BASIC ELECTRICAL ENGINEERING

UNIT - 4

ELECTRICAL MACHINES

Vibha Masti

Feedback/corrections: vibha@pesu.pes.edu

Basics of machines

DC

1) Generator
2) Motor

AC

1) Transformer ($1-\phi$)
2) $3-\phi$ induction motor

Electromagnetic Induction

Faraday's First Law

conductor moving in $\vec{B} \Rightarrow$ emf generated

Faraday's Second Law

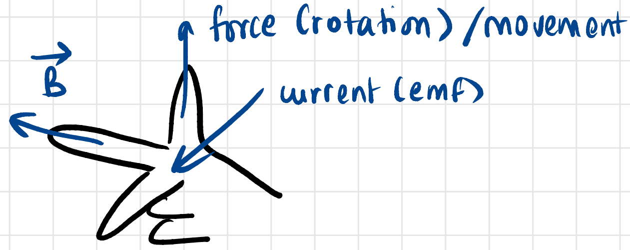
magnitude of emf induced $\propto$ rate of change of flux

Lenz's Law

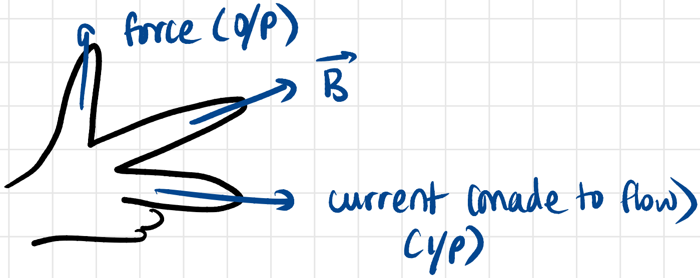
direction always opposes change in flux

Direction of emf induced

Fleming's Right Hand Rule - Generator



Fleming's Left Hand Rule - Motor



Induced emf

1) Statically induced emf

- transformers
- induced with stationary conductors
- allowing an AC
  - ↪ self-induced emf
  - ↪ mutually induced emf

2) Dynamically induced emf

- moving conductors

DC Generator

input energy → DC Generator → output energy
mechanical   electrical

Working Principle

1. Faraday's EM induction

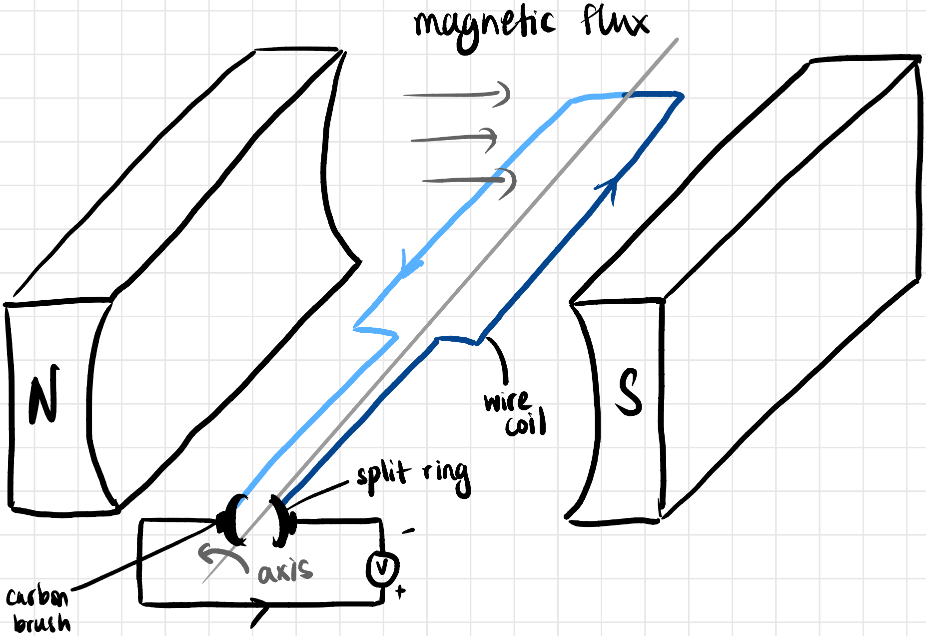
- AWG – American wire Gauge
- SWG — Standard wire gauge
  - SWG-0 : thickest
  - SWG-50 : thinnest

- EMF induced is given by rate of change of flux

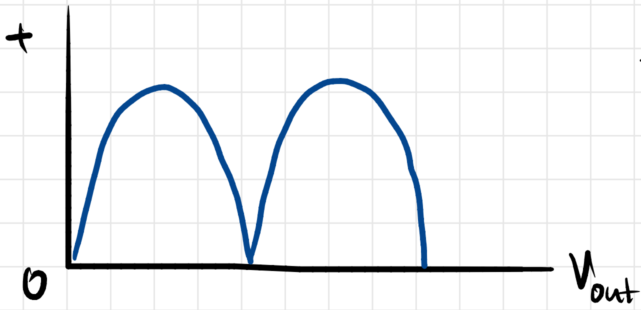
2. Dynamically induced EMF

- rotating pump (conductor)

