DC Machines

The electrical machines deals with the energy transfer either from mechanical to electrical form or from electrical to mechanical form, this process is called electromechanical energy conversion.

An electrical machine which converts mechanical energy into electrical energy is called an electric generator while an electrical machine which converts electrical energy into the mechanical energy is called an electric motor.

A Dc generator is built utilizing the basic principle that emf is induced in a conductor when it cuts magnetic lines of force.

A DC motor works on the basic principle that a current carrying conductor placed in a magnetic field experiences a force.

DC GENERATOR

Working principle: DC generator

All the generators work on the principle of dynamically induced emf.The change in flux associated with the conductor can exist only when there exists a relative motion between the conductor and the flux. The relative motion can be achieved by rotating the conductor w.r.t flux or by rotating flux w.r.t conductor. So, a voltage gets generated in a conductor as long as there exists a relative motion between conductor and the flux. Such an induced emf which is due to physical movement of coil or conductor w.r.t flux or movement of flux w.r.t coil or conductor is called dynamically induced emf.
Whenever a conductor cuts magnetic flux, dynamically induced emf is produced in it according to Faraday's laws of Electromagnetic Induction.
This emf causes a current to flow if the conductor circuit is closed.

So, a generating action requires the following basic components to exist.

1. The conductor or a coil
2. Flux
3. Relative motion between the conductor and the flux.

In a practical generator, the conductors are rotated to cut the magnetic flux, keeping flux stationary. To have a large voltage as output, a number of conductors are connected together in a specific manner to form a winding. The winding is called armature winding of a dc machine and the part on which this winding is kept is called armature of the dc machine.

The magnetic field is produced by a current carrying winding which is called field winding.

The conductors placed on the armature are rotated with the help of some external device. Such an external device is called a prime mover.

The commonly used prime movers are diesel engines, steam engines, steam turbines, water turbines etc.

The purpose of the prime mover is to rotate the electrical conductor as required by Faraday's laws

The direction of induced emf can be obtained by using Flemings right hand rule.

The magnitude of induced emf = $e = BLV \sin\theta = E_m \sin\theta$.

Nature of induced emf

The nature of the induced emf for a conductor rotating in the magnetic field is alternating. As conductor rotates in a magnetic field, the voltage component at various positions is different.

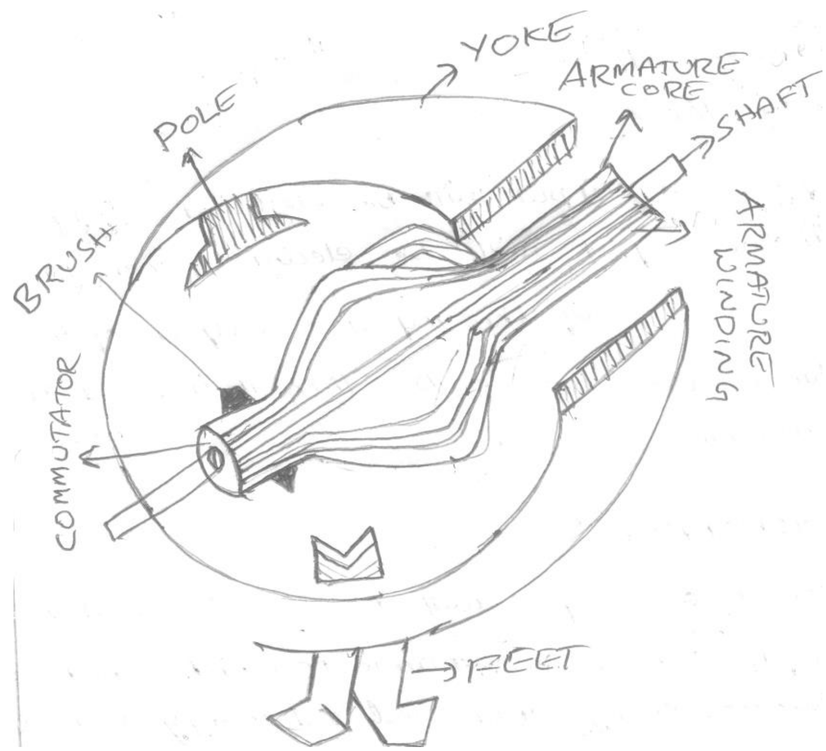
Hence the basic nature of induced emf in the armature winding in case of dc generator is alternating. To get dc output which is unidirectional, it is necessary to rectify the alternating induced emf. A device which is used in dc generator to convert alternating induced emf to unidirectional dc emf is called commutator.

