CHAPTER II

THEORETICAL BACKGROUND

2.1 INTRODUCTION

An electric motor is a machine which converts electrical energy into mechanical energy, i.e. its input is electrical energy and output is mechanical energy. The conversion of electrical energy into mechanical energy which drives the armature of the motor.

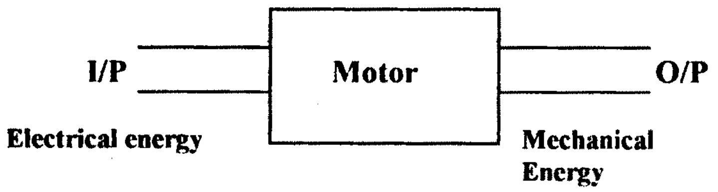


Fig 2.1 Basic Input Output Energy Diagram

Its action is based on the principle that when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Flamingo's left hand rule and whose magnitude is given by

$$F = BIL \text{ Newton.}$$

Where F= Force

B= Magnetic Flux.

I= Current flowing through the conductor.

L= Length of the conductor.

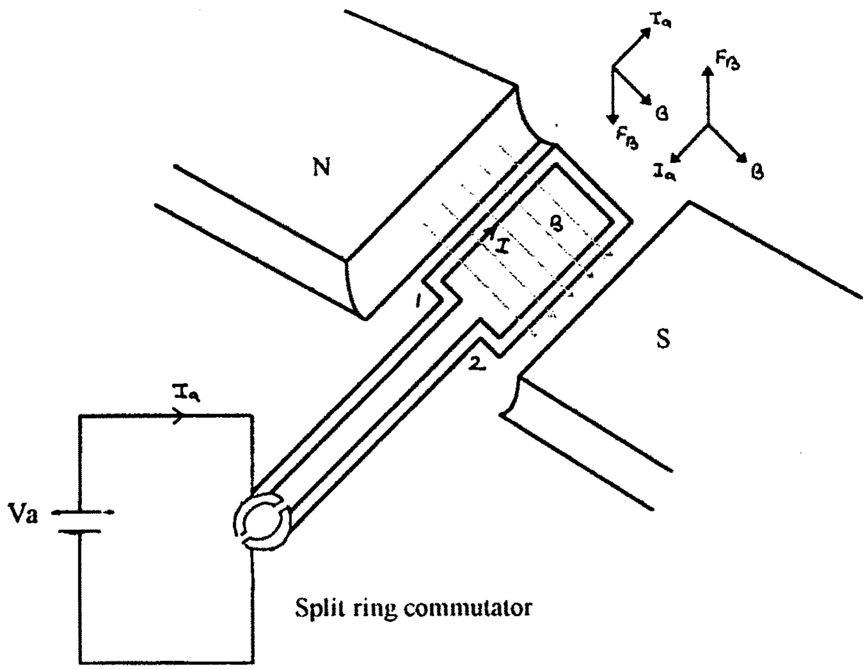


Fig.2.2 Construction of DC motor

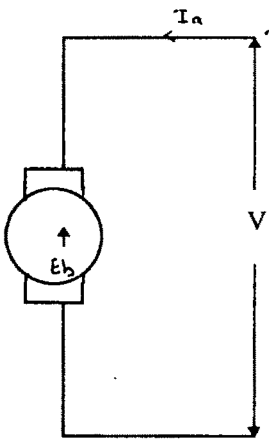


Fig. 2.3 (a)

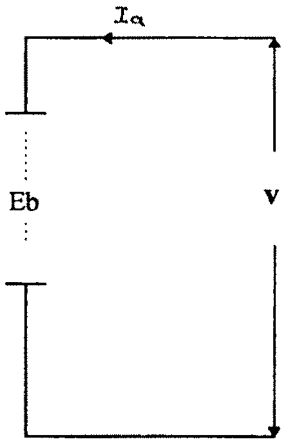


Fig. 2.3 (b)

Significance of back E.M.F.

