EEE363

Electrical Machines

Lecture # 4

Dr Atiqur Rahman

EMF equation

φ= flux/pole in Wb
Z = total number of armature conductors
P = number of poles
A = number of parallel paths = 2 ... for wave winding
= P ... for lap winding
N = speed of armature in r.p.m.
E_g = e.m.f. of the generator = e.m.f./parallel path

Flux cut by one conductor in one revolution of the armature,

$$d\varphi = P\varphi \text{ webers}$$

Time taken to complete one revolution,

$$dt = 60/N \text{ second}$$

e.m.f generated/conductor $= \dfrac{d\varphi}{dt} = \dfrac{P\varphi}{60/N} = \dfrac{P\varphi N}{60}$ volts

e.m.f. of generator,

$$E_g = \text{e.m.f. per parallel path}$$

$$= (\text{e.m.f/conductor}) \times \text{No. of conductors in series per parallel path}$$

$$= \frac{P\varphi N}{60} \times \frac{Z}{A}$$

$$E_g = \frac{P\varphi ZN}{60\ A}$$

Problem#1

Example 26.8. *A four-pole generator, having wave-wound armature winding has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machine when driven at 1500 rpm assuming the flux per pole to be 7.0 mWb ?*

Solution.

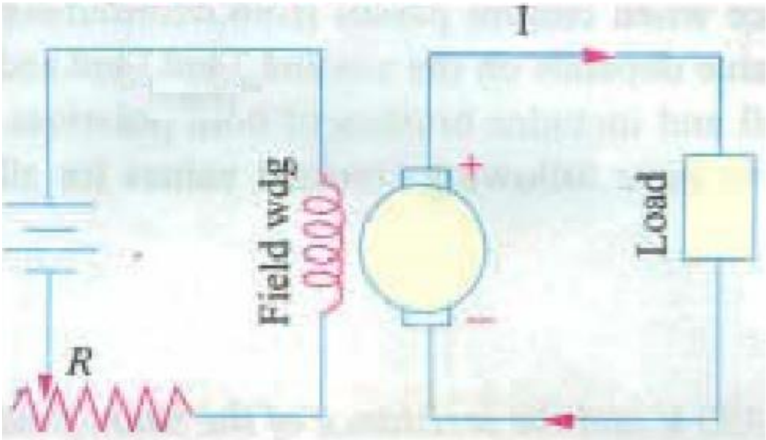
$$E_g = \frac{\Phi Z N}{60}\left(\frac{P}{A}\right) \text{ volts}$$

Here, $\Phi = 7 \times 10^{-3}$ Wb, $Z = 51 \times 20 = 1020$, $A = P = 4$, $N = 1500$ r.p.m.

$$E_g = \frac{7 \times 10^{-3} \times 1020 \times 1500}{60}\left(\frac{4}{2}\right) = \mathbf{178.5\ V}$$

