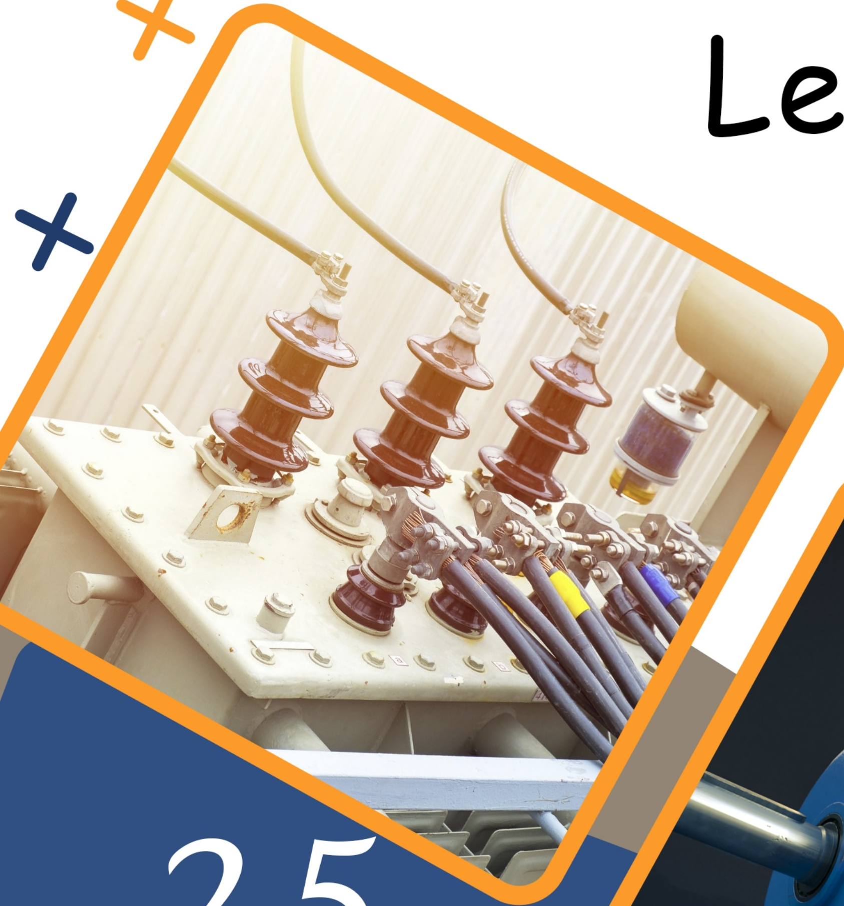
UNIVERSITY OF DIYALA
COLLEGE OF ENGINEERING
DEPARTMENT OF THE ELECTRICAL POWER AND MACHINES ENGINEERING

Second Stage

ELECTRICAL MACHINES

Lecture: 1

Lecturer
Mayyadah Sahib



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D.C. GENERATORS

Introduction:

An electrical generator is a machine which converts mechanical energy (or power) into electrical energy (or power). The energy conversion is based on the principle of the production of dynamically (or motionally) induced e.m.f.

Whenever a conductor cuts magnetic flux, dynamically induced e.m.f. is produced in it according to *Faraday's Laws of Electromagnetic Induction*. This e.m.f. causes a current to flow if the conductor circuit is closed. Hence, two basic essential parts of an electrical generator are:

(*i*) A magnetic field.
(*ii*) A conductor or conductors which can so move as to cut the flux.

Simple Loop Generator:

Construction:

Figure (1) is shown a single-turn rectangular copper coil rotating about its own axis in a magnetic field provided by either permanent magnet or electromagnets. The two ends of the coil are joined to two slip-rings which are insulated from each other and from the central shaft.

Two collecting brushes (of carbon or copper) press against the slip-rings. Their function is to collect the current induced in the coil and to convey it to the external load resistance R. The rotating coil may be called 'armature' and the magnets as 'field magnets'.

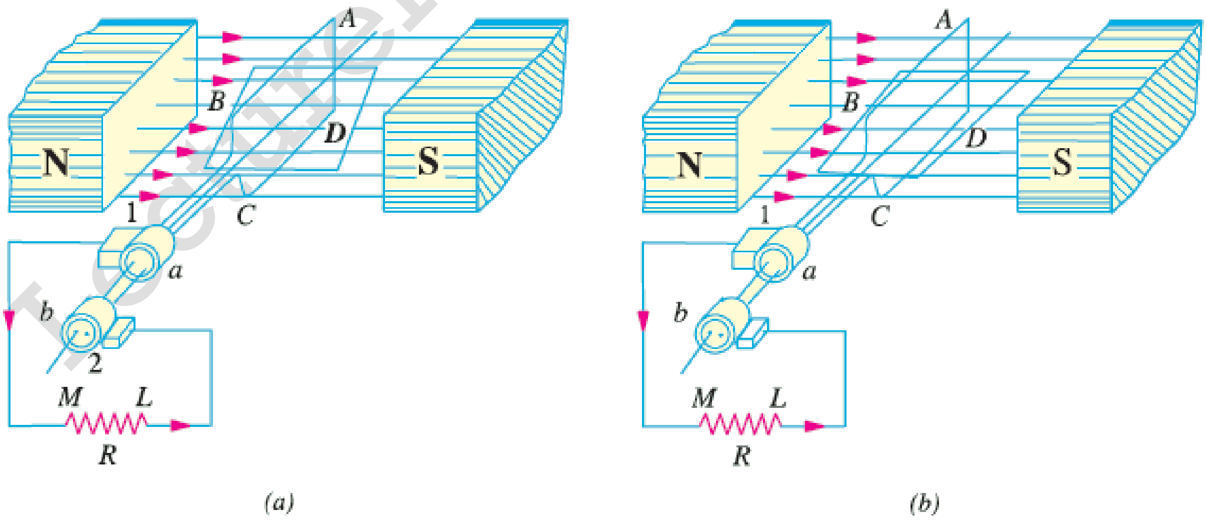
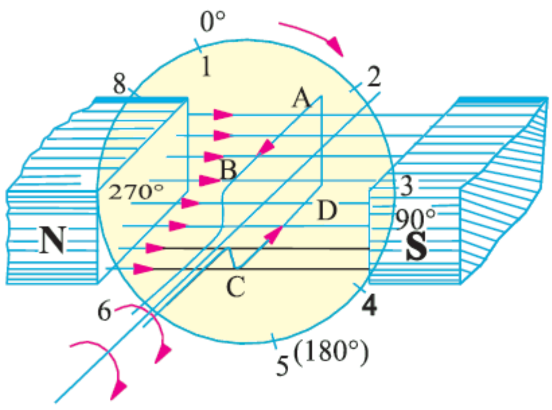