Construction of DC machines :

A D. C. machine consists of two main parts

1. Stationary part: It is designed mainly for producing a magnetic flux.

2. Rotating part: It is called the armature, where mechanical energy is converted into electrical (electrical generate) or conversely electrical energy into mechanical (electric into)



Parts of a Dc Generator:

1) Yoke
2) Magnetic Poles
    a) Pole core
    b) Pole Shoe
3) Field Winding
4) Armature Core
5) Armature winding
6) Commutator
7) Brushes and Bearings

The stationary parts and rotating parts are separated from each other by an air gap. The stationary part of a D. C. machine consists of main poles, designed to create the magnetic flux, commutating poles interposed between the main poles and designed to ensure spark less operation of the brushes at the commutator and a frame / yoke. The armature is a cylindrical body rotating in the space between the poles and comprising a slotted armature core, a winding inserted in the armature core slots, a commutator and brush

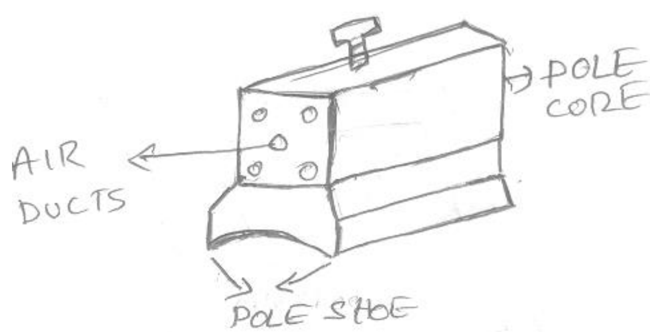
Yoke:

1. It saves the purpose of outermost cover of the dc machine so that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc.
2. It provides mechanical support to the poles.
3. It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux.

Choice of material : To provide low reluctance path, it must be made up of some magnetic material. It is prepared by using cast iron because it is the cheapest. For large machines rolled steel or cast steel, is used which provides high permeability i.e., low reluctance and gives good mechanical strength.

Poles: Each pole is divided into two parts

a) pole core b) pole shoe



Functions: 1. Pole core basically carries a field winding which is necessary to produce the flux.

2. It directs the flux produced through air gap to armature core to the next pole.
3. Pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced emf.

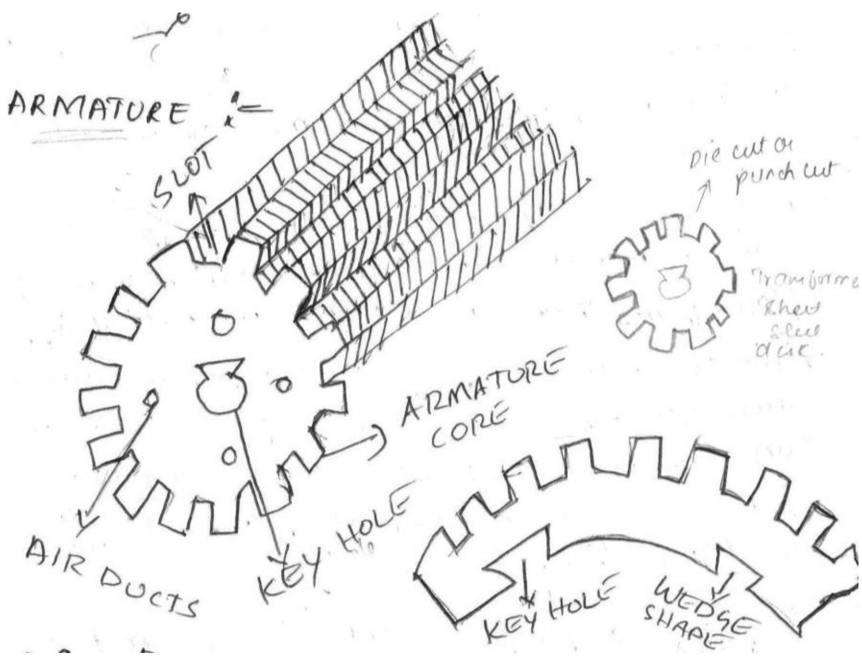
To achieve this, pole core has been given a particular shape.

