4th May, 2023

UNIT-4 Electromagnetism and B-H curve

- → DC machine → Generator / → Motor
- → 3-ϕ I.M

EMF	MMF
I	ϕ
G	μ
R	$S = \frac{l}{\mu_0 \mu_r A}$
$I = \frac{EMF}{R}$	$\phi = \frac{MMF}{S}$

5th May, 2023

Electrical Machine

- AC machine
  - Generator
  - Motor
    - Induction
    - Synchronous
  - Transformer
- DC machine
  - DC Generator
  - DC motor

Magnetic circuit definitions

→ Magnetic Flux Density $B = \frac{\phi}{A}$ T or Wb/m^2

→ Magneto Motive Force $MMF = NI$

current

no. of turns of inductive coil

→ Magnetic Field strength / Magnetic Intensity $H = \frac{NI}{l}$

length of magnetic circuit

$B = \mu H$

μ - permeability $\mu = \mu_0 \mu_r$

vacuum

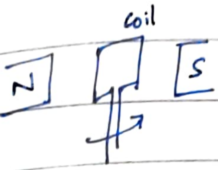
relative permeability of magnetic material

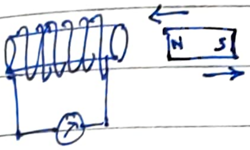
→ Magnetic Reluctance $S = \frac{l}{\mu_0 \mu_r A}$

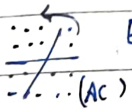
9th May, 2023

EMF can be induced

Dynamically induced EMF
(motion)

1. 

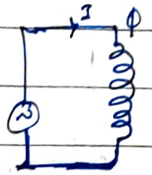
2. 

3. 

$E = Blv\sin\theta$

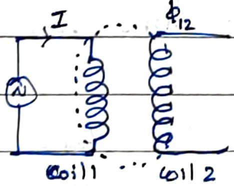
Statically induced EMF
(no motion)

1. self induced emf



$\phi \propto I$

2. mutually induced emf



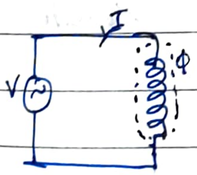
11th May, 2023

Statically induced emf

DERIVATION

Not important

a) Self induced EMF



When current flowing through a coil changes flux linking with coil changes resulting in an emf to be induced is called induced emf.

Let $N \rightarrow$ no. of turns of coil

$$e \propto \frac{di}{dt}$$

$$e = L\frac{di}{dt} \quad -(1)$$

From Faraday's exp

$$e \propto \frac{d\phi}{dt}$$

$$e = N\frac{d\phi}{dt} \quad -(2)$$

(1) = (2) $$L\frac{di}{dt} = N\frac{d\phi}{dt}$$

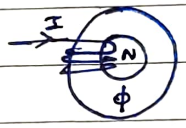
$$\int \Rightarrow LI = N\phi$$

$$\boxed{L = \frac{N\phi}{I}} \quad -(3)$$

co-efficient of self induction

→ Ohm's law of Magnetic current

MMF = Magneto Motive Force



MMF = NI

$\phi \rightarrow$ result / due to MMF

DC
Ohm's law
$V = IR$
$I = \frac{EMR}{R}$

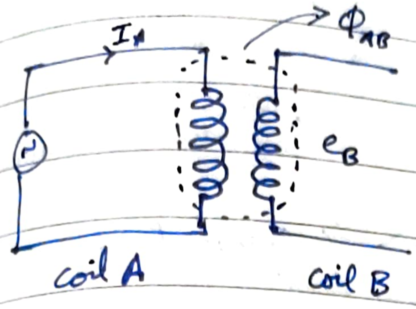
flux $\phi = \frac{MMF}{Rel}$; Reluctance $= \frac{l}{\mu_0 \mu_r A}$

$$\phi = \frac{NI}{l/\mu_0 \mu_r A}$$

(3) $\Rightarrow$ $$L = \frac{N}{\cancel{I}} \cdot \frac{N\cancel{I}}{l/\mu_0\mu_r A}$$

$$\boxed{L = \frac{N^2 \mu_0 \mu_r A}{l}} \quad -(4)$$

b) Mutually induced emf



Let $N_A \rightarrow$ no. of turns of coil A
$N_B \rightarrow$ no. of turns of coil B