Figure (1)



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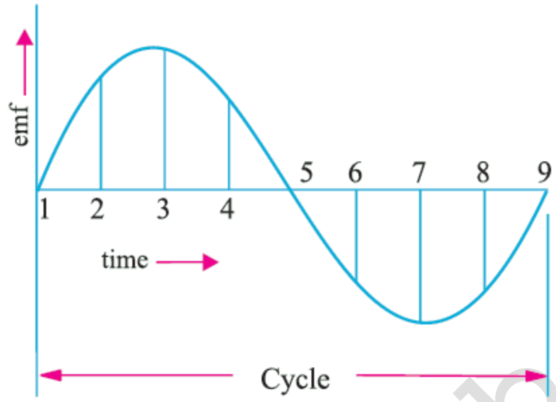

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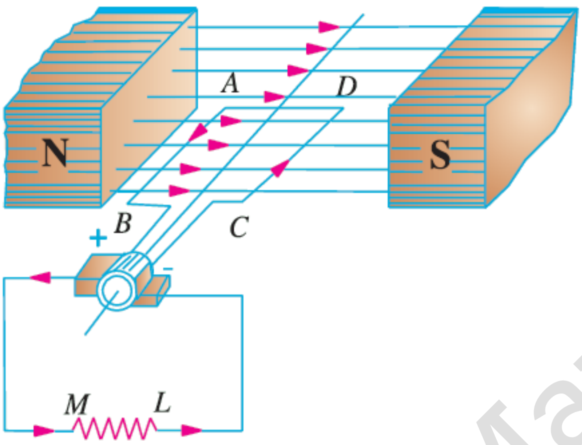

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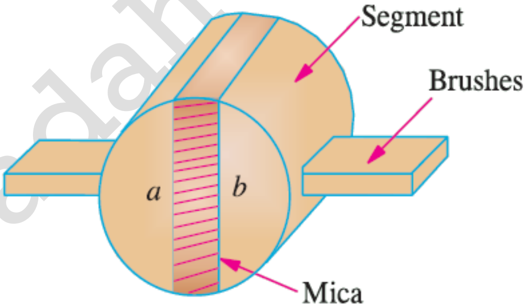

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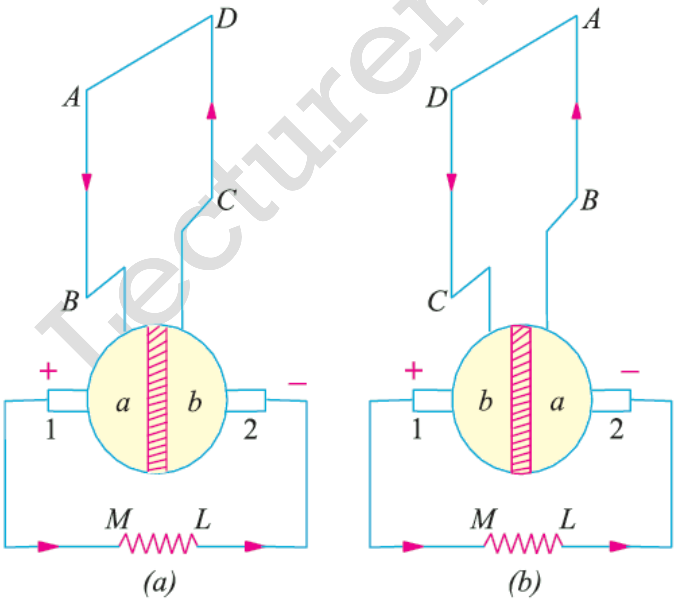

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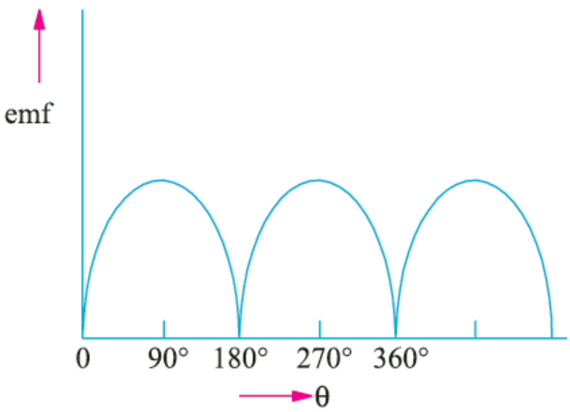


Figure (7)

Construction of Practical D.C. Machine:

The simple loop generator has been considered in detail merely to bring out the basic principle underlying construction and working of an actual generator illustrated in Figure (8) which consists of the following essential parts:

1. Magnetic Frame or Yoke
2. Pole-Cores and Pole-Shoes
3. Pole Coils or Field Coils
4. Armature Core
5. Armature Windings or Conductors
6. Commutator
7. Brushes and Bearings

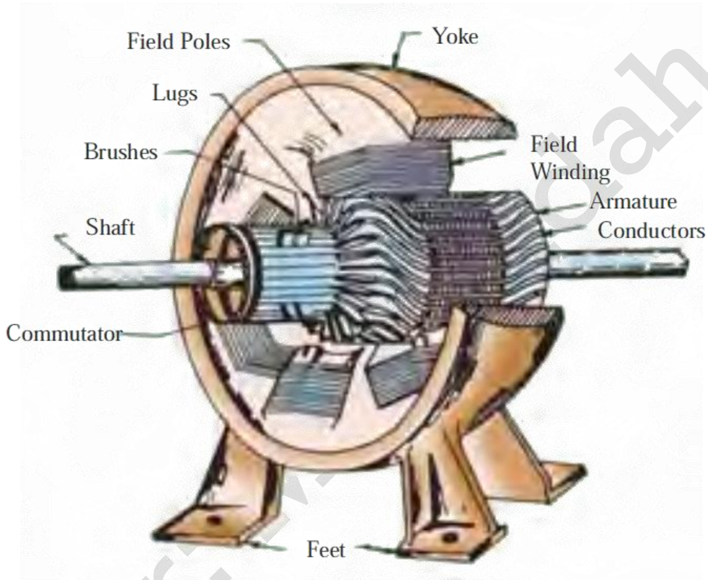


Figure (8)

Of these, the yoke, the pole cores, the armature core and air gaps between the poles and the armature core or the magnetic circuit whereas the rest form the electrical circuit.

1- Magnetic Frame or Yoke:

The outer frame or yoke serves double purpose:

(*i*) It provides mechanical support for the poles and acts as a protecting cover for the whole machine.

(*ii*) It carries the magnetic flux produced by the poles.

