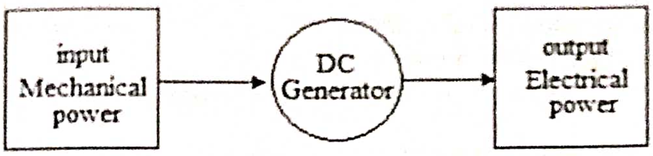
UNIT-II

DC GENERATORS

DC & AC Machines: Principle and operation of DC Generator - EMF equations - OCC characteristics of DC generator – principle and operation of DC Motor – Performance Characteristics of DC Motor - Speed control of DC Motor – Principle and operation of Single Phase Transformer - OC and SC tests on transformer - Principle and operation of 3-phase AC machines [Elementary treatment only]

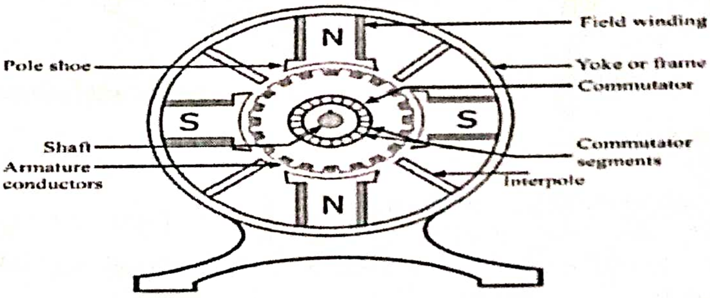
DC Machine: DC machine is a electro mechanical converting device, which converts electrical energy into mechanical energy or mechanical energy into electrical energy.

DC Generator: DC Generator is a machine, which converts mechanical energy into electrical energy.



construction of DC machine:

The dc generators and dc motors have the same general construction. In fact, when the machine is being assembled, the workmen usually do not know whether it is a dc generator or motor. Any dc generator can be run as a dc motor and vice-versa.



Two major parts required for the **construction of DC motor,** namely.

Stator – The static part that houses the field windings and receives the supply and,
Rotor – The rotating part that brings about the mechanical rotations.

The main parts of DC Machine (motor or generator) are as follows:

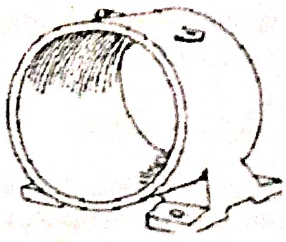
1. **Yoke:**

It is the outer most covering of the machine

- It provide mechanical Support for poles
- It also provide protection to whole machine from dust, moisture e
- It also carries magnetic flux produced by the poles
- Yoke is also called as frame.

Material used

- For small M/C yoke is made of cast iron.
- For large M/C it is made of cast steel or rolled steel.

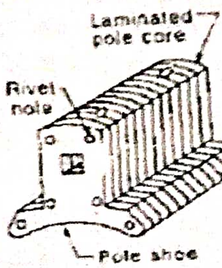


Yoke

2. **Pole & Pole core:**

- Pole of a generator is an electromagnet.
- The field winding is winding over pale.
- Pole provides magnetic flux when field winding is excited.

Material used



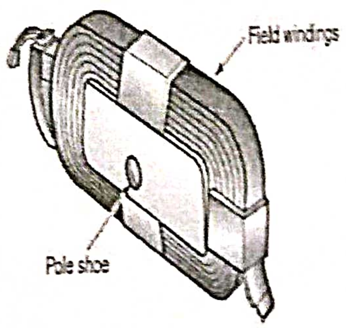
- Pole core or pole made of cast iron or cast steel.
- It built of these laminations of annealed steel. The laminations is done to reduce the power lose due to eddy currents

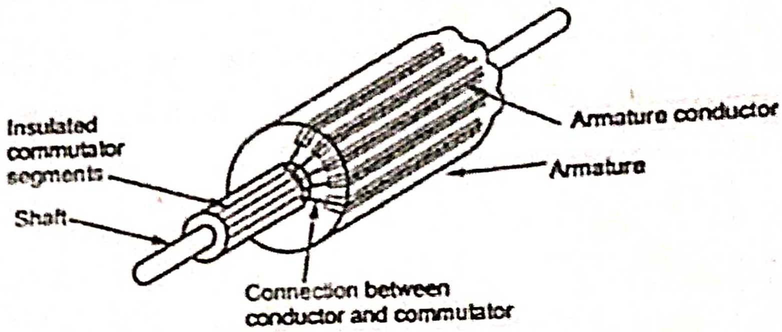
3. **Pole Shoe:**
- It is extended part of pole. It enlarge area of pole
- Due to this enlarged area, flux is spread out in the air gap and more flux can pass through the air gap to armature.

Material used
- It is made of cast iron or cast steed.
- It built of this lamination of annealed steel. the lamination is done to reduce power loss due to eddy currents

4. **Field winding:**
- It is wound around pole core and called as field coil
- it is connected in series to from field winding
- When Current is passed through field winding it electro magnetize the poles which produce necessary flux.

Material used
- The material used for field conductor is copper.





5. **Armature Core:**

Function
- It has large number of slots in its periphery
- Armature conductor, are placed in this slots
- It is also provide path of low reluctance to the flux produced by field winding

Material used
- High permeability low reluctance materials such as cast or iron are used for armature core.
- The lamination is provided so as to reduce the loss due to eddy current.

6. **Armature Winding:**
- Armature conductor are inter connected to form armature Winding
- When armature winding is rotated using prime mover. the magnetic flux and voltage gets induced in it
- Armature winding is connected to external circuit

Material used
- It is made of conducting material such as copper.

7. **Commutator:**

Function
- It Convert alternating current induce in the current in a unidirectional current
- It collects the current form armature conductor and pass it load with the help of brushes
- It also provide unidirectional torque for dc motor

Material used
- It is made of a large number of edge shaped segments of hard drawn copper.
- The Segments are insulated from each other by thin layer of mica.
- The Segment of commutator is made of copper and insulating material between segments is mica.
-

Material used

- It is made of a large number of edge shaped segments of hard drawn copper.
- The Segments are insulated from each other by thin layer of mica
- The Segment of commutator is made of copper and insulating material between segments is mica

8. **Brushes:**
   - Brushes collect the current from commutator and apply it to external load
   - Brushes wear with time and it is should be inspected regularly.

Operating principle of DC Generator:

The DC Generator works on Faraday's laws of electromagnetic induction principle i.e '*Whenever a rotating conductor is placed in magnetic field an emf will induced across the conductors*'.

Let us consider a single turn conductor running with a constant speed is placed in a magnetic field as shown in Fig.(1). The working of the DC Generator is explained as follows:

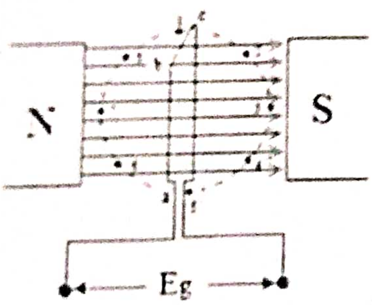


Figure. (1)

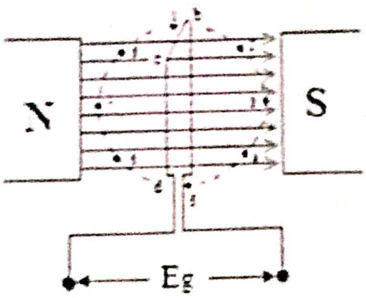


Figure. (2)

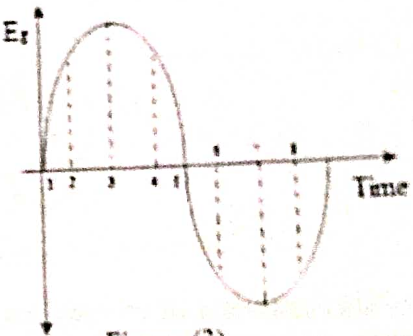


Figure. (3)

When the conductor is in **position-1**, the flux linking with the conductor is maximum and the change in flux ($d\Phi/dt$) is minimum, so the *emf* induced across the conductor is zero.