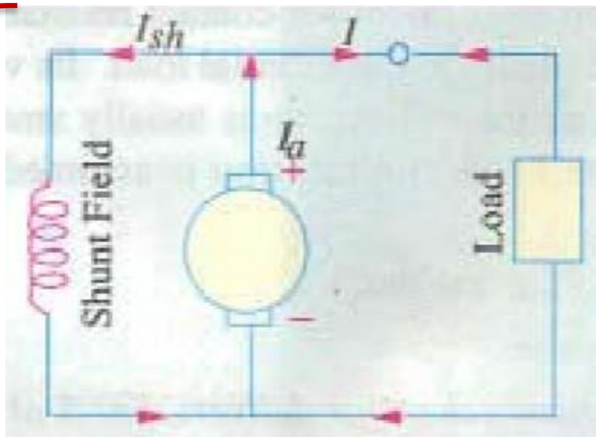
Types of Generator

- Separately excited
- Self excited

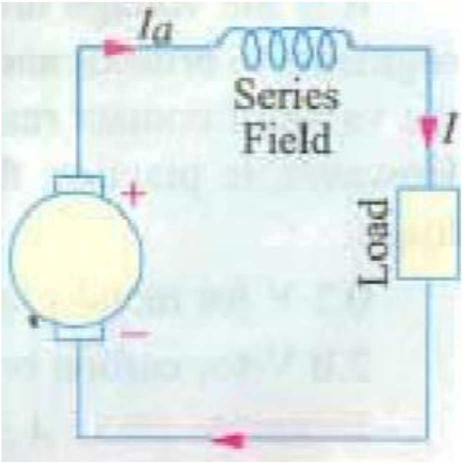


Separately excited

Self excited

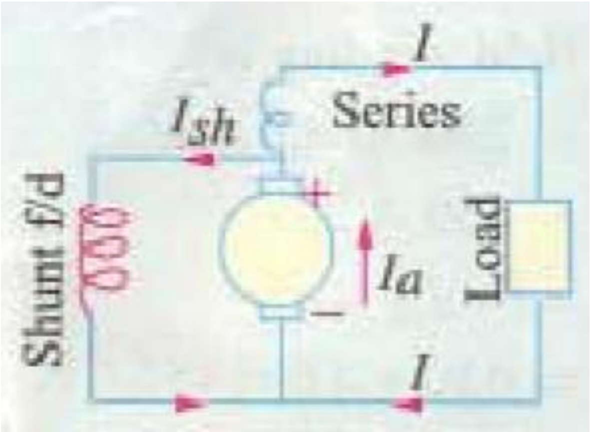


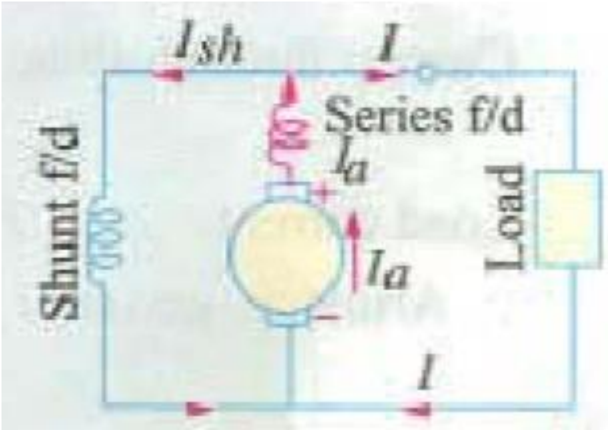
Shunt excitation



Series excitation

Self excited contd…



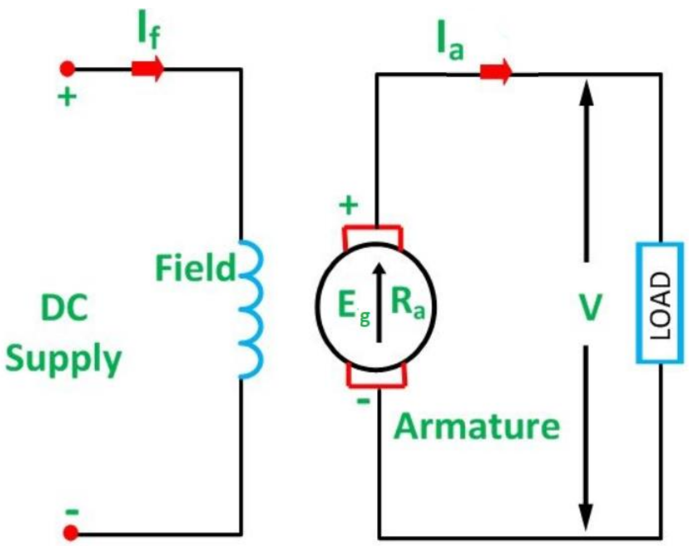


Short shunt

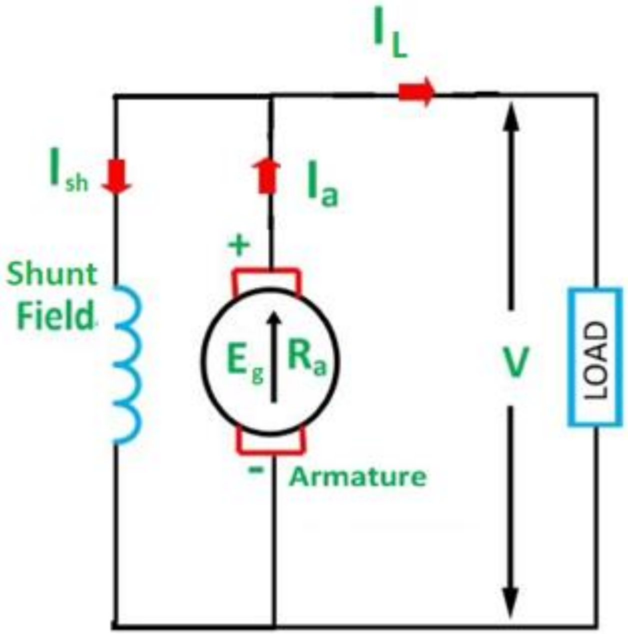
Long shunt

Compound excitation

Generated EMF



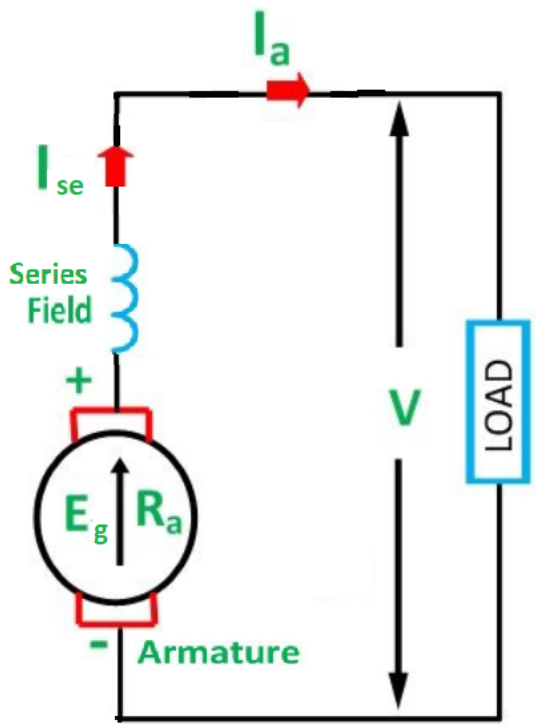
$$E_g = V + I_aR_a$$



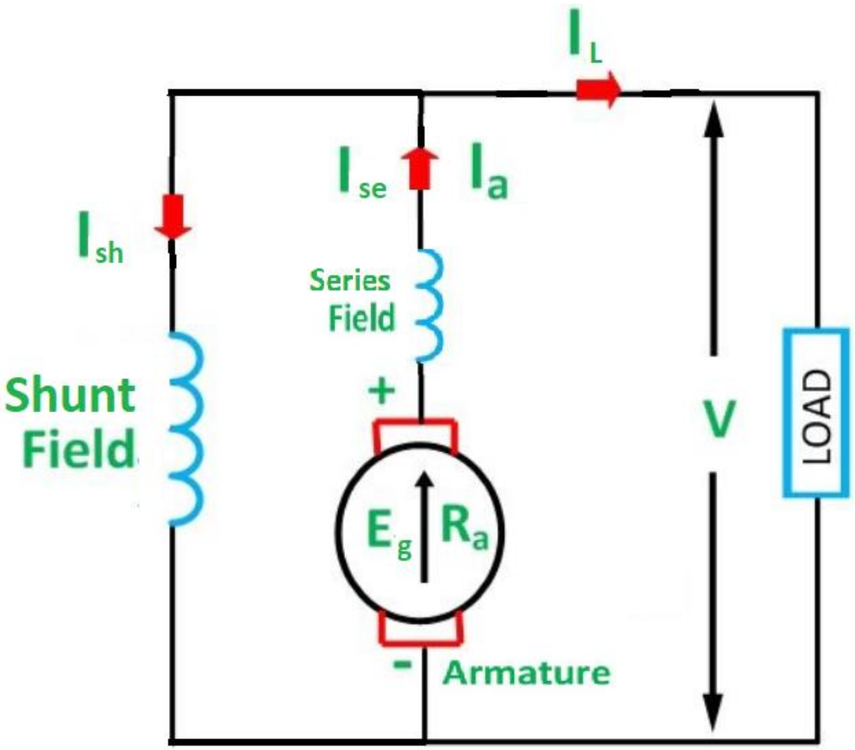
$$I_a + I_L + I_{sh}$$

$$E_g = V + I_aR_a$$