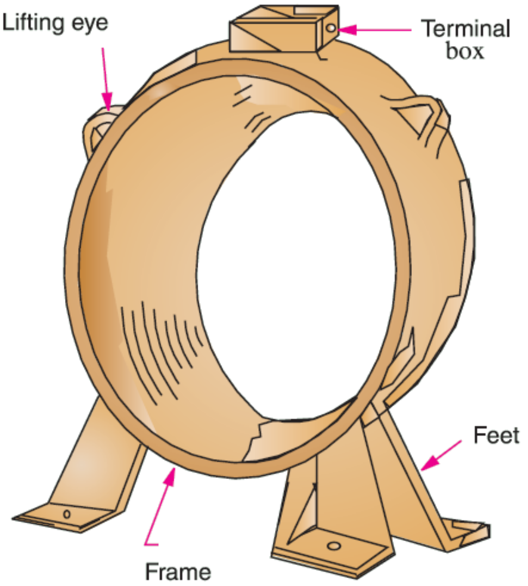


Figure (9)

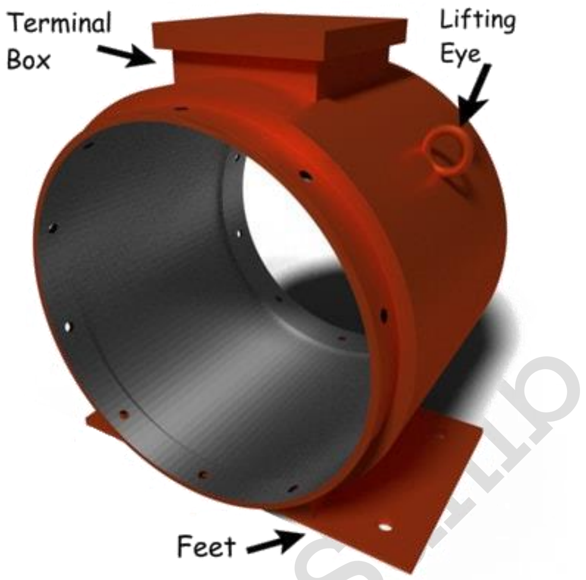


Figure (10)

2- Pole-Cores and Pole-Shoes:

The field magnets consist of pole cores and pole shoes. The pole shoes serve two purposes

(*i*) they spread out the flux in the air gap and also, being of larger cross-section, reduce the reluctance of the magnetic path.

(*ii*) they support the exciting coils (or field coils).

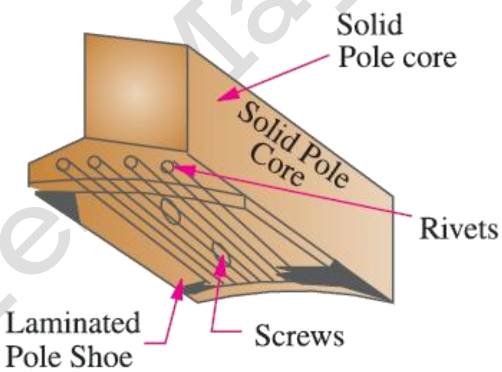
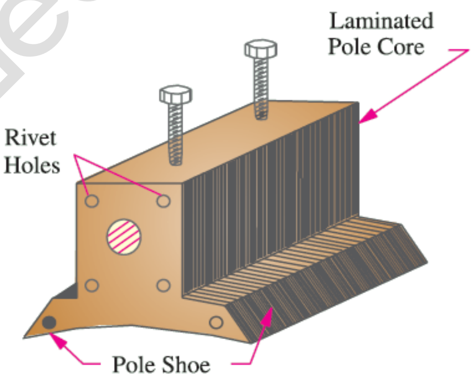


Figure (11)



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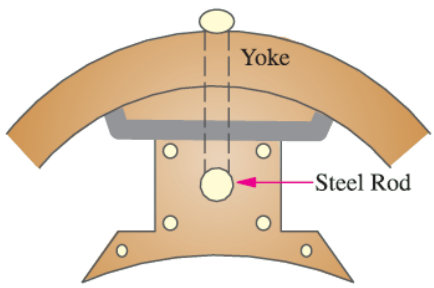


Figure (13)

3- Pole Coils or Field Coils:

The field coils or pole coils, which consist of copper wire or strip, are former-wound for the correct dimension. Then, the former is removed and wound coil is put into place over the core. When current is passed through these coils, they electromagnetise the poles which produce the necessary flux that is cut by revolving armature conductors.

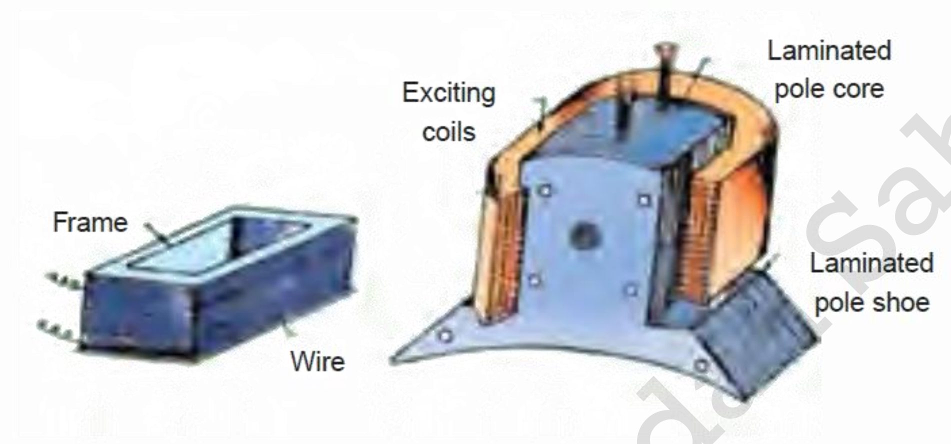


Figure (14) Figure (15)

Note: Field winding is divided into various coils called field coils which connected in series with each other and wound in such a direction around pole cores, such that attains alternate (N) and (S) polarities of poles Figure (16). Poles polarities can be determined using *Right Hand Thumb Rule*.

