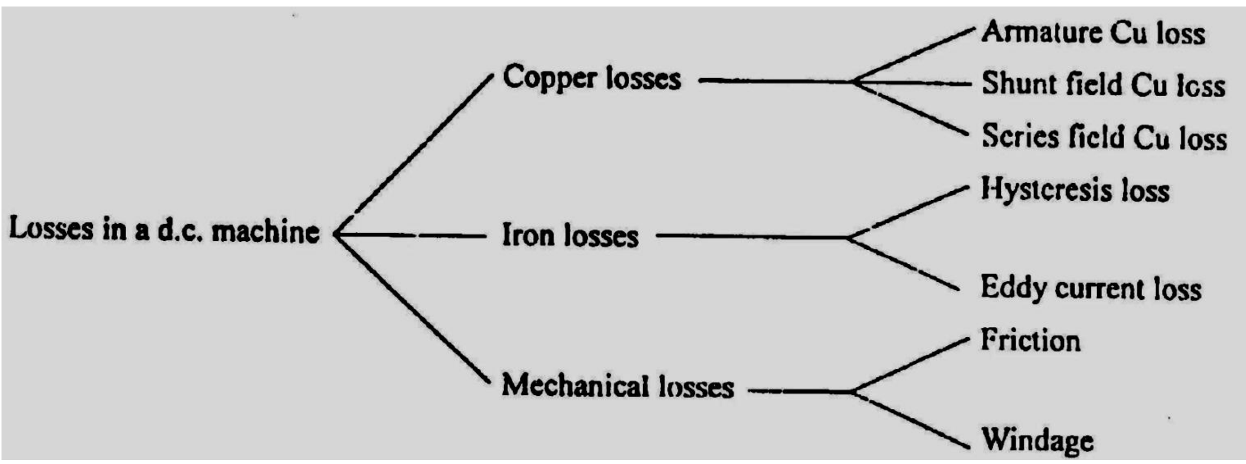
Losses in a D.C. Machine

The losses in a d.c. machine (generator or motor) may be divided into three classes viz (i) copper losses (ii) iron or core losses and (iii) mechanical losses. All these losses appear as heat and thus raise the temperature of the machine. They also lower the efficiency of the machine.



1. Copper losses

These losses occur due to currents in the various windings of the machine.

(i) Armature copper loss = $I_a^2 R_a$

(ii) Shunt field copper loss = $I_{sh}^2 R_{sh}$

(iii) Series field copper loss = $I_{se}^2 R_{se}$

Note. There is also brush contact loss due to brush contact resistance (i.e., resistance between the surface of brush and surface of commutator). This loss is generally included in armature copper loss.

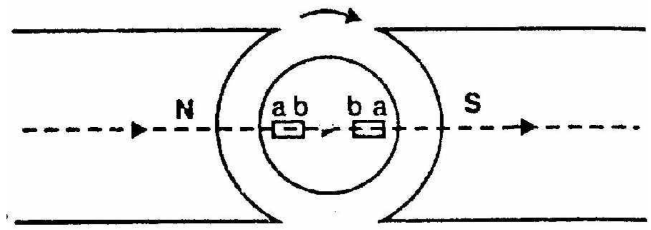


Fig. (1.36)

2. Iron or Core losses

These losses occur in the armature of a d.c. machine and are due to the rotation of armature in the magnetic field of the poles. They are of two types viz., (i) hysteresis loss (ii) eddy current loss.

(i) **Hysteresis loss**

Hysteresis loss occurs in the armature of the d.c. machine since any given part of the armature is subjected to magnetic field reversals as it passes under successive poles. Fig. (1.36) shows an armature rotating in two-pole machine. Consider a small piece ab of the armature. When the piece ab is under N-pole, the magnetic lines pass from a to b. Half a revolution later, the same piece of iron is under S-pole and magnetic lines pass from b to a so that magnetism in the iron is reversed. In order to reverse continuously the molecular magnets in the armature core, some amount of power has to be spent which is called hysteresis loss. It is given by Steinmetz formula. This formula is

$$\text{Hysteresis loss, } P_h = \eta B_{max}^{16} f V \quad \text{watts}$$

where B_{max} = Maximum flux density in armature

f = Frequency of magnetic reversals

= NP/120 where N is in r.p.m.

