Direct current machines

INTRODUCTION

Direct current machines as a class include those machines that either produce or utilize direct current.

In either case the machine functions as an energy conversion device, where the conversion is from mechanical to electrical energy the machine is termed a generator.

If the conversion process proceeds in the other direction the machine is a motor.

Whether a machine operates a motor or a generator in a given situation is largely independent of the machine conditions and parameters but depends on the direction of power flow between the machine and the electrical supply system.

The motor convert the electrical energy into mechanical energy, while the generator convert the mechanical energy into electrical energy.

CONSTRUCTION OF THE DC MACHINE

The essential features of a dc machine are shown in Fig.1.

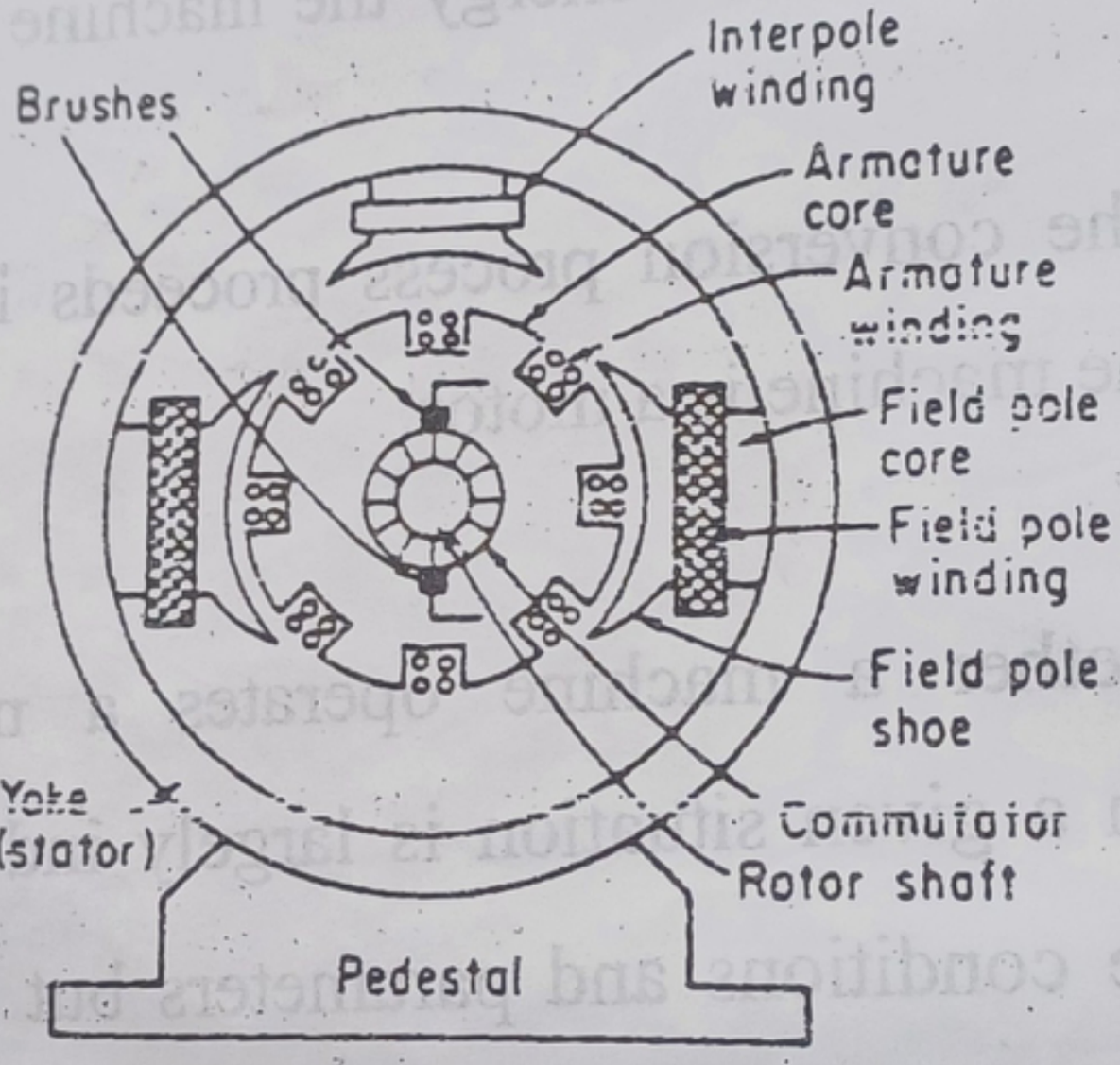
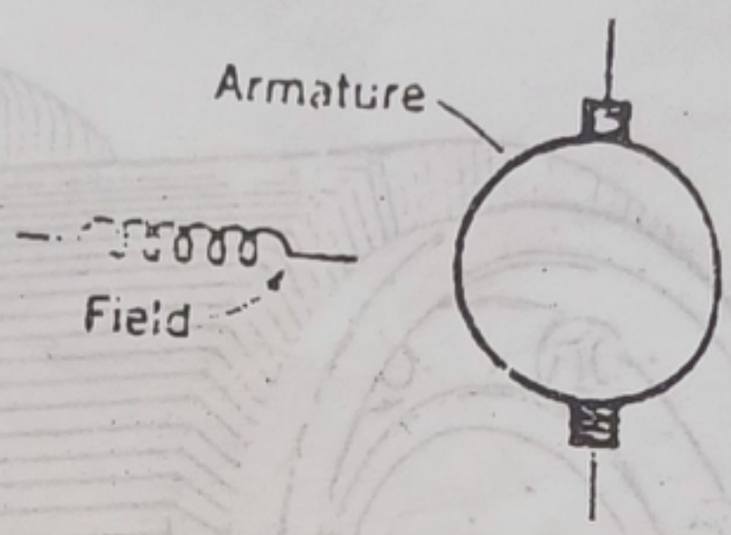


Fig.1

The stator has salient poles and is excited by one or more field coils.