2.2 BASIC DC MOTOR

Motors are transducers that convert energy from electrical form to mechanical form. The electrical current supplied to the motor causes the motor shaft to rotate , depending up on the coupling arrangement between load and motor shaft, the load will undergo prescribed motion.

DC motor consists of stator and armature. The armature has got armature windings and placed inside the stator rests on the bearings. the stator is made up of high grade laminated steel structure and stator windings are wound on it. It serves as a seat of magnetic flux.

2.2.1 CONSTRUCTION OF DC MOTOR

A coil is placed in between two poles of permanent magnet. the two ends of the coil are connected to split rings commutator and the external dc supply is given to the coil through the split rings. As the coil is placed in the permanent magnetic field, the lines of magnetic forces are cut.

When the current is passed through the coil, the direction of force acting on the conductor 1 is downward for the direction of current shown in fig.2.2. The current Ia is due to the flow of electrons in opposite direction and cross product of V and B is in upward direction. When this cross product is multiplied by the -ve electron charge, the correct downward direction of force is obtained and the force acting on the conductor 2 is upward. Therefore torque exists in the anti-clockwise direction.

Now the position of conductors 1 and 2 are reversed, i.e. conductor 2 is now near the north pole and conductor 1 is near the south pole, not only the conductor positions are reversed but the action of commutator reverses the polarity of the externally applied voltage from +ve to -ve for conductor 1 and -ve to +ve for conductor 2. Now force acting on conductor 2 is downward direction and force acting on conductor 1 is upward direction. The result of all this is that the loop is able to complete the remaining 180^0 of the currents once again. The switching action of commutator plays an important role in operation of motor making possible continuous rotation of armature.

If slip rings would have been used then armature would simply rock back and forth and never being able to complete one revolution.

2.2.2 SIGNIFICANCE OF BACK EMF

The equivalent circuit of a motor is shown in fig. 2.3 (b). The rotating armature generating the back emf like a battery of emf Eb, put across a supply mains of V volts. Obviously, V has to drive Ia against the opposition of Eb. The power required to overcome this opposition is Eb.Ia.

$$Ia = \frac{\text{Net Voltage}}{\text{resistance}} = \frac{(V\text{-}Eb)}{Ra} \qquad 2.1$$

Where Ra is the resistance of the armature circuit.

$$Eb = \frac{\phi.\ Z.\ N}{(P/A)}\ \text{Volts} \qquad 2.2$$

Where N is in rad/sec.

Back emf depends , among the other factor is the armature speed. If the speed is high, Eb is large, hence armature current Ia as seen from the above equation is small. If the speed is less then Eb is less, hence more current Ia as seen from the above equation is small. If the speed is less, then Eb is less, hence more current flows, which develops more torque. So we find Eb acts like a governor. i.e. it makes a motor self regulating, so that it draws as much current as it just necessary.

2.2.3 VOLTAGE EQUATION OF MOTOR

The voltage V applied across the motor armature has to overcome the back emf Eb and supply the armature ohmic drop Ia x Ra.

Therefore, $V = Eb + Ia^2 \times Ra$ 2.3

This is known as voltage equation for motor.

Now multiplying both sides by Ia.

$V \times Ia = Eb \times Ia + Ia \times Ra$ 2.4

Where $V \times Ia$ = Electrical input to armature.

$Eb \times Ia$ = Electrical equivalent of power developed in the armature.

$Ia^2 \times Ra$ = Copper loss in the armature.

Hence, out of armature input some is wasted in I^2R loss and the rest is converted in to mechanical power within the armature.

2.2.4 TORQUE

The term torque is meant the turning or twisting moment of force about an axis. It is measured by product of force and radius.

Therefore,

Torque = $F \times r$ .... N/M 2.5

Work done by the force in one revolution

= Force x Distance

= $F \times 2\pi r$ Joules.

Power developed = $F \times 2\pi r \times N$ Joules.