V = Volume of armature in m^3

η = Steinmetz hysteresis co-efficient

In order to reduce this loss in a d.c. machine, armature core is made of such materials which have a low value of Steinmetz hysteresis co-efficient e.g., silicon steel. (ii) **Eddy current loss** In addition to the voltages induced in the armature conductors, there are also voltages induced in the armature core. These voltages produce circulating currents in the armature core as shown in

Fig. (1.37). These are called eddy currents and power loss due to their flow is called eddy current loss. The eddy current loss appears as heat which raises the temperature of the machine and lowers its efficiency.

If a continuous solid iron core is used, the resistance to eddy current path will be small due to large cross-sectional area of the core. Consequently, the magnitude of eddy current and hence eddy current loss will be large. The magnitude of

eddy current can be reduced by making core resistance as high as practical. The In order to reduce this loss in a d.c. machine, armature core is made of such materials which have a low value of Steinmetz hysteresis co-efficient e.g., silicon steel.

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iron sheets called laminations [See Fig. 1.38]. The laminations are insulated from each other with a coating of varnish. The insulating coating has a high resistance, so very little current flows from one lamination to the other. Also, because each lamination is very thin, the resistance to current flowing through the width of a lamination is also quite large. Thus laminating a core increases the core resistance which decreases the eddy current and hence the eddy current loss.

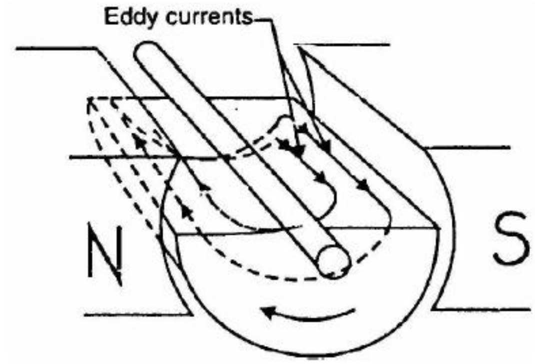

Fig. (1.37)

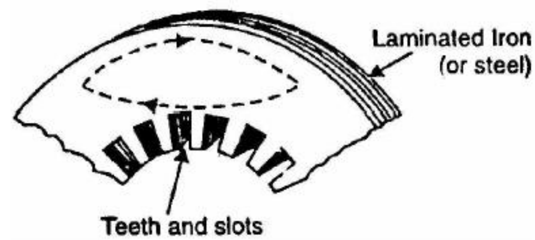

Fig. (1.38)

$$\text{Eddy current loss, } P_e = K_e B_{max}^2 f^2 t^2 V \quad \text{watts}$$

where K_e = Constant depending upon the electrical resistance of core and system of units used

B_{max} = Maximum flux density in Wb/m2

f = Frequency of magnetic reversals in Hz

t = Thickness of lamination in m

V = Volume of core in m^3

It may be noted that eddy current loss depends upon the square of lamination thickness. For this reason, lamination thickness should be kept as small as possible.

3. Mechanical losses

These losses are due to friction and windage. (i) friction loss e.g., bearing friction, brush friction etc. (ii) windage loss i.e., air friction of rotating armature. These losses depend upon the speed of the machine. But for a given speed, they are practically constant.

Note. Iron losses and mechanical losses together are called stray losses.

Constant and Variable Losses

The losses in a d.c. generator (or d.c. motor) may be sub-divided into (i) constant losses (ii) variable losses.

(i) **Constant losses**

Those losses in a d.c. generator which remain constant at all loads are known as constant losses. The constant losses in a d.c. generator are:

(a) iron losses

(b) mechanical losses

(c) shunt field losses

(ii) Variable losses

Those losses in a d.c. generator which vary with load are called variable losses. The variable losses in a d.c. generator are:

(a) Copper loss in armature winding ($I_a^2 R_a$)

(b) Copper loss in series field winding ($I_{se}^2 R_{se}$)

$$\text{Total losses} = \text{Constant losses} + \text{Variable losses}$$

Note. Field Cu loss is constant for shunt and compound generators.

1.28 Power Stages

The various power stages in a d.c. generator are represented diagrammatically in Fig. (1.39).