In the dc M/C the stator called "field", while the rotor called "armature".



When the field winding is connected to the dc source, magnetic flux will produce.

#This flux produced will cut the armature winding and induce in it voltage.

The voltage induce in the armature coil is an alternating voltage, which must be rectified.

In the convential dc machine rectification is provided mechanically by means of a "commutator".

The commutator is a cylinder formed of copper segments insulated from each other by mica and mounted on the rotor shaft as shown in Fig.2.

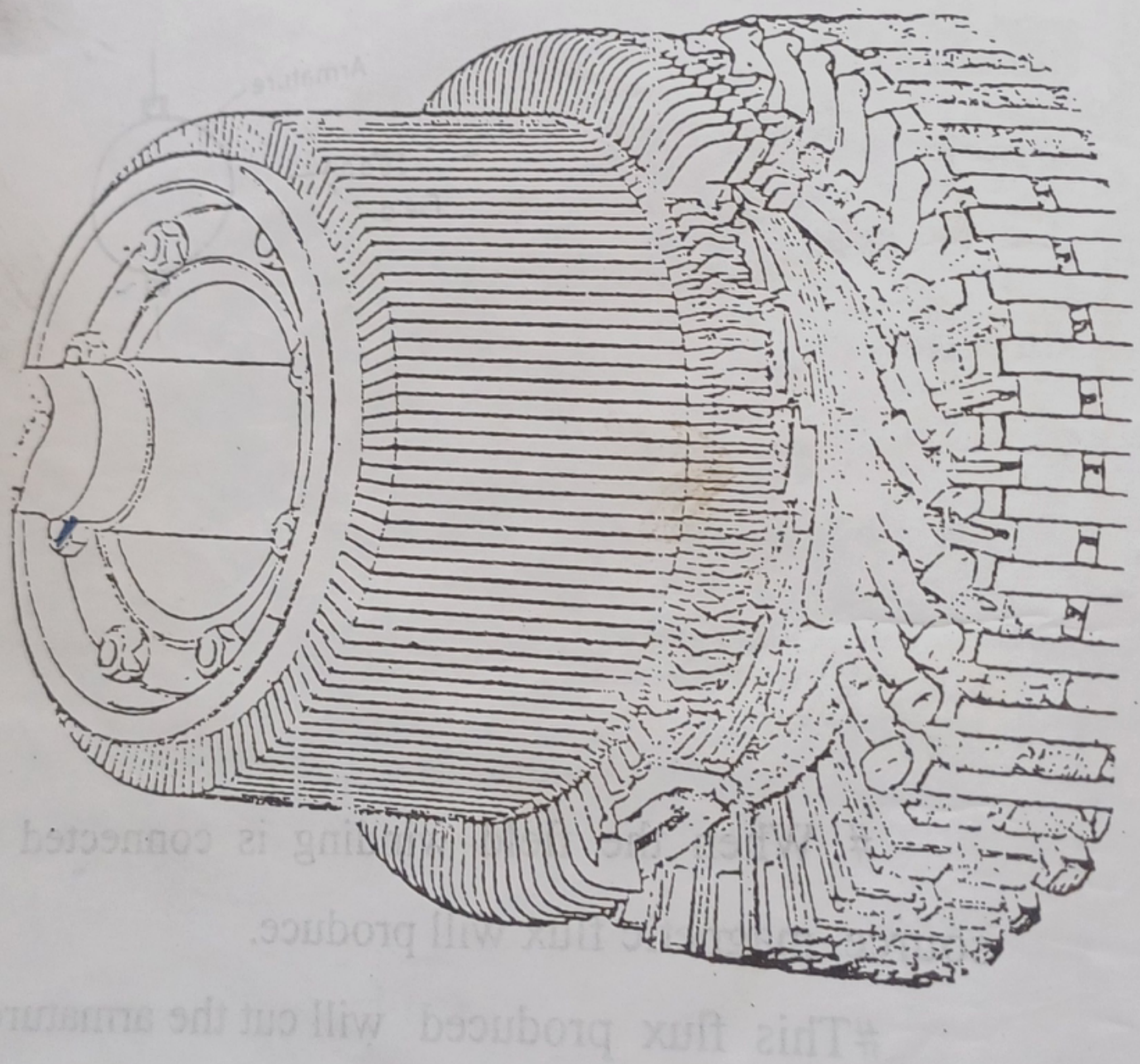


Fig.2

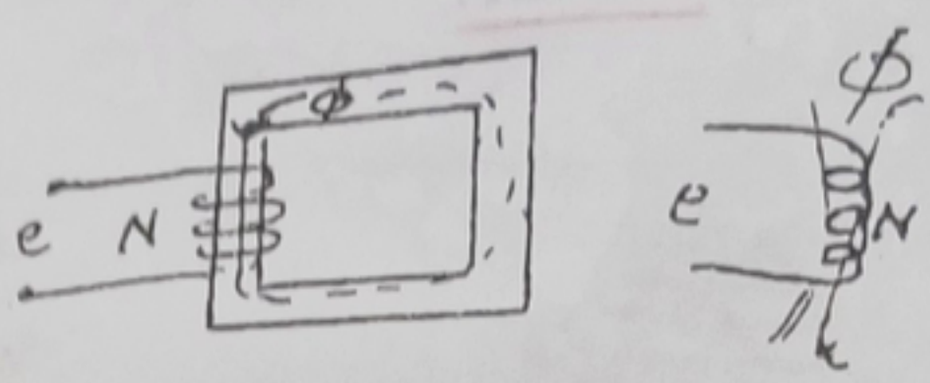
Stationary carbon brushes held against the commutator surface connect the winding to the external armature terminals.

The need for commutation is the reason why the armature windings of dc machines are placed on the rotor.

Faraday's law

When a magnetic field varies with time, an electric field is produced in space. In magnetic structure with winding the varying magnetic field in the core produces an induced voltage e at the terminals, of the value determined by Faraday's law

$$e = N\frac{d\phi}{dt}$$



In case of AC supply $\varphi = \varphi_m \sin wt$