Generated EMF



$$E_g = V + I_a R_a + I_a R_{se}$$

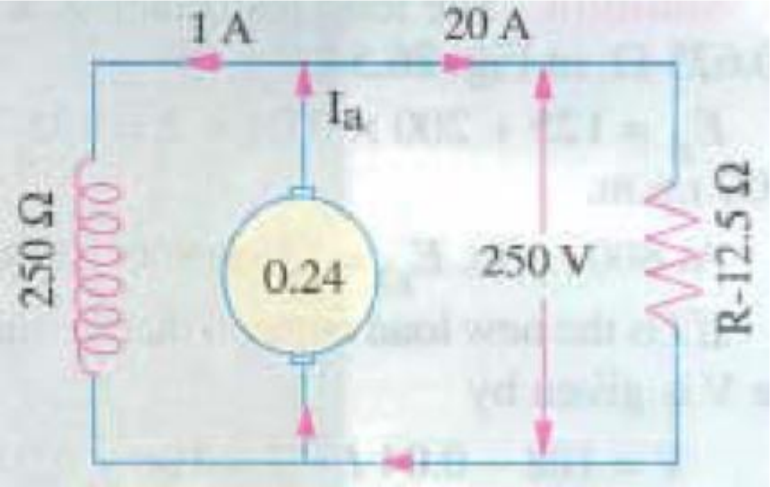


$I_a + I_L + I_{sh}$

$$E_g = V + I_a R_a + I_a R_{se}$$

Problem#2

Example 26.11(a). *An 8-pole d.c. shunt generator with 778 wave-connected armature conductors and running at 500 r.p.m. supplies a load of 12.5 Ω resistance at terminal voltage of 50 V. The armature resistance is 0.24 Ω and the field resistance is 250 Ω. Find the armature current, the induced e.m.f. and the flux per pole.*



Part 1

$$\text{Load current} = V/R = 250/12.5 = 20\ \text{A}$$

$$\text{Shunt current} = 250/250 = 1\ \text{A}$$

$$\text{Armature current} = 20 + 1 = 21\ \text{A}$$

$$\text{Induced e.m.f.} = 250 + (21 \times 0.24) = 255.04\ \text{V}$$

Part 2

$$E_g = \frac{\Phi Z N}{60} \times \left(\frac{P}{A}\right)$$

$$255.04 = \frac{\Phi \times 778 \times 500}{60}\left(\frac{8}{2}\right)$$

$$\Phi = 9.83\ \text{mWb}$$

Problem # 3 (brush drop)

Example 26.4. *A long-shunt compound generator delivers a load current of 50 A at 500 V and has armature, series field and shunt field resistances of 0.05 Ω, 0.03 Ω and 250 Ω respectively. Calculate the generated voltage and the armature current. Allow 1 V per brush for contact drop.*