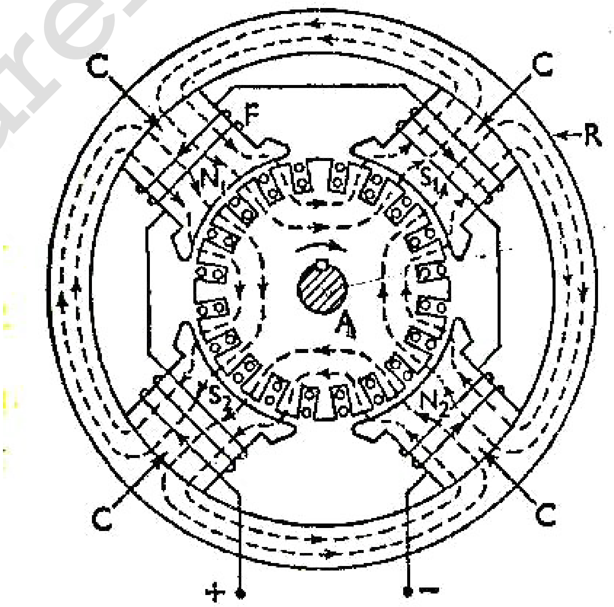


Figure (16)

4- Armature Core:

It houses the armature conductors or coils and causes them to rotate and hence cut the magnetic flux of the field magnets. In addition to this, its most important function is to provide a path of very low reluctance to the flux through the armature from a N − pole to a S − pole.
It is cylindrical or drum-shaped and is built up of usually circular sheet steel discs or laminations approximately 0.5mm thick. The purpose of using laminations is to reduce the loss due to eddy currents. Thinner the laminations, greater is the resistance offered to the induced e.m.f., smaller the current and hence lesser the (I^2R) loss in the core.

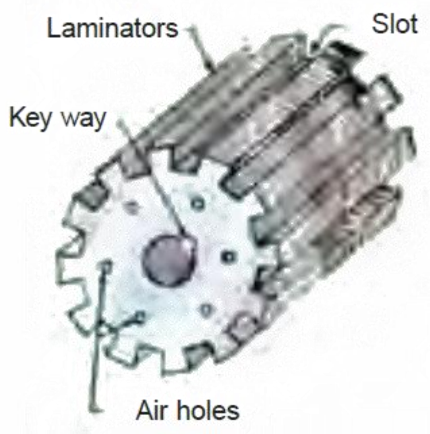


Figure (17)

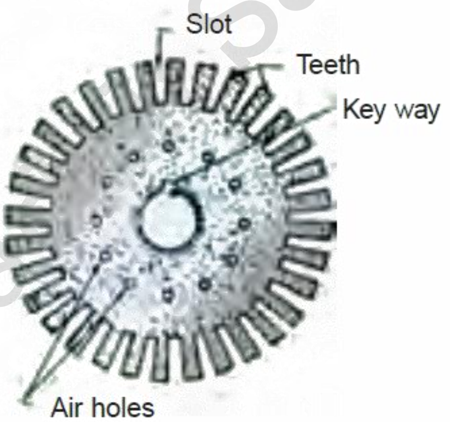


Figure (18)

5- Armature Windings or Conductors:

The armature windings are usually former-wound.
These are first wound in the form of flat rectangular coils and are then pulled into their proper shape in a coil puller. Various conductors of the coils are insulated from each other. The conductors are placed in the armature slots which are lined with tough insulating material. This slot insulation is folded over above the armature conductors placed in the slot and is secured in place by special hard wooden or fibre wedges.

6- Commutator:

The function of the commutator is to facilitate collection of current from the armature conductors. it rectified $i.e.$ converts the alternating current induced in the armature conductors into unidirectional current in the external load circuit. It is of cylindrical structure and is built up of wedge-shaped segments of high-conductivity hard-drawn or drop forged copper.

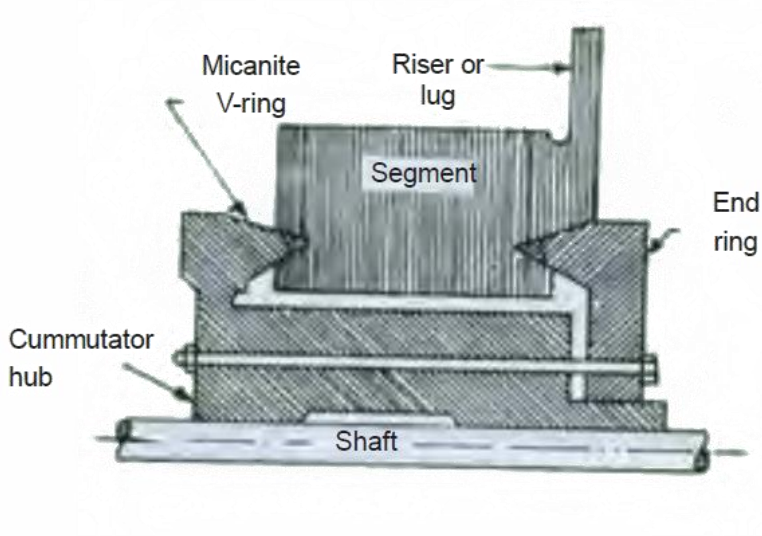


Figure (19)

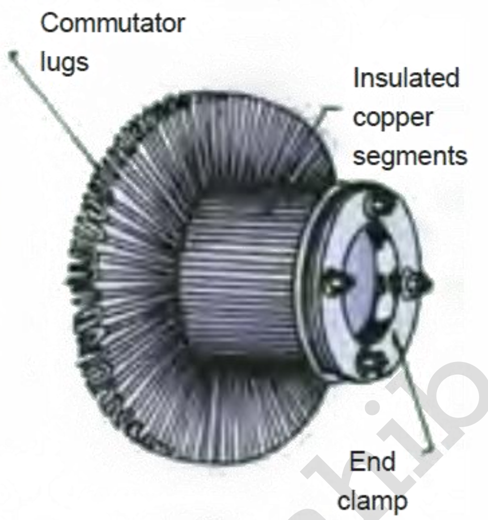
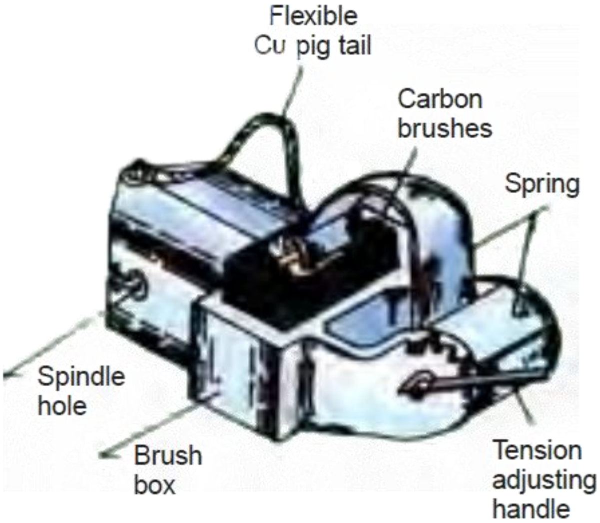


Figure (20)

7- Brushes and Bearings:

The brushes whose function is to collect current from commutator, are usually made of carbon or graphite and are in the shape of a rectangular block. These brushes are housed in brush-holders usually of the box-type variety. The brush-holder is mounted on a spindle and the brushes can slide in the rectangular box open at both ends. The brushes are made to bear down on the commutator by a spring whose tension can be adjusted by changing the position of lever in the notches. A flexible copper pigtail mounted at the top of the brush conveys current from the brushes to the holder. The number of brushes per spindle depends on the magnitude of the current to be collected from the commutator.

