SRI RAAJA RAAJAN
COLLEGE OF ENGINEERING AND TECHNOLOGY
(Approved by AICTE, New Delhi & Affiliated to Anna University)

146 /4B1, Amaravathi Village,
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E-mail : srrcet2010@gmail.com
Website: www.sriraajaraajan.in

Date :

WILLINGNESS REPORT

14.05.2020

From

R.Ashaboshini M.E(EEE),
Asst. Professor,
Department of Electrical and Electronics Engineering,
SRRCET,
Karaikudi-630301

TO

The principal,
SRRCET,
Karaikudi-630301

Sir/ Madam,

Sub: Willingness Report for Subject: - Reg. I hereby express my willingness to handle the following subject in the following order of priority.

S.NO	Name of the Subject	Class	Reason for Selection
1	Microprocessor and Microcontroller	III	Interested
2	Electrical Machines I	II	Interested

Thanking You

Signature of the Staff

Date: 14.05.2020

Time: 11.30 am

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Date : 14.05.2020

Minutes of Subject allocating meeting

I **R.ASHABOSHINI** hereby submit the minutes of department meeting held for the subject allocating on 13/05/2020 at 10.00 am based on the annexure I & annexure II.

S.NO	NAME OF THE STAFF	NAME OF THE SUBJECT	CLASS	NO OF HRS	STAFF SIGN
1	R. ASHABOSHINI	Microprocessor and Microcontroller EE8551	III	4	
2		Electrical Machines I EE8301	II	5	

HOD SIGN

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Date : 14/05/2020

CIRCULAR

Intimation of course allotment for faculties in the department of Electrical and Electronics Engineering during ODD SEMESTER for B.E-ELECTRICAL AND ELECTRONICS ENGINEERING.

S.NO	NAME OF THE FACULTY	TITLE OF COURSE	COURSE CODE	CLASS & YEAR
1	R.ASHABOSHINI ASSISTANT PROFESSOR	Microprocessor and Microcontroller	EE8551	III
		Electrical Machines I	EE8301	II

Note: Faculties are asked to follow the syllabus issued by Anna University, Chennai.

Copy to

1. The HOD.
2. All the faculties of electrical and electronicsdepartment.
3. File copy.

KARAIKUDI

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MASTER TIME TABLE

DAY	HOURS	I	II	BREAK(11.10-11.20)	III	IV	LUNCH(01.00-1.35)	V	VI	VII
	CLASS	9.30-10.20	10.20-11.10		11.20-12.10	12.10-1.00		1.35-2.20	2.20-3.05	3.15-4.00
MONDAY	II YR	EMT	PPE		TPDE	EDC		EM- 1	DLC	EM-1
	III YR	OOPS	DSP		PSA	APCE		C&I LAB		
	IV YR	RES	S & S		PSOC	TQM		DM	HVE	PSOC
TUESDAY	II YR	DLC	TPDE		EMT	EDC		ELECTRONICS LAB		
	III YR	OOPS	MPMC		DSP	OOPS		PE	PSA	MPMC
	IV YR	HVE	RES		S & S	TQM		PSS LAB		
WEDNESDAY	II YR	EMT	TPDE		PPE	DLC		EM- 1 LAB		
	III YR	DSP	HVE		OOPS LAB			OOPS	PE	PSA
	IV YR	RES	TQM		PSOC	S&S		DM	PSOC	RES
THURSDAY	II YR	DLC	EDC		TPDE	PPE		EM-1	EMT	EDC
	III YR	PE	PSA		MPMC	APCE		PE	DSP	MPMC
	IV YR	HVE	TQM		S & S	DM		RES LAB		
FRIDAY	II YR	EMT	EDC		EM-1	TPDE		PPE	DLC	EM-1
	III YR	DSP	PSA		PE	DSP		ENGLISH LAB		
	IV YR	S & S	DM		HVE	RES		TQM	PSOC	DM

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SRI RAAJA RAAJAN COLLEGE OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERInG
ACADEMIC YEAR-2020-2021

TIME TABLE

DAY	I	II	BREAK	III	IV	LUNCH	V	VI	VII
	9.30-10.20	10.20-11.10		11.20-12.10	12.10-1.00		1.35-2.20	2.20-3.05	3.15-4.00
MONDAY							EM- 1		EM- 1
TUESDAY									
WEDNESDAY									
THURSDAY							EM-1		EM-1
FRIDAY				EM-1					

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

S.NO	PARTICULARS	PROPOSED DATE	COMPLETED DATE	TEACHING AIDS
UNIT I MAGNETIC CIRCUITS AND MAGNETIC MATERIALS				
1	Magnetic circuits	07-10-2020	07-10-2020	ON-LINE
2	Laws governing magnetic circuits	07-10-2020	07-10-2020	ON-LINE
3	Flux linkage, Inductance, and energy	08-10-2020	08-10-2020	ON-LINE
4	Flux linkage, Inductance, and energy transfer concepts	08-10-2020	08-10-2020	ON-LINE
5	Torque – Properties of magnetic materials	09-10-2020	09-10-2020	ON-LINE
6	Hysteresis and Eddy Current losses	09-10-2020	09-10-2020	ON-LINE
7	Transformer as a magnetically coupled circuit	10-10-2020	10-10-2020	ON-LINE
8	Problem Solving	10-10-2020	10-10-2020	ON-LINE
UNIT II TRANSFORMERS				
1	Construction	12-10-2020	12-10-2020	ON-LINE
2	equivalent circuit parameters	12-10-2020	12-10-2020	ON-LINE
3	phasor diagrams, losses – testing	13-10-2020	13-10-2020	ON-LINE
4	efficiency and voltage regulation	14-10-2020	14-10-2020	ON-LINE
5	all day efficiency	14-10-2020	14-10-2020	ON-LINE
6	Sumpner's test	15-10-2020	15-10-2020	ON-LINE
7	three phase transformers	15-10-2020	15-10-2020	ON-LINE
8	connections – Scott Connection	16-10-2020	16-10-2020	ON-LINE
9	Phasing of transformer	16-10-2020	16-10-2020	ON-LINE
10	parallel operation of three phase transformers	19-10-2020	19-10-2020	ON-LINE
11	auto transformer	19-10-2020	19-10-2020	ON-LINE
12	tap changing transformers	20-10-2020	20-10-2020	ON-LINE
UNIT III ELECTROMECHANICAL ENERGYCONVERSION AND CONCEPTS IN ROTATING MACHINES				
1	Energy in magnetic system	21-10-2020	21-10-2020	ON-LINE
2	Field energy and	21-10-2020	21-10-2020	ON-LINE

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	Conergy			
3	singly and multiply excited magnetic field systems	22-10-2020	22-10-2020	ON-LINE
4	Winding Inductances	28-10-2020	28-10-2020	ON-LINE
5	magnetic fields in rotating machines	28-10-2020	28-10-2020	ON-LINE
6	Rotating mmfwaves	29-10-2020	29-10-2020	ON-LINE

UNIT IV DC GENERATORS

1	Construction and components of DC Machine	02-11-2020	02-11-2020	ON-LINE
2	Principle of operation	02-11-2020	02-11-2020	ON-LINE
3	Lap and wave windings	03-11-2020	03-11-2020	ON-LINE
4	EMF equations	03-11-2020	03-11-2020	ON-LINE
5	methods of excitation	04-11-2020	04-11-2020	ON-LINE
6	commutation and interpoles	05-11-2020	05-11-2020	ON-LINE
7	compensating winding	05-11-2020	05-11-2020	ON-LINE
8.	Problem solving	06-11-2020	06-11-2020	ON-LINE

UNIT V DC MOTORS

1	Principle and operations - types of DC Motors	09-11-2020	09-11-2020	ON-LINE
2	Speed Torque Characteristics	09-11-2020	09-11-2020	ON-LINE
3	starting and speed control of DC motors	10-11-2020	10-11-2020	ON-LINE
4	Plugging, dynamic and regenerative braking	11-11-2020	11-11-2020	ON-LINE
5	Retardation test	12-11-2020	12-11-2020	ON-LINE
6	Swinburne 's test and Hopkinson's test	17-11-2020	18-11-2020	ON-LINE
7	DC Motor applications	18-11-2020	18-11-2020	ON-LINE
8.	Problem solving	20-11-2020	21-11-2020	ON-LINE

SRI RAAJA RAAJAN COLLEGE OF ENGINEERING AND TECHNOLOGY
KARAIKUDI

DEPARTMENT OF EEE

EE8301 - ELECTRICAL MACHINES – I

II YEAR – III SEMESTER

UNIT 1

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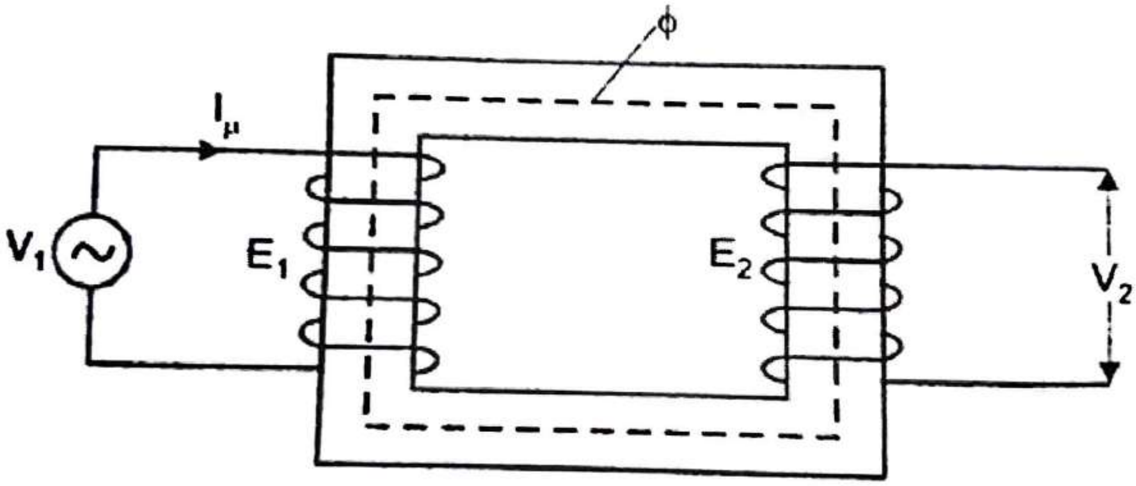
UNIT-I MAGNETIC CIRCUITS ANDMAGNETICMATERIALS

Magnetic circuits –Laws governing magnetic circuits - Flux linkage, Inductance and energy – Statically and Dynamically induced EMF - Torque – Properties of magnetic materials, Hysterisis and Eddy Current losses - AC excitation, introduction to permanent magnets-Transformer as a magnetically coupled circuit.

1.1 Magnetic circuit

- Magnetic circuit is defined as the closed path followed by the flux lines. Electric circuit provides a path for electric current whereas magnetic circuit provides a path for magneticflux.



- In a magnetic circuit, the magnetic line of force leaves the north poles passes through the entire circuit and return the startingpoint.
- A magnetic circuit usually consist of materials having high permeability such as iron, soft steeletc.,
- These materials offer very small opposition to the flow of magnetic flux. consider a coil of N turns would on an iron core

$F=I\,N(AT)$

I=Current through the coil

N=Number of turn in the coil

Ampere's law

The total current piercing the surface enclosed by this path is easily

$$\int_{s}^{0} J.ds = NI = \int_{l}^{0} H.di$$

J=Current density

- The magnetic field intensity H causes a flux density B to be set up at every point along the flux th.Which is givenby

$B= \mu H=H$ (Flux path in core)$\mu 0 \mu r$

$B= \mu H=H$(Flux path inair)$\mu 0$

$\mu 0 = relative\ permiability\ of\ the\ material$

The flux over a given area

$\Phi=\int_{s} B.ds$

The flux set up in air path is known as leakage flux

$F=NI=HcLc$

Hc=Average magnitude of magnetic field intensity in the core

Lc=mean core length(m)

F=MMF in AT Φc=Flux in core,Bc=Flux density in core Ac=Cross section area in core

- Now imagine that the exciting current I vary with time would indicate the Hc will vary in unison with it. Such fields are known as quasi-staticfield.

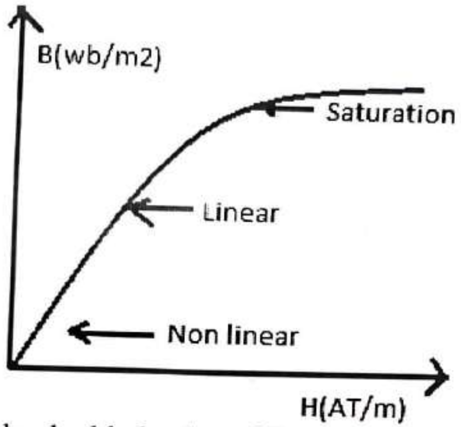
$Bc=\mu c\ Hc$

$\Phi=\int_{s} B.ds=BcAc$

$=\mu c\ Hc\ Ac=NI/(lc/\ c_{\mu}Ac)$

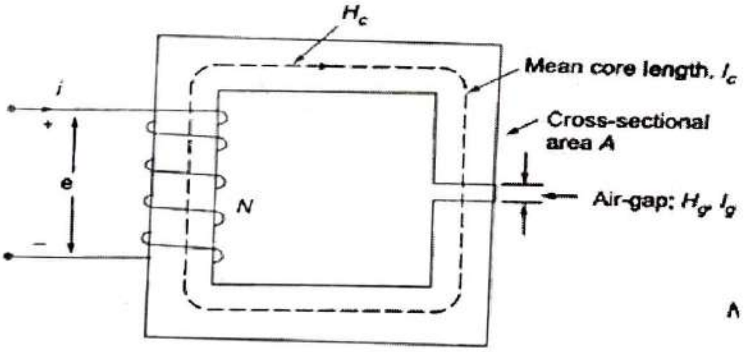
B-H RELATIONSHIP(MAGNETIZATIONCHARACTERISTICS)

- The permeability$\mu 0$is constant so that B-H relationship is linear.B-H relationship is strictly nonlinear in two parts respects-saturation andhysteresis.



Hysteresis on linearity is the doubled value of B-H relationship exhibited in cyclic variation of H.

CORE WITH AN AIRGAP



- Transformers are wound on closed core. Rotating machines have a moving element and must therefore have air gaps in the cores out of necessity. Assume that air gap is narrow and the flux coming out of the core passes straight down the air gap such that the flux density in the air gap is the same as in thecore.
- The flux in the gaps finges out so that the airgap flux density is somewhat less than that of thecore.
- The MMF NI is now consumed in the core plus the gap.

$$NI=H_c l_c+H_g l_g$$

$$NI=B_c l_c/\mu+B_g l_g/_o\mu$$
$$B_g=B_c\ \Phi=B_c A=B_g A$$
$$NI=\phi(l_c/\mu A)+(l_g/_o\mu A)$$

MAGNETIC CIRCUIT CALCULATION

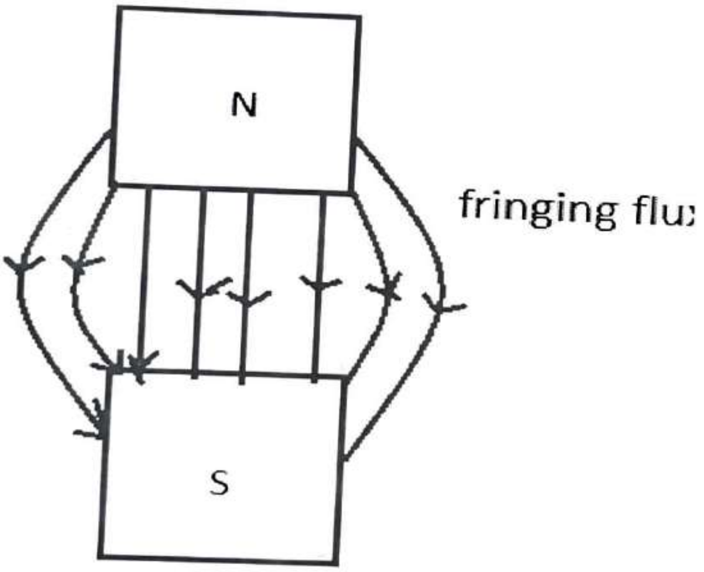
- It required to determine the excitation needed to establish a desired flux or flux density at a given point in a given point in a magneticcircuit.
- The flux is unknown and required to be determined for a given geometry of the magnetic circuit and specifiedmmf.

LEAKAGE FLUX

- A small amount of flux is always leak through the surrounding air. This stray flux is called as leakage flux. Leakage must be made for AC machines and transformers since their performance isaffected.

FRINGING FLUX

- The flux spread out the edge of the airgap is called as fringingflux.
- The effect of fringing flux increases the cross section area of theairgap.



Stacking factor

- Magnetic cores are made up lightly insulated lamination to reduce power loss due to eddycurrent.
- The net cross section area of the core occupied by the magnetic material is less than it gross section their ratio is known as stackingfactor.

1.2 Nature of inducedemf

Whenever the number of magnetic lines of force linking with a current carrying conductor an emf get induced in that coil (or) conductor.

Magnitude of the induced emf is directly proportional to the rate of change of flux linkages

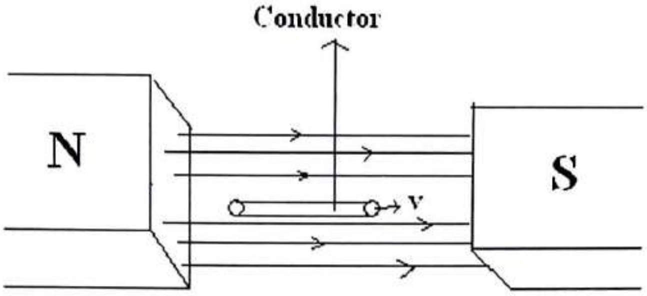
$$E = N\, d\Phi/dt$$

As per lens's law the induced emf set up current in such a direction so as to oppose the very cause producing it.

$$E=-N\, d\Phi/dt$$

1.3 DYNAMICALLY INDUCED EMF

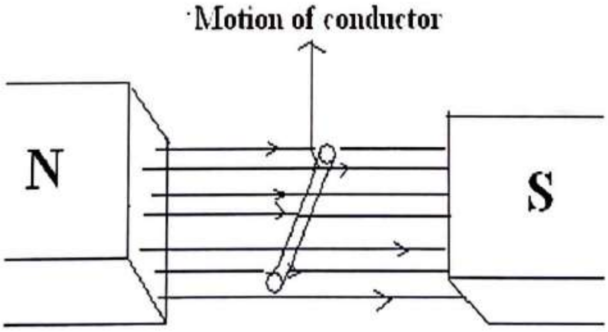
"An induced emf which is due to physical movement of magnet (or) coil is called dynamically induced emf"



Magnitude of dynamically induced emf

- If plane of the motion of the conductor is parallel to the plane of the magnetic field, then there is no cutting of flux lines and there cannot be any induced emf in the conductor.

- When plane of the flux is parallel to the plane of the motion of conductors then there is no cutting of flux, hence no inducedemf.
- Motion of conductor is perpendicular to the flux. Hence whole length of conductor iscuttingthefluxlinehencethereismaximumpossibleinducedemfintheconductor.



Such condition plane of flux and plane of motion are perpendicular to each other.

'When plane of the flux is perpendicular to the plane of the motion of the conductors then the cutting of flux is maximum and hence induced emf is also maximum.'

- Consider a conductor moving with velocity V m/s such that its palne of motion or direction of velocity is perpendicular to the direction of fluxlines.

B=Flux density in wb/m^2

L=Active length of conductor in meters

V=Velocity in m/sec

- This conductor is moved through distance dx in a small time interval and,then Area swept byconductor=l*dx*m^2
- Flux cut by conductor=Flux density*Areaswept

$$d\Phi = B*l*dx \text{ wb}$$

- The magnitude of induced emf is propotional to the rate of change offlux
- E=Flux cut/time= $d\Phi/dt$ [N=1 as singleconductor]

$$=Bl\ dx/dt$$

- dx/dt=rate of change ofdisplacement=V

e=BLV volts is perpendicular to the direction of flux responsible for induced emf.

- The magnitude of inducedemf

$$E= BLV\sin\Theta \text{volts}$$

- If conductor is moving with a velocity V but at a certain angle Θ measured with respect to direction of the field then component of velocityVsin θ

1.4 STATICALLY INDUCED EMF

"The change in flux lines with respect to coil can be achieved without physically moving the coil or magnet is called statically induced emf"

- An induced emf there must be change in flux associated with a coil. The changein flux can be achieved without any physical movement by increasing and decreasing the current producing the flux with respect totime.
- An electromagnet which is producing the necessary flux for producing emf. The current flow through the coil of an alternating one. It means it changes its magnitude periodically withtime.
- There is no physical movement of magnet or conductor, it is the alternating supply which is responsible for an induced emf. The alternating flux linking with the coil itself, the emf gets induced in that coilitself.
- The statically induced emf is classifiedas
  1. Self-inducedemf
  2. Mutually inducedemf

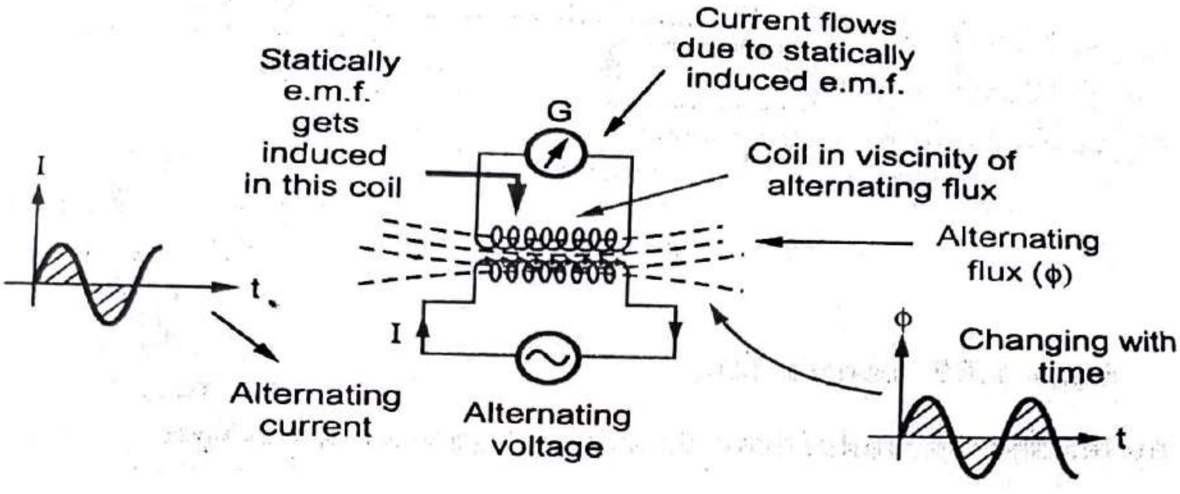
SELF INDUCED EMF

- Consider a coil having 'N' turns and carrying current 'I'. When switch is closed the magnitude of current can be varied with the help of variable resistance. The flux produced by the coil links with the coilitself.
- The current 'I' is changed with the help of variable resistance, then flux produced will

alsochange.

- According to faraday's law due to rate o change of flux linkages there will beinduced emf in thecoil

- So there is no physical moving coil the flux is induced emf the coil itself. This emf is called as self-inducedemf.



SELF INDUCTANCE

- The direction of this induced emf will be oppose the cause producing it. When current is increased, self-induced emf reduces the current tries to keep it to original value.

Let

N- No. of turns

I-Current flowing in coil

Φ – Flux produced by the coil.

By Faradays law,

$$e = -N\frac{d\Phi}{dt} \underline{\qquad\quad} (1)$$

Consider the flux, Φ

$$\Phi = \frac{\Phi}{I} * I$$

Rate of change offlux,

$$d\Phi = \frac{\Phi}{I} * \frac{dI}{dt} - - - - (2)$$

Subs (2) in (1) Weget

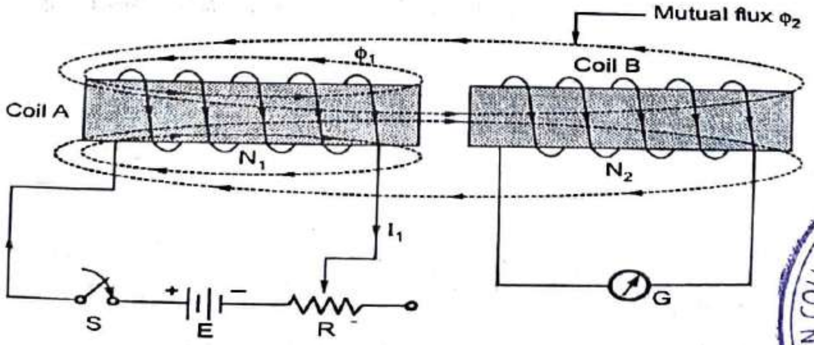
$$e = -N\frac{\Phi}{I} * \frac{dI}{dt}$$

$$e = -\left(\frac{N\Phi}{I}\right) * \frac{dI}{dt}$$

$$e = -L\frac{dI}{dt} \text{Where } L(self\ Inductance) = \frac{N\Phi}{I}$$

1.5 MUTUALLY INDUCED EMF AND MUTUAL INDUCTANCE

"The flux produced by one coil is getting linked with another coil and due to change in flux produced by first coil, there is induced emf I the second coil , then such emf is called mutually inducedemf"



- The coil 'A' has N_1 turns and coil 'B' has N_2 turns .The coil A has switch 'S' with variableresistance.

- Current I_1 produces a total flux Φ_{11} in coil 1. The flux of coil 1 that links coil 1. The resulting self-inductance L_1 of coil 1is

$$e = -N_2 * \frac{d\Phi_2}{dt} \_\_\_\_(1)$$

Consider the flux, Φ

$$\Phi_2 = \frac{\Phi_2}{I_1} * I_1$$

Rate of change of flux,

$$d\Phi_2 = \frac{\Phi_2}{I_1} * \frac{dI_1}{dt} - - - (2)$$

Subs (2) in (1) We get

$$e = -N_2 * \frac{\Phi_2}{I_1} * \frac{dI_1}{dt}$$

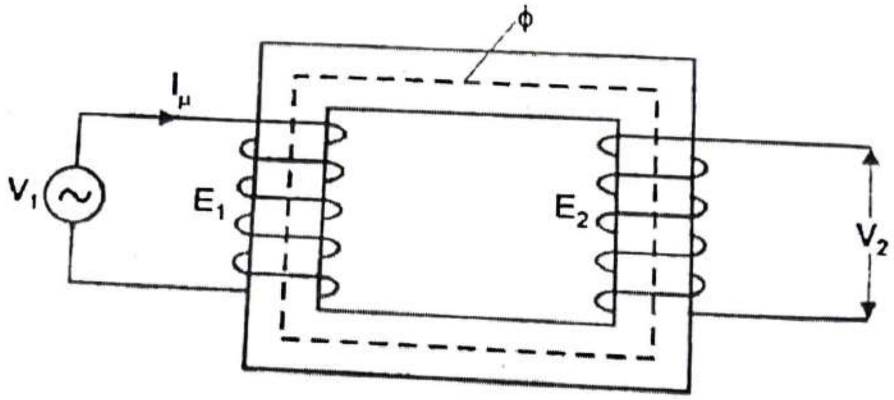
$$e = -\left(\frac{N_2\Phi_2}{I_1}\right) * \frac{dI_1}{dt}$$

$$e = -M * \frac{dI_1}{dt}$$

1.6 AC operation of magnetic circuits

- For establishing a magnetic field, energy must be spent, though to energy is required to maintain it. Take the example of the exciting coils of anelectromagnet.
- The energy supplied to it is spent in twoways,
- (i) Part of it goes to meet I^2R loss and is lost once forall.
- (ii)partofitgoestocreatefluxandisstoredinthemagneticfieldaspotential energy, and is to the potential energy of a raised weight, when a mass M is raised through a height of H.
- When current through an inductive coil is gradually changed from Zero to a maximum, value then every change of it is opposed by the self-induced emf. Produced due to this change. Energy is needed to overcome thisopposition.
- This energy is stored in the magnetic field and is, later on, recovered when the fieldcollapse.
- In many applications and machines such as transformer and a.c machines, the magnetic circuits are excited by a.c supply. In such an operation, Inductance plays vital role even in steady state operation though in d.c it acts as a short circuit. In such a case the flux is

determined by the a.c voltage applied and the frequency, thus the exciting current has toadjust itself according to the flux so that every time B-H relationship issatisfied.



- Consider a coil having N turns wound on iron core. The coil carries an alternating current 'i' varying sinusoidal. The flux Φ produced by the exciting current 'I' is also sinusoidal varying withtime.Let

  N- No. of turns

  I-Current flowing in coil

  Φ – Flux produced by the coil.

By Faradays law,

$$e = N\frac{d\Phi}{dt}$$

For AC Circuit, Φ $\quad \Phi = \Phi_m \sin \omega t$

$$e = N\frac{d(\Phi_m \sin \omega t)}{dt}$$

$$e = N\Phi_m \cos \omega t \,.\, \omega$$

From the above equation consider the magnitude alone,

$$e_m = N\Phi_m \omega$$

RMS value is given by,

$$e_{RMS} = \frac{e_m}{\sqrt{2}}$$

$$e_{RMS} = \frac{N\Phi_m \omega}{\sqrt{2}}$$

Where $\omega = 2\pi f$

$$e_{RMS} = \frac{N\Phi_m (2\pi f)}{\sqrt{2}}$$

$$e_{RMS} = 4.44 N\Phi_m f$$

Energy stored in AC circuit;

Energy is the product of power and time.

$$\text{Energy} = \textbf{power} * \textbf{time}$$

$$\text{Power} = \text{e} * \text{i}$$

$$\text{Power} = \text{e} * \text{i} = \mathbf{N}\frac{\mathbf{d\Phi}}{\mathbf{dt}} * \text{i}$$

$$\text{Power} = \text{i} * \frac{\mathbf{d\lambda}}{\text{dt}}$$

For ACCircuit,**Energy** = W_f

$$W_f = \textbf{power} * \text{time}$$

$$W_f = \int_{t1}^{t2} \text{i} * \frac{\text{d}\lambda}{\text{dt}} * \text{dt}$$

$$W_f = \int_{t1}^{t2} \text{i} * \text{d}\lambda$$

Change the limit,

$$W_f = \int_{\lambda 1}^{\lambda 2} \text{i} * \text{d}\lambda$$

$$W_f = \int_{\lambda 1}^{\lambda 2} \frac{\text{Hl}}{\mathbf{N}} * \mathbf{d\lambda}$$

$$W_f = \int_{\lambda 1}^{\lambda 2} \frac{\text{Hl}}{\text{N}} * \mathbf{Nd\Phi}$$

$$W_f = \int_{\lambda 1}^{\lambda 2} Hl * \text{d}\Phi$$

$$W_f = \int_{\lambda 1}^{\lambda 2} Hl * \text{d}(\mathbf{Ba})$$

$$W_f = \int_{B1}^{B2} Hl * \boldsymbol{a} * \text{dB}$$

The above equation is the energy stored in AC circuit.

Energy per unit volume:

$$W_f = \int_{B1}^{B2} Hla * \text{dB}$$

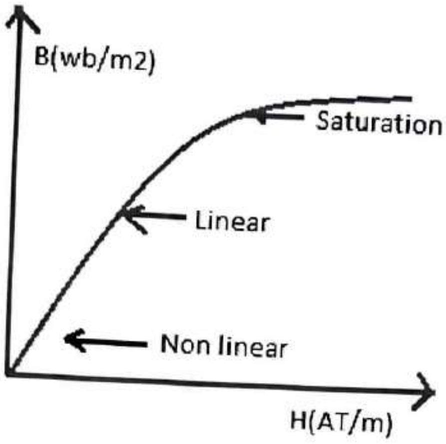
$$W_f = \int_{B2}^{B2} Hla * \text{dB}$$

$$W_f = \int^{B} H * \text{dB}$$

The above equation is the energy stored per unit volume in AC circuit.

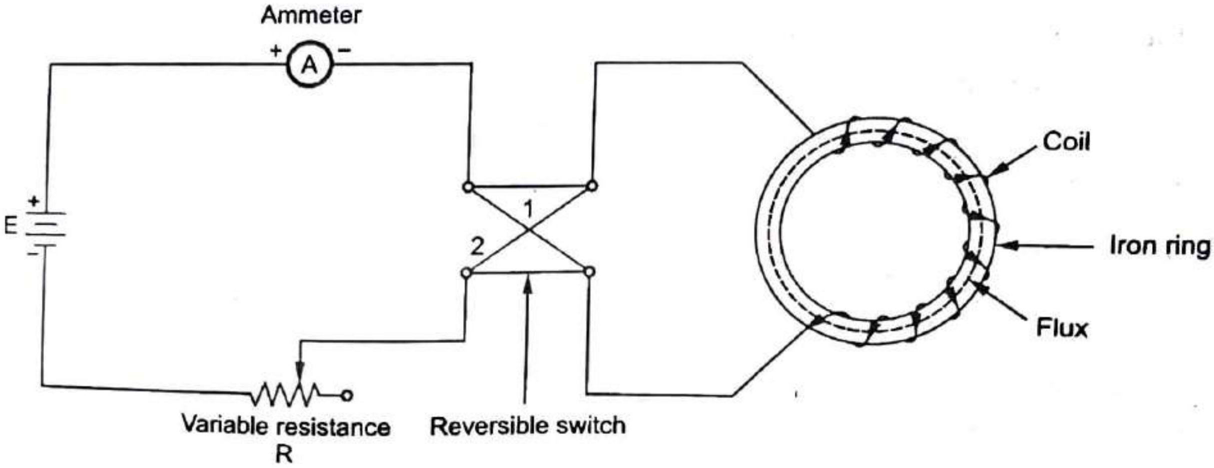
1.7 Hysteresis loop

- The permeability$\mu0$is constant so that B-H relationship is linear-H relationship is strictly nonlinear in two parts respects-saturation andhysteresis.

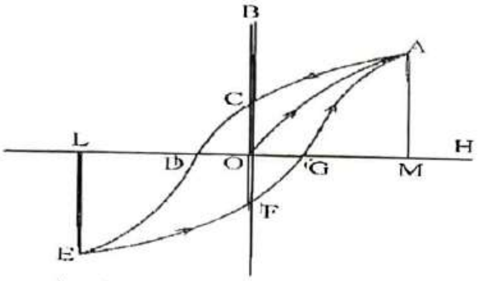


Hysteresis on linearity is the doubled value of B-H relationship exhibited in cyclic variation of H.

- Let us take a un magnetized bar of iron AB and magnetize in by placing it within the magnetizing field of a solenoid (H). The Field can be increased or decreased by increasing or decreasing current through it. Let `H' be increased in step from zero up to a certain maximum value and the corresponding of induction flux density (B) isnoted.
- IfweplottherelationbetweenHandB,acurvelikeOA,asshowninFigure,is obtained. The material becomes magnetically saturated at H = OM and has, at that time, a maximum flux density, established through it. If H is now decreased gradually (by decreasing solenoid current) flux density B will not decrease along AO (as might be expected) but will decrease less rapidly alongAC.



- When it is Zero B is not zero, but has a definite value = OC. It means that on removing the magnetizing force H, the iron bar is not completely demagnetized This value of B (=OC) is called the residual fluxdensity.
- To demagnetize the iron bar we have to apply the magnetizing force H in the reverse direction. When H is reversed by reversing current through the solenoid, then B is reduced to Zero at point D where H -OD.
- This value of H required to wipe off residual magnetism is known as coercive force and is a measure of the coercivity of materials i.e. its `tenacity' with which it holds on to itsmagnetism.



- This value of H required to wipe off residual magnetism is known as coercive force and is a measure of the coercively of materials i.e. its `tenacity' with which it holds on to itsmagnetism.
- After the magnetization has been reduced to zero value of H is further increased in the negative i.e. reverse direction, the iron bar again reaches a state of magnetic saturation represented by point E. By taking H back from its value corresponding to negative saturation (=OL) to its value for positive saturation (=OM), a similar curve EFGA is obtained. If we again start from G, the same curve GACDEFG is obtained onceagain.
- It is seen that B always lags behind H the two never attain zero value simultaneously. This lagging of B, behind H is given the name Hysteresis' which literally means `to lag behind.' The closed Loop ACDEFGA, which is obtained when iron bar is taken through one complete cycle of reversal of magnetization, is known as Hysteresisloop.

1.8 Core Losses

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 thepoles.

  They are of two types i) Hysteresis loss ii) Eddy current loss.