At position-2, the flux linking with the conductor is decreasing and the change in flux ($d\Phi/dt$) is increasing from zero, hence the *emf* induced across the conductor is increasing from zero as shown in fig.(3).

At position-3, the flux linking with the conductor is minimum and the change in flux ($d\Phi/dt$) is maximum, so the *emf* induced across the conductor is maximum.

At position-4, the flux linking with the conductor is increasing from minimum and the change in flux ($d\Phi/dt$) is decreasing from maximum value, hence the *emf* induced across the conductor is decreasing from maximum as shown in fig.(3).

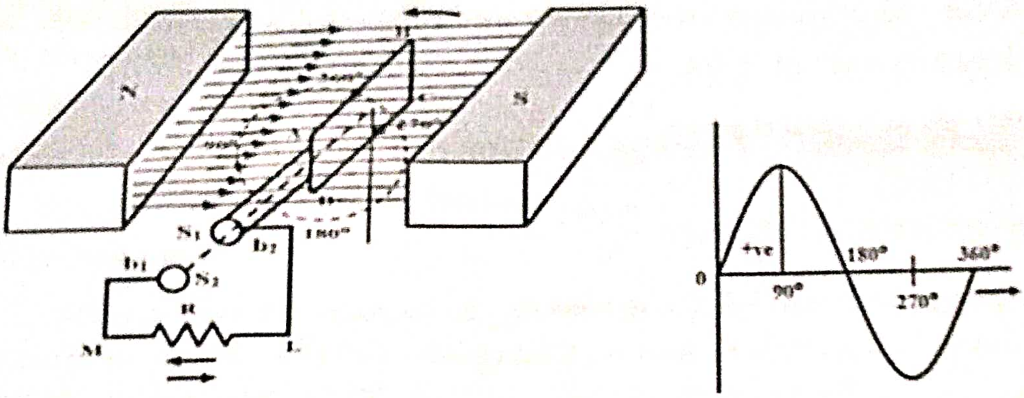
At position-5, the flux linking with the conductor is maximum and the change in flux ($d\Phi/dt$) is minimum, so the *emf* induced across the conductor is minimum.

At position-6, the flux linking with the conductor is decreasing and the change in flux ($d\Phi/dt$) is increasing from zero, hence the *emf* induced across the conductor is increasing from zero as shown in fig.(3) but the direction of induced *emf* is negative from conductor position 5 to 1.

Operating principle of DC Generator:

The DC Generator works on Faraday's laws of electromagnetic induction principle i.e '*Whenever a rotating conductor is placed in magnetic field, an emf will induced across the conductors*'.

Let us consider a single turn conductor running with a constant speed is placed in a magnetic field as shown in Fig.(1). The working of the DC Generator is explained as follows:



Let us assume that the coil starts from the position and rotates at a uniform velocity in a counter-clockwise direction. In its initial position the conductor's AB and CD are moving parallel to the magnetic lines of force hence, induced e.m.f. is zero.
As the coil rotates further (o° to 90°), however, the conductors begin to cut the magnetic lines of force and therefore, the e.m.f. induces in the conductors according to the Faradays Law's of Electromagnetic Induction. The value of induced e.m.f. depends upon the lengths of the conductor, the magnetic field strength, and the speed at which the coil rotates. The conductor has a maximum e.m.f. induced at 90°position, because the conductor moving at right angles to the flux.
In the next quarter revolution i.e. from 90° to 180°, the induced e.m.f. varies from maximum to zero gradually. During this half revolution, The flow of current is along BAMLDCB. i.e., the current through R is from M to L.
In the next half revolution i.e. from 180° to 360°, the variations in the magnitude of e.m.f. are similar to those in the first half revolution, except the direction of the current path is reversed i.e. current flow along CDLMABC and current through R is from L to M

E.M.F. Equation of a D.C. Generator

Let

ϕ = flux/pole in Wb   P = number of poles

Z = No. of armature conductors = No. of slots * conductors/slot

A = No. of parallel paths = P ... for Lap winding

= 2 ... for Wave winding

N = Speed of armature in r.p.m.

E_g = Generated EMF or EMF/parallel path

According to faraday's laws of electromagnetic induction principle, average induced EMF (E_g) = $d\phi/dt$

Where $d\phi$ = Flux cut by a conductor in one revolution = $P\phi$ wb

dt = Time taken to complete one revolution

since N no. of revolutions are made by the generator per minute, no. of revolutions are made by the generator per sec = N / 60

$\therefore$ Time taken to complete one revolution (dt) = $\dfrac{1}{(Ns/60)} = 60/N$

Average value of induced EMF / conductor = $\dfrac{P\Phi}{(60/N)} = \dfrac{P\Phi N}{60}$

The DC generator has Z no. of armature conductors and are divided into A no. of parallel paths, then no. of conductors per each parallel path is Z/A.

$\therefore$ Induced EMF per each parallel path = $\dfrac{P\Phi N}{60} * \dfrac{Z}{A}$

Induced EMF (or) Generated EMF (E_g) = $\dfrac{\Phi Z N}{60} * \dfrac{P}{A}$

Where A = No. of parallel paths = P for lap winding

= 2 for wave winding

Types of D.C. Generators:

DC Generators are generally classified into two according to their field excitation. Those are

(i) Separately excited d.c. generators

(ii) Self-excited d.c. generators

(i) Separately Excited D.C. Generator:

The d.c. generator whose field winding is excited from an independent external d.c. source (battery) is called a separately excited generator. Fig.4 shows the connections of a separately excited generator. The separately excited d.c. generators are rarely used in practice.

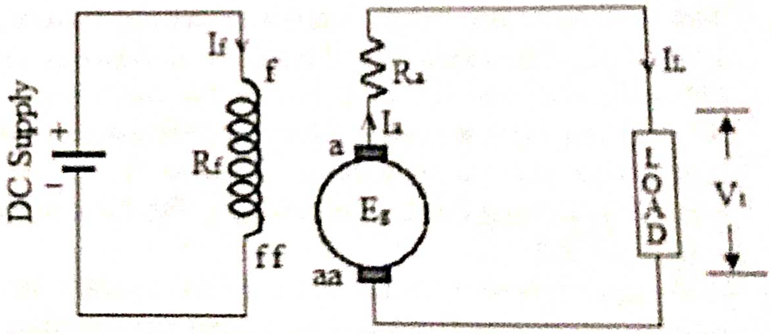


Fig.4

From the diagram $I_a = I_L$ and $E_g = V_t + I_a R_a + B.D$

Electrical power developed = $E_g I_a$ and Power delivered to load = $V_t I_L = V_t I_a$

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current and B.D = Brush contact drop

(ii) Self excited D.C. Generator:

The d.c. generator whose field winding is excited by itself is called a self-excited generator. There are three types of self-excited generators, namely;

(i) DC Shunt generator (ii) DC Series generator (iii) DC Compound generator

DC Shunt generator:

In a DC Shunt Generator, the field winding is connected in parallel with the armature winding as shown in fig (5). The shunt field winding has *many turns* of *thin* wire having high resistance. Therefore, a part of armature current flows through shunt field winding and the remaining current flows through the load.