Figure (21)



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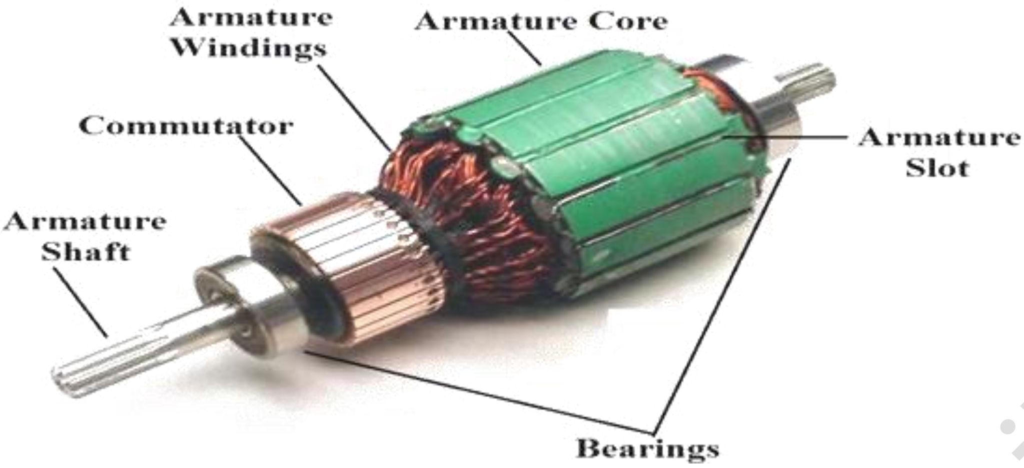


Figure (23) : Armature of D.C. Machine

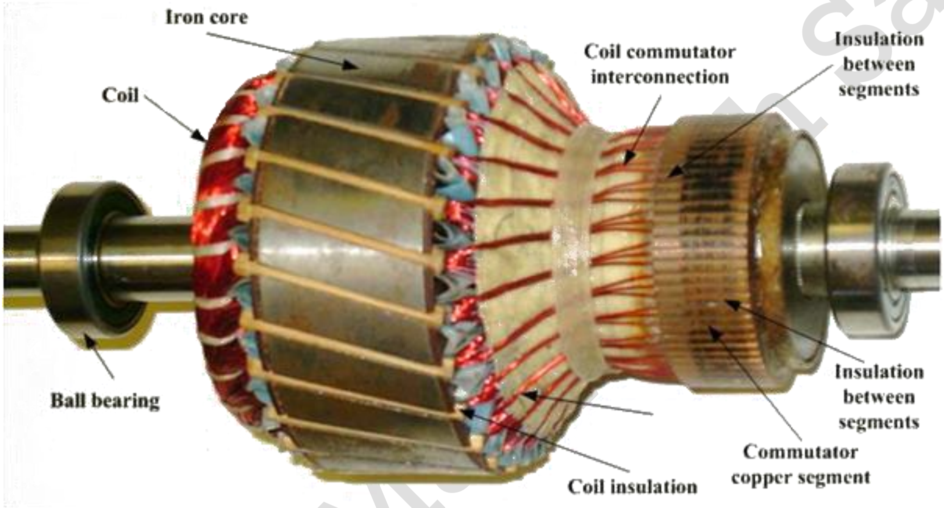


Figure (24) : Armature of D.C. Machine

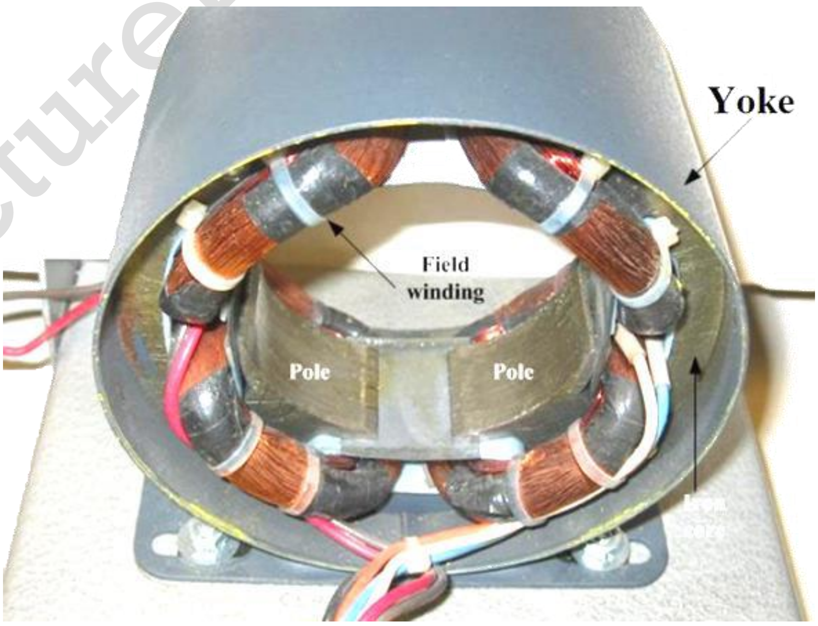


Figure (25) : Yoke of D.C. Machine

Armature Windings:

Now, we will discuss the winding of an actual armature. But before doing this, the meaning of the following terms used in connection with armature winding should be clearly kept in mind.

Types of Generators:

Generators are usually classified according to the way in which their fields are excited. Generators may be divided into

(a) Permanent magnet generators
(b) Electromagnet generators
  (1) Separately-excited generators
  (2) Self-excited generators

(a) Permanent-magnet field:

permanent-magnet D.C. machines are widely found in a wide variety of *low-power* applications. The field winding is replaced by a permanent magnet, resulting in simpler construction. Chief among these is that they do not require external excitation and its associated power dissipation to create magnetic fields in the machine the space required for the permanent magnets may be less than that required for the field winding, and thus machine may be *smaller*, and in some cases *cheaper*, than their externally excited counter parts.