$\phi_{AB} \rightarrow$ flux linking coil B due to change in current in A

$$e_B \propto \frac{dI_A}{dt}$$

$$e_B = M\frac{dI_A}{dt} \quad -(1)$$

$M \rightarrow$ co-efficient of mutual inductance

By Faraday's exp. $\quad e_B \propto \frac{d\phi_{AB}}{dt}$

$$e_B = N_B\frac{d\phi_{AB}}{dt} \quad -(2)$$

(1) = (2),

$$M\frac{dI_A}{dt} = N_B\frac{d\phi_{AB}}{dt}$$

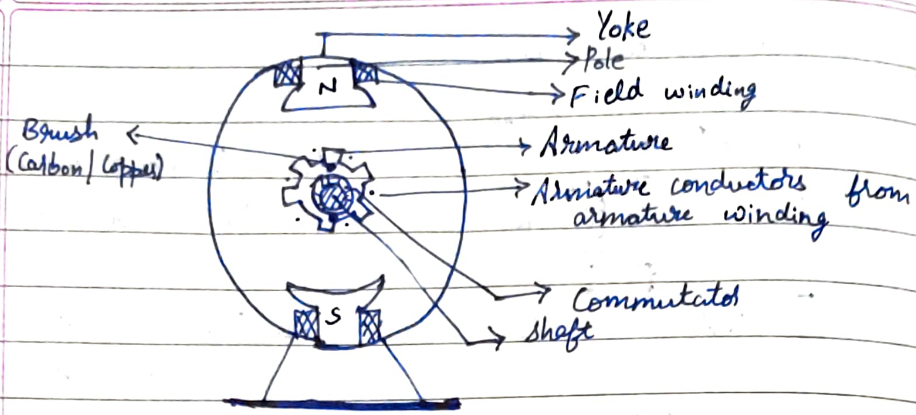
$\int$

$$M I_A = N_B \phi_{AB}$$

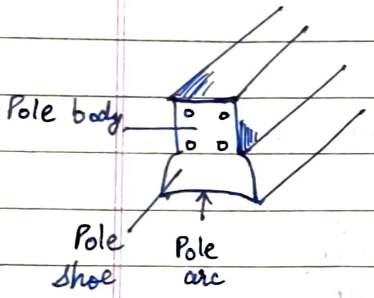
$$\boxed{M = \frac{N_B \phi_{AB}}{I_A}}$$

