Basic Electrical Engineering

Unit No. -1

ELECTROMAGNETISM

Review: EMF, Potential Difference, Current, Resistance

Q.1 Distinguish between resistance and resistivity and state the factors on which resistance and resistivity depends.

Ans: ***<u>Resistance:</u>*** *It is defined on the actual opposition to the flow of current through the material or substance.*

It is denoted by a symbol (R) and it's unit is ohm (Ω). The mathematical expression for resistance is,

$$R = \rho \frac{l}{a} \qquad \ldots \ldots (1)$$

Where,

ρ= Resistivity of material (Ω m),

l = Length of material (m),

a = Cross-sectional area (m^2)

<u>Factors Governing the Resistance Value</u>

From the expression of resistance (Equation 1)

The resistance depends upon the following factors

1. ***Length*** **(l) :** Resistance is directly proportional to length it means as the length of conductor increases, it's resistance also increases and vice-versa.
2. ***Cross-sectional area*** **(a) :** Resistance is inversely proportional to cross sectional area, it means as the cross-sectional area of conductor increases, it's resistance decreases and vice versa.
3. ***Type of material:*** The resistance of material depends on the type of material used.
4. ***Temperature:*** As the temperature of the material changes the resistance also changes. Generally, for conducting materials, as temperature increases, the resistance also increases.

<u>Resistivity</u>: *It is the property by virtue of which it opposes the flow of current.*

Being property it is independent of physical dimensions. It can be measured by considering the specimen of the same material.

<u>Factor governing the Resistivity:</u>

1. **Temperature:** As the temperature of the material increases, it is found that resistivity also increases.
2. **Addition of Impurity:** Resistivity also changes by adding impurity in the material.
3. **Cold Working:** Resistivity also changes with the process of cold working.
4. **Age Hardening:** Due to age hardening, the resistivity of the material also changes.

♦ *Magnetic Circuit*

Q.2 Define the following terms related to magnetic circuit

(i) Magnetic flux (ii) Magnetic flux density (iii) Magnetic field strength (iv)Reluctance (v) Permeance (vi) MMF (vii) Permeability (viii) Absolute permeability (ix)Relative permeability

(i) Magnetic Flux (∅): *The total number of lines of force existing in a particular magnetic field is called magnetic flux.*

The unit of flux is *Weber (wb)* and flux is denoted by symbol (∅).

(ii) Magnetic Flux Density (B): *It can be defined as 'The flux per unit area (a) in a plane at right angles to the flux is known as 'flux density'.*

Mathematically, $B = (\emptyset/a)$

The unit of flux density is $\frac{wb}{m^2}$, also called *Tesla* and denoted as *T*.

(iii) Magnetic Field Strength/ Magnetizing Force/Magnetic Field Intensity (H)

It can be defined as 'the force experienced by a unit N-pole (i.e. N-pole with 1 Wb of pole strength), when placed at any point in a magnetic field is known as magnetic field strength at that point.

For Straight conductor $H = \frac{I}{2\pi r}$

For Solenoid/ Toroid $H = \frac{NI}{l}$

Its unit is *Newton per Weber* i.e. *(N/Wb)* or *Amperes per meter (A/m)* or *Ampere Turns per meter (AT/m)*.

(iv) Reluctance(S): *The opposition offered by the magnetic material to the passage of magnetic flux is called it's reluctance.*

$$S = \frac{l}{\mu_0 \, \mu_r a} \qquad \text{It's unit is } AT/wb$$

***(v)* Permeance:** *It is reciprocal of reluctance and is defined as ease or readiness with which magnetic flux gets developed and is analogous to conductance in an electric circuit.*

$$Permeance = \frac{1}{S} \qquad \text{It's unit is } W_b/AT$$

***(vi)* Magneto motive Force (MMF):** *It is the force required to produce flux in a magnetic circuit.*

$$MMF,\ F = NI = \emptyset S = Hl$$

It's unit is *AT* and corresponds to electromotive force (EMF) in an electric circuit.

(vii)Permeability: *It is defined as ability or ease with which the magnetic flux permeates through a given medium.*

(viii) Absolute permeability (μ): *The ratio of magnetic flux density (B) in a particular medium (other than vacuum or air) to magnetic field strength (H) producing that flux density is called absolute permeability of that medium.*

$$\boldsymbol{\mu = \frac{B}{H}}$$

Its unit is *Henry per metre (H/m).*

(ix)Relative Permeability (μ_r) : *Relative permeability of a material is equal to the ratio of the flux density produced in the material to the flux density produced in vacuum by the same magnetizing force (H).*

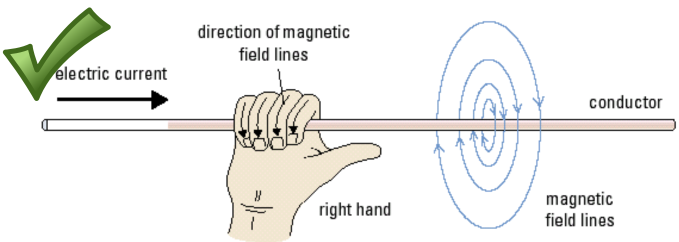
$$\mu_r = \frac{\textbf{B (Material)}}{\textbf{Bo(Vacuum)}} \qquad \mu = \mu_0\, \mu_r$$

Q.3 State (i) Right Hand Thumb rule (ii) Fleming's left hand rule (iii) Fleming's right hand rule. State significance of each.

(i) Right Hand Thumb Rule

This rule is used to find direction of magnetic flux produced by current carrying conductor/coil.

Statement: It states that, "*Hold the current carrying conductor in the right hand such that the thumb pointing in the direction of current and parallel to the conductor, then curled fingers points in the direction of the magnetic flux around it.*"

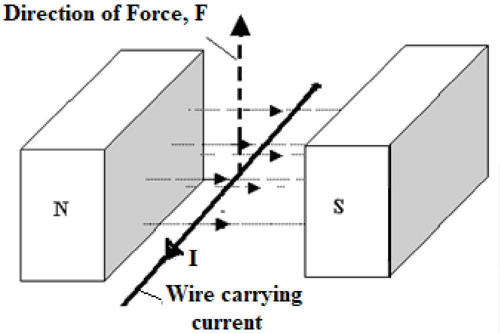


In above case, as per direction of current, the conductor produces flux in clock wise direction. If direction of current is reversed, the conductor produces flux in reverse (anticlockwise) direction.

(ii) Flemings Left hand rule:

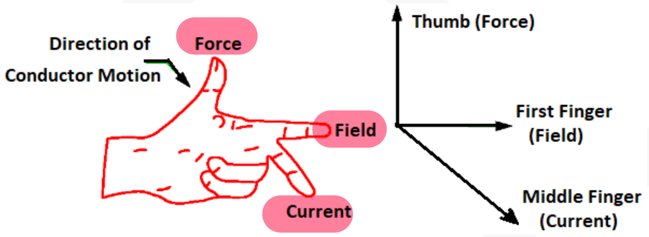
Fleming's left hand rule is used to find direction of the force experienced by current carrying conductor.

Consider a conductor carrying current of ***I*** amp. As per current direction it produces flux around it. So there will be two fluxes. One due to poles and other due to current carrying conductor. Inter reaction between two fluxes, causes the conductor to move in certain direction. Fleming's left hand rule will help to get direction of conductor movement or direction of force.



Statement:

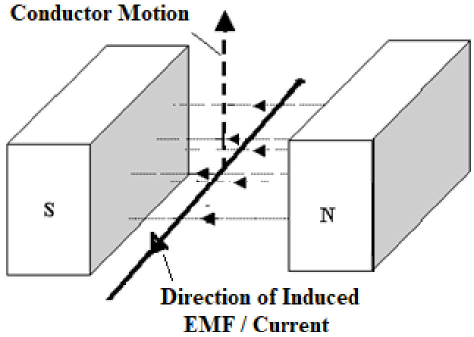
Arrange three fingers of left hand mutually perpendicular to each other. If the forefinger and middle finger gives the direction of magnetic field and current respectively, then the direction of force is given by thumb.