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. shows an armature rotating in two-pole machine. Consider a small piece ab of thearmature.
- When the piece ab is under N-pole, the magnetic lines pass from a to b. Half are volition later, the same piece of iron is under S-pole and magnetic lines pass from b to a In order to reverse continuously the molecular magnets in the armature core,someamountofpowerhastobespentwhichiscalledhysteresisloss.Itis

given by Steinmetz formula. This formula is

Hysteresis loss, $P_h=B^{16}_{max}fV$ watts

where

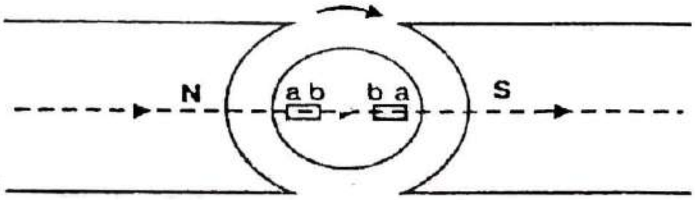
B_{max} = Maximum flux density in armature f

= Frequency of magnetic reversals

V = Volume of armature in m^3

h = 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 Eddy currentloss
- In addition to the voltages induced in the armature conductors, thereare also voltages induced in the armature core. These voltages produce circulating currents in the armaturecore.



- 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 itsefficiency.
- 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 aspractical.
- The core resistance can be greatly increased by constructing the core of thin, round iron sheets called laminations. The laminations are insulated from each other with a coating ofvarnish.
- Thus laminating a core increases the core resistance which decreases the eddy currentloss.

Eddy current loss, $P_e = K_eB^2_{max}f^2t^2V$ watts

where,

K_e = Constant

B_{max} = Maximum flux density in Wb/m^2

f = Frequency of magnetic reversals in Hz

t = Thickness of lamination in m V =
Volume of core in m^3

1.9 Problems:

1. **The total core loss of a specimen of silicon steel is found to be 1500W at 50 Hz, keeping the flux density to be constant, the loss become 3000W. When the frequency is raised to 75 Hz. Calculate the separately hysteresis loss and eddy current losses at each frequency. [Non/Dec15]**

Solution

Hysteresis loss = $(B_M)^{1.6} V k_H f$

$W_h = Af$

$K_e (B_M)^2 t^2 V f^2$

$W_e = Bf^2$

Now core loss, $P = W_e + W_h$

$P = Af + Bf^2$

$P/f = A + Bf$ -------------------- (A)

At 50 Hz, Core loss is 1500W

$1500/50 = A + 50B$

$30 = A + 50B$ ----------(1)

At 75 Hz, Core loss is 3000W

$3000/60 = A + 75B$

$40 = A + 75B$ ----------------(2)

Solving (1) and (2) we get,

$25B = 10$

$B = 0.4$

Therefore

$A = 10$

At 50 Hz

Hysteresis loss = $Af = 10*50 = 500W$ Eddy
current loss=$Bf^2 = 0.4*(50)^2 = 1000W$

At 75 Hz

Hysteresis loss = $Af = 10*75 = 750W$ Eddy
current loss=$Bf^2 = 0.4*(75)^2 = 2250W$

DEPARTMENT OF EEE

EE8301 - ELECTRICAL MACHINES – I

II YEAR – III SEMESTER

UNIT 2

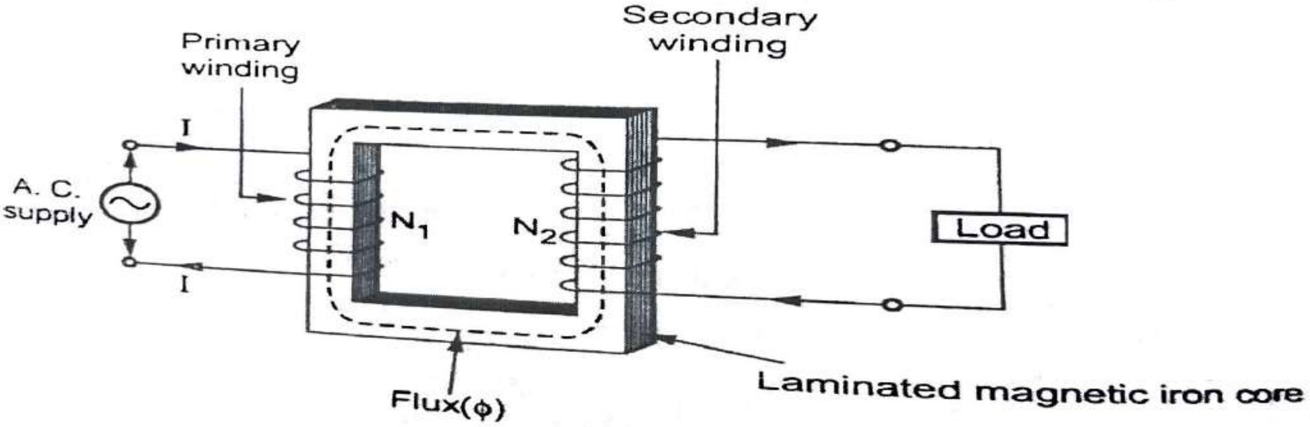
PRINCIPAL
Sri Raaja Raajan College of Engg. & Tech.,
Amaravathipudur, Karaikudi - 630 301
Sivagangai Dist. Tamil Nadu

UNIT – II TRANSFORMERS

Construction – principle of operation – equivalent circuit parameters – phasor diagrams, losses – testing – efficiency and voltage regulation-all day efficiency-Sumpner's test, per unit representation – inrush current - three phase transformers-connections – Scott Connection – Phasing of transformer– parallel operation of three phase transformers-auto transformer – tap changing transformers- tertiarywinding

1.1 Construction and working principle of a transformer

A transformer can be defined as a static device which helps in the transformation of electric power in one circuit to electric power of the same frequency in another circuit. The voltage can be raised or lowered in a circuit, but with a proportional increase or decrease in the currentratings.



The main principle of operation of a transformer is mutual inductance between two circuits which is linked by a common magnetic flux. A basic transformer consists of two coils that are electrically separate and inductive, but are magnetically linked through a path of reluctance. The working principle of the transformer can be understood from the figure

The simple construction of a transformer must need two coils having mutual inductance and a laminated steel core.

The two coils are insulated from each other and from the steel core. The device will also need some suitable container for the assembled core and windings, a medium with which the core and its windings from its container can be insulated.

In order to insulate and to bring out the terminals of the winding from the tank, apt bushings that are made from either porcelain or capacitor type must be used.

In all transformers that are used commercially, the core is made out of transformer sheet steel laminations assembled to provide a continuous magnetic path with minimum of air-gap included. The steel should have high permeability and low hysteresis loss.

For this to happen, the steel should be made of high silicon content and must also be heat treated. By effectively laminating the core, the eddy-current losses can be reduced.

The lamination can be done with the help of a light coat of core plate varnish or lay an oxide layer on thesurface.

For a frequency of 50 Hertz, the thickness of the lamination varies from 0.35mm to 0.5mm for a frequency of 25 Hertz.

Core TypeTransformers

The low voltage windings are placed nearer to the core as it is the easiest to insulate. The effective core area of the transformer can be reduced with the use of laminations andinsulation.

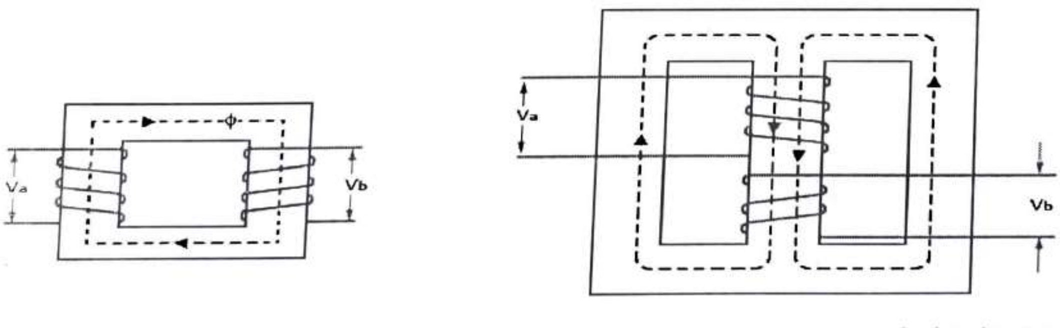
hell-TypeTransformers

In shell-type transformers the core surrounds a considerable portion of the windings. The comparison is shown in the figure below.

Core Type and Shell Type Transformer Winding

The coils are form-wound but are multi-layer disc type usually wound in the form of pancakes. Paper is used to insulate the different layers of the multi-layer discs. The whole winding consists of discs stacked with insulation spaces between the coils. These insulation spaces form the horizontal cooling and insulating ducts. Such a transformer may have the shape of a simple rectangle or may also have a distributed form. Both designs are shown in the figurebelow:

Core Type and Shell Type Transformer Winding



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Shell Type Transformers Distributed Form

A strong rigid mechanical bracing must be given to the cores and coils of the transformers. This will help in minimizing the movement of the device and also prevents the device from getting any insulation damage.

A transformer with good bracing will not produce any humming noise during its working and will also reduce vibration.

A special housing platform must be provided for transformers. Usually, the device is placed in tightly-fitted sheet-metal tanks filled with special insulating oil.

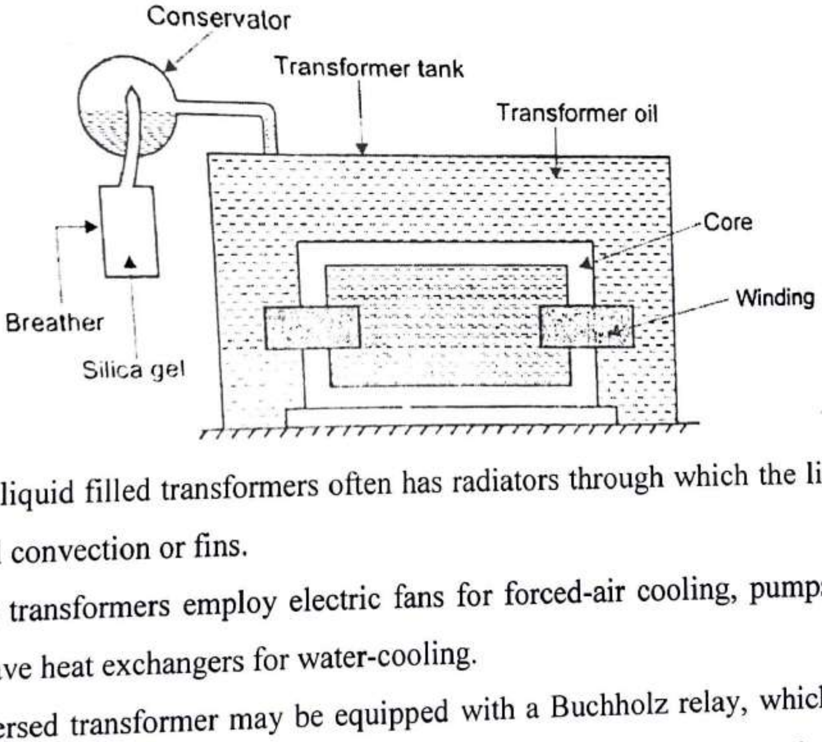
This oil is needed to circulate through the device and cool the coils. It is also responsible for providing the additional insulation for the device when it is left in the air.

The quality, durability and handling of these insulating materials decide the life of the transformer. All the transformer leads are brought out of their cases through suitable bushings. There are many designs of these, their size and construction depending on the voltage of the leads. Porcelain bushings may be used to insulate the leads, for transformers that are used in moderate voltages. Oil-filled or capacitive-type bushings are used for high voltagetransformers.

The selection between the core and shell type is made by comparing the cost because similar characteristics can be obtained from both types. Most manufacturers prefer to use shell-type transformers for high-voltage applications or for multi-winding design.

When compared to a core type, the shell type has a longer mean length of coil turn. Other parameters that are compared for the selection of transformer type are voltage rating, kilo-volt ampere rating, weight, insulation stress, heat distribution and so on.

Transformer tank



The tank of liquid filled transformers often has radiators through which the liquid coolant circulates by natural convection or fins.

Some large transformers employ electric fans for forced-air cooling, pumps for forced-liquid cooling, or have heat exchangers for water-cooling.

An oil-immersed transformer may be equipped with a Buchholz relay, which, depending on severity of gas accumulation due to internal arcing, is used to either alarm or de-energize the transformer.

Oil-immersed transformer installations usually include fire protection measures such as walls, oil containment, and fire-suppression sprinkler systems.

Bushings

Larger transformers are provided with high voltage insulated bushings made of polymers or porcelain. A large bushing can be a complex structure since it must provide careful control of the electric field gradient without letting the transformer leak oil.

Buchholz relay

Buchholz relay is a safety device which is generally used in large oil immersed transformers (rated more than 500 kVA). It is a type of oil and gas actuated protection relay. It is used for the protection of a transformer from the faults occurring inside the transformer, such as impulse breakdown of the insulating oil, insulation failure of turns etc. Working principle of buchholz's relay

The tank of liquid filled transformers often has radiators through which the liquid coolant circulates by natural convection or fins. Some large transformers employ electric fans for forced-air cooling, pumps for forced-liquid cooling, or have heat exchangers for water-cooling. An oil-immersed transformer may be equipped with a Buchholz relay, which, depending on severity of gas accumulation due to internal arcing, is used to either alarm or de-energize the transformer. Oil-immersed transformer installations usually include fire protection measures such as walls, oil containment, and fire-suppression sprinkler systems

Transformer Working

Transformer has primary and secondary windings. The core laminations are joined in the form of strips in between the strips you can see that there are some narrow gaps right through the cross-section of the core. These staggered joints are said to be 'imbricated'. Both the coils have high mutual inductance. A mutual electro-motive force is induced in the transformer from the alternating flux that is set up in the laminated core, due to the coil that is connected to a source of alternating voltage. Most of the alternating flux developed by this coil is linked with the other coil and thus produces the mutual induced electro-motive force. The so produced electro-motive force can be explained with the help of Faraday's laws of Electromagnetic Inductionas

$$e=M*dI/dt$$

If the second coil circuit is closed, a current flows in it and thus electrical energy is transferred magnetically from the first to the second coil.

The alternating current supply is given to the first coil and hence it can be called as the primary winding. The energy is drawn out from the second coil and thus can be called as the secondary winding.

2. The power demand might have increased over a time necessitating augmentation of the capacity. More transformers connected in parallel will then be pressed intoservice.
3. To ensure improved reliability. Even if one of the transformers gets into a fault or is taken out for maintenance/repair the load can have continued to beserviced.
4. To reduce the spare capacity. If many smaller size transformers are used one machine can be used as spare. If only one large machine is feeding the load, a spare of similar rating has to be available. The problem of spares becomes more acute with fewer machines in service at alocation.
5. When transportation problems limit installation of large transformers at site, it may be easier to transport smaller ones to site and work them in parallel. Fig. 37 shows the physical arrangement of two single phase transformers working in parallel on the primary side. Transformer A and Transformer B are connected to input voltage bus bars. After ascertaining the polarities they are connected to output/load bus bars. Certain conditions have to be met before two or more transformers are connected in parallel and share a common load satisfactorily. Theyare,

1. The voltage ratio must be thesame.
2. The per unit impedance of each machine on its own base must be thesame.
3. The polarity must be the same, so that there is no circulating current between the transformers.
4. The phase sequence must be the same and no phase difference must exist between the voltages of the twotransformers.

Where ,V_1=Load bus voltage V_2=Supply voltage

These conditions are examined first with reference to single phase transformers and then the three phase cases are discussed. Same voltage ratio generally the turns ratio and voltage ratio are taken to be the same. If the ratio is large there can be considerable error in the voltages even if the turns ratios are the same. When the primaries are connected to same bus bars, if the secondary's do not show the same voltage, paralleling them would result in a circulating current between the secondaries. Reflected circulating current will be there on the primary side also. Thus even without connecting a load considerable current can be drawn by the transformers and they produce copper losses. In two identical transformers with percentage impedance of 5 percent, a no-load voltage difference of one percent will result in a circulating current of 10 percent of full load current. This circulating current gets added to the load current when the load is connected resulting in unequal sharing of the load

In short, a transformer carries the operations shown below:

- Transfer of electric power from one circuit toanother.
- Transfer of electric power without any change infrequency.
- Transfer with the principle of electromagneticinduction.
- The two electrical circuits are linked by mutualinduction.

This is a very useful device, indeed. With it, we can easily multiply ordivide voltage and current in ACcircuits.

Indeed, the transformer has made long-distance transmission of electric power a practical reality, as AC voltage can be "stepped up" and current "stepped down" for reduced wire resistance power losses along power lines connecting generating stations with loads.

At either end (both the generator and at the loads), voltage levels are reduced by transformers for safer operation and less expensive equipment.

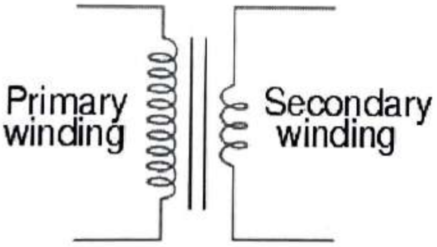
Conversely, a transformer designed to do just the opposite is called a step-down transformer.

Step up Transformer:

A transformer that increases voltage from primary to secondary (more secondary winding turns than primary winding turns) is called a step-up transformer.

Step down Transformer:

A transformer that decreases voltage from primary to secondary (less secondary winding turns than primary winding turns) is called a step-down transformer.

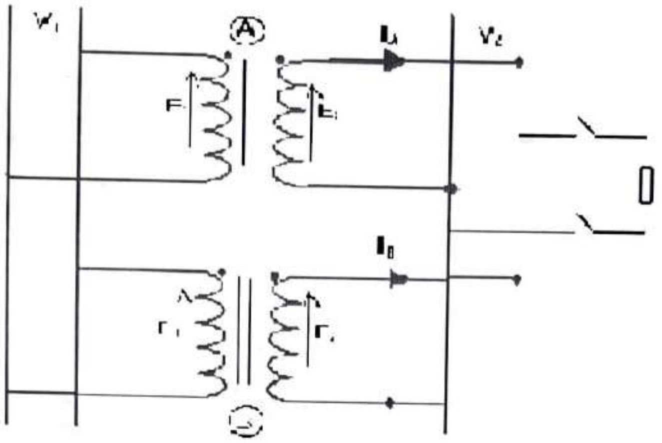


1.2Single Phase Transformer

PARALLEL OPERATION OFTRANSFORMERS

By parallel operation we mean two or more transformers are connected to the same supply bus bars on the primary side and to a common bus bar/load on the secondary side. Such requirement is frequently encountered in practice. The reasons that necessitate parallel operation are as follows.

1. Non-availability of a single large transformer to meet the total loadrequirement.



. $P_A=V_2I_A$

$P_B=V_2I_B$

$P_A=P*(Z_B/Z_A+Z_B)$

$P_B=P*(Z_A/Z_A+Z_B)$

EMF EQUATION OF THE TRANSFORMER

In a transformer, source of alternating current is applied to the primary winding. Due to this, the current in the primary winding (called as magnetizing current) produces alternating flux in the core of transformer. This alternating flux gets linked with the secondary winding, and because of the phenomenon of mutual induction an emf gets induced in the secondary winding. Magnitude of this induced emf can be found by using the following

EMF equation of the transformer.

Let.

N_1 = Number of turns in primary winding N_2 =

Number of turns in secondarywinding

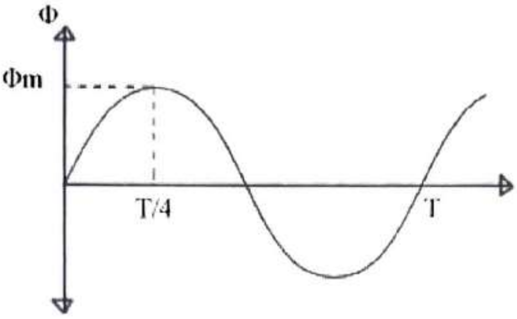
Φ_m = Maximum flux in the core (in Wb) = (B_m x A) f

= frequency of the AC supply (in Hz)

The flux rises sinusoidally to its maximum value Φ_m from0.

It reaches to the maximum value in one quarter of the cycle i.e in T/4sec (where, T

. is time period of the sin wave of the supply =1/f).



Therefore, average rate of change of flux = $\Phi_m/(T/4) = \Phi_m/(1/4f)$ Therefore,

average rate of change of flux $=4f\Phi_m$ .... (Wb/s).

Now, Induced emf per turn = rate of change of flux per turn

Therefore, average emf per turn $=4f\Phi_m$ .... (Volts).

Now, we know,Form factor = RMS value / averagevalue

Therefore, RMS value of emf per turn = Form factor X average emf per turn. As, the flux Φ varies sinusoidally, form factor of a sine wave is 1.11 Therefore, RMS value of emf per turn = $1.11 \times 4f\,\Phi_m = 4.44f\,\Phi_m$

RMS value of induced emf in whole primary winding (E_1) = RMS value of emf per turn X Number of turns in primary winding

$E_1 = 4.44fN_1\Phi_m$ eq1

Similarly, RMS induced emf in secondary winding (E_2) can be given as $E_2 =$

$4.44fN_2\Phi_m$ eq2

from the above equations 1 and 2,

$$E_1/N_1=E_2/N_2=K=4.44f\,\Phi_m$$

- This is called the **emf equation of transformer**, which shows, emf / number of turns is same for both primary and secondarywinding.
- For an ideal transformer on no load, $E_1 = V_1$ and $E_2 = V_2$.
- where, V_1 = supply voltage of primary winding V_2
  = terminal voltage of secondarywinding

Voltage Transformation Ratio (K)

As derived above,

$$E_1/N_1=E_2/N_2$$

Where, K = constant

This constant K is known as **voltage transformation ratio.**

- If $N_2 > N_1$, i.e. $K > 1$, then the transformer is called step-uptransformer.
- If $N_2 < N_1$, i.e. $K < 1$, then the transformer is called step-uptransformer.

1.3 Auto transformer

An **auto transformer** is an electrical transformer having only one winding.The part of the winding both primary andsecondary

The winding has at least three terminals which is explained in the construction details

Some of the **advantages of auto-transformer**are that,

- They are smaller insize,
- Cheap incost,
- Low leakagereactance,
- Increased kVArating,
- Low exciting currentetc.

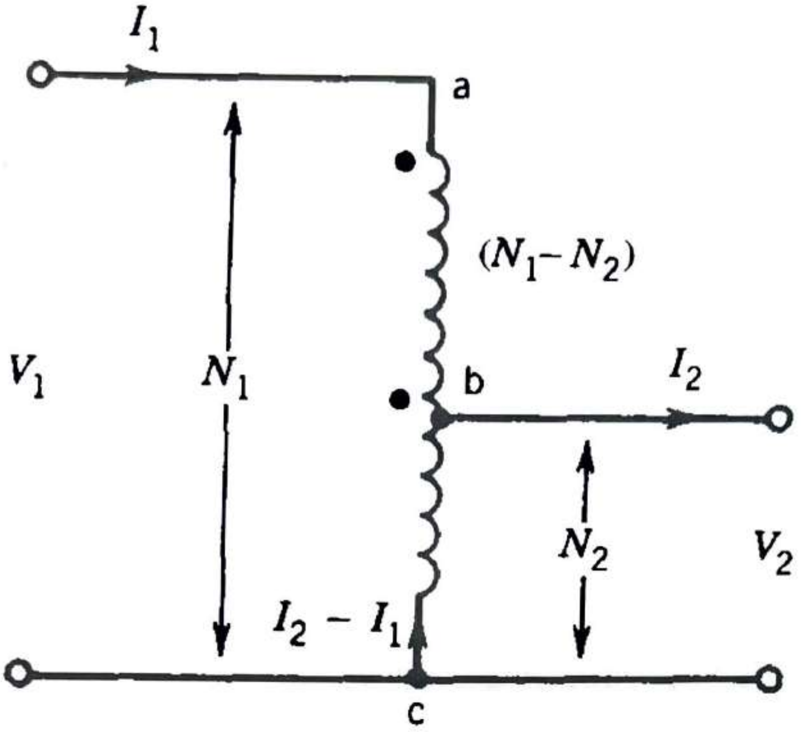
An example of **application of auto transformer** is, using an US electrical equipment rated for 115 V supply (they use 115 V as standard) with higher Indian voltages. Another example could be in starting method of three phase induction motors.

CONSTRUCTION OF AUTO TRANSFORMER

An auto transformer consists of a single copper wire, which is common in both primary as well as secondary circuit. The copper wire is wound a laminated silicon steel core, with at least three tappings taken out. Secondary and primary circuit share the same neutral point of the winding The construction is well explained in the diagram. Variable turns ratio at secondary can be obtained by the tappings of the winding (as shown in the figure), or by providing a smooth sliding brush over the winding. Primary terminals are fixed. Thus, in an auto transformer, you may say, primary and secondary windings are connected magnetically as well as electrically.

Working of auto transformer

As I have described just above, an auto transformer has only one winding which is shared by both primary and secondary circuit, where number of turns shared by



secondary are variable. EMF induced in the winding is proportional to the number of turns. Therefore, the secondary voltage can be varied by just varying secondary number of turns.

As winding is common in both circuits, most of the energy is transferred by means of electrical conduction and a small part is transferred through induction.

$$\frac{\text{Copper inauto transformer}}{\text{Copper in twowindingtransformer}} = \frac{(N_1-N_2)I_1+N_2(I_2-I_1)}{N_1I_1+N_2I_2}$$

$$=1-(2N_2I_1/N_1I_1+N_2I_2)$$

But $N_1I_1=N_2I_2$

The Ratio$=1-(2N_2I_1/2N_1I_1)=1-(N_2/N_1)=1-K$

This means that an auto transformer requires the use of lesser quantity of copper given by the ratio of turns. This ratio therefore denotes the savings in copper. As the space for the second winding need not be there, the window space can be less for an auto transformer, giving some saving in the lamination weight also. The larger the ratio of the voltages, smaller is the savings. As T2 approaches T1 the savings become significant. Thus auto transformers become ideal choice for close ratio transformations. The savings in material is obtained, however, at a price. The electrical isolation between primary and secondary

The considerable disadvantages of an auto transformer are,

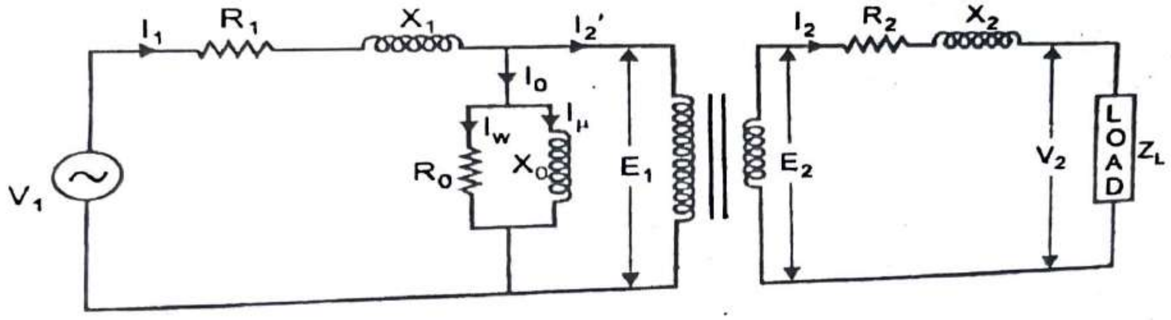
- Any undesirable condition at primary will affect the equipment at secondary (as windings are not electricallyisolated),
- due to low impedance of auto transformer, secondary short circuit currents are veryhigh,
- harmonics generated in the connected equipment will be passed to thesupply.

Advantages of Autotransformers:

- Its efficiency is more when compared with the conventionalone.
- Its size is relatively verysmaller.
- Voltage regulation of autotransformer is muchbetter.
- Lowercost
- Low requirements of excitationcurrent.
- Less copper is used in its design andconstruction
- In conventional transformer the voltage step up or step down value is fixed while in autotransformer, we can vary the output voltage as per out requirements and can smoothly increase or decrease its value as per ourrequirement.

1.4 Equivalent circuit of transformer

Resistances and reactance's of transformer, which are described above, can be imagined separately from the windings (as shown in the figure below). Hence, the function of windings, thereafter, will only be the transforming the voltage.



The no load current I_0 is divided into, pure inductance X_0 (taking magnetizing components I_μ) and non induction resistance R_0 (taking working component I_w) which are connected into parallel across the primary. The value of E_1 can be obtained by subtracting I_1Z_1 from V_1. The value of R_0 and X_0 can be calculated as,

$R_0 = E_1 / I_w$ and $X_0 = E_1 / I_\mu$.

But, using this equivalent circuit does not simplify the calculations. To make calculations simpler, it is preferable to transfer current, voltage and impedance either to primary side or to the secondary side. In that case, we would have to work with only one winding which is moreconvenient.

From the voltage transformation ratio, it is clear that, $E_1 / E_2 = N_1 / N_2 = K$

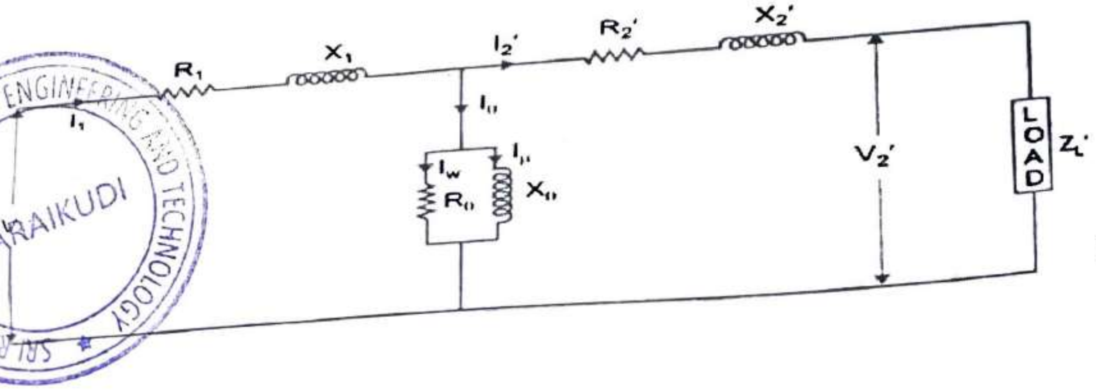
Now, lets refer the parameters of secondary side to primary. Z_2 can be referred to primary as Z_2'

where, $Z_2' = (N_1/N_2)^2Z_2=K^2Z_2$................................where $K=N_1/N_2$.

that is, $R_2'+jX_2' = K^2(R_2+jX_2)$equating real and imaginary parts, $R_2' = K^2R_2$ and $X_2' = K^2X_2$.

And $V_2' = KV_2$

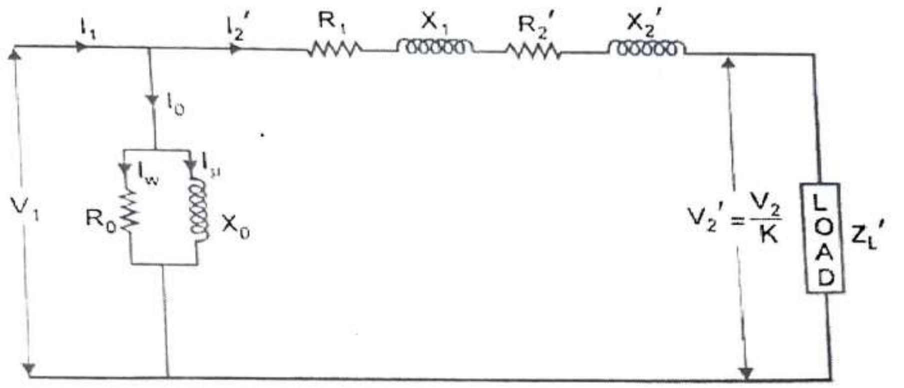
The following figure shows the **equivalent circuit of transformer with**



secondary parameters referred to the primary.

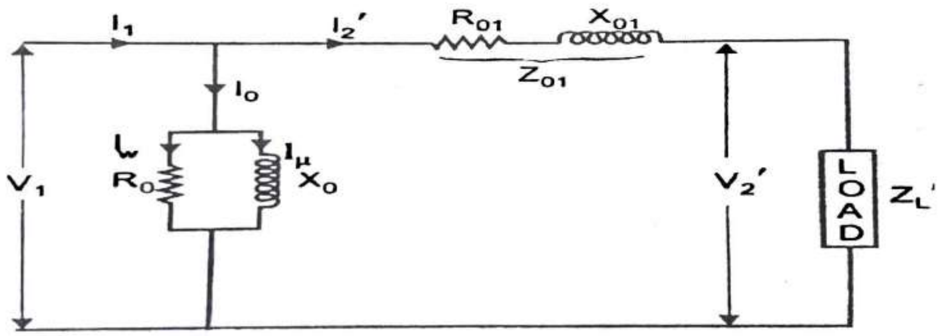
Now, as the values of winding resistance and leakage reactance are so small that, V_1 and E_1 can be assumed to be equal. Therefore, the exciting current drawn bythe

parallel combination of R_0 and X_0 would not affect significantly, if we move it to the input terminals as shown in the figure below.



Now, let $R_1 + R_2' = R'eq$ and $X_1 + X_2' = X'eq$

Then the **equivalent circuit of transformer** becomes as shown in the figure below



1.5 Tap Changing of transformer

Regulating the voltage of a transformer is a requirement that often arises in a power application or power system. In an application it may be needed

1. To supply a desired voltage to theload.
2. To counter the voltage drops due toloads.
3. To counter the input supply voltage changes onload.

On a power system the transformers are additionally required to perform the task of regulation of active and reactive power flows.

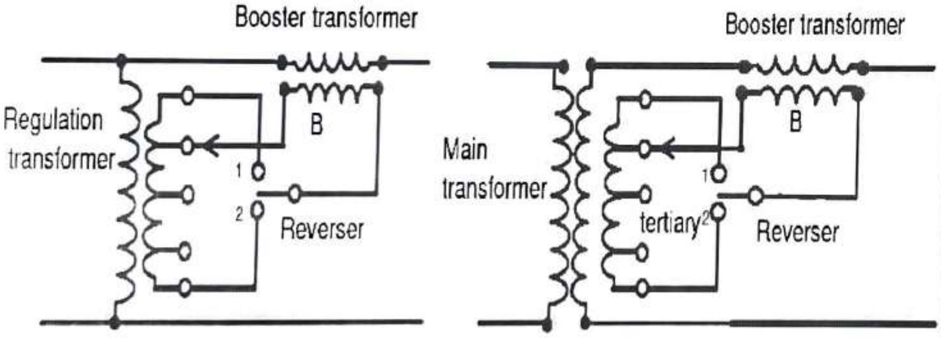
The voltage control is performed by changing the turns ratio. This is done by provision of taps in the winding. The volts per turn available in large transformers is quite high and hence a change of even one turn on the LV side represents a large percentage change in the voltage.

Also the LV currents are normally too large to take out the tapping from the windings. LV winding being the inner winding in a core type transformer adds to the difficulty of taking out of the taps.

Hence irrespective of the end use for which tapping is put to, taps are provided on the HV winding.

This may be called buck-boost arrangement. In addition to the magnitude, phase of the injected voltage may be varied in power systems. The tap changing arrangement and buck boost arrangement with phase shift are shown in Fig.

Tap changing can be effected when a) the transformers is on no- load and b) the load is still remains connected to the transformer



Taps	Switches closed
1	1,S
2	1,2
3	2,S
4	2,3
5	3,S
6	3,4
7	4,S
8	4,5

Provision of taps to control voltage is called tap changing. In the case of power systems, voltage levels are sometimes changed by injecting a suitable voltage in series with the line.

. These are called off load tap changing and on load tap changing. The Off load taps changing relatively costs less. The tap positions are changed when the transformer is taken out of the circuit and reconnected. The on-load tap changer on the other hand tries to change the taps without the interruption of the load current.

In view of this requirement it normally costs more. A few schemes of on-load tap changing are now discussed. Reactor method The diagram of connections is shown in Fig. 43. This method employs an auxiliary reactor to assist tap changing. The switches for the taps and that across the reactor(S) are connected as shown. The reactor has a center tapped winding on a magnetic core. The two ends of the reactor are connected to the two bus bars to which tapping switches of odd/even numbered taps are connected. When only one tap is connected to the reactor the shorting switch S is closed minimizing the drop in the reactor. The reactor can also be worked with both ends connected to two successive taps. In that case the switch 'S' must be kept open. The reactor limits the circulating current between the taps in such a situation.

Thus a four step tapped winding can be used for getting seven step voltage on thesecondary.Reactor method the diagram of connections is shown in Fig. 43. This method

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1. Load need not beswitched.
2. More steps than taps areobtained.
3. Switches need not interrupt load current as a alternate path is alwaysprovided.

The major objection to this scheme seems to be that the reactor is in the circuit always generating extra loss. Parallel winding, transformer method In order to maintain the continuity of supply the primary winding is split into two parallel circuits each circuit having the taps. as

Two circuit breakers A and B are used in the two circuits. Initially tap 1a and 1b are closed and the transformer is energized with full primary voltage. To change the tap the circuit breaker A is opened momentarily and tap is moved from 1a to 2a. Then circuit breaker A is closed. When the circuit A is opened whole of the primary current of the transformer flows through the circuit B. A small difference in the number of turns between the two circuit exists. This produces a circulating current between them. Next, circuit breaker B is opened momentarily, the tap is changed from 1b to 2b and the breaker is closed. In this position the two circuits are similar and there is no circulating current. The circulating current is controlled by careful selection of the leakage reactance.