Simple DC Generator

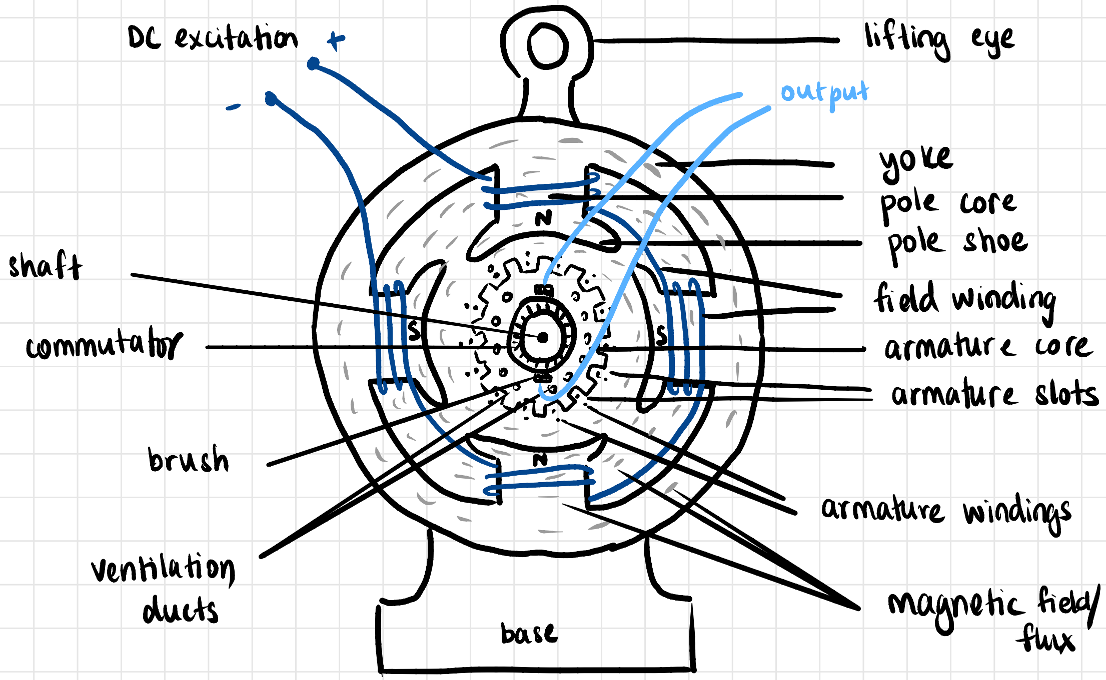


- If slip-rings are used, AC is generated
- If split-rings used, pulsating unidirectional current is generated (not perfect DC)
- Also called commutator (mechanical rectifier); cannot use diodes to rectify
- Brushes collect current / voltage at output



To eliminate pulsating, multiple segments

Construction of DC Machine (Motor or Generator)



Input: primary mover / shaft moved
Output: brushes

Armature system
all moving parts

Field system
all stationary parts

Lifting eye
- on top of machine
- hooking for cranes to lift

Base
- concrete and cement
- machine is bolted & fixed to it
- avoid vibrations

Field System

Yoke
- outer frame of generator / motor
- 2 functions
  1) mechanical support for pole body
  2) Proper path for magnetic field in machine

Pole Core
- stationary
- electromagnets are cheaper, lighter and more flexible
- to hold field windings
- separately excited DC generated
- two adjacent poles with opposing polarities
- four-pole machine shown
- copper field windings

Pole shoe
- cylindrical for uniform $\vec{B}$, at the base of pole body

Air gap
- for armature to easily rotate
- between the stationary and moving parts

Field Windings
- wound on pole cores in opposing directions

DC Excitation

- external supply for field windings (here, separately excited)

Armature System

Armature Core

- laminated and slotted (thin sheets)
- avoid eddy current and hysteresis loss
- slots for armature windings

Armature windings

- emf is induced here
- armature fixed to shaft and rotates
- conductors in slots rotate
- cut $\vec{B}$ and emf induced
- made of Cu

Ventilation ducts

- to dissipate heat

Commutator

- mechanical rectifier for AC → DC
- many split rings
- rotates with armature
- brush forced onto commutator
- armature windings terminate here

Shaft

- armature & commutator attached
- rotates

Brushes

- collect current
- use springs

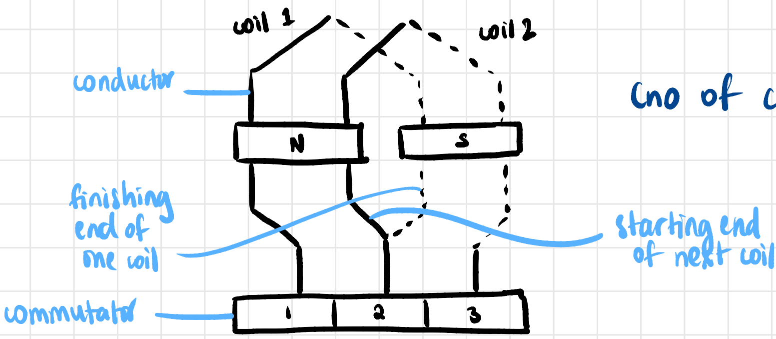
TYPES OF ARMATURE WINDINGS

1. LAP WINDING
2. WAVE WINDING

- Difference in how they terminate at commutator
- Can be simplex, duplex or multiplex

LAP WINDING

two ends of coil connected to adjacent segments of commutator

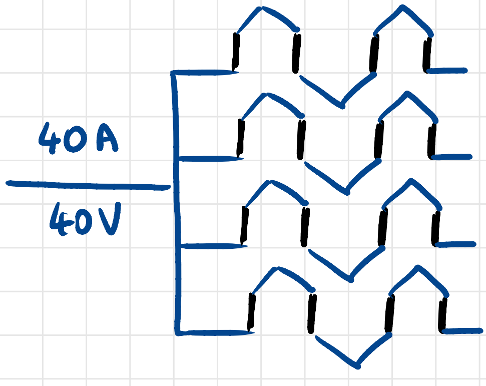


(no of conductors = 4)

no. of parallel paths (A) = no. of poles (P)

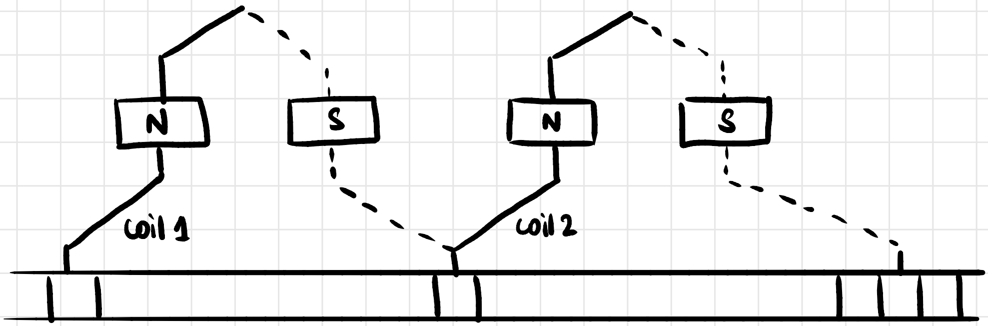
- high current rating, low voltage rating
- no of conductors (Z)

