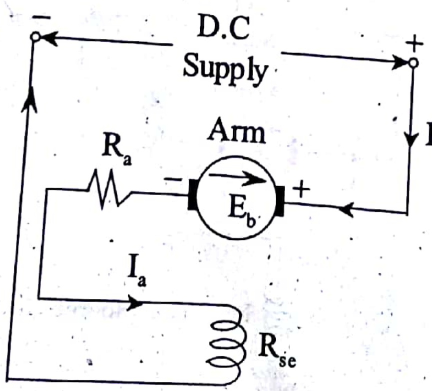

Figure (3)

$$I_a = I_L$$

Terminal voltage, $V_t = E_b + I_a(R_a + R_{se}) + V_{bd}$

$$\therefore \; E_b = V_t - I_a(R_a + R_{se}) - V_{bd}$$

Input power, $P_i = V_t I_L$

Mechanical power, $P_m = E_b I_L$

(c) Compound Wound D.C Motor

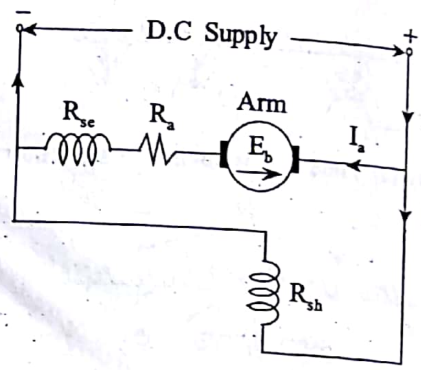

Figure (4): Long Shunt Type

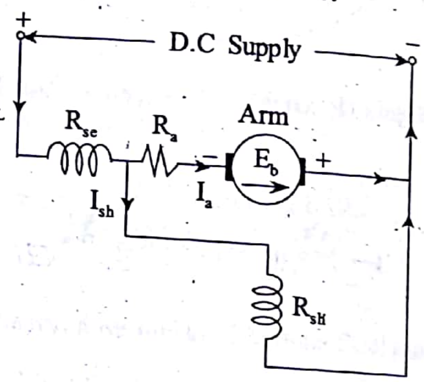

Figure (5): Short Shunt Type

(i) Short Shunt Type

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

$$I_L = I_{se}$$

$$I_{sh} = \frac{E_b - I_a R_a}{R_{sh}}$$

Terminal voltage, $V_t = E_b + I_a R_a + I_L R_{se} + V_{bd}$

$$\therefore \; E_b = V_t - I_a R_a - I_L R_{se} - V_{bd}$$

Input power, $P_i = V_t I_L$

Mechanical power, $P_m = E_b I_L$

(ii) Long Shunt Type

$$I_L = I_{sh} + I_a \qquad \boxed{\because I_{sh} = \frac{V_t}{R_{sh}}}$$

$$I_a = I_{se}$$

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Terminal voltage, $V_t = E_b + I_a R_a + I_a R_{se} + V_{bd}$

$= E_b + I_a(R_a + R_{se}) + V_{bd}$

$\therefore\ E_b = V_t - I_a(R_a + R_{se}) - V_{bd}$

Input power, $P_i = V_t I_L$

Mechanical power, $P_m = E_b I_a$

3.2.2 Torque Equation

Q46. Explain the principle of torque production in a D.C motor.

Ans:

Torque Production in D.C Motor: Consider a D.C motor with stator and rotor. When the stator coils are energized, a stator flux is set up and follows the path as shown in figure (1) with no current in the rotor conductor. magnetic

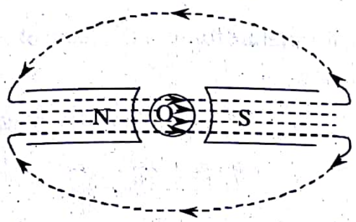


Figure (1)

When rotor conductor carries current, magnetic flux is set up and flows in the direction as shown in figure (2) with no current in the stator coil.

Figure (2)

Now when both the stator coil and the rotor conductor carries current, then an interaction between the stator flux and the flux produced by the rotor takes place and the resultant magnetic field is set up as shown in figure (3).

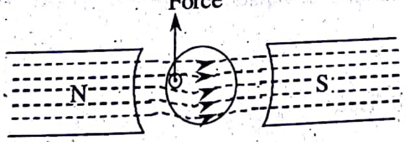


Figure (3)

The rotor conductors experiences a force in the upward direction and develops a torque.

Thus, the torque is produced in a D.C motor when the stator flux and flux produced by the rotor conductor interacts with each other.

Q47. Classify the D.C motors and derive the torque equation of a D.C motor.

Model Paper-I, Q16(b)

Ans:

Classification of D.C Motors

For answer refer Unit-III, Q45.

Torque Equation of D.C Motor

Let,

F – Force in Newton

r – Radius of armature in meter

T_a – Armature torque in N-m

S – Circumferential distance

ϕ – Flux/pole in Wb

p – Number of poles

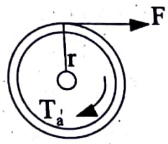
Z – Number of armature conductors

A – Number of armature paths

I_a – Armature current

N – Speed of armature in r.p.m

Consider the following figure,



Figure

Since, torque is the twisting movement produced across the armature.

$\frac{N}{60}$ – Speed in r.p.m

$dt = \frac{60}{N}$ – Time taken for one revolution.

Mechanical work done per second,

$$= \frac{F \times \text{Circumferential distance}}{\text{Time}}$$

$$= \frac{F \times S}{60/N}$$

$$= F \times 2\pi r \frac{N}{60} \qquad [\therefore S = 2\pi r]$$

$$= F \times r \times \frac{2\pi N}{60} \qquad (\therefore T_a = F \times r)$$

$$\therefore \quad \text{W.D/sec} = \frac{T_a \times 2\pi N}{60} \text{ N-m/sec} \qquad \text{... (1)}$$

The electrical work done per second,

$$= E_b \times I_a$$

$$\therefore \quad \text{W.D/sec} = \frac{\phi p N}{60} \times \frac{Z}{A} I_a \qquad \left(\because E_b = \frac{\phi p N}{60} \times \frac{Z}{A}\right)$$

As 1 N-m/sec = 1 Watt

Therefore, equating mechanical and electrical power,

$$\frac{T_a \times 2\pi N}{60} = \frac{\phi p N}{60} \times \frac{Z}{A} I_a$$

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$$\Rightarrow \quad T_a \times 2\pi = \frac{\phi p Z I_a}{A}$$

$$T_a = \frac{1}{2\pi} \cdot \frac{\phi p Z I_a}{A}$$

$$\boxed{T_a = \frac{0.159\,\phi p Z I_a}{A}} \text{ N-m (SI unit)}$$

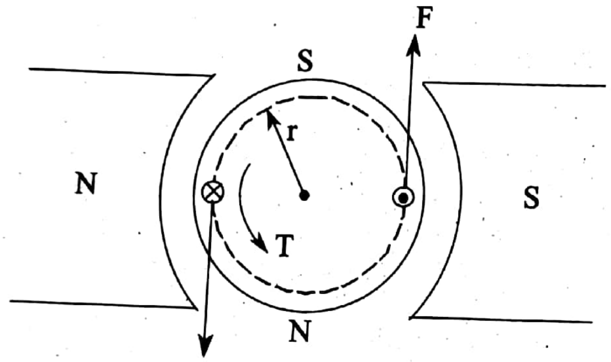
$$T_a = \frac{0.159}{9.81} \cdot \frac{\phi p Z I_a}{A}$$

$$\boxed{T_a = \frac{0.0162\,\phi p Z I_a}{A}} \text{ kg-m (MKS unit)}$$

Q48. Derive the expression for torque developed by the D.C motor using BIL concept.