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1.6 Problem:

1.A 100 KVA, 3300/240 V, 50 Hz single phase transformer has 990 turns on primary. Calculate the number of turns on secondary and the approximate value of primary and secondary full load currents.

Solution:

$V_1 = 3300\ V$

$V_2 = 240\ V$

$N_1 = 990\ V$

$N_2 = ?$

$\frac{N_2}{N_1}$

$$N_2 = \frac{V_2}{V_1} * N_1$$

$$N_2 = \frac{240}{3300} * 990 = 72\ turns$$

$$I_1 = \frac{KVA}{V_1} = \frac{100 * 10^3}{3300} = 30.30\ A$$

$$I_2 = \frac{KVA}{V_2} = \frac{100 * 10^3}{240} = 416.6\ A$$

$$\boldsymbol{I_1 = 30.30\ A}$$

$$\boldsymbol{I_2 = 416.6\ A}$$

2 A 500 KVA transformer has a core loss of 2200 W and a full load copper loss of 7500 w. If the power factor of load is 0.9 lagging. Calculate the full load efficiency and KVA at maximum efficiency.

Solution:

$$P_i = 2200\ W$$

$$P_{cu} = 7500\ W$$

$$p.f = 0.9$$

Efficiency at full load at 0.9 power factor

$$\eta = \frac{n\ KVA \cos\varphi}{n\ KVA \cos\varphi * P_i * n^2 P_{cu}} * 100$$

$$\eta = \frac{1 * 500 * 0.9}{(1 * 500 * 0.9) * 2.200 * 1^2 * 7.500} * 100$$

$$\eta = 97.88\%$$

KVA for maximum efficiency:

$$\text{KVA} = Full\ load\ KVA * \sqrt{\frac{P_i}{P_{cu}}}$$

$$\text{KVA} = 500 * \sqrt{\frac{2.2}{7.5}} = 270.8$$

KVA for maximum efficiency $= 270.8\ KVA$

3 Calculate the efficiency for half and full load of 100 KVA for the power factor of unity and 0.8, the copper loss at full load is 1000 W and iron loss is 1000W.

Solution:

$$P_i = 1000\ W$$

$$P_{cu} = 1000\ W$$

$$KVA = 100$$

At half load and unity power factor.

$$n = 0.5, cos\varphi = \mathbf{1}$$

$$\eta = \frac{n\,KVA\cos\varphi}{n\,KVA\cos\varphi * P_i * n^2 P_{cu}} * 100$$

$$\eta = \frac{0.5 * 100 * 1}{(0.5 * 100 * 1) * 1 * 0.5^{2*}1} * 100$$

$$\eta = 97.56\%$$

At full load and 0.8 power factor

$$n = 1, cos\varphi = \mathbf{0}.8$$

$$\eta = \frac{n\,KVA\cos\varphi}{n\,KVA\cos\varphi * P_i * n^2 P_{cu}} * 100$$

$$\eta = \frac{1 * 100 * 0.8}{(1 * 100 * 0.8) * 1 * 1^{2*}1} * 100$$

$$\eta = 97.56\%$$

4 The primary of the transformer is rated at 10A and 1000V. The open circuit readings are V_1=1000 V, V_2=500 V, I=0.42, P_{ac}=100W. The short circuit readings are I_1=10 A, V_1=125V and P_{ac}=400V. Find the equivalent circuit parameters for the output voltage of Z_L=19+12j ohms.

Solution:

$$P_o = 100\ W$$

$$V_0 = 500\ v$$

$$I_0 = 0.42\ A$$

$$P_o = V_0 I_0 cos\varphi_0$$

open circuit test

$$cos\varphi_0 = \frac{P_o}{V_0 I_0} = \frac{100}{500 * 0.42} = 0.47$$

$$I_0 sin\varphi_0 = 0.369\ A$$

$$I_c = I_0 cos\varphi_0 = 0.1992\ A$$

$$R_o = \frac{V_0}{I_c} = 2532.9\ ohms$$

$$X_o = \frac{V_0}{I_m} = 1355.01\ ohms$$

Short circuit test:

$$k = \frac{V_2}{V_1} = 0.5$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{125}{10} = 12.5\ ohms$$

$$R_{sc} = \frac{W_{sc}}{I_{sc}^2} = \frac{400}{100} = 4\ ohms$$

$$Z_{1e} = \frac{Z_{sc}}{K} = \frac{12.5}{0.5^2} = 50\ ohms$$

$$R_{1e} = \frac{R_{sc}}{K} = \frac{4}{0.5^2} = 16\ ohms$$

$$X_{1e} = \sqrt{\left({Z_{1e}}^2 - R_{1e}^2\right)}$$

$$X_{1e} = \sqrt{(50^2 - 16^2)} \quad = 47.37\ \text{Ohms}$$

DEPARTMENT OF EEE

EE8301 - ELECTRICAL MACHINES – I

IIYEAR – III SEMESTER

UNIT 3

PRINCIPAL
Sri Raaja Raajan College of Engg. & Tech.,
Amaravathipudur, Karaikudi - 630 301
Sivagangai Dist. Tamil Nadu

UNIT III ELECTRO ELECHANICAL ENERGY CONVERSION

Energy in magnetic system – Field energy and co energy-force and torque equations – singly and multiply excited magnetic field systems- mmf of distributed windings – Winding Inductances-, magnetic fields in rotating machines – rotatingmmfwaves – magnetic saturation and leakage fluxes.

1.1 Doubly excited magnetic system

For certain applications like that of electromechanical transducers required specially two excitations

where one is used for establishing the required magnetic field and other for producing an electrical signal proportional to the force or velocity that is to be measured.

An alternator ay even requires multiple excitations such as one concerned with stator and other dealt with rotor. So it becomes essential to analysis a multiple excited system.

$$T_f=-\partial W_f(\lambda 1, \lambda 2,\theta)/\partial\theta$$

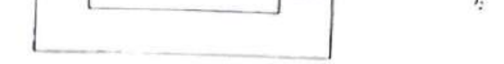
Where, the field energy is given by

$W_f(\lambda_1, \lambda_2,\theta)=+$ ---------------- $1\int_0^{\lambda 1} i1\ d\lambda 1\int_0^{\lambda 2} i2\ d\lambda 2$

Analogous to Equation

$i1=\partial W_f(\lambda 1, \lambda 2,\theta)/\partial \lambda 1$

$i2=\partial W_f(\lambda 1, \lambda 2,\theta)/\partial \lambda 2$



$\lambda_1=L_{11}i_1+L_{12}i_2$ -- 2

$\lambda_2=L_{21}i_1+L_{22}i_2\ (L_{21}=L_{12})$ -- 3

Solving for i1 and i2 in terms of λ_1, λ_2 and substituting in equation 1

Where the inductances are the functions of angle θ

$i_1=\beta_{11}\ \lambda_1+\beta_{12}\ \lambda_2$

$i_2 = \beta_{21} \lambda_1 + \beta_{22} \lambda_2 (\beta_{21} = \beta_{12})$

$Wf(\lambda_1, \lambda_2, \theta) = \int_0^{\lambda 1} (\beta 11 \lambda 1 + \beta 12 \lambda 2)\, d\lambda 1 + \int_0^{\lambda 2} (\beta 21 \lambda 1 + \beta 22 \lambda 2)\, d\lambda 2$

$Wf(\lambda_1, \lambda_2, \theta) = \int_0^{\lambda 1} \beta 11 \lambda 1\, d\lambda 1 + \int_0^{\lambda 1} \beta 12 \lambda 2\, d\lambda 1 + \int_0^{\lambda 2} \beta 21 \lambda 1\, d\lambda 2 + \int_0^{\lambda 2} \beta 22 \lambda 2\, d\lambda 2$

$Wf(\lambda_1, \lambda_2, \theta) = \beta 11 \int_0^{\lambda 1} \lambda 1\, d\lambda 1 + \beta 12 \int_0^{\lambda 1 \lambda 2} d(\lambda 1 \lambda 2) + \beta 22 \int_0^{\lambda 2} \lambda 2\, d\lambda 2$

$Wf(\lambda 1, \lambda 2, \theta) = 1/2\, \beta_{11} \lambda 1^2 + \beta_{12} \lambda 1\, \lambda 2 + 1/2 \beta_{22} \lambda 2^2 \beta_{11} =$

$L_{22} / (L_{11} L_{22} - L_{12}^2)$

$\beta_{22} = L_{11} / (L_{11} L_{22} - L_{12}^2)$

$\beta_{12} = \beta_{21} = -L_{12} / (L_{11} L_{22} - L_{12}^2)$

The self and mutual inductance of the two exciting coils are functions of angle θ If currents are used to describe the system state

$T_f = \partial Wf'(\lambda 1, \lambda 2, \theta) / \partial \theta$

Where the co-energy is given by

$Wf'(i_1, i_2, \theta) = \int_0^{i1} \lambda 1\, di1 + \int_0^{i2} \lambda 2\, di2$

$Wf'(i_1, i_2, \theta) = \int_0^{i1} (L11 i1 + L12 i2)\, di1 + \int_0^{i2} \lambda 2 = (L21 i1 + L22 i2)\, di2$

$Wf'(i1, i2, \theta) = 1/2\, _{11} i_1^2 + _{12} i_1 i_2 + 1/2\, _{22} i_2^2 L\ LL$

1.2singly excited magnetic system

Consider the attracted armature relay excited by an electric source. The field produces a mechanical force $F_f$in the direction indicated which drives the mechanical system.

The mechanical workdone by the field when the armature moves a distance dx in positive directionis

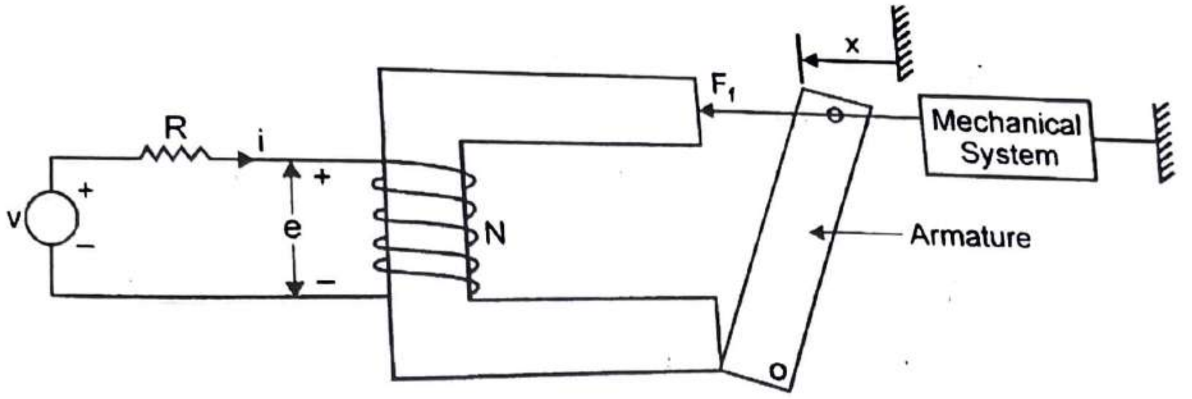
$$dW_m = F_f dx$$

This energy is drawn from the field by virtue of change dx in field configuration. As per the principle of energy conservation

Mechanical energy output=electrical energy input – increase in field energy

$$F_f dx = i d \lambda - dW_f$$

$F_f dx$ is the gross mechanical output, a part of which will be lost in mechanical friction.



$W_{f}= i\lambda - W_{f'}(i,x)$

Then $dW_{f}=d(i\lambda)-dW_{f'}(i,x)$

$dW_{f}=i\,d\lambda+\lambda di-[(\partial W_{f'}/\partial i)\,di+(\partial W_{f'}/\partial x)dx]$

$dW_{f}=i d\lambda - [i d\lambda + \lambda di -((\partial W_{f'}/\partial i)di+(\partial W_{f'}/\partial x)dx)]$

$F_{f}dx=(\partial W_{f'}/\partial i)\,di+(\partial W_{f'}/\partial x)\,dx)$

Because the incremental changes di and dx are independent and di is not present in the left hand side of equation, its coefficient on the ight-hand side must be zero.

$\partial W_{f'}/\partial i-\lambda=0\lambda$

$= \partial W_{f'}/\partial i$

$F_{f}= W_{f'}(i,x)/\partial x$

This expression for mechanical force developed applies when I is an independent variable. It is current excited system.

If(λ, x) are taken as an independent variables,

$W_{f}= W_{f}(\lambda, x)$

$dW_{f}=(\partial W_{f}/\partial \lambda).d\lambda+(\partial W_{f}/\partial x).dx$

Substituting theequation

$F_{f}dx=id\lambda-(\partial W_{f}/\partial \lambda).d\lambda+(\partial W_{f}/\partial x).dx$

$F_{f}dx=-(\partial W_{f}/\partial x).dx+(i-\partial W_{f}/\partial \lambda)d\lambda$

Since d , the independent differential, is not present on the left hand side of this equation

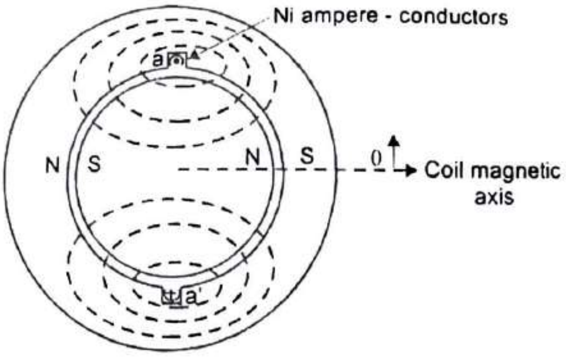
$i-\partial W_{f}/\partial =0$

$i=\partial W_{f}(\lambda, x)/\partial \lambda$

$F_{f}=-\partial W_{f}(\lambda, x)/\partial x$

1.3 MMF in a single coil winding

- A three phase ac machine is considered to possess a cylindrical rotor with a small uniform air gap between the stator androtor.
- Let the coils be full-pitched coils with each coil having n number of turns. It considers the stator to be wound for two poles and to carry single turn full pitchedcoil.

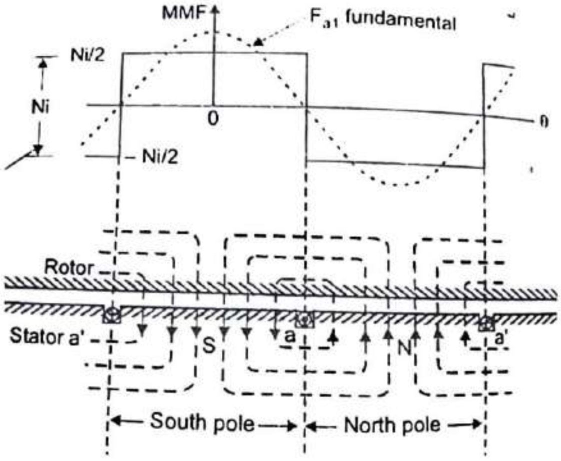


- As the current as an alternating quantity, it sets up a magnetic field with lines of fluxin the direction. These lines found to flow from one end toanother.
- It is conventional that always magnetic lines of flux flow from north pole to south pole. Hence the part of the stator from which the flux lines proceed is assume that to be north and the other end towards which the lux lines flow is assumed to besouth.
- For the machine maintained at synchronous speed, the rotor iron surfaces should have opposite poles induced so as to get attracted and rotatesynchronism.
- So south pole is induced in rotor close to the north pole of stator and a north pole is induced close to the south pole. The reluctance of the air gap is negligible then no mmf is lost Imagnetization.
- Hence one half of this mmf (Ni/2) is used to set up flux linkages from stator (N pole) to rotor (S pole) through air gap and other halfmmf

- (Ni/2) is to established flux linkages from rotor (N pole) to stator(Spole).
- Total change in mmf for the flux to link stator end to end in any slot is givenby,

$$MMF = Ni/2 - (-Ni/2)$$

$$MMF = Ni$$



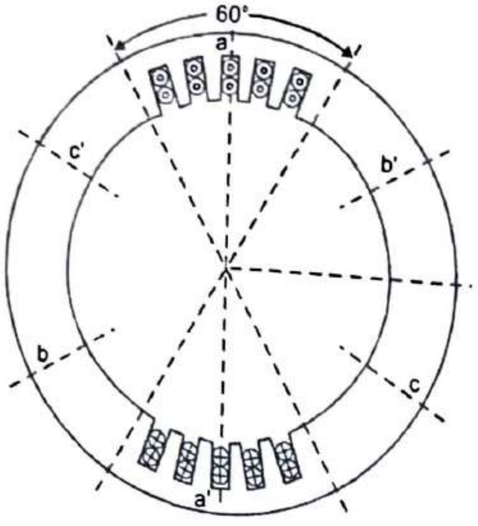
- The fundamental becomes, mmf $f_a = 4/\pi * Ni/2 \cos\theta$

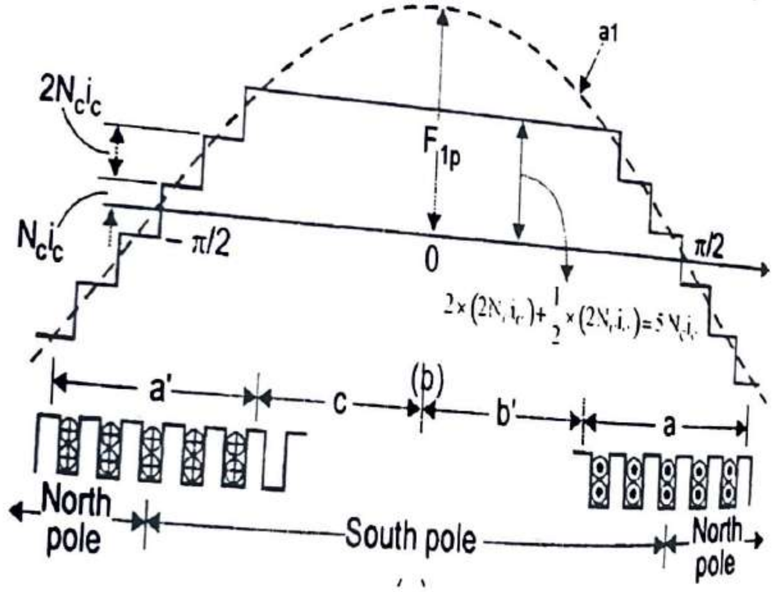
$$AT = F_p \cos\theta F_p$$

$$= 4/\pi * (Ni/2)$$

MMF in a multiple coil distributed winding

- It considers a wound rotor and a two layer winding in the stator with q slots/pole/phase. The mf developed in a single coil in each slot is super imposed to get the resultant mmfdistribution.
- The mf wave becomes a stepped wave that can be approximated to a sinewave.
- The machine is designed for two pole arrangement, then half the ampere conductors of the middle slot of a phase group contributes to establish northpole.
- As a result, the net mmf is calculated as the vector sum of mmf at individual slot pairs separated by a polepitch.
- The fundamental mmf wave are out of phase by $\gamma = \pi P/S$ rads





N_{ph}=Number of turns per phase

I_c=current in a coil

A=Number of parallel paths

At/parallel path=Nph*ic

AT/phase=Nph.ic.A

AT/ph=Nph.ia

I_a=ic*A

AT/phase/pole=Nph*ia/P

For distributed winding

AT/Ph/Pole=Nph*ia*Kb/P

Peak value of fundamental $F_p=4/\pi *(N_i/P)*i_a*K_b$

MMF wave instantaneous value $F_a=F_p\cos\theta$

$F_a=4/\pi *(N_i/P)*i_a*K_b* \cos\theta$

This equation is satisfactory if the coils are full-pitched.

$F_p=4/\pi *(N_{ph}/P)*i_a*K_b*K_p$

$F_a= F_p\cos\theta$

$F_a=4/\pi *(N_{ph}/P)*i_a*K_b*K_p* \cos\theta$

$F_a=4/\pi *(N_{ph}/P)*i_a*K_b* \cos\theta/2* \cos\theta$

$K_w=K_p*K_b$

$F_a=4/\pi *(N_{ph}/P)*i_a*K_w* \cos\theta$

- From the basic properties chorded distributed windings help a lot I minimizing the effect ofharmonics.

Hence the current can be approximated as pure sin wave.

$I_a=I_m\cos\omega t$

$F_a=4/\pi *(N_{ph}/P)*I_m*K_w* \cos\omega t\cos\theta$

$F_a=4/\pi*(N_{ph}/P)*\sqrt{2}*I_{rms}*K_w*\cos\omega t\cos\theta$

$=4\sqrt{2}/\pi*(N_{ph}/P)**I_{rms}*K_w*\cos\omega t\cos\theta$

$F_a=F_m$

$\cos\omega t\cos\theta F_m=4/\pi*(N_{ph}/P)*I_{rms}$

$*K_w\sqrt{2}*$

1.4 Expression of energy through in magnetic field

- When a balanced three phase supply with 120 degree electrical phase angle separation is given to a balanced three phase winding with phases distributed in space so that relative space difference is $2\pi/3$, causes a resultant mmf to rotate in the airgap between stator and rotor at a synchronous speed$N_s=120f/p$(rpm)
- But to justify this concept analytically, it is very important from both design and analysis.

- It considers that the three phase balanced supply allows the following balanced currents to flow through the windingsas

  $I_a=I_m\cos\omega t$

  $I_b=I_m\cos(\omega t-120)$

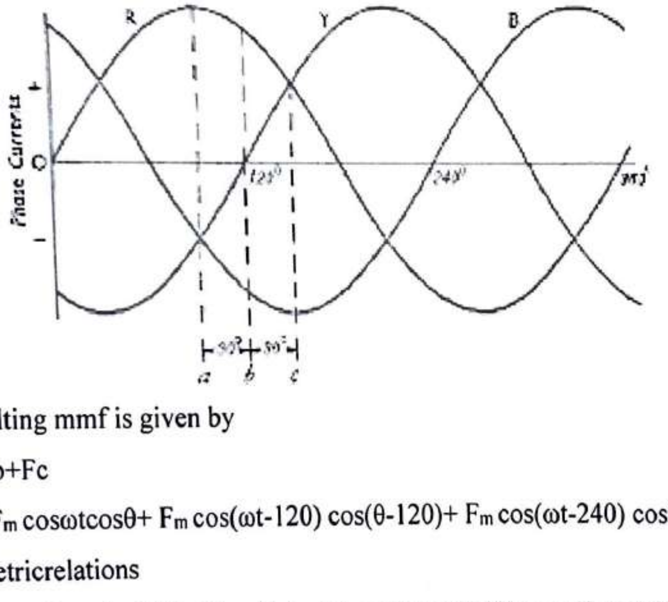
  $I_c=I_m\cos(\omega t-240)$

- The principle of mutual inductance, these currents develop a magnetic field which is also separated by 120 degree with respect to the magneticaxes.

  $F_a= F_m \cos\omega t\cos\theta$

  $F_b= F_m \cos(\omega t-120) \cos(\theta-120)$

  $F_c=F_m \cos(\omega t-240) \cos(\theta-240)$



The resulting mmf is given by

$F=Fa+Fb+Fc$

$F(\theta,t)= F_m \cos\omega t\cos\theta+ F_m \cos(\omega t-120) \cos(\theta-120)+ F_m \cos(\omega t-240) \cos(\theta-240)$

- By trigonometricrelations

  $F(\theta,t)=3/2F_m \cos(\theta -\omega t)+1/2F_m\{(\cos(\theta +\omega t)+ \cos(\theta +\omega t-240)+ \cos(\theta +\omega t-480) \cos(\theta +\omega t-480)+ \cos(\theta +\omega t-480+360)+\cos(\theta +\omega t-120)$

  $F_m=3/2F_m \cos(\theta -\omega t)+1/2F_m\{(\cos(\theta +\omega t)+ \cos(\theta +\omega t-240)+ \cos(\theta +\omega t-120)$

- Algebraic sum of three vectors with a progressive phase difference of 120 degree equals to zero.

  $F(\theta,t)=3/2Fm \cos(\theta -\omega t)$

  Here the peak value of the mmf developed

$F_p=3/2F_m$

Sustituting the expression of Fm from equation

$F_p=3/2\{4\sqrt{2}/\pi*(Nph/P)**Irms\}$

$F_p=3*2\sqrt{2}/\pi*(Nph/P)**Irms$

$F(\theta,t)=3*2\sqrt{2}/\pi*(Nph/P)**Irms*\cos(\theta-\omega t)$ At

$\omega t=0$, theequation

$F(\theta,0)=3*2\sqrt{2}/\pi*(Nph/P)*Irms*\cos\theta$

- The net three phase mmf wave positive developed,attains a maximum current along the axis of phase 'a' when$\theta=0$.
- When the three phase balanced winding is given a three phase balanced supply and also proves that this mmf rotates in the airgap at the synchronousspeed.

$$N_s=120f/P$$

Torque equation of round rotor machine or ACMachines.

Consider a two pole machine i.e stator and rotor has two poles

F_1=MMF produced by stator

F_2=MMF produced by rotor.

F_R=Resultant MMF

By cosine Rule,

$$F_R^2=F_{12}=F_{22}+2F_1F_2\cos\alpha \text{--------------}(1)$$

Assumptions:

The rotor is assumed to be smooth cylindrical, so that the air gap is unifom. The MMF produced by stator and rotor is assumed to be sinusoidal.

The radial length of airgap(g)is very small when compare to the radius of stator.

MMF in air gap, $F_r=H_r*g$

$$H_r=F_r/g.$$

The reluctance of air gap is negligible.

The sinusoidal MMF space wave produces sinusoidal flux density wave is in phase with it.

Let,

α-Angle between F_1 and F_2

D-Diameter of the air gap.

l- Axial length of air gap.

g-Radial length of air gap.

$$Torque = \frac{\partial W_f'}{\partial \alpha} - - - - (2)$$

Average Co-energy produced= $\frac{1}{2}\mu_0[Average\ value\ of\ H^2]$

$$\frac{1}{2}\mu_0\left[\frac{1}{2}H^2{}_r\right]$$

$$= \frac{1}{4}\mu_0 H_r^2$$

Total Co-energy produced= Average Co-energy produced * Volume

$$W_f' = \frac{1}{4}\mu_0 H_r^2 * \pi D l g$$

$$W_f' = \frac{1}{4}\mu_0\left(\frac{F_r}{g}\right)^2 * \pi D l g$$

$$W_f' = \frac{1}{4}\frac{\mu_0}{g}.\pi D l[F_1^2 + F_2^2 + 2F_1F_2\cos\alpha]$$

$$Torque = \frac{\partial w_f'}{\partial \alpha}$$

$$\frac{\partial}{\partial \alpha}\left(\frac{1}{4}\frac{\mu_0}{g}.\pi D l[F_1^2 + F_2^2 + 2F_1F_2\cos\alpha]\right)$$

$$Torque = -\frac{1}{2}\frac{\mu_0.\pi D l}{g}F_1F_2\sin\alpha$$

For 'P' Pole machine,

$$Torque = \frac{P}{2}\left[-\frac{1}{2}\frac{\mu_0.\pi D l}{g}F_1F_2\sin\alpha\right]$$

Part C

1. **Two coupled coils have self and mutual inductances $L_{11} = 3 + \frac{1}{3x}$; $L_{22} = 1 + \frac{1}{3x}$; $L_{21} = L_{12} = \frac{1}{3x}$. Over a certain range of displacement x. The first coil is excited by a constant current of 10A and second coil by a constant current of -5A. Find the mechanical work done if the x changes from 0.5 to 1 and the energy supplied by each electricalsources.**

Solution:

$$W_f^1 = \frac{1}{2}L_{11}i_1^2 + L_{12}i_1i_2 + \frac{1}{2}L_{22}i_2^2$$

$$W_f^1 = \frac{1}{2}\left[3 + \frac{1}{3X}\right](10)^2 + \left[\frac{1}{3X}\right]10.5 + \frac{1}{2}\left[1 + \frac{1}{3X}\right](-5)^2$$

$$= 162.5 + \frac{4.166}{X}$$

(i) $F_f = -\frac{4.166}{X}$

$$\Delta W_m = \int_{0.5}^{1} F_f . dx$$

$$\Delta W_m = \int_{0.5}^{1} -\frac{4.166}{X} . dx = -4.166\ J$$

(ii) $\Delta W_{e1} = \int_{0.5}^{1} i_1 . d\lambda$

$$\lambda_1 = L_{11}i_1 + L_{12}i_2$$

$$=\left[3 + \frac{1}{3X}\right](10) + \left[\frac{1}{3X}\right](-5) = 30 + \frac{1.66}{X}$$

$$\lambda_1\ at\ x_1 = 30 + \frac{1.66}{0.5} = 33.33$$

$$\lambda_1\ at\ x_2 = 30 + \frac{1.66}{1} = 31.66$$

$$\Delta W_{e1} = i_1 . \int_{\lambda_1\ at\ x_2}^{\lambda_1\ at\ x_1} d\lambda_1$$

$$\Delta W_{e1} = 10[31.66 - 33.33] = -16.66\ J$$

(iii) $\Delta W_{e2} = \int_{0.5}^{1} i_2 . d\lambda$

$$\lambda_2 = L_{21}i_1 + L_{22}i_2$$

$$\left[\frac{1}{3X}\right](10) + \left[1 + \frac{1}{3X}\right](-5) = -5 + \frac{1.66}{X}$$

$$\lambda_2\ at\ x_1 = -5 + \frac{1.66}{0.5} = -1.667$$

$$\lambda_2\ at\ x_2 = -5 + \frac{1.66}{1} = -3.333$$

$$\Delta W_{e2} = i_2 . \int_{\lambda_2\ at\ x_2}^{\lambda_2\ at\ x_1} d\lambda_2$$

$$\Delta W_{e2} = -5[3.333 + 1.667] = 8.333J$$

(iv) Net electricalinput

$$= = -16.667+8.333 = -8.333 J \Delta W_{e1} + \Delta W_{e2}$$

2. Two windings one mounted on the stator and the other mounted on a rotor have self-inductance of L_{11}=4.5 H, L_{22}=2.5 H, and L_{12}=2.8 cos θ H, Where θ is the angle between the axis of winding. The resistances of the winding may be neglected. Winding 2 is short circuited and the current in winding as a function of time i_1= 10 sin ωtA. Derive an expression for the numerical value of the instantaneous torque on the rotor in N-m in terms of angleθ

Solution:

L_{11}=4.5

H,

L_{22}=2.5

H

L_{12}=2.8 cos θ H

i_1= 10 sin ωt A

$$T_f = \frac{\partial W_f'(i_1, i_2, \theta)}{\partial \theta}$$

$$T_f = \frac{\partial}{\partial \theta}\left[\frac{L_{11} \cdot {i_1}^2}{2} + \frac{L_{22} \cdot {i_2}^2}{2} + L_{12} \cdot i_1 \cdot i_2\right]$$

$$T_f = 0 - 2.8 sin\theta \; i_1 i_2 + 0$$

$$T_f = 2.8 sin\theta \; i_1 i_2 - - - - - (1)$$

$$V_m \cos \omega t = 4.5 \frac{di_1}{dt} + [2.8 \cos \theta] \frac{di_2}{dt}$$

$$\frac{di_2}{dt} = -\frac{2.8}{2.5} \cos \theta \frac{di_1}{dt}$$

$$i_2 = -1.12 \cos \theta i_1$$

Given $i_1 = 10 \sin \omega t$and $i_2 = -1.12 \cos \theta * 10 \sin \omega t$

Using Equation 1,

$$T_f = 0 - 2.8 sin\theta \; i_1 i_2$$

$$T_f = 2.8 sin\theta \; [10 \sin \omega t][-1.12 \cos \theta * 10 \sin \omega t]$$

$$T_f = 313.6 sin\theta . \cos\theta . sin^2 \omega t$$

This is the instantaneous torque on rotor in Nm in terms of angle θ.

3. Derive the torque developed in doubly excited magneticsystem.

Let

$i_1 - Current\ due\ to\ source\ 1$

$i_2 - Current\ due\ to\ source\ 2$

$\lambda_1 - Flux\ linlage\ due\ to\ i_1$

$\lambda_2 - Flux\ linlage\ due\ to\ i_2$

$$W_f = \int_0^{\lambda_2} i_1 . d\lambda_1 + \int_0^{\lambda_2} i_2 . d\lambda_2 - - - - - - - - - - (1)$$

From circuit,

$$\lambda_1 = L_{11}.i_1 + L_{12}.i_2 - - - - - - - - (2)$$

$$\lambda_2 = L_{22}.i_2 + L_{21}.i_1 - - - - - - - - (3)$$

From Equation (2),

$$L_{11}.i_1 = \lambda_1 - L_{12}.i_2$$

$$i_1 = \frac{\lambda_1 - L_{12}.i_2}{L_{11}} \quad - - - - - - - - (4)$$

Subs (4) in (3),We get

$$\lambda_2 = L_{22}.i_2 + L_{21}.\left[\frac{\lambda_1 - L_{12}.i_2}{L_{11}}\right]$$

$$\lambda_2 = L_{22}.i_2 + \left[\frac{L_{21}\lambda_1 - L_{12}{}^2.i_2}{L_{11}}\right]$$

$$\lambda_2 = L_{22}.i_2 + \left[\frac{L_{21}\lambda_1 - L_{12}{}^2.i_2}{L_{11}}\right]$$

$$\lambda_2 = \frac{L_{11}.L_{22}.i_2 + L_{21}.\lambda_1 - L_{12}{}^2.i_2}{L_{11}}$$

$$\lambda_2 L_{11} = L_{11} L_{22} . i_2 + L_{21} \lambda_1 - L_{12}{}^2 . i_2$$

$$L_{12}{}^2 . i_2 - L_{11} L_{22} . i_2 = L_{21} . \lambda_1 - \lambda_2 . L_{11}$$

$$i_2 \left[L_{12}{}^2 - L_{11} L_{22} \right] = L_{21} . \lambda_1 - \lambda_2 . L_{11}$$

$$i_2 = \frac{L_{21} . \lambda_1 - \lambda_2 . L_{11}}{L_{12}{}^2 - L_{11} L_{22}}$$

$$i_2 = \frac{L_{21}}{L_{12}{}^2 - L_{11} L_{22}} . \lambda_1 + \frac{L_{11}}{L_{12}{}^2 - L_{11} L_{22}} . \lambda_2$$

$$i_2 = \beta_{12} . \lambda_1 + \beta_{22} . \lambda_2 \text{ -------- } (5)$$

$$i_1 = \beta_{11} . \lambda_1 + \beta_{12} . \lambda_2 \text{ -------- } (6)$$

Similarly,

$$W_f = \int_0^{\lambda_1} (\beta_{11} . \lambda_1 + \beta_{12} . \lambda_2) . d\lambda_1 + \int_0^{\lambda_2} (\beta_{12} . \lambda_1 + \beta_{22} . \lambda_2) . d\lambda_2$$

$$W_f = \frac{\beta_{11} . \lambda_1{}^2}{2} + \frac{\beta_{22} . \lambda_2{}^2}{2} + \beta_{12} . \lambda_1 . \lambda_2$$

$$\dot{W}_f = \int_0^{i_1} \lambda_1 . di_1 + \int_0^{i_2} \lambda_2 . di_2 \text{ -------- } (7)$$

Subs (2) & (3) in (7),

$$\dot{W}_f = \int_0^{i_1} (L_{11} . i_1 + L_{12} . i_2) . di_1 + \int_0^{i_2} (L_{22} . i_2 + L_{21} . i_1) . di_2$$

$$\dot{W}_f = \frac{L_{11} . i_1{}^2}{2} + \frac{L_{22} . i_2{}^2}{2} + L_{12} . i_1 . i_2$$

Therefore torque is given by,

$$T_f = \frac{\partial}{\partial\theta} \left[\frac{L_{11} . i_1{}^2}{2} + \frac{L_{22} . i_2{}^2}{2} + L_{12} . i_1 . i_2 \right]$$

DEPARTMENT OF EEE

EE8301 - ELECTRICAL MACHINES – I

IIYEAR – III SEMESTER

UNIT 4

PRINCIPAL
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UNIT IVDC GENERATORS

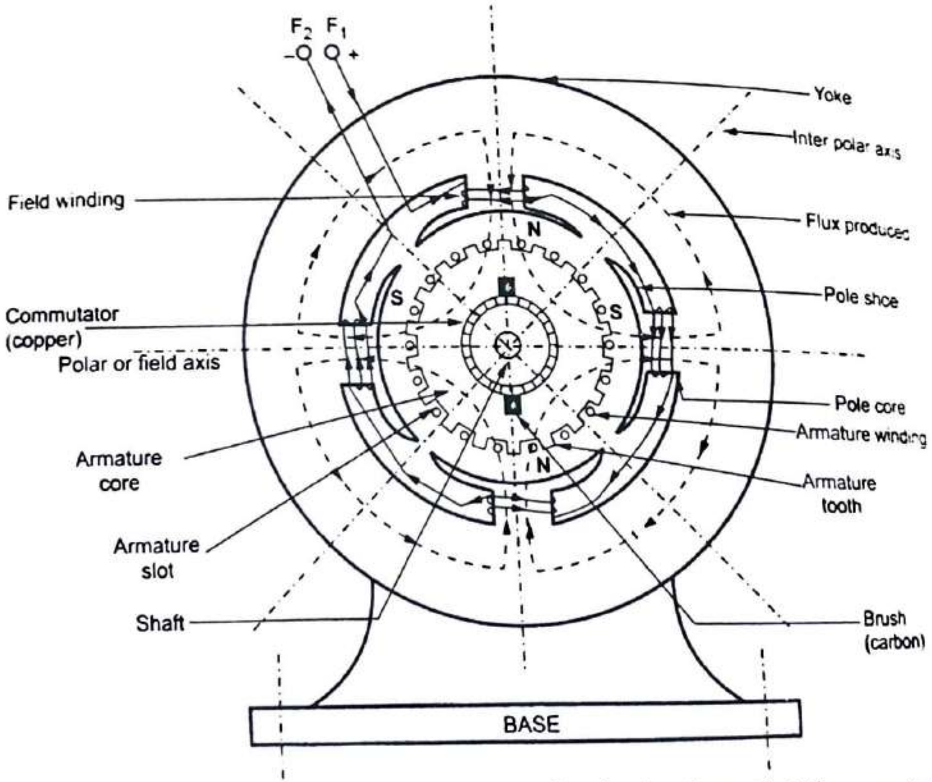
Construction and components of DC Machine – Principle of operation - Lap and wave windings-EMF equations– circuit model – armature reaction –methods of excitation-commutation and interpoles -compensating winding –characteristics of DC generators.