Eg: Machine rating for $Z = 16$, $V(\text{cond}) = 10V$, $I(\text{cond}) = 10A$
$P = 4$



— WAVE WINDING

two end connections not adjacent

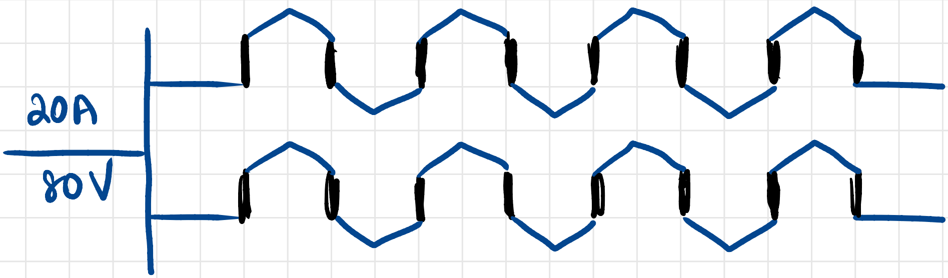


no matter the number of poles,

no. of parallel paths (A) = 2

- low current, high voltage

Eg: Machine rating for $Z = 16$, $V(\text{cond}) = 10V$, $I(\text{cond}) = 10A$
$P = 4$



EMF Equation for DC Generator

Nomenclature

Z = no. of armature conductors
ϕ = useful flux per pole
N = speed of armature in rpm
P = no. of poles
A = no. of parallel paths
E_g = EMF induced in any parallel path

Flux cut by a single conductor in one revolution

$$= P\phi$$

Time taken by conductor to complete one revolution

$$= \frac{60}{N} \text{ sec}$$

EMF induced in 1 conductor

$$E = \frac{d\phi_{tot}}{dt} = \frac{P\phi}{\left(\frac{60}{N}\right)}$$

$P\phi$ → flux linkage
$\left(\frac{60}{N}\right)$ → time

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

EMF induced per parallel path

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

$\frac{Z}{A}$: no. of conductors per parallel path

For lap, $P = A$

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

For wave, $A = 2$

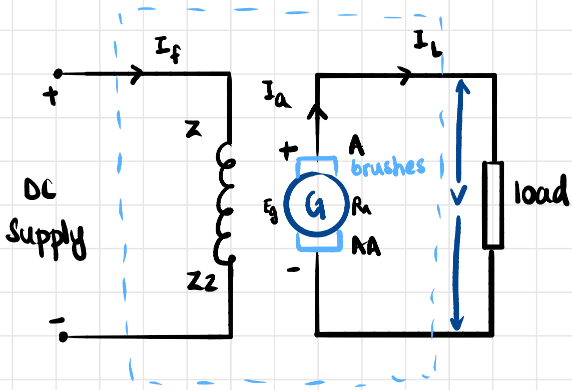
$$E_g = \frac{P\phi N Z}{60 \times 2}$$

$$\boxed{\text{TYPES OF DC GENERATORS}}$$

1. SEPARATELY EXCITED

2. SELF EXCITED
   - ↳ series wound
   - ↳ shunt wound
   - ↳ compound wound

1. Separately Excited DC Generator



- Single letter: +ve, double letter: -ve
- G: generator
- Field altered by external DC supply
- Single entity, not separate

- E_g: emf generated
- V: terminal voltage
- I_a: armature winding current
- I_L: load current
- I_f: field current

Relationships

$$I_a = I_L$$

drop in armature

$$E_g = V - I_a R_a$$

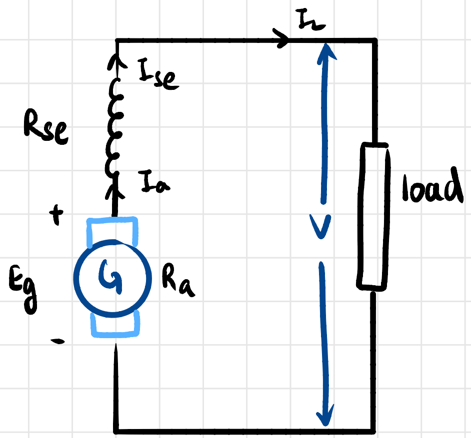
(in parallel paths)

Power developed = $E_g I_a$

Power delivered = $V I_L$

2. Self Excited DC Generator

a. Series Wound DC Generator



Field windings:

- low no. of turns
- thick conductor (low resistance)
- carries load current
- delivers load voltage