(iii) Fleming's right hand rule

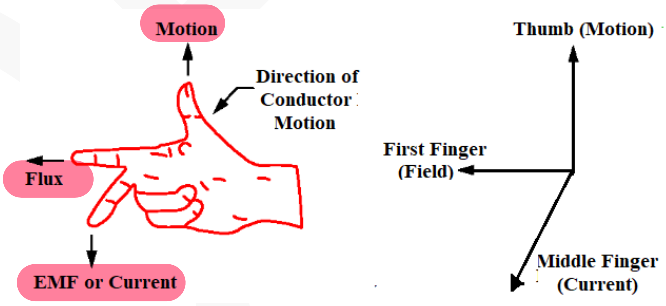
Fleming's right hand rule is used to find direction of the EMF / current induced in the conductor.

The conductor inside the magnetic field is moved in upward direction with some external arrangement. The conductor cuts flux due to its movement inside magnetic field. The cutting of flux induces an EMF inside the conductor. Fleming's right hand rule will help to get direction of induced EMF or current.



Statement:

Arrange three fingers of right hand mutually perpendicular to each other. If the forefinger and thumb gives the direction of magnetic field and conductor movement (motion) respectively, then middle finger gives direction of induced emf / current.



Q. Define Reluctance. State the factors on which it depends

Reluctance is defined as the opposition offered by the magnetic material to the passage of magnetic flux is called it's reluctance.

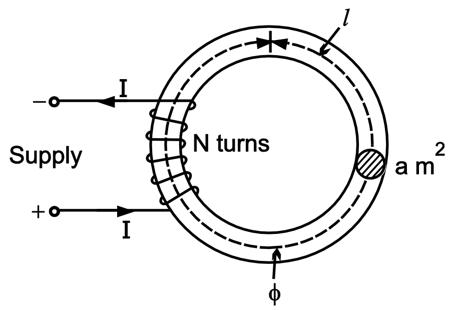
$$S = \frac{l}{\mu_0 \mu_r a}$$ It's unit is *AT/wb*

Factors on which Reluctance depends

1. Length of the magnetic path
2. Relative permeability of the magnetic material
3. Cross section area of the magnetic path

Q. Find the relation between MMF, Reluctance and flux in case of simple magnetic circuit.

Consider a solenoid or a toroidal iron ring having a magnetic path of l meter, area of cross section **a** m^2 and a coil of N turns carrying I amperes wound on it as shown in figure



The magnetic field strength inside the solenoid is

$$H=\frac{NI}{l}\,\frac{AT}{m}$$

Now, $B=\mu_o\mu_r H = \dfrac{\mu_o\mu_r NI}{l}$ Wb/m^2

Total flux $\phi = B \times a = \dfrac{\mu_o\mu_r aNI}{l}$ Wb

$\therefore\ \phi = \dfrac{NI}{l/\mu_o\mu_r a}$ Wb

The numerator *'NI'* which produces a magnetization in magnetic circuit is known as magneto motive force (MMF)

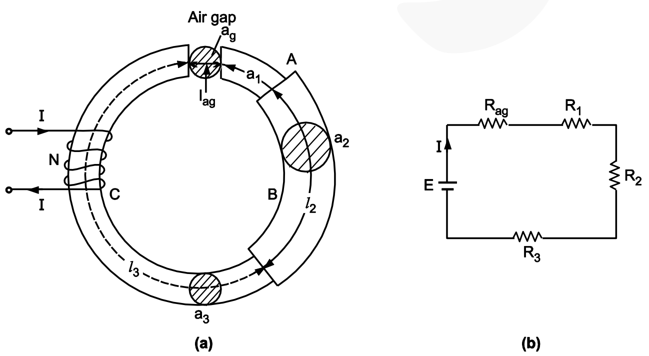
Obviously it's unit is Ampere Turn (AT). It is analogous to EMF in an electric circuit.

The denominator $\dfrac{l}{\mu_o\mu_r A}$ is called the reluctance of the circuit and is analogous to resistance in electric circuits.

$\therefore$ Flux$=\dfrac{\text{m.m.f.}}{\text{Reluctance}}$

Or $\phi=\dfrac{F}{S}$

Q.4 Explain Series Magnetic Circuit



a) Series magnetic circuit (b) Equivalent Electrical Circuit

Figure shows a composite series magnetic circuit consisting of three different magnetic materials A, B, C of different permeabilities μ_{r1}, μ_{r2} and μ_{r3} and lengths l_1, l_2 and l_3 and one air gap ($\mu_r = 1$). Each path will have its own reluctance.

The total reluctance is the sum of individual reluctances as they are joined in series.

$$\text{Total reluctance } S_T = \sum\frac{l}{\mu a}$$

= reluctance of A + reluctance of B + reluctance of C + reluctance of air

$$=\frac{l_1}{\mu_0\mu_{r1}\,a_1}+\frac{l_2}{\mu_0\mu_{r2}\,a_2}+\frac{l_3}{\mu_0\mu_{r3}\,a_3}+\frac{l_{ag}}{\mu_0 a_g}$$

$$Flux\ \emptyset = \frac{Total\ MMF}{S_T} \quad \text{as} \quad NI = \emptyset\, S_T$$

Total MMF= $NI=\emptyset$ (*reluctance of part A, B & C+ reluctance of air*) $=\emptyset\,(S_T)$

$$=\emptyset\left[\frac{l_1}{\mu_0\mu_{r1}\,a_1}+\frac{l_2}{\mu_0\mu_{r2}\,a_2}+\frac{l_3}{\mu_0\mu_{r3}\,a_3}+\frac{l_{ag}}{\mu_0 a_g}\right]$$

Also $H=\dfrac{NI}{l}\dfrac{AT}{m}$ Or $NI=H\,l$

$$\text{Total MMF}=\emptyset\left[\frac{l_1}{\mu_0\mu_{r1}\,a_1}+\frac{l_2}{\mu_0\mu_{r2}\,a_2}+\frac{l_3}{\mu_0\mu_{r3}\,a_3}+\frac{l_{ag}}{\mu_0 a_g}\right]$$

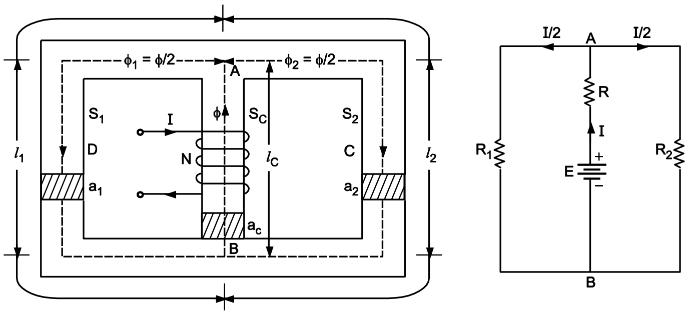
$$=\frac{\emptyset}{a_1}\frac{1}{\mu_0\mu_{r1}}[l_1]+\frac{\emptyset}{a_2}\frac{1}{\mu_0\mu_{r2}}[l_2]+\frac{\emptyset}{a_3}\frac{1}{\mu_0\mu_{r3}}[l_3]+\frac{\emptyset}{a_g}\frac{1}{\mu_0 a_g}[l_{ag}]$$

$$=B_1\frac{1}{\mu_0\mu_{r1}}[l_1]+B_2\frac{1}{\mu_0\mu_{r2}}[l_2]+B_3\frac{1}{\mu_0\mu_{r3}}[l_3]+B_g\frac{1}{\mu_0 a_g}[l_{ag}]$$

$$NI=H_1[l_1]+H_2[l_2]+H_3[l_3]+H_g[l_{ag}]$$

Q.5 Explain Parallel Magnetic Circuit

Figure shows the parallel magnetic circuit consisting of three parallel magnetic paths ACB, ADB and AB acted upon by the same MMF



(a) Parallel magnetic circuit (b)Equivalent Electrical Circuit

The flux produced by the coil wound on central core is divided equally at point A between the two outer parallel paths. Fig. (b) Shows the equivalent electrical circuit where the resistance offered to the EMF source is $R \parallel R = \dfrac{R}{2}$.