Introduction to Electrical machines

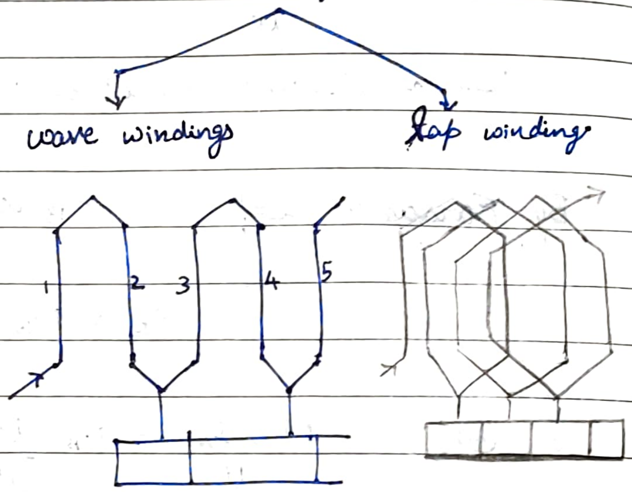
→ DC machine



Pole



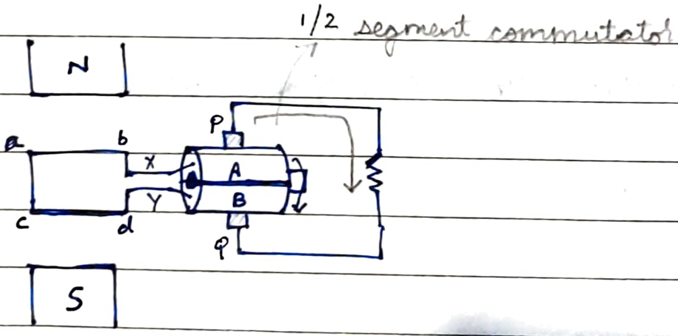
Armature windings

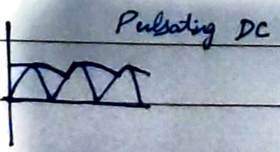


25th May, 2023

DC generator working principle & emf eqn.
(W.P)

→ DC generator W.P





→ DC generator EMF equation

DERIVATION: Let $P \rightarrow$ no. of poles
$\phi \rightarrow$ flux per pole
$Z \rightarrow$ total no. of conductors
$N \rightarrow$ speed of rotation
$A \rightarrow$ no. of parallel paths

$A = 2$ (wave winding)
$A = P$ (lap winding)

Time taken by the conductor to complete one revolution $\} = \frac{60}{N}$ s

one conductor when it completes one revolution passes $P\phi$ amount of flux.

avg. emf induced in 1 conductor $\} = \frac{\text{flux cut}}{\text{Time taken}}$

$$= \frac{P\phi}{60/N} = \frac{P\phi N}{60}$$

There are Z no. of conductors and A no. of parallel paths.

$\therefore \frac{Z}{A}$ no. of conductors are in series

$$\Rightarrow E = \frac{P\phi N}{60} \cdot \frac{Z}{A}$$

$$\boxed{E = \frac{\phi Z N P}{60A}}$$

$$\boxed{E \propto \phi N}$$

$$\boxed{\phi \propto I_f}$$

q.1 A 8 pole lap connected armature has 960 conductors, a flux of 40 mWb per pole at a speed of 400 rpm. Calculate emf generated

Sol. $E = \dfrac{\phi Z N P}{60\cancel{0} A}$

lap ⇒ $E = \dfrac{\phi Z N \cancel{P}}{600\ \cancel{P}}$

$= \dfrac{40 \times 10^{-3} \times 960 \times 400}{60}$

$= 256\ V$

26th Maths, 2023

q.2 A 8 pole wave connected armature has 480 conductors. A flux of 80 mWb per pole generates 400 V on open circuit. Find the speed at which the generator is running.

Sol. wave $A = 2$

$E = \dfrac{\phi Z N P}{60\,(2)}$

$N = \dfrac{60\,(2)\,(E)}{\phi Z P}$

$N = 156.25 \approx 156$ rpm

q.3 A DC generator develops an EMF of 300V when driven at 1000 rpm. If the flux per pole of 0.01 Wb, If this EMF is to be increased to 320V at 1100 rpm. What is the new value of flux per pole.

$$E = \frac{\phi N Z P}{60\ A}$$

$E \propto \phi N$

E_1 300 N_1 1000 $\phi_1 = 0.01$

E_2 320 N_2 1100 $\phi_2 = ?$

$$\frac{E_1}{E_2} = \frac{N_1 \phi_1}{N_2 \phi_2} \Rightarrow \frac{300}{320} = \frac{1000}{1100} \times \frac{0.01}{\phi_2}$$

$$\phi_2 = 9.69\ mWb$$

Q4 The armature of 4 pole shunt motor accomodated in 60 slots each containing 20 conductors. If useful flux per pole is 23 mWb. Calculate the Total Torque developed when the armature current is 50 A.

Sol. $Z = 60(20)$

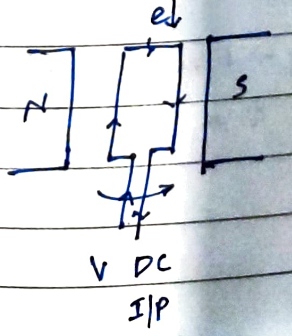
$$T = \frac{1}{2\pi} \frac{\phi Z P I_a}{A}$$

sneak peak

$$= \frac{1}{2\pi} \times \frac{23 \times 10^{-3} \times 60(20) \times 4 \times 50}{4}$$

$$= 219.6\ N \cdot m$$

DC Motor



$e \xrightarrow{opposes} V\ I/P$

$\Downarrow$

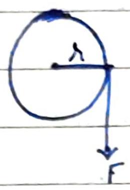
Back EMF $E_b = \frac{\phi Z N P}{60 A}$

→ Torque Equation

Let r be the radius of armature
F be the force on armature
due to this force let the armature rotate
at the speed of N.