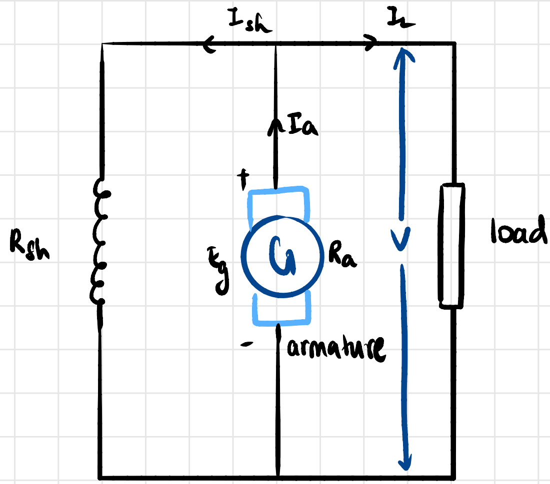
Relationships

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

Power developed = $E_g I_a$

Power delivered = $V I_L$

b. Shunt wound DC Generator



Relationships

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

$$I_{sh} = \frac{V}{R_{sh}}$$

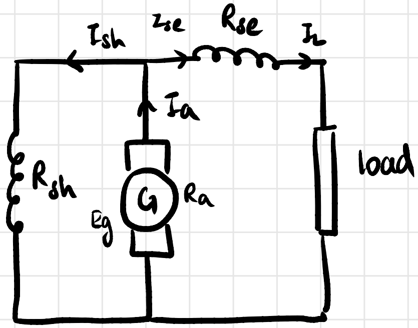
$$E_g = V + I_a R_a$$

Power developed = $E_g I_a$

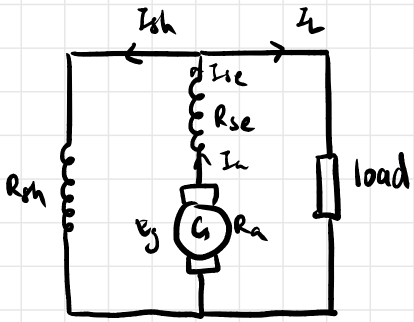
Power delivered = $V I_L$

c. Compound wound DC Generator

(i) Short shunt



(ii) Long shunt



Q: A six-pole wave-wound armature has 300 conductors and runs at a speed of 1000 rpm. The emf generated on open circuit is 400 V. Find the useful flux per pole.

poles speed conductors

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

parallel paths

$$400 = \frac{(\cancel{6})\,\phi\,(100\cancel{0})\,(\overset{150}{\cancel{300}})}{(\cancel{60})\,(\cancel{2})}$$

$$\phi = \frac{400}{100 \times 150} = \frac{2}{75} \text{ Weber}$$

$$\phi = 26.67 \text{ mWeber}$$

Q: A four-pole 1500 rpm dc generator has a lap-wound armature having 32 slots and 8 conductors per slot. If the flux per pole is 0.04 Weber, calculate emf induced in the armature.

What would be the emf induced if the winding was wave connected?

Lap:

$$E_g = \frac{\cancel{P}\phi N Z}{60\,\cancel{A}}$$

no. of conductors

$$= \frac{(0.04)(1500)(32)(8)}{(60)} = 256 \text{ V}$$

Wave:

$$E_g = \frac{P\phi NZ}{60A}$$

$$= \frac{(256)(4)}{(2)} = 512\,V$$

Q: A 4-pole wave connected generator has a useful flux of 0.02 webers per pole. If the emf induced is 288 V at 1200 rpm, find Z in armature. If each slot contains 10 conductors find no. of slots.

$$E_g = \frac{P\phi NZ}{60A}$$

$$288 = \frac{(4)(0.02)(1200)Z}{(60)(2)}$$

$$Z = 360 \text{ conductors}$$

no. of slots = 36

Q: The armature of a 4-pole lap wound shunt generator has 120 slots with 4 conductors per slot. The flux per pole is 0.05 weber. The armature resistance is 0.05 Ω. The shunt field resistance is 50 Ω. Find the speed of the machine when supply 450 A, V = 250 V

$Z = 120 \times 4$ $\qquad I_L = 450\,A$
$\phi = 0.05$ weber $\qquad V = 250\,V$
$R_a = 0.05\,\Omega$
$R_{sh} = 50\,\Omega$

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

$$I_a = I_{sh} + I_L = 455A$$

$$E_g = V + I_a R_a$$
$$= 272.75$$

$$E_g = \frac{\cancel{P}\Phi N Z}{60\cancel{A}} = \frac{(0.05)(N)(\overset{2}{\cancel{120}}\times 4)}{(\cancel{60})}$$

$$N = \frac{(272.75)}{8\times 0.05}$$

$$= 681.875$$

Q: A 6-pole armature is wound with 498 conductors. The speed and flux are such that the average emf generated in each conductor is 2V. The current in each conductor is 120 A. Find total current and generated emf of armature if the armature coils are

(i) wave wound

(ii) Lap wound

Also find the total power generated in each case.

$P=6$ $\quad E_{cond} = 2V$ $\quad I_a = ?$ $\quad E_g = ?$ $\quad power = ?$

$Z = 498$ $\quad I_{cond} = 120A$

(i) wave

$A = 2$

$$E_g = \frac{Z}{A} \times E_{cond}$$

$$E_g = \left(\frac{498}{\cancel{2}}\right)(\cancel{2}) = 498\,V$$

$$I_a = I_{cond} \times A = 240\,A$$

$$\text{power generated} = E_g \cdot I_a = 119.52\,kW$$

(ii) lap

$A = P = 6$

$$E_g = \frac{Z}{A} \times E_{cond} = \frac{498}{6} \times 2$$

$$E_g = 166\,V$$

$$I_a = I_{cond} \times A = 120 \times 6$$

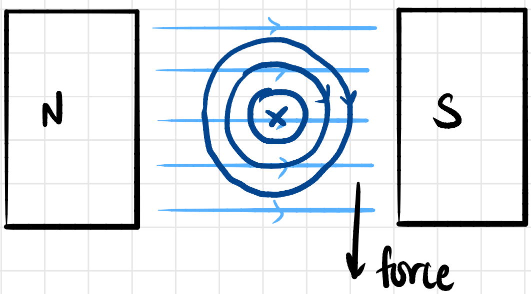
$$I_a = 720\,A$$

$$\text{power delivered} = 119.52\,kW$$

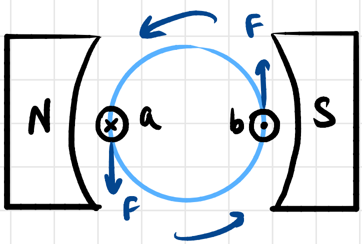
DC Motor

- Electrical $\longrightarrow$ mechanical
- Principle: a current-carrying conductor experiences a force when placed in a uniform $\vec{B}$ (Fleming's Left Hand Rule)

Fleming's Left Hand Rule (also $\vec{F} = I(\vec{l} \times \vec{B})$)