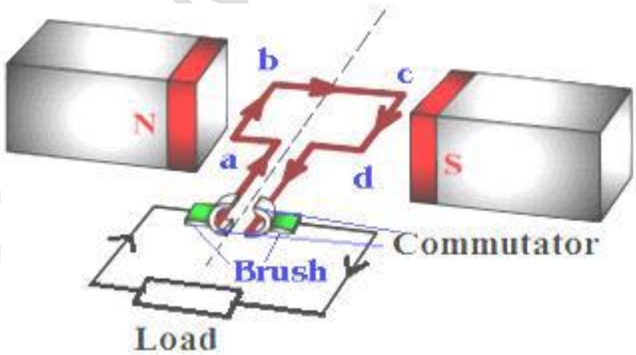


Figure (26): permanent magnet D.C. generator

(b) Electromagnet generators:

(1) Separately-excited generators:

are those whose field magnets are energised from an independent external source of D.C. current. It is shown in Figure (27).

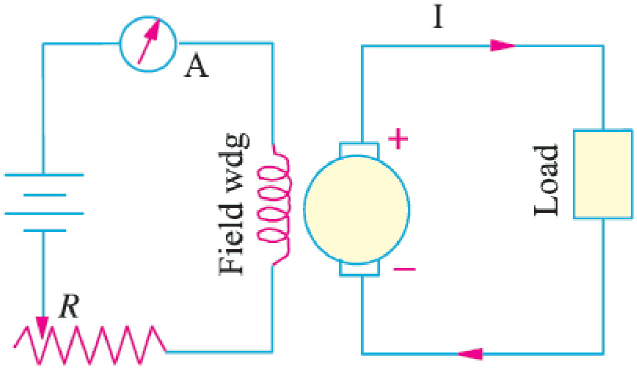


Figure (27): Schematic Diagram of Separately excited generators

$I_a = I_L$

$E_g = V + I_a R_a + V_{\text{brushes}}$

Where:

I_a: armature current

I_L: load current

E_g: generated voltage

V: terminal voltage

R_a: armature winding resistance

V_{brushes}: total brush contact drop

(2) Self-excited generators:

Are those whose field magnets are energised by the current produced by the generators themselves. Due to residual magnetism, there is always present some flux in the poles. When the armature is rotated, some e.m.f. and hence some induced current is produced which is partly or fully passed through the field coils thereby strengthening the residual pole flux.

There are three types of self-excited generators named according to the manner in which their field coils (or windings) are connected to the armature.

(*i*) Shunt wound:

The field windings are connected across or in parallel with the armature conductors and have the full voltage of the generator applied across them Figure (28).

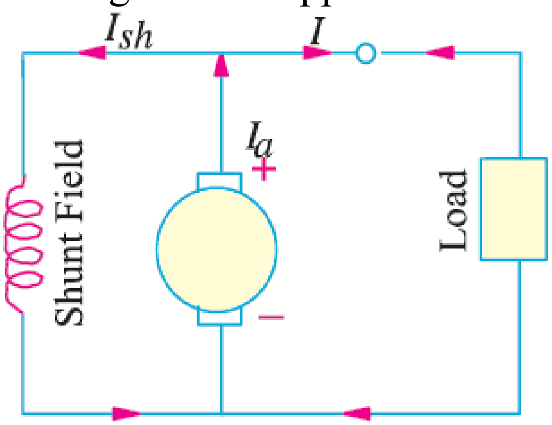


Figure (28): Schematic Diagram of Shunt Wound generators

$$I_a = I_L + I_{sh}$$
$$I_{sh} = \frac{V}{R_{sh}}$$
$$E_g = V + I_a R_a + V_{\text{brushes}}$$

Where:
I_{sh}: shunt field winding current
R_{sh}: shunt field winding resistance

(*ii*) Series Wound:

In this case, the field windings are joined in series with the armature conductors Figure (29). As they carry full load current, they consist of relatively few turns of thick wire or strips. Such generators are rarely used except for special purposes i.e. as boosters etc.

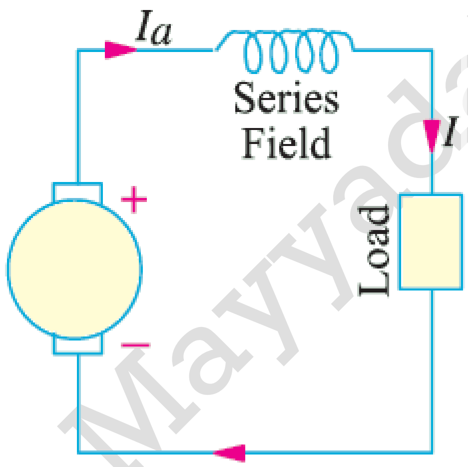


Figure (29): Schematic Diagram of Series Wound Generators

$$I_a = I_{se} = I_L$$
$$E_g = V + I_a R_a + I_a R_{se} + V_{\text{brushes}}$$
$$E_g = V + I_a (R_a + R_{se}) + V_{\text{brushes}}$$

Where:
I_{se}: series field winding current
R_{se}: series field winding resistance

(*iii*) Compound Wound:

It is a combination of a few series and a few shunt windings and can be either short-shunt or long-shunt as shown in Figure (30-a) and Figure (30-b) respectively. In a compound generator, the shunt field is stronger than the series field. When series field aids the shunt field, generator is said to be *cumulatively-compounded*. On the other hand if series field opposes the shunt field, the generator is said to be *differentially compounded*.

For short shunt:

$$I_L = I_{se}$$
$$I_a = I_L + I_{sh}$$
$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}}$$
$$E_g = V + I_a R_a + I_L R_{se} + V_{\text{brushes}}$$

For long shunt:

$$I_a = I_{se}$$
$$I_a = I_L + I_{sh}$$
$$I_{sh} = \frac{V}{R_{sh}}$$
$$E_g = V + I_a R_a + I_a R_{se} + V_{\text{brushes}}$$
$$E_g = V + I_a (R_a + R_{se}) + V_{\text{brushes}}$$

(a) Short-Shunt Compound Generator (b) Long-Shunt Compound Generator

Figure (30): Compound wound D.C. Generator

Brush Contact Drop:

It is the voltage drop over the brush contact resistance when current passes from commutator segments to brushes and finally to the external load. Its value depends on the amount of current and segments to brushes and finally to the external load. Its value depends on the amount of current and However, in practice, the brush contact drop is assumed to have following constant values for all loads.

0.5V for metal-graphite brushes.

2.0V for carbon brushes.