Choice of material : It is made up of magnetic material like cast iron or cast steel. As it requires a definite shape and size, laminated construction is used. The laminations of required size and shape are stamped together to get a pole which is then bolted to yoke.

Armature: It is further divided into two parts namely,

(1) Armature core (2) Armature winding.

Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.



Functions:

1. Armature core provides house for armature winding i.e., armature conductors.
2. To provide a path of low reluctance path to the flux it is made up of magnetic material like cast iron or cast steel.

Choice of material : As it has to provide a low reluctance path to the flux, it is made up of magnetic material like cast iron or cast steel.

It is made up of laminated construction to keep eddy current loss as low as possible.

A single circular lamination used for the construction of the armature core is shown below.

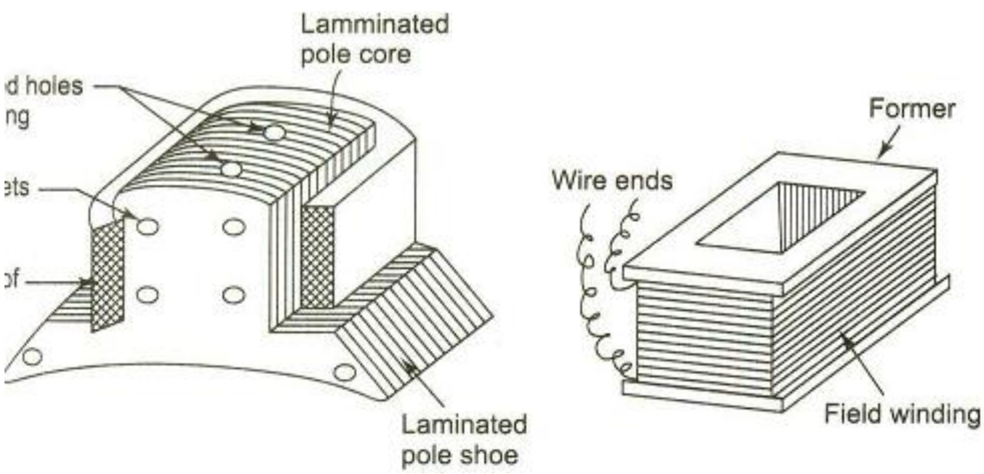
2. **Armature winding:** Armature winding is nothing but the inter connection of the armature conductors, placed in the slots provided on the armature core. When the armature is rotated, in case of generator magnetic flux gets cut by armature conductors and emf gets induced in them.

Function:

1. Generation of emf takes place in the armature winding in case of generators.
2. To carry the current supplied in case of dc motors.
3. To do the useful work it the external circuit.

Choice of material : As armature winding carries entire current which depends on external load, it has to be made up of conducting material, which is copper.

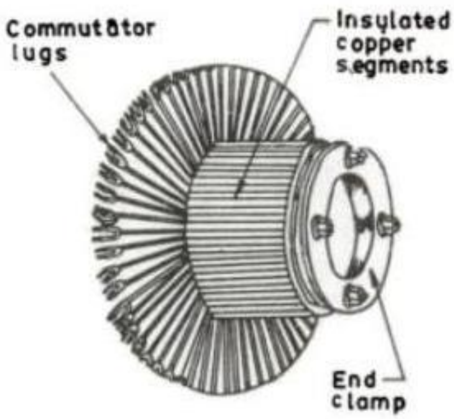
Field winding: The field winding is wound on the pole core with a definite direction.



Functions: To carry current due to which pole core on which the winding is placed behaves as an electromagnet, producing necessary flux.
As it helps in producing the magnetic field i.e. exciting the pole as electromagnet it is called '**Field winding'** or '**Exciting winding'.**

Choice of material : As it has to carry current it should be made up of some conducting material like the aluminum or copper.
But field coils should take any type of shape should bend easily, so copper is the proper choice.
Field winding is divided into various coils called as field coils. These are connected in series with each other and wound in such a direction around pole cores such that alternate N and S poles are formed.

Commutator: The rectification in case of dc generator is done by device called as commutator.