$\therefore$ Flux ϕ divides equally at point A

$\therefore$ Current I divides equally at point A

The mean length of path ADB $= l_1$ m

The mean length of path ACB $= l_2$ m

The mean length of path AB $= l_c$ m

The reluctance of path ADB, ACB and AB is S_1, S_2 and S_C $\dfrac{AT}{Wb}$ respectively

For path ADBA, NI= $\phi S_c + \phi_1 S_2$

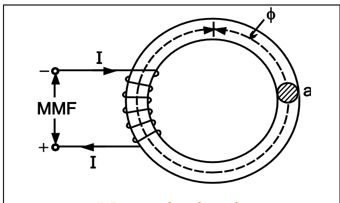
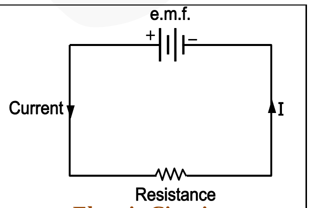
For path ACBA, NI= $\phi S_c + \phi_2 S_2$

where, $S_1 = \dfrac{l_1}{\mu_0 \mu_{r1} a_1}$; $S_2 = \dfrac{l_2}{\mu_0 \mu_{r2} a_2}$

$S_c = \dfrac{l_c}{\mu_0 \mu_{rc} a_c}$

Total MMF = $\phi S_c + \phi_1 S_1 = \phi S_c + \phi_2 S_2$

Q. 6 Compare electrical and magnetic circuits

 Magnetic circuit	 Electric Circuit
Similarities	
Provides path for magnetic flux	Provides path for electric current
MMF (F) ; Amp Turn	EMF (E) ; Volt
Flux (Ø); Wb	Current (I); Amp
$\emptyset = \dfrac{MMF}{Reluctance}$	$I = \dfrac{EMF}{Resistance}$
Reluctance $(S) = \dfrac{l}{\mu_0 \mu_r a}$	Resistance $(R) = \rho \dfrac{l}{a}$
Permeance = $\dfrac{1}{\text{Reluctance}}$	Conductance = $\dfrac{1}{\text{Resistance}}$
Flux density; $B = \dfrac{\emptyset}{a}$ (wb/m^2)	Current density; $J = \dfrac{I}{a}$ (A/m^2).
Permeability	Conductivity
Kirchhoff's MMF and flux law is applicable to the magnetic circuit.	Kirchhoff's voltage and current law is applicable to the electric circuit.

Dissimilarities

Magnetic Circuit	Electric Circuit
Flux does not actually flows in the sense which current flows.	The current actually flows i.e. there is movement of electrons in electric circuit.
No magnetic insulator as flux can pass through all the materials, even air.	Many insulators like air, P.V.C., synthetic resin etc. from which current cannot pass.
Energy is required to create the magnetic flux, but not required to maintain it.	Energy must be supplied continuously to maintain the flow of current.
Reluctance of a magnetic circuit depends on flux (and hence flux density).	Resistance of an electric circuit is constant and is independent of the current (or current density) as long as temperature is kept constant.

♦ *Electromagnetic Induction*

State faradays first and second laws of electromagnetic induction

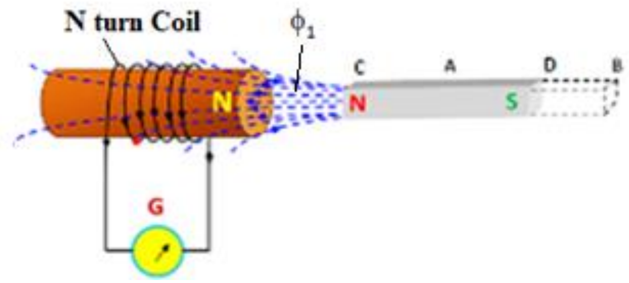
Faradays first law:

An EMF get induced in the coil or conductor, when the magnetic flux linking with it changes.

Faradays second law:

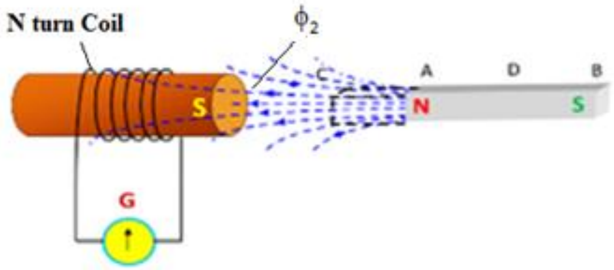
The magnitude of EMF induced is directly proportional to the rate of change of flux linkages.

Consider a coil having N turns. The initial flux linking with coil is Φ_1.



Hence, initial flux linkages=$N\,\Phi_1$.

When, the position of the magnet is changed, then the flux linking with coil changes to Φ_2 within the time interval of dt seconds.



Hence, Final Flux linkages=$N\,\Phi_2$.

Rate of change of flux linkages=$\frac{N\,\Phi_2 - N\,\Phi_2}{dt}$

As per second law, $e = \frac{N\,\Phi_2 - N\,\Phi_2}{dt} = N\frac{d\Phi}{dt}$

This EMF induced in coil produces a current in such a direction to oppose the main cause responsible for producing it **(Lenz's Law)**

Thus the induced emf is mathematically expressed as $e = -N\frac{d\Phi}{dt}$

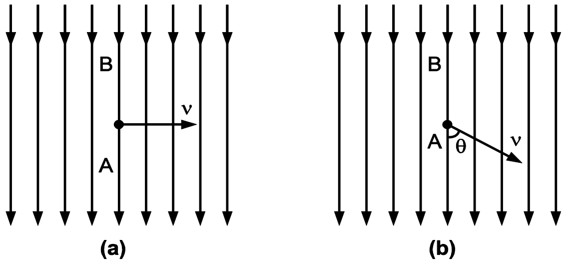
Q 7. Explain the following terms:

1. Dynamically EMF 2. Statically induced EMF

Ans: **1. Dynamically induced EMF:** *The EMF induced in a conductor due to the relative physical movement with respect to steady magnetic field.*

Explanation: Consider conductor A of length 'l' mtr. as shown below within a uniform magnetic field of B wb/m^2.

Suppose the conductor moves through a small distance dx in dt seconds, across the right angle to the magnetic field. The area swept by the conductor is l dx.



According to Faraday's law of electromagnetic induction, EMF induced in the conductor is given by,

$$EMF\ Induced = \frac{Flux\ Cut}{Time}$$

Flux cut by conductor = Flux density x area swept by conductor = $B\ (\ l\ dx)$

$$EMF\ Induced = \frac{Flux\ Cut}{Time} = \frac{B\ l\ dx}{dt} = Blv\quad volt$$

If the conductor moves at an angle θ to the magnetic field then e.m.f. induced in the conductor,

$$EMF\ Induced = Blv\ sin\theta\quad volt$$

The direction of the induced EMF can be determined by *Fleming's right hand rule*.

Example: D.C. Generator.

2. Statically induced EMF:

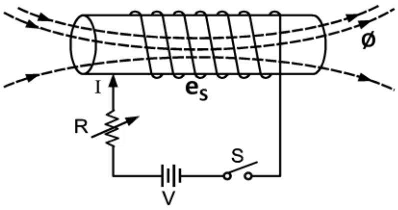
The EMF induced in a conductor when it links with time varying magnetic field without any relative physical movement with respect to magnetic field.

Statically induced EMF is further divided into following types:

Self Induced EMF

Self-induced EMF is the EMF induced in the coil due to the varying flux produced by it linking with its own turns.