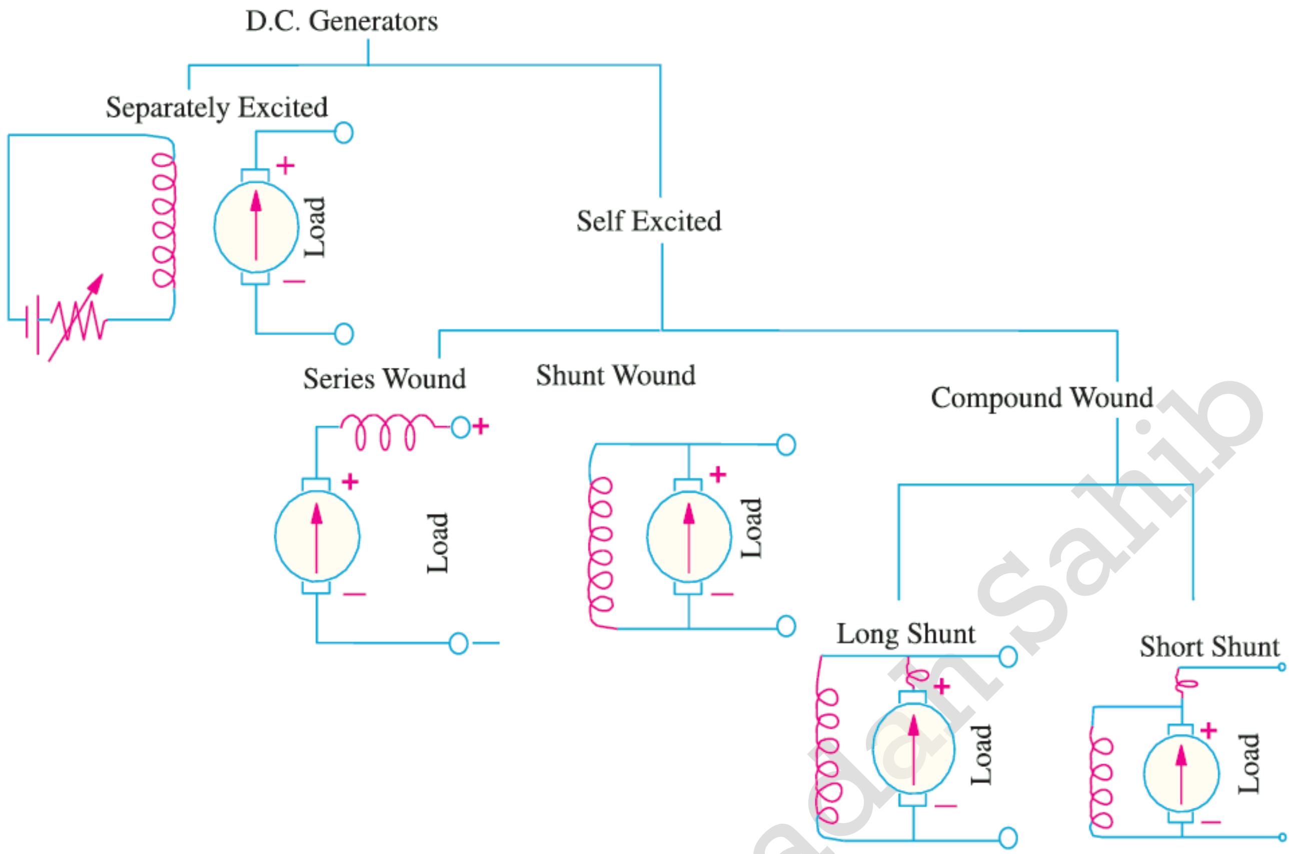


Figure (31)

Example 1: A shunt generator delivers 450A at 230V and the resistance of the shunt field and armature are 50Ω and 0.03Ω respectively. Calculate the generated e.m.f.

Solution: Generator circuit is shown in Figure (32):

Current through shunt field winding is:

$$I_{sh} = \frac{230}{50} = 4.6\text{A}$$

Load current $I = 450\text{A}$

$\therefore$ Armature current $I_a = I + I_{sh}$

$$I_a = 450 + 4.6 = 454.6\text{A}$$

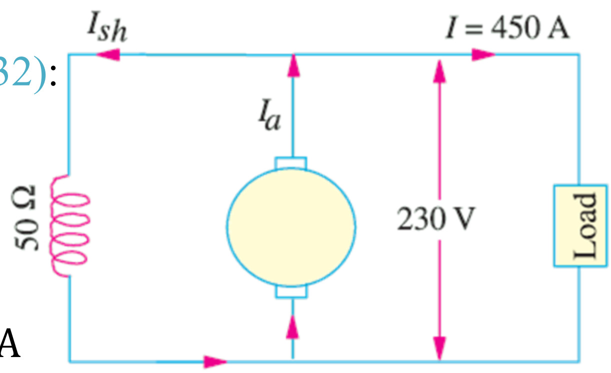


Figure (25)

Armature voltage drop

$$I_a R_a = 454.6 \times 0.03 \cong 13.6\text{V}$$

$$E_g = \text{terminal voltage} + \text{armature drop}$$

$$E_g = V + I_a R_a$$

$\therefore$ e.m.f. generated in the armature

$$E_g = 230 + 13.6 = 243.6\text{V}$$

Example 2: A D.C. shunt generator has an induced voltage on open-circuit of 127V. When the machine is on load, the terminal voltage is 120V . Find the load current if the field circuit resistance is 15Ω and the armature-resistance is 0.02Ω. Ignore armature reaction.

Solution: Generator on no load:

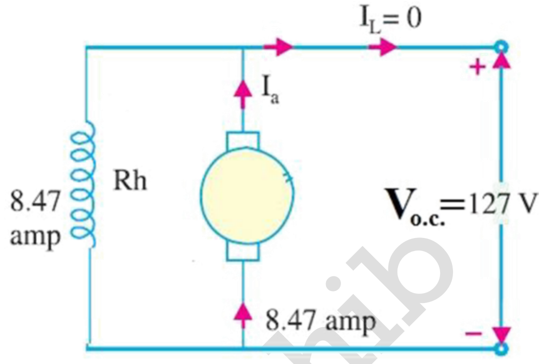
in this case we can find the generated e.m.f. directly because there is no voltage drop on load ($I_L = 0$, so $I_a = I_{sh}$), so the generated e.m.f. can be found by adding the O.C. voltage and voltage drop on armature resistance, as shown in Figure (33-a),

$$V_{o.c.} = 127V$$

$$I_a = I_{sh} = \frac{V}{R_{sh}} = \frac{V_{o.c.}(\text{or e.m.f})}{R_{sh}} = \frac{127}{15} = 8.47A$$

$$E_g = V_{o.c.} + I_a R_a$$

$$= 127 + (8.47 \times 0.02) = 127.17V$$



(a) Generator on no-load

Figure (33-a)