1.1 construction and principle of operation of DC generator

Construction:

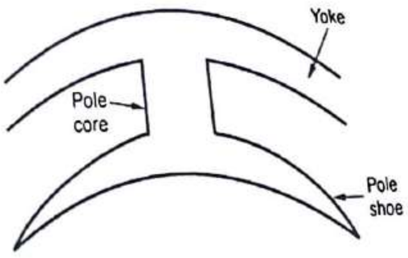
DC Generators or Dynamos are still in general use for many industrial applications, and small ones for speed measurement - tachogenerators - in some domestic gear as well as industrial. There are many types, with slightly different variations in operation depending on their usage.The basics are a Field, Armature, Commutator and Brushgear (plus casing &bearings).

The combination of field system and casing could be called a stator.



The field system provides a magnetic field to fixed pole pieces that the armature rotates within. with some units, the field uses permanent magnets. With others, the field is wound and powered, as an electromagnet. This allows the output voltage or power to be varied while the machine is run at fixedRPM.

The armature has a number of magnetic pole pieces made of a magnetically soft iron (that does not retain any magnetic field) arranged around a shaft that supports it and fits through the bearings in the casing. The pole piece area is often made from a stack of thin iron laminations with insulated surfaces, to avoid the circulating currents that could occur in a single large piece of metal. The poles are fitted with coils in a symmetrical pattern, and as the armature turns through the magnetic field from the field windings, voltage is induced in to the armature coils. The coils are connected to the commutator, which has a set of 'finger' contacts embedded in insulation & is attached to the armature shaft at on end of the windings.



The brushes are fitted in holders attached to (but insulated from) the casing, These are pressed against the commutator spring pressure, and pick up power from the armature windings at the optimum position in their rotation. (If an armature coil was directly connected to a load, the output would be AC - it would be working as an alternator. The commutator constantly connects the output, via the brushes, to the correct points in the armature windings to give a DCoutput.)

Above figure shows the constructional details of a simple 4-pole DC generator. A DC generator consists two basic parts, stator and rotor. Basic constructional parts of a DC generator are described below.

1. Yoke: The outer frame of a generator or motor is called as yoke. Yoke is made up of cast iron or steel. Yoke provides mechanical strength for whole assembly of the generator (or motor). It also carries the magnetic flux produced by thepoles.
2. Poles: Poles are joined to the yoke with the help of screws or welding. Poles are to support field windings. Field winding is wound on poles and connected in series or parallel with armature winding or sometimesseparately.

Pole shoe: Pole shoe is an extended part of the pole which serves two purposes, (i)to prevent field coils from slipping and (ii)to spread out the flux in air gap uniformly

1. Armature core: Armature core is the rotor of a generator. Armature core is cylindrical in shape on which slots are provided to carry armaturewindings.
2. Commutator and brushes: As emf is generated in the armature conductor's terminals must be taken out to make use of generated emf. But if we can't directly solder wires to commutator conductors as they rotate. Thus commutator is connected to the armature conductors and mounted on the same shaft as that of armature core. Conducting brushes rest on commutator and they slide over when rotor (hence commutator) rotates. Thus brushes are physically in contact with armature conductors hence wires can be connected tobrushes.

The rotor in a dc machine is called an armature. The armature has cylindrical steel core that is composed of a stack of slotted laminations. Slots in laminations are aligned axially along rotor or shaft. Armature windings are placed inslots.

The stator in a dc machine is the field part of the machine. Field poles are located on stator and project inward. Each pole has a narrow iron core around which the exciting winding or field coil is placed. Field coil may consist of two or more separate windings.

A pole shoe distributes pole flux over rotor surface across a narrow air gap. Leads from the armature coils are connected to the commutator. Commutator consists of radial copper segments separated by an insulating material, usually mica. Current is conducted to the armature by carbon brushes that are held against the surface of the commutator by springs. Brushes wear with time, must be inspected regularly, and occasionally replaced.

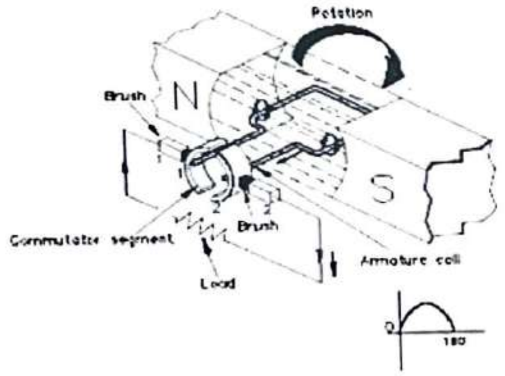
Copper commutator segments wear also and sometimes have to be resurfaced, or "turned down." If not, the harder mica protrudes above the copper, and the brushes bounce, resulting in arcs that damage the commutatorsurface.

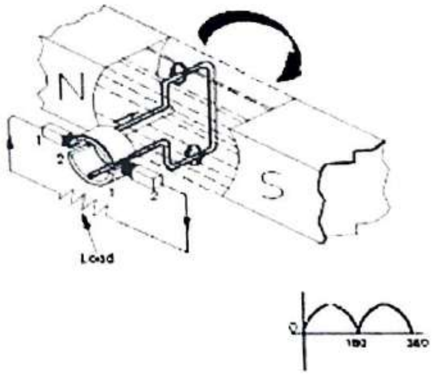
Recall from Module 3, DC Circuits, that there are three conditions necessary to induce a voltage into a conductor.

1. A magneticfield
2. Aconductor
3. Relative motion between the two A DC generator provides these three conditions to produce a DC voltageoutput.

Theory of Operation

A basic DC generator has four basic parts: (1) a magnetic field; (2) a single conductor, or loop; (3) a commutator; and (4) brushes (Figure 3). The magnetic field may be supplied by either a permanent magnet or an electromagnet. For now, we will use a permanent magnet to describe a basic DC generator.





A single conductor, shaped in the form of a loop, is positioned between the magnetic poles.As long as the loop is stationary, the magnetic field has no effect (no relative motion). If we rotate the loop, the loop cuts through the magnetic field, and an EMF (voltage) is induced into the loop. When we have relative motion between a magnetic field and a conductor in that magnetic field, and the direction of rotation is such that the conductor cuts the lines of flux, an EMF is induced into the conductor. The magnitude of the induced EMF depends on the field strength and the rate at which the flux lines are cut, as given in equation (5-1). The stronger the field or the more flux lines cut for a given period of time, the larger the induced EMF.

$E_g = K\Phi N$

where

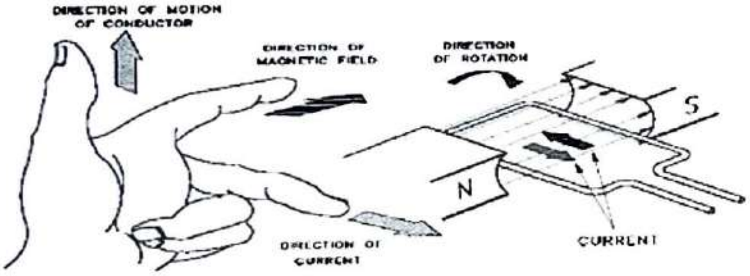
E_g = generated voltage K

= fixed constant

Φ = magnetic flux strength N

= speed in RPM

The direction of the induced current flow can be determined using the "left-hand rule" for generators. This rule states that if you point the index finger of your left hand in the direction of the magnetic field (from North to South) and point the thumb in the direction of motion of the conductor, the middle finger will point in the direction of current flow (Figure 4). In the generator shown in Figure 4, for example, the conductor closest to the N pole is traveling upward across the field; therefore, the current flow is to the right, lower corner. Applying the left-hand rule to both sides of the loop will show that current flows in a counter-clockwise direction in theloop.



The commutator converts the AC voltage generated in the rotating loop into a DC voltage. It also serves as a means of connecting the brushes to the rotating loop. The purpose of the brushes is to connect the generated voltage to an external circuit. In order to do this, each brush must make contact with one of the ends of the loop. Since the loop or armature rotates, a direct connection is impractical. Instead, the brushes are connected to the ends of the loop through the commutator.

In a simple one-loop generator, the commutator is made up of two semi cylindrical pieces of a smooth conducting material, usually copper, separated by an insulating material. Each half of the commutator segments is permanently attached to one end of the rotating loop, and the commutator rotates with the loop.

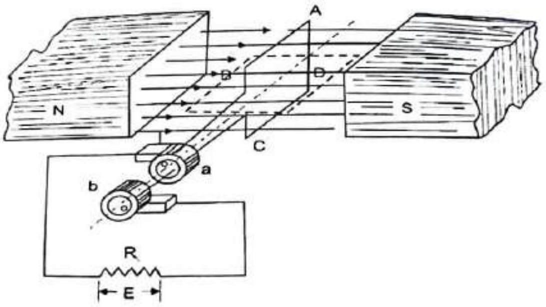
The brushes, usually made of carbon, rest against the commutator and slide along the commutator as it rotates. This is the means by which the brushes make contact with each end of the loop.

Each brush slides along one half of the commutator and then along the other half. The brushes are positioned on opposite sides of the commutator; they will pass from one commutator half to the other at the instant the loop reaches the point of rotation, at which point the voltage that was induced reverses the polarity.

Every time the ends of the loop reverse polarity, the brushes switch from one commutator segment to the next. This means that one brush is always positive with respect to another.

The voltage between the brushes fluctuates in amplitude (size or magnitude) between zero and some maximum value, but is always of the same polarity in this manner, commutation is accomplished in a DC generator.

A dc generator is an electrical machine which converts mechanical energy into direct current electricity. This energy conversion is based on the principle of production of dynamically induced emf.



According to Faraday's law of electromagnetic induction, when a conductor moves in a magnetic field (thereby cutting the magnetic flux lines), a dynamically induced emf is produced in the conductor. The magnitude of generated emf can be given by emfequation of DC generator. If a closed path is provided to the moving conductor, then generated emf causes a current to flow in the circuit.

Thus in DC generators, as we have studied earlier, when armature is rotated with the help of a prime mover and field windings are excited (there may be permanent field magnets also), emf is induced in armature conductors. This induced emf is taken out via commutator-brush arrangement.

1.2 EMF equation of a DC generator

Let

Ø = flux/pole in Wb (weber)

Z = total no. of armature conductors P

= No. of generator poles

A = No. of parallel paths in armature

N = rotational speed of armature in revolutions per min. (rpm) E =

emf induced in any parallel path in armature

By Faradays law,

$$e = \frac{d\Phi}{dt}$$

$$d\Phi = P\Phi, dt = \frac{60}{N}$$

$$e = \frac{P\Phi}{\frac{60}{N}} = \frac{PN\Phi}{60}$$

Consider that there is Z conductors placed in A parallel path, So the induced emf is given by

$$e = \frac{PN\Phi}{60} * \frac{Z}{A}$$

$$e = \frac{\mathbf{PN\Phi Z}}{\mathbf{60A}}$$

This is the induced emf in generator.

For lap winding,A=P

$$e = \frac{N\Phi Z}{60}$$

For lap winding,A=2

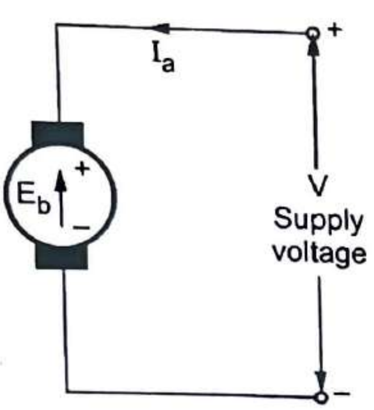
$$e = \frac{PN\Phi Z}{120}$$

Significance of back emf

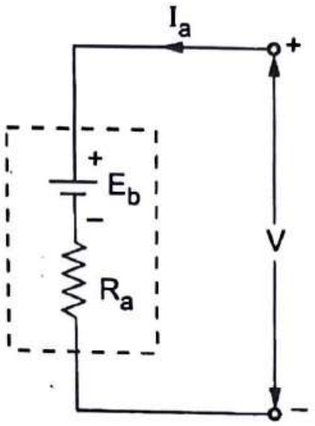
A DC motor is also a generator at the same time and the voltage it would produce under rotation when it's disconnected from the supply is the back emf, also called counter emf because it's in opposite polarity to the supply voltage and tends to cause outward current flow from machine tosupply

A DC machine working as a motor will have its counter emf always less than the supply voltage. The difference would depend on amount of mechanical load tied to the motor. As a result, current would flow into the machine. When it's working as a generator

the counter emf is more than supply voltage (0) and as a result current flows out of the machine. Similarly, during regenerative braking the counter emf is more than supply voltage and as a result current flows out of the machine.



(a) Back e.m.f. in a d.c. motor



(b) Equivalent circuit

It is seen in the generating action, that when a conductor cuts the lines of flux, e.m.f. gets induced in the conductor. In a d.c. motor after a motoring action armature starts rotating and armature conductors cut the main flux. So there is a generating action existing in a motor.

After a motoring action, there exists a generating action. There is an induced emf in the rotating armature conductors according to Faraday's law of electromagnetic induction. This induced emf in the armature always acts in the opposite direction of the supply voltage. This is according to the Lenz's law which states that the direction of the induced emf is always so as to oppose the cause producing it.

In a DC motor, electrical input, i.e. the supply voltage is the cause and hence this induced e.m.f. opposes the supply voltage. This emf tries to set up a current through the armature which is in the opposite direction to that, which supply voltage is forcing through the conductor.

So as this e.m.f. always opposes the supply voltage, it is called back emf and denoted as Eb. Though it is denoted as Eb., basically it gets generated by the generating action which we have seen earlier in case of generators. So its magnitude can be determined by the e.m.f. equation which is derived earlier. So

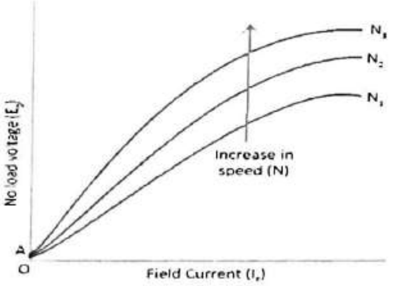
$$e = \frac{\mathbf{P}N\Phi\mathbf{Z}}{60A}$$

1.3 characteristics of DC generator

Three characteristics of DC generators are taken into considerations: (i) Open Circuit Characteristic (O.C.C.), (ii) Internal or Total Characteristic and (iii) External Characteristic. These characteristics of DC generators are explained below.

1. OPEN CIRCUIT CHARACTERISTIC (O.C.C.)(E_0/I_F)

   Open circuit characteristic is also known as **magnetic characteristic** or **no-load saturation characteristic**. This characteristic shows the relation between generated emf at no load (E_0) and the field current (I_f) at the given fixed speed. The O.C.C. curve is just the magnetization curve and it is practically similar for all type of generators. The data for O.C.C. curve is obtained by operating the generator at no load and keeping speed constant. Field current is varied and the corresponding terminal voltage is recorded.



Open Circuit Characteristic (O.C.C.)

   The above figure shows a typical no-load saturation curve or open circuit characteristics for all types of DC generators.

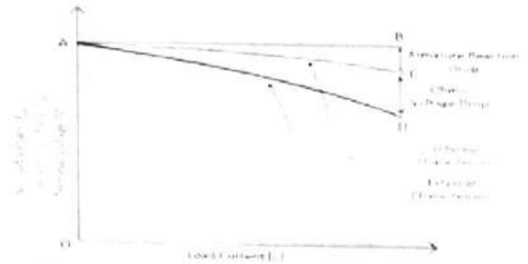
2. Internal or Total Characteristic(E/I_a)

   The internal characteristic curve shows the relation between the on-load generated emf (Eg) and the armature current (I_a). The on-load generated emf Eg is always less than E_0 due to armature reaction. Eg can be determined by subtracting the drop due to demagnetizing effect of armature reaction from no-load voltage E_0. Therefore, internal characteristic curve lies below O.C.C.curve.

3. External Characteristic(V/I_L)

   The external characteristic curve shows the relation between the terminal voltage (V) and load current (I_L). The terminal voltage V is less than generated emf Eg due to voltage drop in the armature circuit.

Therefore, the external characteristic curve lies below the internal characteristic curve. External characteristics are very important to determine the suitability of a generator for a given purpose.



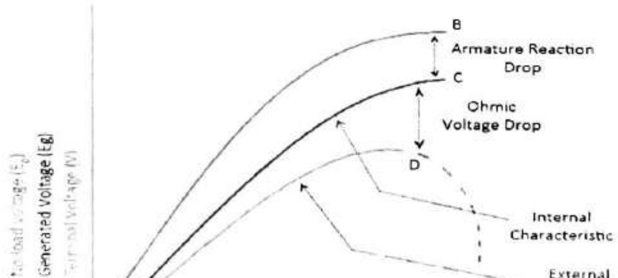
Characteristics of separately excited DC generator

Internal and external characteristic curves are shown below for each type ofgenerator.

If there is no armature reaction and armature voltage drop, voltage will remain constant for any load current.

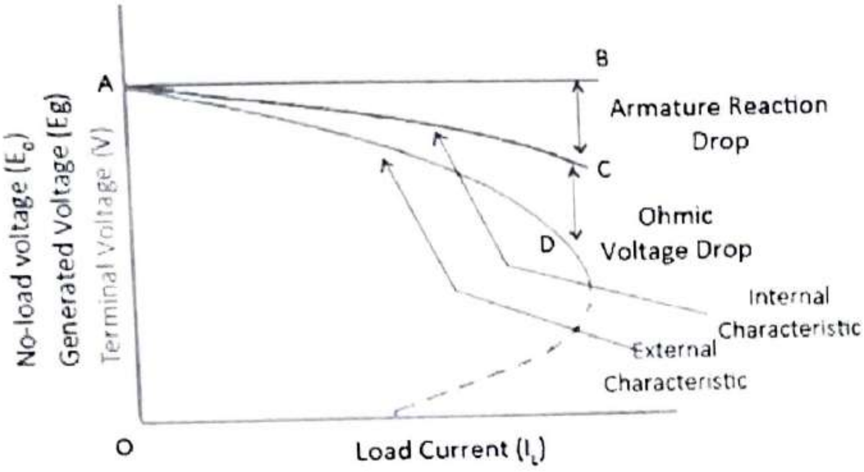
Thus the straight line AB in above figure represents the no-load voltage vs. load current I_L. Due to demagnetizing effect of armature reaction the on-load generated emf is less than the no-load voltage. The curve AC represents the on-load generated emf E_G vs. load current I_L i.e. internal characteristic. The curve AD represents the terminal voltage vs. load current i.e. externalcharacteristic.

Characteristics of DC Series Generator



Characteristics of DC series generator

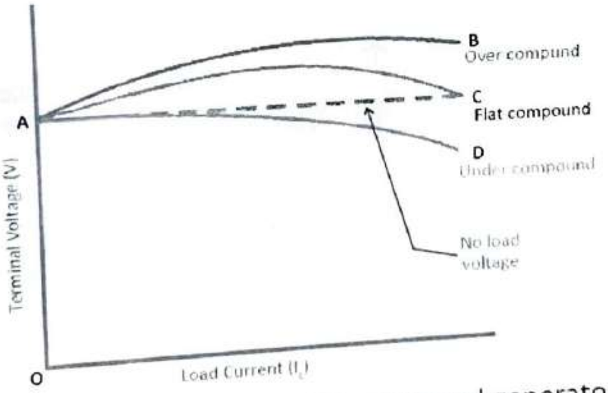
The curve AB in above figure identical to open circuit characteristic (O.C.C.) curve. This is because, in DC series generators field winding is connected in series with armature and load. Hence, here load current is similar to field current. The curve OC and OD represents internal and external characteristicrespectively.



Characteristics of DC shunt generator

When load resistance is decreased in DC shunt generator, the load current increases. But, load resistance can be decreased upto a certain limit, beyond this limit any further decrease in load resistance results in decreasing load current and terminal voltage. Consequently, the external characteristic curve turns back as shown by dotted line in above figure.

Characteristics of DC Compound Generator



External characteristic of DC compound generator

The above figure shows the external characteristic of DC compound generators. If series winding is adjusted so that, increase in load current causes increase in terminal voltage then the generator is called to be over compounded.

The external characteristic for over compounded generator is shown by the curve AB in above figure.

If series winding is adjusted so that, terminal voltage remains constant even the load current is increased, then the generator is called to be flat compounded.

The external characteristic for a flat compounded generator is shown by the curve AC. If the series winding has lesser number of turns than that would be required to be flat compounded, then the generator is called to be under compounded. The external characteristics for an under compounded generator is shown by the curve AD.

1.4 Armature reaction of D.C machines

ARMATURE REACTION

"The effect of armature flux on main flux is called as armature reactio*n*"In a unloaded d.c machine armature current is vanishingly small and the flux per pole is decided by the field current alone.

The uniform distribution of the lines of force gets upset when armature too carries current due to loading. In one half of the pole, flux lines are concentrated and in the other half they are rarefied.

Qualitatively one can argue that during loading condition flux per pole will remain same as in no load operation because the increase of flux in one half will be balanced by the decrease in the flux in the other half.

Since it is the flux per pole which decides the emf generated and the torque produced by the machine, seemingly there will be no effect felt so far as the performance of the machine is concerned due to armature reaction. This in fact is almost true when the machine is lightly or moderatelyloaded.

The effect of magnetic field set up by armature current on the distribution of flux under main poles of a generator. The armature magnetic field has two effects:

(i) It demagnetizes or weakens the main fluxand

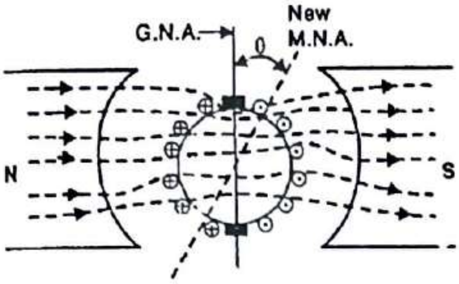
(ii) It cross-magnetizes or distortsit.

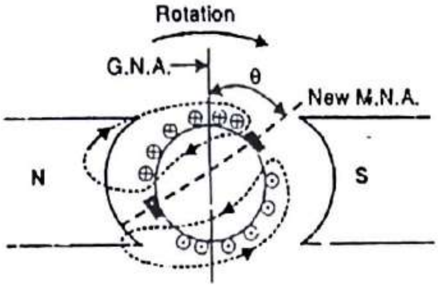
The flux distribution of a bipolar generator when there is no current in the armature conductors. The brushes are touching the armature conductors directly, although in practice, they touch commutatorsegments,

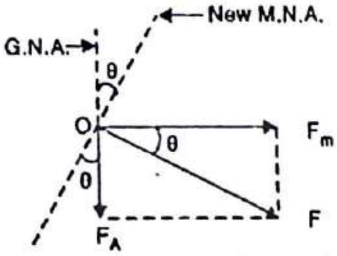
It is seen that:

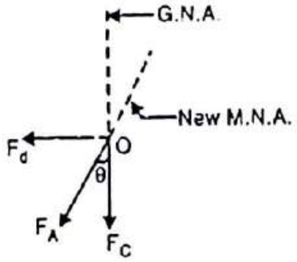
(a) the flux is distributed symmetrically with respect to the polar axis, which is the line joining the centers of NSpoles.

(b) The magnetic neutral axis (M.N.A.) coincides with the geometrical neutral axis (G.N.A.). Magnetic neutral axis may be defined as the axis along which no emfis produced in the armature conductors because they move parallel to the lines of flux. Or M.N.A. is the axis which is perpendicular to the flux passing through the armature.









Brushes are always placed along M.N.A. Hence, M.N.A. is also called 'axis of commutation' because reversal of current in armature conductors takes place across this axis. Vector Of which represents, both magnitude and direction, the mmf of producing the main flux.

The field (or flux) set up by the armature conductors alone when carrying current, the field coils being unexcited. The current direction is downwards in conductors under N-pole and upwards in those under S-pole.

However, at rated armature current the increase of flux in one half of the pole is rather less than the decrease in the other half due to presence of saturation. In other words there will be a net decrease in flux per pole during sufficient loading of the machine.

This will have a direct bearing on the emf as well as torque developed affecting the performance of themachine.

The armature mmf (depending on the strength of the armature current) is shown separately both in magnitude and direction by the vector OFA. Under actual load conditions, the two mmf exist simultaneously in the generator.

It is seen that the flux through the armature is no longer uniform and symmetrical about the pole axis, rather it has been distorted. The flux is seen to be crowded at the trailing pole tips but weakened or thinned out at the leading pole tips (the pole tip which is first met during rotation by armature conductors is known as the leading pole tip and the other as trailing poletip).

The resultant mmf OF (The new position of M.N.A.) which is found by vectorially combining OFm and OFA. And the new position of M.N.A which is always perpendicular to the resultant mmf vector OF, is also shown in the figure. With the shift of M.N.A., say through an angle θ brushes are also shifted so as to lie along the new position of M.N.A. Due to this brush shift, the armature conductors and hence armature current is redistributed.

All conductors to the left of new position of M.N.A.but between the two brushes, carry current downwards and those to the right carry current upwards. The armature mmf is found to lie in the direction of the new position of M.N.A. (or brush axis). The armature mmf is now represented by the vector OFA.

OFA can now be resolved into two rectangular components, OFD parallel to polar axis and OFC perpendicular to this axis. We find that:

(i) Component OFC is at right angles to the vector OFm representing the mainmmf It produces distortion in the main field and is hence called the cross-magnetizing or distorting component of the armaturereaction.

(ii) The component OFd is in direct opposition of OFm which represents the main mmf It exerts a demagnetizing influence on the main pole flux. Hence, it is called the demagnetizing or weakening component of the armaturereaction.

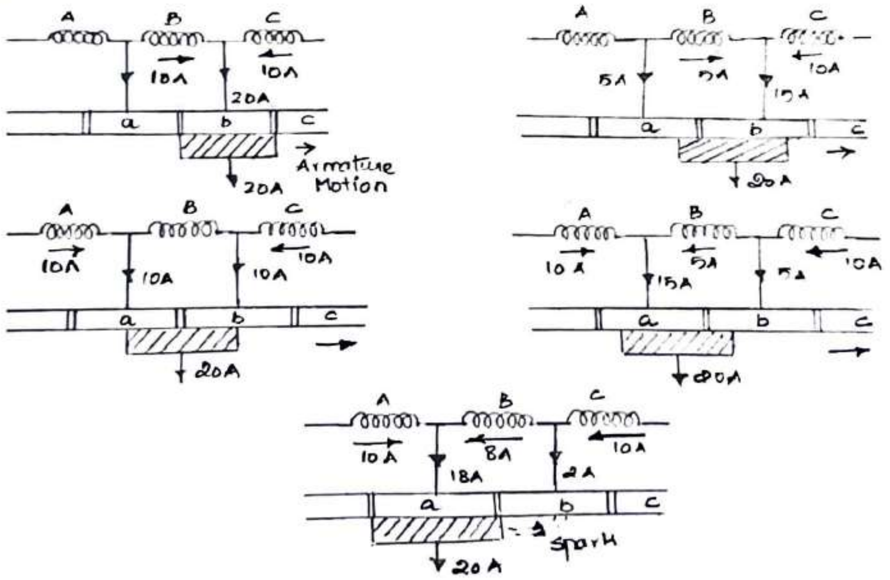
Apart from this, due to distortion in the flux distribution, there will be some amount of flux present along the q-axis (brush axis) of the machine. This causes commutation difficult. In the following sections we try to explain armature reaction in somewhat detail considering motor and generator mode separately.

1.5COMMUTATION

- The emf induced in the conductors are always sinusoidal and commutator converts this sinusoidal emf into Unidirectionalemf.

"The reversal of current is likely to take place in short interval when a coil is short circuited by a brush. So that transfer of current from one diction to other is carried out without any sparking. This process is called commutation"

- Thus a process by which current in the shot circuited coil is reversed while it crosses the MNA. The time during which the coil remains shot circuited is known as commutation period. This period is generally the order of 0.0005 to0.002sec.
- The commutation is said to be ideal when current changes from +I to zero and zeroto –I the commutation period.
- The sparking is produced between the commutation and brush if current is not reversed by that time. This will lead to damage of commutator as well as brush. Hence for satisfactory operation of DC machine proper commutation isrequired.
- Consider coil B is about to be short circuited. The brush is about to come in conduct with commutator segment 'a' suppose that coil is carrying current of 10 A so that total brush current 20A as every coil meeting at the brush supplies half the brush current independent of lap or wave woundarmature.
- The coil B is entering short circuit period. The current in the coil B has reduced from 10A to 5A as the other 5A flows via segment 'a'. The total current remaining same at 20A. But area of contact of the bush is more with segment 'b' than segment'a'.



- The coil b is in the middle of its short circuit period the current I coil B is reduced to zero.
- The current 10A pass to the brush directly from coils A andC.
- The total current again 20A and the contact area of brush with the segments 'a' and 'b' areequal.

- The coil b is now under group of coils to the right ofbrush.
- The contact area of the brush with segment ‘b’ decreasing whereas with segment ‘a’ isincreasing.
- Coil b is now carrying 5A in other direction. Thus current of 15A is passed segment ‘a’ to the brush while the other 5A is supplied by coil C and pass from segment ‘b’ to the brush. Again the total current is20A.
- Ideal commutation is assumed then current through coil B will reverse at the end of commutation.
- The current flowing through coil B is only 8A instead of 10A. So difference I coil current is 2A jumps directly through segment ‘b’ to the brush through air and produce spark.

Under commutation

- The current varies uniformly represented y straight line BC the commutation is said to be linearcommutation.
- But it observes self-induced emf in the coil will try to maintain the current in the same direction. The commutation is said to be undercommutation.

Over commutation

- If reversal of current in the coil is faster than ideal or linear commutation than also sparking may be occurred. This commutation is known as overcommutation

DEPARTMENT OF EEE

EE8301 - ELECTRICAL MACHINES – I

II YEAR – III SEMESTER

UNIT 5

PRINCIPAL
Sri Raaja Raajan College of Engg. & Tech.,
Amaravathipud aikudi - 630 301
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UNIT VDC MOTOR

Principle and operations - types of DC Motors – Speed Torque Characteristics of DC Motors-starting and speed control of DC motors –Plugging, dynamic and regenerative braking-testing and efficiency – Retardation test- Swinburne's test and Hopkinson's test - Permanent magnet dc motors(PMDC)-DC Motorapplications.

1.1 TESTING OF DC MACHINE

Swinburne's Test

For a d.c shunt motor change of speed from no load to full load is quite small.

Therefore, mechanical loss can be assumed to remain same from no load to full load.

Also if field current is held constant during loading, the core loss too can be assumed to remain same.

In this test, the motor is run at rated speed under no load condition at rated voltage. The current drawn from the supply I_{Lo} and the field current I_f are recorded (figure 40.3). Now we note that:

Input power to the Motor, $P_m=VI_{Lo}$

Cu loss in the field circuit $P_{fl}=VI_f$

Power input to the armature $=VI_{Lo}-VI_f$

$=V(I_{Lo}-I_f)$

$=VI_{ao}$

Cu loss in the armature circuit $=I_{ao}^2r_a$

Gross power developed y armature$=VI_{ao}-I_{ao}^2r_{ao}$

$=(V-I_{a0}r_{ao})I_{ao}$

$=E_{bo}I_{ao}$

Net mechanical output power, Pnet,mech $=E_b I_a-P_{rot}$

Efficiecy of theloadedmotor $=(E_bI_a-P_{rot})/VI_L$

Since the motor is operating under no load condition, net mechanical output power is zero. Hence the gross power developed by the armature must supply the core loss and friction & windage losses of the motor.Therefore,

$$P_{core}+P_{friction}=(V-I_{ao}r_a)I_{ao}=E_{bo}I_{ao}$$

Since, both P_{core} and $P_{friction}$ for a shunt motor remains practically constant from no load to full load, the sum of these losses is called constant rotational loss i.e.,

Constant rotational loss, $P_{rot}=P_{core}+P_{friction}$

In the Swinburne's test, the constant rotational loss comprising of core and friction loss is estimated from the above equation.