In rotating machines are generated in winding or group of coils by rotating these winding mechanically through a magnetic field.

In the case of a dc machine $\varphi = cons\tan t$

$$e = N\frac{d\varphi}{dt} = N\frac{\Delta\varphi}{\Delta t}$$

$$\Delta\varphi = +\varphi - (-\varphi) = 2\varphi$$

$$\therefore e = N\frac{2\varphi}{\Delta t}$$

METHODS OF FIELD EXCITATION

DC machines may be magnetized by currents obtained from a separate source, such as a battery or an auxiliary dynamo called an exciter, or they may generate their own magnetizing currents. These two "separate excitation" and "self excitation" respectively.

(A) Separate excitation

In fig.3 the diagram of the essential connection of separate excitation is given.

Separate excitation is largely used in the works testing of dc machines for determination of the open-circuit or magnetization characteristic.

Separate excitation has the great advantage that the value of the exciting current is independent of that of the load.

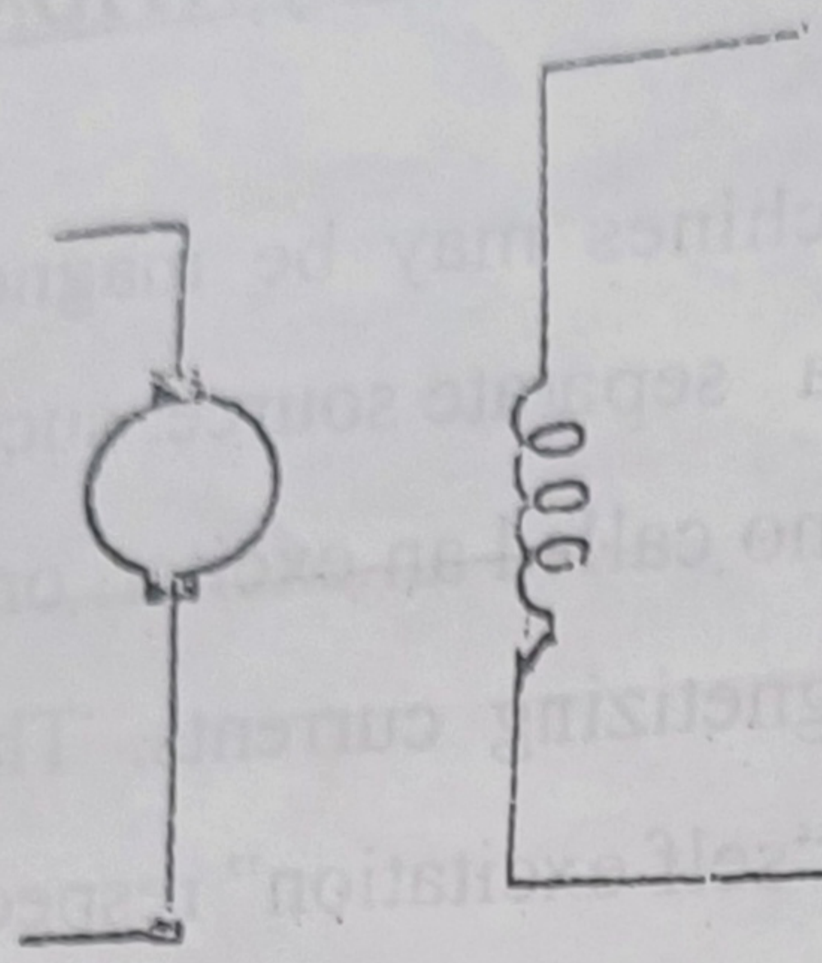


Fig.3

(B) Self excitation

The field windings of self-excited dc machines may be supplied in three different ways.

a-The field may be connected in series with the armature (fig.4), resulting "**series machine**".