Explanation: As shown in Fig., when the current through the coil is changed by changing resistance inserted in series with it, a magnetic field produced gets changed.



This variable flux when links with coil induces an EMF in the coil. This EMF is known as *self-induced EMF*. The EMF induced in terms of Inductance L is given as

$$e_s = -L\frac{di}{dt}$$

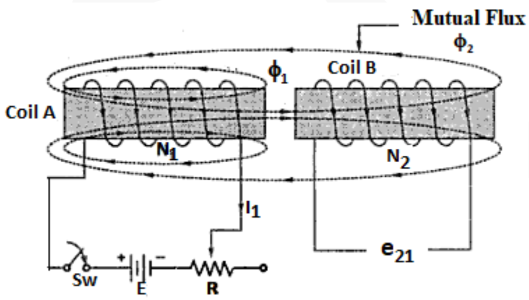
The EMF induced in the primary winding of the transformer is a good example of statically self-induced EMF.

Mutually Induced EMF

EMF induced in a coil when varying magnetic flux created by some other coil links with it.

Example: EMF induced in the *secondary winding* of the *transformer.*

Explanation:



Let us consider the two ***coils A*** and ***B*** placed adjacent to each other as shown in Figure. Part of the flux produced by ***coil A*** links the ***coil B***. If the current flowing through ***coil A*** changes, the flux produced by ***coil A*** changes. Hence the flux linking to the ***coil B*** also changes, thus EMF is induced in the ***coil B***. The EMF induced in the ***coil B*** is called as *mutually induced EMF*. The magnitude of mutually-induced EMF is given by

$$e_M = e_{21} = -N_2\frac{d\phi_2}{dt} = -\frac{N_2\,\phi_2}{I_1}\frac{di_1}{dt} = -M\frac{di_1}{dt}$$

(EMF induced in second coil due to current change in first coil)

$$e_M = e_{12} = -N_1\frac{d\phi_1}{dt} = -\frac{N_1\,\phi_1}{I_2}\frac{di_2}{dt} = -M\frac{di_2}{dt}$$

(EMF induced in first coil due to current change in second coil)

Q8. Define the following terms

1. Self inductance 2. Mutual inductance

1. Self inductance

When current in the coil increases, the changing magnetic field produced by the current links with coil, hence according to Faraday's law's an EMF is induced in the coil. The EMF induced in the coil opposes the cause producing it i.e. it opposes increase in current in the coil. When current in the coil decreases, the changing magnetic field again induces EMF in the coil which opposes decrease in current in the coil.

This property of the coil which opposes change in current through it is called as self inductance or inductance of the coil.

$$L = \frac{N\phi}{I} = \frac{N^2}{S} = \frac{N^2\mu_0\mu_r a}{l}\ Henry$$

2. Mutual inductance

A coil possesses an inductance whenever the flux linking with it is changed. If the flux produced by some another coil get linked with coil then the inductance possessed by the coil is called as mutual inductance.

The mutual inductance is defined as it is flux linkage to one coil with respect to change in current in other coil. It is denoted by M and measured in *Henry.*

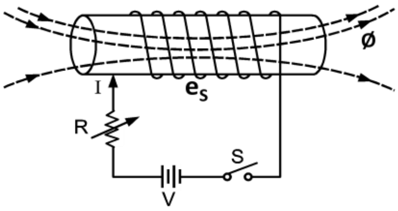
$$M = \frac{N_2\phi_2}{I_1} = \frac{N_1\phi_1}{I_2} = \frac{N_1N_2}{S} = \frac{N_1N_2\mu_0\mu_r a}{l}\ Henry$$

Q 9. Derive Expression for following terms

1. Self-induced EMF and Self Inductance

2.Mutually induced EMF and Mutual Inductance

Self Induced EMF



A coil possesses an inductance whenever the flux linking with it is changed. If the own flux link with the coil then the inductance possessed by the coil is called as self-inductance.

As shown in above figure, current I is responsible for producing flux ϕ. Therefore,

$$\phi \propto i$$

$$\phi = Ki$$

$$K = \frac{\phi}{I} \quad = \text{constant}$$

The flux ϕ can be written as,

$$\phi = \frac{\phi}{I} \; i$$

$$\phi = \frac{\phi}{I} \; i$$

Differentiating, $\frac{d\phi}{dt} = \frac{\phi}{I}\frac{di}{dt}$ …(1)

When current i in the coil is changed EMF induced in the coil is given by,

$$E = -N\frac{d\phi}{dt}$$

From equation (1), $e = -N\frac{\phi}{I}\frac{di}{dt}$

$$\boxed{e = -L\frac{di}{dt}} \quad \text{…(A)}$$

Self Inductance

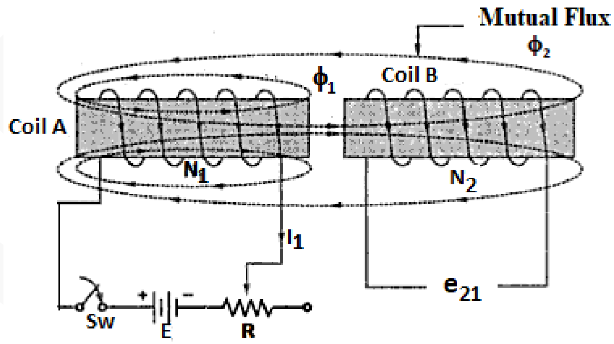
where, $L = \frac{N\phi}{I}$ …(B)

L $\rightarrow$ Self inductance of the coil

Mutual Induced EMF

If the flux produced by some another coil get linked with coil then the inductance possessed by the coil is called as mutual inductance.

The mutual inductance is defined as it is flux linkage to one coil with respect to change in current in other coil. It is denoted by M and measured in Henry.



Let, ϕ_1 : Flux produced by current I_1 again called as self-flux of coil A.

ϕ_2 : Part of ϕ_1 linking with coil B, again called as mutual flux.

As $\phi_2 \propto \phi_1$ and

$$\phi_1 \propto i_1$$

$$\therefore \phi_2 \propto i_1$$

$$\phi_2 = K\, i_1$$

$$K = \frac{\phi_2}{I_1} \quad = \text{constant}$$

$$\phi_2 = \frac{\phi_2}{I_1} \cdot i_1$$

Differentiating, $\frac{d\phi_2}{dt} = \frac{\phi_2}{I_1}\frac{di_1}{dt}$ …(1)

When ϕ_{21} links with coil B, according to Faraday's law a mutually induced e.m.f. e_{21} is induced in coil B given by:

$$e_{21} = -N_2\frac{d\phi_2}{dt}$$

From (1) $e_{21} = \frac{-N_2\phi_2}{I_1}\frac{di_1}{dt}$

$$e_{21} = -M\frac{di_1}{dt} \quad \text{…(A)}$$

This is magnitude of mutually induced e.m.f.

Mutual Inductance

$$M = \frac{N_2 \phi_2}{I_1}$$

=Mutual inductance

As ϕ_2 is part of ϕ_1

$\therefore \phi_2 = K_1 \phi_1$

K_1 indicate amount of flux linking with coil B

$$\therefore M = \frac{N_2 K_1 \phi_1}{I_1} \qquad \ldots(2)$$

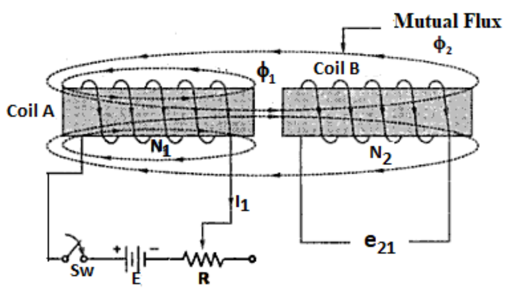
Q 10. State the factors on which self inductance and mutual inductance depends.