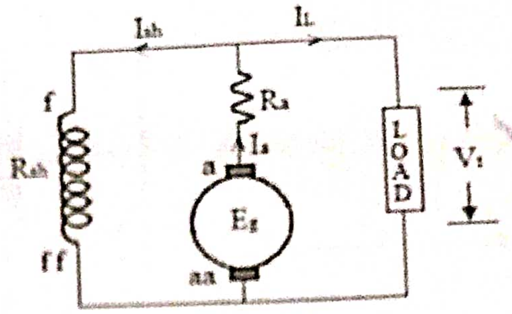


Figure (5)

From the diagram

Shunt field current $I_{sh} = V_t / R_{sh}$

Armature current $I_a = I_L + I_{sh}$ (or) $I_L = I_a - I_{sh}$

Generated EMF $E_g = V_t + I_a R_a + B.D$

Terminal voltage $V_t = E_g - I_a R_a - B.D$

Power developed in armature = Eg Ia

Power delivered to load = $V_t I_L = V_t (I_a - I_{sh})$

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current

and B.D = Brush contact drop

DC Series generator:

If the field winding is connected in series with armature winding as shown in fig.(6) is called DC Series Generator. The series field winding has a *few turns* of *thick* having low resistance. The DC Series generators are rarely used except for special purposes e.g., as boosters.

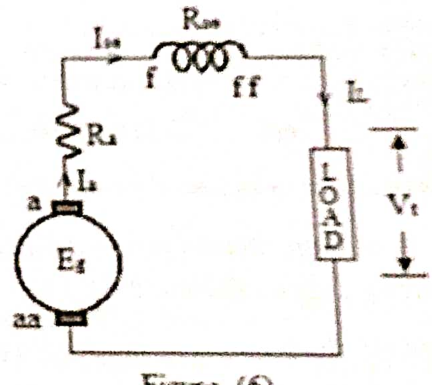


Figure. (6)

From the circuit,

Armature current = Series field current = Load current

$I_a = I_{se} = I_L$

Generated EMF $E_g = V_t + I_a R_a + I_{se} R_{se} + B.D$

$= V_t + I_a (R_a + R_{se}) + B.D$

∴ Terminal voltage, $V_t = E_g - I_a (R_a + R_{se}) - B.D$

Power developed in armature = Eg Ia

Power delivered to load = $V_t I_L = V_t I_a$ (since $I_a = I_L$)

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current

DC Compound generator:

In a DC compound generator, there are two sets of field windings on each pole, one is in series with the armature and the other in parallel with the armature. Based on these field winding connections, the DC compound generators are classified into

(i) Long shunt compound generator (ii) Short shunt compound generator

Long shunt compound generator:

In a Long Shunt Compound generator, the shunt field winding is in parallel with both series field and armature winding as shown in fig. (7).

From the diagram

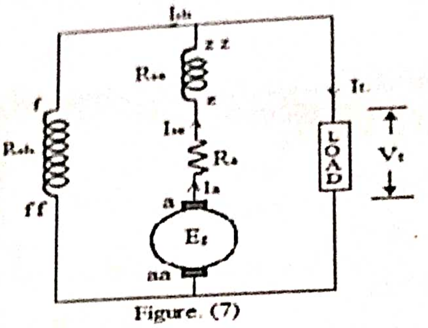


Figure. (7)

Shunt field current $I_{sh} = V_t / R_{sh}$

Armature current $I_a = I_{se} = I_L + I_{sh}$ (or) $I_L = I_a - I_{sh}$

Generated EMF $E_g = V_t + I_a R_a + I_{se} R_{se} + B.D$

$= V_t + I_a (R_a + R_{se}) + B.D$

Terminal voltage $V_t = E_g - I_a (R_a + R_{se}) - B.D$

Power developed in armature = Eg Ia

Power delivered to load = $V_t I_L = V_t (I_a - I_{sh})$

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current

and B.D = Brush contact drop

Short shunt compound generator:

In a Short Shunt Compound generator, the shunt field winding is connected in parallel with armature winding only as shown in fig. (8).

From the diagram

Series field current $I_{se} = I_L$ and Armature current $I_a = I_{se} + I_{sh}$

Shunt field current $I_{sh} = \dfrac{V_t + I_{se}R_{se}}{R_{sh}}$

Generated EMF $E_g = V_t + I_a R_a + I_{se} R_{se} + B.D$

Terminal voltage $V_t = E_g - I_a R_a - I_{se} R_{se}) - B.D$

Power developed in armature = Eg Ia

Power delivered to load = $V_t I_L = V_t (I_a - I_{sh})$

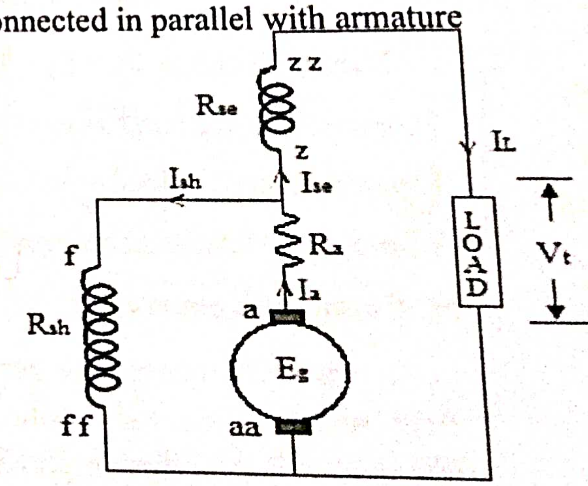


Figure (8)

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current

and B.D = Brush contact drop

Technical Academy Kavali

Magnetization or Open Circuit Characteristic (O.C.C.):

This curve shows the relation between the generated e.m.f. at no-load (E_0) and the field current (I_f) at constant speed. It is also known as magnetic characteristic or no-load saturation curve. Its shape is

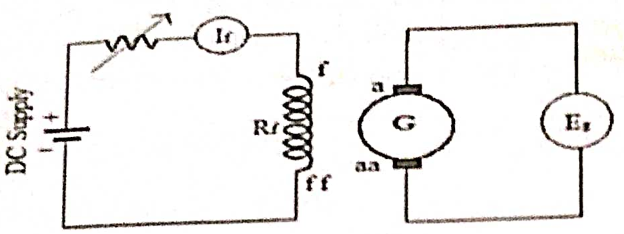


Figure (9)

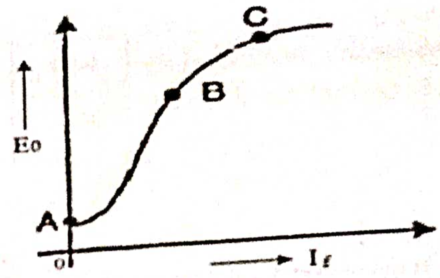
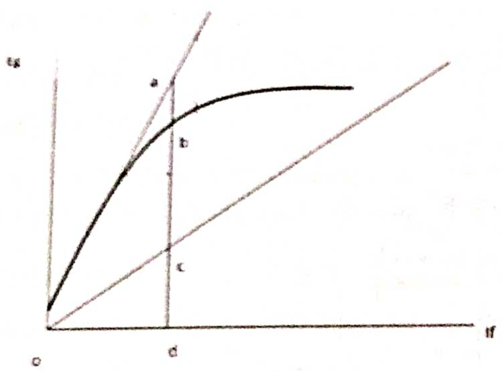


Figure (10)



Critical field resistance (Rc) $= \frac{bd}{od}$

Critical speed (Nc) $=$ rated speed $\frac{cd}{ad}$

practically the same for all generators whether separately or self-excited. The data for O.C.C. curve are obtained experimentally by operating the generator at no load and constant speed and recording the change in terminal voltage as the field current is varied.