The power loss in the series field windings equal to $I_f^2 R_{f(series)}$.

$$I_f = I_a$$

$$R_{f(series)} = \rho L/a$$

As the armature current is determined by the load, to reduce this power loss the series field resistance should be decreased, consequently the cross section of

the series field winding is big (thick wire with small number of turns are used).

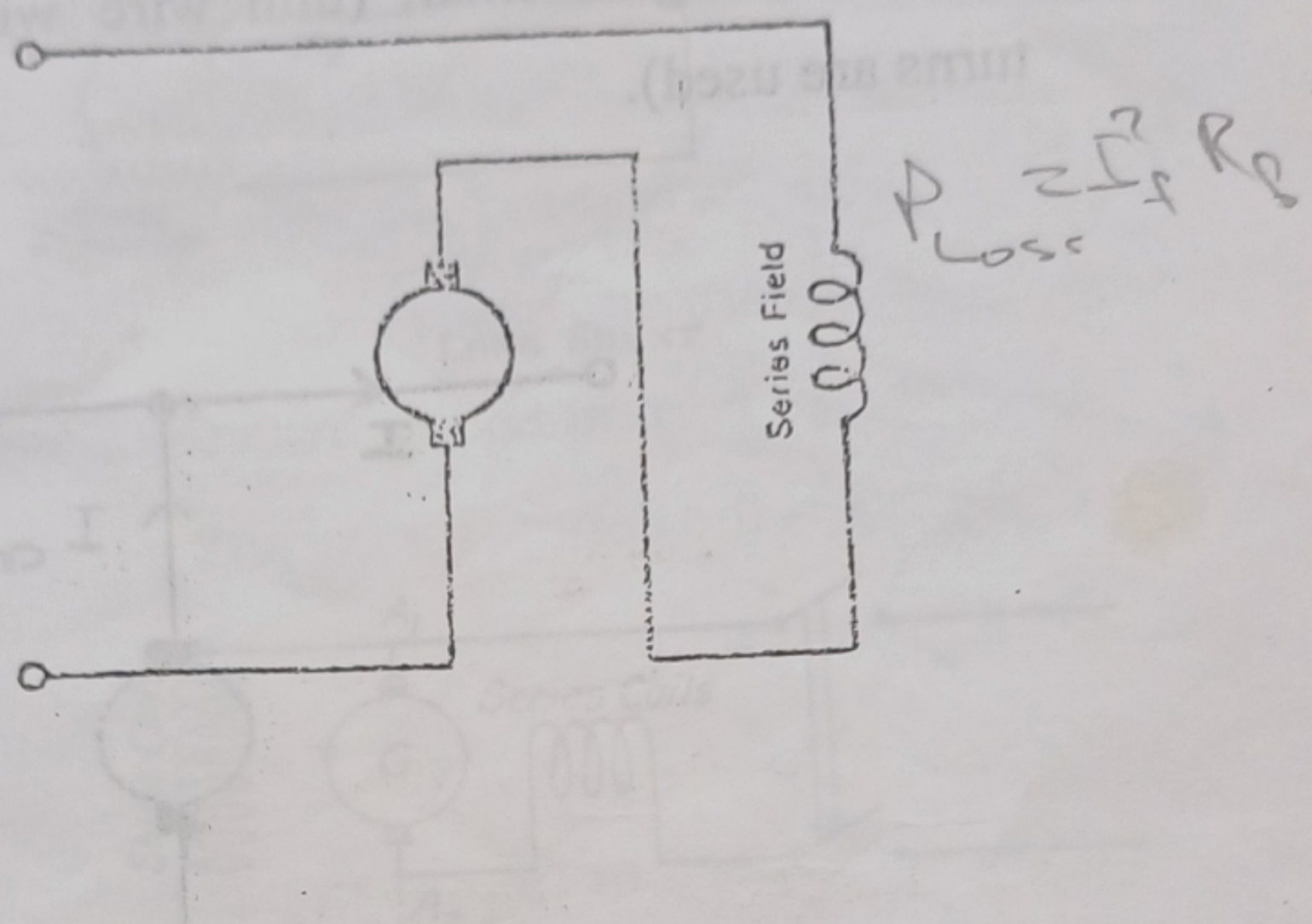


Fig.4

b-The field may be connected in shunt with the armature(fig.5), resulting a "**shunt machine**".

The power loss in the shunt field windings equals

$$P_{loss} = I_f^2 R_{f(shunt)}$$

$$= (V / R_{f(shunt)})^2 R_{f(shunt)}$$

$$= V^2 / R_{f(shunt)}$$

$$R_{f(shunt)} = \rho L / a$$

As the supply voltage (V) is constant, to reduce this power loss the shunt field resistance should be increased, consequently the cross section of the shunt field winding is small (thin wire with large number of turns are used).