Ans:

Whenever a coil is placed in magnetic field, equal forces act on two sides of the coil with opposite direction as shown in figure



Figure

The cause of mechanical rotation is due to the impact of torque.

Let,

T_c – Conductor torque N-m

F_c – Force on conductor in Newton

l – Length of conductor

D – Diameter of armature

I_c – Conductor current

B – Magnetic field density

r – Radius of armature

ϕ – Flux/pole in Wb

p – Number of poles

Force on the conductor,

$$F_c = BI_c l$$

We have, torque developed per conductor,

$$\text{Torque, } T_c = F_c \times r$$

$$\boxed{T_c = BI_c l \times r}$$

Where,

$$B = \frac{\phi p}{\pi D l}$$

$$I_c = \frac{I_a}{A}$$

[i.e., current per conductor = $\frac{\text{Armature current}}{\text{Parallel path}}$]

$$r = \frac{D}{2}$$

$$\therefore \quad \text{Torque, } T_c = \frac{\phi p}{\pi D l} \times \frac{I_a l}{A} \times \frac{D}{2}$$

$$\therefore \quad T_c = \frac{1}{2\pi} \times \frac{\phi p I_a}{A}$$

$$= \frac{0.159\,\phi p I_a}{A}$$

But, total armature torque is the sum of torque developed by each conductor,

$$\therefore \quad T_a = T_c \times \text{Number of conductors}$$

$$= \frac{0.159\,\phi p I_a}{A} \times Z$$

$$\boxed{\text{Armature torque, } T_a = \frac{0.159\,\phi p Z I_a}{A} \text{ N-m}}$$

Q49. A 6-pole D.C motor has a wave connected armature with 87 slots, each slot containing 6 conductors. The flux per pole is 20 mWb and the armature has a resistance of 0.13 ohm when the motor is connected to 240 V supply and the armature draws a current of 80 A driving a load of 15 kW. Calculate,

(i) Speed

(ii) Armature torque and

(iii) Shaft torque.

Ans:

Given that,

D.C motor with wave connected armature

Number of poles, $p = 6$

Number of slots $= 87$

Conductors per slot $= 6$

Flux per pole, $\phi = 20$ mWb $= 20 \times 10^{-3}$ Wb

Armature resistance, $R_a = 0.13\ \Omega$

Supply voltage, $V = 240$ V

Armature current, $I_a = 80$ A

Output $= 15$ kW $= 15 \times 10^3$ W

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(i) Speed, $N = ?$

(ii) Armature torque, $T_a = ?$

(iii) Shaft torque, $T_{sh} = ?$

The voltage equation of a motor is given by,

$$V = E_b + I_a R_a$$

$$\Rightarrow E_b = V - I_a R_a$$

$$= 240 - (80 \times 0.13)$$

$$\therefore E_b = 229.6 \text{ V}$$

Total number of conductors,

$$Z = \text{Number of slots} \times \text{Conductors per slot}$$

$$= 87 \times 6$$

$$\therefore Z = 522$$

Number of parallel paths, $A = 2 (\because$ Wave winding)

(i) **Speed:** The back e.m.f is given by,

$$E_b = \frac{\phi ZN}{60} \times \frac{p}{A}$$

$$\therefore \text{Speed, } N = \frac{60 \times E_b \times A}{\phi Z p}$$

$$= \frac{60 \times 229.6 \times 2}{20 \times 10^{-3} \times 522 \times 6}$$

$$= \frac{27552}{62.64}$$

$$= 439.85$$

$$\therefore \text{Speed, } N = 440 \text{ r.p.m}$$

(ii) **Armature Torque:** The armature torque of a motor is given by,

$$T_a = 0.159 \times \phi Z I_a \times \left(\frac{p}{A}\right) \text{N-m}$$

$$= 0.159 \times 20 \times 10^{-3} \times 522 \times 80 \times \left(\frac{6}{2}\right)$$

$$= 398.39 \text{ N-m}$$

(iii) **Shaft Torque:** The shaft torque of a motor is given by,

$$T_s = 9.55 \times \frac{\text{Output}}{\text{N}} \text{ N-m}$$

$$= 9.55 \times \frac{15 \times 10^3}{440}$$

$$= 9.55 \times 34.09$$

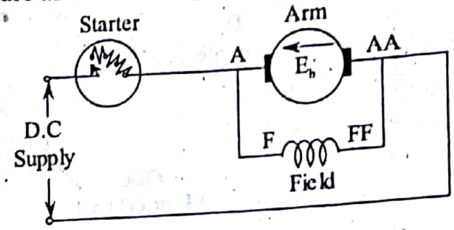
$$= 325.57 \text{ N-m}$$

3.2.3 3-Point Starter

Q50. Write briefly about necessity of starter to start a D.C motor.

Ans:

A starter is necessary at the time of starting of any D.C motor. Starter is nothing but a resistor, which has the property that opposes the current to flow through it and it will be in series with armature as shown in figure.



Figure

From voltage equation of a D.C machine at steady state operating conditions, armature current can be written as,

$$V = E_b + I_a R_a \quad \text{... (1)}$$

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

At stand still position of the motor back e.m.f, E_b is zero. Then armature current is the ratio of voltage to resistance.

We know that armature has very low resistance therefore, starting current is very high approximately 50 times to that of rated current.

Such high value of starting current may result in,

(i) High sparking at commutator.

(ii) Heavy voltage drops in terms of heat, by which armature winding will burn out.

(iii) Large voltage dips, which effects the operation of other electrical apparatus connected to the same supply mains.

Thus in order to overcome the above problems or to protect the motor from high starting currents, starter is necessary.

However, after attaining the motor's rated speed, starter is removed from the circuit otherwise, it would cause additional loss of energy there by operating speed and efficiency will reduce.

Q51. Explain construction and working of 3-point startor with neat sketch.

Ans: Model Paper-II, Q13(a)

Construction: In this type of starter, the starting resistance 'R' is divided into several sections and is connected in series with the armature. The tapping points of starting resistances are brought to a number of studs. A pivoted starter arm 'A' moves against the spiral spring and makes contact with each stud during starting operation cutting out more and more starting resistance as it passes over each stud in clockwise direction.

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One end of the shunt field winding is connected to stud No. 1, through no volt coil (or HOLD ON Coil) (N-V coil) and brass arc, whereas the other end is connected to the far side of supply. The N-V coil is a small electromagnet having many turns carrying field current. On the starter arm there is a soft iron piece which when on final stud gets attracted to N-V coil.

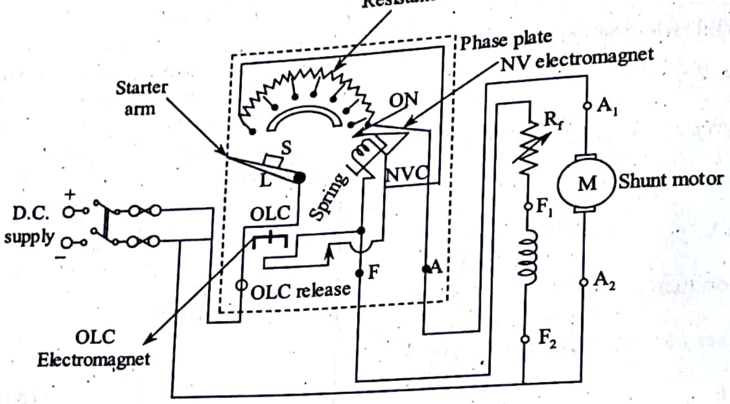


Figure (1)

There is another electromagnet called overload release connected in series with the line and carries the main current. This magnet carries an arm which short circuits the N-V coil when current exceeds a predetermined value.

