Magnetic Circuits & Electromagnetic Induction

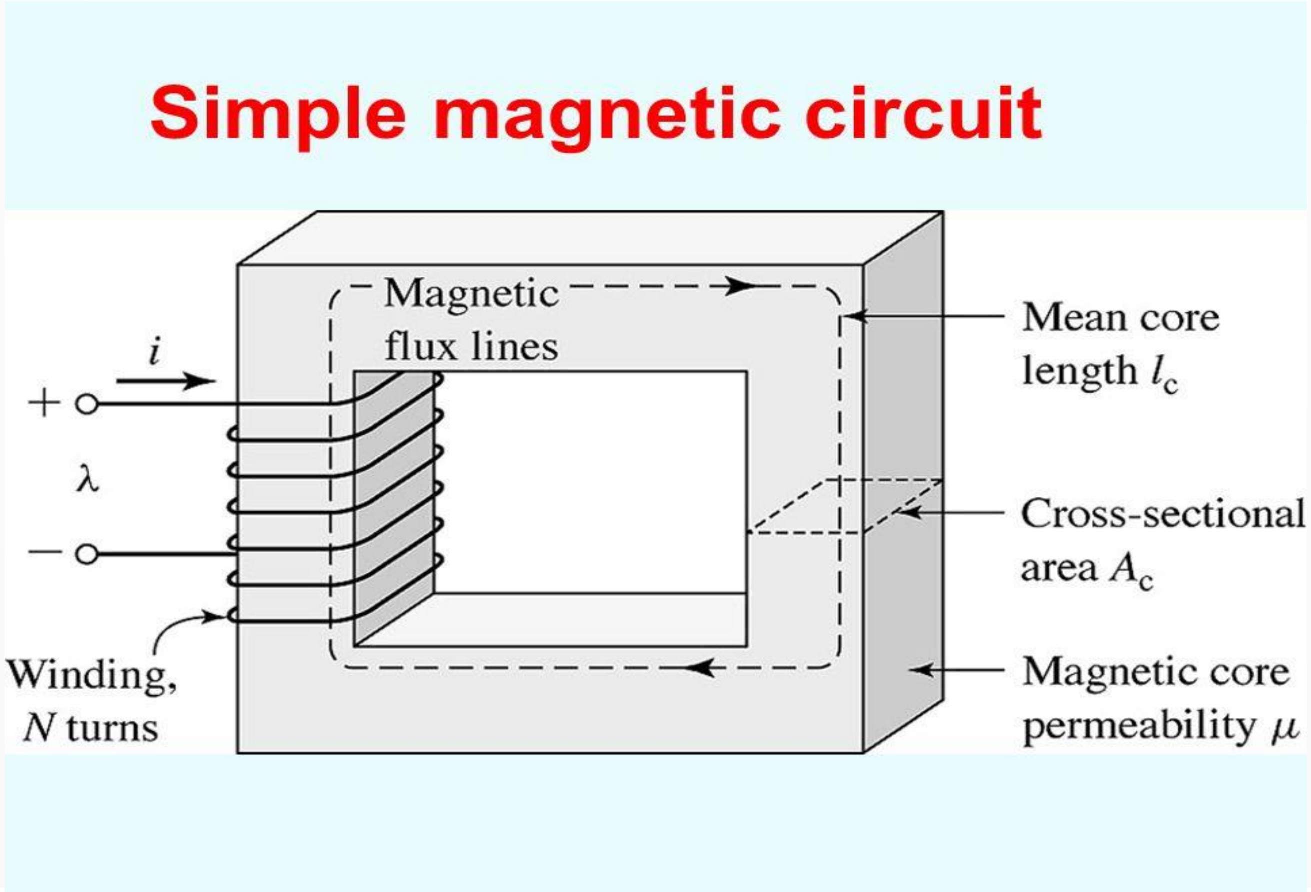
Instructor : E.A Affum
Phone: 0547926139
Room: 316
Assistants: A. Robert & W. Fortunatus
Phone: Robert- 0576951231 Fortunatus - 0247296728
E-mail: infotee7@gmail.com

Lecture Outline

- Definition of terms
- Characteristics of magnetic fields
- Simple and Composite magnetic circuits
- Comparison Between Magnetic and Electric Circuits
- Examples
- Electromagnetic Induction

Magnetic Circuits

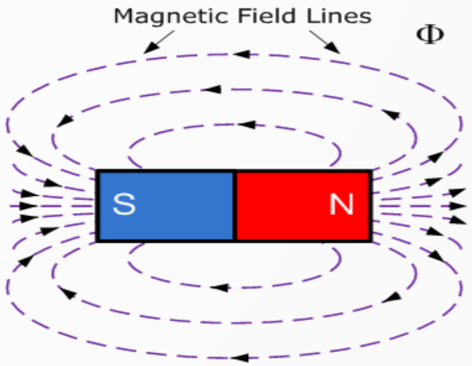
A magnetic circuit is a complete closed path followed by any group of lines of magnetic flux.



Definition of terms

Magnetic Flux (∅) – The magnetic lines of force, the amount of magnetic field quantitively produced by a magnet. Its unit is Weber

$$1\,wb = 10^8\,magnetic\ lines = 10^8\,Maxwells$$



Characteristics of magnetic lines

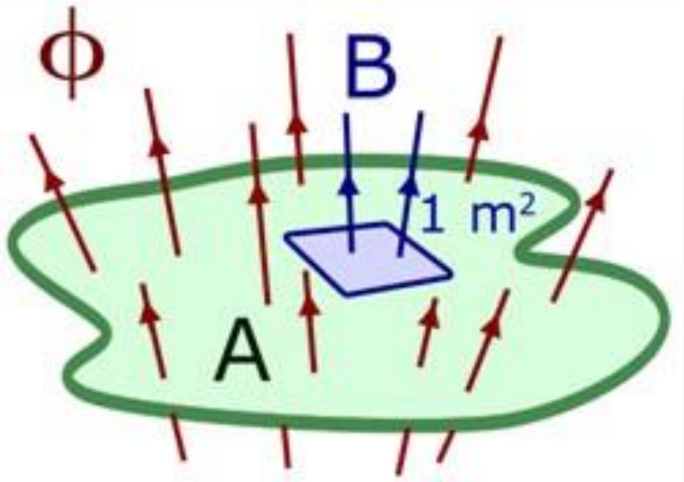
- They do not have physical existence.
- Each line of magnetic flux is a closed loop by itself.
- Magnetic flux lines never meet.
- Line of magnetic flux closer to each other and having the same direction repel each other.
- Line of magnetic flux closer to each other and having opposite directions attract each other.
- The direction of magnetic flux lines is defined as he direction on which an isolated north pole would move if it were placed in a magnetic filed.