∴ Mechanical work done by the force in 1s

$$= F \times 2\pi r \times \frac{N}{60}$$



$T = r \times F$

$$= \frac{2\pi N T}{60}$$

Mechanical Power developed by armature $\Big\} = \frac{2\pi N T}{60}$

Electrical input to the armature $= \underset{\text{back emf}}{E_b} \; \underset{\text{armature current}}{I_a}$

equating electrical input to Mechanical Power developed

$$E_b I_a = \frac{2\pi N T}{60}$$

$$\frac{\phi Z \cancel{N} P}{\cancel{6}0\, A} \cdot I_a = \frac{2\pi \cancel{N} T}{6\cancel{0}}$$

$$\boxed{T = \frac{1}{2\pi} \frac{\phi Z P I_a}{A}}$$

$\boxed{T \propto \phi I_a}$

$\boxed{T \propto I_f I_a}$

$I_f \to$ Field current

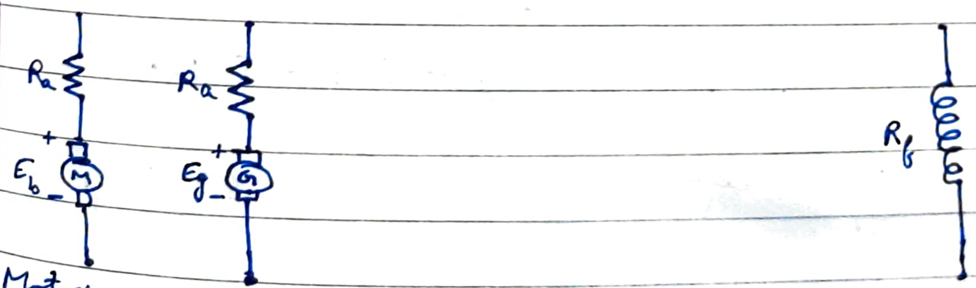
$\phi \propto I_f$

Q5. A series motor of resistance 1Ω

NOTATION : Components of machine electrically

Armature

Field System

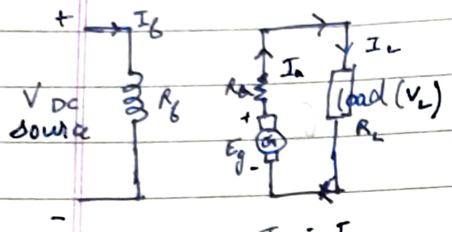


Motor
current will enter

Generator
current will exit

Generator

- Seperately Excited
- Self Excited
  - Series
  - Shunt
  - Compound (Not in Syll)

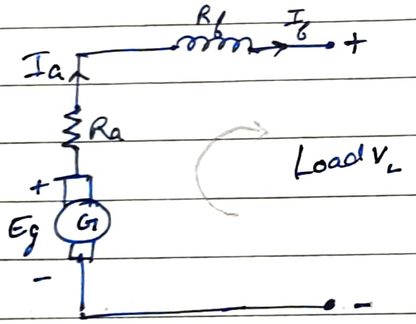


$I_a = I_L$

$$E_g - TBD - I_a R_a - I_L R_L = 0$$

TBD: Total Brush Drop

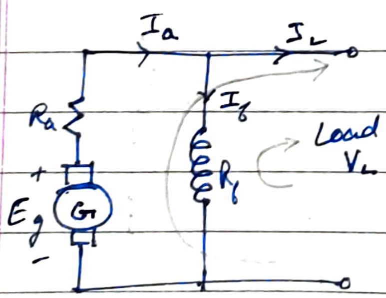
- Series generator : Field is connected in series with armature.