$$I_{sh} = 500/250 = 2 \text{ A}$$

Current through armature and series winding is

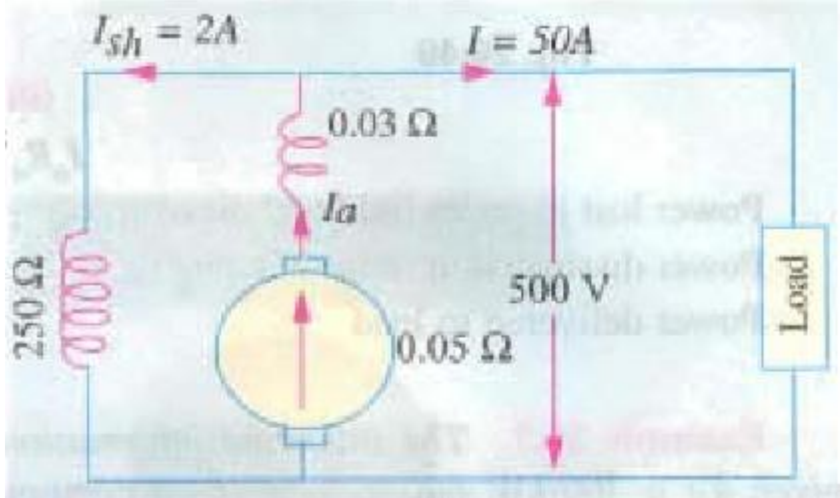
$$= 50 + 2 = 52 \text{ A}$$

Voltage drop on series field winding

$$= 52 \times 0.03 = 1.56 \text{ V}$$

Armature voltage drop

$$I_a R_a = 52 \times 0.05 = 2.6 \text{ V}$$



Drop at brushes = 2 × 1 = 2 V

Now, $E_g = V + I_a R_a$ + series drop + brush drop

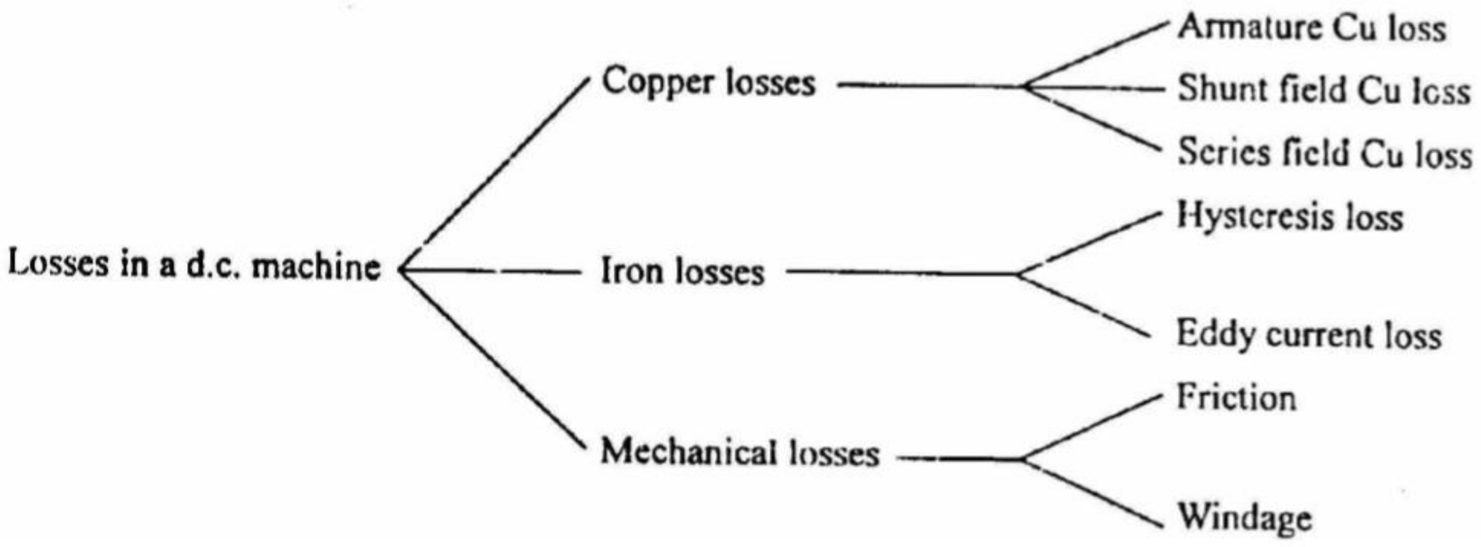
$= 500 + 2.6 + 1.56 + 2 =$ **506.16 V**

Losses in a D.C. Machine

(i) Copper losses

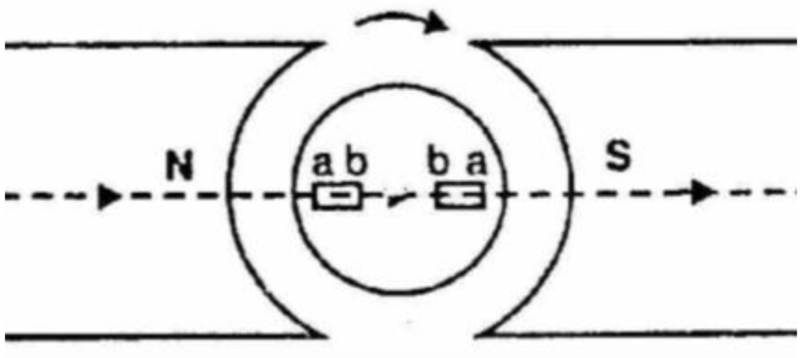
(ii) Iron or core losses and

(iii) Mechanical losses.



Hysteresis loss