Definition of terms

Magnetic Flux Density (B) – It is the flux per unit area at right angles to the flux. The concentration of lines of force in a magnetic circuit.

$$B = \frac{\emptyset}{a} \quad Units\ is\ wb/m^2\ or\ \text{T(Tesla)}$$

Where $\emptyset$(wb) is the magnetic flux and a (m^2) is the area of cross section.

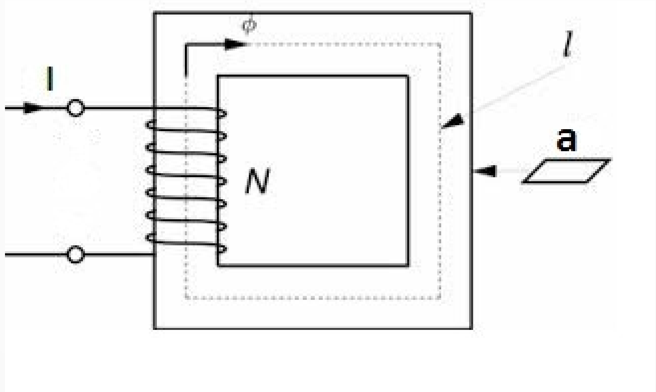


Definition of terms

Magneto Motive Force (MMF)– It is the “driving force” that causes a magnetic field. MMF is the cause for producing flux in magnetic circuit. It is obtained as the product of the current (I amps) flowing through a coil of N turns.

$$F = NI\ Amps$$

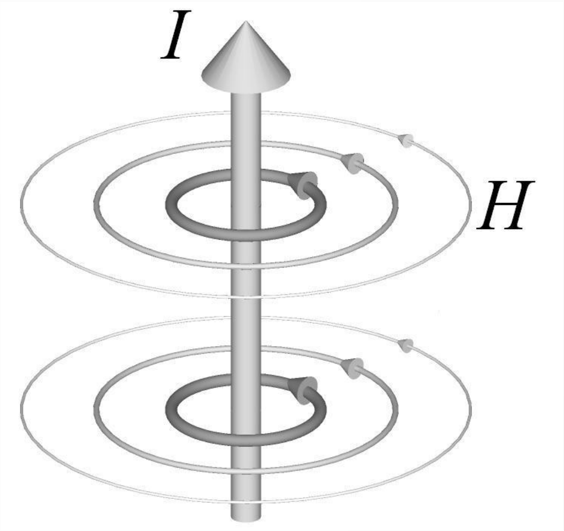
The term MMF is normally referred to as Ampere Turns (AT).



Definition of terms

Magnetic Field intensity / Magnetizing Force (H) – It is defined as the MMF per unit length of the magnetic flux path. It is a measure of the ability of a magnetized body to produce magnetic induction in other magnetic substances.

$$H = \frac{F}{l} = \frac{NI}{l}$$



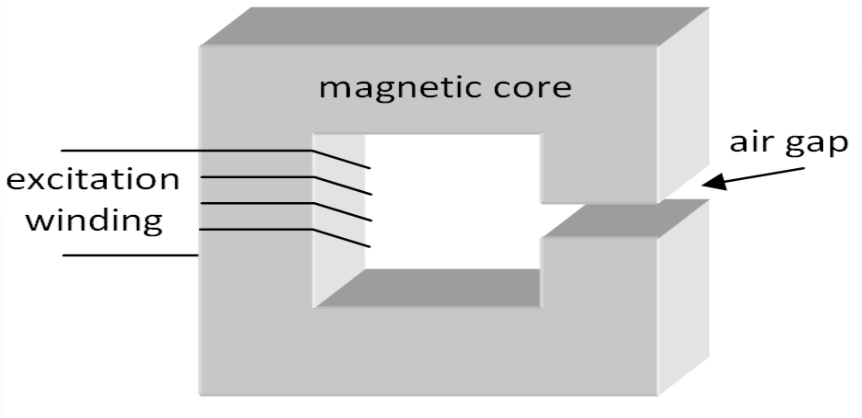
Definition of terms

Permeability (μ)– This relates magnetic flux density and magnetic field intensity. Flux density is proportional to the magnetizing force which produces it.

$$B \propto H$$

$$B = \mu H$$

$$\text{Hence } \mu = \frac{B}{H}$$



Where μ is the constant of proportionality.

Permeability of free space (air (μ_0)) it is given by

$$\mu_0 = 4\pi 10^{-7} Wb/A \text{ or } H/m$$

Definition of terms

Relative Permeability(μ_r) – Relative permeability of a medium is the ratio of the flux density produced in that medium or material to the flux density produced in vacuum by the same magnetizing force.

$$\mu_r = \frac{\mu}{\mu_0} = \frac{Magnetic\ Flux\ Density\ in\ the\ meduim}{Magnetic\ flux\ density\ in\ vacuum}$$

NB: The permeability of any other medium is $\mu = \mu_0 \times \mu_r$

Also $\mu_r = 1$ for air, free space or vacuum.

Definition of terms

Reluctance(S) – The measure of "opposition" a magnetic circuit offers to the flux. It is defined as the ratio of the magneto motive force to the flux. The unit of reluctance is Amp/Weber

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

Where l is length of magnetic path in meters and A is the cross sectional area in square meter.

Permeance(P) – It is the reciprocal of reluctance and it is the readness with which magnetic flux is developed. It is analogous to conductance in an electric circuit. Its unit I weber per Amp

Magnetic Circuit Analysis

Magnetic circuit is the path followed by magnetic flux.

Magnetic flux follows a complete loop or circuit back to its starting point. In any magnet, magnetic flux leaves its north pole, passing though air, enters the magnet at its south pole.