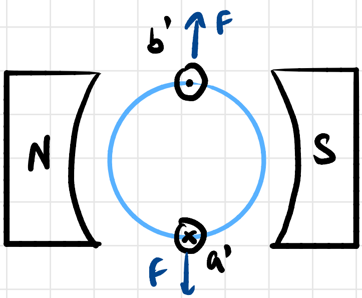


Simple Case of 2 conductors (1 coil)



rotated by 90°

Dead Centre

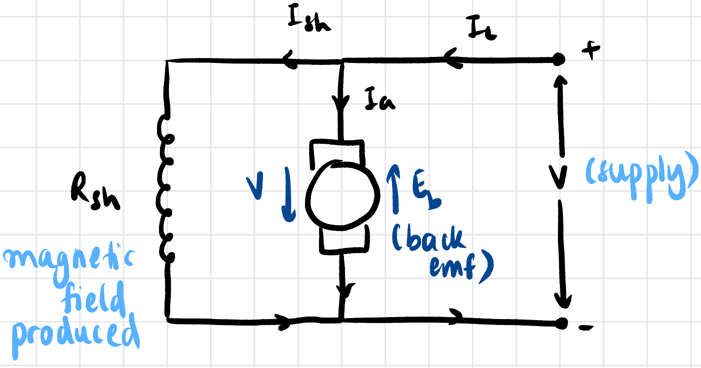


- when two conductors are perpendicular to magnetic field lines, there is no net torque (motor stops)
- Dead centre: forces equal and in same line
- Therefore, we use multiple conductors

- when the conductors are displaced slightly from dead centre, the torque is restoring
- The dead centre is a stable equilibrium
- We obtain pulsating torque
- Therefore, we use a commutator to change the direction of the current at the dead centre region

Back emf

Shunt motor — in syllabus



$I_L = I_a + I_{sh}$

- Armature starts rotating under the influence of magnetic field (windings)
- emf produced by armature that opposes supply voltage is called back emf.

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

$$V = I_a R_a + E_b$$

$$V I_a = E_b I_a + I_a^2 R_a$$

VI_a: power given to armature

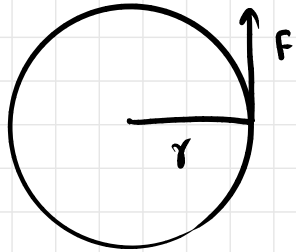
$E_b I_a$: electric form of mech. energy

$I_a^2 R_a$: electrical loss in armature windings

- Due to back emf, DC motor is a self-regulating machine
- Automatically adjusts speed based on load

Torque Equation of DC Motor

$$T_a = r \times F \quad Nm$$



armature

work done by armature in one rotation

$$W = F \times 2\pi r \quad \text{Joule}$$

Power developed in armature = work done in 1 sec

N = rev per min

$\frac{N}{60}$ = rev per sec

$\frac{60}{N}$ = time per rev

$$\therefore P = \frac{F \times 2\pi r}{\frac{60}{N}} = \frac{\overbrace{F \times 2\pi r}^{T_a} \times N}{60}$$

$$P = \frac{2\pi N T_a}{60}$$

Power developed = elec. eq. of mech energy

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

$$\frac{2\pi \cancel{N} T_a}{\cancel{60}} = \frac{P\phi \cancel{N} Z}{\cancel{60} A} I_a$$

$$\boxed{T_a = \frac{1}{2\pi} \frac{P\phi Z I_a}{A}}$$ Torque equation

constants

$$T_a = 0.159 \frac{P\phi Z I_a}{A} \quad Nm$$

$$T_a \propto \phi I_a$$

ϕ = flux produced by machine
↓
current in field windings
I_{sh}

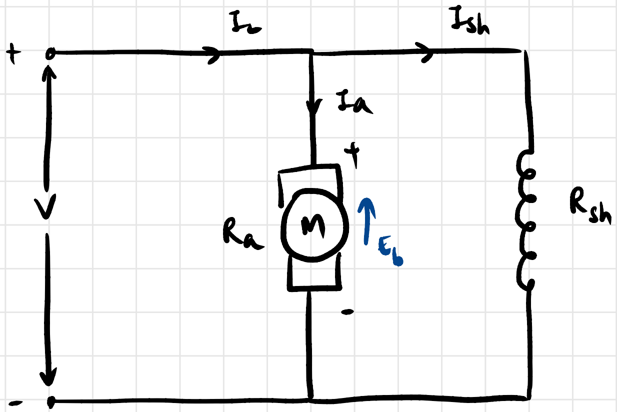
$$I_{sh} = \frac{V}{R_{sh}} = \text{constant}$$

$$\therefore T_a \propto I_a$$

TYPES OF DC MOTORS

1) DC Shunt → syllabus
2) DC Series
3) DC compound

DC Shunt Motor



small drop in brush

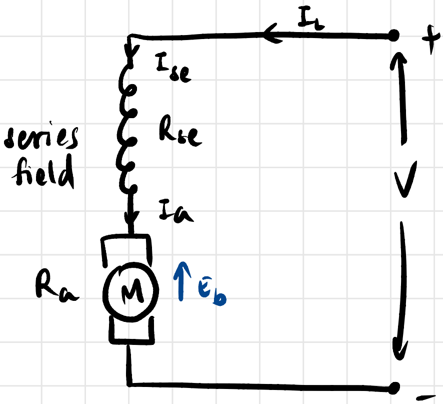
$$V = E_b + I_a R_a + V_{brush}$$

$V_{brush} \approx 0$

$$I_a = I_L - I_{sh}$$

$$I_{sh} = \frac{V}{R_{sh}}$$

DC Series Motor



Loses in DC Machine

+ stray losses ~1% of power

Copper loss (resistance)

1) Armature Cu loss
2) Series field Cu loss
3) Shunt field Cu loss

1) and 2): Variable losses

3): constant (const. cur. through shunt field)

Iron Loss (core)

1) Eddy current loss
2) Hysteresis loss

$\underbrace{}_{\text{constant}}$

Mechanical Loss

1) Friction loss
2) Windage loss

$\underbrace{}_{\text{constant}}$

Q: 4-pole wave wound motor is connected to 500 V DC supply and takes $I_a = 80$ A. $R_a = 0.4\,\Omega$, $Z = 522$, useful $\phi = 0.025$ Wb. Calculate back emf, speed (N), T_a.