A – B = Iron and friction losses

B – C = Copper losses

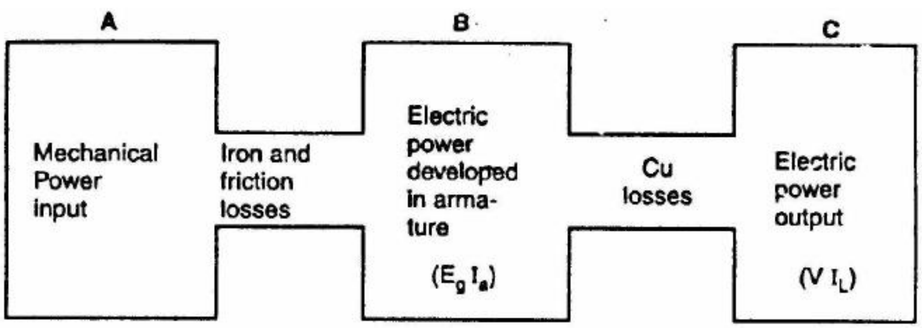

Fig. (1.39)

(i) Mechanical efficiency

$$\eta_m = \frac{B}{A} = \frac{E_g I_a}{\text{Mechanical power input}}$$

(ii) Electrical efficiency

$$\eta_e = \frac{C}{B} = \frac{V\,I_L}{E_g\,I_a}$$

(iii) Commercial or overall efficiency

$$\eta_c = \frac{C}{A} = \frac{V\,I_L}{\text{Mechanical power input}}$$

Clearly $\eta_c = \eta_m \times \eta_e$

Unless otherwise stated, commercial efficiency is always understood.

Now, commercial efficiency, $\eta_c = \frac{C}{A} = \frac{\text{output}}{\text{input}} = \frac{\text{input} - \text{losses}}{\text{input}}$

1.29 Condition for Maximum Efficiency

The efficiency of a d.c. generator is not constant but varies with load. Consider a shunt generator delivering a load current I_L at a terminal voltage V.

$$\text{Generator output} = V\,I_L$$

$$\begin{aligned}\text{Generator input} &= \text{Output} + \text{Losses}\\ &= V\,I_L + \text{Variable losses} + \text{Constant losses}\\ &= VI_L + I_a^2R_a + W_C\\ &= VI_L + (I_L + I_{sh})^2R_a + W_C \qquad [\because\ I_a + I_L + I_{sh}]\end{aligned}$$

The shunt field current I_{sh} is generally small as compared to I_L and, therefore, can be neglected.

$$\therefore \quad \text{Generator input} = VI_L + I_L^2R_a + W_C$$

Now
$$\eta = \frac{\text{output}}{\text{input}} = \frac{VI_L}{VI_L + I_L^2R_a + W_C}$$

$$= \frac{1}{1 + \left(\dfrac{I_LR_a}{V} + \dfrac{W_C}{VI_L}\right)} \qquad \text{(i)}$$

The efficiency will be maximum when the denominator of Eq.(i) is minimum i.e.,

$$\frac{d}{dI_L}\left(\frac{I_LR_a}{V} + \frac{W_C}{VI_L}\right) = 0$$

or
$$\frac{R_a}{V} - \frac{W_C}{VI_L^2} = 0$$

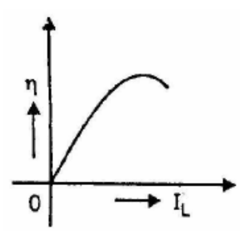

Fig. (1.40)

or $$\frac{R_a}{V} = \frac{W_C}{VI_L^2}$$

or $$I_L^2 R_a = W_C$$

i.e. Variable loss = Constant loss $(\because\ I_L \simeq I_a)$

The load current corresponding to maximum efficiency is given by;

$$I_L = \sqrt{\frac{W_C}{R_a}}$$

Hence, the efficiency of a d.c. generator will be maximum when the load current is such that variable loss is equal to the constant loss. Fig (1.40) shows the variation of η with load current.

Example 26.23. *A 10 kW, 250 V, d.c., 6-pole shunt generator runs at 1000 r.p.m. when delivering full-load. The armature has 534 lap-connected conductors. Full-load Cu loss is 0.64 kW. The total brush drop is 1 volt. Determine the flux per pole. Neglect shunt current.*

Solution. Since shunt current is negligible, there is no shunt Cu loss. The copper loss occurs in armature only.