$$I_L = I_f = I_a$$

$$E_g - TBD - I_a R_a - I_a R_f - V_L = 0$$

- Shunt generator



$$I_a = I_f + I_L$$

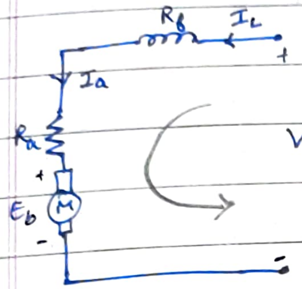
$$E_g - TBD - I_a R_a - V_L = 0$$

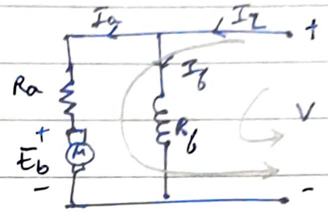
$$V_L = I_f R_f$$

29th May, 2023

Motor

Series Motor | Shunt Motor





$I_a = I_f = I_L$

$V - I_aR_f - I_aR_a - TBD - E_b = 0$

$I_L = I_a + I_f$

$V = I_f R_f$

$V - I_aR_a - TBD - E_b = 0$

Q6. A 250V shunt motor on no load runs at 1000 rpm and takes a current of 5A. Armature resistance is 0.2 Ω. Shunt field resistance is 250 Ω. Calculate speed when loaded taking a current of 50 A.

Sol. No load

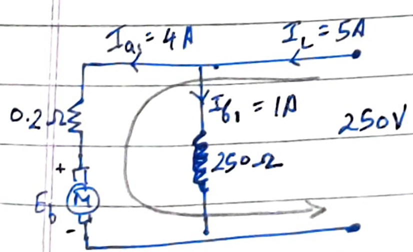
$N_1 = 1000$ rpm

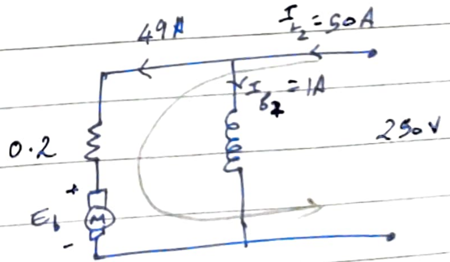
$I_{L_1} = 5A$

Loaded

$N = ?$

50 A





$I_{f_1} = \frac{250}{250} = 1A$

$I_{a_1} = 5 - 1 = 4 A$

$250 - 4(0.2) - E_{b_1} = 0$

$E_{b_1} = 249.2$

$250 - 49(0.2) - E_b = 0$

$E_b = 240.2V$

$$E_b = \frac{NP\phi Z}{60A}$$

$$E_b \propto \phi N$$

$$\phi \propto I_f$$

$I_{f_1} = I_{f_2} \Rightarrow \phi$ is same

$$\therefore \frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2} \Rightarrow \frac{244.2}{240.2} = \frac{1000}{N_2}$$

$$N_2 = 963.8 \text{ rpm}$$

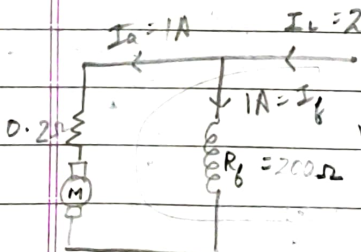
q.7. A 200 V DC shunt motor on no load takes a current of 2 A and speed is 1000 rpm. Calculate speed on full load taking a current of 20 A, armature resistance 0.2 Ω, shunt field resistance 200 Ω and brush drop = 1 V/brush.