After knowing the value of P_{rot} from the Swinburne's test, we can fairly estimate the efficiency of the motor at any loading condition. Let the motor be loaded such that new current drawn from the supply is I_L and the new armature current is I_a

Input power to the motor, $P_m=VI_L$

Cu loss in the field circuit $P1=VI_f$

Power input to the armature $=VI_L-VI_f$

$=V(I_L-I_f)$

$=Vi_a$

Cu loss in the armature circuit $=I_{a2}r_a$

Gross power developed y armature$=V_{ia}-I_{a2}r_a$

$=(V-I_Ar_a)I_a$

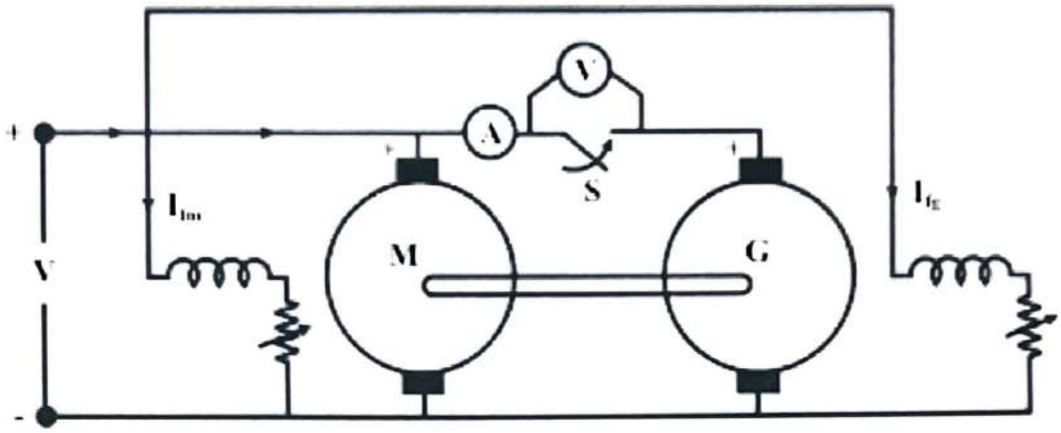
$=E_bI_a$

Net mechanical output power, $P_{net,mech}=E_b\ I_a-P_{rot}$

Efficiecy of the loaded motor $=(E_bI_a-P_{rot})/VI_L$

Hopkinson's test

This as an elegant method of testing d.c machines. Here it will be shown that while power drawn from the supply only corresponds to no load losses of the machines, the armature physically carries any amount of current (which can be controlled with ease).Suchascenariocanbecreatedusingtwosimilarmechanicallycoupledshunt machines. Electrically these two machines are eventually connected in parallel and controlled in such a way that one machine acts as a generator and the other as motor. In other words, two similar machines are required to carry out this testing which is not a bad proposition for manufacturer as large numbers of similar machines are manufactured



Procedure

Connect the two similar (same rating) coupled machines as shown in figure With switch S opened, the first machine is run as a shunt motor at rated speed. It may be noted that the second machine is operating as a separately excited generator because its field winding is excited and it is driven by the first machine. Now the question is what will be the reading of the voltmeter connected across the opened switch S? The reading may be (i) either close to twice supply voltage or (ii) small voltage. In fact the voltmeter practically reads the difference of the induced voltages in the armature of the machines. The upper armature terminal of the generator may have either + ve or negative polarity. If it happens to be +ve, then voltmeter reading will be small otherwise it will be almost double the supplyvoltage

Since the goal is to connect the two machines in parallel, we must first ensure voltmeter reading is small. In case we find voltmeter reading is high, we should switch off the supply, reverse the armature connection of the generator and start afresh. Now voltmeter is found to read small although time is still not ripe enough to close S for paralleling the machines. Any attempt to close the switch may result into large circulating current as the armature resistances are small. Now by adjusting the field current $I_{fg}$of the generator the voltmeter reading may be adjusted to zero ($E_g \approx E_b$) and S is now closed. Both the machines are now connected in parallel

Loading the machines

After the machines are successfully connected in parallel, we go for loading the machines

i.e., increasing the armature currents. Just after paralleling the ammeter reading A will be close to zero as $E_g \approx E_b$. Now if $I_{fg}$is increased (by decreasing R_{fg}), then E_g becomes greater than E_b and both I_{ag} and I_{am} increase, Thus by increasing field current of generator (alternatively decreasing field current of motor) one can make $E_g > E_b$ so as to make the second machine act as generator and first machine as motor. In practice, it is also required to control the field current of the motor $I_{fm}$to maintain speed constant at rated value. The interesting point to be noted here is that I_{ag} and I_{am} do not reflect in the supply side line. Thus current drawn from supply remains small (corresponding to losses of both the machines). The loading is sustained by the output power of the generator running the motor and vice versa. The machines can be loaded to full load current without the need of any loadingarrangement

Calculation of efficiency

Let field currents of the machines be are so adjusted that the second machine is acting as generator with armature current I_{ag} and the first machine is acting as motor with armature current I_{am} as shown in figure 40.7. Also let us assume the current drawn from the supply be I_l. Total power drawn from supply is VI_l which goes to supply all the losses (namely Cu losses in armature & field and rotational losses) of both the machines

Power drawn from supply=VI_l

Field Cu loss for motor=VIf_m Field

Cu loss for generator =VI_{fg}

Armature Cu loss for motor =$I^2_a r_{am}$

Armature Cu loss for generator=$I^2_{ag} r_{ag}$

Rotational losses of both the machines=$VI_l-(VI_{fm}+VI_{fg}+I^2_{am}r_{am}+I^2_{ag}r_{ag})$

Speed of both the machines are same, it is reasonable to assume the rotational losses of both the machines are equal; which is strictly not correct as the field current of the generator will be a bit more than the field current of the motor, Thus, Once P_{rot} is estimated for each machine we can proceed to calculate the efficiency of the machines as follows,

Rotational loss of each machine, $P_{rot}= [VI_l-(VI_{fm}+VI_{fg}+I^2_{am}r_{am}+I^2_{ag}r_{ag})]/2$

Efficiency of the motor

As pointed out earlier, for efficiency calculation of motor, first calculate the input power and then subtract the losses to get the output mechanical power as shown below,

Total power input to the motor=power input to its field+ power input to the armature

$P_{inm}=VI_{fm}+VI_{am}$

Losses of the motor$=VI_{fm}+I^2_{am}r_{am}+P_{rot}$

Net mechanical output power $P_{outm}=P_{ing}-(VI_{fm}+I^2_{am}r_{am}+P_{rot})$

$$\eta m=P_{outm}/P_{inm}$$

EFFICIENCY OF GENERATOR

Losses of the generator$=VI_{fg}+I^2_{ag}r_{ag}+P_{rot}$

Net mechanical input power $P_{ing}=P_{outg}-(VI_{fg}+I^2_{ag}r_{ag}+P_{rot})$

$$\eta g=P_{outm}/P_{inm}$$

Advantages of Hopkinson's Test

1. This test requires very small power compared to full-load power of the motor-generator coupled system. That is why it iseconomical.
2. Temperature rise and commutation can be observed and maintained in the limit because this test is done under full loadcondition.
3. Change in iron loss due to flux distortion can be taken into account due to the advantage of its full loadcondition

Disadvantages of Hopkinson's Test

1. It is difficult to find two identical machines needed for Hopkinson'stest.
2. Both machines cannot be loaded equally all thetime.
3. It is not possible to get separate iron losses for the two machines though they are different because of theirexcitations.

It is difficult to operate the machines at rated speed because field currents vary widely

1.2 STARTER

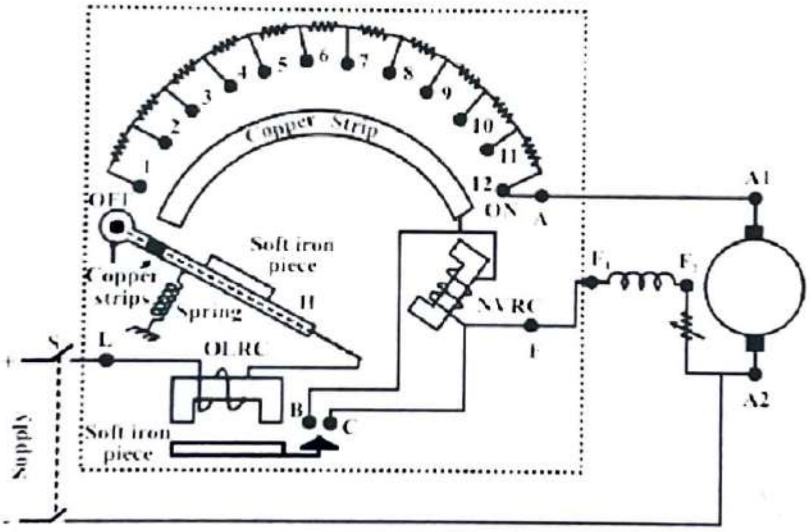
Three Point Starter

A "3-point starter" is extensively used to start a D.C shunt motor. It not only overcomes the difficulty of a plain resistance starter, but also provides additional protective features such as over load protection and no volt protection.

The diagram of a 3-point starter connected to a shunt motor is shown in figure. Although, the circuit looks a bit clumsy at a first glance, the basic working principle is same as that of plain resistance starter. The starter is shown enclosed within the dotted rectangular box having three terminals marked as A, L and F for external connections.

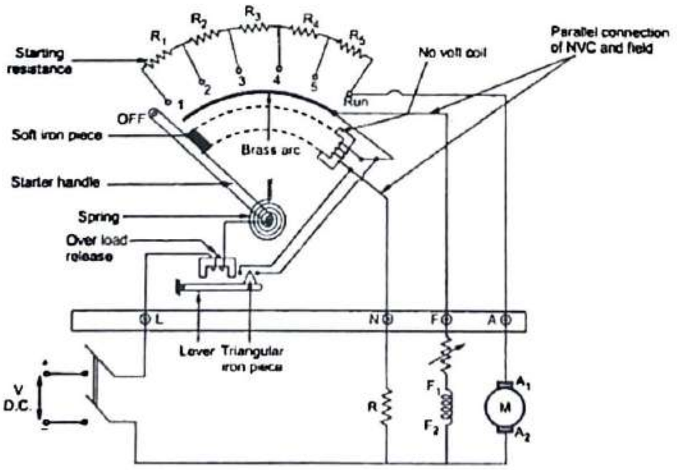
Terminal A is connected to one armature terminal Al of the motor. Terminal F is connected to one field terminal F1 of the motor and terminal L is connected to one supply terminal as shown. F2 terminal of field coil is connected to A2 through an external variable field resistance and the common point connected to supply (-ve).

The external armatures resistances consist of several resistances connectedin



The starter also provides over load protection for the motor. The other electromagnet, OLRC overload release coil along with a soft iron piece kept under it, is used to achieve this. The current flowing through OLRC is the line current IL drawn by the motor. As the motor is loaded, Ia hence IL increases. Therefore, IL is a measure of loading of the motor. Suppose we want that the motor should not be over loaded beyond rated current. Now gap between the electromagnet and the soft iron piece is so adjusted that for $I_L \leq$ Irated the iron piece will not be pulled up. However, if IL≤Irated force of attraction will be sufficient to pull up iron piece. This upward movement of the iron piece of OLRC is utilized to de-energize NVRC. To the iron a copper strip is attached. During over loading condition, this copper strip will also move up and put a short circuit between two terminals B and C. Carefully note that B and C are nothing but the two ends of the NVRC. In other words, when over load occurs a short circuit path is created across the NVRC. Hence NVRC will not carry any current now and gets de-energized. The moment it gets deenergised, spring action will bring the handle in the OFF position thereby disconnecting the motor from the supply. Three-point starter has one disadvantage. If we want to run the machine at higher speed (above rated speed) by field weakening (i.e., by reducing field current), the strength of NVRC magnet may become so weak that it will fail to hold the handle in the ON position and the spring action will bring it back in the OFF position. Thus we find that a false disconnection of the motor takes place even when there is neither over load nor any sudden disruption ofsupply.

Four-Point Starter



The four-point starter eliminates the drawback of the three-point starter. In addition to the same three points that were in use with the three-point starter, the other side of the line, L1, is the fourth point brought to the starter when the arm is moved from the "Off" position. The coil of the holding magnet is connected across the line.

The holding magnet and starting resistors function identical as in the three - point starter.

The possibility of accidentally opening the field circuit is quite remote. The four - point starter provides the no-voltage protection to the motor. If the power fails, the motor is disconnected from the line.

1.3Characteristics of DC motors

Generally, three characteristic curves are considered for DC motors which are, (i) Torque vs. armature current (Ta - Ia), (ii) Speed vs. armature current and (iii) Speed vs. torque. These are explained below for each type of DC motor. These characteristics are determined by keeping following two relations in mind. $Ta\ \alpha \Phi.Ia$and $N\ \alpha\ Eb/\Phi$

Characteristics of DC seriesmotors

Torque vs. armature current (Ta-Ia)

This characteristic is also known as electrical characteristic. We know that torque is directly proportional to armature current and flux, $Ta\ \alpha\ \Phi.Ia$. In DC series motors, field winding is connected in series with armature. Thus, before magnetic saturation of the

field, flux Φ is directly proportional to Ia. Therefore, before magnetic saturation $Ta\ \alpha\ Ia^2$. At light loads, Ia as well as Φ is small and hence the torque increases as the square of the armature current.

Therefore, the Ta-Ia curve is parabola for smaller values of Ia. After magnetic saturation of the field winding, flux Φ is independent of armature current Ia.

Therefore, the torque varies proportional to Ia only, $T\ \alpha\ Ia$. Therefore, after magnetic saturation, Ta-Ia curve becomes straight line.The shaft torque (Tsh) is less than armature torque (Ta) due to straylosses.

In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required

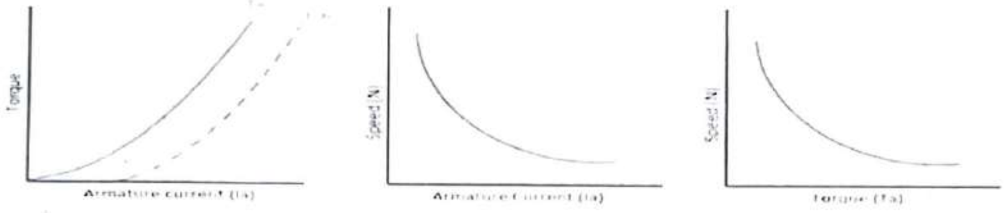
Speed vs. armature current (N-Ia)

We know the relation, $N\ \alpha\ Eb/\Phi$. For small load current (and hence for small armature current) change in back emf Eb is small and it may be neglected. Thus, for small currents speed is inversely proportional to Φ. As we know, flux is directly proportional to Ia, speed is also inversely proportional to Ia.

When armature current is very small the speed becomes dangerously high. That is why a series motor should never be started without some mechanical load.But, at heavy loads, armature current Ia is large. And hence speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current isallowed.

Speed vs. torque (N-Ta)

This characteristic is also called as mechanical characteristic. From the above two characteristics of DC series motor, it can be found that when speed is high, torque islow and vice versa. Characteristics of DC shunt motors



Characteristics of DC series motor

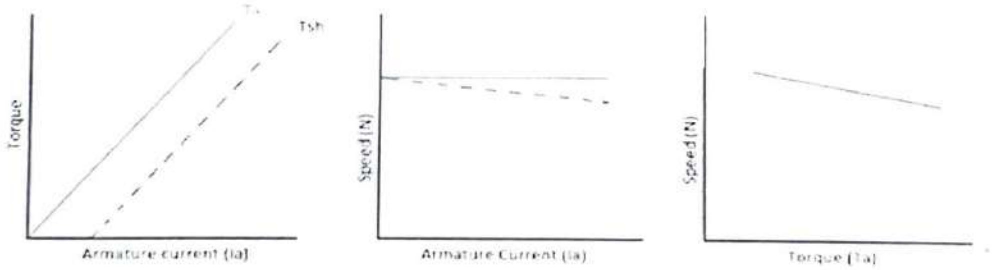
Torque vs. armature current (Ta-Ia)

In case of DC shunt motors we can assume the field flux Φ to be constant. Though at heavy loads, Φ decreases in a small amount due to increased armaturereaction. But as we are neglecting the change in the flux Φ, we can say that torque is proportionaltoarmaturecurrent.HencetheTa-Iacharacteristicforadcshuntmotorwill

be a straight line through origin. Since, heavy starting load needs heavy starting current, shunt motor should never be started on a heavy load.

Speed vs. armature current (N-Ia)

As flux Φ is assumed constant, we can say N α Eb. But, back emf is also almost constant, the speed remains constant. But practically, Φ as well as Eb decreases with increase in load. But, the Eb decreases slightly more than Φ, and hence the speed decreases slightly. Generally, the speed decreases by 5 to 15% of full load speed only. And hence, a shunt motor can be assumed as a constant speed motor.



Characteristics of DC shunt motor

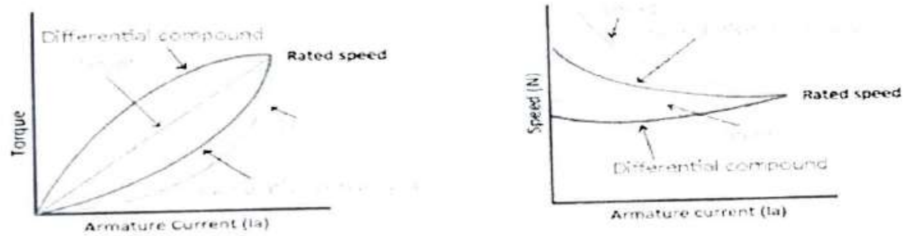
Characteristics of DC compound motor

DC compound motors have both series as well as shunt windings.In a compound motor series and shunt windings are connected such that series flux is in direction with shunt flux then the motor is said to be cumulatively compounded. And if series flux is opposite direction as that of the shunt flux, then the motor is said to be differentially compounded.

Characteristics of both these types are explained below.

(a) Cumulative compoundmotor

Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors are generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.



Characteristics of DC compound motor

(b) Differential compoundmotor:

In differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load. Differential compound motors are not commonly use, but they find limited applications in experimental and research work.

1.4 Speed control

Back emf of a DC motor E_b is the induced emf due to rotation of the armature in magnetic field. Thus value of the E_b can be given by the EMF equation of a DCgenerator.

$$E_b = {}^{P\phi NZ}/_{60A}$$

(where, P= no. of poles, Ø=flux/pole, N=speed in rpm, Z=no. of armature conductors,
A=parallel paths)

E_b can also be given as,

$$E_b = V - I_a R_a$$

thus from above equations

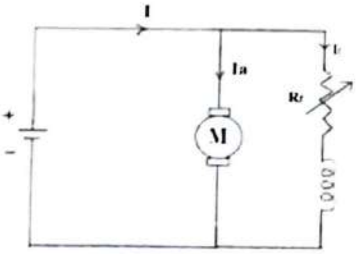
$$N = {}^{E_b \, 60A}/_{P\phi Z}$$

but, for a DC motor A, P and Z are constant N α
K^{E_b}/ϕ (where, K=constant)

thus, it shows speed is directly proportional to back emf and inversely proportional to the flux per pole.

Speed control of Shunt motor

1. Flux controlmethod



It is seen that speed of the motor is inversely proportional to flux. Thus, by decreasing flux speed can be increased and vice versa. To control the flux, a rheostat is added in series with the field winding, as shown in the circuit diagram.

Adding more resistance in series with field winding will increase the speed, as it will decrease the flux. Field current is relatively small and hence I^2R loss is small, hence this method is quite efficient. Though speed can be increased by reducing flux with this method, it puts a limit to maximum speed as weakening of flux beyond the limit will adversely affect the commutation

2. Armature control method

Speed of the motor is directly proportional to the back emf E_b and E_b = V- I_aR_a. That is when supply voltage V and armature resistance R_a are kept constant, speed is directly proportional to armature current I_a. Thus, if we add resistance in series with armature, I_a decreases and hence speed decreases. Greater the resistance in series with armature, greater the decrease in speed.

3. Voltage ControlMethod

A) Multiple voltagecontrol:

In this method the shunt filed is connected to a fixed exciting voltage, and armature is supplied with different voltages. Voltage across armature is changed with the help of a suitable switchgear. The speed is approximately proportional to the voltage across the armature.

B) Ward-LeonardSystem:

This system is used where very sensitive speed control of motor is required (e.g.electric excavators, elevators)M_2 is the motor whose speed control is required$_1$may be any AC motor or DC motor with constant speed. G is the generator directly coupled to M_1. In this method the output from the generator G is fed to the armature of the motor M_2 whose speed is to be controlled. The output voltage of the generator G can be varied from zero to its maximum value, and hence the armature voltage of the motor M_2 is varied very smoothly. Hence very smooth speed control of motor can be obtained by this method.

4. Speed control of series motor

1. Flux control method

A) Fielddiverter:

A variable resistance is connected parallel to the series field. This variable resistor is called as diverter, as desired amount of current can be diverted through this resistor and hence current through field coil can be decreased. Hence flux can be decreased to desired amount and s speed can be increased.

B) Armature diverter:

Diverter is connected across the armature for a given constant load torque, if armature current is reduced then flux must increase.

As $T_a \alpha ØI_a$

This will result in increase in current taken from the supply and hence flux Ø will increase and subsequently speed of the motor will decrease.

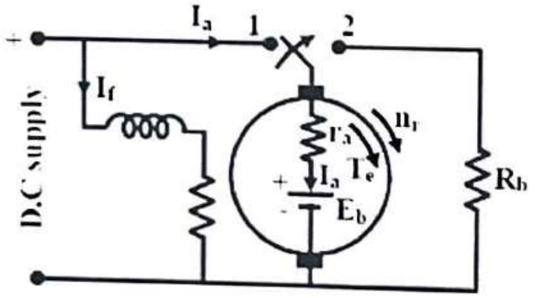
C) Tapped field control:

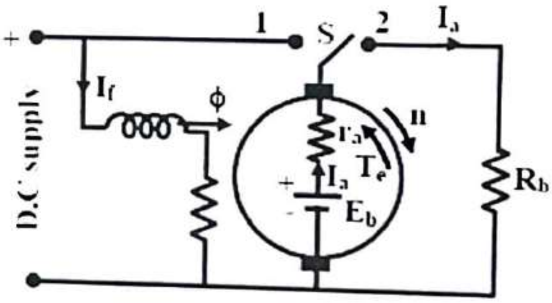
Field coil is tapped dividing number of turns. Thus, we can select different value of Ø by selecting different number of turns.

1.5 BRAKING OF DC MOTOR

Rheostat braking

Consider a d.c shunt motor operating from a d.c supply with the switch S connected to position 1. S is a single pole double throw switch and can be connected either to position 1 or to position 2. One end of an external resistance R_b is connected to position 2 of the switch S as shown





Let with S in position 1, motor runs at n rpm, drawing an armature current $I_a$and the back emf is $E_b = k\varphi$ n. Note the polarity of E_b which, as usual for motor mode in opposition with the supply voltage. Also note T_e and n have same clockwise direction.

Now if S is suddenly thrown to position 2 at t = 0, the armature gets disconnected from the supply and terminated by R_b with field coil remains energized from the supply. Since speed of the rotor cannot change instantaneously, the back emf value E_b is still maintained with same polarity prevailing at $t = 0_-$. Thus at $t = 0_+$, armature current will be $I_a = E_b/(r_a + R_b)$ and with reversed direction compared to direction prevailing during motor mode at t= 0.

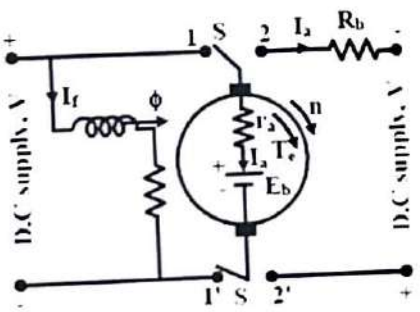
Obviously for t > 0, the machine is operating as generator dissipating power to R_b and now the electromagnetic torque T_e must act in the opposite direction to that of n since $I_a$has changed direction but φ has not (recall $T_e \propto \varphi I_a$). As time passes after switching, n decreases reducing K.E and as a consequence both E_b and I_a decrease. In other words, value of braking torque will be highest at $t = 0_+$, and it decreases progressively and becoming zero when the machine finally come to astop.

Plugging or dynamic braking

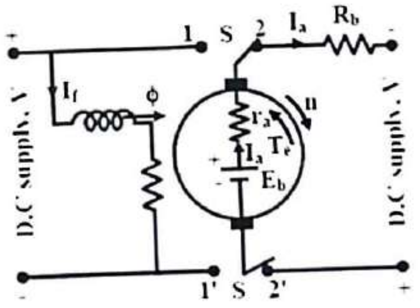
. Here S is a double pole double throw switch. For usual motoring mode, S is connected to positions 1 and 1'. Across terminals 2 and 2', a series combination of an external resistance R_b and supply voltage with polarity as indicated is connected. However, during motor mode this part of the circuit remains inactive.

To initiate braking, the switch is thrown to position 2 and 2' at $t = 0$, thereby disconnecting the armature from the left hand supply. Here at $t = 0_+$, the armature current will be $I_a = (E_b + V)/(r_a + R_b)$ as E_b and the right hand supply voltage have additive polarities by virtue of the connection. Here also I_a reverses direction producing T_e in opposite direction to n

I_a decreases as E_b decreases with time as speed decreases. However, $I_a$cannot become zero at any time due to presence of supply V. So unlike rheostat braking, substantial magnitude of braking torque prevails. Hence stopping of the motor is expected to be much faster than rheostat breaking. But what happens, if S continuous to be in position 1' and 2' even after zero speed has beenattained.



Machine operates as motor



Machine operates as generator during braking (plugging).

The answer is rather simple; the machine will start picking up speed in the reverse direction operating as a motor. So care should be taken to disconnect the right hand supply, the moment armature speed becomes zero.

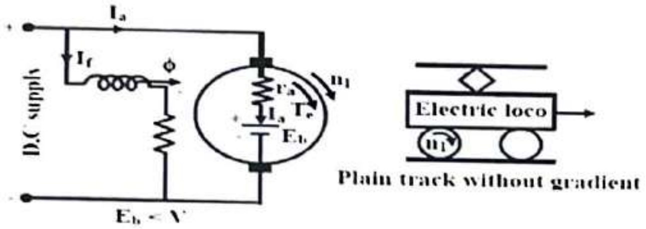
Regenerative braking

A machine operating as motor may go into regenerative braking mode if its speed becomes sufficiently high so as to make back emf greater than the supply voltage i.e., $E_b > V$. Obviously under this condition the direction of $I_a$will reverse imposing torque which is opposite to the direction ofrotation.

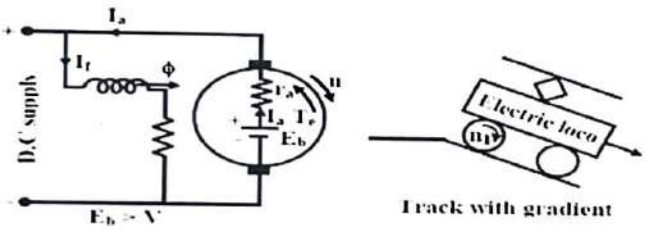
The normal motor operation is shown in figure 39.27 where armature motoring current I_a is drawn from the supply and as usual $E_b < V$. Since $E_b = k\varphi n_1$. The question ishowspeedonitsownbecomelargeenoughtomakeE_b<Vcausingregenerative

braking. Such a situation may occur in practice when the mechanical load itself becomes active.

Imagine the d.c motor is coupled to the wheel of locomotive which is moving along a plain track without any gradient Machine is running as a motor at a speed of n_1 rpm. However, when the track has a downward gradient, component of gravitational force along the track also appears which will try to accelerate the motor and may increase its speed to n_2 such that $E_b = k\varphi n_2 > V$.



Machine operates as motor



Direction of I_a reverses, feeding power back to supply. Regenerative braking here will not stop the motor but will help to arrest rise of dangerously high speed.

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SUBJECT CODE:EE8301-ELECTRICAL MACHINES-1
INTERNAL ASSESMENT-1

DATE:
TIME:

YEAR:IV
SEM:VIII

PART A (any 10*2=20)

1. Mention the factors on which hysteresis loss depends.

2. Define flux linkage.

3. Define mmf and reluctance.

4. A coil of 1500 turns carrying a current of 5amps produces a flux of 25 mwb.find the self inductance of the coil.

5. Define leakage inductance or winding inductance.

6.Give the expression for the load current when the transformer operates at it maximum efficiency.

7. State the different connections of three phase transformer.

8. State the advantages of three phase transformer.

9. Define all day efficiency of a transformer.

10.which equivalent circuit parameters can be determined from the open cdircuit test on a transformer?

PART B(5*16=80)

11. a) Explain the series magnetic circuits and series magnetic circuit with air gap?

OR

b)Draw the expression for self inductance and mutual inductance and also define coefficient of coupling.

12. a) A Ring composed of threesections. The cross section area is $0.001m^2$ for each section. The mean arc length are la=0.3m, lb =0.2m, lc=o.1m,an air gap length of 0.1mm is cut in the ring, μ_r for section a,b,c are 5000, 1000 and 10000 respectively flux in the air gap is 7.5×10^{-4}wb. Find i) mmf ii)Exciting current if the coil has 100 turns iii) Reluctance of the sections.

OR

b)With circuit explain Sumpner's test and how to obtain efficiency of a transformer.

13) a) Explain about the magnetic field in rotating machines.

OR

b) Explain in detail step by step the procedure to draw the equivalent circuit of transformer.

14. a) A 3 phase step down transformer is connected to 6600 volts mains and it takes 10A. calculate the secondary line voltage, line current, and out for the following connections a) Delta-Delta b)Star- Star c) Star- Delta d) Delta- Star. Turns Ratio/phase is 12. Draw connection diagrams.

OR

b) Explain the principle operation of a transformer. Derive its EMF equation.

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15. a) A transformer with normal voltage impressed has a flux density of 1.2 T and core loss comprising 1200W eddy current loss and 3500W hysteris loss. What do these losses become under the following conditions.

i) Increasing the applied voltage by 5% at rated frequency.
ii) Reducing the frequency 5% with normal voltage impressed.
iii) Increasing both impressed voltage and frequency by 5%.

OR

b) Explain the Hystersis and Eddy current losses and obtain its expression.

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SUBJECT CODE: EE8301-ELECTRICAL MACHINES-I

INTERNAL ASSESMENT-I

ANSWER KEY

YEAR:IV
SEM:VIII

PART A (any 10*2=20)

1. **Mention the factors on which hysteresis loss depends.**

Hysteresis loss is directly proportional to the frequency of the field, magnetic flux intensity, and volume of the material.

2. **Define flux linkage.**

The product of the magnetic flux and the number of turns in a given coil.

3. **Define mmf and reluctance.**

MMF:

The **magnetomotive force**, mmf, is analogous to the electromotive force and may be considered the factor that sets up the flux. The mmf is equivalent to a number of turns of wire carrying an electric current and has units of ampere-turns.

4. **A coil of 1500 turns carrying a current of 5amps produces a flux of 25 mwb.find the self inductance of the coil.**

$N = 1500$

$I = 5A$

$\varphi = 2.5mWb$

$L = N\varphi / I$

$= 1500 * 2.5 * 10^{-3} / 5$

$= 0.75H$

5. **Define leakage inductance or winding inductance.**

Leakage inductance in a transformer is an inductive component that results from the imperfect magnetic linking of one winding to another. In an ideal transformer, 100% of the energy is magnetically coupled from the primary to the secondary windings. ... This series inductance is the "leakage inductance."

6. **Give the expression for the load current when the transformer operates at it maximum efficiency.**

The **Efficiency** of the transformer is defined as the ratio of useful output power to the input power. The input and output power are measured in the same unit. Its unit is either in Watts (W) or KW. **Transformer efficiency** is denoted by **η**.

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$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{\text{output power}}{\text{output power} + \text{losses}}$$

$$\eta = \frac{\text{output power}}{\text{output power} + \text{iron losses} + \text{copper losses}}$$

$$\eta = \frac{V_2 I_2 \cos\varphi_2}{V_2 I_2 \cos\varphi_2 + P_i + P_c}$$

7. **State the different connections of three phase transformer.**

Δ – Δ (Delta – Delta) Connection.
Y – Y (Star – Star) Connection.
Δ – Y (Delta – Star) Connection.
Y – Δ (Star – Delta) Connection.

8. **State the advantages of three phase transformer.**
   - It is lighter and smaller.
   - It requires less space to install.
   - Low cost compared with three units of single phase transformers.
   - Transportation is easy and also transportation cost is less.

9. **Define all day efficiency of a transformer.**

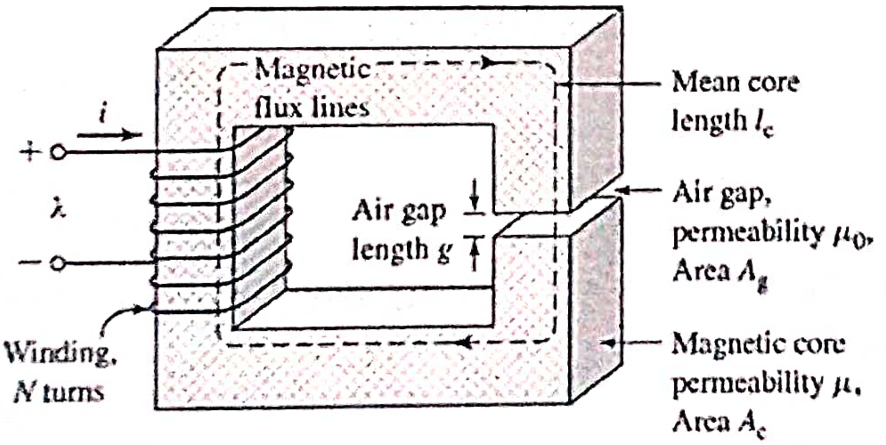
All Day Efficiency is defined as the ratio of total energy output for 24 hrs i.e. for the whole day to the total energy input for the same day. All Day Efficiency is basically Energy Efficiency of Transformer calculated for a period of 24 hrs.

10.which equivalent circuit parameters can be determined from the open cdircuit test on a transformer?

This test is performed to find out **the shunt or no load branch parameters** of equivalent circuit of a transformer. This test results the iron losses and no load current values, thereby we can determine the no load branch parameters with simple calculations.

PART B(5*16=80)

11. a) Explain the series magnetic circuits and series magnetic circuit with air gap?



Series Magnetic Circuit with an Air gap

As we know that permeability of any material can be stated as the ratio of the magnetic flux density to the magnetic fie intensity of a material. It can be expressed as below,

$\mu = B / H$

where, μ is permeability of a material, in henrys/meter

H is magnetic field strength, in ampere-turns/meter

B is flux density, in teslas

Solving the above equation for B, we get

$B = \mu \times H$ .... (Equation 1)

Now, magnetizing force of the air gap is determined as below,

$H = Fm / l$ .... (Equation 2)

where, Fm is Magnetomotive force (mmf), in ampere-turns, l is length of material (gap), in meters

Substituting the value of H from Equation 2 into Equation 1, we get

$B = \mu \times (Fm/l)$

Solving the above equation for magnetomotive force, we get

$Fm = Bl / \mu$ .... (Equation 3)

Let's assume that we have an air gap, and the permeability of air (free space) is a constant

$\mu_{o} = 4\pi \times 10^{\cdot}$ H/m

Replacing the value for μ in Equation 3, we come up with a very basic formula for determining the magnetomotive for required to set up a particular flux in an air gap.

$F_{m} = BL / (4\pi \times 10^{\cdot})$

The air gap can take different form, shape and size depending on the type of magnetic circuit and its shape. In some circuits it

OR

b)Draw the expression for self-inductance and mutual inductance and also define coefficient of coupling.

SELF INDUCTANCE

- The direction of this induced emf will be oppose the cause producing it. When current is increased, self-induced emf reduces the current tries to keep it to original value.

Let

N- No. of turns

I-Current flowing in coil

Φ – Flux produced by the coil.

By Faradays law,

$$e = -N\frac{d\Phi}{dt} \_\_\_\_\_\_\_ (1)$$

Consider the flux, Φ

$$\Phi = \frac{\Phi}{I} * I$$

Rate of change offlux,

$$d\Phi = \frac{\Phi}{I} \cdot \frac{dI}{dt} - - - - (2)$$

Subs (2) in (1) Weget

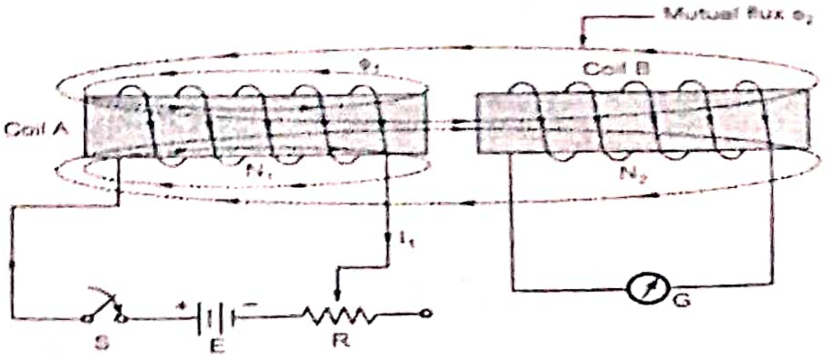
$$e = -N\frac{\Phi}{I} \cdot \frac{dI}{dt}$$

$$e = -\left(\frac{N\Phi}{I}\right) \cdot \frac{dI}{dt}$$

$e = -L\frac{dI}{dt}$ Where $L(self\ Inductance) = \frac{N\Phi}{I}$

MUTUAL INDUCTANCE

"The flux produced by one coil is getting linked with another coil and due to change in flux produced by first coil, there is induced emf I the second coil , then such emf is called mutually inducedemf"



$$e = -N_2 \cdot \frac{d\Phi_2}{dt} \_\_\_\_\_ (1)$$

Consider the flux, Φ

$$\Phi_2 = \frac{\Phi_2}{I_1} \cdot I_1$$

Rate of change of flux,

$$d\Phi_2 = \frac{\Phi_2}{I_1} \cdot \frac{dI_1}{dt} - - - (2)$$

Subs (2) in (1) We get

$$e = -N_2 \cdot \frac{\Phi_2}{I_1} \cdot \frac{dI_1}{dt}$$

$$e = -\left(\frac{N_2\Phi_2}{I_1}\right) \cdot \frac{dI_1}{dt}$$

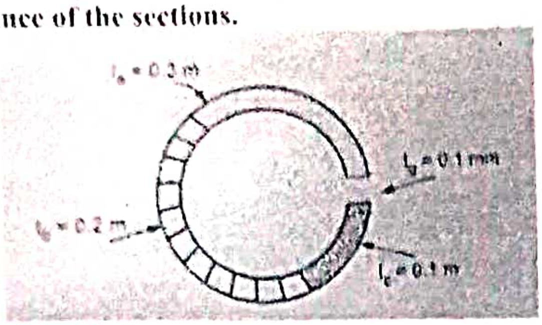
$$e = -M \cdot \frac{dI_1}{dt}$$

Where M= $\frac{N_2\Phi_2}{I_2}$

Coefficient of coupling:

- The Coefficient of coupling can be defined as the fraction of the magnetic flux produced by the current in one coil that links with the other coil. It is represented by the symbol (k) and the amount of coupling between two inductively coupled coils is expressed in terms of the coefficient of coupling.