$I = I_a = 10{,}000/250 = 40$ A ; $I_a^2 R_a$ = Arm. Cu loss or $40^2 \times R_a = 0.64 \times 10^3$; $R_a = 0.4\ \Omega$

$I_a R_a$ drop $= 0.4 \times 40 = 16$ V ; Brush drop $= 2 \times 1 = 2$ V

$\therefore$ Generated e.m.f. $E_g = 250 + 16 + 1 = 267$ V

Now, $E_g = \dfrac{\Phi Z N}{60}\left(\dfrac{P}{A}\right)$ volt $\therefore\ 267 = \dfrac{\Phi \times 534 \times 1000}{60}\left(\dfrac{6}{6}\right)$ $\therefore\ \Phi = 30 \times 10^{-3}$ Wb = **30 mWb**

Example 26.24(*a*). *A shunt generator delivers 195 A at terminal p.d. of 250 V. The armature resistance and shunt field resistance are 0.02 Ω and 50 Ω respectively. The iron and friction losses equal 950 W. Find*

(a) *E.M.F. generated* ***(b)*** *Cu losses* ***(c)*** *output of the prime motor*

(d) *commercial, mechanical and electrical efficiencies.*

Solution. (*a*) $I_{sh} = 250/50 = 5$ A ; $I_a = 195 + 5 = 200$ A

Armature voltage drop $= I_a R_a = 200 \times 0.02 = 4$ V

$\therefore$ Generated e.m.f. $= 250 + 4 =$ **254 V**

(*b*) Armature Cu loss $= I_a^2 R_a = 200^2 \times 0.02 = 800$ W

Shunt Cu loss $= V.I_{sh} = 250 \times 5 = 1250$ W

$\therefore$ Total Cu loss $= 1250 + 800 =$ **2050 W**

(*c*) Stray losses $= 950$ W ; Total losses $= 2050 + 950 = 3000$ W

Output $= 250 \times 195 = 48{,}750$ W ; Input $= 48{,}750 + 3000 = 51750$ W

$\therefore$ Output of prime mover $=$ **51,750 W**

(*d*) Generator input $= 51{,}750$ W ; Stray losses $= 950$ W

Electrical power produced in armature $= 51{,}750 - 950 = 50{,}800$

$\eta_m = (50{,}800/51{,}750) \times 100 =$ **98.2%**

Electrical or Cu losses $= 2050$ W

$\therefore$ $\eta_e = \dfrac{48{,}750}{48{,}750 + 2{,}050} \times 100 =$ **95.9%**

and $\eta_c = (48{,}750/51{,}750) \times 100 =$ **94.2%**

Example 26.26. *A long-shunt dynamo running at 1000 r.p.m. supplies 22 kW at a terminal voltage of 220 V. The resistances of armature, shunt field and the series field are 0.05, 110 and 0.06 Ω respectively. The overall efficiency at the above load is 88%. Find* **(a)** *Cu losses* **(b)** *iron and friction losses* **(c)** *the torque exerted by the prime mover.*

Solution. The generator is shown in Fig. 26.64.

$I_{sh} = 220/110 = 2$ A

$I = 22{,}000/220 = 100$ A,

$I_a = 102$ A

Drop in series field winding $= 102 \times 0.06 = 6.12$ V

(*a*) $I_a^2 R_a = 102^2 \times 0.05 = 520.2$ W

Series field loss $= 102^2 \times 0.06 = 624.3$ W

Shunt field loss $= 4 \times 110 = 440$ W

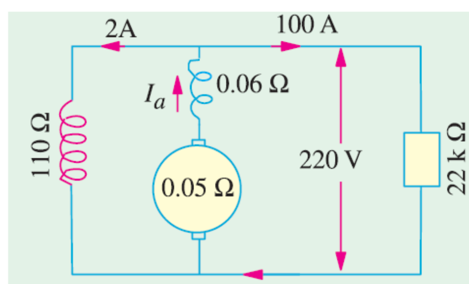

Fig. 26.64

Total Cu losses $= 520.2 + 624.3 + 440 =$ **1584.5 W**

(*b*) Output $= 22{,}000$ W ; Input $= 22{,}000/0.88 = 25{,}000$ W

$\therefore$ Total losses $= 25{,}000 - 22{,}000 = 3{,}000$ W

$\therefore$ Iron and friction losses $= 3{,}000 - 1{,}584.5 =$ **1,415.5 W**

Now, $T \times \dfrac{2\pi N}{60} = 25{,}000$; $T = \dfrac{25{,}000 \times 60}{1{,}000 \times 6.284} =$ **238.74 N-m**