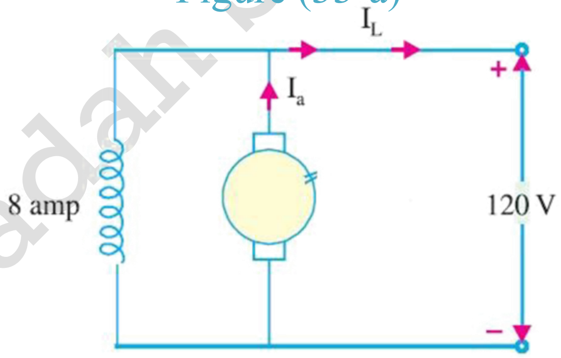
Figure (33-b), represent load cases,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{120}{15} = 8A$$

$$E_g = V + I_a R_a = 127.17 = 120 + I_a(0.02)$$

$$I_a = \frac{127.17 - 120}{0.02} = 358.5A$$

$$\therefore \quad I_L = I_a - I_{sh} = 358.5 - 8 = 350.5A$$



(b) Loaded Generator

Figure (33-b)

Example 3: An 8-pole D.C. shunt generator with 778 wave-connected armature conductors and running at 500 $r.p.m.$ supplies a load of 12.5Ω resistance at terminal voltage of 250V. The armature resistance is 0.24Ω and the field resistance is 250Ω. Find the armature current, the induced e.m.f. and the flux per pole.

Solution:

Load current $= \frac{V}{R} = \frac{250}{12.5} = 20A$

Shunt current $= \frac{250}{250} = 1A$

Armature current $= 20 + 1 = 21A$

Induced e.m.f. $= 250 + (21 \times 0.24) = 255.04V$

generated e.m.f. $E_g = \frac{\Phi Z N}{60}\left(\frac{P}{A}\right)$

$$255.04 = \frac{\Phi \times 778 \times 500}{60}\left(\frac{8}{2}\right)$$

$$\therefore \quad \Phi = 9.83mWb$$

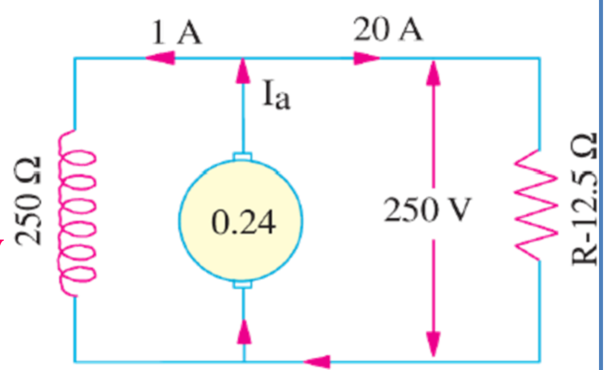


Figure (34)

Example 4: A long-shunt compound generator delivers a load current of 50A at 500V and has armature, series field and shunt field resistances of 0.05Ω , 0.03Ω and 250Ω respectively. Calculate the generated voltage and the armature current. Allow 1V per brush for contact drop.

Solution: Generator circuit is shown in Figure (35):

$I_{sh} = \frac{500}{250} = 2A$

Current through armature and series winding is

$= 50 + 2 = 52A$

Voltage drop on series field winding

$= 52 \times 0.03 = 1.56V$

Armature voltage drop

$I_a R_a = 52 \times 0.05 = 2.6V$

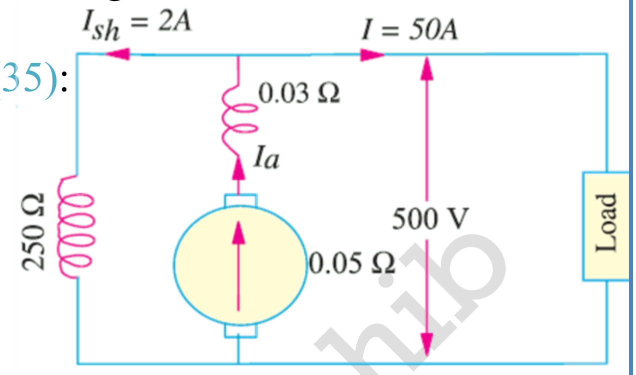


Figure (35)

Note: If there is no information about the number of brushes or the type of winding in the question, then we assume that the number of brushes are two (means wave winding).

Drop at brushes

$= 2 \times 1 = 2V$

$E_g = V + I_a R_a + \text{series drop} + \text{brush drop}$

$= 500 + 2.6 + 1.56 + 2 = 506.16V$

Example 5: A short-shunt compound generator delivers a load current of 30A at 220V, and has armature, series-field and shunt-field resistances of 0.05Ω, 0.30Ω and 200Ω respectively. Calculate the induced e.m.f. and the armature current. Allow 1.0V per brush for contact drop.

Solution: Generator circuit diagram is shown in Figure (36):

Voltage drop in series winding $= 30 \times 0.3 = 9V$

Voltage across shunt winding $= 220 + 9 = 229V$

$I_{sh} = \frac{229}{200} = 1.145A$

$I_a = 30 + 1.145 = 31.145A$

$I_a R_a = 31.145 \times 0.05 \cong 1.56A$

Brush drop $= 2 \times 1 = 2V$

$E_g = V + \text{series drop} + \text{brush drop} + I_a R_a$

$E_g = 220 + 9 + 2 + 1.56 = 232.56V$

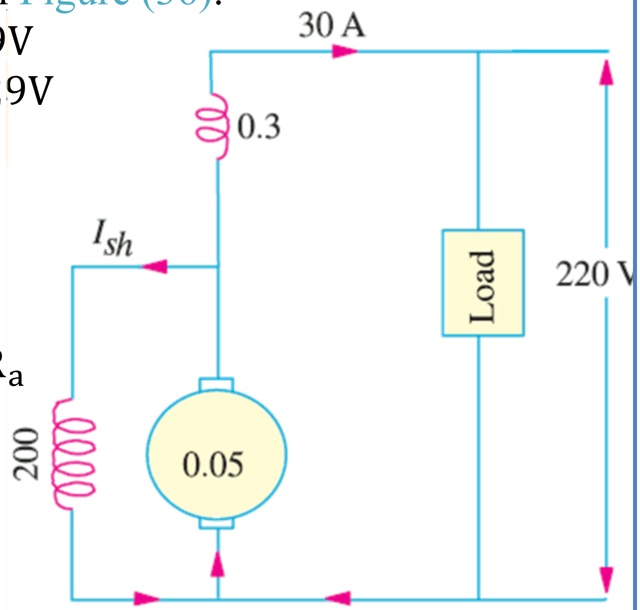


Figure (36)