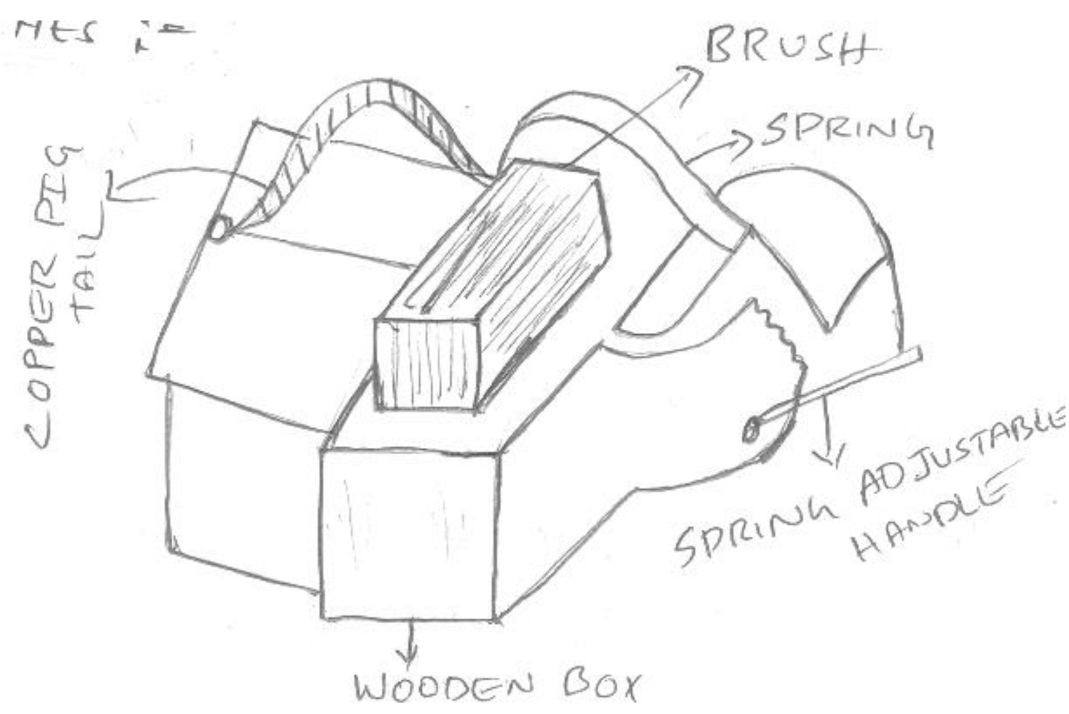


Functions: 1. To facilitate the collection of current from the armature conductors.

2. To convert internally developed alternating emf to in directional (dc) emf
3. To produce unidirectional torque in case of motor.

Choice of material : As it collects current from armature, it is also made up of copper segments. It is cylindrical in shape and is made up of wedge shaped segments which are insulated from each other by thin layer of mica.

Brushes and brush gear : Brushes are stationary and rest on the surface of the commutator. Brushes are rectangular in shape. They are housed in brush holders, which are usually of box type. The brushes are made to press on the commutator surface by means of a spring, whose tension can be adjusted with the help of lever. A flexible copper conductor called pigtail is used to connect the brush to the external circuit.



Functions: To collect current from commutator and make it available to the stationary external circuit.

Choice of material : Brushes are normally made up of soft material like carbon.

Bearings: Ball-bearings are usually used as they are more reliable. For heavy duty machines, roller bearings are preferred.

Working of DC generator

The generator is provided with a magnetic field by sending dc current through the field coils mounted on laminated iron poles and through armature winding.

A short air gap separates the surface of the rotating armature from the stationary pole surface. The magnetic flux coming out of one or more worth poles crossing the air gap , passes through the armature near the gap into one or more adjacent south poles.

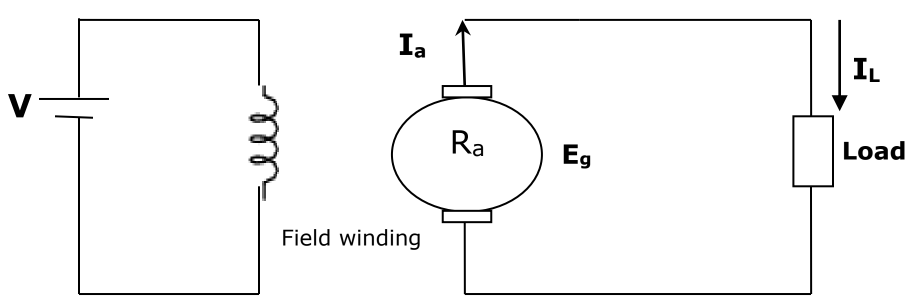
The direct current leaves the generator at the positive brush, passes through the circuit and returns to the negative brush.