Working: To start with, the D.C supply is switched ON with the starter arm in OFF position. The handle is now moved clockwise to the first stud. As soon as the handle makes contact with the first stud the field winding is connected across the supply while the entire resistance is brought in series with armature. As the starter arm is gradually moved towards the final stud, the starting resistance is gradually cut out in steps from the armature circuit and when it finally comes to final stud the entire resistance is cut out from the armature.

Function of No Volt Release: When the motor is supplied through a D.C three-point starter and the starter arm is in ON position, the resistance is completely cutoff and motor will run at normal speed. If the supply is disconnected, the starting arm will remain in ON position and when the supply is switched ON, no back e.m.f will act in the circuit and the armature being directly on supply mains excessive current will flow through it and it will get damaged. Hence to protect the motor from this situation an automatic arrangement is made by providing no volt release or coil. When there is no volt across this coil, it demagnetizes and releases the handle to OFF position by the action of control spring.

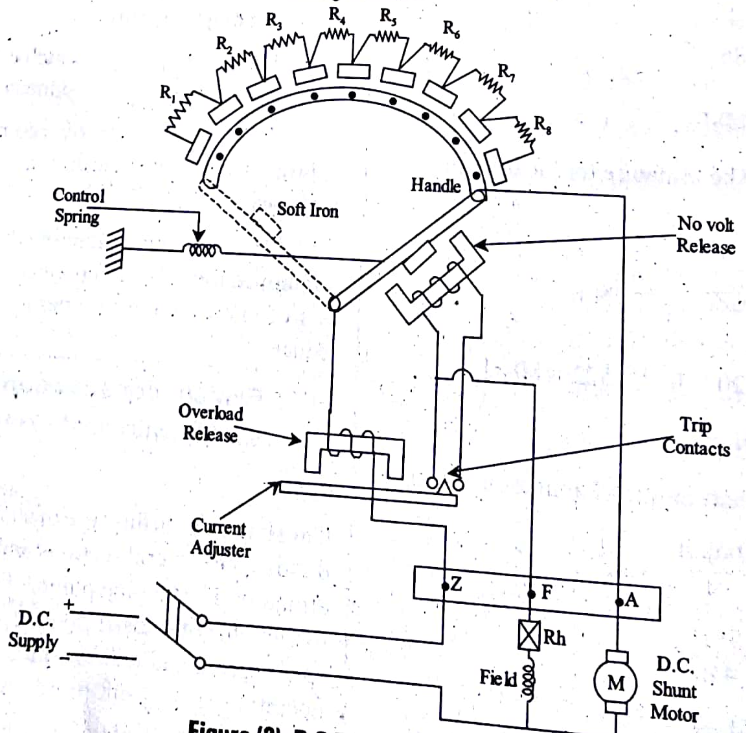


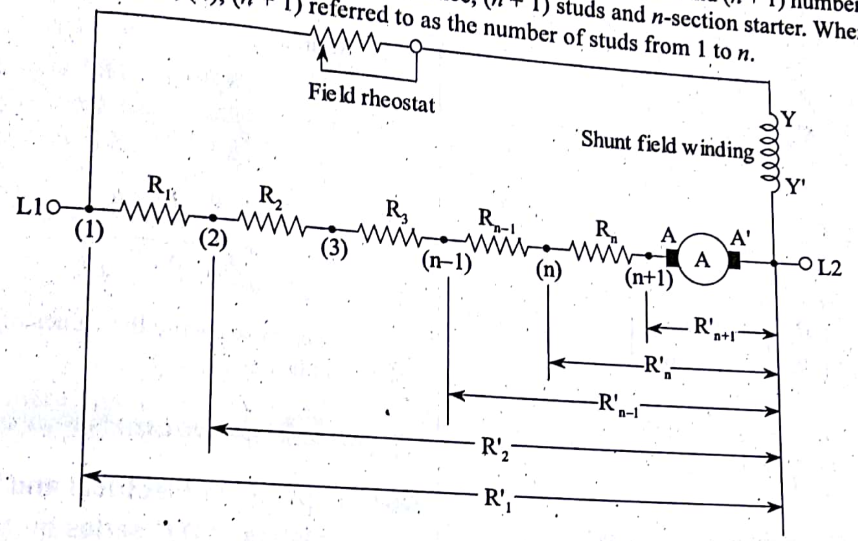
Figure (2): D.C Three-point Starter

Function of Overload Release: This coil is provided for the protection of motor from overloading. This coil is connected in series with the motor winding to carry the rated current. When the motor is overloaded, it draws heavy current which also flows through the same coil and magnetizes in such a way that it short circuits the no volt coil under the short circuit condition. The no volt coil demagnetizes and releases the handle back to OFF position by the action of control spring. Thus the motor is disconnected from the supply and protected against the overloading.

Q52. Deduce the expression for the number of steps, number of studs and resistance for each step of a 3-point starter.

Ans:

Figure shown below represents a D.C shunt motor with 'n' number of resistances and $(n + 1)$ number of studs. Due to the arrangement of the starter, this starter is known as an n-resistance, $(n + 1)$ studs and n-section starter. Where $R_1, R_2, ..., R_n$ are the resistances numbered (1), (2), ..., (n), $(n + 1)$ referred to as the number of studs from 1 to n.



Figure

The stud number $(n + 1)$ is not included but is said as off-stud. This is known as grading of resistances with n number of elements having $(n + 1)$ studs.

Here, the resistances are written as,

$$R_1' = R_1 + R_2 + R_3 + ... + R_n + R_a \quad ...(1)$$

Where, R_a is the resistance of armature of the motor.

The total armature circuit resistance designated as R_1' should be equal to that of, at the time of starting of the motor,

$$R_1' = \frac{V}{I_1'}$$

$\therefore$ The maximum armature current I_1' is equal to $\frac{V}{R_1'}$.

When the handle comes on stud (1), the motor accelerates and an amount of e.m.f induces which decreases the value of armature current I_1' and the minimum current dropped by I_1' is I_2'.

$$\therefore \quad E_1' = V - I_2' R_1'$$

$$R_1' = \frac{V - E_1'}{I_2'} \quad ...(2)$$

Due to the minimum current I_2', the resistance R_1 of stud (1) is cut-off by moving the handle from stud (1) to stud (2). This process of cutting-off of resistance is known as notching-up process. The e.m.f induced during this process is negligible in each section, resulting in increased value of current i.e., I_1'. Therefore,

$$E_1' = V - I_1' R_2'$$

$$R_2' = \frac{V - E_1'}{I_1'} \quad ...(3)$$

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From equations (2) and (3), we can write the relation,

$$\frac{R_2'}{R_1'} = \frac{I_2'}{I_1'}$$

$$= \frac{\text{Minimum current across armature}}{\text{Maximum current across armature}} \quad \text{... (4)}$$

Similarly, for other studs i.e., for (2), (3), ... (*n*), we can write from equation (4) as,

$$\frac{R_2'}{R_1'} = \frac{R_3'}{R_2'} = \frac{R_4'}{R_3'} = ... = \frac{R'_n}{R'_{n-1}}$$

$$= \frac{R_a}{R'_n} = \frac{I_2'}{I_1'} = \beta$$

Also,

$$\beta^n = \frac{R_2'}{R_1'} \times \frac{R_3'}{R_2'} \times \frac{R_4'}{R_3'} \cdots \frac{R'_n}{R'_{n-1}} \times \frac{R_a}{R'_n} = \frac{R_a}{R_1'}$$

$$\therefore \; \beta = \left(\frac{R_a}{R_1'}\right)^{\frac{1}{n}} = \left(\frac{I_1'R_a}{I_1'R_1'}\right)^{\frac{1}{n}}$$

$$\beta = \left(\frac{I_1'R_a}{V}\right)^{\frac{1}{n}}$$

$$\text{Also, } \beta^{n-1} = \left(\frac{I_1'R_a}{V}\right)^{\frac{1}{(n-1)}}$$

$$\beta^{n+1} = \left(\frac{I_1'R_a}{V}\right)^{\frac{1}{(n+1)}}$$

From equation (4), values of resistance can be determined as,

$$R_2' = \beta \times R_1'$$

$$R_1 = R_1' - R_2'$$

$$= R_1' - \beta R_1'$$

$$= (1-\beta) R_1'$$

$$\Rightarrow \; R_1' = \frac{R_1}{(1-\beta)}$$

Where, 'R_1' is the resistance of the circuit field at stud (1), as shown in figure.