12. a) **A Ring composed of threesections. The cross section area is $0.001m^2$ for each section. The mean arc length are la=0.3m, lb =0.2m, lc=o.1m,an air gap length of 0.1mm is cut in the ring, μ_r for section a,b,c are 5000, 1000 and 10000 respectively flux in the air gap is 7.5×10^{-4}wb. Find i) mmf ii)Exciting current if the coil has 100 turns iii) Reluctance of the sections.**



a= 0.001m2 same for all sections,

$\varphi= 7.5\times10^{-4}$ Wb

N= 100

$$S = \frac{l}{\mu_0\mu_r A}$$

$S_a= 0.3/4\pi\times10^{-7}\times5000\times0.001$
$= 47746.4829$ AT/Wb
$S_b=159154.9431$ AT/Wb
$S_c=7957.7471$ AT/Wb
$S_g= 79577.4715$ AT/Wb
Total reluctance=$S_T= S_a+S_b+ S_c+ S_g$
$= 294.4366\times10^3$ AT/Wb

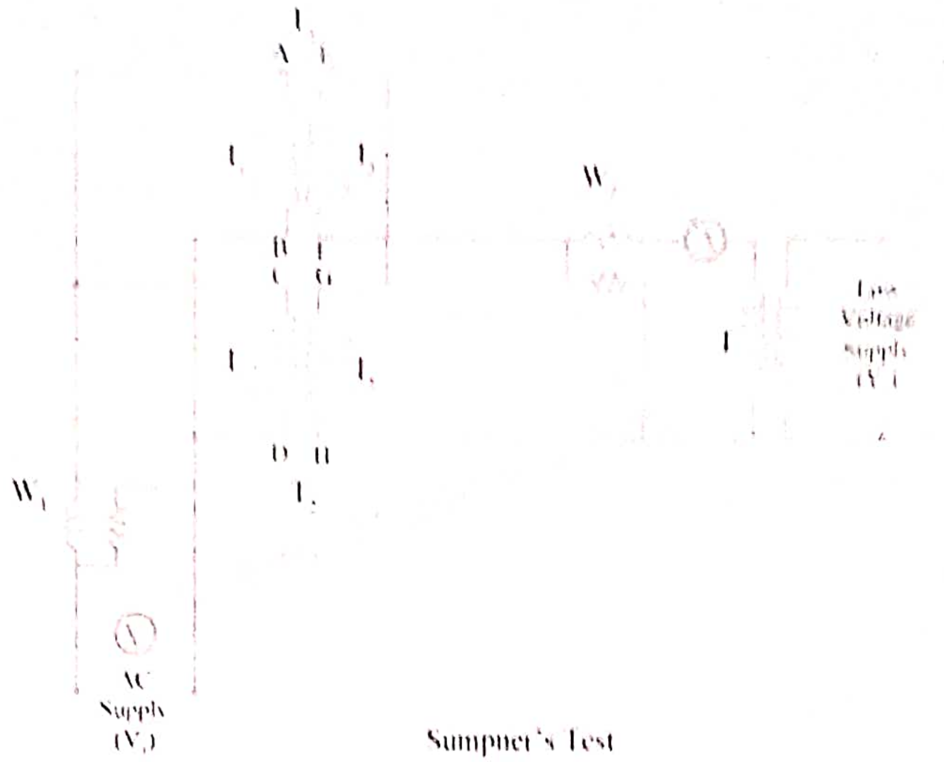
$\varphi=$m.m. f/ S_T
7.5×10^{-4} Wb =m.m. f/ 294.4366×10^3
m.m.f = 220.8275 AT
m.m. f= NI
I= 220.8275/100= 2.2082A

OR

b) With circuit explain Sumpner's test and how to obtain efficiency of a transformer.

Sumpner's Test

Sumpner's test or back-to-back test can be employed only when two identical transformers are available. Both transformers are connected to supply such that one transformer is loaded on another. Primaries of the two identical transformers are connected in parallel across a supply. Secondaries are connected in series such that emf's of them are opposite to each other. Another low voltage supply is connected in series with secondaries to get the readings, as shown in the circuit diagram shown below.



Sumpner's Test

i.e. iron loss per transformer Pi = W1/2.

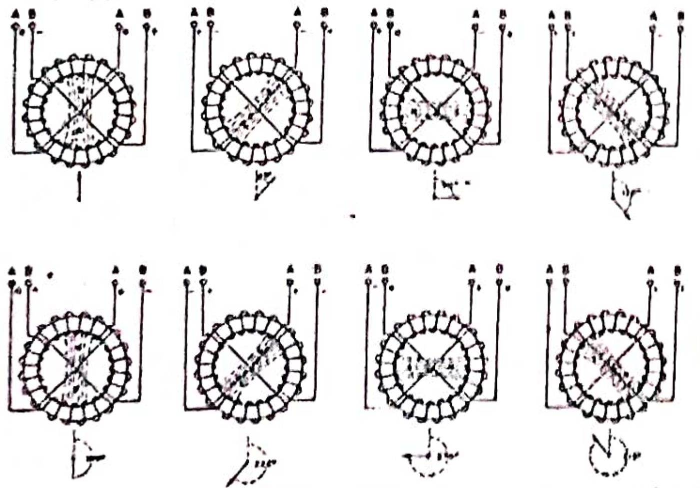
i.e. copper loss per transformer P_{cu} = W2/2.

From above test results, the **full load efficiency of each transformer** can be given as -

$$\%\ \text{full load efficiency of each transformer} = \frac{\text{output}}{\text{output} + \frac{W_1}{2} + \frac{W_2}{2}} \times 100$$

13) a) Explain about the magnetic field in rotating machines.

A rotating magnetic field is the resultant magnetic field produced by a system of coils symmetrically placed and supplied with polyphase currents.



A permanent magnet in such a field will rotate so as to maintain its alignment with the external field. This effect was utilized i early alternating-current electric motors. A rotating magnetic field can be constructed using two orthogonal coils with a 90-degree phase difference in their alternating currents. However, in practice, such a system would be supplied through a three-wire arrangement with unequal currents. This inequality would cause serious problems in the standardization of the conductor size. In order to overcome this, three-phase systems are used in which the three currents are equal in magnitude and have a 12 degree phase difference. Three similar coils having mutual geometrical angles of 120 degrees will create the rotating magnetic field in this case. The ability of the three-phase system to create the rotating field utilized in electric motors is one of the main reasons why three-phase systems dominate the world's electric power-supply systems

OR

b) Explain in detail step by step the procedure to draw the equivalent circuit of transformer.

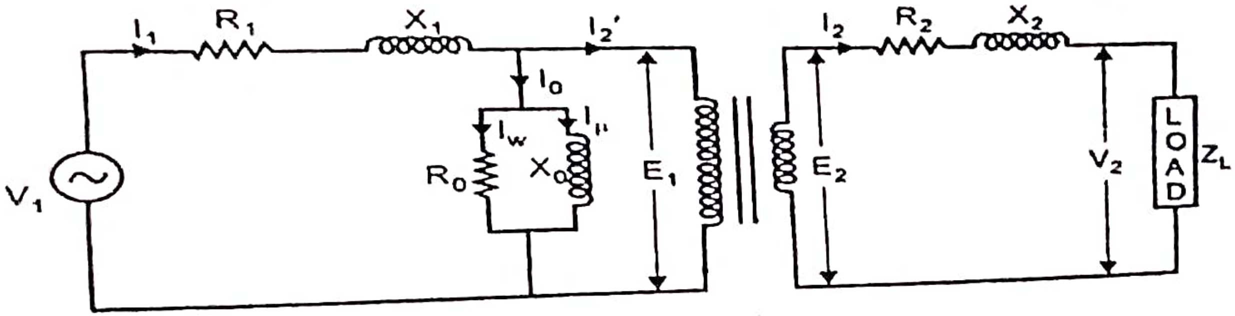
The assumption made are,

(a) Some leakage flux is present at both primary and secondary sides. This leakage gives rise to leakage reactance's at both sides, which are denoted as X_1 and X_2respectively.

(b) Both the primary and secondary winding possesses resistance, denoted as R_1 and R_2respectively. These resistances cause voltage drop as, I_1R_1 and I_2R_2 and also copper loss $I_{12}R_1$ and$I_{22}R_2$.

(c) Permeability of the core cannot be infinite hence some magnetizing current is needed. Mutual flux also causes core loss in iron parts of thetransformer.

Equivalent circuit of transformer



The no load current I_0 is divided into, pure inductance X_0 (taking magnetizing components I_μ) and non-induction resistance R_0 (taking working component I_w) which are connected into parallel across the primary. The value of E_1 can be obtained by subtracting I_1Z_1 from V_1. The value of R_0 and X_0 can be calculated as,

$R_0 = E_1 / I_w$ and $X_0 = E_1 / I_\mu$.

But, using this equivalent circuit does not simplify the calculations. To make calculations simpler, it is preferable to transfer current, voltage and impedance either to primary side or to the secondary side. In that case, we would have to work with only one winding which is moreconvenient.

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From the voltage transformation ratio, it is clear that, $E_1 / E_2 = N_1 / N_2 = K$

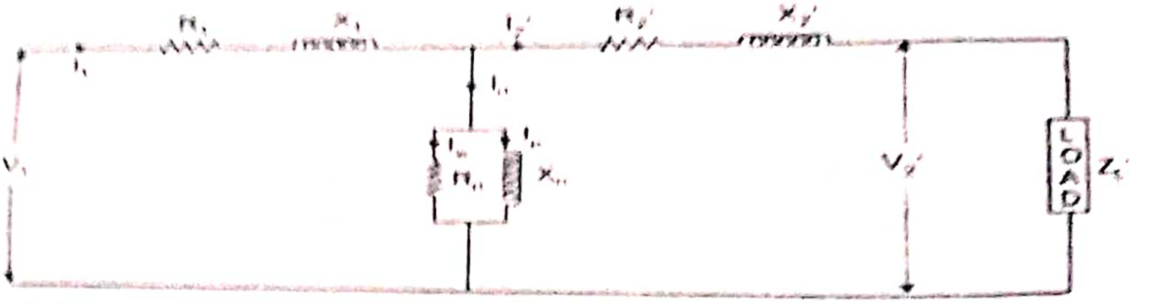
Now, lets refer the parameters of secondary side to primary. Z_2 can be referred to primary as Z_2'

where, $Z_2' = (N_1/N_2)^2 Z_2 = K^2 Z_2$ where $K = N_1/N_2$

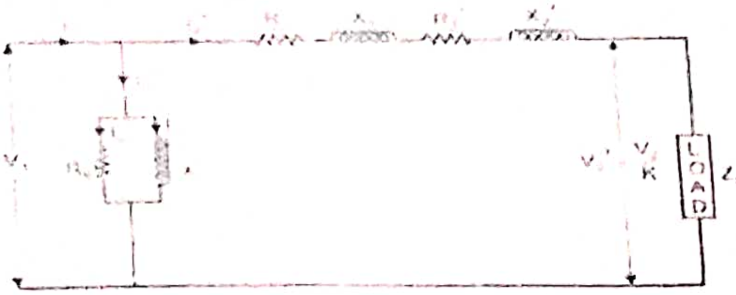
that is, $R_2' + jX_2' = K^2(R_2 + jX_2)$ equating real and imaginary parts, $R_2' = K^2 R_2$ and $X_2' = K^2 X_2$.

And $V_2' = KV_2$

The following figure shows the equivalent circuit of transformer with secondary parameters referred to the primary:



parallel combination of R_0 and X_0 would not affect significantly, if we move it to the input terminals as shown in the figure below.



Now, let $R_1 + R_2' = R'eq$ and $X_1 + X_2' = X'eq$

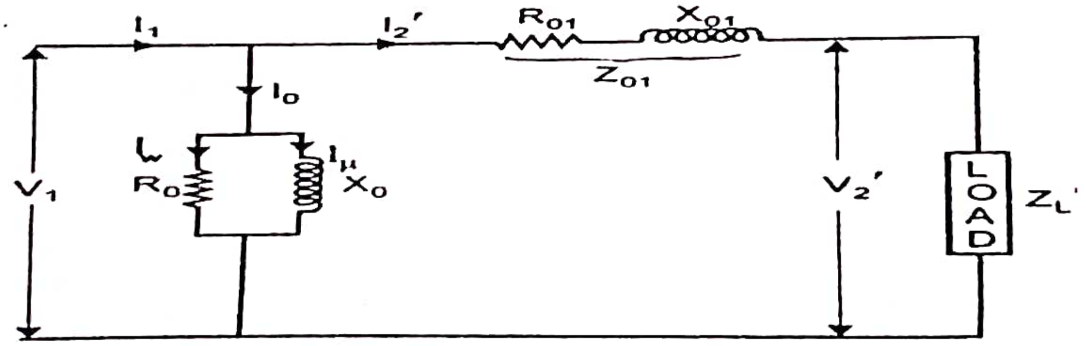
Then the **equivalent circuit of transformer** becomes as shown in the figure below

Tap Changing

1. To supply a desired voltage to theload.
2. To counter the voltage drops due toloads.
3. To counter the input supply voltage changes onload.

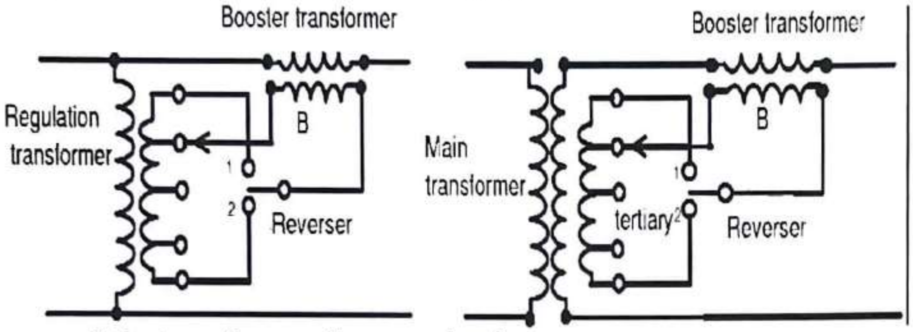
On a power system the transformers are additionally required to perform the task of regulation of active and reactive power flows.

The voltage control is performed by changing the turns ratio. This is done by provision of taps in the winding. The volts per turn available in large transformers is quite high and hence a change of even one turn on the LV side represents a large percentage change in the voltage. Also the LV currents are normally too large to take out the tapping from the windings. LV winding being the inner winding in a core type transformer adds to the difficulty of taking out of the taps.



Hence irrespective of the end use for which tapping is put to, taps are provided on the HV winding.

This may be called buck-boost arrangement. In addition to the magnitude, phase of the injected voltage may be varied in power systems. The tap changing arrangement and buck boost arrangement with phase shift are changing can be affected when



a) the transformers is on no- load

b) the load is still remains connected to the transformer

Taps	Switches closed
1	1,S
2	1,2
3	2,S
4	2,3
5	3,S
6	3,4
7	4,S
8	4,5

14. a) A 3 phase step down transformer is connected to 6600 volts mains and it takes 10A. calculate th secondary line voltage line current, and out for the following connections a) Delta-Delta b)Star- Star c) Star- Delta d) Delta- Star. Turns Ratio/phase is 12. Draw connection diagrams.

i)DELTA- DELTA CONNECTION:

$V_{L1}=V_{ph1}=6600V$

$V_{ph2}= 550\ V$

Since secondary is also connected in delta

$V_{L2}= V_{ph2}=550V$

$I_{ph2}= 69.28\ A$

$I_{L2}=120A$

Secondary Output = 114.315kVA

ii) STAR- STAR CONNECTION

$V_{L1}=6600V$

$V_{ph1}=3810.5118\ V$

$I_{L1}= I_{ph1} = 10A$

$I_{ph2}= 120A$

Since secondary is also connected in star

$I_{L2}= 120A$

$V_{ph2}= 317.543V$

$V_{L2}= 550V$

Secondary Output = 114.315Kva

iii) STAR-DELTA CONNECTION

Since primary is also connected in star

$V_{L1}=6600V$

$V_{ph1}=3810.51\ V$

V_{ph2}= 317.543V

V_{L2}= V_{ph2}=317.543 V

I_{ph2} = 120A

I_{L1}= 207.846A
Secondary output =114.315kVA

iv)DELTA -STAR CONNECTION

Since primary is also connected in delta,

V_{L1}=6600V

I_{ph1}= 5.7735A
I_{ph2} = 69.282A

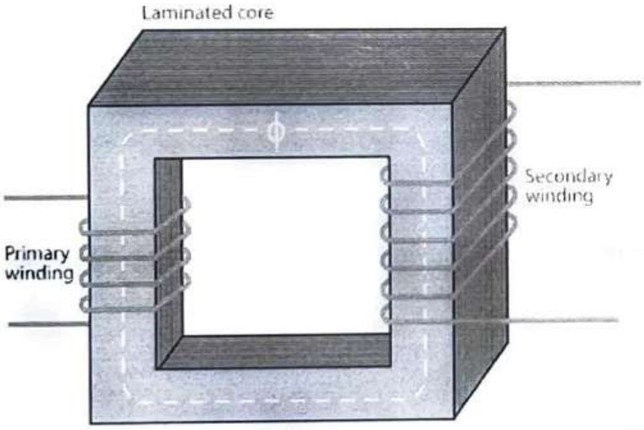
Since secondary is connected in star

I_{L2}=Iph2=69.282A

V_{ph2}= 550V
V_{L2}=952.62 V
Secondary output = 114.315 kVA

OR

b) Explain the principle operation of a transformer. Derive its EMF equation.



1. Core

The core acts as a support to the winding in the transformer. It also provides a low reluctance path to the flow of magnetic flu The winding is wound on the core as shown in the picture. It is made up of a laminated soft iron core in order to reduce the losses in a transformer. The factors such as operating voltage, current, power etc decide core composition. The core diameter i directly proportional to copper losses and inversely proportional to iron losses.

2. Windings

Windings are the set of copper wires wound over the transformer core. Copper wires are used due to:

- The high conductivity of copper minimizes the loss in a transformer because when the conductivity increases, resistance to current flow decreases.
- The high ductility of copper is the property of metals that allows it to be made into very thin wires.

There are mainly two types of windings. Primary windings and secondary windings.

- Primary winding: The set of turns of windings to which supply current is fed.
- Secondary winding: The set of turns of winding from which output is taken.

The primary and secondary windings are insulated from each other using insulation coating agents.

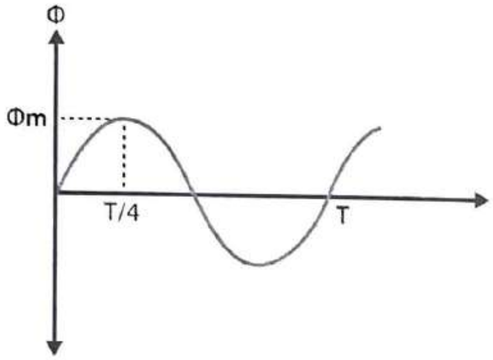
3. Insulation Agents

Insulation is necessary for transformers to separate windings from each other and to avoid short circuit. This facilitates mutual induction. Insulation agents have an influence on the durability and the stability of a transformer.

Ideal Transformer

The ideal transformer has no losses. There is no magnetic leakage flux, ohmic resistance in its windings and no iron loss in the core.

EMF Equation of Transformer



N_1 – number of turns in primary.

N_2 – number of turns in secondary.

Φ_m – maximum flux in weber (Wb).

T – time period. Time is taken for 1 cycle.

The flux formed is a sinusoidal wave. It rises to a maximum value Φ_m and decreases to negative maximum Φ_m. So, flux reaches a maximum in one-quarter of a cycle. The time taken is equal to T/4.

Average rate of change of flux = $\Phi_m/(T/4) = 4f\Phi_m$

Where f = frequency

$T = 1/f$

Induced emf per turn = rate of change of flux per turn

Form factor = rms value / average value

Rms value = $1.11\ (4f\Phi_m) = 4.44\ f\Phi_m$ [form factor of sine wave is 1.11]

RMS value of emf induced in winding = RMS value of emf per turn x no of turns

Primary Winding

Rms value of induced emf = $E_1 = 4.44\ f\Phi m * N_1$

Secondary winding:

Rms value of induced emf = $E_2 = 4.44\ f\Phi m * N_2$

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44 f\,\Phi m$$

Voltage Transformation Ratio

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

K is called the voltage transformation ratio, which is a constant.

Case1: if N_2. N_1 K>1 it is called a step-up transformer.

Case 2: if $N_2 < N_1$, K<1 it is called a step-down transformer.

Transformer Efficiency

$\boldsymbol{Efficiency(\eta)}=_{InputpowerOutputpower}\times\mathbf{100}$

$\boldsymbol{Efficiency(\eta)}=_{P_{out}+P_{loses}P_{out}}\times\mathbf{100}$

$\boldsymbol{Efficiency(\eta)}=_{V_2I_2cos\theta+P_c+P_{cm}V_2I_2cos\theta}\times\mathbf{100}$

Where $P_{cu} = P_{sc}$
$P_c = P_{oc}$

$\boldsymbol{\eta}(_{fullload})=_{VAcos\theta+P_c+P_{cm}VAcos\theta}\times\mathbf{100}$

$\boldsymbol{\eta}(_{loadn})=_{nVAcos\theta+P_c+n_2P_{cm}nVAcos\theta}\times\mathbf{100}$

Applications Of Transformer

- The transformer transmits electrical energy through wires over long distances.
- Transformers with multiple secondary's are used in radio and TV receivers which require several different voltages.
- Transformers are used as voltage regulators.

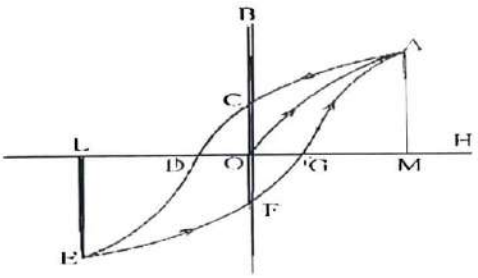
15. a) A transformer with normal voltage impressed has a flux density of 1.2 T and core loss comprising 1200W eddy current loss and 3500W hysteresis loss. What do these losses become under the following conditions.
i) Increasing the applied voltage by 5% at rated frequency.
ii) Reducing the frequency 5% with normal voltage impressed.
iii) Increasing both impressed voltage and frequency by 5%.

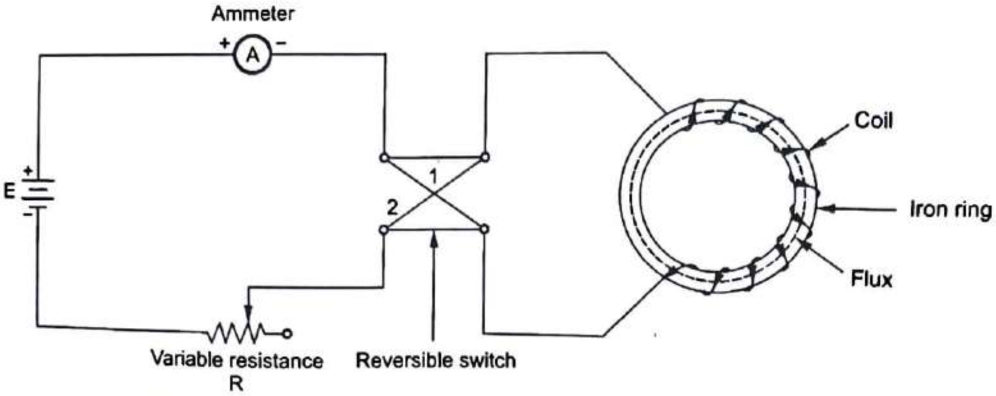
P_h= Hysteresis loss
P_e = Eddy current loss
$E = 4.44\phi_m f N = 4.44B_{max} afN$

i)Voltage increased by 5%
$E_2 = 1.05E_1$
$P_{h2} = 3797.12$ W
$P_{e2} = 1323$ W

II) Frequency reduced by 5%
$F_2 = f_1 - 5\% f_1 = 0.95 f_1$
$P_{h2} = 3622.37$W
$P_{e2} = 1200$ W

iii) Both voltage and f increased by 5%
$E_2 = 1.05 E_1$
$f_2 = 1.05 f_1$
$P_{h2} = 3674.85$ W





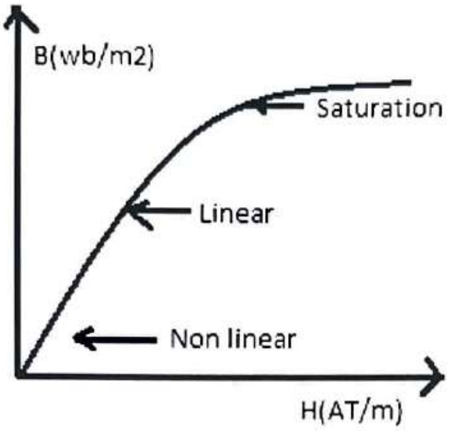
- This value of H required to wipe off residual magnetism is known as coercive force and is a measure of the coercively of materials i.e. its `tenacity' with which it holds on to itsmagnetism.
- After the magnetization has been reduced to zero value of H is further increased in the negative i.e. reverse direction, the iron bar again reaches a state of magnetic saturation represented by point E. By taking H back from its value corresponding to negative saturation (=OL) to its value for positive saturation (=OM), a similar curve EFGA is obtained. If we again start from G, the same curve GACDEFG is obtained onceagain.
- It is seen that B always lags behind H the two never attain zero value simultaneously. This lagging of B, behind H is given the name Hysteresis' which literally means `to lag behind.' The closed Loop ACDEFGA, which is obtained when iron bar is taken through one complete cycle of reversal of magnetization, is known as Hysteresisloop.

P_{e2}= 1323 W

OR

b) Explain the Hysteresis and Eddy current losses and obtain its expression.

- The permeability$\mu 0$is constant so that B-H relationship is linear-H relationship is strictly nonlinear in two parts respects-saturation andhysteresis.



Hysteresis on linearity is the doubled value of B-H relationship exhibited in cyclic variation of H.

- Let us take a un magnetized bar of iron AB and magnetize in by placing it within the magnetizing field of a solenoid (H). The Field can be increased or decreased by increasing or decreasing current through it. Let `H' be increased in step from zero up to a certain maximum value and the corresponding of induction flux density (B) isnoted.
- IfweplottherelationbetweenHandB,acurvelikeOA,asshowninFigure,is

obtained. The material becomes magnetically saturated at H = OM and has, at that time, a maximum flux density, established through it. If H is now decreased gradually (by decreasing solenoid current) flux density B will not decrease along AO (as might be expected) but will decrease less rapidly alongAC.

- When it is Zero B is not zero, but has a definite value = OC. It means that on removing the magnetizing force H, the iron bar is not completely demagnetized This value of B (=OC) is called the residual fluxdensity.
- To demagnetize the iron bar we have to apply the magnetizing force H in the reverse direction. When H is reversed by reversing current through the solenoid, then B is reduced to Zero at point D where H -OD.
- This value of H required to wipe off residual magnetism is known as coercive force and is a measure of the coercivity of materials i.e. its `tenacity' with which it holds on to itsmagnetism.

SRI RAAJA RAAJAN COLLEGE OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

SUBJECT CODE:EE8301-ELECTRICAL MACHINES-1
INTERNAL ASSESMENT-II

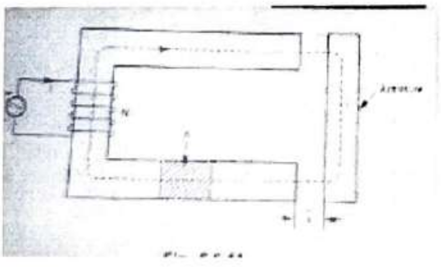
DATE: **YEAR: IV**
TIME: **SEM: VIII**

PART A (any 10*2=20)

1. Why the i-λ relationship of a magnetic circuit is almost linear?
2. Give the examples for multiply excited magnetic field systems and explain the term multiply excited system.
3. Write an expression for the stored energy in the magnetic field.
4. Define rotating magnetic field.
5. What is two-layer winding?
6. Write down the expression for the torque developed in a round rotor machine in terms of stator and rotor m.m.f.s.
7. State the emf equation of a D.C machine.
8. State the advantages of double layer winding.
9. Define critical speed.
10. What are the major parts of a D.C generators?

PART B(5*16=80)

11\. a) The electromagnetic relay shown in fig. is excited from a voltage source of $v = 2$ V sin ωt. Assuming the reluctance of the magnetic circuit to be constant, find the expression for the average force on the armature, when the armature is held fixed at distance x.



OR

b) With an example explain the Multiple – excited magnetic field system.

12\. a) i) Drive an expression for emf generated in a D.C machine. (13)

ii) A 4 pole, d.c machine has a lap connected armature having 60 slots with 8 conductors per slot. The flux per pole is 30 mWb. If the armature is rotated at 1000 rpm, find the e.m.f available across the armature terminals.

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OR

b) Explain in detail the basic concept of a synchronous generator with a neat diagram and the necessary space waveform.

13. a) A 3- phase, 50HZ, star- connected alternator with 2-layer winding is running at 600 r.p.m. It has 12 turns/coil, 4 slots/pole/phase and a coil- pitch of 10 slots. If the flux/pole is 0.035 Wb sinusoidally distributed, find the phase and line emf's induced. Assume that the total turns/phase are series connected.

OR

b) Explain in detail about singly excited magnetic system.

14. a) Derive the EMF equation of a DC generator and explain about the significance of back emf.

OR

b) With schematic diagrams, explain the working principle of different types of d.c generator based on its excitation.

15. a) Two shunt generators are connected in parallel to supply a load of 5000 A. Each machines have a armature resistance of 0.03 ohms and field resistance of 60 ohms. EMF in one machine is 600 V and other machines is 640 V. What power does the machines supply?

OR

b) A four-pole lap wound shunt generator supplies 60 lamps of 100W, 240 V each; the field and armature resistance are 55Ω and 0.18Ω respectively. If the brush drop is 1V for each brush find i) Armature current ii) current per path iii) generatedemf iv) power output of DC machine.

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

SUBJECT CODE:EE8301-ELECTRICAL MACHINES-1
INTERNAL ASSESMENT-II
ANSWER KEY

YEAR: IV
SEM: VIII

PART A (any 10*2=20)

1. Why the i-λ relationship of a magnetic circuit is almost linear?

   As i is similar to H while λ i.e. Nø is similar to flux density B hence i-λ relationship is similar to B-H relationship which is linear till saturation.

2. Give the examples for multiply excited magnetic field systems and explain the term multiply excited system.

   Alternators, synchronous motors.

3. Write an expression for the stored energy in the magnetic field.

4. Define rotating magnetic field.

   A rotating magnetic field is **the resultant magnetic field produced by a system of coils symmetrically placed and supplied with polyphase currents.**

5. What is two-layer winding?

   In double-layer winding, **all coils are of the same shape and size**. Each coil has its one coil-side in top half of one slot and other coil-side in the bottom half of some other slot. The problem of overhang does not exist in double layer winding as it is in single layer winding as it is in single layer winding

6. Write down the expression for the torque developed in a round rotor machine in terms of stator and rotor m.m.f.s.

$$T = -\left(\frac{P}{2}\right)\frac{\mu_0 \pi Dl}{2g} F_2 F_r \sin\delta$$

7. State the emf equation of a D.C machine.

$$E = \frac{P\varphi N}{60} \times \frac{Z}{A} = \frac{PZ\varphi N}{60\,A} \text{ volts}$$

8. State the advantages of double layer winding.

   - Ease in manufacture of coils and lower cost of winding.

Less number of coils are required as spare in the case of winding repairs.
Fractional slot windings can be employed.

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- Fractional pitch coil can be used.

9. Define critical speed.

The speed for which the given field resistance acts as critical resistance is called the critical speed denoted as Nc.

10. What are the major parts of a D.C generators?

❖ Stator. The main function of the stator is to provide magnetic fields where the coil spins. ...

❖ Rotor. A rotor in a DC machine includes slotted iron laminations with slots that are stacked to shape a cylindrical armature core.

❖ Armature Windings.

❖ Yoke.

❖ Poles.

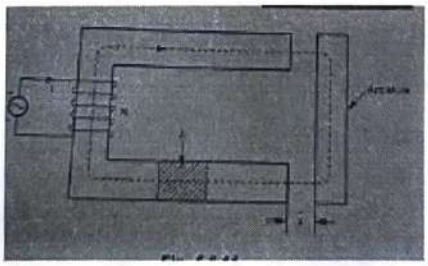
❖ Pole Shoe.

❖ Commutator.

❖ Brushes.

PART B(5*16=80)

11. a) The electromagnetic relay shown in fig. is excited from a voltage source of $v = \sqrt{2}\, V \sin \omega t$. Assuming the reluctance of the magnetic circuit to be constant, find the expression for the average force on the armature, when the armature is held fixed at distance x.



[illegible]

Reluctance of Iron path = S_i

Reluctance of air gap $= \frac{l_g}{\mu_0 A}$

$$= \frac{2x}{\mu_0 A} = bx.$$

Total Reluctance $S_T = S_i + bx$

$W_f(\lambda, x) = \frac{1}{2}\frac{\lambda^2}{L(x)}$ but $\lambda = N\phi$ and $L(x) = \frac{N^2}{S(x)}$

$$W_f(\phi, x) = \frac{1}{2} \times \frac{N^2\phi^2}{\left[\frac{N^2}{S(x)}\right]} = \frac{1}{2} S_T(x)\phi^2 \ldots S = S_T$$

$$F_f = -\frac{\partial W_f(\phi, x)}{\partial x} = -\frac{\partial}{\partial x}\left[\frac{1}{2} S_T(x)\phi^2\right]$$

$$= -\frac{\phi^2}{2}\frac{\partial}{\partial x}\left[S_i + bx\right] = -\frac{1}{2}b\phi^2$$

$\ldots S_i$ is constant

Applying KVL to the coil.

$$v(t) = iR + L\frac{di}{dt}$$

differential eqn:-

$$I = \frac{V}{\sqrt{R^2 + X_L^2}} \angle -\tan^{-1}\frac{X_L}{R}$$

$$X_L = \omega L$$

V is the R.M.S value of the voltage

Current $i(t) = I_m \sin(\omega t - \Phi)$

$$= \frac{\sqrt{2}V}{\sqrt{R^2 + X_L^2}} \sin\left[\omega t - \tan^{-1}\frac{X_L}{R}\right]$$

$$L = \frac{N^2}{S} \text{ and } L = \frac{N\phi}{i}$$

$$\phi = \frac{Ni}{S}$$

$$\phi = \frac{\sqrt{2}\, NV}{\sqrt{(R S_1)^2 + (N^2 \omega)^2}} \sin\left[\omega t - \tan^{-1} \frac{\omega N^2}{R S_T}\right]$$

$$X_L^2 = \omega^2 L^2$$

$$L = \frac{N^2}{S_T}$$

$$\omega^2 L^2 = \frac{\omega^2 N^2}{(S_T)^2}$$

OR

b) With an example explain the Multiple – excited magnetic field system.

$$T_f = -\frac{\partial W_f(\lambda_1, \lambda_2, \theta)}{\partial \theta} \qquad (4.62)$$

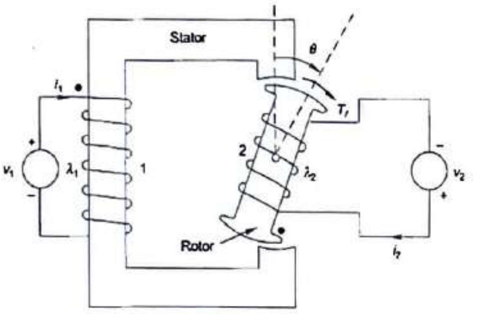


Fig. 4.15

where the field energy is given by

$$W_f(\lambda_1, \lambda_2, \theta) = \int_0^{\lambda_1} i_1\, d\lambda_1 + \int_0^{\lambda_2} i_2 d\lambda_2$$

Analogous to Eq. (4.28)

$$i_1 = \frac{\partial W_f(\lambda_1, \lambda_2, \theta)}{\partial \lambda_1}$$

$$i_2 = \frac{\partial W_f(\lambda_1, \lambda_2, \theta)}{\partial \lambda_2}$$

Assuming linearity

$$\lambda_1 = L_{11} i_1 + L_{12} i_2$$
$$\lambda_2 = L_{21} i_1 + L_{22} i_2; \; (L_{12} = L_{21})$$

If currents are used to describe the system state

$$T_f = \frac{\partial W_f'(i_1, i_2, \theta)}{\partial \theta}$$

where the coenergy is given by

$$W_f'(i_1, i_2, \theta) = \int_0^{i_1} \lambda_1 \, di_1 + \int_0^{i_2} \lambda_2 \, di_2$$

In the linear case

$$W'_f(i_1, i_2, \theta) = \frac{1}{2} L_{11} i_i^2 + L_{12} i_1 i_2 + \frac{1}{2} L_{22} i_2^2$$

$$W_f(\lambda_1, \lambda_2, \theta) = \frac{1}{2} \beta_{11} \lambda_1^2 + \beta_{12} \lambda_1 \lambda_2 + \frac{1}{2} \beta_{22} \lambda_2^2$$

where

$$\beta_{11} = L_{22}/(L_{11}L_{22} - L_{12}^2)$$

$$\beta_{22} = L_{11}/(L_{11}L_{22} - L_{12}^2)$$

$$\beta_{12} = \beta_{21} = -L_{12}/(L_{11}L_{22} - L_{12}^2)$$

12. a) i) Drive an expression for emf generated in a D.C machine. (13)

As the armature rotates, a voltage is generated in its coils. In the case of a generator, the emf of rotation is called the **Generated emf** or **Armature emf** and is denoted as Er = Eg. In the case of a motor, the emf of rotation is known as **Back emf** or **Counter emf** and represented as Er = Eb.

