Core loss or iron loss occurs in the armature core is due to the rotation of armature core in the magnetic flux produced by the field system. Iron loss consists of a) Hysteresis loss and b) Eddy current loss.

a) **Hysteresis loss:** This loss is due to the reversal of magnetization of armature core as the core passes under north and south poles alternatively. This loss depends on the volume and grade of iron, maximum value of flux density BM and frequency. Hysteresis loss W_h is given by Steinmetz formula.

$W_h = K_h B_m 1.6$ f v joule/sec. or watt

where K_h = Constant of proportionalitiy - depends on core material.

B_m = Maximum flux density in wb/m^2

F = Frequency in hertz

V = Volume of the armature core in m^3

b) Eddy Current loss: Eddy currents are the currents set up by the induced emf in the armature core when the core cuts the magnetic flux. The loss occurring due to the flow of eddy current is known as eddy current loss. To reduce this loss, the core is laminated, stacked and riveted. These laminations are insulated from each other by a thin coating of varnish. The effect of lamination is to reduce the current path because of increased resistance due to reduced cross section area of laminated core. Thus the magnitude of eddy current is reduced resulting in the reduction of eddy current loss.

Eddy Current loss W_e is given by

$W_e = K_e B^2{}_m f^2 t^2 v$ Watt

Where K_e = Constant of Proportionality

B_m = Maximum flux density in Wb/m^2

f = Frequency in Hz.

t = Thickness of the lamination in meters

v = Volume of the armature core in m^3.

ii **Mechanical loss:** these losses include losses due to windage, brush friction and bearing friction losses.

2) **Variable losses:** Variable losses consist of (i) Copper loss:

Armature copper loss ($I_a{}^2 r_a$) loss: This loss occurs in the armature windings because of the resistance of armature windings, when the current flows through them. The loss occurring is termed as copper loss or $I_a{}^2 r_a$ loss. This loss varies with the varying load.

b) **Field contact drop:** This is due the contact resistance between the brush and the commutator. This loss remains constant with load.

c) **Brush contact drop:** This is due the contact resistance between the brush and the commutator. This loss remains constant with load.

ii) **Stray load loss:** The additional losses which vary with the load but cannot be related to current in a simple manner are called stray load loss. Stray load losses are.

i) **Copper stray load loss :** The loss occuring in the conductor due to skin effect and loss due to the eddy currents in the conductor. Set up by the flux passing through them are called copper stray load loss.

ii) **Core stray load loss:** When the load current flows through the armature conductors, the flux density distribution gets distorted in the teeth and core. The flux density decreases at one end of the flux density wave and increases at the other. Since the core loss is proportional to the square of the flux density, the decrease in flux density will be less than the increase due to the increase in flux density, resulting in a net increase in the core loss predominantly in the teeth, known as stray load loss in the core.

Further under highly saturated conditions of teeth, flux leaks through the frame and end shields causing eddy current loss in them. This loss is a component of stray load loss. Stray load loss is difficult to calculate accurately and therefore it is taken as 1 % of the output of DC machine.

Efficiency of a DC generator

Power flow in a DC generator is shown in Figure 35.

$$= \frac{\text{output}}{\text{output} + \text{losses}} = \frac{VI}{VI + I_a^2 r_a + W_e}$$

where w_e is constant loss

Condition for maximum efficiency

Generator output = VI

Generator input = output+losses

$= VI + I^2 a R_a + W_e$

$= VI + (I + I_{sh})^2 R_a + W_e \quad \therefore I_a = (I + I_{sh})$

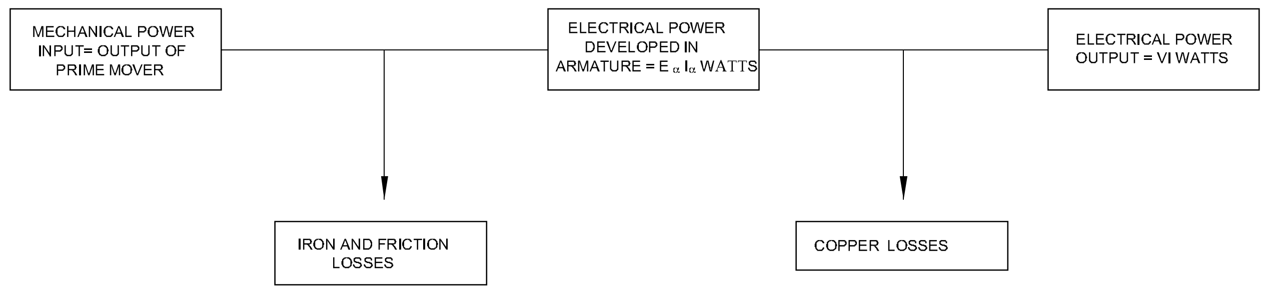
However, if I_{sh} is negligible as compared to load current I_a=I (approx.)

$$\because \eta = \frac{\text{output}}{\text{input}} = \frac{VI}{VI + I^2 a R_a + W_e} = \frac{VI}{VI + I^2 R_a + W_e}$$

Efficiency is maximum when variable loss = constant loss.