Magnetic circuits can be classified into simple and composite and parallel circuits.

Magnetic Circuit Analysis

Simple: It is made up of single magnetic material, thus reflects the magnetic properties of the magnetic material

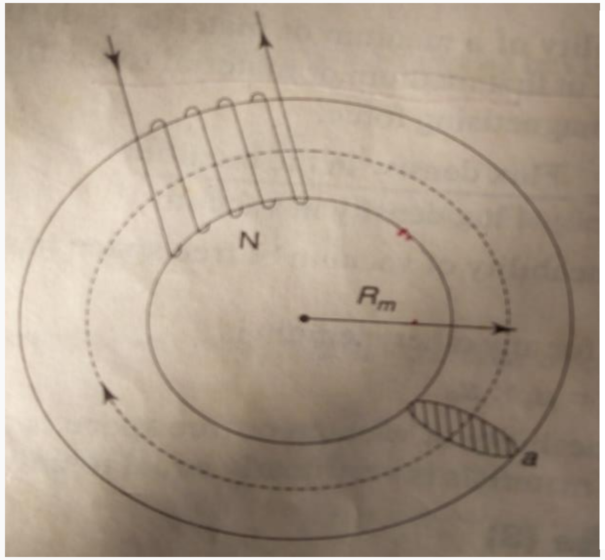
Composite: It has a minimum of two different specimens offering different magnetic properties, both may be magnetic or one magnetic and the other non-magnetic such as air

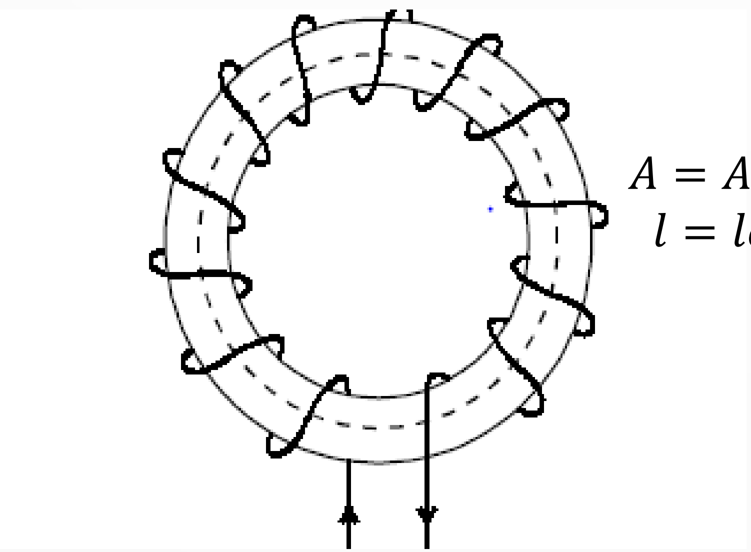
Parallel: It is said to be parallel if it has more than one closed path for flux.

Analysis of Simple magnetic circuits

Simple Magnetic Circuit

Consider a closed solenoid or a toroidal iron ring having magnetic path of "l" meters, area of cross-section "a" and a coil of N turns carrying I amperes wound anywhere on it as shown in the figure below.





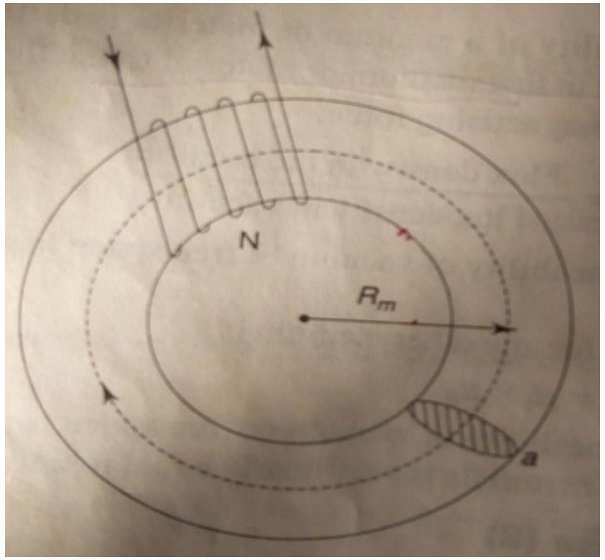
$$Let\ I = current\ through\ the\ coil$$
$$\emptyset = flux\ in\ the\ iron\ ring(wb)$$
$$A = Areas\ of\ th\ cross\ section\ of\ the\ ring\ (m^2)$$
$$l = length\ of\ the\ mafnetic\ path\ in\ meteres$$

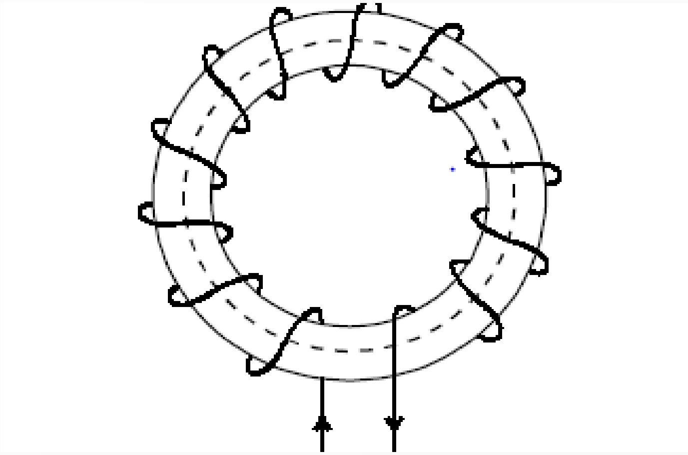
Simple magnetic circuits cont…

M. M. F Produced $= NI\ Amps$

According to definition of H, the field-strength inside the solenoid is

$$H = \frac{NI}{l}\ (Amp\ per\ metre)$$





$$But\ l = 2\pi R_m$$

$$H = \frac{NI}{2\pi R_m}$$

$Now\ B = \mu_0 \mu_r$H, where $\mu_0\ \mu_r = \mu \quad (\mu = \frac{B}{H})$

$$B = \frac{\mu_0 \mu_r \text{H}}{l} = \frac{\mu_0 \mu_r \text{NI}}{l} wb/m^2$$

Simple magnetic circuits cont…

Total Flux produced

$$\emptyset = Ba = \frac{\mu_0 \mu_r \, a \, NI}{l} \; wb$$

Also,

$$\emptyset = \frac{\frac{NI}{l}}{\mu_0 \mu_r \, a} = \frac{NI}{S} \; wb$$

Hence from the above Reluctance(S) is given by:

$$S = \frac{NI}{\emptyset}, Thus\ the\ denominator\ \frac{l}{\mu\, a}\ or \frac{l}{\mu_0 \mu_r \boldsymbol{a}}$$

$$is\ the\ reluctance\ of\ the\ circuit\ and\ is\ analogous\ to\ resistance\ in\ electric\ circuit.$$