The self and mutual inductance's are given as…

$$L = \frac{N^2 \mu_0 \mu_r A}{l}, \qquad M = \frac{N_1 N_1 \mu_0 \mu_r A}{l}$$

1. Self-inductance is directly proportional to square of *number of turns* of the coil.
2. Mutual inductance is directly proportional to product of *number of turns* of both coils.
3. They are directly proportional to *cross sectional area* of magnetic circuit.
4. They are inversely proportional to *length* of magnetic circuit.
5. They are directly proportional to *relative permeability* (μ_r) of core. Coils having magnetic material as a core possesses large inductance as compared to the coils having non-magnetic material as a core like air possesses less inductance.
6. As μ_r varies with flux density, the inductance varies with respect to flux density.

Q11. Derive expression for coefficient of coupling.



The mutually induced EMF in coil B due to current I_1 is..

$$e_{21} = -M \frac{di_1}{dt} \qquad \text{---(1)}$$

The mutually induced EMF in coil A due to current I_2 is..

$$e_{12} = -M \frac{di_2}{dt} \qquad \text{---(2)}$$

Hence, the mutual inductance between the two coils is given by ………

$$M = \frac{N_2 \emptyset_2}{I_1} = \frac{N_2 K_1 \emptyset_1}{I_1} \qquad \text{---(3)}$$

$$M = \frac{N_1 \emptyset_1}{I_2} = \frac{N_1 K_2 \emptyset_2}{I_2} \qquad \text{---(4)}$$

Multiplying equation (1) and (2)

$$M^2 = \frac{N_2 K_1 \emptyset_1}{I_1} \frac{N_1 K_2 \emptyset_2}{I_2} = K_1 K_2 \frac{N_1 \emptyset_1}{I_1} \frac{N_2 \emptyset_2}{I_2}$$

$$M^2 = K_1 K_2 \, L_1 L_2$$

where, $L_1 = \frac{N_1 \emptyset_1}{I_1}$ and $L_2 = \frac{N_2 \emptyset_2}{I_2}$

Taking square root

$$M = \sqrt{K_1 K_2} \, L_1 L_2$$

Whenever there is 100% flux linkage between two coils, the mutual inductance between the two coils is said to be maximum. ($K_1 = K_2 = 1$)

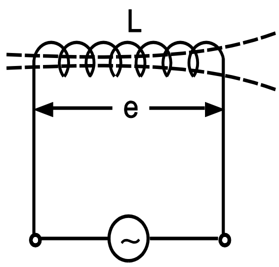
If $K = \sqrt{K_1 K_2}$

Then coefficient of coupling

$$K = \frac{M}{\sqrt{L_1 L_2}} \qquad \text{---(5)}$$

From above equation coefficient of coupling is defined as *it is a ratio of actual mutual inductance between the two coils to maximum possible mutual inductance between two coils.*

Q12. Derive expression for energy stored in inductor per unit volume.



When the coil of inductance 'L' Henry is connected across supply, the lines of forces are created.

Due to the lines of force linking to the coil, EMF is induced in the coil. It is given as

$$e = -L\frac{di}{dt}$$

But e = –v (as induced e.m.f. is always opposed by the cause producing it as per Lenz's law)

$$-v = -L\frac{di}{dt} \quad , \quad v = L\frac{di}{dt} \quad \ldots (1)$$

Multiplying both sides of equation (1) by $i\,dt$ we have

$$v\,i\,dt = L\,i\,di$$

But $v\,i\,dt$ be the electrical energy supplied to the coil by source.

Total energy supplied by the source to the coil when current varies from 0 to I

$$Energy\ stored\ = \int vidt\ = \int_0^I Lidi$$

$$= L\left[\frac{i^2}{2}\right]_0^I = \frac{1}{2}LI^2 \text{ Joule}$$

Energy stored per unit volume

$Energy\ stored = \frac{1}{2}\frac{N\emptyset}{I}I^2 = \frac{1}{2}NI\emptyset$ (As $L = \frac{N\emptyset}{I}$)

Also $MMF = NI = Hl\ \ and\ \emptyset = B\,a$

$Therefore\ Energy\ stored = \frac{1}{2}BHal$

(where $a\,l$ is the volume)

Energy stored per unit volume $=\frac{1}{2}BH\ \ Joule$

List of Formulas

- $B = \frac{\emptyset}{a}$
- $H = \frac{NI}{l}$;
- $\mu = \mu_0\,\mu_r$;
- $MMF = NI = \emptyset S = Hl$;
- $s = \frac{l}{\mu_0\,\mu_r a}$
- e $=-N\frac{d\emptyset}{dt}$ Volt;
- e $= Blv\,sin\theta\ \ volt$;
- $e_s = -L\frac{di}{dt}$
- $e_M = e_{21} = -N_2\frac{d\emptyset_2}{dt} = -\frac{N_2\,\emptyset_2}{I_1}\frac{di_1}{dt} = -M\frac{di_1}{dt}$;
- $e_M = e_{12} = -N_1\frac{d\emptyset_1}{dt} = -\frac{N_1\,\emptyset_1}{I_2}\frac{di_2}{dt} = -M\frac{di_2}{dt}$
- $L = \frac{N\emptyset}{I} = \frac{N^2}{S} = \frac{N^2\mu_0\mu_r a}{l}$;
- $M = \frac{N_2\emptyset_2}{I_1} = \frac{N_1\emptyset_1}{I_2} = \frac{N_1N_2}{S} = \frac{N_1N_2\mu_0\mu_r a}{l}$
- $M = K\sqrt{L_1L_2}$
- Energy Stored$=\frac{1}{2}LI^2$ Joule;
- Energy Stored per unit volume $= \frac{1}{2}BH$ Joule

Solved Numericals

Part A: Magnetic Circuit

1) A straight conductor 40 cm long carries a current of 12 A and lies at right angles to a uniform field of 2.5 Wb/m^2. Find the mechanical force on the conductor when (*i*) it lies in the given position (*ii*) it lies in a position such that it is inclined at an angle of 30° to the direction of field.

Force Experienced by current carrying Conductor,

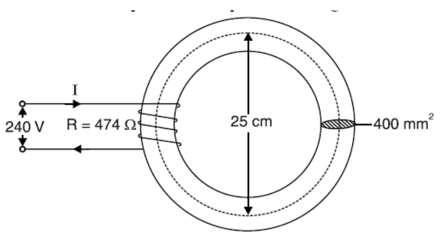
$F = BIl \sin\theta$ Newton

(i)When θ=90^0, F=2.5x 12x 0.4xsin90=**12 N**

(ii)When θ=30^0, F=2.5x12x0.4x sin 30=**6 N**

2) An iron ring has a cross-sectional area of 400 mm^2 and a mean diameter of 25 cm. It is wound with 500 turns. If the value of relative permeability is 250, find the total flux set up in the ring. The coil resistance is 474 Ω and the supply voltage is 240 V.