- Due to the reversal of magnetization 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.



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

B_{max} = Maximum flux density in armature

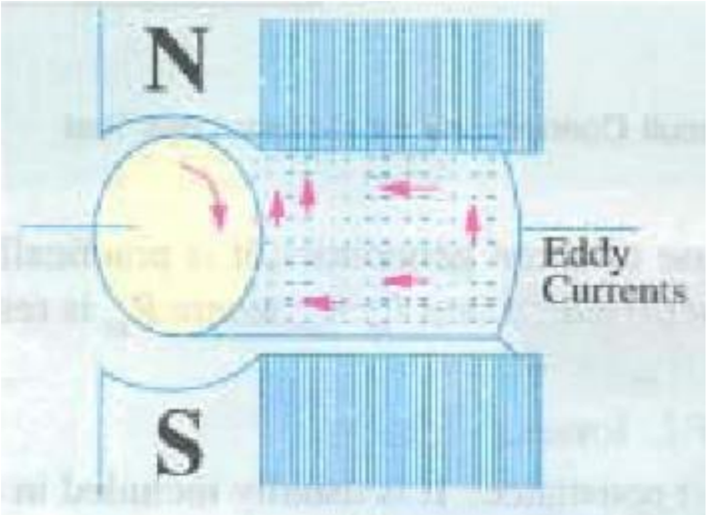
f = Frequency of magnetic reversals

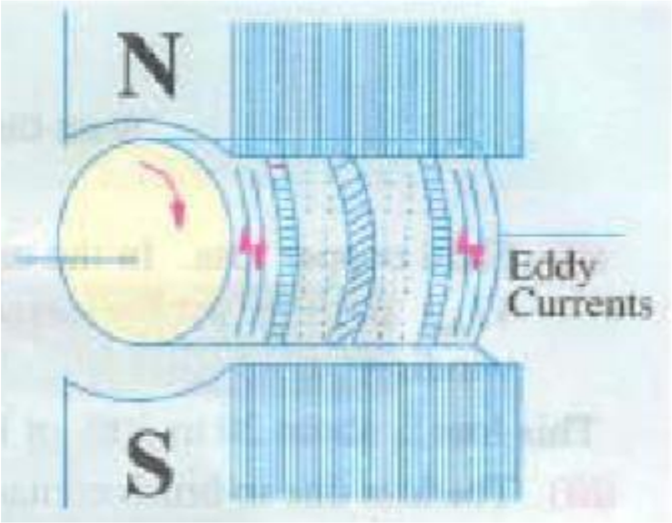
V = Volume of armature in m^3

η = Steinmetz hysteresis co-efficient

Eddy current loss

Due to the EMF induced in the armature core





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

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

Remedy

Slicing the core (laminations)

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.