$V = 500$ V $A = 2$

$I_a = 80$ A $Z = 522$

$R_a = 0.4\,\Omega$

$$V = E_b + I_a R_a$$

$$E_b = 468 \text{ V}$$

$$E_b = \frac{P \phi N Z}{60 A} \Rightarrow N = \frac{60 \times E_b \times A}{P \phi Z}$$

$$N = 1075.86$$

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

$$T_a = 332.31 \text{ Nm}$$

Q: Armature, $R_a = 0.1\,\Omega$, 250 V supply. Calculate emf generated when it is

(i) generator giving 80 A

(ii) motor giving 60 A

(i) generator

$$E_g = V + I_a R_a$$
$$= 250 + 80 \times 0.1$$
$$= 258\ V$$

(ii) Motor

$$E_b = V - I_a R_a$$
$$= 250 - 60 \times 0.1$$
$$= 244\ V$$

Q: A 4-pole DC shunt motor takes 22.5 A from 250 V supply. Armature resistance = 0.5 Ω. Field resistance = 125 Ω. Wave wound. $Z = 300$. $\phi = 0.02$ wb. Calculate N, T_a, P.

$$I_{sh} = 2A \qquad I_L = 22.5$$

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

$$I_a = 20.5\ A$$

$$E_b = V - I_a R_a = 250 - 10.25 = 239.75$$

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

$$N = \frac{60 \times E_b \times A}{P \phi Z} = 1198.75\ \text{min}^{-1}$$

$$T_a = \frac{1}{2\pi} \frac{P \phi Z I_a}{A} = 39.15\ \text{Nm}$$

$$P = E_b I_a = 4.915\ \text{kW}$$

Q: 25 kW, 250V DC shunt machine has armature and field resistance of 0.06 Ω and 100 Ω respectively. Determine total armature power developed when working as

(i) generator delivering 25 kW output.

(ii) motor taking 25 kW input

(i) $I_L = \dfrac{25 \times 1000}{250} = 100\,A$

$R_a = 0.06\,\Omega \quad R_{sh} = 100\,\Omega \Rightarrow I_{sh} = 2.5\,A$

$I_a = I_L + I_{sh}$

$I_a = 102.5\,A$

$E_g = V + I_a R_a = 250 + 6.15 = 256.15\,V$

$P_{tot} = E_g I_a = 26.255\,kW$

(ii) $I_L = \dfrac{25000}{250} = 100\,A$

$I_L = I_a + I_{sh}$

$I_{sh} = \dfrac{250}{100} = 2.5\,A$

$I_a = 97.5\,A$

$E_b = V - I_a R_a = 244.15\,V$

$P_{tot} = 23.804\,kW$

Q: 10 kW, 250 V DC shunt motor with armature resistance of 0.8 Ω and field resistance 275 Ω takes 3.91 A when running on light at rated voltage and rated speed.

(a) Find constant loss

(b) Calculate machine efficiency as a generator when delivering output of 10 kW at rated voltage and speed and used as a motor drawing input of 10 kW.

Running on light = no load

ideally, no power

power to meet its losses

total loss of machine

(a) $P = V I_L = 250 \times 3.91 = 977.5 \, W$ (var + const)

Total loss = constant loss + variable loss

$W_T = W_C + W_V$ ← only Cu, no field

$W_V = I_a^2 R_a$

$I_a = I_L - I_{sh} = I_L - \dfrac{V}{R_{sh}} = 3 \, A$

$W_V = 7.20 \, W$

$W_C = 977.5 - 7.20 = 970.3 \, W$

(b) As a generator

Output Power $P_{out} = 10\,kW$

$P_{in} = P_{out} + \text{losses}$

$P_{out} = 10\,kW$

$P_{in} = 10\,kW + W_v + W_c$

$$I_L = \frac{P_{out}}{V} = \frac{10000}{250} = 40\,A$$

$I_a = I_L + I_{sh} = 40 + 0.91$

$I_a = 40.91\,A$

$W_v = 1338.8\,W$

W_c is constant with diff. loads

$P_{in} = 10000 + 1338.8 + 970.3$
$= 12309.14\,W$

$\eta = 81.24\,\%$

η as motor

$I_L = 40\,A$
$I_a = 39.09$

$W_v = 1222.48$

$$\eta = \frac{7807.22}{10000} = 78.07\,\%$$

AC MACHINES

↪ Transformer
↪ Induction Motor

TRANSFORMER

- Static device - no moving parts
- Eddy current losses, hyste
- Varies voltage
- High efficency

Parts

- core
- primary windings - input
- secondary windings - load

Principle:

- mutual induction

Types of Transformers

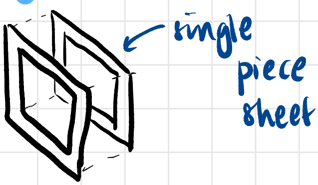
1. Step up
2. step down

core

- cores are laminated to avoid Eddy current losses

Lamination of Core

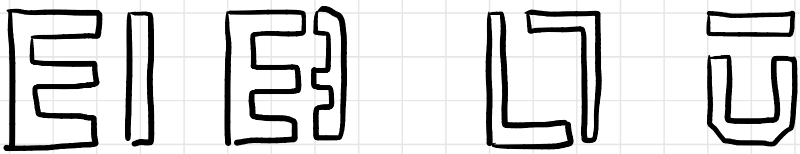
1) Single Lamination



2) Multiple laminations

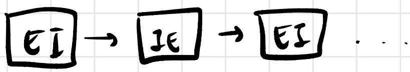
(i) Shell-type

(ii) Core-type



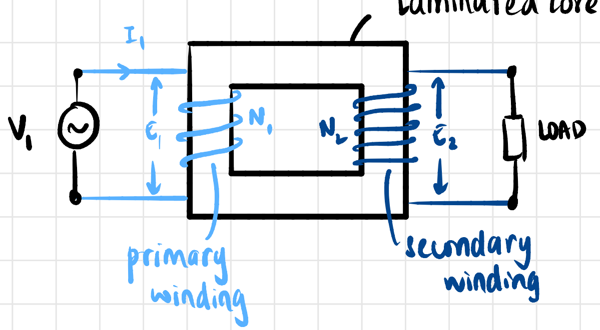
E-I E-E L-L U-I

alternate orientation of layers



Working Principle

Mutual induction between two magnetically coupled windings.