$S = \frac{l}{\mu_0 \mu_r \boldsymbol{a}}$, $\text{Flux} = \frac{mmf}{reluctance}$

The above equation is also known as “Ohm’s law of magnetic circuit, because is resembles

$$Current = \frac{emf}{resistance}$$

Simple magnetic circuits cont…

If the amp turns to produce a given flux (Ø) or flux density(B) in a magnetic circuit is to be determined, the steps to be followed are as under:

$$\text{Magnetic Flux Density (B)} = \frac{\emptyset}{a}$$

Magnetizing force/ Magnetic field intensity (H)

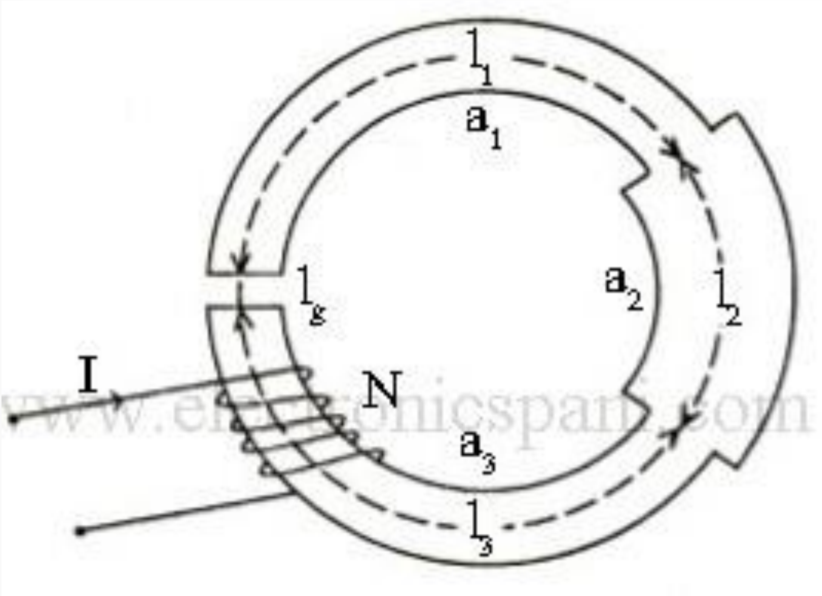
$$\text{H} = \frac{B}{\mu_0 \mu_r}$$

$$\text{Magneto Motive Force (mmf)} = Hl$$

NB: if the ampere turns for any part of magnetic circuit = magnetizing force in that part multiplied by length of that part

Analysis of Composite Magnetic Circuits

Practically the magnetic circuits are formed by more than one material, with different permeability. Such materials can have various length and cross-sectional area. This circuit is called as composite circuit. When those materials are connected one after the other to form a magnetic circuit is called to be **series magnetic circuit**



Let $l_1 l_2\ l_3$ be the lengths of various magnetic materials used in the series magnetic circuit.

Let $A_1 A_2\ A_3$ be the areas of the cross-section of the respective parts f the series magnetic circuit.

Lets l_g be the length of the air gap and

Lets a_g be the area of the cross-section at the air gap.

Composite Magnetic Circuits Cont…

Each part of the series circuit will offer reluctance to the magnetic flux () the amout of reluctance will depend upon the dimensions and relative permeabilities of that part.

Since different parts of the circuit are in series, the total reluctance is equal to the sum of reluctances of individual parts.

Total reluctance(S) = $S_1 + S_2 + S_3 + S_g$ but Reluctance (S) $= \frac{l}{\mu_0 \mu_r a}$, Hence…..

Total reluctance(S) = $S_1 + S_2 + S_3 + S_g = \frac{l_1}{\mu_0 \ \mu_{r_1} a_1} + \frac{l_2}{\mu_0 \ \mu_{r_2} a_2} + \frac{l_3}{\mu_0 \ \mu_{r_3} a_3} + \frac{l_g}{\mu_0 \ \mu_{r_g} a_g}$

Just as in electrical circuit where Total emf = Current × Total Resistance. In magnetic circuit:

Total mmf = Magnetic flux × Total reluctance = $\emptyset S_1 + \emptyset S_2 + \emptyset S_3 + \emptyset S_g$

Composite Magnetic Circuits Cont…

Total mmf = Magnetic flux × Total reluctance = $\emptyset S_1 + \emptyset S_2 + \emptyset S_3 + \emptyset S_g$

$$\text{Total mmf} = \emptyset\left[\frac{l_1}{\mu_0\ \boldsymbol{\mu}_{r_1}\ a_1} + \frac{l_2}{\mu_0\ \boldsymbol{\mu}_{r_2} a_2} + \frac{l_3}{\mu_0\ \boldsymbol{\mu}_{r_3} a_3} + \frac{l_g}{\mu_0\ \boldsymbol{\mu}_{r_g} a_g}\right]$$

$$\text{Total mmf} = \emptyset\left[\left(\frac{\emptyset}{\mu_0\ \boldsymbol{\mu}_{r_1}\ a_1} \times l_1\right) + \cdots \left(\frac{\emptyset}{\mu_0\ \boldsymbol{\mu}_{r_2} a_2} \times l_2\right) + \cdots \left(\frac{\emptyset}{\mu_0\ \boldsymbol{\mu}_{r_3} a_3} \times l_3\right) + \cdots \left(\frac{\emptyset}{\mu_0\ \boldsymbol{\mu}_{r_g} a_g} \times l_g\right)\right]$$