Solution:



Current through the coil,

$I = V/R = 240/474 = 0{\cdot}506$ A

Mean length of magnetic circuit is given by ; $l = \pi \times (25 \times 10^{-2}) = 0.7854$ m

Magnetizing force, $H = (NI)/l$

$= (500 \times 0.506)/0.7854 = 322.13$ AT/m

Flux density, $B = \mu_0\,\mu_r\,H$

$= (4\pi\times10^{-7})\times250 \times 322.13 = 0.1012$ Wb/m^2

Flux in the ring, $\varnothing = B \times a$

$= 0.1012 \times (400 \times 10^{-6}) =$ **40.48×10^{-6} Wb**

3) An iron ring having mean diameter of 25 cm and cross section area of 2 cm^2 is uniformly wound with 400 turn's carries current of 5 Amp. The permeability of iron is 450. Calculate (i) MMF (ii) Reluctance (iii) Flux and (iv) Flux density

Solution:

MMF= NI= 400 x 5= 2000 AT

Reluctance,

$$S_i = \frac{l_i}{\mu_0\mu_{ri}a} = \frac{\pi x\, diameter}{\mu_0\mu_{ri}a} = \frac{3.14\,x\,0.25}{4\pi x10^{-7}x1000x450x2x10^{-4}} = 6.944x10^6 AT/Wb$$

$$\text{Flux } \phi = \frac{\text{MMF}}{\text{Reluctance}}$$

$$= \frac{2000}{6.944x10^6} = 2.88 \text{ x } 10^{-4} \text{ Wb} = 0.288 \text{ mWb}$$

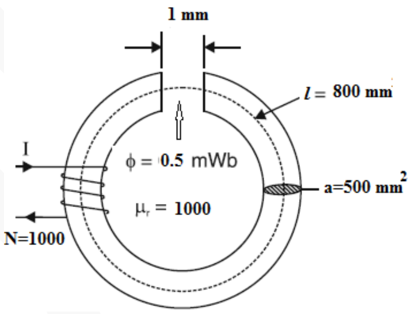
$$\text{Flux density B} = \frac{\text{Flux}}{\text{Area}} = \frac{0.288 \text{ x } 10^{-4}}{2x10^{-4}} = \mathbf{1.44\ T}$$

4) A laminated soft iron ring of relative permeability 1000 has a mean circumference of 800 mm and a cross-sectional area 500 mm^2. A radial air-gap of 1 mm width is cut in the ring which is wound with 1000 turns. Calculate the current required to produce flux of 0.5 mWb in an air-gap (Neglect magnetic leakage and magnetic fringing).

Solution:

Current through the coil, I = (Ø x Total Reluctance (S_T))/ N (as NI= Ø S)

Total Reluctance, S_T= Reluctance of Iron (S_i) + Reluctance of an air gap (S_{ag})



$$S_i = \frac{l_i}{\mu_0\mu_{ri}a} = \frac{800\,x10^{-3} - 1x10^{-3}}{4\pi x10^{-7}x1000x500x10^{-6}}$$

$$= 1.272x10^6 AT/Wb$$

$$S_{ag} = \frac{l_{ag}}{\mu_0\mu_{r(ag)}a} = \frac{1x10^{-3}}{4\pi x10^{-7}x1x500x10^{-6}}$$

$$= 1.592x10^6 AT/Wb$$

$$S_T = (1.272 + 1.592)x10^6$$

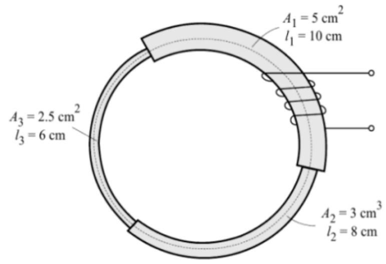
$$= 2.864x10^6 AT/Wb$$

Current through the coil,

$I = (0.5x10^{-3}x2.864x10^6)/(1000)=$**1.432 Amp**

5) An iron ring made up of three parts has l_1 = 10 cm, a_1 = 5 cm^2, l_2 = 8 cm, a_2 = 3 cm^2, l_3 = 6 cm, a_3 = 2.5 cm^2. It is wound with a coil of 250 turns. Calculate the current required to produce a flux of 0.4 mWb in the ring. μ_{r1} = 2670, μ_{r2} = 1050, μ_{r3} = 650.

Solution:



Total reluctance of the ring,

$$S= \frac{l_1}{\mu_o \mu_{r1} a_1} + \frac{l_2}{\mu_o \mu_{r2} a_2} + \frac{l_3}{\mu_o \mu_{r3} a_3} =$$

$$\frac{1}{4\pi x 10^{-7}}\left[\frac{0.1}{2670 x 5 x 10^{-4}} + \frac{0.08}{1050 x 3 x 10^{-4}} + \frac{0.06}{650 x 2.5 x 10^{-4}}\right]$$

$$= \quad 5.555 \times 10^5 \text{ AT/Wb}$$

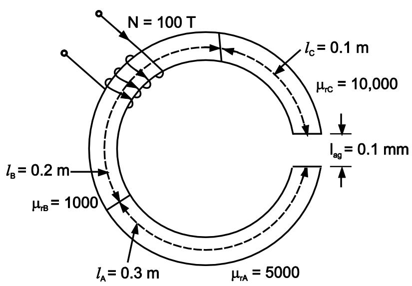
$$\therefore \text{ Flux } \phi = \frac{\text{m.m.f.}}{\text{Reluctance}}$$

$$\therefore \text{ m.m.f.} = \phi.S$$

$$\therefore \text{ I} = \frac{\phi.S}{N}$$

$$= \frac{0.4 \times 10^{-3} \times 5.55 \times 10^5}{250} = \mathbf{0.88\ A}$$

6) A ring composed of three sections. The cross-section area is 0.001 m^2 for each section. The mean lengths are for part A = 0.3 m, part B = 0.2 m, part C = 0.1 m. A air gap of 0.1mm is cut in the ring. The μ_r for the section A, B and C are 5000, 1000 and 10,000 respectively. Flux in the air gap is 7.5 x 10^{-4} Wb. Find the (1) Reluctance of each section. (2) MMF (3) Exciting current if the coil has 100 turns.



Solution : l_A = 0.3 m, l_B = 0.2m, l_C = 0.1 m, l_{ag} =0.1mm, μ_{r_A}=5000, μ_{r_B}=1000, μ_{r_C} = 10000

Total reluctance = Reluctance of part A + reluctance of part B + reluctance of part C + reluctance of air gap.

$$S_T = S_A + S_B + S_C + S_{ag}$$

$$= \left[\frac{l_A}{\mu_o \mu_{r_A} a}\right] + \left[\frac{l_B}{\mu_o \mu_{r_B} a}\right] + \left[\frac{l_C}{\mu_o \mu_{r_C} a}\right] + \left[\frac{l_{ag}}{\mu_o a}\right]$$

$$= \left[\frac{0.3}{4\pi \times 10^{-7} \times 5000 \times 0.001}\right] + \left[\frac{0.2}{4\pi \times 10^{-7} \times 1000 \times 0.001}\right] + \left[\frac{0.1}{4\pi \times 10^{-7} \times 10000 \times 0.001}\right] + \left[\frac{0.1 \times 10^{-3}}{4\pi \times 10^{-7} \times 0.001}\right]$$

$$= \quad 47770 + 159236 + 7961 + 79618$$

$$= \quad 294585 \text{ AT}$$

Reluctance of each section, **S_A=47770 AT**, **S_B=159236 AT**, **S_C=7961 AT**, **S_{ag}=79618 AT**

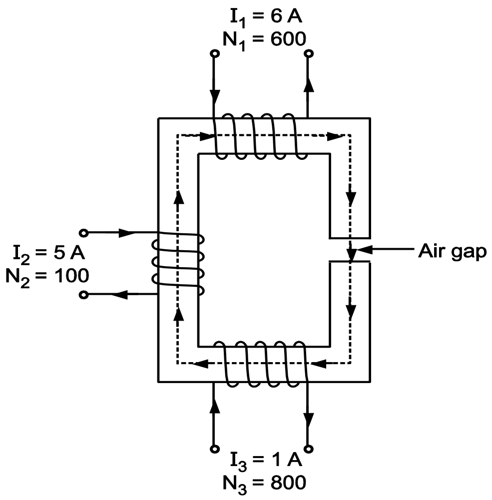
Total MMF= NI=$\phi \cdot$

S_T =7.5x 10^{-4}x 294585=**221 AT**

$$I = \frac{\phi \cdot S_T}{N} = \frac{7.5 \times 10^{-4} \times 294585}{100}$$

$$= \frac{221}{100} = 2.21 \text{ Amp}$$

7) A magnetic circuit is excited by three coils as shown in Fig. Calculate the flux produced in the air gap. The material used for core is iron having relative permeability of 800. The length of the magnetic circuit is 1000 with an air gap of 2 mm in it. The core has uniform cross-section of 6 cm^2.