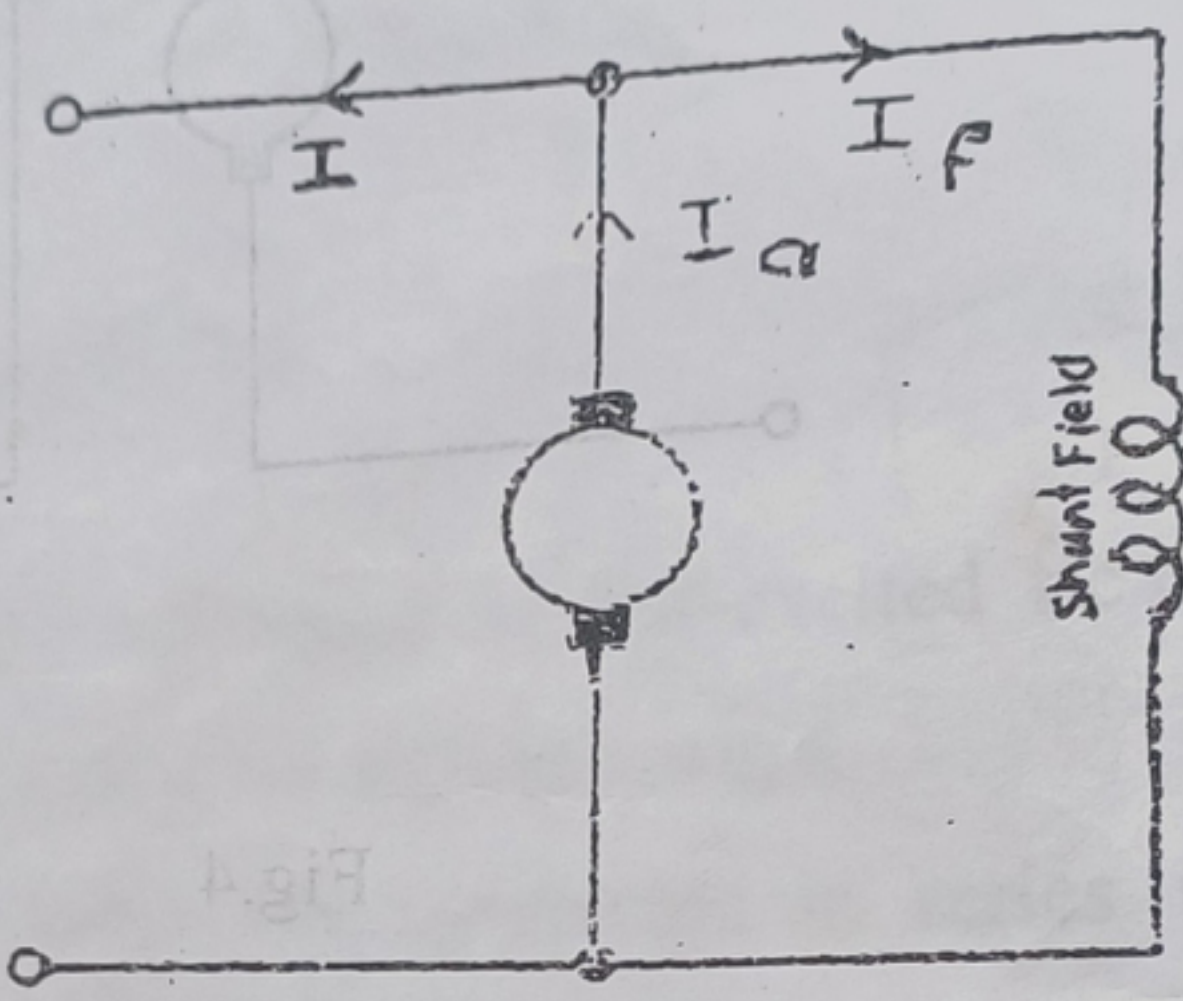
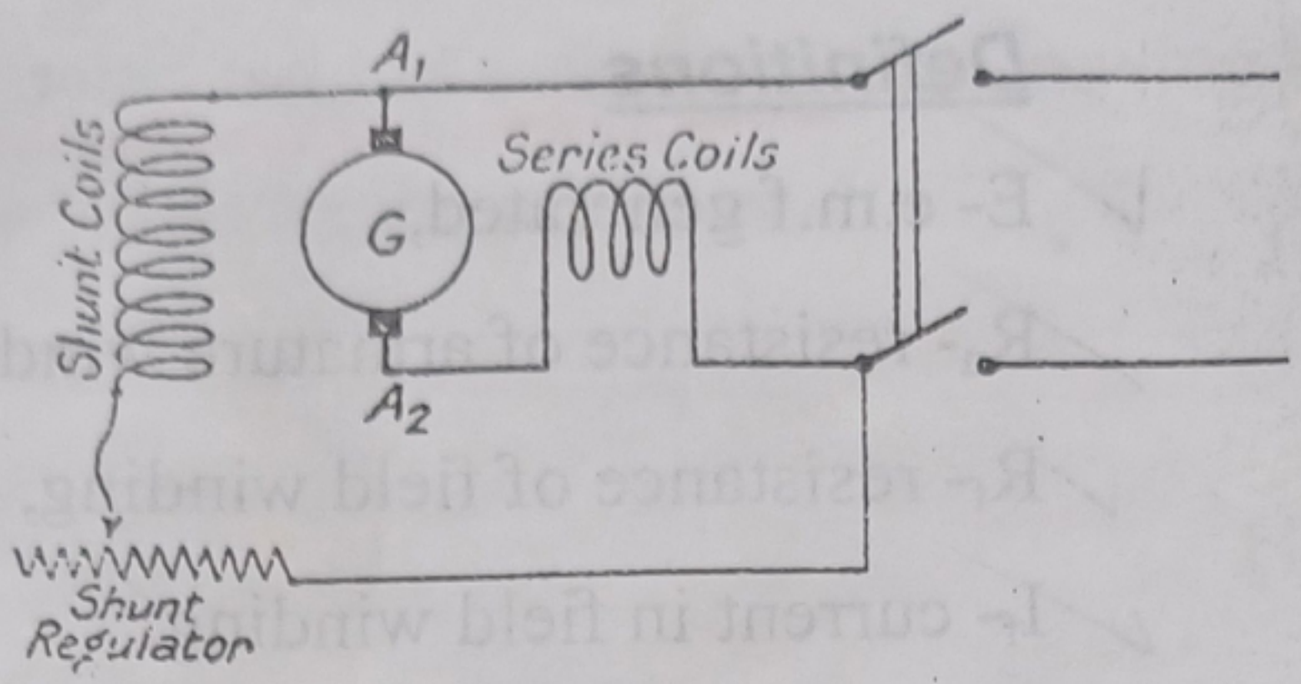