(we know $\boldsymbol{\mu}_{r_g}$ = 1 for air) hence…

$$\text{Total mmf} = \frac{B_1}{\mu_0\ \boldsymbol{\mu}_{r_1}} \times l_1 + \frac{B_2}{\mu_0\ \boldsymbol{\mu}_{r_2}} \times l_2 + \frac{B_3}{\mu_0\ \boldsymbol{\mu}_{r_3}} \times l_3 + \frac{B_1}{\mu_0} \times l_g$$

$$\text{Total mmf} = H_1\, l_1 + H_2\, l_2 + H_3\, l_3 + H_g\ l_l \qquad \left[\therefore H = \frac{B}{\mu_0\ \boldsymbol{\mu}_r}\right]$$

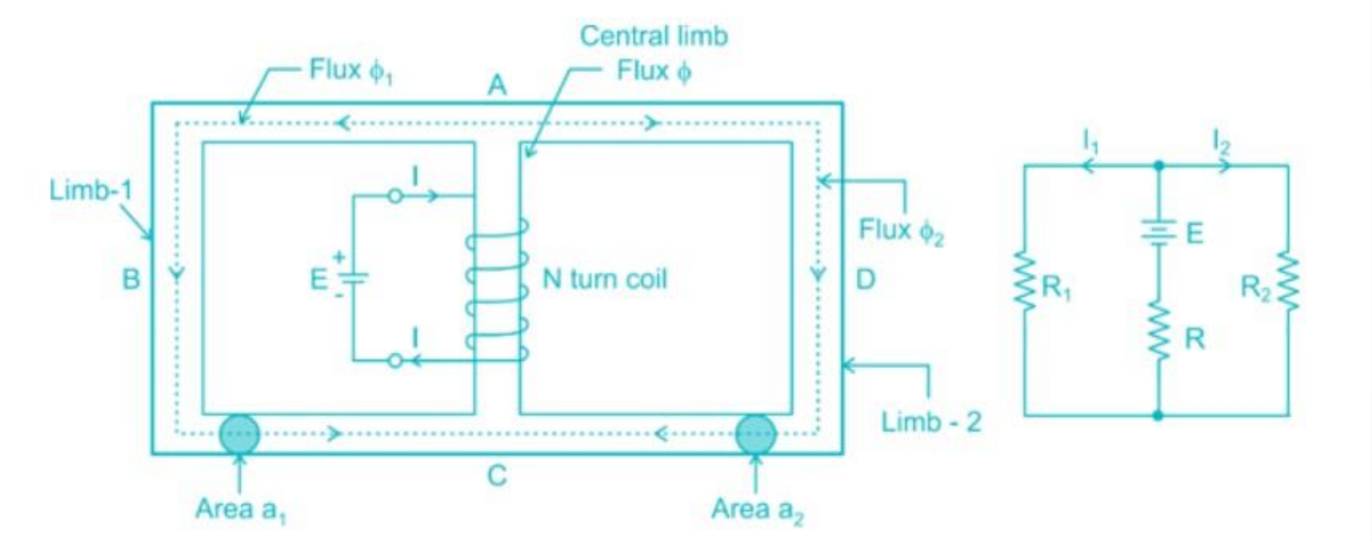
Composite Magnetic Circuits Cont…

From the previous derivation, for series circuit,

- The magnetic flux though all materials is same.
- The equivalent reluctance(S) is the sum of the individual material reluctance (say, $S_1 + S_2$.....)
- The total mmf required is the sum of the mmf's of the individual material

Parallel Magnetic Circuits

A magnetic circuit is said to be parallel connected if it has more than one closed path for flux. In parallel magnetic circuits, the total flux exists in a common section of the magnetic circuit which contains the existing coil. Then it divides into two or more parts, follows the different paths and recombines at the other end of the common section.



Let $\emptyset$ = Total flux in the above circuit
Let $\emptyset_1$ = Flux in the path ABCA
Let $\emptyset_2$ = Flux in the path ADCA

Parallel Magnetic Circuits cont….

From the previous slide….

Part of circuit	Length	Cross-Sectional Area	Magnetizing force(Magnetic filed intensity)	Reluctance
ABCA	l_1	a_1	H_1	S_1
ADCA	l_2	a_2	H_2	S_2
AC	l_3	a_3	H_3	S_3

Parallel Magnetic Circuits cont….

Total flux $\emptyset = \emptyset_1 + \emptyset_2$

Total mmf $= \{Total\ mmf\} = (mmf\ of\ path\ ABCA) + (mmf\ for\ AC\ or\ mmf\ for\ path\ ADCA)$

Total mmf (F) = NI = $\emptyset_1 S_1 + \emptyset_2 S_2$

$$or$$

Total mmf $(F) = NI = \emptyset_1 S_1 + \emptyset_3 S_3$

Where….. $S_1 = \frac{l_1}{\mu_0\ \mu_{r_1}\ a_1}$, $S_2 = \frac{l_2}{\mu_0\ \mu_{r_3}\ a_3}$, $S_3 = \frac{l_3}{\mu_0\ \mu_{r_3}\ a_3}$

NB: Total mmf required = AT/mmf for common section + AT for any one of the parallel path. The above is based on Kirchhoff's laws for Magnetic Circuits stated in the next slides…..

Analysis of linear magnetic circuits

Magnetic circuits are analyzed by drawing an equivalent electric circuit and applying the laws used to analyze electric circuits. The following similarities exit.

- Flux is similar to current
- Magnetomotive force is similar to electromotive force
- Reluctance is similar to resistance

Analysis of linear magnetic circuits

Not all the laws of electric circuits can be applied to magnetic circuits. Kirchhoff's laws are applicable and when applied to magnetic circuits are stated as follows:

First Law: The total flux towards a node is equal to the total flux away from the node in any magnetic circuit.