Power developed = $(F \times r) \times 2\pi N$ Watt. 2.6

2.2.5 ARMATURE TORQUE OF THE MOTOR

If Ta is torque developed by armature of motor running at N rpm. then power developed = $T_a \times 2\pi N$ watt 2.7

Also electrical power converted into mechanical power in armature = $E_b.I_a$ 2.8

from (1) and (2)

$T_a \times 2\pi N = E_b.I_a$

as $E_b = \phi ZN (P/A)$ Volts

$T_a \times 2\pi N =. \phi ZN (P/A) I_a$

$T_a = 0.159. \phi ZN (P/A) I_a$ 2.9

from the we find $T_a \propto I_a$

a) For series motors $\phi \propto T_a$ because field winding carry full armature current

Therefore $T_a \propto I_a^2$ 2.10

Therefore $Ta\ \alpha\ Ia^2$ 2.10

b) For shunt motors, ϕ is proportionally constant

Therefore $Ta\ \alpha\ Ia$

If N is in rpm. then

$Ta = 9.55\ Eb/Ia$ N/m. 2.11

2.2.6 SPEED OF DC MOTOR

From voltage equation of motor,

$Eb = V.\ IaRa$ OR $(\phi\ Z\ N/60)x(\ P/A) = V - IaRa$

$N = (V - IaRa/\phi)\ x\ [(60\ x\ A)\ x\ (Z.P)]$ rpm

$N = (Eb/\phi)\ x\ (60.A/ZP)$ rpm.

$N = K\ .\ (Eb/\phi)$ 2.12

This shows speed is directly proportional to back emf Eb and inversely proportional to the flux ϕ or N.

Therefore, $N \propto Eb/\phi$ 2.13

2.2.7 SPEED REGULATION

The speed is defined as the change in the speed. When the load on the motor is reduced from rated value to zero, expressed as percent of rated load speed.

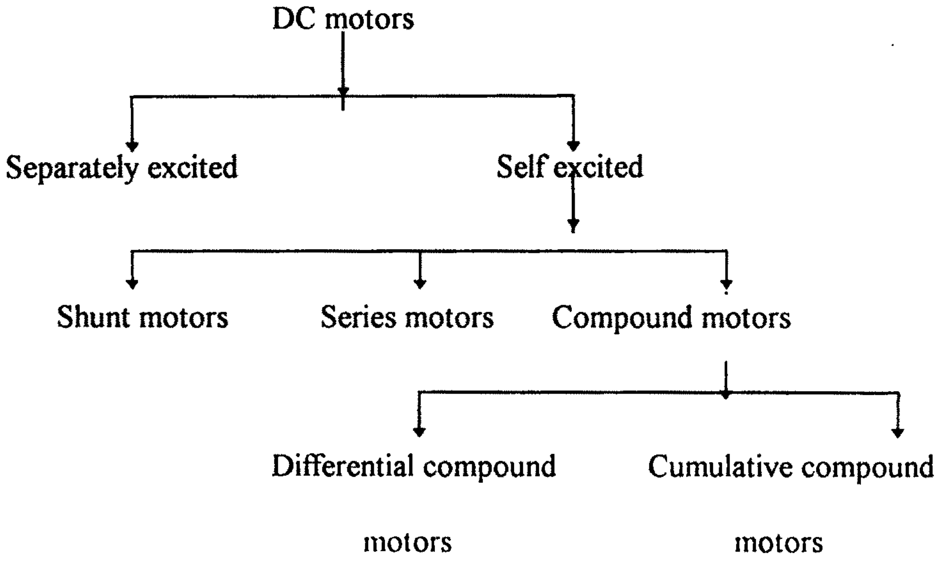
$$\text{Percentage of speed regulation} = \frac{\text{No load speed - Full load speed}}{\text{Full load speed}} \text{X } 100 \qquad 2.15$$

2.2.8 TORQUE AND SPEED OF DC MOTOR

We know that Ta α Ia

From the above it is seen that increase in flux decreases the speed ,but increases the armature torque. It can't be so because torque always tends to produce rotation. If torque increases, motor speed increases, rather than decrease.