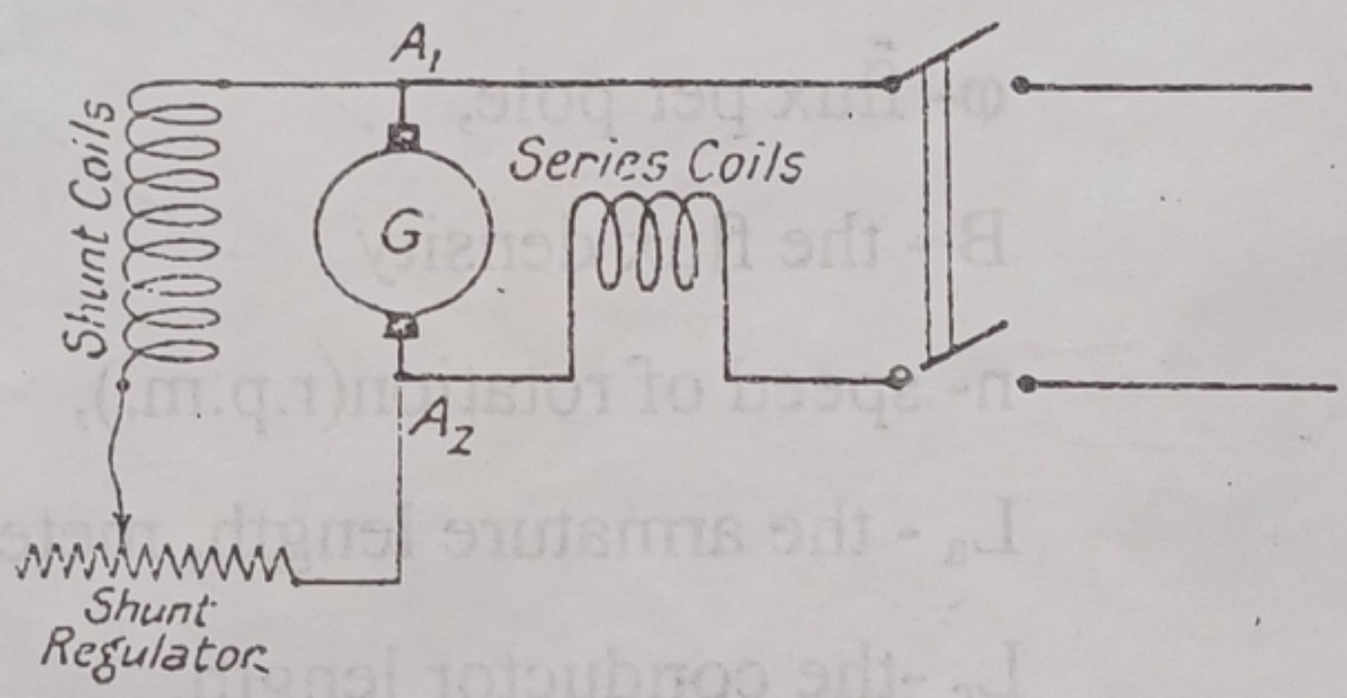