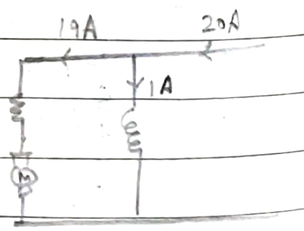
Sol. No load — 2A — 1000 rpm

Full load — $N_2 =$ — 20A

no. of brushes not given, take it as 2

min no. of brushes





200.0
− 2.2
197.8

$$200 - 1(0.2) - 1(\overset{\text{TBD}}{2}) - E_{b_1} = 0$$

$$E_{b_1} = \cancel{199.6}\ 197.8\text{V}$$

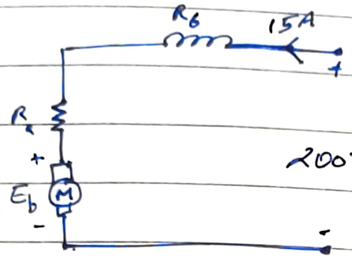
$$200 - 19(0.2) - 2 - E_{b_2} = 0$$

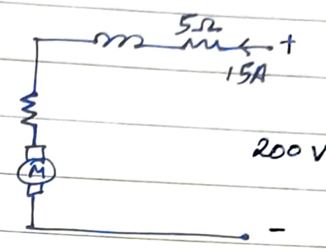
$$E_{b_2} = 194.2 \text{ V}$$

$$\frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2} \qquad N_2 = 981.7 \text{ rpm}$$

98. A series motor of resistance 1Ω b/w the terminals runs at 800 rpm at 200V with a current of 15A. Find the speed at which it will run when connected in series with 5Ω resistance taking same current with same supply voltage.

Sol.





$R_a + R_f = 1\Omega$

$200 - 15(5) - 15(1) - E_{b_2} = 0$

$E_{b_2} = 110\,V$

$200 - 15(R_a + R_f) - E_{b_1} = 0$

$200 - 15(1) = E_{b_1}$

$E_{b_1} = 185\,V$

@ 800 rpm

$\frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2} \Rightarrow \frac{185}{110} = \frac{800}{N_2}$

$N_2 = 475.6$ rpm

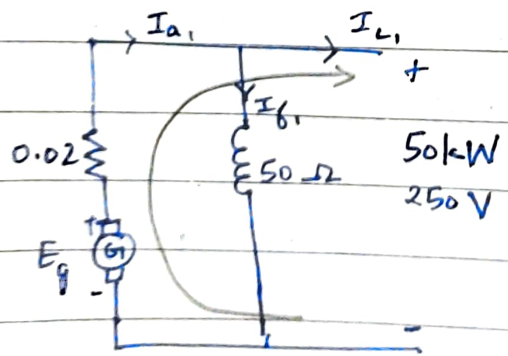
99. A 8 pole armature is wound with 480 conductors, the magnetic flux and the speed are such that the avg. emf generated in each conductor is 2V and the conductor is capabale of carrying a full load of 50A. Calculate the terminal voltage on load, o/p current on full load, total power generated on full load when the armature is
i) lap connected ii) wave connected

ans: i) 400 A, 48 kW
ii) 100 A, 48 kW

30th May, 2023

q. A shunt generator delivers 50 kW at 250 V and runs at 400 rpm. The armature and field resistances are 0.02 Ω and 50 Ω respectively. Calculate the speed of machine as shunt motor taking 50 kW at 250 V. Brush Drop = 1V/brush