The O.C.C. for a d.c. generator is determined as follows. The field winding of the d.c. generator (series or shunt) is separately excited from an external d.c. source as shown in Fig. (9). Now the field current (I_f) is increased from zero in steps and the corresponding values of generated e.m.f. (E_0) are noted. Now plot the graph between E_0 and I_f to get the open circuit characteristic as shown in Fig.(10).

The following points may be noted from O.C.C.:

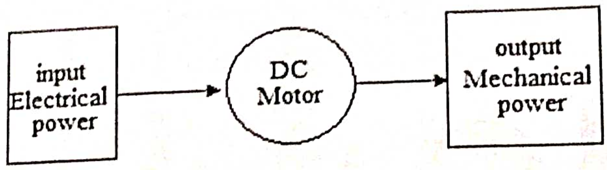
(i) When the field current is zero, there is some generated e.m.f. OA. This is due to *the residual magnetism* in the field poles.

(ii) Upto certain range of field current (upto point B in the curve), the curve is linear, because reluctance of iron is negligible as compared with that of air gap. The air gap reluctance is constant and hence linear relationship.

(iii) After point C on the curve, the poles get saturated and hence the magnetic flux varies slowly with field current.

DC MOTORS

DC Motors: DC Motor is a Machine which converts Electrical energy into Mechanical energy. Dc motors are used in steel plants, paper mills, textile mills, cranes, printing presses, Electrical locomotives etc.



Kavali

Operating (or) working principle:

It works on principle that '*When a current carrying conductor is placed in magnetic field, it experiences a force and the direction of the force is given by Fleming's left hand rule*'. Fleming's left hand rule states that " Stretch out the first finger, second finger and thumb of your left hand so that they are at right angles to one another. The first finger point the direction of magnetic field from N-pole to S-pole, second finger points the direction of current and thumb will indicates the direction rotation of conductor"

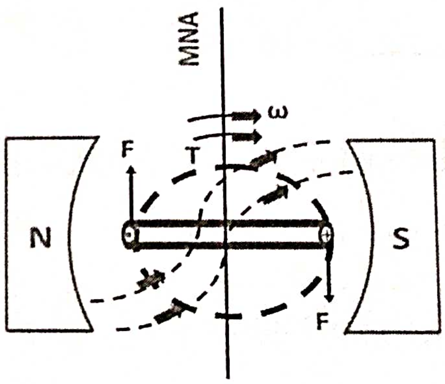


Figure C

Consider a conductor is placed in magnetic field. When a DC supply is connected to conductor, current flows through it which set up its own flux around the conductor as shown in fig By applying Fleming's Left-Hand Rule, the conductor on the left side always experiences a force in an upward direction while the conductor on the right side experiences a downward force. Hence, a unidirectional torque is achieved in dc motors.

Back EMF & its significance:

When a current carrying conductor (Armature winding) is placed in a magnetic field, torque develops and conductor (Armature) rotates the armature conductors cut the magnetic field and an *emf* is induced across the armature conductors. The direction of induced *emf* is opposite to the applied voltage. That is why this induced *emf* is called back emf (E_b) and the

magnitude of the back emf is $(E_b) = \dfrac{\Phi ZN}{60} * \dfrac{P}{A}$

Types of D.C. Motors:

DC Motors are generally classified into three groups according to their field excitation. Those are

(i) d.c. Shunt Motor (ii) d.c. Series Motor (iii) d.c Compound Motor

DC Shunt Motor:

In a DC Shunt Motor, the field winding is connected in parallel with the armature winding as shown in fig (5). The shunt field winding has *many turns* of *thin* wire having high resistance. Therefore, a part of armature current flows through shunt field winding and the remaining current flows through the load.

From the diagram

Shunt field current $I_{sh} = V_t / R_{sh}$

Armature current $I_L = I_a + I_{sh}$ (or) $I_a = I_L - I_{sh}$

Terminal voltage $V_t = E_b + I_a R_a + B.D$

Generated EMF $E_b = V_t - I_a R_a - B.D$

Power developed in armature $= E_b I_a$

Power delivered to load $= V_t I_L = V_t (I_a - I_{sh})$

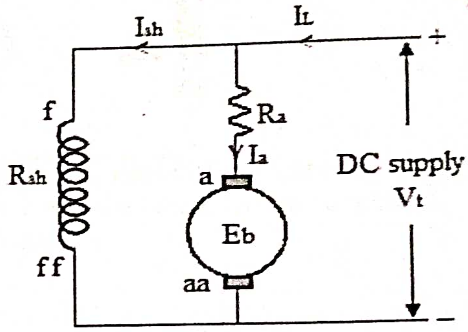


Figure (5)

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current

and B.D = Brush contact drop

DC Series Motor:

If the field winding is connected in series with armature winding as shown in fig.(6) is called DC Series Motor. The series field winding has a *few turns* of *thick* having low resistance.

From the circuit,

Armature current = Series field current = Load current

i.e $I_a = I_{se} = I_L$

Terminal voltage, $V_t = E_b + I_a R_a + I_{se} R_{se} + B.D$

$= E_b + I_a (R_a + R_{se}) + B.D$

$\therefore$ Generated EMF $E_b = V_t - I_a (R_a + R_{se}) - B.D$

Power developed in armature = Eb Ia

In put Power $= V_t I_L = V_t I_a$ (since $I_a = I_L$)

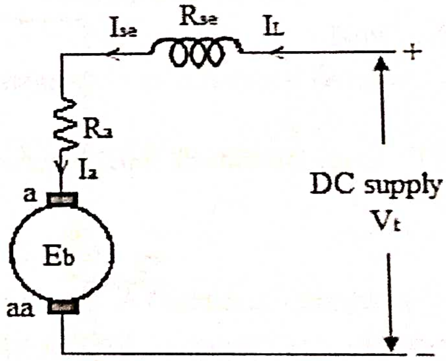


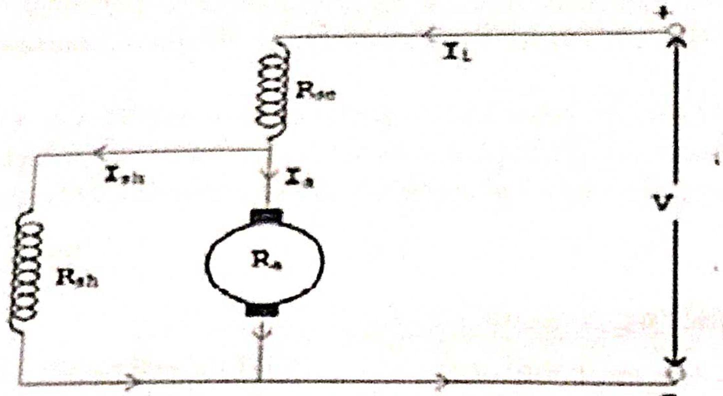
Figure (6)

Where I_a = Armature current, R_a = Armature Resistance, V_t = Terminal voltage, I_L = Load current