Fig.5

c-The field may be in two sections (fig.6), one of which is connected in series and the other in shunt with the armature, resulting a "**compound machine**".



LONG SHUNT



SHORT SHUNT

Fig.6

With self-excited machines residual magnetism must be present in the machine iron to get the self-excitation process started.

Definitions

E- e.m.f generated,

R_a- resistance of armature winding

R_f- resistance of field winding,

I_f- current in field winding,

I_a- armature current,

I_S - current taking from the supply,

I_c - the conductor current

φ- flux per pole,

B - the flux density

n- speed of rotation(r.p.m.),

L_a - the armature length, meter

L_c -the conductor length,

D_a - the armature diameter,

A - the area under the pole,

Z - the number of armature conductors,

E_b - the back e.m.f,

T - the torque ,

T_L- the load torque,

T_D- the torque due to damping (friction)

T_{pm}- the prime-mover torque.

صفوت احمد

The e.m.f (e_c) induced in a conductor of length L_c located in a magnetic field of a density B and moving by a linear speed " v " can be expressed as

$$e_c = BL_c v \qquad (1)$$

$$B = \frac{\varphi}{A} \qquad (2)$$

$$A = \frac{\Pi D_a}{2p} L_a$$

$$\therefore e_c = \frac{\varphi L_a}{\Pi D_a L_a / 2p} \frac{\Pi D_a n}{60}$$

$$\therefore e_c = \varphi 2pn / 60 \qquad (3)$$

The e.m.f induced in all conductors is

$$e_z = \frac{\varphi}{60} 2pnZ \qquad (4)$$

The e.m.f induced in the armature is

$$E = \frac{e_Z}{2a}$$

is the number of current paths.

$$\therefore E = \frac{2p}{2a}\frac{Z}{60}n\varphi \qquad (5)$$

$$k_e = \frac{2p}{2a}\frac{Z}{60}$$

$$\therefore E = kn\varphi$$

⊗For the Motor case

$$V = E_b + I_a R_a$$

$$\therefore E_b = V - I_a R_a \qquad (6)$$

where

V is called the applied voltage on the terminals of the armature,

E_b is back emf

For wave wound armature a will be equal 2 but for Lap wound armature a will be equal the number of poles.

⊗For the Generator case

$$E_{in} = V + I_a R_a \qquad (7)$$

where

V is called the terminal voltage appears on the terminals of generator.

E_{in} is induced emf

Example A six pole wave wound (a=2) d.c generator has Z = 410 active conductors. If the generator is driven at n = 750 rpm: cadculate the open circuit volts if the useful flux per pole is $\phi = .03$ Webers

Solution: —

Z = 410, p = 6, a = 2, $\phi = .03$ Webers

n = 750 rps.

$$E = \frac{\phi Z n}{60} \times \frac{p}{a}$$

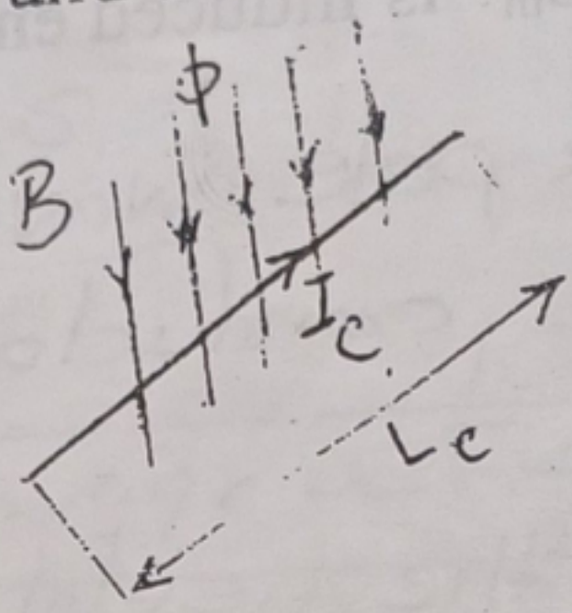
$$= \frac{.03 \times 410 \times 750}{60} \times \frac{6}{2} = 461 \text{ volts.}$$

The principle of operation of the dc motor

Motor action is based upon the fact that a mechanical force is exerted on a current carrying conductor in a magnetic field.

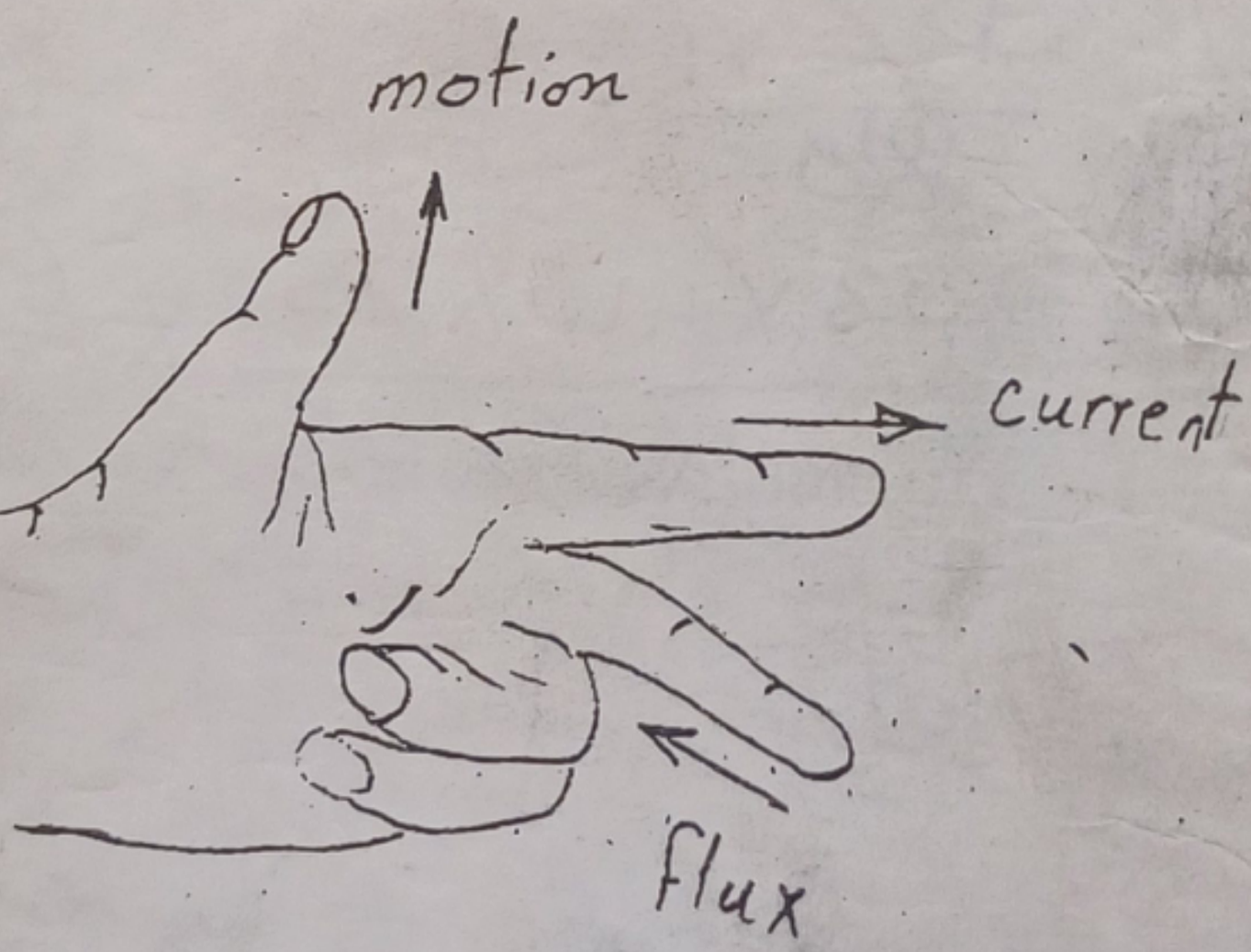
The magnitude of the force (F) is proportional to the product of the field strength and the current.