The terminal voltage of a dc generator may be increased by increasing the current in the field coil and may be reduced by decreasing the current.

Generators are generally run at practically constant speed by their prime mores.

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

a) **Separately excited generators:** These are generators whole field magnets are energized from an independent external source of dc current.



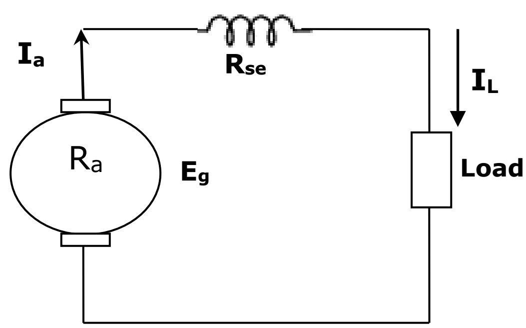
b) **Self-excited generators:** These are generators whose field magnets are energized by the current produced by the generators themselves.

Due to residual magnetism, there is always present some flux in the poles when the armature is rotated, some emf and hence some induced current is produced which is partly or fully passed through the field coils thereby strengthening the residual pole flux.

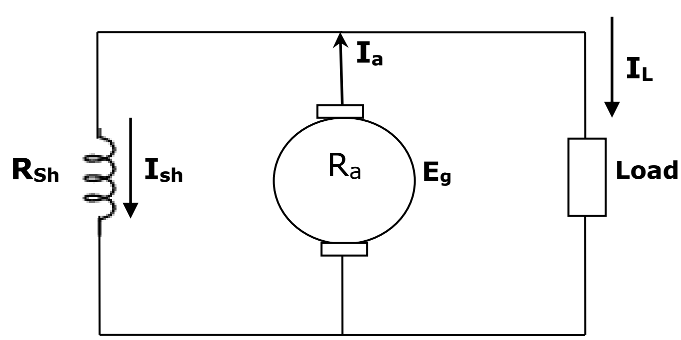
The self-excited generators are again divided into three types according to the manner in which their field coils or winding are connected to the armature.

1)Series Generator
2)Shunt Generator
3)Compound Generator
 i.Long Shunt Compound Generator
 ii. Short Shunt Compound Generator

Series Generator: It is a generator where the field winding is connected in series with the armature



Shunt Generator: It is a generator where the field winding is connected in series with the armature

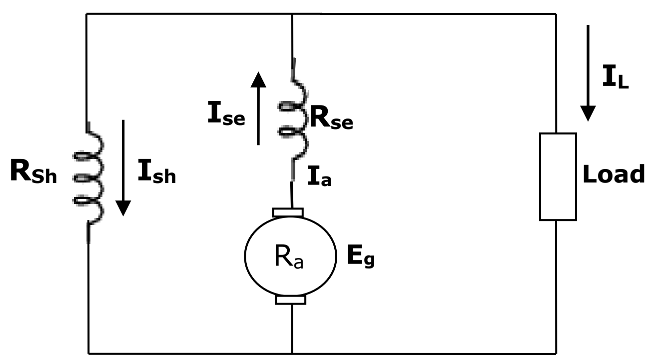


Compound Generator: It is generator which has both Series and Shunt Windings. Compound generators are of two types.

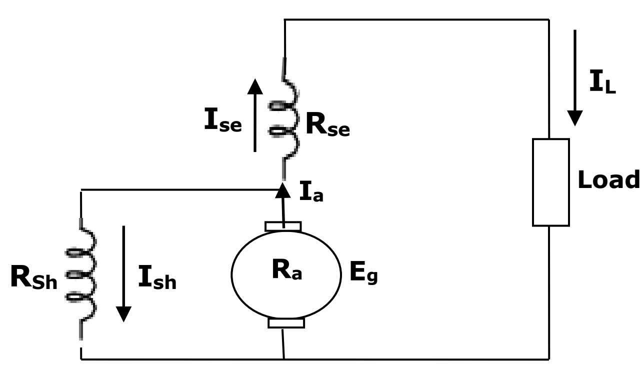
a)Long Shunt Compound Generator

b)Short Shunt Compound Generator

Long Shunt Compound Generator:



Short Shunt Compound Generator:



Types of armature winding

Armature conductors are connected in a specific manner called as armature winding and according to the way of connecting the conductors, armature winding is divided into two types.

Lap winding: In this case, if connection is started from conductor in slot 1 then the connections overlap each other as winding proceeds, till starting point is reached again.