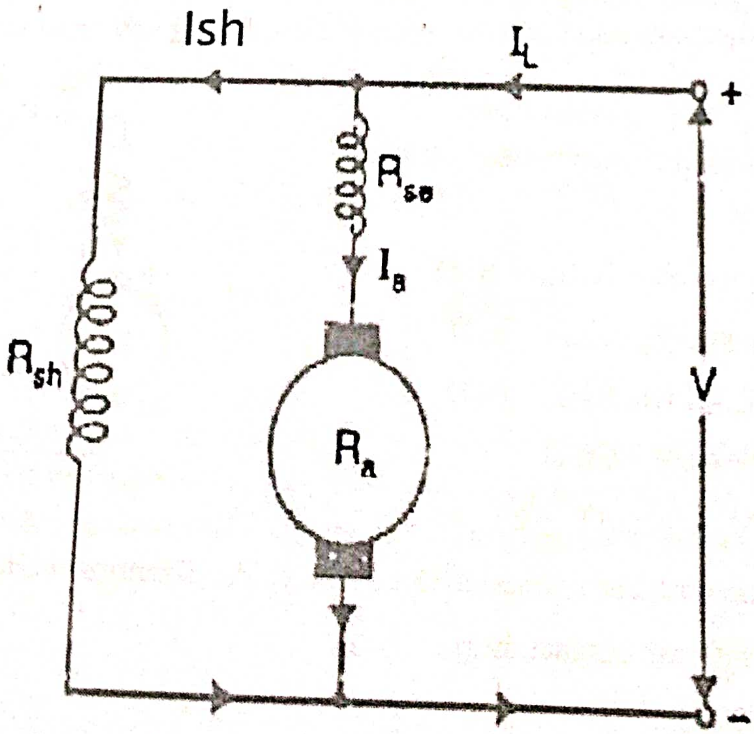
and B.D = Brush contact drop

Compound Wound Motor

A DC Motor having both shunt and series field windings is called a **Compound Motor**. The connection diagram of the compound motor is shown below:



Short Shunt Connetcion



Long-shunt connection

Speed Control of D.C. Shunt Motor:

There are two methods to control the speed of a d.c. motor, namely:

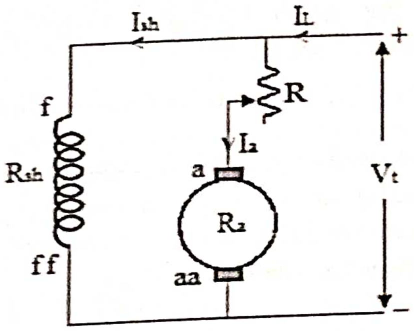
(i) Armature Control Method (ii) Flux Control Method

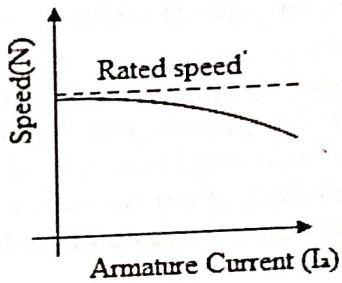
Armature Control Method:

We know that the speed of a d.c. motor is $N \alpha \frac{E_b}{\phi}$

or $N = K \frac{V_t - I_a R_a}{\phi}$

from the above equation it is clear that, by varying the back emf (E_b) the speed of the motor can be varied. The following figure shows the arrangement for armature control method. In this method an additional resistance of R ohms is connected in series with the armature.





Now the speed of the motor $N \propto E_b$ i.e $N \propto V_t - I_a (R_a + R_{se})$. Due to voltage drop in resistance (R), the back e.m.f. (Eb) is decreased. Since $N \propto$ Eb, the speed of the motor is reduced from the normal speed. This method gives the speeds always less than the normal speeds.

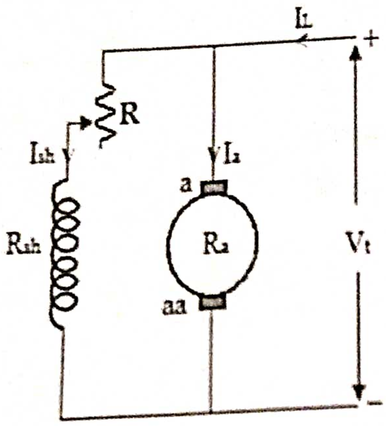
The main drawbacks of this method are

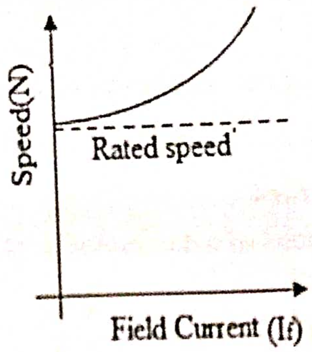
(i) A large amount of power is wasted in the resistance (R) since it carries full armature current Ia.
(ii) The output and efficiency of the motor are reduced due to large amount of power is wasted in the resistance (R).
(iii) This method results in poor speed regulation.

Flux or Field Control Method:

We know that the speed of a d.c. motor is $N \alpha \frac{E_b}{\phi}$

from the above equation it is clear that, by varying the flux(Φ), the speed of the motor can be varied hence it is called flux or field control method. The following figure shows the arrangement for flux control method. In this method an additional resistance of R ohms is connected in series with the shunt field winding.





Kavali

By increasing the additional resistance, the flux (Φ) decreases, this results in increase in speed from the normal speed. This method always gives the speeds above the normal speed.

Advantages:

(i) This is an easy and convenient method.

(ii) It is an inexpensive method since very little power is wasted in additional resistance (R) due to Shunt field current I_{sh}.

The main drawback of this method is only speeds higher than the normal speed can be obtained since the total field circuit resistance cannot be reduced below the shunt field resistance (R_{sh}).

Characteristics Of DC Motors

Generally, three characteristic curves are considered important for DC motors which are, (i) Torque vs. armature current, (ii) Speed vs. armature current and (iii) Speed vs. torque

These characteristics are determined by keeping the following two relations in mind.

$T_a \propto \phi.I_a$ and $N \propto E_b/\phi$

Characteristics Of DC Series Motors

Torque vs. armature current

This characteristic is also known as **electrical characteristic**. We know that torque is directly proportional to the product of armature current and field flux, $T_a \propto \phi.I_a$. In DC series motors, field winding is connected in series with the armature, i.e. $I_a = I_f$.
Hence, before magnetic saturation $T_a \propto I_a^2$. Therefore, the Ta-Ia curve is parabola for smaller values of I_a.

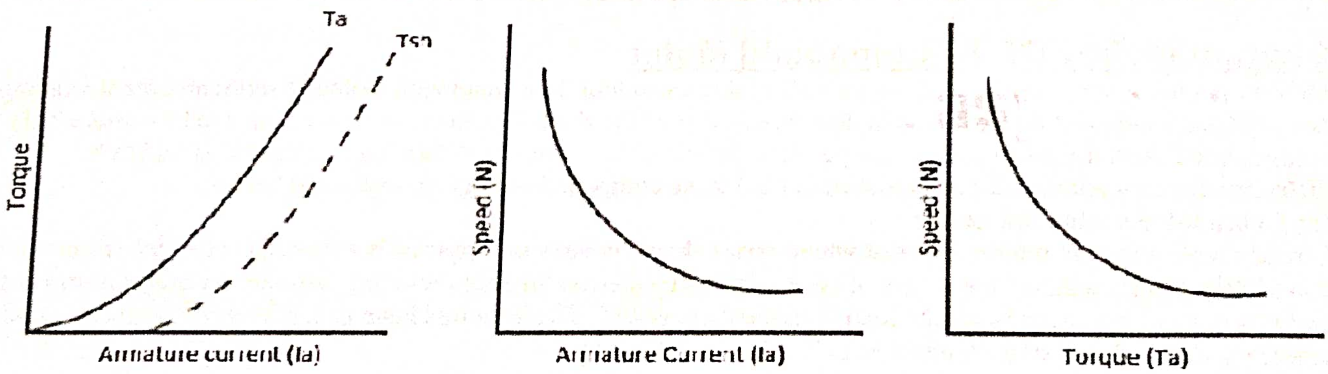
Speed Vs. Armature Current (N-Ia)

We know the relation, $N \propto E_b/\phi$

For small load current (and hence for small armature current) change in back emf Eb is small and it may be neglected. Hence, for small currents speed is inversely proportional to ϕ. As we know, flux is directly proportional to Ia, speed is inversely proportional to Ia. Therefore, when armature current is very small the speed becomes dangerously high. That is why **a series motor should never be started without some mechanical load.**

Speed Vs. Torque (N-Ta)

This characteristic is also called as **mechanical characteristic**. From the above two **characteristics of DC series motor**, it can be found that when speed is high, torque is low and vice versa.