Iron losses and mechanical losses together are called stray losses

Constant and Variable Losses

(i) Constant losses

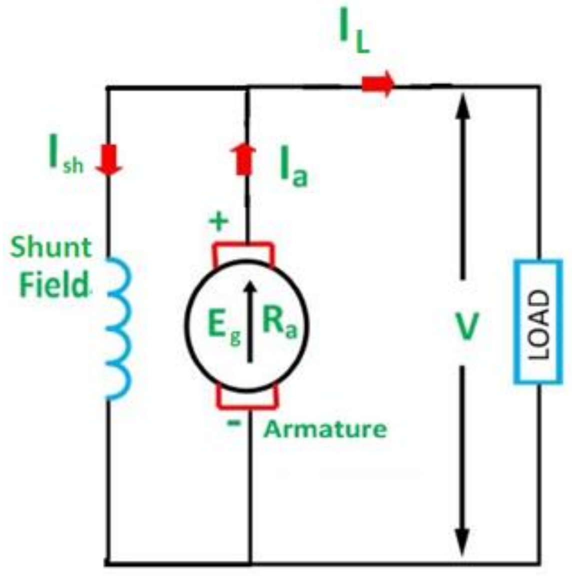
(a) iron losses (b) mechanical losses (c) shunt field losses

(ii) Variable losses

(a) Copper loss in armature winding
(b) Copper loss in series field winding

Condition for Maximum Efficiency

$$\text{Generator output} = V\,I_L$$
$$\text{Generator input} = \text{Output} + \text{Losses}$$
$$= V\,I_L + \text{Variable losses} + \text{Constant losses}$$
$$= VI_L + I_a^2R_a + W_C$$
$$= VI_L + (I_L + I_{sh})^2R_a + W_C$$



$$I_a + I_L + I_{sh}$$

The shunt field current Ish is generally small as compared to IL and, therefore, can be neglected.

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

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

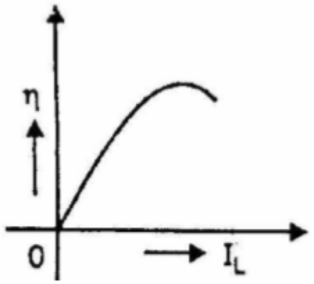
$$= \frac{1}{1 + \left(\frac{I_LR_a}{V} + \frac{W_C}{VI_L}\right)}$$

The efficiency will be maximum when the denominator of the expression is minimum

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

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

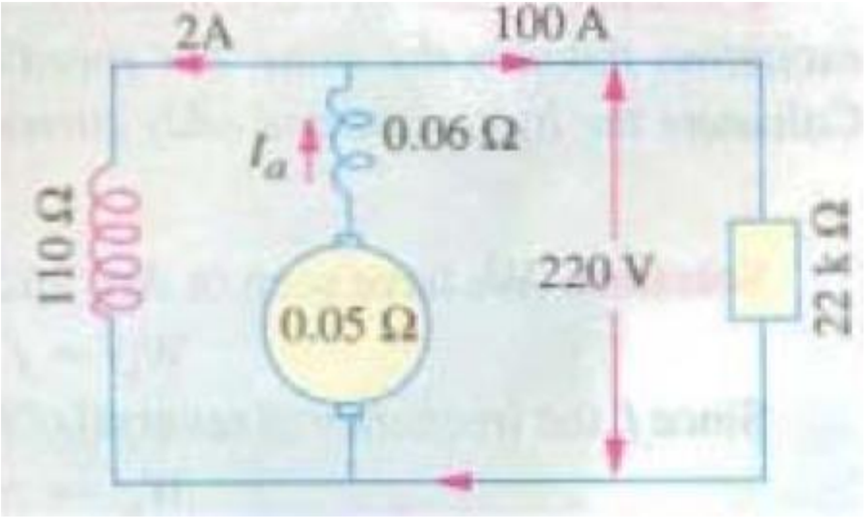
$$\frac{R_a}{V} = \frac{W_C}{VI_L^2} \quad \text{or} \quad I_L^2R_a = W_C$$



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

Problem # 4

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.*



$$I_{sh} = 220/110 = 2\text{ A}$$
$$I = 22{,}000/220 = 100\text{ A},$$
$$I_a = 102\text{ A}$$

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

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

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

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

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

(c)
$$T \times \frac{2\pi N}{60} = 25{,}000$$

$$T = \frac{25{,}000 \times 60}{1{,}000 \times 6.284} = \textbf{238.74 N-m}$$

Self excited contd…