2.3 TYPES OF DC MOTORS



2.3.1 SEPARATELY EXCITED DC MOTOR

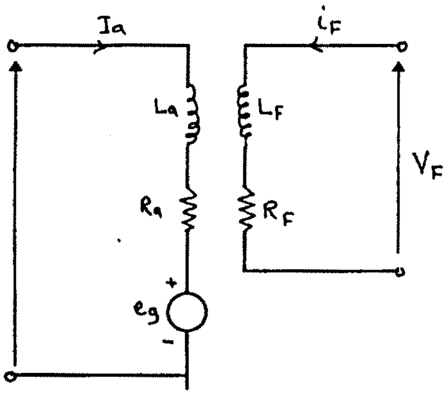


Fig 2.4 Equivalent circuit of Separately Excited Motor

Whereω = Motor speed

Td = Developed Torque

Ra = Armature Resistance

Rf = Field Resistance

Lf = Field Inductance

if = Instantaneous Field

eg = Back emf

Separately excited dc motor consists of two separate supply for armature excitation and field excitation. When a separately excited motor is excited by a field current of i_f and an armature current i_a, current flows in the armature circuit. The motor develops a back emf and a torque to balance the load torque at a particular speed. The field current i_f of separately excited motor is independent of armature current i_a and any change in the armature current has no effect on field current. The field current is normally less than the armature current. The instantaneous field current i_f is described as

$$V_f = R_f i_f + L_f di_f /dt \qquad 2.16$$

The instantaneous armature current is given by

$$Va = Ra\ Ia + La\ dia/dt + eg \qquad 2.17$$

The back emf is given by eg

$$eg = KvWif \qquad 2.18$$

Torque developed by the motor is $Td = Kti_f i$ 2.19

But under the steady state conditions the time derivation in these equations are zero, and the steady state average quantities are $V_f = R_f I_f$. 2.20

$$Eg = K_v W I_f \qquad 2.21$$

$$V_a = R_a I_a + Eg$$

$$V_a = R_a I_a + K_v W I_f \tag{2.22}$$

$$Td = K_t I_f I_a \tag{2.23}$$

Where Kv = Voltage constant.

The power developed is $P.D. = Td\,\varpi$ 2.24

The speed of separately excited motor can be found from

$$\varpi = (V - IaRa)/ K_v\ I_f$$

$$\varpi = (V - IaRa)/ [(K_v\ I_f)/ R_f] \tag{2.25}$$

Hence we note that from the above equation (2.25) the motor speed can be varied by

1) Controlling armature voltage, Va, known as voltage control

2) Controlling the field current, I_f ,known as field control.

The speed which corresponds to the rated armature voltage, rated field current and rated armature current is known as base speed. For a speed less than base speed, in order to meet the torque demand, the armature current and field currents are maintained constant and the armature voltage Va is varied to control the speed.

For speed higher than base speed, the armature voltage is maintained at a rated value and field current is varied to control the speed. However the power developed by the motor remains constant. The characteristics of separately excited motor are shown in fig. 2.5.