Characteristics of DC series motor

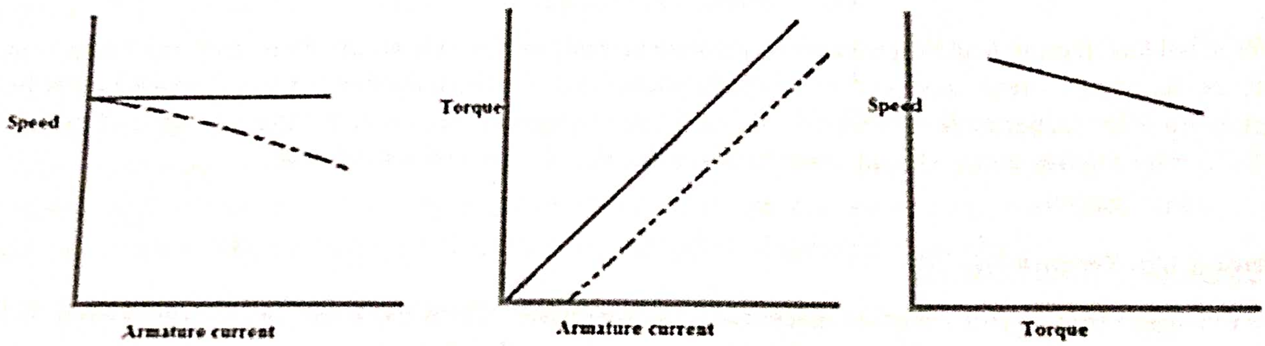
Characteristics Of DC Shunt Motors

Torque Vs. Armature Current (Ta-Ia)

In case of DC shunt motors, we can assume the field flux ϕ to be constant. Though at heavy loads, ϕ decreases in a small amount due to increased armature reaction. As we are neglecting the change in the flux ϕ, we can say that torque is proportional to armature current. Hence, the Ta-Ia characteristic for a dc shunt motor will be a straight line through the origin.
Since heavy starting load needs heavy starting current, **shunt motor should never be started on a heavy load.**

Speed Vs. Armature Current (N-Ia)

As flux ϕ is assumed to be constant, we can say N $\propto$ Eb. But, as back emf is also almost constant, the speed should remain constant. But practically, ϕ as well as Eb decreases with increase in load. Back emf Eb decreases slightly more than ϕ, therefore, the speed decreases slightly. Generally, the speed decreases only by 5 to 15% of full load speed. Therefore, **a shunt motor can be assumed as a constant speed motor.** In speed vs. armature current characteristic in the following figure, the straight horizontal line represents the ideal characteristic and the actual characteristic is shown by the dotted line.



Characteristics Of DC Compound Motor

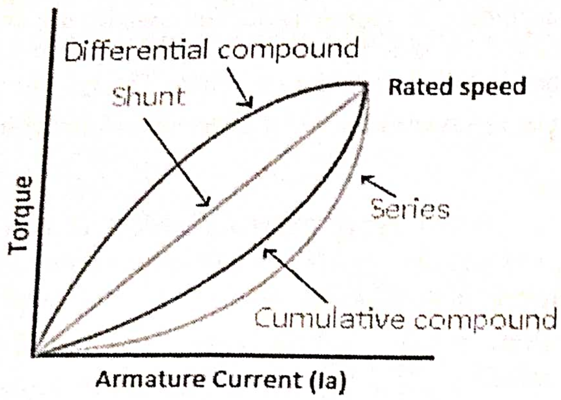
DC compound motors have both series as well as shunt winding. In a compound motor, if series and shunt windings are connected such that series flux is in direction as that of the shunt flux then the motor is said to be cumulatively compounded. And if the series flux is opposite to the direction of the shunt flux, then the motor is said to be differentially compounded. Characteristics of both these compound motors are explained below.

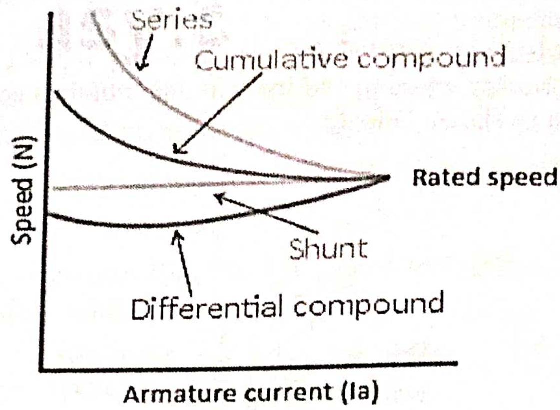
(a) Cumulative compound motor

Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors have generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.

(b) Differential compound motor

Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load (N $\propto$ E_b/ϕ). Differential compound motors are not commonly used, but they find limited applications in experimental and research work.

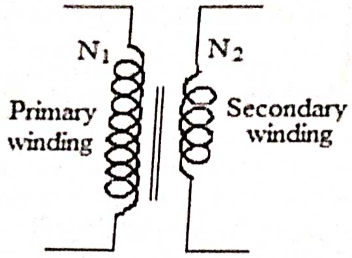




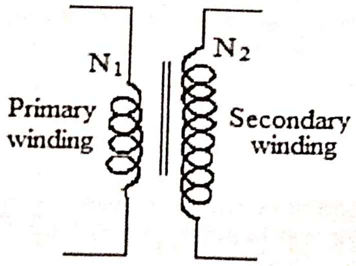
Characteristics of DC compound motor

SINGLE PHASE TRANSFORMERS

Transformer is a static device which transfers the A.C electrical power from one circuit to another circuit without changing the frequency, but voltage levels are changed according to requirement. The transformer consists of two windings called as Primary Winding and Secondary Winding. The winding which is connected to ac supply is called primary winding and the winding which is connected to load is called secondary winding. The symbol of transformer is as shown below.



Step down transformer

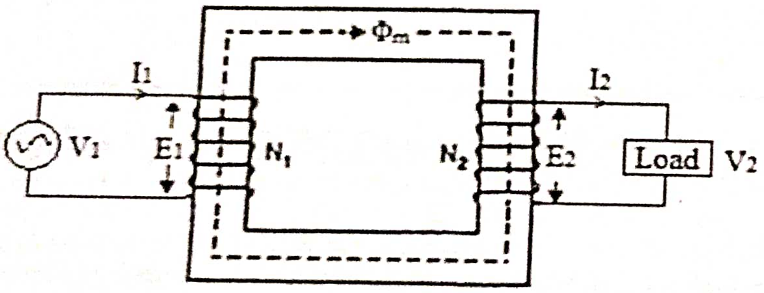


Step up transformer

If the secondary voltage (V_2) is greater than primary voltage (V_1), then the transformer is called step up transformer and if the secondary voltage (V_2) is less than primary voltage (V_1), then the transformer is called step down transformer. In another way, if the secondary winding turns (N_2) is greater than primary winding turns (N_1), then the transformer is called step up transformer and if the secondary winding turns (N_2) is less than primary winding turns (N_1), then the transformer is called step down transformer

Working or Working principle of Transformer:

The transformer works on *mutual induction* principle. The transformer consists of two windings and are placed on laminated core as shown in figure.(1).