Solution : $N_1 = 600$, $I_1 = 6$ A, $N_2 = 100$, $I_2 = 5$ A, $N_3 = 800$, $I_3 = 1$ A, $l_T = 100$ cm = 1 m.

$l_i = l_T - l_g = 1\text{m} - 2 \times 10^{-3} = 0.998$ m

$l_g = 2 \times 10^{-3}$ m

$\mu_r = 800$

$a = \frac{\pi}{4}(d)^2 = \frac{\pi}{4}(6 \times 10^{-2})^2 = 28.27 \times 10^{-4}\,\text{m}^2$

Now, total reluctance,

$S_T = S_i + S_g$

$S_i = \frac{l_i}{\mu_o \mu_r a}$

$= \frac{0.998}{4\pi \times 10^{-7} \times 800 \times 28.27 \times 10^{-4}}$

$= 351106.05$ AT/Wb

$S_g = \frac{l_g}{\mu_o\, a} = \frac{2 \times 10^{-3}}{4\pi \times 10^{-7} \times 28.27 \times 10^{-4}}$

$= 562981.76$ AT/Wb

$\therefore$ $S_T = S_i + S_g = 914087.8$ AT/Wb

Let us find the direction of flux due to various coils using right hand thumb rule.

As shown in Figure MMF of coils (1) and (2) are in same direction while MMF of coil (3) is in opposite direction.

$\therefore$ Net MMF $= (N_1I_1) + (N_2I_2) - (N_3I_3)$

$= (600 \times 6) + (100 \times 5) - (1 \times 800)$

NI = 3300 AT

$\therefore\ \phi = \frac{\text{MMF}}{\text{Reluctance}} = \frac{NI}{S} = \frac{3300}{914087.8}$

$\therefore$ Flux in air gap,

$\phi = 3.6101$ mWb

Part B: Electromagnetic Induction

8) A conductor of length 80 cm moves at right angles to a uniform magnetic field of flux density 1.5 Wb/m^2 with a velocity of 50 metre/second. Calculate the e.m.f. induced in it. Find also the value of induced e.m.f. when the conductor moves at an angle of 30º to the direction of the field.

Solution. Here $B = 1.5$ Wb/m^2, $l = 80$cm, $\upsilon = 50$ m/s ; $e = ?$

As emf induced is $e = Bl\upsilon \sin\theta$

(i) $\theta = 90^0$, e= $1.5 \times 0.8 \times 50 \times 1 =$ **60 V.**

(ii) $\theta = 30^o$, e=$1.5 \times 0.8 \times 50 \times 0.5 =$ 30V

9) A coil consists of 750 turns and a current of 10 A in the coil gives rise to a magnetic flux of 1.2 mWb. Calculate the inductance of the coil. If the current in the coil is reversed in 0.01s, determine the average voltage induced in the coil.

Solution : N = 750, I = 10 A, $\phi = 1.2$ mWb $= 1.2 \times 10^{-3}$Wb

$L = \frac{N\phi}{I} = \frac{1.2 \times 10^{-3} \times 750}{10} = 0.09$ H

Initial current =10 A, Final current = – 10 A.

Change in current= –10–10 =– 20 Amp. = di

Time taken for this change= dt = 0.01sec

Induced voltage, $e = -L\frac{di}{dt}$

$= -0.09 \times \frac{(-20)}{0.01} =$ **180 volt.**

10) A length of an air-cored solenoid is 1.7 m and area of cross section is 12 cm^2. The number of turns of coil is 1000. Calculate: (i) The self inductance, (ii) The energy stored in magnetic field when a current of 10 A flows through the coil.

Solution : $l = 1.7$ m, a = 12 cm^2 = 12×10^{-4}m^2, $\mu_o = 4\pi \times 10^{-7}$, N = 1000, I=10 A

$$S= \frac{l}{\mu_o a} = \frac{1.7}{4\pi \times 10^{-7} \times 12 \times 10^{-4}}$$

$=1.1273 \times 10^9$ AT/Wb.... $\mu_r = 1$ as air cored

$$L = \frac{N^2}{S} = \frac{(1000)^2}{1.1273 \times 10^9}$$

$=8.87 \times 10^{-4}$ H = 0.886 mH

Energy Stored $E=\frac{1}{2} LI^2$

$= \frac{1}{2} \times (0.886 \times 10^{-3}) \times (10)^2 =$ **0.0443 J**

11)Two coils having 3000 and 2000 turns are wound on a magnetic ring. 60% of flux produced in first field coil links with the second coil. A flux of 0.5 mWb in the first coil and 0.3 mWb in the second coil is produced when the current of 3 A flows separately through them. Determine the mutual inductance and coefficient of coupling.

Solution : N_1=3000, N_2=2000, ϕ_1 = 0.5 mWb, ϕ_2 = 0.3 mWb, $I_1 = I_2$ = 3 A and $\phi_2 = 0.6\ \phi_1$

$$M = \frac{N_2\phi_2}{I_1} = \frac{2000 \times 0.3 \times 10^{-3}}{3} = 0.2 \text{ H}$$

$$L_1 = \frac{N_1\phi_1}{I_1} = \frac{3000 \times 0.5 \times 10^{-3}}{3} = 0.5 \text{ H}$$

$$L_2 = \frac{N_2\phi_2}{I_2} = \frac{2000 \times 0.3 \times 10^{-3}}{3} = 0.2 \text{ H}$$

$$K = \frac{M}{\sqrt{L_1L_2}} = \frac{0.2}{\sqrt{0.5 \times 0.2}} = 0.6324$$

12) Two coils having 1000 and 300 turns are wound on a common magnetic path with perfect magnetic coupling. The reluctance of the path is 3x10^6 AT/Wb. Find the mutual inductance between them. If the current in 1000 turns coil changes uniformly from 5 A to zero in 10 milliseconds, find the induced e.m.f. in the other coil.

Solution : N_1 = 1000, N_2 = 300, K = 1, S = 3×10^6 AT/Wb

$$\text{Now, } M=\frac{N_1N_2}{S} = \frac{1000 \times 300}{3 \times 10^6} = 0.1 \text{ H}$$

$$e_{21} = -M\frac{dI_1}{dt} = -0.1 \times \left(\frac{0\text{-}5}{10 \times 10^{-3}}\right) = \textbf{50 V}$$

13) There are two coils having coefficient of coupling 0.8. The current in coil 1 is 3 A and the total flux 0.4 mWb. The voltage induced in coil 2 is 85 volts when the current in coil is reduced to zero in 3 m sec. The no of turns in coil 1 is 300. Determine L_1, L_2, M and N_2.

Solution :

$$L_1 = \frac{N_1\emptyset_1}{I_1} = \frac{300x0.4x10^{-3}}{3} = 40\ mH$$

$$e_{21} = -M\frac{di_1}{dt} = -M\frac{0-3}{3x10^{-3}} = 85\ volt$$

M = 0.085 H= ***85 mH***

$$K= \frac{M}{\sqrt{L_1L_2}} = \frac{85x10^{-3}}{\sqrt{40x\ 10^{-3}L_2}} =0.8$$

L_2=***282 mH***

The flux that links the coil 2 is:

$\emptyset_2$=k $\emptyset_1$=0.8 x 0.4=0.32 mWb

$$M=\frac{N_2\phi_2}{I_1} = \frac{N_2 \times 0.32 \times 10^{-3}}{3} = 85 \text{ mH}$$

N_2= **79.7 turns**

In-Sem Exam Sept 2019

A Coil of 500 turns is uniformly wound on a ring of mean circumference 25cm having cross section of 15cm2. When a coil carries a current of 1 Amp, it produces a flux density of 0.8 T. Calculate (1) Magnetizing force (2) Flux (3) Inductance (iv) μ_r of iron.