Second Law: In any magnetic circuit, the sum of the product of the magnetizing force in each part of the magnetic circuit and the length of that part is equal to the resultant mmf

Example1

The flux produced in the air gap between electromagnetic poles is $5 \times 10^{-2} wb$. If the cross sectional area of the air gap is 0.2 m^2. Find, 1. Flux Density 2. Magnetizing force 3. reluctance 4. Permeance of the airgap. Find also the mmf dropped in the air gap given the length of the air gap to be 1.2cm

Solution

$\emptyset = 5 \times 10^{-2} wb$, a=$0.2m^2$, l_g = 1.2cm = 0.012m , $\mu_r = \mathbf{1}$

1. Flux Density(B) = $\frac{\emptyset}{a} = \frac{5\times10^{-2}}{0.2} = 0.25 wb/m^2$

2. Magnetic field intensity(H) = $\frac{NI}{l}$ $, but\ B = \mu H, hence\ H = \frac{B}{\mu}\ where \mu = \mu_0 \times \mu_r$

$$H = \frac{B}{\mu_0 \times \mu_r} = \frac{0.25}{1} = 1.9894x10^5 A/m$$

3. Reluctance(S) $= \frac{l_g}{a\mu} = \frac{0.012}{0.2\ x 4\pi 10^{-7}\ x\ 1} = 47746.48\ A/wb$

4. Permeance $= 1/\text{Reluctance} = 1/\ 47746.48 = 2.0944x10^{-5} wb/A$

5. mmf in the air gap $= \emptyset \text{ x Reluctance} = 5 \times 10^{-2} \text{ x } 47746.48$

Example2

A current of 2 amp is flowing through each of the conductors in a coil containing 15 such conductors. If a point of unit strength is placed at a perpendicular distance of 10cm from the coil, determine the filed intensity at the point.

Solution

Given data: I = 2, N = 15, d = 10cm = 0.1m

$$H = \frac{NI}{l = 2\pi d} = \frac{15 \times 2}{2 \times \pi \times 0.1} = 47.74\ AT/m$$

Example3

Example : *A solenoid of 100 cm is wound on a brass tube. If the current through the coil is 0.5 A, calculate the number of turns necessary over the solenoid to produce a field strength of 500 AT/m at the center of the coil.*

Solution : The field strength on the axis of a long solenoid is given by

$$H = \frac{NI}{l} \text{ AT/m}$$

l = Length of coil = 100 cm = 1 m , N = Number of turns

I = Current = 0.5 A

$$\therefore \quad 500 = \frac{N \times 0.5}{1}$$

$$N = 1000$$

So 1000 turns on solenoid are necessary to produce the required field strength.

Example 4

Steel ring 30 cm mean diameter and of circular section 2 cm in diameter has an air gap 1 mm long. It is wound uniformly with 600 turns of wire carrying current of 2.5 A. Find (1) total mmf (2) total reluctance (3) flux. Neglect magnetic leakage. The iron path takes 40% of the total mmf.

Given Data:

Mean Diameter $D = 30 \text{ cm}, \quad d = 2 \text{ cm}, \quad l_g = 1 \text{ mm}$

$N = 600, \quad I = 2.5 \text{ A},$

SOLUTION

Mean length of the steel ring, $l = \pi D - l_g$

$$= \pi \times 30 \times 10^{-2} - 1 \times 10^{-3}$$

$$l = 0.941 \text{ m}$$

Cross sectional area of the magnetic circuit,

$$A = \pi r^2 = \pi \times \left(\frac{2 \times 10^{-2}}{2} \right)^2$$

Example 4 cont.....

(i) Total Magnetomotive force, $= NI$

$= 600 \times 2.5 = 1500$ AT

$\boxed{\text{Total mmf } = \mathbf{1500\ AT}}$

mmf of the steel ring, $= \frac{40}{100} \times 1500 = 600$ AT

mmf of the air-gap $= \frac{60}{100} \times 1500 = 900$ AT

(ii) Total reluctance

Reluctance of air gap, $S_g = \frac{l_g}{\mu_o \mu_r A}$

$$= \frac{0.001}{4\pi \times 10^{-7} \times 1 \times 3.14 \times 10^{-4}}$$

$S_g = 2534$ AT/Wb

Reluctance of steel ring, $S_i = \frac{l}{\mu_o \mu_r A}$

$$= \frac{0.941}{4\pi \times 10^{-7} \times 1 \times 3.14 \times 10^{-4}}$$

$= 2385$ AT/Wb

Total Reluctance, $S = S_i + S_g$

$= 2385 + 2534$

$\boxed{\mathbf{S = 4919\ AT/Wb}}$

(iii) Flux

$$\phi = \frac{\text{mmf of air gap}}{\text{Reluctance of airgap}} = \frac{900}{2534} = 0.355 \text{ Wb}$$

$\boxed{\mathbf{\phi = 0.355\ Wb}}$

Example 5

A coil of 1500 turns is wound on a circular wooden former which has a mean circumference of 30cm and a cross-sectional area of 4cm2. Calculate (a) the flux density in the ring when the coil carries a current of 0.4 A (b) the flux in the ring in webers. When the wooden former was replaced with a steel former of the same dimensions, the total flux became 600µWb for a current of 0.4 A. Calculate the relative permeability of the steel and the reluctance of the magnetic circuit at this flux density.

Solution

The coil of 1500 turns in wound on a circular wooden former….

$$H = \frac{F}{L} = \frac{NI}{L} \quad = \frac{0.4 \times 1500}{0.3} \quad = 2000AT/m$$

$$B = \mu_0 H \quad = 4\pi \times 10^{-7} \times 2000$$

$$= 2.513mWb/m^2$$

$$\varphi = BA \quad = 2.513 \times 10^{-3} \times 4 \times 10^{-4}$$

$$= 1.005\mu Wb$$

Example 5 cont….