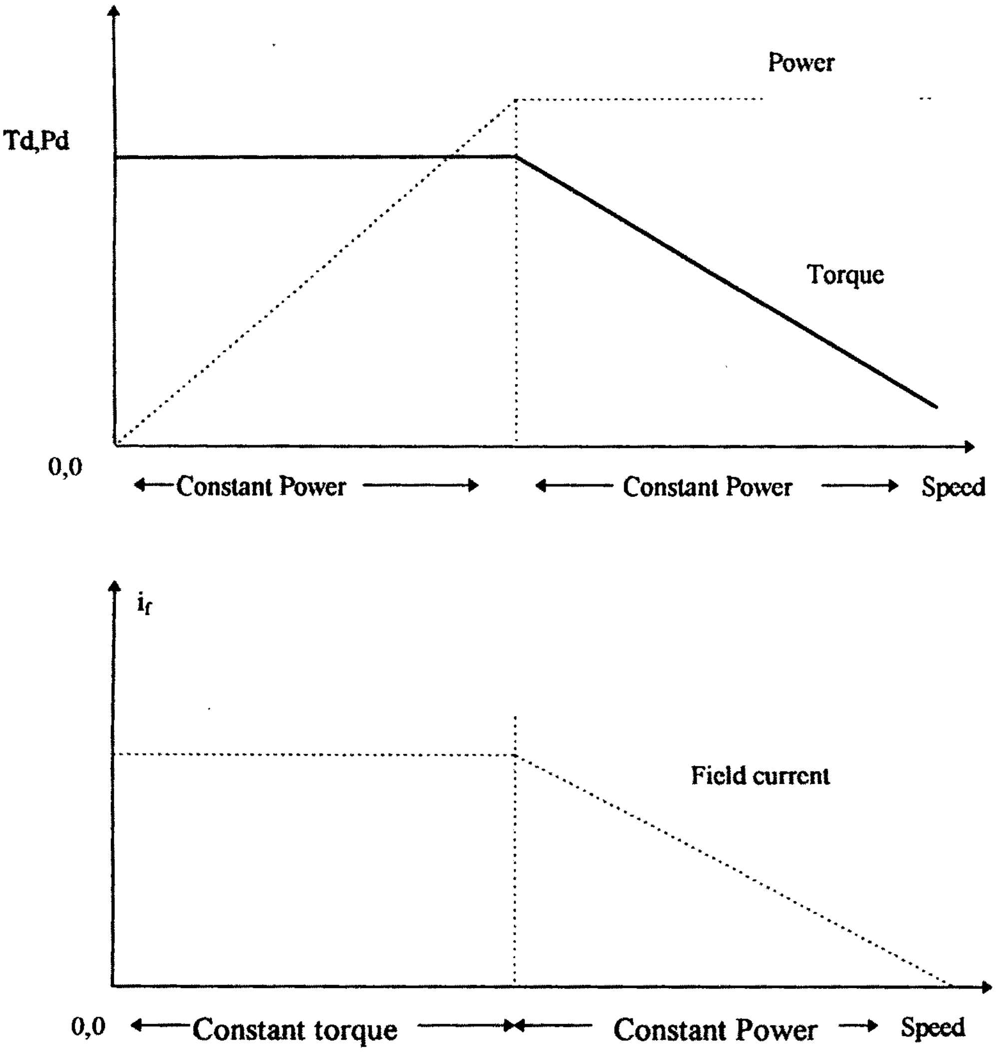


Fig 2.5 Characteristics of Separately Excited Motors

2.3.2 SERIES MOTORS

In case of series motors the field windings are in series with that of the armature windings as shown in fig 2.6.

CHARACTERISTICS

1) Ta / Ia characteristics

We know that $Ta \propto \phi Ia$, in this case, as the field windings also carry the armature current up to point of magnetic saturation. Hence, before saturation, $Ta \propto Ia^2$.

At light loads, Ia is less and hence ϕ is small,. But as Ia increases as the square of the current. The curve is shown in fig. 2.7 (a). After saturation, ϕ is almost independent of Ia, hence ~~$Ta \propto Ia$~~ only . So the characteristics becomes a straight line.

The shaft torque T_{sh} is less than armature torque due to stray losses. It is shown dotted in fig. 2.7(a). So we conclude that on heavy loads, a series motor exerts a torque proportional to the square of the armature current.

2) N / Ia CHARACTERISTICS

Variations of speed can be deduced from the formula

$N \propto Eb / \phi$ Change in Eb for various load currents is small and hence may be neglected for the time being. With increased Ia, ϕ also increases. Hence , speed varies inversely as armature current as shown in fig. 2.7.(b). When load is heavy, Ia is large. Hence speed is low,