Similarly,

$$R_2 = R_2' - R_3'$$

$$= R_2' - R_2'\beta$$

$$= R_2'(1-\beta)$$

$$R_2 = R_1'.\beta(1-\beta)$$

On simplifying further, the resistance becomes as,

$$R_1 = R_1'(1-\beta)$$

$$R_2 = R_2' - R_3'$$

$$= R_2'(1-\beta)$$

$$= \beta R_1'(1-\beta)$$

$$= \beta . \frac{R_1}{(1-\beta)}(1-\beta)$$

$$\boxed{R_2 = \beta R_1}$$

Similarly,

$$R_{n-1} = \beta^{n-2} . R_1$$

$$\boxed{R_{n-1} = \beta . R_{n-2}}$$

$$R_n = \beta^{n-2} R_1$$

$$\boxed{R_n = \beta . R_{n-1}}$$

Thus, by knowing the values of n, I_1' and R_a the above values can be determined.

3.2.4 Characteristics of D.C Motors

Q53. Explain the Electrical and mechanical characteristics of D.C series motor.

Ans:

Electrical Characteristics

The term electrical characteristics refers to torque and armature current (T/I_a) characteristics. To plot these characteristics, using these relation.

$$T_a \propto \phi I_a \qquad [\because \text{ In D.C motor}]$$

But in D.C series motor, we have,

$$\phi \propto I_a$$

$$\therefore \; T_a \propto I_a^2$$

Hence, when load increases, armature current increases which inturn leads to the increase of torque as a proportion to the square of armature current. This torque increase with armature current only upto the saturation point because after saturation point flux ϕ becomes constant. Hence curve drawn between T_a and I_a is a parabola upto saturation point. After saturation point, flux ϕ is almost is independent of excitation current and so $T_a \propto I_a$. Hence the characteristics from these becomes a straight line. The electrical characteristics of a D.C series motor are shown in figure (1).

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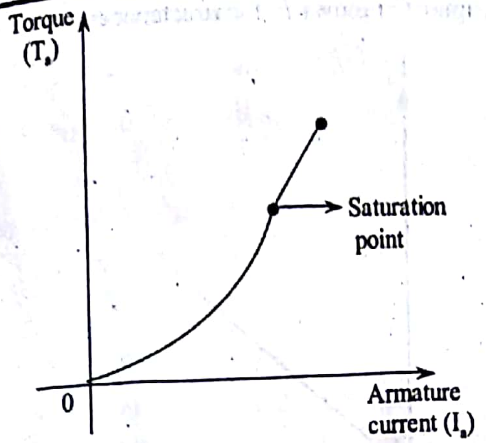


Figure (1)

Mechanical Characteristics: The term mechanical characteristics refers to speed and torque (N/T_a) characteristics we know that for a series motor.

$$T \propto I_a^2 \quad \text{... (1)}$$

$$\Rightarrow \quad \sqrt{T} \propto I_a \quad \text{... (2)}$$

And,

$$N \propto \frac{1}{I_a} \quad \text{... (3)}$$

On using equations (2) and (3), we can write,

$$N \propto \frac{1}{\sqrt{T}} \quad \text{... (4)}$$

Therefore, when load increases torque also increases.

But when torque increases, speed decreases [since from equation (4)]. Also on no load, the torque is very less and these may lead to dangerously high speeds of the motor. These characteristics are derived by using both electrical and speed characteristics of D.C series motors. The mechanical characteristics of a D.C series motor are shown in figure (2).

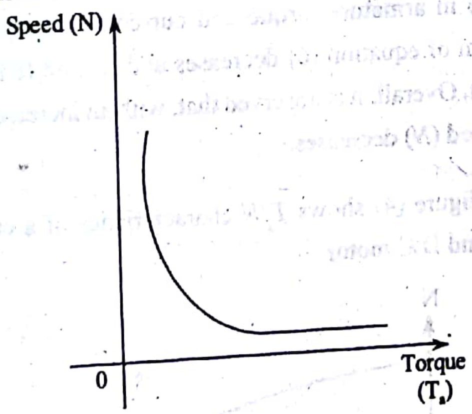


Figure: (2)

Q54. Draw the performance characteristics of D.C shunt motor.

Ans:

Electrical and Mechanical Characteristics

For answer refer Unit-I, Q13.

Speed Characteristics

The term speed characteristics refers to the speed and armature current (N/I_a) characteristics. The speed characteristics of a D.C shunt motor is shown in figure.

Shunt Motor Characteristics

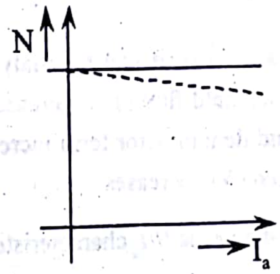
N/I_a Characteristics

We know that $N \propto \frac{E_b}{\phi}$

Since 'ϕ' is practically constant in shunt motor,

$$\therefore \quad N \propto E_b \propto (V - I_a R_a)$$

With the increase in load current I_L, the I_a also increases [$\because I_a = I_L - I_{sh}$, as I_{sh} is constant]. With the increase in load current, the speed slightly falls due to increase in voltage drop in armature.



Figure

Since voltage drop in armature at full-load is very small as compared to applied voltage, so drop in speed from no-load to full-load is very small and for all practical purposes the shunt motor is taken as a constant speed motor.

Because of the constancy of speed they are best suited for driving line shafts, milling machine's conveyors, fans etc.

Q55. Explain the operating characteristics of D.C compound motors.

Ans:

Characteristics of D.C Compound Motor

Figure (1) shows the connection diagram of a long shunt cumulative compound motor.

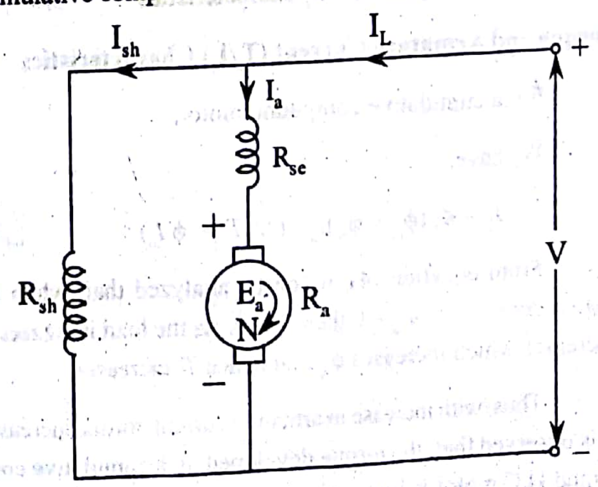


Figure (1)

Speed and Armature Current (N/I_a) Characteristics

For a cumulative compound D.C motor,

Terminal voltage,

$$V = E_a + I_a(R_a + R_{se})$$

$$\Rightarrow \quad E_a = V - I_a(R_a + R_{se}) \quad \text{... (1)}$$

Also,

$$E_a = K_N(\phi_{sh} + \phi_{se}).N \quad (\because E \propto \phi N)$$

$$N = \frac{E_a}{K_N(\phi_{sh} + \phi_{se})} \quad \text{... (2)}$$

Substituting equation (1) in equation (2), we get,

$$N = \frac{1}{K_N(\phi_{sh} + \phi_{se})} \cdot [V - I_a(R_a + R_{se})] \quad \text{... (3)}$$

From equation (3), it can be analyzed that, when I_a increases, the series field flux (ϕ_{se}) increases. The numerator term decreases and denominator term increases. Hence, as I_a increases, the speed (N) decreases.