Ans: $H = \frac{NI}{l} = \frac{500\,x\,1}{0.25} = \mathbf{2000\ AT/m}$

$$B = \frac{\emptyset}{a}, \qquad Hence\ \emptyset = Bxa = 0.8x15x10^{-4}$$

$$= \mathbf{1.2\ x10^{-3}Wb}$$

$$L = \frac{N\emptyset}{I} = \frac{500x1.2x10^{-3}}{1} = \mathbf{0.6\ H}$$

$$B = \mu_0\mu_r H$$

$$\mu_r = \frac{B}{\mu_0 H} = \frac{0.8}{4\pi x10^{-7}x2000} = \mathbf{318.47}$$

An iron ring of mean diameter 20 cm has area of cross section of 2cmx2cm and is uniformly wound with 600 turns. μ_r of iron is 1000. Calculate (1) Self Inductance of coil (2) If μ_r is doubled, then find new value of Inductance.

Ans: $L = \frac{N^2}{S} = \frac{N^2}{\frac{l}{\mu_0\ \mu_r\ a}} = \frac{N^2}{l}\mu_0\ \mu_r\ a$

$$= \frac{600^2}{0.628}x\ 4\pi x10^{-7}x1000x4x10^{-4} = \mathbf{0.288\ H}$$

As L α μ_r

Lnew = 2 times L=2x0.288 H=**0.576 H**

Numericals for Practise:

1. A coil of 500 turns and resistance 20 Ohm is wound uniformly on an iron ring of mean circumference 50 cm and cross-sectional area 4cm^2. It is connected to a 24 V d. c. supply. Under these conditions, the relative permeability of iron is 800. Calculate the values of (i) Magneto motive force of the coil (ii) Magnetizing force (iii) Total flux in iron (iv) Reluctance of the ring **[600AT, 1200 AT/m, 0.483mWb, 1.24x10^6 AT/Wb]**

2. A magnetic circuit consists of an iron ring of mean circumference 80cm with cross-sectional area 12cm^2 throughout. A current of 2A in magnetizing coil of 200 turns produces a total flux of 1.2 mWb in the iron. Calculate: i) Flux density in the iron ii) Absolute and relative permeability of iron iii) Reluctance of the circuit

[1 Wb/m^2, 0.002 H/m, 1590, 3.33x10^6 AT/Wb]

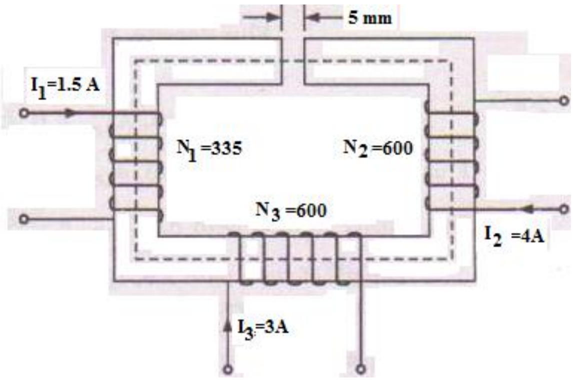
3. A mild steel ring of 30 cm mean circumference has a cross sectional area of 6 cm^2 and has a winding of 500 turns on it. The ring is cut through at a point so as to provide an air gap of 1mm in the magnetic circuit. It is found that current of 4 Ampere in the winding produces a flux density of 1T in the air gap. Find (i) Relative permeability of mild steel (ii) L of winding. **[197.5, 0.075 H]**

4. A closed magnetic circuit is composed of two sections. Section A has a length of 40 cm and cross sectional area of 10mm^2. Section B has a length of 50 cm and cross sectional area of 14mm^2. Both the sections are made up of same material having permeability of 650. A coil with 400 turns is wound over one of the section. Find the current required in the coil so as to develop a flux density of 1.4 Tesla in section B. **[4.54 Amp]**

5. A ring has a diameter of 21 cm and across sectional area of 10 cm^2.The ring is made up of semicircular sections of cast iron and cast steel with each joint having reluctance equal to an air gap of 0.2mm. Find the Ampere turns required to produce a flux of 8 x 10^{-4}Web. The relative permeability of cast steel and cast iron are 800 and 166 respectively. **[1783]**

6. A rectangular iron core is shown in the fig. It has a mean length of magnetic path of 100 cm, cross section of (2cm x 2cm), relative permeability of 1400 and an air-gap of 5 mm cut in core. The three coils carried by the core have number of turns N_1 = 335, N_2 = 600 and N_3= 600;

and the respective currents are 1.5 A, 4 A and 3 A. The direction of currents are as shown. Find the flux in the air-gap. **[97μWb]**



7. An iron ring of 40 cm diameter and 7 cm^2 cross section has an air gap of 2mm.it is uniformly wound with 750 turns of wire and carries a current of 3 Ampere. The iron takes 60 % of the total mmf. Find the (i) Total mmf ii) Flux iii) Reluctance iv) Flux density **[2250AT, 0.395mWeb, 5.696 x10^6 AT/ Web, 0564 T]**

8. A 100 cm long straight conductor carrying 50 A lies perpendicular to a uniform field of 1 Web/m^2. Find i) force on the conductor ii) power required to move the conductor at a uniform speed of 5 m/s. **[50 N , 250 Watt]**

9. A conductor carrying a current of 100 A at a right angle to the magnetic field has a density of 0.5 Tesla. Calculate the force on the conductor per meter length. Also find emf generated by a conductor in 1 second when the flux of 0.5 Web is cut at a uniform rate. **[50 N/m, 0.5 V]**

10. A magnetic flux of 900 μWb passing through a coil of 1000 turns is reversed in 0.2 Sec. Calculate average value of emf induced. **[9 V]**

11. Calculate the inductance of a toroidal coil of 100 turns wound uniformly on a nonmagnetic core of mean diameter 140 mm and cross section area of 750 mm^2 **[21.4 Micro-Henry]**

12. Calculate the inductance of a toroid 25 cm mean diameter and cross section area 6.25 cm^2 wound uniformly with 1000 turns of a wire. Also calculate the emf induced when a current increasing at the rate of 200 A/S flows in the winding. **[1mH , - 0.2 V]**

13. Calculate the inductance of a ring shaped coil having a mean diameter of 200 mm wound on a wooden core of diameter 20 mm. The winding is evenly wound and contains 500 turns.
If the wooden core is replaced by an iron core which has relative permeability of 600 when the current is 5 A, calculate the new value of inductance. **[157 mH , 94.2 mH]**

14. Two identical coils P and Q each with 1500 turns, are placed in parallel planes near to each other, so that 70% of the flux produced by current in coil P links with coil Q. If a current of 4 A is passed through any one coil, it produces a flux of 0.04 mWb linking with itself. Find the self-inductances of the two coils, the mutual inductance and coefficient of coupling between them. **[15 mH, 15 mH , 10.5 mH , .7 V]**

15. Two coils A and B in a magnetic circuit have 600 and 500 turns respectively. A current of 8 Amp in coil A produces a flux of 0.04 wb. If the co-efficient of coupling is 0.2. Calculate (i) The self inductance of coil A when B is open circuited, (ii) Flux linkage with coil B, (iii) Mutual inductance, (iv) Emf induced in B when flux changes from zero to full value in 0.02 sec.
[3 H , 4 Web-T ,0.5 H , -200 V]

16. Two coils A and B have self-inductances of 120 mH and 300 mH respectively. A current of 1 A through coil 'A' produces flux linkage of 100 μWb turns in coil 'B'. Calculate, (i)Mutual inductance between the coils.(ii) Average e.m.f. induced in coil 'B' if current of 1A in coil 'A' is reversed at a uniform rate in 0.1 sec. Also find the coefficient of coupling. **[100 μH, 0.2 mV, 0.527]**

17. A conductor of length 10 cm carrying 5 A is placed in a uniform magnetic field of flux density 1.25 tesla. Find the force acting on the conductor if it is placed (i) along the lines of magnetic flux, (ii) perpendicular to the lines of flux, and (iii) at 30° to the flux. **[0, 0.625 N, 0.3125 N]**