The load current corresponding to maximum efficiency is given by the relation.

Fig 35



$$I^2R_a = We$$

$$I = \sqrt{\frac{W_e}{R_a}}$$

Efficiency of DC motor

The power flow in a DC motor is shown in Figure 36

$$\text{Efficiency of a DC motor} = \frac{\text{input} - \text{losses}}{\text{input}}$$

$$= \frac{VI - I_a^2 r_a - w_c}{VI}$$

The condition for maximum power developed

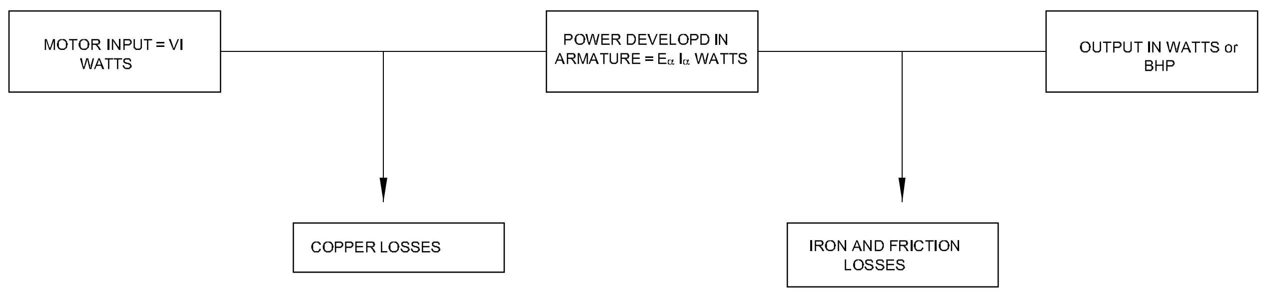
$$E_b = \frac{V}{2} = I_a r_a$$

This is shown in equation

The condition for maximum efficiency is variable loss = constant loss

$$I^2 r_a = w_e$$

Fig 36



Losses in a DC generator and DC motor

A DC generator converts mechanical power into electrical power and a DC motor converts electrical power into mechanical power. Thus, for a dc generator, input power is in the form of mechanical and the output power is in the form of electrical. On the other hand, for a dc motor, input power is in the form of electrical and output power is in the form of mechanical. In a practical machine, whole of the input power cannot be converted into output power as some power is lost in the conversion process. This causes the efficiency of the machine to be reduced. Efficiency is the ratio of output power to the input power. Thus, in order to design rotating dc machines (or andy electrical machine) with higher efficiency, it is important to study the losses occurring in them. Various losses in a rotating DC machine (DC generator or DC motor) can be characterised as follows:

Losses in a rotating DC machine

- **Copper losses**
  - Armature Cu loss
  - Field Cu loss
  - Loss due to brush contact resistance
- **Iron losses**
  - Hysteresis loss
  - Eddy current loss

- **Mechanical losses**
  - Friction loss
  - Windage loss

The above tree categorizes various types of losses that occur in a dc generator or a dc motor. Each of these is explained in details below.

Copper Losses

These losses occur in armature and field copper windings. Copper losses consist of Armature copper loss, Field copper loss and loss due to brush contact resistance.

Armature copper loss = $I_a^2R_a$ (where, $I_a^2R_a$ (where, I_a = Armature current and R_a = Armature resistance)

This loss contributes about 30 to 40% to full load losses. The armature copper loss is variable and depends upon the amount of loading of the machine.

Field copper loss = $I_f^2R_f$ (where, I_f = field current and R_f = field resistance) In the case of a shunt wounded field, field copper loss is practically constant. It contributes about 20 to 30% to full load losses.

Brush contact resistance also contributes to the copper losses. Generally, this loss is included into armature copper loss.

Iron losses (Core losses)

As the armature core is made of iron and it rotates in a magnetic field, a small current gets induced in the core itself too. Due to this current, eddy current loss and hysteresis loss occur in the armature iron core. Iron losses are also called as Core losses or magnetic losses.