Figure (2) shows the N/I_a characteristics of a cumulative compound motor.

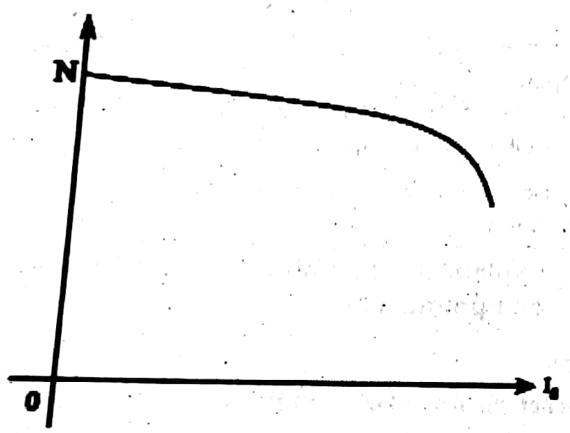


Figure (2): N/I_a Characteristics

Torque and Armature Current (T_a/I_a) Characteristics

For a cumulative compound motor,

We have,

$$T_a = K_T(\phi_{se} + \phi_{sh})I_a \quad (\because T_a \propto \phi I_a) \quad \text{... (4)}$$

From equation (4), it can be analyzed that, when the load is zero, $I_a = 0$, $\phi_{se} = 0$ then $T_a = 0$. As the load increases, I_a increases which increases ϕ_{se} and hence T_a increases.

Thus, with increase in armature current, torque increases. It is observed that, the torque developed by a cumulative compound D.C motor is higher than a D.C shunt motor.

Figure (3) shows T_a/I_a characteristics.

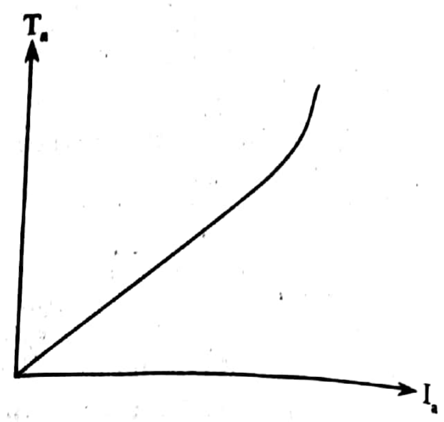


Figure (3): T_a/I_a Characteristics

Speed and Torque (N/T_a) Characteristics

From equation (4), we have,

$$I_a = \frac{T_a}{K_T(\phi_{se} + \phi_{sh})} \quad \text{... (5)}$$

Substituting equation (5) in equation (3), we get,

$$N = \frac{1}{K_N(\phi_{se} + \phi_{sh})}\left[V - \frac{T_a}{K(\phi_{se} + \phi_{sh})}(R_a + R_{sh})\right]$$

$$= \frac{V}{K_N(\phi_{se} + \phi_{sh})} \quad \frac{T_a}{K_N K_T(\phi_{se} + \phi_{sh})^2}(R_a + R_{sh}) \quad \text{... (6)}$$

From equation (6), it is clear that, ϕ_{se} increase with increase in armature torque and current. Consequently, the first term of equation (6) decreases and second term remains constant. Overall, it is observed that, with an increase in torque (T_a), speed (N) decreases.

Figure (4) shows T_a/N characteristics of a cumulative compound D.C motor.

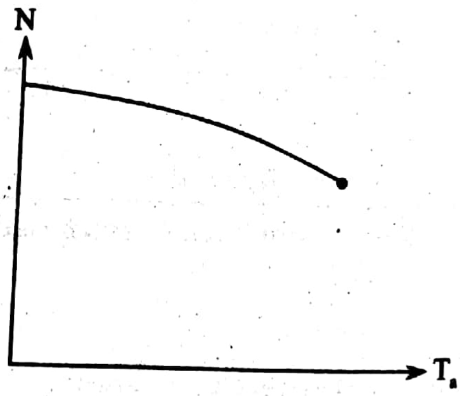


Figure (4): T_a/N Characteristics

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3.2.5 Speed Control of D.C Shunt Motor

Q56. What are the different speed control methods of D.C shunt motor?

Ans:

Speed Control of D.C Shunt Motors: The different methods of speed control of D.C shunt motor are given below,

1. Armature control method
2. Field control method
3. Ward-Leonard method.

1. **Armature Control Method:** In this method of speed control, an external variable resistance is connected between the armature terminals and the line. When the resistance added is maximum due to higher resistance, the current flowing through the armature would be reduced proportionally.

The field flux remains unchanged thus, with the reduction in the armature current, the torque is also reduced,

$$\boxed{\therefore\ T = k_a \phi I_a}$$

As the torque of the machine is reduced, the speed also reduces.

If the armature resistance is kept minimum, the rated current flows through the armature keeping the speed at rated value. Thus by analysis, it could be noted that the speed variation is possible only below the rated speed but not above the rated speed. The circuit and the characteristics are as shown in figure (1).

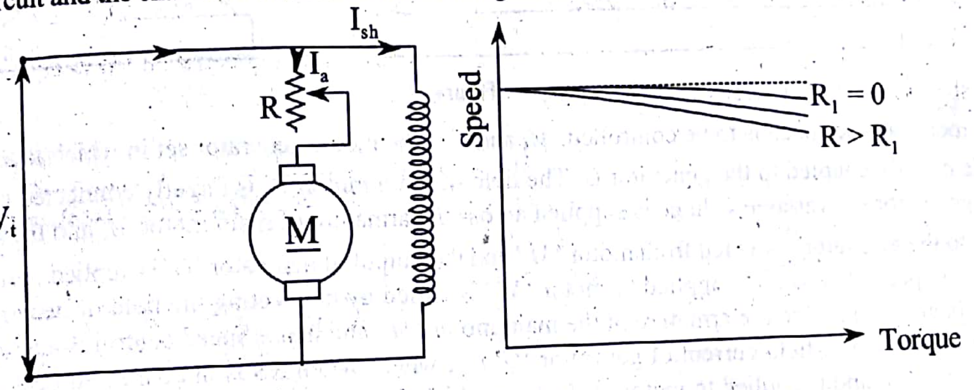

Figure (1)

2. **Field Control Method:** In field control method, a varying external resistance is connected in the field circuit. When the resistance added to the field is zero then the current through the armature would be the rated value. As the resistance increases the current through the field reduces thereby, reducing the flux of the machine, but this reduction of current in the field increases the current through the armature above the rated value and thus, the operating torque also increases which in turn increases the speed above the rated value. While starting, the field resistance should be kept minimum else huge currents flows through the armature which damages the armature coils. So, from this we can say that the variation of speed above the rated speed can also be obtained by increasing the field resistance.