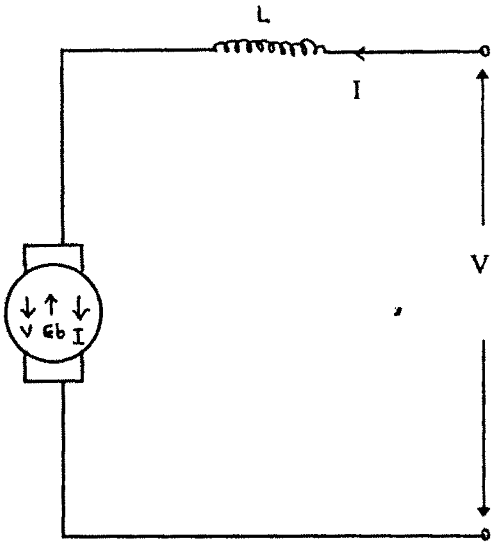
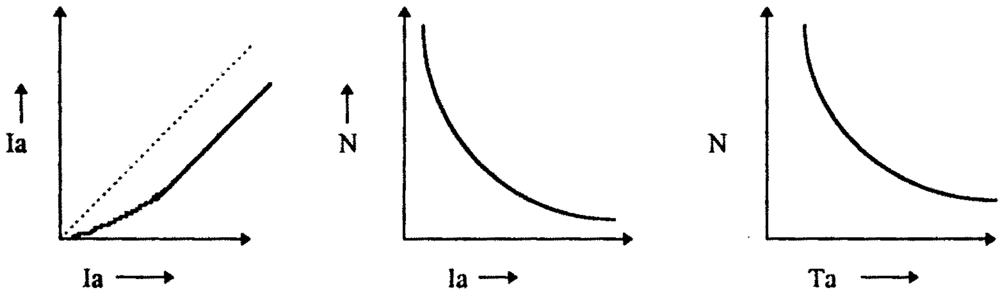


Fig 2.6 Equivalent circuit Diagram of Series Motor



(a) (b) (c)

Fig. 2.7 Characterstics of Series motor

3) N / Ta MECHANICAL CHARACTERISTICS

From the above characteristics when speed is high, torque is low and vice versa. The relation between two is shown in fig. 2.7(c).

2.3.3 SHUNT MOTOR

The field windings are parallel to that of armature windings as shown in fig.2.8.

1) Ta / Ia CHARACTERISTICS

Assuming ϕ to be practically constant. We know that Ta $\propto$Ia. Hence the electrical characteristic shown in fig. 2.9(a)is practically straight line through the origin. Shaft torque is shown in dotted line. Hence heavy starting load will need a heavy starting current. Shunt motor never be started on heavy load.

2) N / Ia CHARACTERISTIC

If ϕ is assumed constant, then N < Eb, is also practically constant, speed for most purposes is constant shown in fig. 2.9(b). But strictly speaking, both Eb and ϕ decreases with increasing load. However Eb decreases slightly more than ϕ so that as a whole ,there is some decrease in speed which is shown by dotted line in fig. 2.9(b).

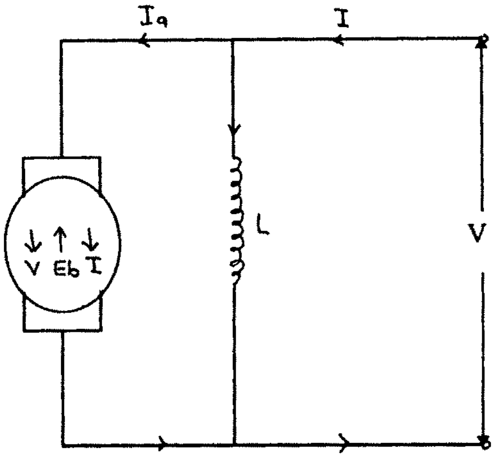
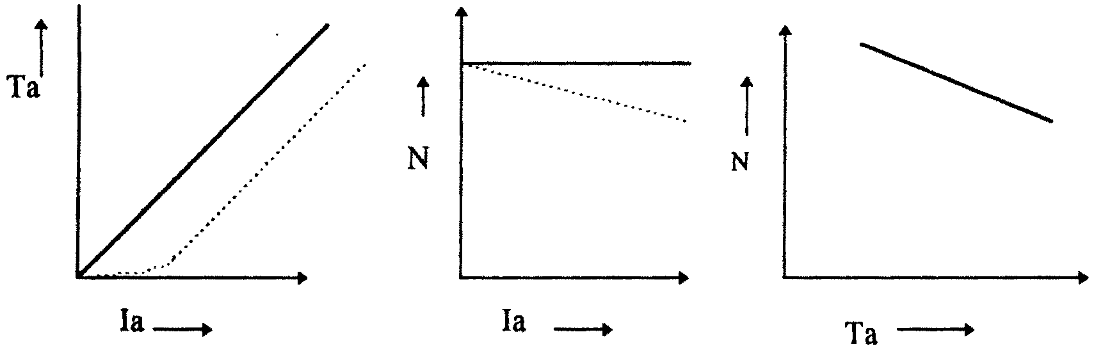