With steel (magnetic) former….

$$H = 2000AT/Wb \qquad \varphi = 600\mu Wb$$

$$\therefore B = \frac{\varphi}{A} = \frac{600 \times 10^{-6}}{4 \times 10^{-4}} = 1.5Wb/m^2$$

$$\mu_r = \frac{B}{\mu_0 H} = \frac{1.5}{4\pi \times 10^{-7} \times 2000} = 597$$

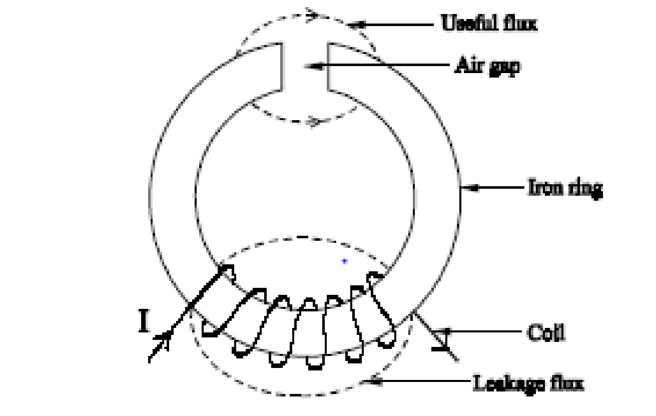
$$S = \frac{F}{\varphi} = \frac{NI}{\varphi} = \frac{1500 \times 0.4}{600 \times 10^{-4}} = 10^4 AT/Wb$$

Leakage flux

The flux that follows an undesired path is called the leakage flux. To utilize the magnetic flux established by the magnetic material, we provide an air gap. The flux in the air gap is called useful flux.

The flux which does not pass through the air gap, can not be utilized and hence it is considered as leakage flux which can be determined by a compass. Though, this leakage flux does not affect the efficiency of the electrical machine directly, it does increase the weight and cost and hence it is undesirable. It cannot be totally avoided but can be minimized by winding the exciting coils of closely as possible to the air gap

$$leakage\ coefficient = \lambda = \frac{total\ flux}{useful\ flux} = \frac{\phi + \phi'}{\phi}$$



Comparison between magnetic and electric circuit

Similarities

S.No	Magnetic Circuit	Electric Circuit
1	The path traced by magnetic flux is defined as magnetic circuit.	Path traced by the current is called as electric circuit.
2	MMF is the driving force in the magnetic circuit (Unit is Ampere turns)	Emf is the driving force in an electric circuit. (Unit is volts)
3	There will be the presence of flux, (Wb)	There will be the presence of current, *I* *(A)*
4	The magnetic lines will decide the flux	The electrons will decide the current.
5.	Opposing force for flux is reluctance. $S = \frac{l}{\mu_0 \mu_r A}$. Unit is AT/Wb.	Opposing force for current is resistance $R = \frac{\rho l}{A}$. Unit is ohm (Ω)
6.	Flux, $\phi = \frac{\text{mmf}}{\text{reluctance}}$	Current, $I = \frac{emf}{\text{Resistance}}$
7.	Reciprocal of reluctance is permeance	Reciprocal of resistance is conductance

Comparison between magnetic and electric circuit

Dissimilarities

Sl. No.	Magnetic Circuit	Electric Circuit
1.	The flux will be just established in the circuit, because of magneto motive force. But it will not actually flow in the magnetic circuit.	Due to emf, the current will flow through whole magnetic circuit.
2.	Energy is required to create the flux and not to maintain it.	Energy is required to create and maintain the current.
3.	Magnetic lines of flux are closed. They flow from N pole to S pole externally and S pole to N pole internally.	Electric lines of flux is not closed. They start from positive charge and end on negative charge.
4.	There is no continuous consumption of magnetic energy.	There is continuous consumption of electrical energy.

Electromagnetic Induction

We have seen the magnetic effects of an electric current. Then it was Michael Faraday who made attempts, to get emf from magnetic flux. This is called to be electromagnetic induction
Law of Electromagnetic Induction

Faraday's law

Whenever the magnetic flux linking a conductor changes, an emf is always induced in it. The magnitude of induced emf is proportional to the rate of change of flux linkages.

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

Where e= induced emf in V N= Number of turns

$d\Phi/dt$ = Rate of change of flux.

Electromagnetic Induction

Lenz's Law

This law states that any induced emf will circulate a current in such a direction so as to oppose the cause producing it.

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

Where e= induced emf in V

N= Number of turns

$d\Phi/dt$ = Rate of change of flux.

Nature of induced emf

We can get induced emf from a conductor, whenever there is change in flux, with that conductor.

We can obtain this from two methods. So, the emf is classified as,

I. Dynamically induced emf and

II. Statically induced emf.

Dynamically Induced emf

When the induced emf is from the mechanical movement of coil with respect to flux, (or) movement of magnet with respect to stationary coil, then it is called Dynamically induced emf. Eg: DC generator, AC generator. The induced emf will be given by,

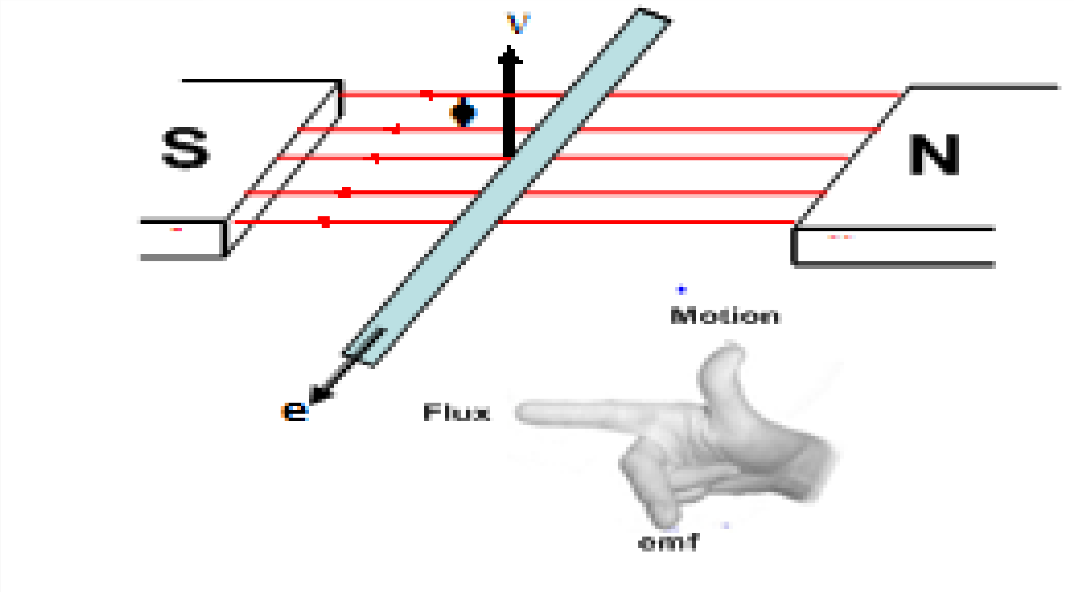
$$e = Blv \sin \theta \text{ (V)}.$$

Direction of dynamically induced emf is found by Fleming's Right Hand Rule.