Sol. As shunt generator



$$I_{L_1} = \frac{P}{V} = \frac{50 \times 10^3}{250} = 200A$$

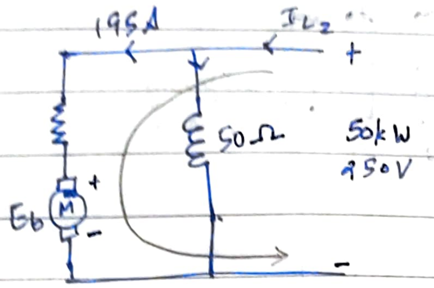
$$I_{f_1} = \frac{250}{50} = 5A$$

$$I_{a_1} = 200 + 5 = 205A$$

$E_g - 205(0.02) - 2(1) - 250 = 0$

$E_g = 256.1\ V$ @ 4000 rpm

As motor



$I_{L_2} = 200A$

$I_{f_2} = 5A$

$I_{a_2} = 195A$

$250 - 195(0.02) - 2(1) - E_b = 0$

$E_b = 244.1\ V$

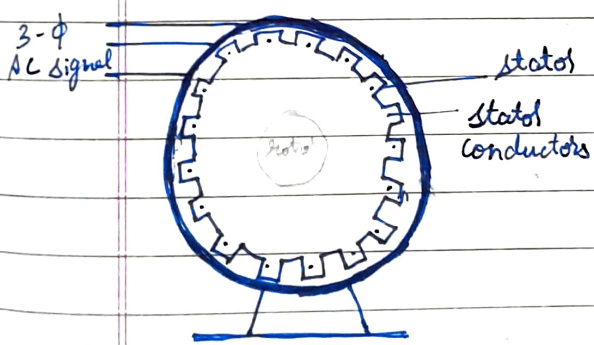
$\frac{E_g}{E_b} = \frac{N_g}{N_m}$ $N_m = 38[illegible].90$ rpm

Induction Motor

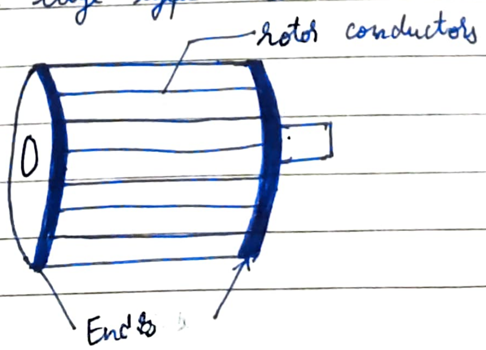
- Construction
- working
- numericals

Stator

Rotor → squirrel cage type rotor → slip ring type rotor

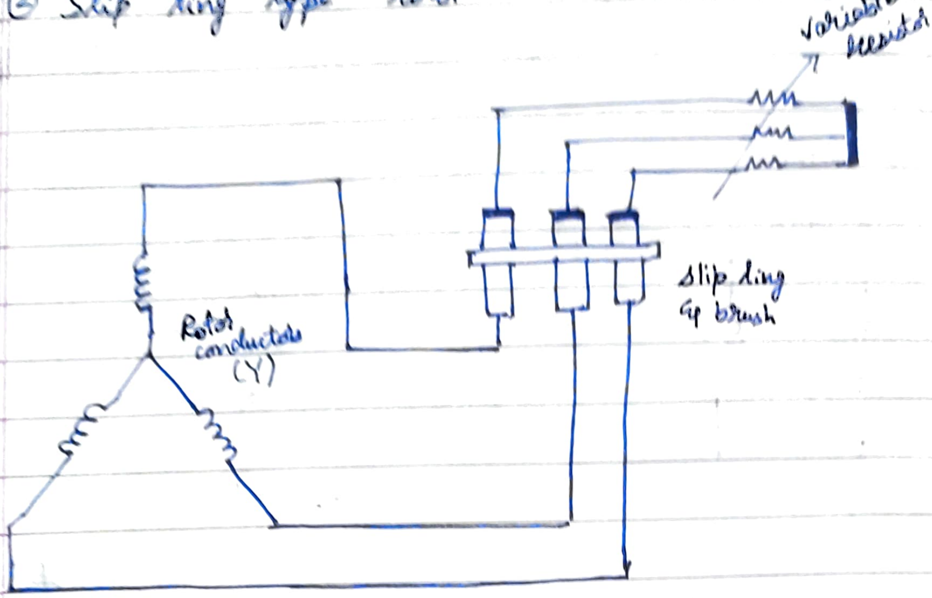


① Squirrel cage type rotor



Rotating magnetic field ⑧

② Slip ring type rotor



31st May, 2023

1. Synchronous speed

$$N_s = \frac{120f}{P}$$

$N \rightarrow$ speed of rotor

2. $\%$slip or $\% S = \frac{N_s - N}{N_s} \times 100$, $N = N_s(1-s)$

3. freq. of induced current $f_r = sf$

q. A 3-ϕ, 4 Pole 400V 50Hz induction motor runs with a slip of 4% find the rotor speed and freq. of induced currents.