$$F = BL_cI_c \qquad (7.a)$$



Where a motor is being considered , the basic rule is Flemings Left Hand Rule.

The direction of the force exerted on a current carrying conductor in a magnetic field is shown in fig.



The torque equation of dc motors

Where the conductor is pivoted and the radial distance between the conductor and the axis of rotation is denoted by the symbol $D_a/2$, the torque developed in the armature (T) is given by the expression

Torque developed in one conductor

$$T_{cond} = F.D_a/2$$

$$T_{cond} = BL_cI_cD_a/2 \qquad (7.b)$$

$$T = ZBL_cI_cD_a/2$$

$$T = Z\left(\frac{\varphi}{\frac{\Pi D_a L_a}{2p}}\right)L_a\left(\frac{I_a}{2a}\right)(D_a/2)$$

$$T = \frac{2P}{2a}\frac{Z}{2\Pi}\varphi I_a \qquad K_t$$

$$\therefore T = k_t\varphi I_a \qquad (7.c)$$

$$k_1 = \frac{2P}{2a}\frac{Z}{2\Pi}$$

Another derivation to the torque equation of the dc machines

The torque developed in the armature is expressed by

$$P = E_b I_a = T\omega \qquad (8)$$

Back e.m.f Back current

$$T = \frac{E_b I_a}{\omega}$$

$$T = \frac{\frac{(2p)Z}{(2a)60} n\varphi I_a}{\frac{2\pi n}{60}}$$

Ex A four pole Lap wound armature has a total of 970 conductors. If the flux per pole is 0.06 Wb and the armature current is 48.6 A. Calculate the torque developed.

$$T = \frac{(2\ p)\ Z}{(2\ a)(2\ \pi)} \varphi\ I_a$$

$$k_t = \frac{2\ p}{2\ a}\ \frac{Z}{2\ \pi}$$

$$T = k_t \varphi I_a \qquad (9)$$

For the dc motor case

$$T = T_L + T_D \qquad (10)$$

For the dc generator case

$$T_{pm} = T + T_D \qquad (11)$$

Solution

$$T = \frac{Z \Phi I_a}{2\pi} \frac{P}{a}$$

$$= \frac{970 \times 0.06 \times 456}{2\pi} = 450\ N.m$$

Losses in dc motors

1) Copper losses

- armature copper loss $I_a^2R_a$
- field copper loss $I_f^2R_f$

2) Iron (core) losses

- hysterises losses
- eddy current losses

3) Mechanical losses

- friction losses at bearing and commutator
- air friction or windage losses of rotating armature.

Ex: A 10 Kw, 250 v dc, shunt motor has an armature resistance of 0.39 Ω. a strunt field resistance of 200Ω and a stray Loss of 200w. Calculate efficiency for an input of 11 Kw.

Solution

$P_{in} = 11000$ Watts, $I = \frac{P}{V_t} = \frac{11000}{250} = 44$ A

$I_f = \frac{V_t}{R_f} = \frac{250}{200} = 1.25$ A, $I_a = I - I_f$

$I_a = 44 - 1.25 = 42.75$ A, $I_a^2R_a = (42.75)^2 \times 0.39$

$= 712.74$ W

$I_f^2R_f = (1.25)^2 \times 200 = 312.5$, stray Loss $= 200$ W

$\eta = \frac{P_{out}}{P_{in}} = \left(\frac{10000}{10000 + 712.75 + 312.5 + 200}\right) \times 100$

$= 89.82\%$