Nature of induced emf

Fleming's Right Hand Rule

Stretch the fore finger, middle finger and thumb of right hand mutually perpendicular to each other. If fore finger represents the direction of magnetic field, thumb represents the direction of motion of conductor then the middle finger will represent the direction of induced emf.



Nature of induced emf

Statically induced emf.

The induced emf in a coil without any mechanical movement of coil (or) magnet is called stationary induced emf (or) statically induced emf.

This is achieved by changing the flux associated with a coil, by increasing (or) decreasing the current through it rapidly. Statically induced emf is further classified as,

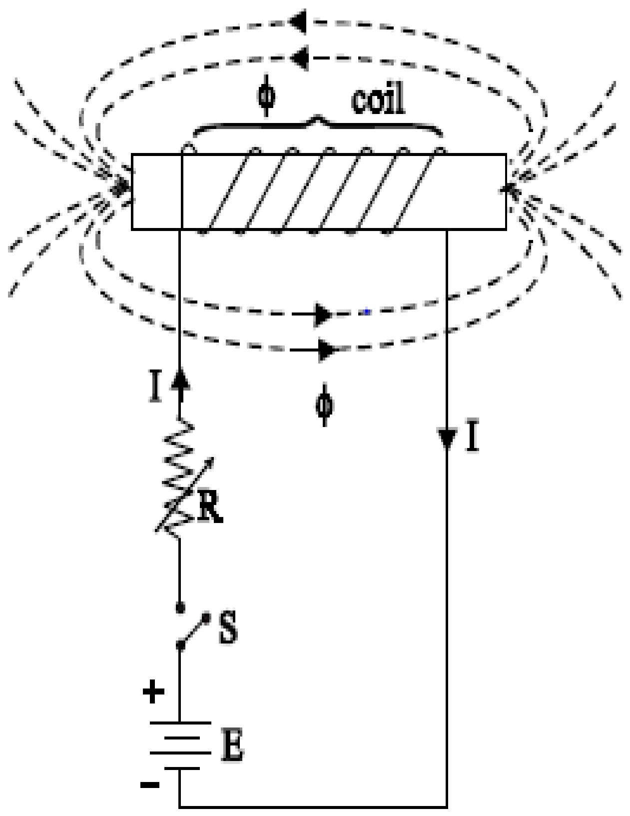
(a) Self induced emf

(b) Mutually induced emf

Nature of induced emf

Self induced emf

In the set up shown in Fig. the coil is carrying a current of I, amps.
Due to this current, flux will be established. When this current is varied by varying the value of resistance, the flux linking the coil also changes. So, an emf will be induced. This is called self-induced emf. Simply, the emf induced in a coil due to the change of its own flux linked with it is called self induced emf. The self induced emf will be induced till the current in the coil is changing and also its direction can be obtained from Lenz's law.



Nature of induced emf

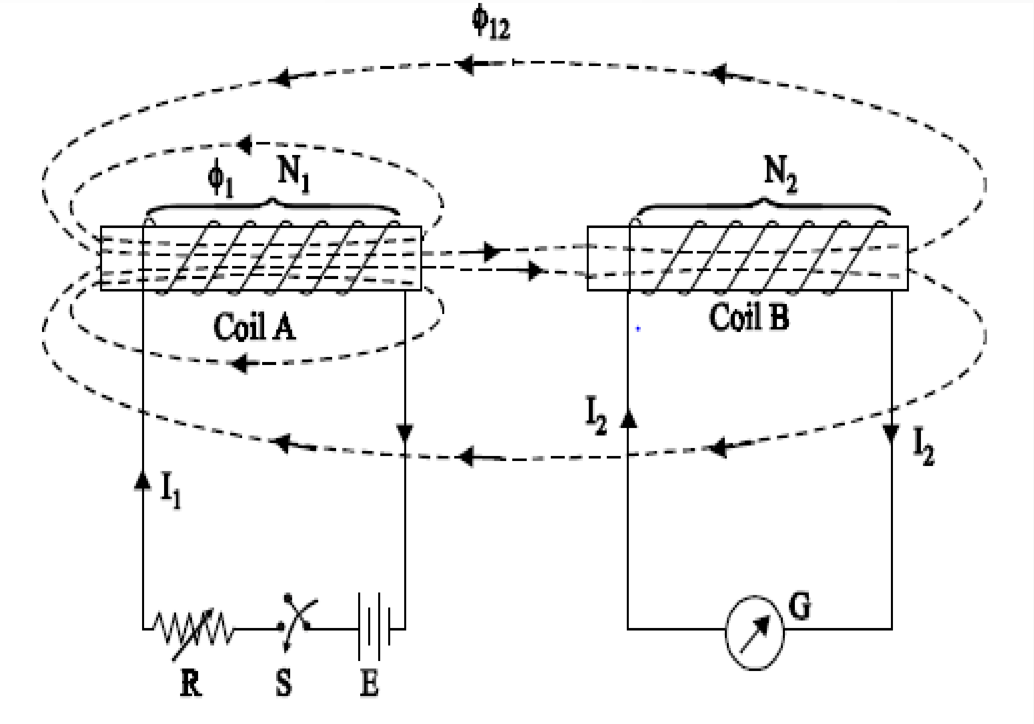
Mutually induced emf

Consider two coils (Say A and B) which are kept near by. The change in flux in coil A will change the flux linking with coil B. Due to this an emf will be induced in coil B. This induced emf is called as mutually induced emf. Simply, the emf induced in a circuit due to the change in the near by circuit is called as mutually induced emf.

In the Figure to the right, the flux in coil A is linking the coil B. So, when the current flowing through coil A (I1) is varied, then Φ1 will be varied, which in turn changes Φ 12, the flux linking coil A and coil B.

Due to this variation in the flux linkage, emf will be induced in coil B and the galvanometer pointer will deflect in one direction.

The current I1 is varied by varying the resistance R, in the coil A circuit.



There is more detailed information on electromagnetic induction on the google classroom

Thank You