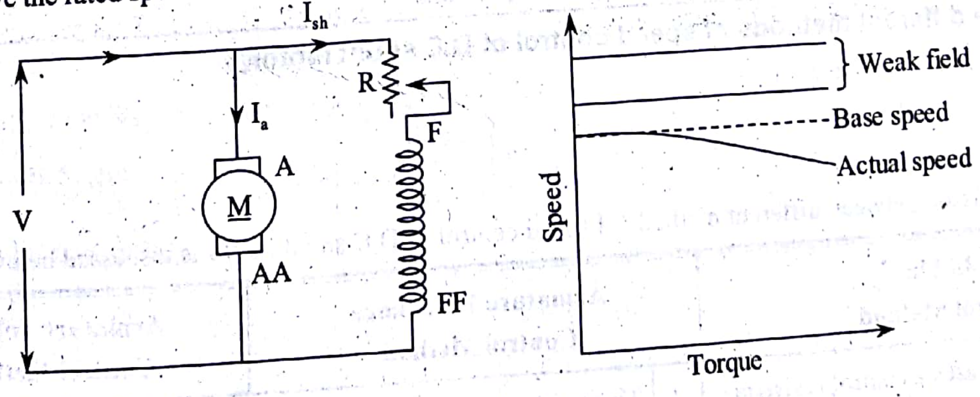

Figure (2)

3. **Ward-Leonard Method**

For answer refer Unit-III, Q57.

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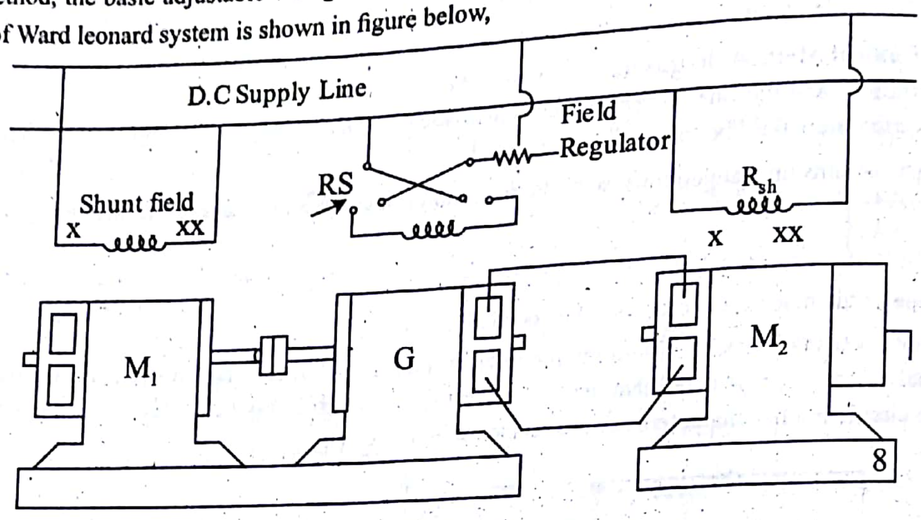
Q57. Explain the Ward Leonard system of speed control with a neat circuit diagram.

Ans:

Ward Leonard System

Ward Leonard system is used to control the speed of D.C shunt motors. It comes under the category of voltage control method. In this method, the basic adjustable voltage to the armature is achieved by means of an adjustable voltage generator. The arrangement of Ward leonard system is shown in figure below,



Figure

M_1 is the motor whose speed is to be controlled. M_2 and G is the motor-generator set in which motor may be a D.C or an A.C motor and is directly coupled to the generator G. The field of main motor M_1 is directly connected to the D.C supply lines with the help of generator G, variable voltage is supplied across the armature of main motor M_1 and the speed is controlled.

The input to the generator 'G' is fed from motor 'M_2' and the output of generator 'G' is applied to motor 'M_1'. Motor 'M_2' operates at constant speed. The voltage applied to motor 'M_1' is varied by connecting the field of generator to a regulator and hence variable voltage is applied to the armature of the main motor 'M_1' and hence speed control is achieved. The switch RS is used to reverse the direction of field current of generator 'G' i.e., when switch RS is in connected position, reverse voltage is generated in generator 'G' and is applied to motor 'M_1' due to which the direction of rotation of motor 'M_1' reverses.

Applications

Despite of its disadvantages, Ward Leonard system is used for the speed control of D.C shunt motor for many applications due to its unusually wide range and very sensitive speed control. The applications are listed below,

1. Colliery winders
2. Electric excavators
3. Elevators
4. Main drives in steel mills and blooming and paper mills.

Q58. Compare different methods of speed control of D.C shunt motor.

Ans:

Comparison

The comparison between different methods of speed control of D,C shunt motor is discussed below.

Field Flux Control Method	Armature Resistance Control Method	Armature Voltage Control Method
1. This method uses a control resistance inserted in the field circuit of the D.C shunt motor.	1. This method uses a variable D.C resistance connected in series with the armature of a D.C shunt motor.	1. This method uses a variable voltage source separated from the source supplying the field current of D.C shunt motor.

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2.	Speed is varied by varying the field flux.	2.	Speed is varied by varying armature circuit resistance and hence, the voltage across the armature.	2.	In this method output delivered by the motor is decreased by decreasing the applied voltage and hence, decre--ase in speed of the motor is achieved.
3.	In this method, the speed of D.C shunt motor can only be varied above its base speed.	3.	In this method, the speed control can be achieved only for speeds below base speed and the speed cannot be increased above the base speed.	3.	In this method, speed control is possible only for below base speed values.
4.	This method of speed control is very simple and most efficient.	4.	This method gives lower efficiency and poor speed regulation.	4.	This method gives high efficiency and good speed regulation.
5.	This method is more economical.	5.	This method requires high operational cost at reduced speed.	5.	This method is more expensive in initial cost

Q59. A 4-pole, lap connected 230 V shunt motor has 410 armature conductors. It takes 41 A on full load the flux per pole is 0.05 Wb. The armature and field resistances are 0.1 Ω and 230 Ω respectively. Contact drop per brush = 1 V. Determine,

(i) Speed of the motor

(ii) Total torque developed in the motor.

Model Paper-I, Q13(b)

Ans:

Given that,

Lap connected shunt motor,

Poles, $p = 4$

Rated voltage, $V = 230$ V

Armature conductors, $Z = 410$

Full load current, $I_L = 41$ A

Flux per pole, $\phi = 0.05$ Wb

Armature resistance, $R_a = 0.1\ \Omega$

Field resistance, $R_{sh} = 230\ \Omega$

Contact drop per brush = 1 V

To calculate,

(i) Speed of the motor, $N = ?$

(ii) Total torque developed in the motor, $T = ?$

(i) Speed of the Motor

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

$$= \frac{230}{230}$$

$$= 1\text{ A}$$

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

$$= 41 - 1$$

$$= 40\text{ A}$$

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$\therefore$ Back e.m.f, $E_b = V - I_a R_a$

$= 230 - (40 \times 0.1)$

$= 230 - 4$

$$\boxed{\therefore E_b = 226 \text{ Volts}}$$

Also,

$$\text{Back e.m.f, } E_b = \frac{\phi ZN}{60} \times \frac{P}{A}$$

$$\therefore \text{Speed of the motor, } N = \frac{E_b \times 60}{\phi Z} \times \frac{A}{P}$$

$$= \frac{226 \times 60}{0.05 \times 410} \times \frac{4}{4}$$

[$\because$ In lap wound, $A = P$]

$= 661.46$

$\simeq 661$ r.p.m

$$\boxed{\therefore N = 661 \text{rpm}}$$

(ii) Total Torque Developed in the Motor

$$\text{Total torque, } T = 0.15\, \phi I_a \frac{PZ}{A}$$

$$= 0.159 \times 0.05 \times 40 \times \frac{4 \times 410}{4}$$

$$\boxed{\therefore T = 130.38 \text{ Nm}}$$

3.2.6 Losses and Efficiency, Applications

Q60. Explain the losses occurring in a D.C motor.

Ans:

Copper or Electrical Losses

(a) **Armature Copper Losses:** This loss is given as $I_a^2 R_a$.

(b) **Field Copper Loss:** This loss is further classified into three types. They are,

(i) **Shunt Field Copper Loss**

I_{sh}^2, R_{sh} or VI_{sh} and is practically constant which incurs in shunt and compound motors.