In one revolution of the armature, the flux cut by one conductor is given as:

$$\text{Flux cut by one conductor} = P\varphi \quad \text{wb} \dots \dots (1)$$

Time taken to complete one revolution is given as:

$$t = \frac{60}{N} \quad \text{seconds} \quad \dots \dots (2)$$

$$E = \frac{P\varphi N}{60} \text{ x } \frac{Z}{A} = \frac{PZ\varphi N}{60\ A} \text{ volts}$$

$$E = \frac{PZ\varphi n}{A} \quad \dots\dots.(5)$$

$$E = K\varphi n$$

$$E_b = \frac{PZ\ \varphi\ N}{60\ A} \quad \text{volts}$$

ii) A 4 pole, d.c machine has a lap connected armature having 60 slots with 8 conductors per slot. The flux per pole is 30 mWb. If the armature is rotated at 1000 rpm, find the e.m.f available across the armature terminals.

$$E_b = \frac{PZ\ \varphi\ N}{60\ A} \quad \text{volts}$$

$$= 594 \text{ V}$$

OR

b) Explain in detail the basic concept of a synchronous generator with a neat diagram and the necessary space waveform.

A *synchronous generator* is a synchronous machine which converts mechanical power into AC electric power through the process of electromagnetic induction.

Construction of Synchronous Generator or Alternator

As alternator consists of two main parts viz.

- **Stator** – The stator is the stationary part of the alternator. It carries the armature winding in which the voltage is generated. The output of the alternator is taken form the stator.
- **Rotor** – The rotor is the rotating part of the alternator. The rotor produces the main field flux.

1.Stator Construction of Alternator
2. Rotor Construction of Alternator
3. Salient Pole Rotor

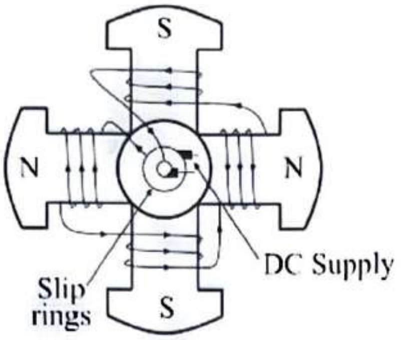
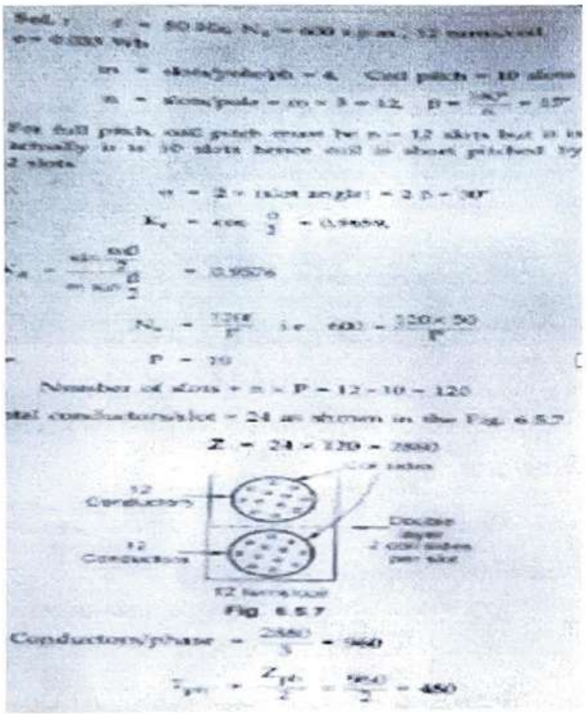


Fig. - Salient Pole Rotor

13. a) A 3- phase, 50HZ, star- connected alternator with 2-layer winding is running at 600 r.p.m. It has 12 turns/coil, 4 slots/pole/phase and a coil- pitch of 10 slots. If the flux/pole is 0.035 Wb sinusoidally distributed, find the phase and line emf's induced. Assume that the total turns/phase are series connected.



Sol. : f = 50 Hz, N_s = 600 r.p.m., 12 turns/coil, ϕ = 0.035 Wb

m = slots/pole/ph = 4, Coil pitch = 10 slots

n = slots/pole = m × 3 = 12, $\beta = \frac{180°}{n} = 15°$

For full pitch, coil pitch must be n = 12 slots but it is actually is 10 slots hence coil is short pitched by 2 slots.

$$\alpha = 2 \times (\text{slot angle}) = 2\beta = 30°$$

$$K_c = \cos\frac{\alpha}{2} = 0.9659$$

$$K_d = \frac{\sin\frac{m\beta}{2}}{m\sin\frac{\beta}{2}} = 0.9576$$

$$N_s = \frac{120f}{P} \quad \text{i.e.} \quad 600 = \frac{120 \times 50}{P}$$

$$P = 10$$

Number of slots = n × P = 12 × 10 = 120

Total conductors/slot = 24 as shown in the Fig. 6.57

$$Z = 24 \times 120 = 2880$$

12 Conductors
Coil sides
12 Conductors
Double layer 2 coil sides per slot
12 turns/coil

Fig 6.57

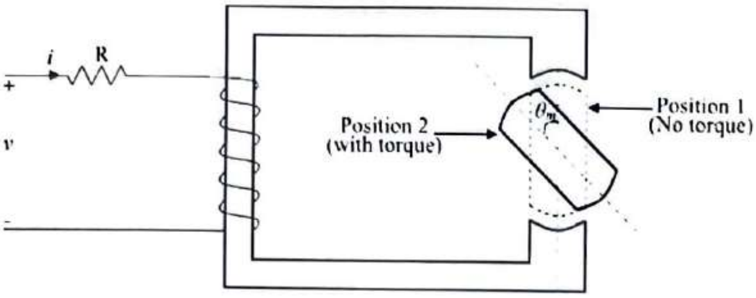
$$\text{Conductors/phase} = \frac{2880}{3} = 960$$

$$T_{ph} = \frac{Z_{ph}}{2} = \frac{960}{2} = 480$$

OR

b) Explain in detail about singly excited magnetic system.

singly-excited system is type of excitation system used in electromechanical energy conversion which requires only one coil to produce the magnetic field. In the singly-excited system, there is only one set of electrical input terminals and one set of mechanical output terminals.



In order to analyse a singly-excited system, following assumptions are made –

- For any rotor position the relationship between flux linkage (ψ) and current is linear.
- The coil has negligible leakage flux.
- Hysteresis and eddy-current losses are neglected.
- All the electric fields are neglected and the magnetic field is predominating.

Stored Energy in the Magnetic Field
Wf=ψ22L=12Li2
Electromagnetic Torque
τe=i22dLdθm

14. a) Derive the EMF equation of a DC generator and explain about the significance of back emf.

Derivation of EMF Equation of DC Generator

Let

φ=MagneticfluxperpoleinWbφ=MagneticfluxperpoleinWb

Z=Totalnumberofarmatureconductors

P=Numberofpolesinthemachine

A=Numberofparallelpaths

Where,A=P…forLAPWinding=2…forWaveWinding

N=SpeedofarmatureinRPM

Eg=GeneratedEMF=EMFperparallelpath

Therefore, the magnetic flux cut by one conductor in one revolution of the armature being,

φ=MagneticfluxperpoleinWbdφ=P×φWbφ=MagneticfluxperpoleinWbdφ=P×φWb

Time taken in completing one revolution is given by,

dt=60Nsecondsdt=60Nseconds

Hence, according to law of electromagnetic induction, the emf generated per conductor is, Eg/Perconductor=dφdt=Pφ60/N=PφN60Eg/Perconductor=*dφdt*=*P*φ60/*N*=*P*φ*N*60

Since, the number of conductors in series per parallel path is,

No. of Conductors/ParallelPath=ZANo. ofConducters/Parallel Path=*ZA*

Therefore,

TotalGeneratedEMF,Eg=EMFPerParallelPath

⇒Eg=(Eg/Per conductor)
×(No.ofConducters/ParallelPath)⇒Eg=(Eg/Perconductor)×(No.ofConducters/ParallelPath)

⇒Eg=PφN60×ZA⇒Eg=*P*φ*N*60×*ZA*

Hence, the EMF equation of a DC generator is,

Eg=PφNZ60A…(1)Eg=*P*φ*NZ*60*A*

It is clear from eqn. (1), that for any dc generator Z, P and A are constant so that $E_g \propto N_\phi$. Therefore, for a given DC generator, the induced EMF in the armature is directly proportional to the flux per pole and speed of rotation.

Case 1 – For *Lap winding*, number of parallel paths A = P. Thus,

Eg=φNZ60…(2)Eg=φ*NZ*60

Case 2 – For *Wave winding*, number of parallel paths A = 2. Thus,

Eg=PφNZ120

OR

b) With schematic diagrams, explain the working principle of different types of d.c generator based on its excitation.

1. **Permanent Magnet DC Generators** – Field coils excited by permanent magnets
2. **Separately Excited DC Generators** – Field coils excited by some external source
3. **Self Excited DC Generators** – Field coils excited by the generator itself

Self-excited C generators can further be classified depending on the position of their field coils. The three types of self-excited DC generators are:

1. Series Wound Generators
2. Shunt Wound Generators
3. Compound Wound Generators

15. a) The Hopkinson test on two similar shunt machines gave the following data's line voltage =110V, line current 48A, Armature current 230A, field current 3A and 3.5A for motor and generator respectively. Armature resistance is 0.035 ohms. Calculate efficiency for bothmachines.

I_1=48A

I_1+I_2=233A

I_4=3A

I_2=185A

Efficiency of Motor:

$$\text{Efficiency} = \frac{output\ power}{input\ power}$$

$$\text{Efficiency} = \frac{input\ power - losses}{input\ power}$$

$$\text{Efficiency} = \frac{V(I_1+I_2) - [\text{Total loss of motor} + \text{Ws}/2]}{V(I_1+I_2)}$$

$$\text{Efficiency} = \frac{110(233) \quad [2181.5 + 734.9]}{110(233)}$$

$$\text{Efficiency} = 88.6\%$$

Efficiency of Generator:

$$\text{Efficiency} = \frac{output\ power}{input\ power}$$

$$\text{Efficiency} = \frac{output\ power}{Output\ power + losses}$$

$$\text{Efficiency} = \frac{(110 * 185)}{(110 * 185) + [1628.6 + 734.9]}$$

$$\text{Efficiency} = 89.5\%$$

OR

b) A four-pole lap wound shunt generator supplies 60 lamps of 100W, 240 V each; the field and armature resistance are 55Ω and 0.18Ω respectively. If the brush drop is 1V for each brush find i) Armature current ii) current per path iii) generated emf iv) power output of DC machine.

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KARAIKUDI

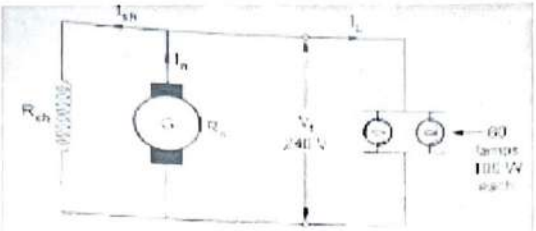

Fig. 7.19.4

$$R_{sh} = 55\,\Omega, \quad R_a = 0.18\,\Omega$$

$$V_{brush} = 2 \times 1\text{ V/brush} = 2\text{ V}$$

For each lamp, $I = \frac{P}{V_t} = \frac{100}{240} = 0.4167\text{ A}$

$\therefore$ $$I_L = I_{lamp} \times 60 = 0.4167 \times 60$$
$$= 25\text{ A}$$

$$I_{sh} = \frac{V_t}{R_{sh}} = \frac{240}{55} = 4.3636\text{ A}$$

i) $$I_a = I_L + I_{sh} = \mathbf{29.3636\text{ A}}$$

ii) $$A = P = 4 \text{ as lap wound}$$

$$\text{current/path} = \frac{I_a}{A} = \frac{29.3636}{4} = 7.341\text{ A}$$

iii) $$E_g = V_t + I_a R_a + V_{brush}$$
$$= 240 + (29.3636 \times 0.18) + 2$$
$$= 247.285\text{ V}$$

iv) $$P_{out} = V_t I_L = 240 \times 25 = 6000\text{ W}$$

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

SUBJECT CODE:EE8301-ELECTRICAL MACHINES-I
MODEL EXAM-I

DATE:
TIME:

YEAR:II
SEM:III

PART A (any 5*2=10)

1. Mention the types of electrical machines.
2. Mention the magnetic materials with example.
3. Distinguish between leakage flux and fringing flux.
4. What is core loss and eddy current loss? What is its significance in electric machines?
5. How will you find the direction of force produced using Fleming's left hand rule?
6. Why transformers are rated in kVA?
7. Give the emf equation of a transformer.
8. What are the typical uses of auto transformer?
9. What happen when a DC supply is applied to a transformer?
10. Distinguish power transformers & distribution transformers?

PART - B (5x16=80marks)

11. a) Explain in detail about statically and dynamically induced emf.

OR

b) The total core loss of a specimen of silicon steel is found to be 1500W at 50 Hz, keeping the flux density to be constant, the loss become 3000W. When the frequency is raised to 75 Hz. Calculate the separately hysteresis loss and eddy current losses at each frequency.

12. a) Explain AC operation of magnetic circuits and derive the energy stored in magnetic field.

OR

b) A steel ring has a mean diameter of 20cm and cross sectional area 0f 25 cm2 and a radial air gap of 0.8 mm. when excited by a current of 1A through a coil of 1000 turns wound on the ring core, it produces a air gap flux of 1 mWb Neglect the leakage flux. Calculate Relative permeability of steel and total reluctance of magnetic circuit.

KARAIKUDI

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13. a) Explain the Hysteresis loop that occurs in magnetic circuits in B-H relationship. (magnetization characteristics)

OR

b) A iron bar of 30 cm long and 2 cm in diameter is bent into a circular shape. It is then wound into with a wi of 600 turns. Calculate the current require to produce a flux of 0.5mWb. If with no air gap and with a air ga of 1mm and μ_r =4000.

14. a) Describe the Construction and working principle of a transformer.

OR

b) The primary of the transformer is rated at 10A and 1000V. The open circuit readings are V_1=1000 V, V_2=500 V, I=0.42, P_{ac}=100W. The short circuit readings are I_1=10 A, V_1=125V and P_{ac}=400V. Find the equivalent circuit parameters for the output voltage of Z_L=19+12j ohms.

15. a) Explain parallel operation of single phase transformer. and derive the emf equation of transformers.

OR

b) A 100 KVA, 3300/240 V, 50 Hz single phase transformer has 990 turns on primary. Calculate the number of turns on secondary and the approximate value of primary and secondary full load currents.

SRI RAAJA RAAJAN COLLEGE OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

SUBJECT CODE:EE8301-ELECTRICAL MACHINES-1
MODEL EXAM-I
ANSWER KEY

YEAR:II
SEM:III

PART A

1. Mention the types of electrical machines.

There are three basic rotating machines types, namely

a. The dcmachines

b. the poly phase synchronous machine(ac)
Poly and single phase induction machine (ac)and a stationary machine, namely

2. Mention the magnetic materials with example.

Dia Magnetic Materials

The materials whose permeability is below unity are called Dia magnetic materials. They are repelled by magnet.

Ex. Lead, gold, copper, glass, mercury

Para Magnetic Materials

The materials with permeability above unity are called Para magnetic materials. The force of attraction by a magnet towards these materials islow.

Ex.: Copper Sulphate, Oxygen, Platinum, Aluminum.

Ferro Magnetic Materials

The materials with permeability thousands of times more than that of paramagnetic materials are called Ferro magnetic materials. They are very much attracted by the magnet.

Ex. Iron, Cobalt, Nickel.

Permanent Magnet

Permanent magnet means, the magnetic materials which will retain the magnetic property at a] l times permanently. This type of magnets is manufactured by aluminum, nickel, iron, cobalt steel(ALNICO).

3. Distinguish between leakage flux and fringing flux.

The small amount of flux always leak to the airgap that flux is called as leakage flux.The Flux spread out the edge of the airgap that flux is called as fringing flux

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4. What is core loss and eddy current loss? What is its significance in electric machines?

When a magnetic material undergoes cyclic magnetization, two kinds of power losses occur on it. Hysteresis and eddy current losses are called as core loss. It is important in determining heating, temperature rise, rating & efficiency of transformers, machines & other A.C run magnetic devices.

When a magnetic core carries a time varying flux, voltages are induced in all possible path enclosing flux. Resulting is the production of circulating flux in core. These circulating current do no useful work are known as eddy current and have power loss known as eddy current loss.

5. How will you find the direction of force produced using Fleming's left hand rule?

The thumb, forefinger & middle finger of left hand is held so that these fingers are mutually perpendicular to each other, then forefinger gives the direction of magnetic field, middle finger gives the direction of the current and thumb gives the direction of the force experienced by the conductor.

6. Why transformers are rated in kVA?

Copper loss of a transformer depends on current & iron loss on voltage. Hence total losses depend on Volt-Ampere and not on PF. That is why the rating of transformers are in kVA and not inkW.

7. Give the emf equation of a transformer.

Emf induced in coil

$$e_{RMS} = 4.44 N \Phi_m f$$

f-frequency of AC input

Φ_m-maximum value of flux

8. What are the typical uses of auto transformer?

(i) To give small boost to a distribution cable to correct for the voltagedrop. (ii)As induction motorstarters.

(iii) As furnacetransformers

(iv) As interconnectingtransformers

(v) In control equipment for single phase and 3 phase electivelocomotives

9. What happen when a DC supply is applied to a transformer?

Due to saturation of magnetic core a large current flows through the windings, without induced any emf. This large current burns the windings of the transformer.

10.Distinguish power transformers & distribution transformers?

PowertransformershaveveryhighratingintheorderofMVA.Theyareusedingeneratingandreceiving stations.Sophisticatedcontrolsarerequired.Voltageranges willbeveryhigh.Distributiontransformersareusedinreceivingside.Voltagelevelswillbemedium.PowerrangingwillbesmallinorderofkVA.Complicatedcontrolsarenot needed.

PART - B (5x16=80marks)

11. a) Explain in detail about statically and dynamically induced emf.

STATICALLY INDUCED EMF

"The change in flux lines with respect to coil can be achieved without physically moving the coil or magnet is called statically induced emf"

- An induced emf there must be change in flux associated with a coil. The change in flux can be achieved without any physical movement by increasing and decreasing the current producing the flux with respect to time.
- The statically induced emf is classifieds
  1. Self-inducedemf
  2. Mutually inducedemf

SELF INDUCED EMF

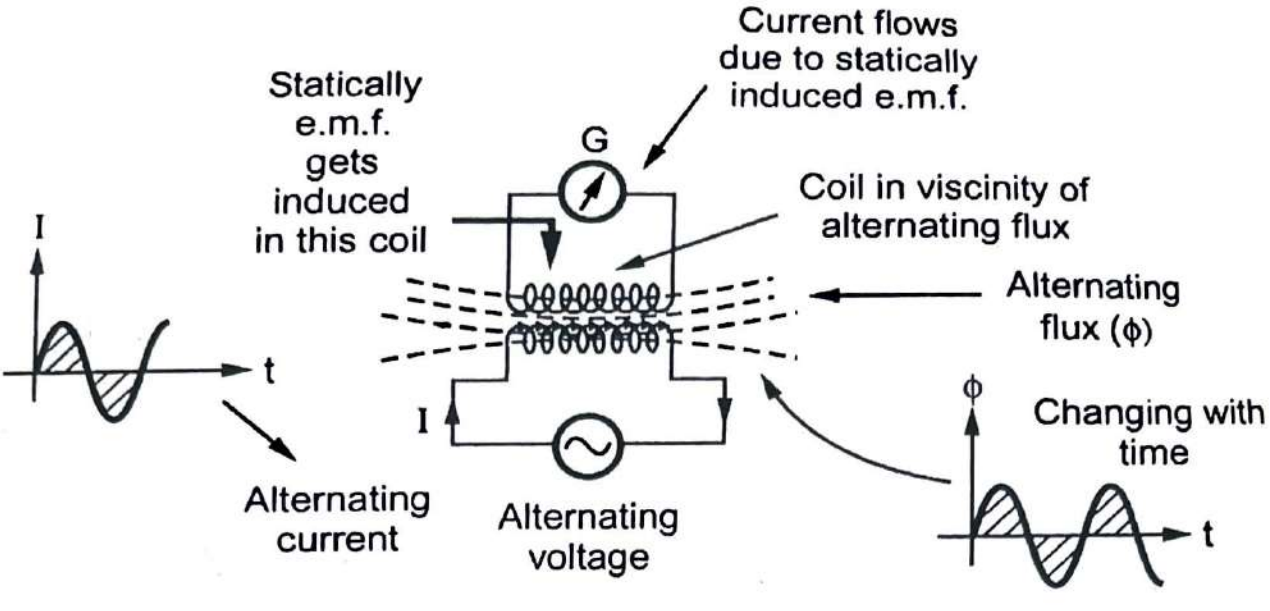
Consider a coil having 'N' turns and carrying current 'I'. When switch is closed the magnitude of current can be varied with the help of variable resistance.

The flux produced by the coil links with the coil itself.

The current 'I' is changed with the help of variable resistance, then flux produced will alsochange.

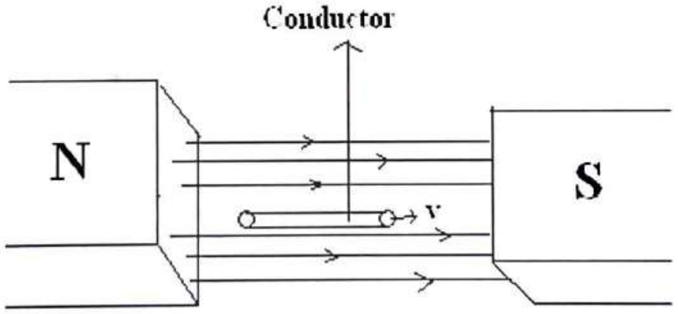
According to faraday's law due to rate o change of flux linkages there will be induced emf in the coil.

So there is no physical moving coil the flux is induced emf the coil itself. This emf is called as self-induced emf.



DYNAMICALLY INDUCED EMF

"An induced emf which is due to physical movement of magnet (or) coil is called dynamically induced emf"



Magnitude of dynamically induced emf

- If plane of the motion of the conductor is parallel to the plane of the magnetic field, then there is no cutting of flux lines and there cannot be any induced emf in the conductor.

- When plane of the flux is parallel to the plane of the motion of conductors then there is no cutting of flux, hence no inducedemf.

-

B=Flux density in wb/m_2

L=Active length of conductor in meters

OR

b) The total core loss of a specimen of silicon steel is found to be 1500W at 50 Hz, keeping the flux density to be constant, the loss become 3000W. When the frequency is raised to 75 Hz. Calculate the separately hysteresis loss and eddy current losses at each frequency.

Solution

Hysteresis loss = $(B_M)^{1.6}Vk_Hf$

$W_h=Af$

$Ke(B_M)^2 t^2Vf^2$

$W_e= Bf^2$ Now

core loss, $P=W_e+W_h$

$P=Af+Bf_2$

$P/f=A+Bf$ (A)

At 50 Hz, Core loss is 1500W

$1500/50=A+50B$

$30=A+50B$ (1)

At 75 Hz, Core loss is 3000W

$3000/60=A+75B$

$40=A+75B$ (2)

Solving (1) and (2) we get,

$25B=10$

$B=0.4$

Therefore

$A=10$

At 50 Hz

Hysteresis loss = $Af= 10*50=500W$ Eddy current loss$=Bf_2=0.4*(50)_2=1000W$

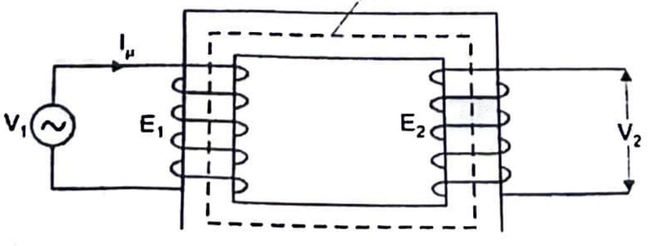
At 75 Hz

Hysteresis loss = $Af= 10*75=750W$ Eddy current loss$=Bf_2=0.4*(75)_2=2250W$

12. a) Explain AC operation of magnetic circuits and derive the energy stored in magnetic field.

Magnetic circuit is defined as the closed path followed by the flux lines. Electric circuit provides a path for electric current whereas magnetic circuit provides a path for magneticflux.

F=I N(AT)



V=Velocity in m/sec

- This conductor is moved through distance dx in a small-time interval and,then Area

swept by conductor=$l*dx*m_2$

- Flux cut by conductor=Flux density*Area swept

$$d\Phi = B*l*dx \text{ wb}$$

- The magnitude of induced emf is proportional to the rate of change of flux
- E=Flux cut/time= $d\Phi/dt$ [N=1 as single conductor]

$$=Bl\, dx/dt$$

- dx/dt=rate of change of displacement=V

e=BLV volts is perpendicular to the direction of flux responsible for induced emf.

- The magnitude of inducedemf

$$E= BLV\sin\Theta \text{volts}$$

- If conductor is moving with a velocity V but at a certain angle Θ measured with respect to

direction of the field then component of velocity sin Θ

I=Current through the coil

N=Number of turn in the coil

Ampere's law

The total current piercing the surface enclosed by this path is easily

$$\int_s^0 J.ds = NI = \int_l^0 H.dl$$

J=Current density

- The magnetic field intensity H causes a flux density B to be set up at every point along the flux twitch is givenby

B= μH=H *(Flux path in core)*$^{\mu 0 \mu r}$

B= $\underset{\mu}{}$ H=H*(Flux path inair)*$^{\mu 0}$

$\mu 0 = relative\ permiability\ of\ the\ material$

The flux over a given area

$$\Phi = \int_s B.ds$$

The flux set up in air path is known as leakage flux

F=NI=HcLc

Hc=Average magnitude of magnetic field intensity in the core

Lc=mean core length(m)

F=MMF in AT Φc=Flux in core, Bc=Flux density in core Ac=Cross section area in core

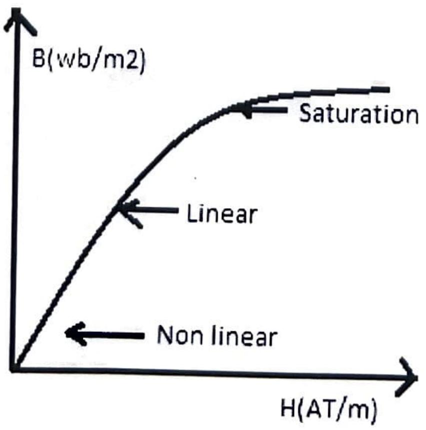
- Bc= $\mu c\ Hc$

$\Phi = \int_s B.ds$=BcAc

$= \underset{\mu}{c}$ Hc Ac=NI/(lc/ $\underset{\mu}{c}$ Ac)

RELATIONSHIP(MAGNETIZATIONCHARACTERISTICS)

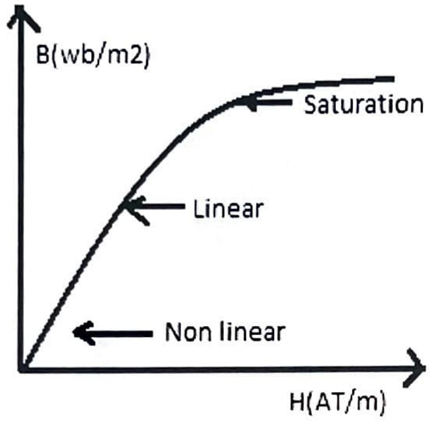
- The permeability$^{\mu 0}$is constant so that B-H relationship is linear.B-H relationship is strictly nonlinear in two parts respects-saturation andhysteresis.



Hysteresis on linearity is the doubled value of B-H relationship exhibited in cyclic variation of H.

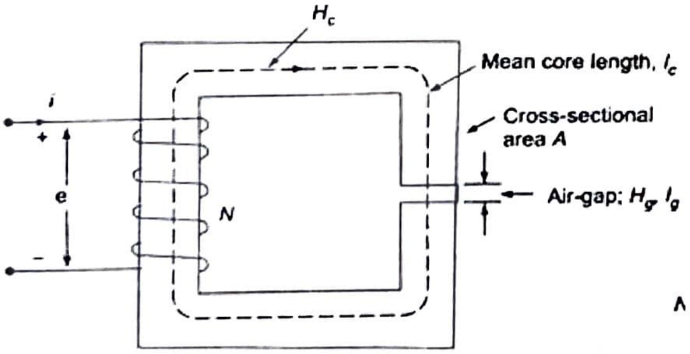
RELATIONSHIP(MAGNETIZATIONCHARACTERISTICS)

➢



Hysteresis on linearity is the doubled value of B-H relationship exhibited in cyclic variation of H.

CORE WITH AN AIRGAP



➢ The MMF NI is now consumed in the core plus the gap.

$NI=H_c l_c+H_g l_g$

$NI=B_c l_c/\mu+B_g l_g/\mu_0$

$B_g=B_c$

$\Phi=B_c A=B_g A$

$NI=\phi(l_c/\mu A)+(l_g/\mu_0 A)$

OR

b) A steel ring has a mean diameter of 20cm and cross-sectional area Of 25 cm2 and a radial air gap of 0.8 mm. when excited by a current of 1A througha coil of 1000 turns wound on the ring core, it produces a air gap flux of 1 mWb Neglect the leakage flux. Calculate Relative permeability of steel and total reluctance of magnetic circuit.

Solution:

$A = 25\ \text{cm}_2$

$L_g = 0.8\text{mm}$

I=1A

N=1000 turns

Φ=1mWb

Mean diameter=20 cm

Length of air gap=πd – length of air gap.

$= \pi(20 * 10_{-2}) - (0.8 * 10_{-3})$

$L_i = 0.6272\text{m}$

$$\varphi = \frac{NI}{S_t}$$

$$S_t = \frac{NI}{\varphi} = \frac{1000 * 1}{1 * 10^{-3}}$$

$$S_t = 1000000 AT/Wb$$

$$S_t = S_i + S_g \qquad S_i = 745222 AT/Wb$$

$$S_g = \frac{L_g}{\mu_0 A} = \frac{0.8 * 10^{-3}}{\mu_0 * 25 * 10^{-2}}$$

$$S_g = 254777\ AT/Wb$$

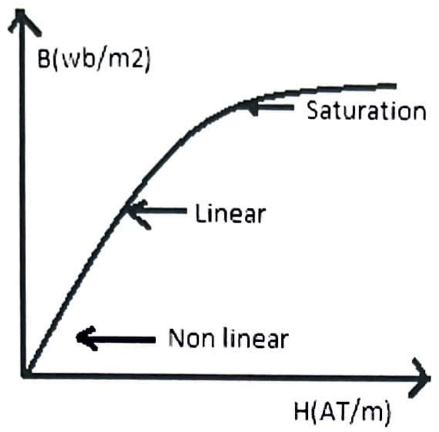
$$S_i = \frac{L_i}{\mu_0\, \mu_r A} \qquad \mu_r = \frac{L_i}{\mu_0 S_i A} = \frac{0.6272}{4\pi * 10^{-7} * 25 * 10^{-2} * 745222}$$

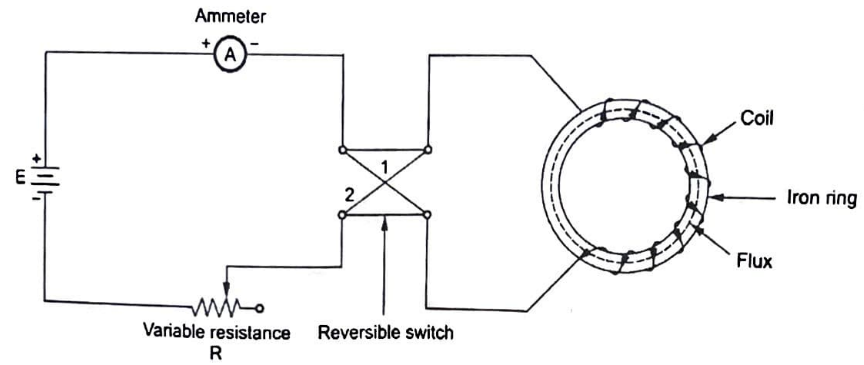
$$S_i = S_T + S_g = 1000000 - 254777$$

$$\mu_r = 268$$

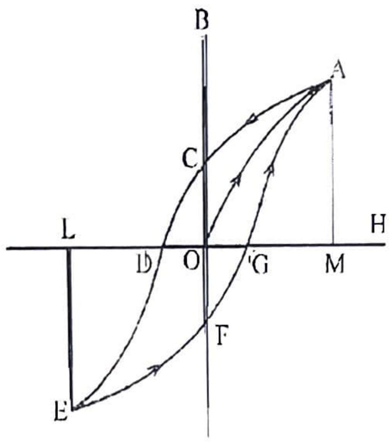
13. a) Explain the Hysteresis loop that occurs in magnetic circuits in B-H relationship. (Magnetizationcharacteristics).

- The permeability $\mu 0$ is constant so that B-H relationship is linear-H relationship is strictly nonlinear in two parts respects-saturation andhysteresis.





Hysteresis on linearity is the doubled value of B-H relationship exhibited in cyclic variation of H.



- This value of H required to wipe off residual magnetism is known as coercive force and is a measure of the coercively of materials i.e. its `tenacity' with which it holds on to itsmagnetism.
- After the magnetization has been reduced to zero value of H is further increased in the negative i.e. reverse direction, the iron bar again reaches a state of magnetic saturation represented by point E. By taking H back from its value corresponding to negative saturation (=OL) to its value for positive saturation (=OM), a similar curve EFGA is obtained. If we again start from G, the same curve GACDEFG is obtained onceagain.
- It is seen that B always lags behind H the two never attain zero value simultaneously. This lagging of B, behind H is given the name Hysteresis' which literally means `to lag behind.' The closed Loop ACDEFGA, which is obtained when iron bar is taken through one complete cycle of reversal of magnetization, is known as Hysteresisloop.

OR

b) A iron bar of 30 cm long and 2 cm in diameter is bent into a circular shape.

Itisthenwoundintowithawireof600turns.Calculatethecurrentrequire to produce a flux of 0.5mWb. If with no ai
μ_r
gap and with a air gap of 1mm and =4000.

Solution:

$$L_i = 30 \cdot 10^{-2} m$$

$$d = 2 \times 10^{-2} m$$

$N =$ 600 turns

(i) With No airgap

$$A = \frac{\pi d^2}{4} = \frac{\pi (2 \times 10^{-2})^2}{4} = \pi \times 10^{-4} m^2$$

$$S_i = \frac{L_i}{\mu_0 \mu_r A} = \frac{30 \times 10^{-2}}{4\pi \cdot 10^{-7} \times 4000 \cdot \pi \times 10^{-4}}$$

$$S_i = 1.9 \times 10^5 \; AT/Wb$$

$$\varphi = \frac{NI}{S_i}$$

$$0.5 * 10^{-3} = \frac{600 * I}{1.9 * 10^5}$$

$$I = 0.158A$$

(ii) With airgap

$$S_g = \frac{L_g}{\mu_0 \mu_r A} = \frac{1 * 10^{-3}}{4\pi * 10^{-7} * 1 * \pi * 10^{-4}}$$

$$S_g = 25.33 * 10^5 AT/Wb$$

$$S_t = S_i + S_g = 1.9 * 10^5 + 25.33 * 10^5$$

$$S_t = 27.1 * 10^5 AT/Wb$$

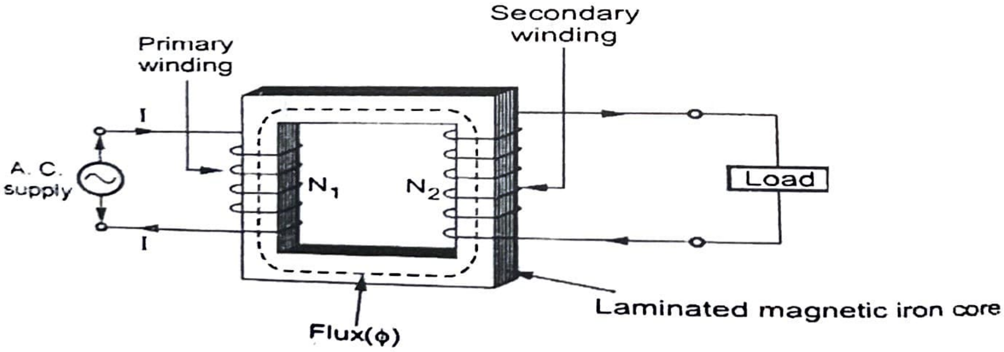
$$\varphi = \frac{NI}{S_t}$$

$$0.5 * 10^{-3} = \frac{600 * I}{27.1 * 10^5}$$

$$I = 2.258A$$

14. a) Describe the Construction and working principle of a transformer.