Two winding Transformer

$$E_1 = -N_1 \frac{d\phi}{dt} \qquad E_2 = -N_2 \frac{d\phi}{dt}$$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

if $N_2 > N_1$: step up transformer

if $N_1 > N_2$: step down transformer

For ideal transformer

input (VA) = output (VA)

$$E_1 I_1 = E_2 I_2$$

$$\frac{I_2}{I_1} = \frac{E_1}{E_2} = \frac{N_1}{N_2}$$

TYPES OF TRANSFORMERS

how windings are wound around core

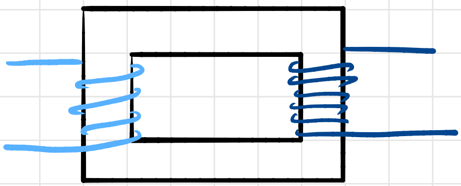
1) Core Type
2) Shell Type

Core Type

- 2 limbs
- single-piece or U-I or L-L
- Flux leakage is more

- inter-leaving (half & half windings) to reduce flux leakage

- Core used for high rating transformers

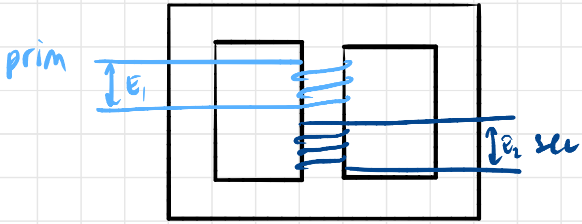


Shell Type

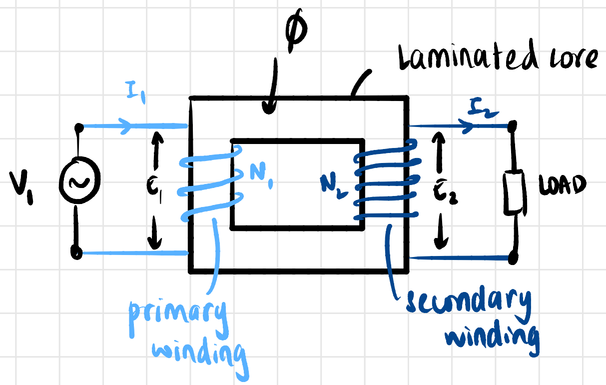
- 3 limbs
- all windings on central limb
- low flux leakage

- low rating (~120 VAC o/p)

- E-E and E-I



EMF Equation



$$V_1 = V_m \sin \omega t$$

$$\phi = \phi_m \sin \omega t$$

$$e_1 = -N_1 \frac{d\phi}{dt}$$ (self induced)

$$e_1 = -N_1 \omega \phi_m \cos \omega t$$

$$e_1 = -2\pi f N_1 \phi_m \sin(\omega t - 90^\circ)$$

$$e_m = \omega N_1 \phi_m$$ (peak value)

$$E_1 = \frac{e_m}{\sqrt{2}} = \frac{\omega N_1 \phi_m}{\sqrt{2}}$$ (rms value) $$= \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

$$E_1 = 4.44 f N_1 \phi_m$$

$$E_2 = 4.44 f N_2 \phi_m$$

Difference between DC Motor and Induction Motor

Nicholas Tesla invented

DC Motor	AC Motor
• Armature made to rotate using supply through brushes and commutator	• Rotor rotates due to EMI
• Conduction motor	• Induction motor

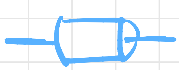
Advantages of 3ϕ Induction Motor

- self-starting
- high efficiency
- simple construction (no brushes/commutators)
- maintenace cheaper
- industry use
- simple

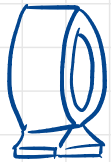
Construction

- two main parts

↳ rotor

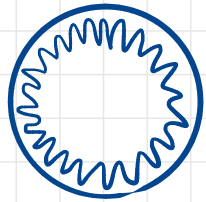


↳ stator



supplied to stator windings → creates flux (rmf : rotating magnetic flux)

Stator



- Laminated core ✓ oc: outer
- slots at inner periphery
- Insulated stator conductors placed inside the slots

- star or delta — 3ϕ

Rotor

1) Squirrel Cage Rotor

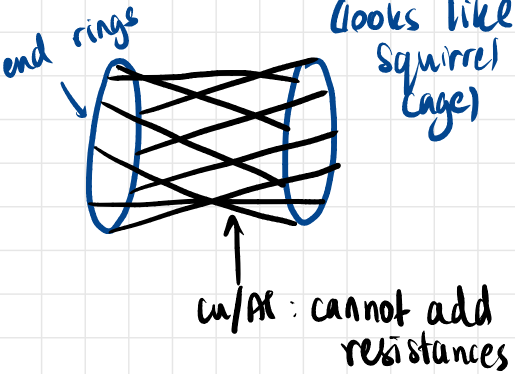
- no wires; Al/Cu bars in rotor slots
- short-circuited by end rings (short circuiting rings)
- low torque
- low cost

2) Phase Wound Rotor / Slip Ring Rotor

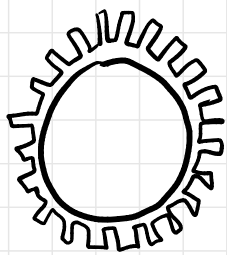
- one end left open & connected to brush & slip
- high starting torque
- can include resistance

1) Squirrel Cage

- slots in outer periphery
- laminated core



(looks like squirrel cage)