Sol. $P = 4$, $f = 50Hz$ $s = 0.04$

$$N_s = \frac{120(50)}{4} = 1500$$

Date
Page

$$0.04 = \frac{1500 - N}{1500}$$

$$N = 1440 \text{ Hz}$$

$$f_r = 0.04(50) = 2 \text{ Hz}$$

Q: A 6 Pole alternator (3-ϕ AC generator) running at 1200 rpm supplies to a 10 Pole, 3-ϕ induction motor, if the rotor induced EMF makes 3 alterations per second, find rotor speed.

Sol. Alternator (3-ϕ AC gen.)

$P_1 = 6$

$N_1 = 1200$ rpm

$$f = \frac{PN}{120}$$

$$= \frac{6 \times 1200}{120} = 60 \text{ Hz}$$

3-ϕ I.M

$P_2 = 10$

$f = 60$ Hz

3 alts / sec

$f_r = 3$

$f_r = sf$

$s = 0.05$

$$N_s = \frac{120 \times f}{P} = \frac{120 \times 60}{10}$$

$= 720$ rpm

$N = N_s(1-s)$

$= 720(1 - 0.05)$

$= 684$ rpm

Q. freq. of emf of a 4 Pole IM is 50Hz in stator and rotor is 1.5Hz what is the slip and at what speed the rotor is running

Sol. $f = 50$ Hz $\quad f_r = 1.5 \quad f_r = sf$

$s = 0.03$

$$N_s = \frac{120 \times 50}{4} = 1500$$

$N = N_s(1-s) = 1455$ rpm

q. A 3ϕ IM has 6 Poles and runs at 960 rpm it is supplied from an alternator having 4 Poles and running at 1500 rpm calculate the full load slip of the motor.

Sol. alternator

$P = 4$

$N = 1500$

$$f = \frac{PN}{120}$$

$$= \frac{\cancel{4} \times 1500}{\cancel{120}\,30}$$

$f = 50$

IM

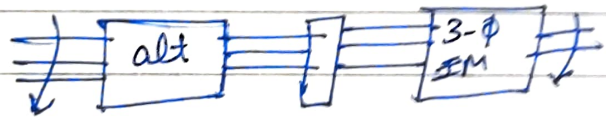
$N = 960$

$f = 50Hz$

$$N_s = \frac{120 \times 50}{6} = 1000\ rpm$$

$$s = \frac{N_s - N}{N_s} = \frac{1000 - 960}{1000}$$

$s = 0.04 = 4\%$



q. A 3ϕ 6 Pole IM runs at 960 rpm from 50Hz supply. Find the slip and no. of cycles of rotor induced emf per min.

Sol. $N_s = \frac{120 f}{P} = \frac{120 \times 50}{6} = 1000\ rpm$

$$\text{slip} = \frac{1000 - 960}{1000} = 0.04$$

$f_r = sf = 0.04(50) = 2Hz$

$= 2 \times 60$ cycles/min

$= 120$ cycles/min

q. A 6 Pole IM is supplied by a 8 Pole alternator which is driven at 750 rpm. If the IM runs at 930 rpm determine the percentage slip.

Sol. alternator $P = 8$

$N = 750$ rpm

$f = \frac{PN}{120} = \frac{8 \times 750}{120} = 50\,Hz$

IM : $P = 6$

$N = 930$ rpm

$f = 50\,Hz$

$N_s = \frac{120 \times 50}{6}$

$= 1000$ rpm

$\% \; s = \frac{1000 - 960}{1000} = 7\%$

* slip at the point of starting of motor = 1

q. A 12 Pole 3-ϕ alternator is coupled to an engine running at 500 rpm, it supplies to an induction motor which has full load speed of 1440 rpm. Find $\% s$ & no. of poles of motor.

Sol:

500 rpm $\quad$ $P_1 = 12$

$N_1 = 500$ rpm

$$f = \frac{PN}{120}$$

$$= \frac{12 \times 500}{120}$$

$$= 50 Hz$$

$\rightarrow$ $N = 1440$ rpm

$f = 50 Hz$

$$N_s = \frac{120(50)}{P}$$

$P = 2$, $N_s = 3000$ ✓

$P = 4$ $\quad N_s = 1500$ ✓

$P = 6$ $\quad N_s = 1000$ ✗

$P = 4$