There is overlapping of coils while proceeding. Due to such connection, the total number of conductors get divided into 'P' number of parallel paths, where

P = number of poles in the machine.

Large number of parallel paths indicate high current capacity of machine hence lap winding is pertained for high current rating generators.

Wave winding: In this type, winding always travels ahead avoiding over lapping. It travels like a progressive wave hence called wave winding.

Both coils starting from slot 1 and slot 2 are progressing in wave fashion.

Due to this type of connection, the total number of conductors get divided into two number of parallel paths always, irrespective of number of poles of machine.

As number of parallel paths are less, it is preferable for low current, high voltage capacity generators.

Sl. No.	Lap winding	Wave winding
1.	Number of parallel paths (A) = poles (P)	Number of parallel paths (A) = 2 (always)
2.	Number of brush sets required is equal to number of poles	Number of brush sets required is always equal to two
3.	Preferable for high current, low voltage capacity generators	Preferable for high current, low current capacity generators
4.	Normally used for generators of capacity more than 500 A	Preferred for generator of capacity less than 500 A.

EMF equation of a generator

Let P = number of poles

ϕ = flux/pole in webers

Z = total number of armature conductors.

= number of slots x number of conductors/slot

N = armature rotation in revolutions (speed for armature) per minute (rpm)

A = No. of parallel paths into which the 'z' no. of conductors are divided.

E = emf induced in any parallel path

E_g = emf generated in any one parallel path in the armature.

Average emf generated/conductor = $d\phi/dt$ volt

Flux current/conductor in one revolution

$$d\phi = \phi \times p$$

In one revolution, the conductor will cut total flux produced by all poles = $\phi \times p$

No. of revolutions/second = $N/60$

Therefore, Time for one revolution, $dt = 60/N$ second

According to Faraday's laws of Electromagnetic Induction, emf generated/conductor = $d\phi/dt = \phi \times p \times N / 60$ volts

This is emf induced in one conductor.

For a simplex wave-wound generator

No. of parallel paths = 2

No. of conductors in (series)in one path = $Z/2$

EMF generated/path = $\phi PN/60 \times Z/2 = \phi ZPN/120$ volt

For a simple lap-wound generator

Number of parallel paths = P

Number of conductors in one path = Z/P

EMF generated/path = $\phi PN/60 \ (Z/P) = \phi ZN/60$

$A = 2$ for simplex – wave winding

$A = P$ for simplex lap-winding

Characteristics of dc generators

The dc generators have the following characteristics in general

1. Magnetization characteristics
2. Load characteristics

Magnetization characteristics

It is also known as no-load saturation characteristics or open-circuit characteristics (OCC)

This characteristics is the graph of the no-load generated emf Eo and the field current If, at a given speed.

As it is plotted without load with open output terminals it is also called no load characteristics or open circuit characteristics.

No-load curve for self-excited generator

The O.C.C. or no-load curves for self-excited generators whether shunt or series-connected are obtained in a same way.

The field winding of the generator (wheeler shunt or series world) is disconnected from the machine and connected to an external source of direct current.

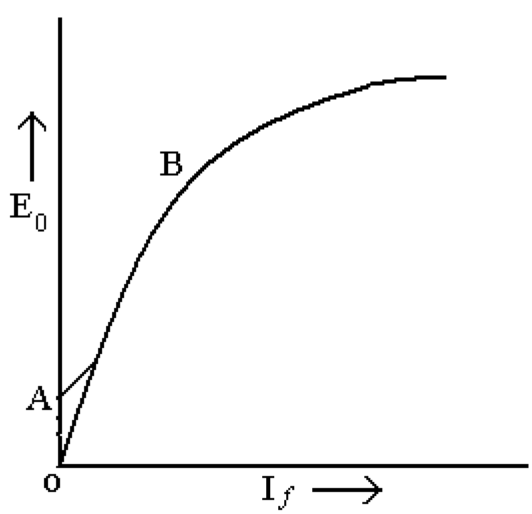
The field or exciting current If is varied the statically its value is read on the armature A.

The machine is driven at constant speed by the prime moves and the generated emf on on-load is measured by the voltmeter connected across the armature.

I_f is increased by suitable steps starching from zero and the corresponding values of Eo are measured on plotting the relation between If and Eo a curve of the forms shown in obtained.

Due to residual magnetism in the poles some emf is generated even when If = 0 hence the curve starts from point A.