(ii) **Series Field Copper Loss**

$I_{se}^2\ R_{se}$ which incurs only in series and compound.

(iii) **Interpole Loss:** $I_a^2 R_i$

Magnetic or Iron Losses

These are also called core losses and are present in any part of machine which is made up of iron and subjected to variations of flux. Iron loss consist of,

(a) **Hysteresis Losses:** The hysteresis loss depends upon the volume and grade of iron, B_{max} and frequency of magnetic reversals. According to Steinmetz formula, it is given as,

$$W_h = \eta B_{max}^{1.6} fV \text{ watt}$$

Where,

η – Steinmetz hysteresis coefficient which is 502 J/m³ for dynamo sheet steel and 191J/m³ for silicon steel.

V – Volume of core in m³

f – Frequency of magnetic reversals = $PN/120$.

(b) **Eddy Current Losses:** When the armature core rotates, it also cuts the magnetic flux. Hence, an e.m.f is induced in the core according to Faraday's law of electromagnetic induction. This e.m.f though small, sets up huge current in the core due to its small resistance. This current is also known as eddy current. The power loss due to the flow of this current is known as eddy current loss [$\therefore R = \frac{\rho l}{A}$. If core is made of solid piece, the area of cross-section is large hence R is small and eddy current is high].

Instead of a solid piece if the core is made up of laminations. [Area of cross-section decreases thus resistance increases and hence eddy current is low and thus eddy current loss decreases].

The eddy current loss is given as,

$$W_e = K B_m^2 f^2 V t^2$$

Where,

K_e = Constant depending upon the electrical resistance of magnetic material

B_m = Maximum flux density

t = Thickness of lamination

V = Volume of core.

Mechanical Losses: These losses consist of power losses due to friction of the bearings, air friction or windage caused by the motion of moving parts through surrounding medium and friction between brushes and commutator rings.

[Rotational] Stray losses = Magnetic losses + Mechanical losses

Constant losses = Stray losses + Shunt field copper losses

Standing losses = Magnetic losses + Mechanical losses + Shunt field copper losses.

[Therefore, all the three losses are constant]

$\therefore$ Total losses = Armature copper losses + Constant losses

Total losses = Variable losses + Constant losses.

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Q61. Draw the power stage diagram of D.C motor.

Ans:

The various power stages in a D.C motor are shown in figure below

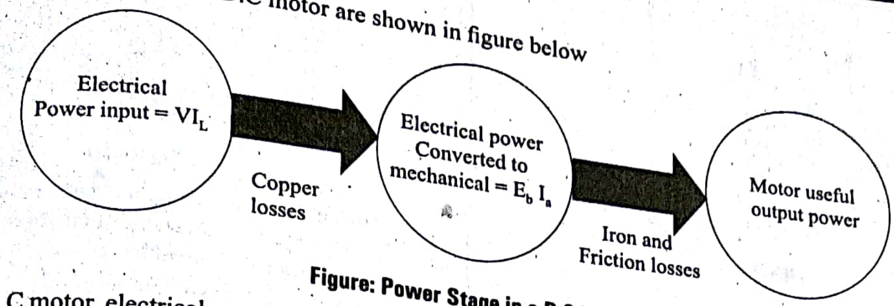

Figure: Power Stage in a D.C Motor

In case of D.C motor, electrical power is given as input. Copper losses takes place before the conversion of electrical form to mechanical form. Iron and friction losses takes place after the conversion of electrical form to mechanical form.

By using the power flow diagram the various efficiencies in a D.C motor are listed below.

Commercial efficiency or overall efficiency,

$$\eta_c = \frac{\text{Motor useful output power}}{\text{Electrical power input}}$$

$$= \frac{\text{Motor output power}}{VI}$$

Electrical efficiency,

$$\eta_e = \frac{\text{Electrical power converted to mechanical}}{\text{Electrical power input}}$$

$$= \frac{E_b I_a}{VI_L}$$

Mechanical efficiency,

$$\eta_m = \frac{\text{Motor useful output power}}{\text{Electrical power converted to mechanical}}$$

$$= \frac{\text{Motor output power}}{E_b I_a}$$

Q62. Deduce the condition for maximum efficiency for a D.C motor.

Ans:

Condition for Maximum Efficiency

The condition for maximum efficiency for both D.C generator and D.C motor is same.

Generator output = VI

Generator input, P_{in} = Output + Losses

$$= VI + I_a^2 R_a + P_i$$

Where,

$I_a = I + I_{sh}$ and

P_i = Constant losses.

$$P_{in} = VI + I^2 R_a + P_i \quad [\because I_{sh} << I_a, I_a \cong I]$$

$$\therefore \eta = \frac{\text{Output}}{\text{Input}} = \frac{VI}{VI + I^2 R_a + P_i}$$

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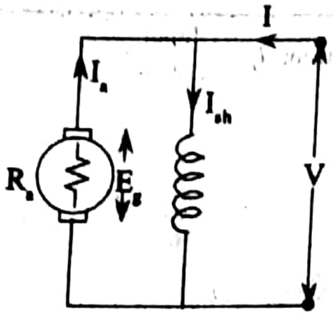

Figure

$$= \frac{1}{1+\left(\frac{IR_a + \frac{P_i}{I}}{V}\right)}$$

For efficiency to be maximum, $\frac{d\eta}{dI} = 0$

$$\Rightarrow \quad \frac{d}{dI}\left[\frac{IR_a}{V} + \frac{P_i}{VI}\right] = 0$$

$$\Rightarrow \quad \frac{R_a}{V} - \frac{P_i}{VI^2} = 0$$

$$\frac{R_a}{V} = \frac{P_i}{VI^2}$$

$$\boxed{\therefore P_i = I^2 R_a}$$

Thus, efficiency is maximum when variable or copper losses are equal to constant losses. The load current corresponding to maximum efficiency is given by the relation,

$$I = \sqrt{\frac{P_i}{R_a}}$$

Q63. Name different types of D.C motors and state their application.

Ans:

There are three types of D.C motors, namely,

(i) Series motors

(ii) Shunt motors

(iii) Compound motors.

The usage of D.C motors for particular application depends upon comparison, not only on advantages and disadvantages but also on economic and technical features with other competing (A.C) motors.

Application of D.C Series Motors

From speed-torque characteristics graph of a D.C series motor as shown in figure (1), we can conclude that,

$$\text{Speed, } N \propto \frac{1}{\sqrt{T}} \quad (\because \text{ V is constant})$$

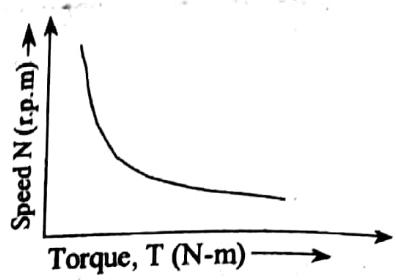

Figure (1)

Hence, from figure (1), it is known that D.C series motor provides high starting torque so that these are applicable for driving hoists trains, excavators, cranes etc., series motors can be used to drive permanently connected loads, such as fan load.

Series motors are also applicable to battery driven automobiles with the chopper control mechanism, by this application pollutions is avoided. For traction purpose, series motor is the only choice.

Application of D.C Shunt Motors

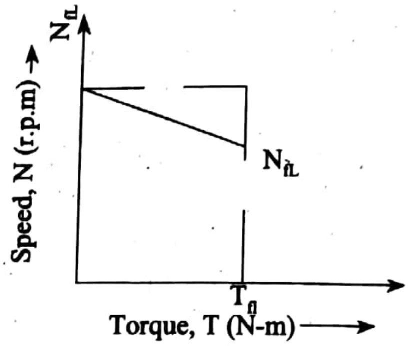

Figure (2)

From figure (2), it is clear that the speed drops from no-load to full-load is very small hence, shunt motor are suitable for constant-speed with medium starting torque applications. Shunt motors are applicable in industry where wide range of speed control is required. Like lathes, centrifugal, pumps, reciprocating pumps, fans, blowers, conveyors, wood working machines, spinning and weaving machines etc. Shunt motors are also applicable to steel and aluminum rolling mills and in ward-leonard systems of speed control when its field winding is separately exited.