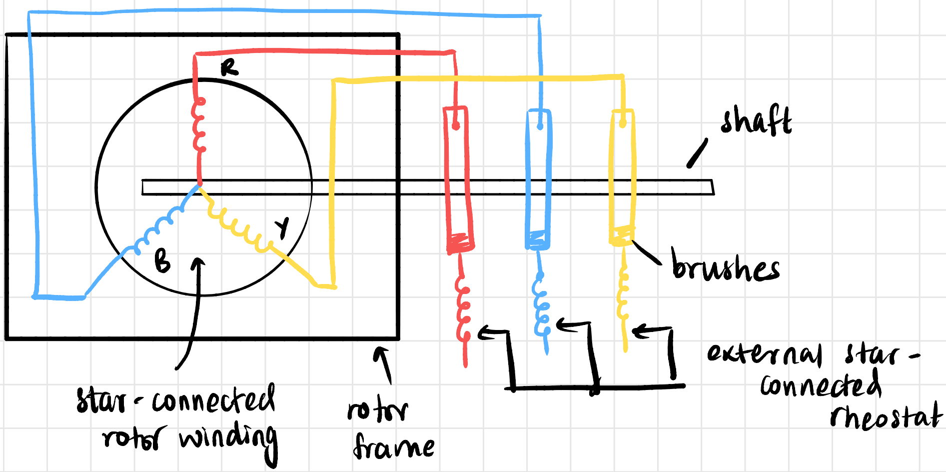


- not exactly parallel to prevent magnetic locking and humming (skewed)
- no of slots on stator ≠ no. of slots on rotor

locking; motor will not start

2) Phase Wound Rotor / Slip Ring

- expensive, high maintenance
- 3ϕ winding, usually star
- slip ring at other end



Concept of RMF

- Self-starting induction motors
- 3-ϕ flux created of constant magnitude
- flux rotating at speed called synchronous speed (N_s)
- rotating magnetic field

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

f = frequency
P = no. of poles

Slip

Speed of rotor (N) < synchronous speed (N_s)

never catches up (otherwise slows down)

$$\text{slip} = N_s - N$$

$$\%S = \frac{N_s - N}{N_s} \times 100\%$$

Q: A 50 kVA transformer has 300 turns on primary winding and 20 turns on secondary winding connected to 2200 V, 50 Hz supply. Calculate
(i) secondary voltage on no load
(ii) appox. value of I_1 and I_2 on full load
(iii) max value of flux

$N_1 = 300$
$N_2 = 20$
$E_1 = 2200$ V

also as 300:20 turns

(i) $\frac{E_1}{E_2} = \frac{N_1}{N_2} \Rightarrow E_2 = \frac{E_1 N_2}{N_1} = \frac{440}{3}$ V

$E_2 = 146.67$ V

(ii) power = 50 KVA

input power = output power

$E_1 I_1 = E_2 I_2 = 50$ kVA

$I_1 = \frac{250}{11} = 22.72$ A

$I_2 = 340.90$

(iii) $E_1 = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$ or $4.44 f N_1 \phi_m$

$2200 = 4.44 \times 50 \times 300\, \phi_m$

$\phi_m = 0.033$ Wb

Q: A 250 kVA 11000 V / 415 V, 50 Hz single phase transformer with 80 turns on secondary winding, calculate
(i) primary, secondary currents
(ii) no. of primary turns
(iii) max. value of flux
(iv) voltage induced per turn

$E_1 = 11000\ V$
$E_2 = 415\ V$
$N_2 = 80$

$P = 250\ kVA$

power rating (apparent power)

(i) $E_1 I_1 = 250\ kVA$
$I_1 = 22.73\ A$

$E_2 I_2 = 250\ kVA$
$I_2 = 602.41\ A$

dummy coil

(ii) $N_1 = \frac{E_1}{E_2} \times N_2 = 2120.5 = 2121$

(iii) $E_2 = 4.44\, f N_2 \phi_m$

$\phi_m = 23.37\ mWb$

(iv) voltage induced per turn:

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 5.19\ V$$

Q: The primary winding of a transformer is connected to 240 V, 50 Hz supply. The secondary winding has 1500 turns. If the max. value of the core flux is 2.07 mWb determine

(i) secondary induced emf

(ii) no. of turns on primary

(iii) core area of cross-section if the flux density has its max. value of 0.465 Tesla

$E_1 = 240\,V \qquad f = 50\,Hz$

$N_2 = 1500$

$\phi_m = 2.07\,mWb$

(i) $E_2 = 4.44 f N_2 \phi_m$

$E_2 = 689.76\,V$

(ii) $N_1 = N_2 \times \frac{E_1}{E_2} = 522.61 = 523$

(iii) $\frac{\phi_m}{A} = 0.465 \Rightarrow A = 4.45 \times 10^{-3}\,m^2$

$= 44.5 \times 10^{-4}\,m^2$

$= 44.5\,cm^2$

Q: A single phase 20 KVA transformer has 1000 primary turns and 2500 secondary turns. The net cross sectional area of the core is $100\,cm^2$. When primary winding is connected to 500V, 50 Hz supply, calculate the max value of flux density in the core, voltage induced in the secondary winding, primary and secondary currents.

$N_1 = 1000$ $\quad E_1 = 500V$ $\quad f = 50Hz$

$N_2 = 2500$ $\quad P = 20\ kVA$

$A = 100\ cm^2$

(i) flux density (max)

(ii) E_2

(iii) I_1

(iv) I_2

$$E_1 = \sqrt{2}\pi f N_1 \phi_m$$

$$\phi_m = \frac{\cancel{500}}{\sqrt{2}\pi(50)(\cancel{1000})\,2} = \frac{1}{\sqrt{2}\times 100\pi}$$

$$\phi_m = 2.25\times 10^{-3}\ Wb$$

(i) $\frac{\phi_m}{A} = 0.225\ T$

(ii) $\frac{N_1}{N_2} = \frac{E_1}{E_2} \Rightarrow E_2 = 1250\ V$

(iii) $E_1 I_1 = 20\times 10^3 = E_2 I_2$

$$I_1 = \frac{20\times 10^3}{500} = 40A$$

(iv) $E_2 I_2 = 20\times 10^3$

$$I_2 = 16A$$

Q: A six-pole induction motor is connected to a 50Hz supply. It is running at a speed of 970 rpm. Find synchronous speed and slip.

$P = 6 \quad f = 50 Hz \quad N = 970 rpm$

$$N_S = \frac{120f}{P} = \frac{\overset{20}{\cancel{120}} \times 50}{\cancel{6}} = 1000 \text{ rpm}$$

$$\% S = \frac{1000 - 970}{1000} = 3\%$$