Eo vs If → magnetization characteristics.



Critical resistance for shunt generator

Critical resistance is that value of resistance in the field circuit, which enables the machine just to start building up.
Now, connect the field windings back to the armature and run the machine as a shunt generator.
Due to residual magnetism, some initial emf and hence current, would be generated.
This current while passing through the field coils will strengthen the magnetisation at the poles.
This will increase the pole flux which will further increases the generated emf.
Increased emf means more current which further increases the flux and so on.
The value of the resistance represented by the tangent to the curve is known as critical resistance Rc for a given speed.

Thus induced emf increases directly as If increases. But after certain time, If core gets saturated flux f also remains constant through If increases.
Induced emf also varies with speed, we will get a family of parallel characteristics for lower speeds, generated voltage are less so characteristics for lower speeds are below the characteristics for higher

Losses in a Dc Generator:

Variable losses : The armature current varies with load . The copper losses that occur in the armature also vary w.r.t to load Ar Cu loss = Ia^2 Ra

Magnetic losses :
Hysteresis : The property of a magnetic material to retain a part of the magnetism achieved by it, one removal of the driving force is called hysteresis.
The power required to overcome this hysteresis effect is called hysteresis loss. It is denoted by Wn.

$W_h \alpha f$

$\alpha B_m^{1.6}$

$W_h = \eta B_m^{1.6} f V$

Where , η=Steinmetz Constant
B=Flux Density
F=Frequency
V=Volume Of the core

Eddy current losses : When the iron part (rotor) rotates in the stationary field, there is an induced emf in the iron part also apart from the emf induced in the copper windings. This emf is called eddy emf. The iron part provides a closed path for the eddy emf to circulate a current. This current is called eddy current.

The power required to be generated by the machine to over come the effect of eddy current is called eddy current loss. It is denoted by w_e.
$W_e \alpha B_m^2 f^2 t^2$.

Mechanical losses :

1. Friction losses : The rotation of the armature inside the bearings causes friction to be developed. In order to over come this, the prime more has to supply more power.
2. Windage losses : An extra mounting on the shaft of the armature such as fan to provide air for cooling purposes causes an extra burden on the prime mover. The extra power required to drive the fan is termed as windage loss. (constant)

Stray losses :
The magnetic and mechanical looks are collectively known as stray losses.
These are also known as rotational losses
Constant and standing losses: The field current loss is constant. Hence, stray loses and shut current loses are content these loses are together known as **standing** or **constant loses Wc.**
Hence, for shunt and compound generators.
Total loss = armature cu loss + wc
$= I_a^2$ Ra + wc
$(I + I^{gh})^2$ Ra + Wc
An current loss, I_a^2 Ra is known as variable loss because it varies with the current.
Total loss = variable loss + constant loss wc.

Efficiency of a DC Generator:

Shunt Generator:

Output Power= Input Power- Losses
Input Power=VI
Losses=Armature Copper Losses($I_a^2R_a$)+Constant Losses(Wc)
Efficiency=Output/Input=Input-Losses/Input
η= VI-($I_a^2R_a$+ Wc)/ VI
In a Shunt Generator $I=I_a+I_{sh}$
Here Ish is neglible
So I=Ia

So, η= VI_a-($I_a^2R_a$+ Wc)/ VI_a
$=1-(I_aR_a/V)-W_c/VI_a$-------------------------(1)

Condition for maximum efficiency:

For maximum efficiency differentiate equation (1) and equate to zero

$d(\eta)/dI_a = d(1-(I_aR_a/V)-W_c/VI_a)/dI_a = 0$

$= 0 - R_a/V + W_c/VI_a^2 = 0$

$R_a/V = W_c/VI_a^2$

$\mathbf{W_c = I_a^2 R_a}$

1)Mechanical efficiency =

$$\mu_m = \frac{B}{A} = \frac{total\ walts\ gented\ in\ arnature}{mechanical\ power\ \sup plied}$$

$$\frac{E_g\ I_a}{output\ of\ during\ enzime}$$

2. Electrical efficiency

$$\mu_c = \frac{C}{B} = \frac{watts\ available\ in\ local\ circut}{total\ watts\ generated} = \frac{vI}{E_g\ I_a}$$

3.Overall efficiency

$$\mu_c = \frac{C}{A} = \frac{watts\ available\ in\ local\ circut}{mechanical\ power\ \sup plied} = \mu_c = \mu_m + \mu_e$$