Application of D.C Compound Motors.

A compound motor with a strong series field, has its characteristic approaching that of a series motor. Therefore, such types of compound motors are used for loads requiring heavy starting torque which are likely to be reduced to zero.

A compound motor with weak series field has its characteristic approaching that of a shunt motor. Weak series field causes more dropping speed-torque characteristic than with an ordinary shunt motor. Such compound motors with more steeper characteristic, are used where load fluctuates between wide limits intermittently.

A differential compound motor is almost never used. In this motor, shunt and series fields oppose each other and it is possible that at some state of operation, there may be zero flux in the air gap.

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When this occurs, motor speed becomes dangerously high and armature current increases to a very high value and this shows a differential compound motor is associated with increased armature current at high operating speed. This motor may also draw increased armature current during its starting.

This increased armature current during starting or during high-speed operation becomes dangerously so high that it may damage the commutator and armature windings. So, a differential compound motor is rarely used in practice.

Q64. The input to a 250 V, D.C shunt motor is 10 kW. The other particulars of the motor are no load current is 6 A, no load speed is 1000 r.p.m, armature resistance is 0.4 Ω and shunt field resistance is 125 Ω. Calculate efficiency and speed of the motor.

Ans:

Given that,

D.C shunt motor

Supply voltage, $V = 250$ V

Input = 10 kW = 10×10^3 W

No-load current, $I_o = 6$ A

No-load speed, $N_o = 1000$ r.p.m

Armature resistance, $R_a = 0.4\ \Omega$

Shunt field resistance, $R_{sh} = 125\ \Omega$

Efficiency, $\eta = ?$

Speed, $N = ?$

At No-load Condition

No-load input $= VI_o$

$= 250 \times 6$

$= 1500$ W

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

$= \dfrac{250}{125}$

$= 2$ A

No-load armature current, $I_{a_o} = I_o - I_{sh}$

$= 6 - 2$

$= 4$ A

No-lod amautre copper losses $= I_{a_o}^2 R_a$

$= (4)^2 \times 0.4$

$= 6.4$ W

Constant losses = No-load input – No-load armature copper losses

$= 1500 - 6.4$

$= 1493.6$ W

At Load Condition

Input = 10 kW = 10×10^3 W

Load current, $I_L = \dfrac{\text{Input}}{\text{Voltage}}$

$= \dfrac{10 \times 10^3}{250}$

$= 40$ A

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

$= \dfrac{250}{125}$

$= 2$ A

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

$= 40 - 2$

$= 38$ A

Armature copper losses $= I_a^2 R_a$

$= (38)^2 \times 0.4$

$= 577.6$ W

Total losses = Armature copper losses + Constant losses

$= 577.6 + 1493.6$

$= 2071.2$ W

Motor output = Input – Losses

$= (10 \times 10^3) - (2071.2)$

$= 7928.8$ W

Efficiency, $\eta = \dfrac{\text{Output}}{\text{Input}} \times 100$

$= \dfrac{7928.8}{10000} \times 100$

$= 79.28\%$

Back e.m.f on no-load, $E_{b_o} = V - I_{a_o} R_a$

$= 250 - (4 \times 0.4)$

$= 248.4$ V

Back e.m.f on load, $E_b = V - I_a R_a$

$= 250 - (38 \times 0.4)$

$= 234.8$ V

We have,

$E_b \propto N$

$\Rightarrow \dfrac{E_b}{E_{b_o}} = \dfrac{N}{N_o}$

$\therefore$ Speed of the motor, $N = \dfrac{E_b}{E_{b_o}} \times N_o$

$= \dfrac{234.8}{248.4} \times 1000$

$= 945$ r.p.m.

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Q65. A 220 V shunt motor takes a total current of 80 A and runs at 800 r.p.m. Shunt field resistance and armature resistance are 50 Ω and 0.1 Ω respectively. If iron and friction losses amount to 1600 W. Find,

(i) Copper losses

(ii) Armature torque

(iii) Shaft torque

(iv) Efficiency.

Ans:

Given that,

Voltage, $V = 220$ V

Current, $I_L = 80$ A

Speed, $N = 800$ r.p.m

Shunt field resistance, $R_{sh} = 50\ \Omega$

Armature resistance, $R_a = 0.1\ \Omega$

Iron and friction losses, $P_c = 1600$ W

To determine,

(i) Copper losses, $P_{Cu} = ?$

(ii) Armature torque, $T_a = ?$

(iii) Shaft torque, $T_{sh} = ?$

(iv) Efficiency, $\eta = ?$

Now,

The shunt field current is given as,

$$I_{sh} = \frac{V}{R_{sh}}$$

$$\Rightarrow \quad I_{sh} = \frac{220}{50}$$

$$\Rightarrow \quad I_{sh} = 4.4 \text{ Amps}$$

And also,

The armature current is given as,

$$\Rightarrow \quad I_a = I_L - I_{sh} \qquad [\because I_L = I_a + I_{sh}]$$

$$\Rightarrow \quad I_a = 80 - 4.4$$

$$\Rightarrow \quad I_a = 75.6 \text{ Amps}$$

We know that,

The back e.m.f of a motor is given as,

$$E_b = V - I_a R_a$$

Substituting all the values, we get,

$$E_b = 220 - (75.6 \times 0.1)$$

$$= 220 - 7.56$$

$$= 212.44 \text{ V}$$

And also,

The input power is given as,

$$P_i = V \times I_L$$

$$\Rightarrow \quad P_i = 220 \times 80$$

$$\Rightarrow \quad P_i = 17600 \text{ watts}$$

Therefore,

The power developed in an armature is given as,

Power developed in armature,

$$P_{out} = E_b \times I_a$$

$$= 212.44 \times 75.6$$

$$= 16060.464 \text{ Watts}$$

(i) Copper Losses

The copper losses is given as,

Copper loss,

$$P_{Cu} = P_i - \text{Power developed in armature}$$

$$= 17600 - 16060.464$$

$$= 1539.536 \text{ Watts}$$

(ii) Armature Torque

The armature torque is given by,

$$T_a = 9.55 \times \frac{E_b I_a}{N}$$

Substituting all the values, we get,

$$T_a = 9.55 \times \frac{212.11 \times 75.6}{800}$$

$$\Rightarrow \quad T_a = \frac{138099.112}{800}$$

$$\therefore \quad T_a = 191.72 \text{ Nm}$$

(iii) Shaft Torque

The shaft torque is given as,

$$T_{sh} = 9.55 \times \frac{\text{Output Power}}{\text{N}}$$

$$\Rightarrow \quad T_{sh} = 9.55 \times \frac{P_{out} - P_c}{n}$$

Substituting all the values, we get,

$$\Rightarrow \quad T_{sh} = 9.55 \times \left[\frac{16060.464 - 1600}{800}\right]$$

$$\Rightarrow \quad T_{sh} = 9.55 \times \frac{14460.464}{800}$$

$$\Rightarrow \quad T_{sh} = \frac{138099.112}{800}$$

$$\Rightarrow \quad T_{sh} = 172.623 \text{ N-m}$$

(iv) Efficiency

The efficiency is given as,

$$\eta = \frac{P_{out}}{P_i} \times 100$$

$$= \frac{16060.464}{17600} \times 100$$

$$= 0.91253 \times 100$$

$$= 91.253\%$$

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