Hysteresis loss is due to the reversal of magnetization of the armature core. When the core passes under one pair of poles, it undergoes one complete cycle of magnetic reversal. The frequency of magnetic reversal is given by, f=P.N/120 (where, P = no. of poles and N = Speed in rpm)

The loss depends upon the volume and grade of the iron, frequency of magnetic reversals and value of flux density. Hysteresis loss is given by, Steinmetz formula: $W_h = \eta B_{max}^{1.6} fV$ (watts), η = Steinmetz hysteresis constant V = volume of the core in m^3

Eddy current loss: When the armature core rotates in the magnetic field, an emf is also induced in the core (just like it induces in armature conductors), according to the Faraday's law of electromagnetic induction. Though this induced emf is small, it causes a large current to folw in the body due to the low resistance of the core. This current is known as eddy current. The powe loss due to this current is known as eddy current loss.

Mechanical losses

Mechanical losses consist of the losses due to friction in bearings and commutator. Air friction loss of rotating armature also contributes to these. These losses are about 10 to 20% of full load losses.

Stray losses

In addition to the losses stated above, there may be small losses present which are called as stray losses or miscellaneous losses. These losses are difficult to account. They are usually due to inaccuracies in the designing and modeling of the machine. Most of the times, stray losses are assumed to be 1% of the full load.

Power flow diagram

The most convenient method to understand these losses in a dc generator or a dc motor is using the power flow diagram. The diagram visualizes the amount of power that has been lost in various types of losses and the amount of power which has been actually converted into the output. Following are the typical flow diagrams for a dc generator and a dc motor. (Fig 37 & 38)

Fig 37

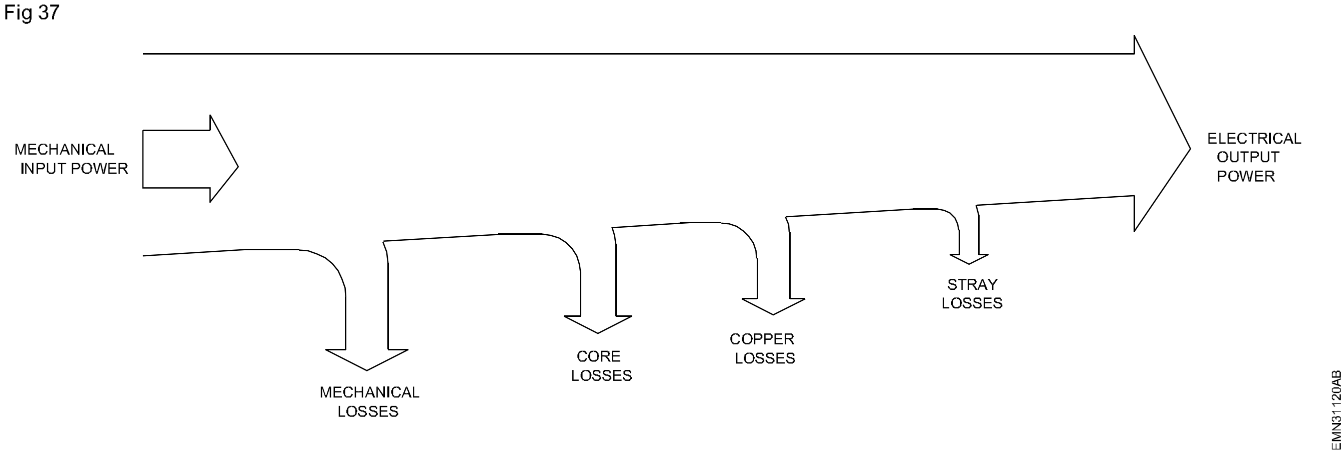
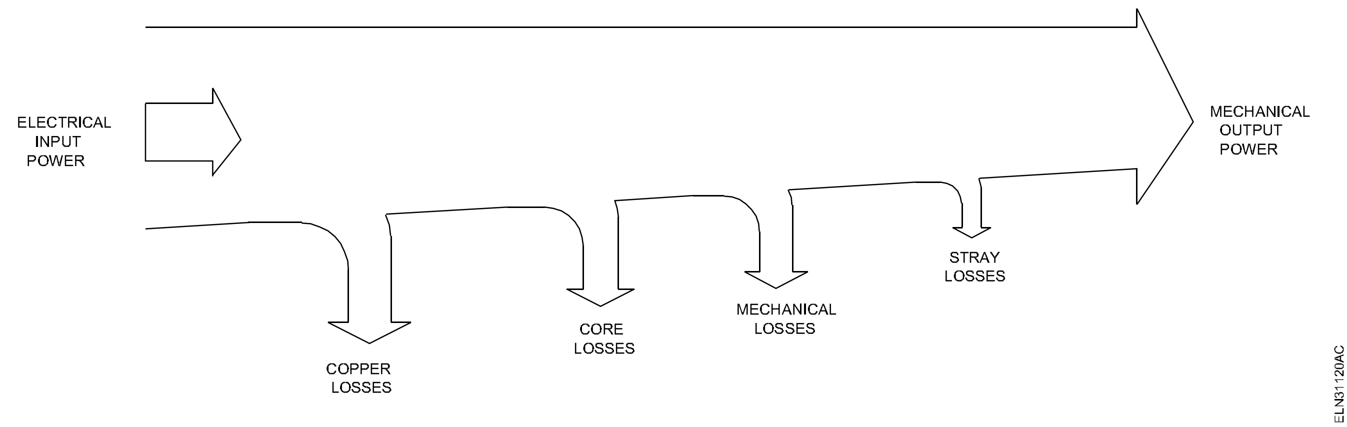