When an AC supply of V_1 volts is connected to primary winding, an alternating flux is set up in the core. This alternating flux is linked with the secondary winding, an emf will induced acrosssecondary winding called secondary emf (E_2) and the same flux is linking with the

primary winding also, it produces an emf called primary emf (E_1). Both the primary and secondary emf directions are opposite to supply voltage (V_1) according to Lenz's law.

Ideal Transformer:

An ideal transformer is a transformer whose winding resistance (Primary or Secondary) is zero and no magnetic leakage flux i.e the total flux produced in the core links with primary and as well as secondary. Since the winding resistance and magnetic leakage flux is zero, Copper and Iron (Core) losses are zero respectively. That means in ideal transformer the output (VA) equal to input(VA) i.e

$$E_2 I_2 = E_1 I_1$$

$$\frac{E_2}{E_1} = \frac{I_1}{I_2}$$

but the EMF is proportional to no .of turns (N) i.e $E_1 \propto N_1$ & $E_2 \propto N_2$. Since it is a ideal transformer, the primary and secondary winding resistance is zero so $E_1 = V_1$ & $E_2 = V_2$.

Transformation ratio is *the ratio of secondary turns to primary turns* and is represented by K.

EMF equation of 1-Ph Transformer:

When an AC voltage is applied to primary winding of transformer, a sinusoidal flux (Φ_m) as shown infig.() is setup in the transformer core which links with both primary and secondary windings

Let Φ_m = Maximum flux in wb = $B_m \cdot A$

f = Frequency of the supply in Hzs.

N_1 = No. of turns in Primary winding.

N_2 = No. of turns in Secondary winding.

E_1 = EMF across Primary winding.

E_2 = EMF across Secondary winding.

According to faraday's law of electromagnetic inductionprinciple, the average induced emf per turn is $d\Phi/dt$.

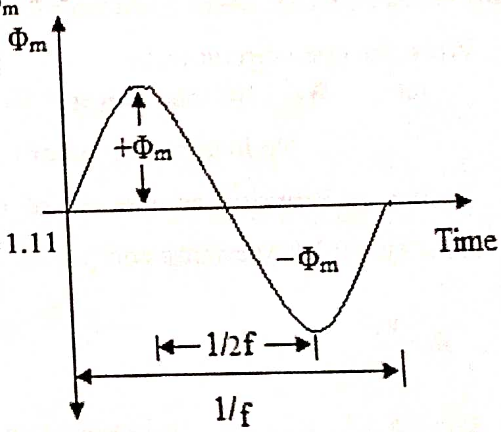
Where $d\Phi$ = Change in flux from $+\Phi_m$ to $-\Phi_m$

$= +\Phi_m - (-\Phi_m)$

$= 2\,\Phi_m$

and dt = Time required to change in flux from $+\Phi_m$ to $-\Phi_m$

$= 1/2f$



$\therefore$ Average induced emf per turn $= \dfrac{2\phi_m}{1/2f}$

$= 4\,\Phi_m f$ volts

But we know that for sine wave, Form factor $= \dfrac{\text{RMS value}}{\text{Average value}} = 1.11$

RMS value of EMF per turn = 1.11 ($4\,\Phi m f$) volts

$= 4.44\,\Phi m f$ volts

Since the primary and secondary windings has N1 and N2 no. of turns respectively RMS value of EMF in primary winding (E1) = $4.44\,\Phi m f N1$ volts

Similarly RMS value of EMF in secondary winding (E2) = $4.44\,\Phi m f N2$ volts

Note: if Bm is maximum flux density, A is area of the transformer core, then flux Φm = Bm A and EMF (E) = 4.44 Bm A fN.

O.C & S.C Tests on 1-Ph Transformer:

Open Circuit (or) No load test: This test is conducted to determine the Iron or Core losses and also to determine the no load parameters (R_o and X_o) of transformer. This test is conducted on L V side of the transformer as shown in fig. (8).

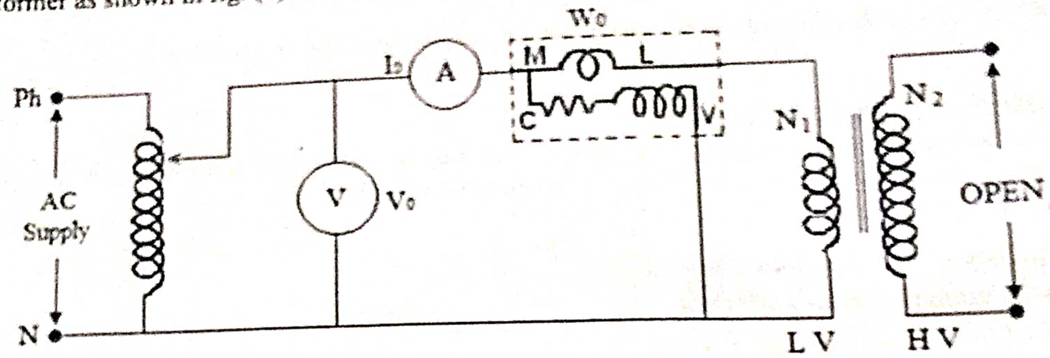


Fig.(8): Opne Ciruit Test on 1-Ph Transformer

The primary winding (L V side) is connected to a supply voltage V_1 and secondary winding (HV side) is open circuited. By applying the rated voltage as given on name plate detail to primarywinding of transformer, measure the value of supply voltage V_1, No load current I_0 and no load power W_0. Since the secondary winding is open and the primary current is low at no load, the copper losses at primary and secondary copper losses are neglected. Therefore, at no load condition the transformer has only core or iron losses and are equal to no load power.

From the open circuit test,

let W_0 = No load power = $V_1 I_0 \cos\phi_0$ = Iron losses (W_i)

$\therefore$ No load power factor $\cos\phi_0 = W_0 / V_1 I_0$

Active or Working component of no load current $I_w = I_0 \cos\phi_0$

Reactive or Magnetizing component of no load current $I_\mu = I_0 \sin\phi_0$

$R_o = \frac{V1}{Iw}$ $\quad X_0 = \frac{V1}{Iu}$

Short Circuit Test: This test is conducted to determine the full load copper losses and to find the equivalent resistance and reactance referred to metering side. In this test the secondary winding (L V winding)is short circuited by a thick conductor and primary winding (H V winding) is connected to low voltage, usually 5 % to 7% of rated voltage. Since the applied voltage is low so the flux setup in the core is small and therefore, iron losses are small and are neglected.

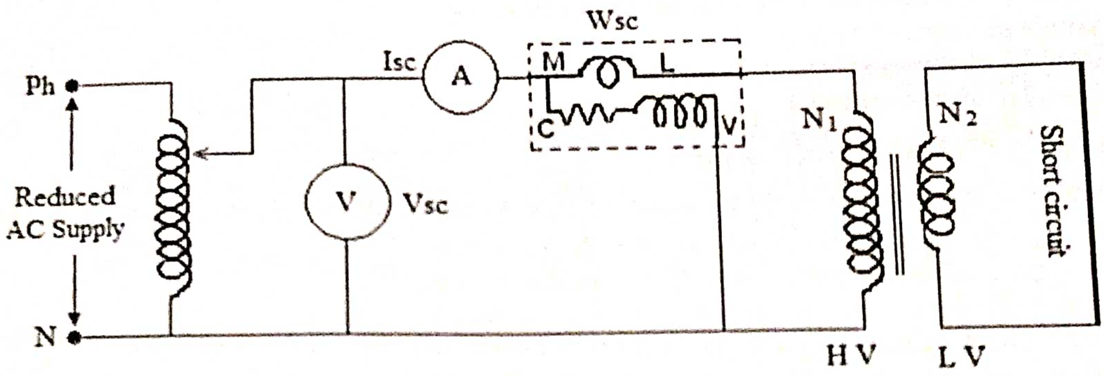


Fig.(9): Short Circuit Test on 1-Ph Transformer

By applying the reduced voltage to primary winding of transformer, measure the value of SC voltage V_{sc}, SC Current I_{sc} and SC Power W_{sc}.