Fig. 2.8 Equivalent circuit of Shunt Motor



(a) (b) (c)

Fig 2.9 Characterstics of Shunt Motors

2.3.4 COMPOUND MOTOR

These motors have both series and shunt windings. If series excitation helps the shunt excitation i.e. series flux is in the same direction then the motor is said to be cumulatively compound. If on the other hand., series field opposes the shunt field ,then the motor is said to be differentially compound.

CHARACTERISTICS

The characteristics of such motor lie in between those of shunt and series motor shown in fig. 2.11.

Cumulative motors are used where series characteristics are required and where, in addition, the load is likely to be removed totally such as in some types of load cutting machines.

In differential compound motors series field opposes the shunt field, the flux is decreased as the load is applied to the motor. This results the motor speed remaining almost constant or even increasing with the load. Due to this reason, there is decrease in the rate at which the motor torque increases with load. Such motors are not in common use.

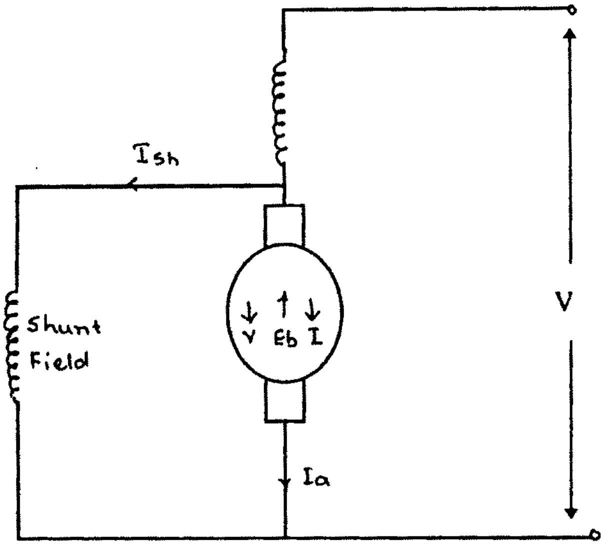
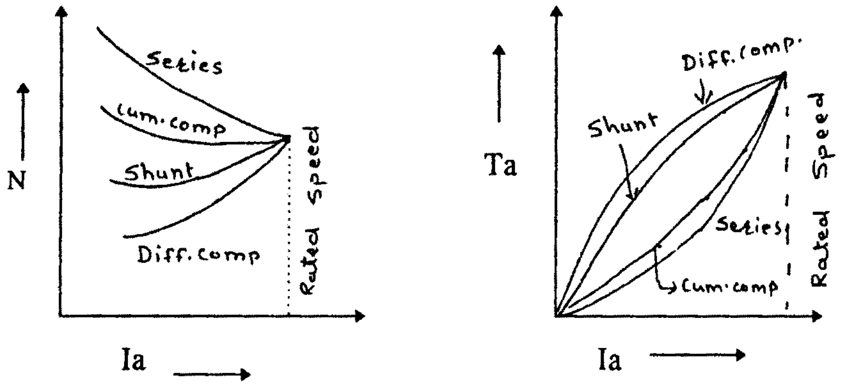


Fig 2.10 Equivalent Circuit of Compound Motor



(a)

(b)

Fig 2.11 Characterstics of Compound motors