Fig 38



Efficiency of DC generator

Efficiency is simply defined as the ratio of output power to the input power. Let R = total resistance of the armature circuit (including the brush contact resistance, at series winding resistance, inter-pole winding resistance and compensating winding resistance). The efficiency of DC generator is explained in the line diagram Fig 39

I is the output current

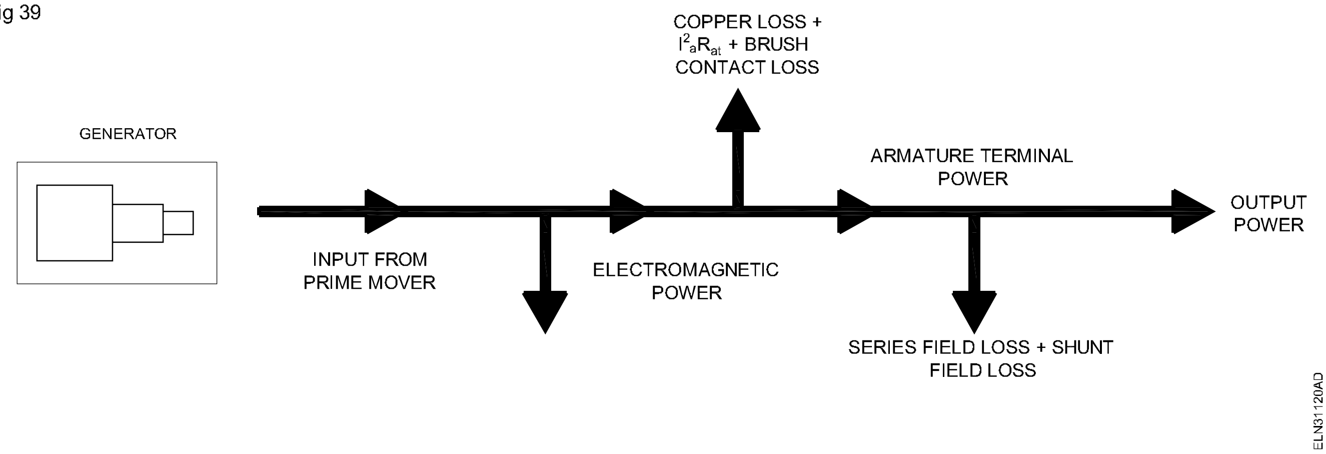
I_{sh} is the current through the shunt field

I_a is the armature current = I + I_{sh}

V is the terminal voltage.

Total copper loss in the armature circuit = $I_a{}^2R_{at}$

Fig 39



Power loss in the shunt circuit = V_{Ish} (this includes the loss in the shunt regulating resistance).

Mechanical losses = friction loss of bearings + friction loss at a commutator + windage loss.

Stray loss = mechanical loss + core loss

The sum of the shunt field copper loss and stray losses may be considered as a combined fixed (constant) loss that does not vary with the load current I.

Therefore, the constant losses (in shunt and compound generators) = stray loss + shunt field copper losses.

Generator efficiency is given by the equation shown below.

$$\eta_G = \frac{\text{Generator output}}{\text{Generator output} + \text{losses}}$$

$$\eta_G = \frac{VI}{VI + I_a^2 R_{at} + V_{BD} \; I_a + P_k}$$

$$I_a = I + I_{sh}$$