Equivalent resistance referred to HV side, $R01 = W_{sc}/ I_{sc}^2$

Equivalent impedance referred to HV side, $Z01 = V_{sc} / I_{sc}$

Equivalent leakage reactance referred to HV side, $X01 = \sqrt{(Z^2 01 - R^2 01)}$

And also short circuit power factor, $\cos \Phi_{sc} = W_{sc}/V_{sc}I_{sc}$

Equivalent circuit:

The equivalent circuit of the1-Ph transformer by conducting OC & SC tests is as shown below fig.(10).

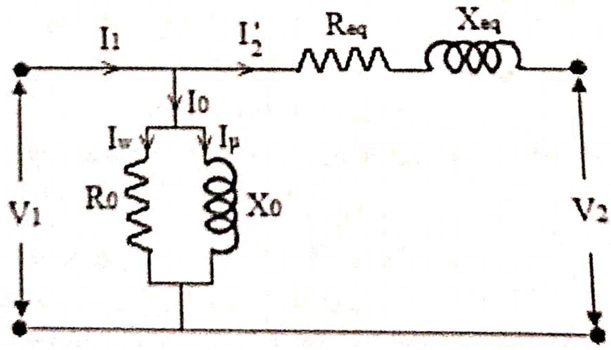


Fig.(10): Equivalent circuit of 1-ph Transformer

Poly phase Induction Motors

Advantages of 3-Ph Induction Motor:

The Induction motor is an ac machine which converts ac electrical energy into mechanical energy. The 3-Ph induction motor is commonly used ac motor for industrial/commercial applications because of the following advantages:

i. It is cheaper in cost
ii. Its construction is simple and robust i.e mechanically strong.
iii. It has more Effiency and more reliable.
iv. It requires less maintenance and has more overload capacity.
v. Its starting (T_{st}) torque is more.

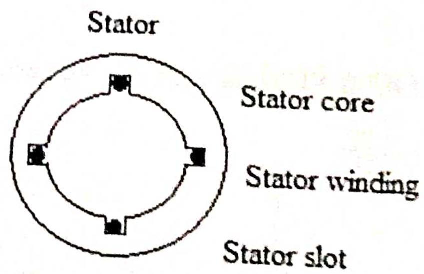
Construction of 3-Ph Induction Motor:

The 3-Ph induction motor mainly consists of two parts: (i) Stator (ii) Rotor

Stator: Stator is a stationary part. It is made-up of high grade steel laminations to reduce eddy current losses. The laminations are insulated from each other and slots are provided as shown in fig (i) to place the 3-ph stator winding in the stator slots. The stator winding is made of copper material and the stator winding may be star or delta connection. Here the stator poles are created by providing the stator slots. When the 3-ph ac supply is given to the stator, a 3-ph alternating flux will setup in stator core and this stator flux is running with synchronous speed ($N_s = \frac{120\ f}{P}$) alon with stator core.

Rotor: Rotor is rotating part. The rotor is in cylindrical shape and is laminated to reduce the eddy current losses. The rotor has rotor slots to house the rotor winding. Constructionally, the rotors are classified as two types. Those are

(i) Squirrel cage rotor
(ii) Phase wound or Slip ring rotor.

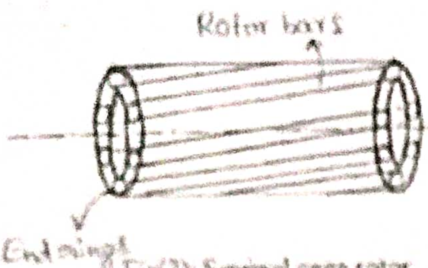


Squirrel cage rotor:

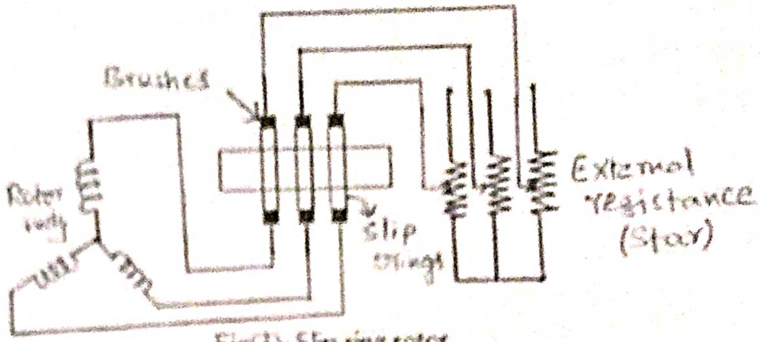
The squirrel cage rotor consists of cylindrical laminated core with slots nearly parallel to shaft as shown in fig fig(2) called *skewed.* At each end of the rotor, the rotor bar conductors are

short circuited with end rings. The conductors and end rings combinely forms a cage as shown in fig(2). The skewing of rotor bars offers the following advantages:

(i) The locking tendency of the rotor is reduced.
(ii) More torque produced i.e noise is reduced during the operation.



Fig(2): Squirrel cage rotor



Fig(3). Slip ring rotor

Phase wound or Slip ring rotor:

This type of rotor consists of three slip-rings which are mounted on the shaft with brushes resting on them as shown in fig (3). The brushes are connected to star connected variable resistor. The main use of brushes and slip-rings are to connect the external resistance to rotor. The use of connecting external resistance to rotor circuit is

(i) It increases the starting torque and decreases the starting current.
(ii) It controls the speed of the motor.

Operating or Working principle or why the 3-ph induction motor is selfstarting machine:

When the 3-ph AC supply is given to stator of Induction motor, a rotating magnetic field of constant magnitude and rotating with synchronous speed is produced. This rotating magnetic field cuts the stationary rotor conductor and an emf is induced across the rotor conductors. The magnitude of this emf depends on relative speed between the stator flux and rotor conductors. Since the rotor conductors forms a closed circuit, current will passes through the rotor conductors called rotor current. Now around the current carrying rotor conductors a magnetic field will setup in the form of concentric circles as shown in fig.(a). The direction of the magnetic field around the rotor conductors is determined by skew rule or right hand thumb rule.

Now, because of interaction of stator flux and flux around the current rotor conductors, the flux is strengthens right and weakens on left of the rotor conductors at top of the rotor cond rotor conductors at bottom of the rotor conductors as shown in fig. (b). This result in movement in the rotor in anti clock wise direction.

From the above discussion it is clear that an induction motor is a self starting motor

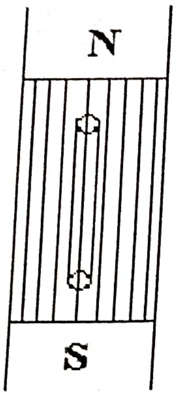


Fig. (a)

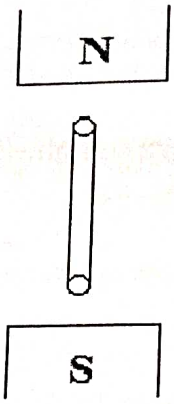


Fig. (b)