A transformer can be defined as a static device which helps in the transformation of electric power in one circuit to electric power of the same frequency in another circuit. The voltage can be raised or lowered in a circuit, but with a proportional increase or decrease in the currentratings.



The main principle of operation of a transformer is mutual inductance between two circuits which is linked by a common magnetic flux. A basic transformer consists of two coils that are electrically separate and inductive, but are magnetically linked through a path of reluctance.

The lamination can be done with the help of a light coat of core plate varnish or lay an oxide layer on thesurface.

For a frequency of 50 Hertz, the thickness of the lamination varies from 0.35mm to 0.5mm for a frequency of 25 Hertz.

Core TypeTransformers

The low voltage windings are placed nearer to the core as it is the easiest to insulate. The effective core area of the transformer can be reduced with the use of laminations andinsulation.

Shell-TypeTransformers

In shell-type transformers the core surrounds a considerable portion of the windings. The comparison is shown in the figure below.

OR

b) The primary of the transformer is rated at 10A and 1000V. The open circuit readings are V_1=1000 V, V_2=500 V, I=0.42, P_{ac}=100W. The short circuit readings are I_1=10 A, V_1=125V and P_{ac}=400V. Find the equivalent circuit parameters for the output voltage of Z_L=19+12j ohms.

Solution:

$$P_o = 100\ W$$

$$V_0 = 500\ v$$

$$I_0 = 0.42\ A$$

$$P_o = V_0 I_0 cos\varphi_0$$

open circuit test

$$\cos\varphi_0 = \frac{P_o}{V_0 I_0} = \frac{100}{500 * 0.42} = 0.47$$

$$I_m = I_0 \sin\varphi_0 = 0.369\ A$$

$$I_c = I_0 \cos\varphi_0 = 0.1992\ A$$

$$R_o = \frac{V_0}{I_c} = 2532.9\ ohms$$

$$X_o = \frac{V_0}{I_m} = 1355.01\ ohms$$

Short circuit test:

$$k = \frac{V_2}{V_1} = 0.5$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{125}{10} = 12.5\ ohms$$

$$R_{sc} = \frac{W_{sc}}{I_{sc}^2} = \frac{400}{100} = 4\ ohms$$

$$Z_{1e} = \frac{Z_{sc}}{K} = \frac{12.5}{0.5^2} = 50\ ohms$$

$$R_{1e} = \frac{R_{sc}}{K} = \frac{4}{0.5^2} = 16\ ohms$$

$$X_{1e} = \sqrt{(Z_{1e}{}^2 - R_{1e}^2)}$$

=47.37 Ohms

$$X_{1e} = \sqrt{(50^2 - 16^2)}$$

15. a) Explain parallel operation of single-phase transformer. and derive the emf equation of transformers.

1\. Non-availability of a single large transformer to meet the total loadrequirement.

1\. The power demand might have increased over a time necessitating augmentation of the capacity. More transformers connected in parallel will then be pressed intoservicc.

2\. To ensure improved reliability. Even if one of the transformers gets into a fault or is taken out for maintenance/repair the load can have continued to beserviced.

3\. To reduce the spare capacity. If many smaller size transformers are used one machine can be used as spare. If only one large machine is feeding the load, a spare of similar rating has to be available. The problem of spares becomes more acute with fewer machines in service at alocation.

4\. When transportation problems limit installation of large transformers at site, it may be easier to

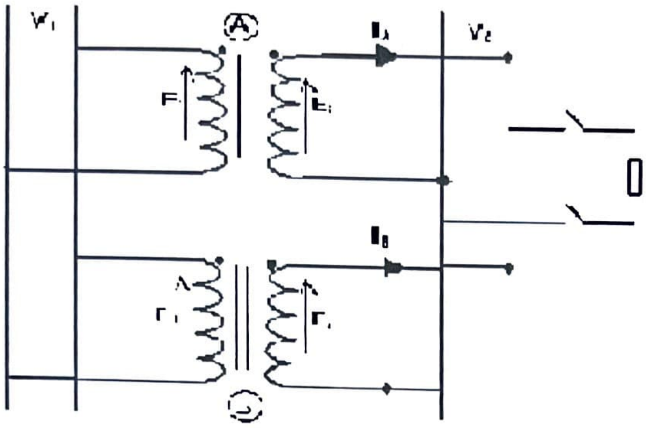
1\. The voltage ratio must be thesame.

2\. The per unit impedance of each machine on its own base must be thesame.

3.The polarity must be the same, so that there is no circulating current between the transformers.

4.The phase sequence must be the same and no phase difference must exist between the voltages of the twotransformers.

Where, V1=Load bus voltage V2=Supply voltage



. $P_A=V_2I_A$

$P_B=V_2I_B$

$P_A=P*(Z_B/Z_A+Z_B)$

$P_B=P*(Z_A/Z_A+Z_B)$

OR

b) A 100 KVA, 3300/240 V, 50 Hz single phase transformer has 990 turns on primary. Calculate the number of turns on secondary and the approximate value of primary and secondary full load currents.

$V_1 = 3300\ V$

$V_2 = 240\ V$

$N_1 = 990\ V$

$N_2 = ?$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$N_2 = \frac{V_2}{V_1} * N_1$$

$$N_2 = \frac{240}{3300} * 990 = \mathbf{72\ \textit{turns}}$$

$$I_1 = \frac{KVA}{V_1} = \frac{100 * 10^3}{3300} = 30.30\ A$$

$$\mathbf{I_1 = 30.30\ A}$$

$$I_2 = \frac{KVA}{V_2} = \frac{100 * 10^3}{240} = 416.6\ A$$

$$\mathbf{I_2 = 416.6\ A}$$

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

SUBJECT CODE:EE8301-ELECTRICAL MACHINES-1
MODEL EXAM-II

DATE:
TIME:

YEAR:IV
SEM:VIII

PART A (any 10*2=20)

1. Write an expression for synchronous speed.
2. A Conductor 80 cm long moves at right angle to its length at a constant speed of 30m/s in a uniform magnetic field of flux density 1.2 T. find the emf induced when the conductor motion is normal to the field flux.
3. State the different losses which occur in a transformer.
4. Mention the properties of oilused in transformer.
5. State the principle of electromechanical energy conversion.
6. What is the fuction of an exciter?
7. Define commutation and commutation period.
8. State the methods of improving commutation.
9. Mention the factor affecting the speed of a D.C motor.
10. What are the advantage and disadvantage of Brake test?

PART - B (5x16=80marks)

11. a) Draw and explain the typical magnetic circuit with airgap and its equivalent electric circuit.Hence derive the expression for air gap.

OR

b) Explain the Hysteresis loop that occurs in magnetic circuits in B-H relationship

12. a) A 20KVA, 2000/200 v, 50 HZ transformer is operated at no-load on rated voltages, the input being 150 W at 0.12 p.f. When it is operating at rated load, the voltage drops in the total leakage reactance and the total resistance are, respectively 2 and 1 % of rated voltage. Determine the input power and power factor when the transformer delivers10 kW at 200 V at 0.8 p.f. lagging to a load on the LV side.

OR

b) Describe the Construction and working principle of a transformer.

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13. a) With neat diagrams, explain the mmf space wave of one phase of a three phase distributed winding in a 2-pole machine and derive the expression for the fundamental mmf wave of the distributed winding in it.

OR

b)Write an example the multiple-excited magnetic field system.

14. a) Drive the emf equation of a d.c generator.

OR

b) Two coupled coils have self and mutual inductances $L_{11} = 3 + \frac{1}{3x}$; $L_{22} = 1 + \frac{1}{3x}$; $L_{21} = L_{12} = \frac{1}{3x}$.

Over a certain range of displacement x. The first coil is excited by a constant current of 10A and second coil by a constant current of -5A. Find the mechanical work done if the x changes from 0.5 to 1 and the energy supplied by each electrical sources.

15. a) Explain how to obtain efficiency of a D.C machine by conducting brake test.State its advantages and disadvatages.

OR

b) Explain any two methods of testing of DC machines.

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SUBJECT CODE:EE8301-ELECTRICAL MACHINES-1
MODEL EXAM-II
ANSWER KEY

YEAR:IV
SEM:VIII

PART A

1. Write an expression for synchronous speed.

The synchronous speed is the speed of the revolution of the magnetic field in the stator winding of the motor. It is the speed at which the electromotive force is produced by the alternating machine.

$$N_S = \frac{120\,f}{P}$$

2. A onductor 80 cm long moves at right angle to its length at a constant speed of 30m/s in a uniform magnetic field of flux density 1.2 T. find the emf induced when the conductor motion is normal to the field flux.

$e = Blv \sin\theta$

$\theta = 90^\circ$

$e = 28.8\ V$

3. State the different losses which occur in a transformer.

- Eddy Current Loss
- Hysteresis losses
- Copper losses

4. Mention the properties of oil used in transformer.
   1. Good conductor of heat.
   2. High coefficient of volume expension.
   3. High insulating strength.
   4. Free from impurities like alkalies, sulphur etc.
   5. Free from moisture content.

5. State the principle of electromechanical energy conversion.

A device which converts electrical energy into mechanical energy or mechanical energy into electrical energy is known as *electromechanical energy conversion*.

6. What is the fuction of an exciter?

The exciter is used to excite the field winding of synchronous machine by a d.c supply.

7. Define commutation and commutation period.

A process by which current in the short circuited coil is reversed while it crosses the MNA is called commutation. The time during which the coil remains short circuited is known as commutation period.

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8. State the methods of improving commutation.

   1. Resistance commutation
   2. Giving a brush shift
   3. Use of interpoles. The methods 2 and 3 are the parts of E.M.F commutation.

9. Mention the factor affecting the speed of a D.C motor.

   1.The flux .

   2. The voltage across the armature .

   3. The applied voltage V.

10. What are the advantage and disadvantage of Brake test?

Advantage:

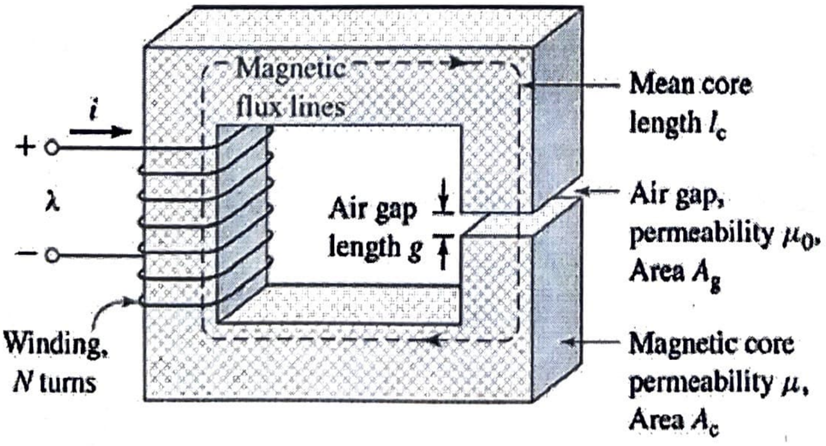
- The test requires no other machines thereby reducing the cost and energy.
- This method is very simple.
- Very much convenient for small dc motors.
- The efficiency can be determined under any actual load conditions from no-load to full-load.

Disadvantages :

- This test is performed on small motors only. In case of large motors, it is difficult to dissipate the large amount of heat generated at the brake.
- The drawback of the brake test is we cannot determine unavoidable errors occurring in spring balance. Due to which there causes errors while determining the losses and efficiency of the machine.
- While performing brake test on series motors, it must ensure that belt on the pulley must be tight enough. Otherwise, the series motors without load or with light loads attain dangerously high speeds.

PART - B (5x16=80marks)

11. a) Draw and explain the typical magnetic circuit with airgap and its equivalent electric circuit.Hence derive the expression for air gap.



Series Magnetic Circuit with an Air gap

Flux Density in an Air Gap:

Let's look at the basic formula to calculate flux density.

Flux density, $B_g = \Phi_g / A_g$

where, B is magnetic flux density in Teslas (T)

Φ is magnetic flux in Webers (Wb)

A is area in square meters (m2)

As we know that permeability of any material can be stated as the ratio of the magnetic flux density to the magnetic field intensity of a material. It can be expressed as below,

$\mu = B / H$

where, μ is permeability of a material, in henrys/meter

H is magnetic field strength, in ampere-turns/meter

B is flux density, in teslas

Solving the above equation for B, we get

$B = \mu \times H$ ..... (Equation 1)

Now, magnetizing force of the air gap is determined as below,

$H = Fm / l$ ..... (Equation 2)

where, Fm is Magnetomotive force (mmf), in ampere-turns, l is length of material (gap), in meters

Substituting the value of H from Equation 2 into Equation 1, we get

$B = \mu \times (Fm/l)$

Solving the above equation for magnetomotive force, we get

$Fm = Bl / \mu$ .... (Equation 3)

Let's assume that we have an air gap, and the permeability of air (free space) is a constant

$\mu_{air} = 4\pi \times 10^{-7}$ H/m

Replacing the value for μ in Equation 3, we come up with a very basic formula for determining the magnetomotive force required to set up a particular flux in an air gap.

$F_m = BL / (4\pi \times 10^{-7})$

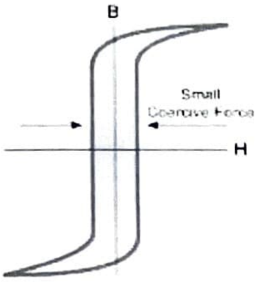
The air gap can take different form, shape and size depending on the type of magnetic circuit and its shape. In some circuits it might be actually an integral part ensuring correct performance of the device, but in other cases it should be as small as possible. Such requirements will be determined by the operating principle, performance, size, efficiency, and many other technological factors.

OR

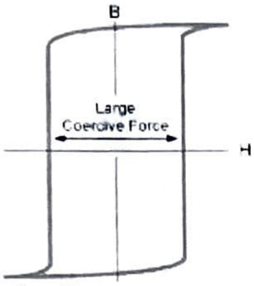
b) Explain the Hysteresis loop that occurs in magnetic circuits in B-H relationship

A hysteresis loop shows the relationship between the induced magnetic flux density B and the magnetizing force H. It is often referred to as the B-H loop. The loop is generated by measuring the magnetic flux B of a ferromagnetic material while the magnetizing force H is changed.

Hysteresis loop



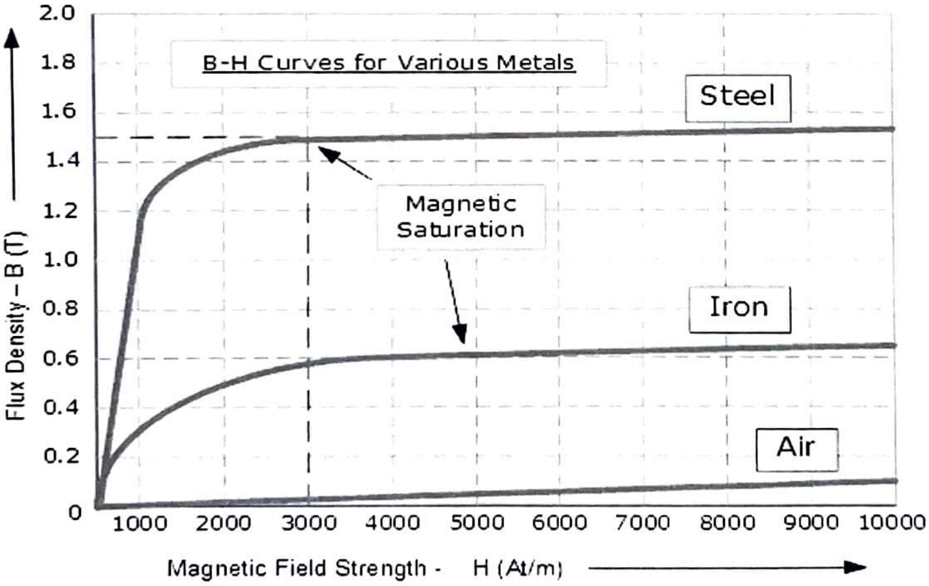
"Soft" Ferromagnetic Material

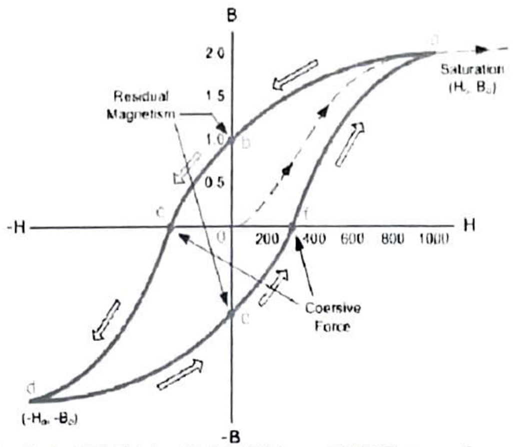


"Hard" Ferromagnetic Material

$$B = \frac{\Phi}{A} \quad \text{and} \quad \frac{B}{H} = \mu_0$$

B-H curves:





12. a) A 20KVA, 2000/200 v, 50 HZ transformer is operated at no-load on rated voltages, the input being 150 W at 0.12 p.f. When it is operating at rated load, the voltage drops in the total leakage reactance and the total resistance are, respectively 2 and 1 % of rated voltage. Determine the input power and power factor when the transformer delivers10 kW at 200 V at 0.8 p.f. lagging to a load on the LV side.

$W_0 = 150$ W

$\cos \varphi_0 = 0.12$ lag

$V_0 = 2000$ V

$P_2 = V_2 I_2 \cos \varphi_2$

$P_2 = 10$ kW

$V_2 = 200$ V

$\cos \varphi_2 = 0.8$ lag

$I_2 = 62.5$ A

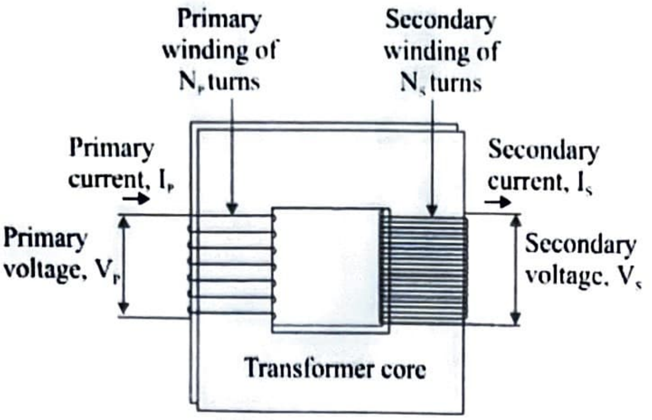
$K = 0.1$

$I'_2 = 6.25$ A

OR

b) Describe the Construction and working principle of a transformer.

Construction and working of transformer: Principle: The principle of transformer is the mutual induction between two coils. That is, when an electric current passing through a coil changes with time, an emf is induced in the neighbouring coil.



Working:

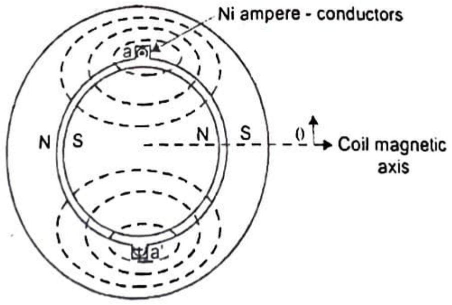
If the primary coil is connected to a source of alternating voltage, an alternating magnetic flux is set up in the laminated core. If there is no magnetic flux leakage, then whole of magnetic flux linked with primary coil is also linked with secondary coil. This means that rate at which magnetic flux changes through each turn is same for both primary and secondary coils. As a result of flux change, emf is induced in both primary and secondary coils. The emf induced in the primary coil εp is almost equal and opposite to the applied voltage v.

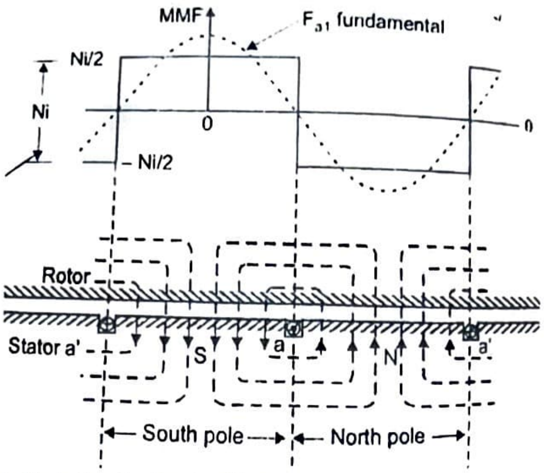
13. a) With neat diagrams, explain the mmf space wave of one phase of a three phase distributed winding in a 2-pole machine and derive the expression for the fundamental mmf wave of the distributed winding in it.

a. An efficient design and satisfactory magnitude of emf to be induced or generated from an ac machine

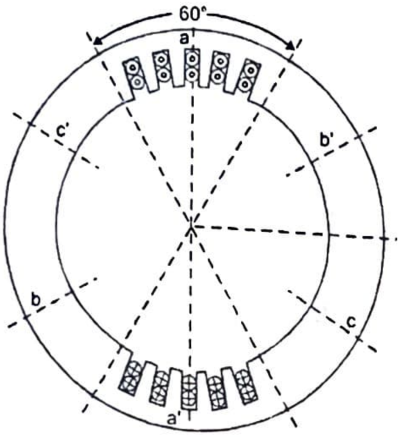
b. It is preferred to have distributed windings in the armature with number of slots distributed over the periphery accommodating open coils of distributed type as an AC machines found to have satisfactory.

MMF in a single coil winding





MMF in a multiple coil distributed winding



Nph=Number of turns per phase

Ic=current in a coil

A=Number of parallel paths

At/parallel path=Nph*ic

AT/phase=Nph.ic.A

AT/ph=Nph.ia

Ia=ic*A

AT/phase/pole=Nph*ia/P

For distributed winding

AT/Ph/Pole=Nph*ia*Kb/P

Peak value of fundamental Fp=4/π *(Ni/P)*ia*Kb

MMF wave instantaneous value $Fa=Fp \cos\theta$

$Fa=4/\pi *(Ni/P)*ia*Kb* \cos\theta$

This equation is satisfactory if the coils are full-pitched.

$Fp=4/\pi *(Nph/P)*ia*Kb*Kp$

$Fa= Fp \cos\theta$

$Fa=4/\pi *(Nph/P)*ia*Kb*Kp* \cos\theta$

$Fa=4/\pi *(Nph/P)*ia*Kb* \cos\theta/2* \cos\theta$

$Kw=Kp*Kb$

$Fa=4/\pi *(Nph/P)*ia*Kw* \cos\theta$

i. From the basic properties chorded distributed windings help a lot I minimizing the effect of harmonics.

Hence the current can be approximated as pure sin wave. $Ia=Im \cos\omega t$

$Fa=4/\pi *(Nph/P)*Im*Kw* \cos\omega t \cos\theta$ $Fa=4/\pi *(Nph/P)*\sqrt{2}*Irms*Kw* \cos\omega t \cos\theta$

$=4\sqrt{2}/\pi *(Nph/P)**Irms*Kw* \cos\omega t \cos\theta$

$Fa=Fm \cos\omega t \cos\theta$ $Fm=4/\pi *(Nph/P)*Irms*Kw\sqrt{2}$

b)Write an example the multiple-excited magnetic field system.

This system has two independent sources of excitations. One source is connected to coil on stator while other is connected to coil on rotor.

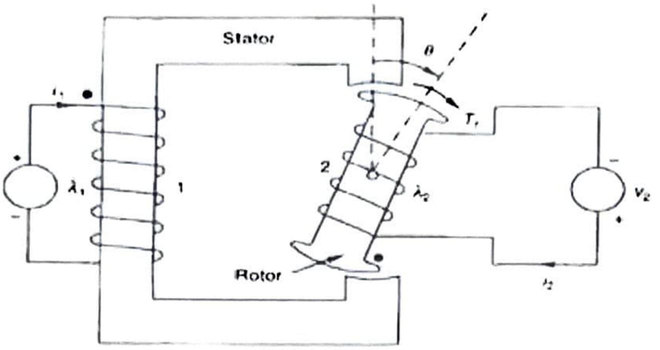
$T_f=-\partial W_f(\lambda 1, \lambda 2,\theta)/ \partial\theta$ Where, the field energy is given by

$Wf(\lambda_1, \lambda_2,\theta) =\int_0^{\lambda 1} i1\, d\lambda 1 \int_0^{\lambda 2} i2\, d\lambda 2$............ 1

Analogous to Equation

$i1=\partial Wf(\lambda 1, \lambda 2,\theta)/ \partial \lambda 1$

$i2=\partial Wf(\lambda 1, \lambda 2,\theta)/ \partial \lambda 2$



$\lambda_1 = L_{11} i_1 + L_{12} i_2$ --- 2

$\lambda_2 = L_{21} i_1 + L_{22} i_2$ ($L_{21} = L_{12}$) --- 3

Solving for i1 and i2 in terms of λ_1, λ_2 and substituting in equation 1

Where the inductances are the functions of angle θ

$i_1 = \beta_{11} \lambda_1 + \beta_{12} \lambda_2$

$i_2 = \beta_{21} \lambda_1 + \beta_{22} \lambda_2$ ($\beta_{21} = \beta_{12}$)

$Wf(\lambda_1, \lambda_2, \theta) = \int_0^{\lambda 1} (\beta_{11} \lambda 1 + \beta_{12} \lambda 2)\, d\lambda 1 + \int_0^{\lambda 2} (\beta_{21} \lambda 1 + \beta_{22} \lambda 2)\, d\lambda 2$

$Wf(\lambda_1, \lambda_2, \theta) = \int_0^{\lambda 1} \beta_{11} \lambda 1\, d\lambda 1 + \int_0^{\lambda 1} \beta_{12} \lambda 2\, d\lambda 1 + \int_0^{\lambda 2} \beta_{21} \lambda 1\, d\lambda 2 + \int_0^{\lambda 2} \beta_{22} \lambda 2\, d\lambda 2$

$Wf(\lambda_1, \lambda_2, \theta) = \beta_{11} \int_0^{\lambda 1} \lambda 1\, d\lambda 1 + \beta_{12} \int_0^{\lambda 1 \lambda 2} d(\lambda 1 \lambda 2) + \beta_{22} \int_0^{\lambda 2} \lambda 2\, d\lambda 2$

$Wf(\lambda 1, \lambda 2, \theta) = 1/2\, \beta_{11} \lambda 1^2 + \beta_{12} \lambda 1\, \lambda 2 + 1/2\, \beta_{22} \lambda 2^2$ $\beta_{11} =$

$L_{22} / (L_{11} L_{22} - L_{12}^2)$

$\beta_{22} = L_{11} / (L_{11} L_{22} - L_{12}^2)$

$\beta_{12} = \beta_{21} = -L_{12} / (L_{11} L_{22} - L_{12}^2)$

The self and mutual inductance of the two exciting coils are functions of angle θ

If currents are used to describe the system state

$T_f = \partial Wf'(\lambda 1, \lambda 2, \theta) / \partial \theta$

Where the co-energy is given by

$Wf'(i_1, i_2, \theta) = \int_0^{i1} \lambda 1\, di1 + \int_0^{i2} \lambda 2\, di2$

$Wf'(i_1, i_2, \theta) = \int_0^{i1} (L11i1 + L12i2)\, di1 + \int_0^{i2} \lambda 2 = (L21i1 + L22i2)\, di2$

$Wf'(i1, i2, \theta) = 1/2\ {}_{11} i_1^2 + {}_{12} i_1 i_2 + 1/2\ {}_{22} i_2^2 L\ LL$

14. a) Drive the emf equation of a d.c generator.

Let

φ=Magneticfluxperpolein Wb

Z=Totalnumberofarmatureconductors

P=Numberofpolesinthemachine
A=Numberofparallelpaths
Where,A=P...forLAPWinding=2...forWaveWinding
N=SpeedofarmatureinRPM
Eg=GeneratedEMF=EMFperparallelpath

Therefore, the magnetic flux cut by one conductor in one revolution of the armature being,

φ=Magneticfluxperpolein Wbdφ=P×φWb
Time taken in completing one revolution is given by,
dt=60Nseconds
Hence, according to law of electromagnetic induction, the emf generated per conductor is,
Eg/Perconductor=dφdt=Pφ60/N=PφN60
Since, the number of conductors in series per parallel path is,
No.of Conductors/ParallelPath=ZA
Therefore,
TotalGeneratedEMF,Eg=EMFPerParallelPath
⇒Eg=(Eg/Perconductor)×(No.ofConducters/ParallelPath
⇒Eg=PφN60×ZA
Hence, the EMF equation of a DC generator is,
Eg=PφNZ60A...(1)
It is clear from eqn. (1), that for any dc generator Z, P and A are constant so that $E_g \propto N_\phi$. Therefore, for a given DC generator, the induced EMF in the armature is directly proportional to the flux per pole and speed of rotation.
Case 1 – For *Lap winding*, number of parallel paths A = P. Thus,
Eg=φNZ60...(2)
Case 2 – For *Wave winding*, number of parallel paths A = 2. Thus,
Eg=PφNZ120...(3)

OR

b) Two coupled coils have self and mutual inductances $L_{11} = 3 + \frac{1}{3X}$; $L_{22} = 1 + \frac{1}{3X}$; $L_{21} = L_{12} = \frac{1}{3X}$. Over a certain range of displacement x. The first coil is excited by a constant current of 10A and second coil by a constant current of -5A. Find the mechanical work done if the x changes from 0.5 to 1 and the energy supplied by each electrical sources.

Solution:

$$W_f^1 = \frac{1}{2}L_{11}i_1^2 + L_{12}i_1i_2 + \frac{1}{2}L_{22}i_2^2$$

$$W_f^1 = \frac{1}{2}\left[3 + \frac{1}{3X}\right](10)^2 + \left[\frac{1}{3X}\right]10.5 + \frac{1}{2}\left[1 + \frac{1}{3X}\right](-5)^2$$

(i) $F_f = \frac{4.166}{x}$

$$\Delta W_m = \int_{0.5}^{1} \Gamma_f . dx$$

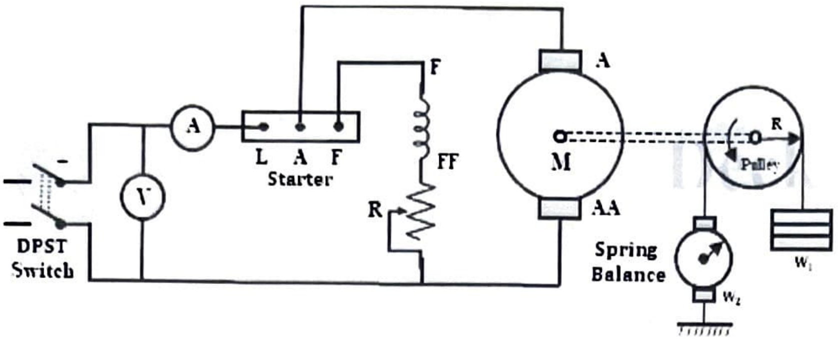
$$\Delta W_m = \int_{0.5}^{1} -\frac{4.166}{X} . dx = -4.166\,J$$

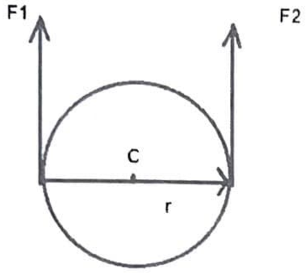
(ii) $\Delta W_{e1} = \int_{0.5}^{1} i_1 . d\lambda$

$$\lambda_1 = L_{11} i_1 + L_{12} i_2$$

$$=$$

$$\lambda_1 \; at \; x_1 = 30 + \frac{1.66}{0.5} = 33.33$$





Here F1 = S1 x 9.8
F2 = S2 x9.8

here acceleration due to gravity g = 9.8 has been taken into account.

As the torque because of force F1 and F2 are opposing each other, therefore net torque will be subtraction of torque because of F1 and F2.
Therefore,
Motor Output = ω (S1 – S2) x r x9.8 Watt
Now assuming the terminal voltage of DC Motor to be V_t and I_L to be the load current then,
Power input to the DC Motor = $V_t I_L$
Thus the efficiency of DC Motor can be calculated as below.
Efficiency = Output / Input
= [ω (S1 – S2) x r x9.8 Watt] / $V_t I_L$
For conducting Brake Test on DC Series Motor, it must be ensured that belt is sufficiently tight before the motor is switched on to the sully as DC Series Motor shall not be started at no load.

Advantages of Brake Test :

- The test requires no other machines thereby reducing the cost and energy.
- This method is very simple.
- Very much convenient for small dc motors.
- The efficiency can be determined under any actual load conditions from no-load to full-load.

Disadvantages of Brake Test :

- This test is performed on small motors only. In case of large motors, it is difficult to dissipate the large amount of heat generated at the brake.
- The drawback of the brake test is we cannot determine unavoidable errors occurring in spring balance. Due to which there causes errors while determining the losses and efficiency of the machine.
- While performing brake test on series motors, it must ensure that belt on the pulley must be tight enough. Otherwise, the series motors without load or with light loads attain dangerously high speeds.

OR

b) Explain any two methods of testing of DC machines.
The main tests used for DC machines are:

- Open circuit test
- Short circuit test
- Load test
- Determination of efficiency

Open circuit test

The open circuit test is needed to determine the open circuit characteristic or magnetizing characteristic of a dc machine. The open circuit test gives the mmf and hence the excitation current or field current needed to generate the required voltage on no load at a fixed speed. The open circuit characteristic curve shows the variation of induced emf as a function of field current at constant speed and zero load current.

Short Circuit Test

The short circuit test is needed to determine the voltage drop across the armature at any load current. In this **testing of DC machine** the armature is short circuited with an ammeter to get the short circuit current. Short circuit test gives the short circuit characteristic curve which shows the variation of short circuit current as a function of excitation current.

Load test

The load testing of DC machine is needed to determine the rating of a machine. When we run a machine, then some energy is lost in the machine, which converts into the heat and cause temperature rise. If a machine produces too much heat then it can affect the insulation of the machine and ultimately it can cause the breakdown of the machine.

Determination of Efficiency

$$Efficiency\ (\eta) = \frac{output}{input} \quad \cdots\cdots(1)$$

$$or,\ \eta = \frac{input - losses}{input} \quad \cdots\cdots(2)$$

$$or,\ \eta = \frac{output}{output + losses} \quad \cdots\cdots(3)$$

The efficiency of DC machine like any other machine is determined by the ratio of output power to that of the input power.

There are three methods of determining the efficiency of a machine:

1. Direct method
2. Indirect method
3. Regenerative method

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

SUBJECT CODE:EE8301-ELECTRICAL MACHINES-1
TEST PERIOD ANALYSIS

INTERNAL MARKS STATEMENT

S.NO	REG.NO	NAME OF THE STUDENT	IM2	IM3	IM4
1	912519105001	ILANDEVAN S	89	89	86
2	912519105002	KALEESWARAN S	92	82	89
3	912519105003	KALIRAJAN K	86	80	82
4	912519105004	MARIMUTHU K	91	86	89
5	912519105006	RAMANAN S	89	84	91
6	912519105007	VIGNESHWARAN A	95	81	96
7	912519105008	VILLAVAN S	91	80	92
8	912519105301	PRAGATHI P	92	93	91
9	912519105302	PRIYANKA R	89	90	93
10	912519105303	SURESHPANDI R	86	88	84
11	912519105304	VEERAMANIKANDAN P	91	91	92

INTERNAL 1 :

ALL CLEAR	75-80	81 -90	91-100
11	NIL	5	6

INTERNAL 2:

ALL CLEAR	75-80	81 -90	91-100
11	2	7	2

INTERNAL 3 :

ALL CLEAR	75-80	81 -90	91-100
11	NIL	5	6

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

NAME OF THE STAFF: R. ASHABOSHINI **CLASS:II– EEE**

SEMINAR GIVEN DATE: 07. 10. 2020 **SEMINAR TAKEN DATE:** 16-10-202

S.NO	NAME OF THE STUDENT	TOPIC
1	ILANDEVAN.S	AC operation of magnetic circuits
2	MARIMUTHU.K	Tap Changing of transformer
3	KALIRAJAN.K	Auto transformer
4	VIGNESHWARAN.A	Characteristics of DC generator
5	PRIYANKA.R	Hopkinson's test
6	VEERAMANIKANDAN.P	Stater

SRI RAAJA RAAJAN COLLEGE OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
ASSIGNMENT TOPICS

S.NO	REGISTER NO	NAME	DATE	ASSIGNMENT TOPICS
1.	912519105002	S.KALEESWARAN	10-10-2020	Magnetic circuit
2.	912519105006	S.RAMANAN	22-10-2020	PARALLEL OPERATION OFTRANSFORMERS
3.	912519105007	A.VIGNESWARAN	06-11-2020	Armature reaction of D.C machines