Unit 1 – MAGNETIC CIRCUITS

Definition of MMF, Flux and Reluctance - Leakage Factor - Reluctances in Series and Parallel (Series and Parallel Magnetic Circuits) - Electromagnetic Induction - Fleming's Rule - Lenz's Law - Faraday's laws - statically and dynamically induced EMF - Self and mutual inductance - Analogy of Electric and Magnetic Circuits.

Definition of MMF, Flux and Reluctance - Leakage Factor

Magneto motive force (MMF)

Magneto motive force, also known as magnetic potential, is the property of certain substances or phenomena that gives rise to magnetic fields. Magneto motive force is analogous to electromotive force or voltage in electricity .The standard unit of magneto motive force is the ampere-turn (AT), represented by a steady, direct electrical current of one ampere (1A) flowing in a single-turn loop of electrically conducting material in a vacuum .

$$\text{Magneto motive force (mmf)}\, F = NI(\text{ampere} - \text{turns})$$

Sometimes a unit called the gilberts (G) is used to quantify magneto motive force. The gilberts is defined differently, and is a slightly smaller unit than the ampere- turn. To convert from ampere-turns to gilberts, multiply by 1.25664. Conversely, multiply by 0.795773.

Flux

Magnetic flux (most often denoted as Φ_m), is the amount of magnetic field (also called "magnetic flux density") passing through a surface (such as a conducting coil). The SI unit of magnetic flux is the Weber (Wb) (in derived units: volt-seconds). The CGS unit is the Maxwell.

Reluctance

Magnetic reluctance, or magnetic resistance, is a concept used in the analysis of magnetic circuits. It is analogous to resistance in an electrical circuit, but rather than dissipating electric energy it stores magnetic energy. In likeness to the way an electric field causes an electric current to follow the path of least resistance, a magnetic field causes magnetic flux to follow the path of least magnetic reluctance. It is a scalar, extensive quantity, akin to electrical resistance. The unit for magnetic reluctance is inverse henry, H^{-1}.Reluctance depends on the dimensions of the core as well as its materials.

Reluctance = l/μA.(A- t/Wb)

Permeability

The total magnetic flux in an electric rotating machine or transformer divided by the useful flux that passes through the armature or secondary winding. Also known as leakage coefficient. There are three categories of magnetic materials: diamagnetic, in which the material tends to exclude magnetic fields; paramagnetic, in which the material is slightly magnetized by a magnetic field; and ferromagnetic, which are materials that very easily become magnetized. The vast majority of materials do not respond to magnetic fields, and their permeability is very close to that of free space. The materials that readily accept magnetic flux—that is, ferromagnetic materials—are principally iron, cobalt, and nickel and various alloys that include these elements. The units of permeability are webers per amp-turn-meter (Wb/A-t-m). The permeability of free space is given by

Permeability of free space $\mu_0 = 4\pi \times 10{-}7$ Wb/A-t-m

Oftentimes, materials are characterized by their relative permeability, μ_r, which for ferromagnetic materials may be in the range of hundreds to hundreds of thousands. As will be noted later, however, the relative permeability is not a constant for a given material: It varies with the magnetic field intensity. In this regard, the magnetic analogy deviates from its electrical counterpart and so must be used with some caution.

Relative permeability = $\mu_r = \mu\mu_0$

Magnetic flux density

Another important quantity of interest in magnetic circuits is the magnetic flux *density*, *B*. As the name suggests, it is simply the -density‖ of flux .Unit is Tesla.

Magnetic flux density $B = \varphi/A$ webers/m^2 or tesla (T)

Magnetic field intensity

The magnetic field intensity is defined as the magnetomotive force (mmf) per unit of length around the magnetic loop. With *N* turns of wire carrying current i, the mmf created in the circuit is *Ni* ampere-turns. With *l* representing the mean path length for the magnetic flux, the magnetic field intensity is therefore

Magnetic field intensity H =NI/L ampere-turns/meter

We arrive at the following relationship between magnetic flux density *B* and magnetic field intensity as B = μH

Problems:

1. **Given a copper core with: Susceptibility as -9.7*10^6 ,Length of core L = 1 m, Gap length g = .01 m, Cross sectional area A = .1 m, Current I = 10A,N = 5 turns. Find: Bg**

$\mu = \mu_0(1 + \chi_m)$ **, Now using the length, cross sectional area, and permeability of the core we can solve for reluctance** R_c **by:**

$$R_C = \frac{L}{\mu_A} = \frac{1}{1.2566 * 10^{-6} * .1} = \mathbf{7.96 * 10^6}$$

Similarly, to get the reluctance of the gap

$$R_g = \frac{g}{\mu_o(\sqrt{A} + g)^2} = \frac{.01}{4\pi \times 10^{-7}(\sqrt{.1} + .01)^2} = 74.8 \times 10^3$$

Now recall the equation for the magnetic field of a gap as seen in

$$B_g = \frac{NI}{(R_g R_c)(\sqrt{A} + G)^2}$$

$$B_g = \frac{5 \times 10}{74.8 \times 10^3 \times 7.96 \times 10^6 \times (\sqrt{.1} + .01)^2}$$

2. **A coils of 200 turns is wound uniformly over a wooden ring having a mean circumference of**

Solution:

First we need to find the permeabilit of copper given by the equation

y

600 mm and a uniform cross sectional area of 500 mm2 . If the current through the coil is 4 A, calculate: (a) the magnetic field strength, (b) the flux density, and (c) the total flux

Answer: 1333 A/m, 1675×10-6 T, 0.8375 mWb

3. A mild steel ring having a cross sectional area of 500 m2 and a mean circumference of 400 mm has a coil of 200 turns wound uniformly around it. Calculate: (a) the reluctance of the ring and (b) the current required to produce a flux of 800 mWb in the ring. (Given that mr is about 380).

Answer: 1.677×106 A/Wb, 6.7 A.

Reluctance in Series (Composite Magnetic Circuit)

A magnetic circuit having a number of parts of different magnetic materials and different dimensions carrying the same magnetic field is called a Series Magnetic Circuit. It is also known as Composite Magnetic Circuit. One such circuit is shown in figure.

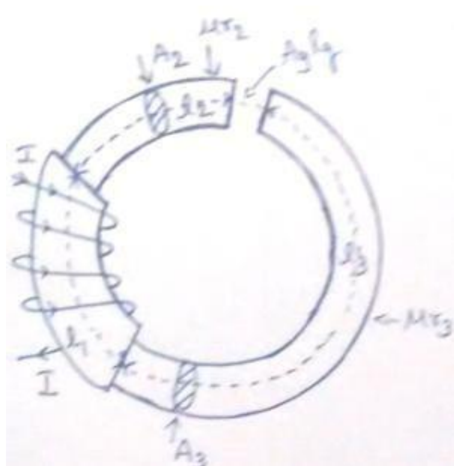


Figure. Reluctance in series

It consist of 3 different magnetic material and one air gap . Since materials are different the permeability are different. Assume that the length and the areas of cross-section are also different . Then the reluctance of each path will be different.

As the reluctance are in series, the total reluctance is the sum of the reluctance of different paths.

Total reluctance = $S = S_1 + S_2 + S_3 + Sg$

Total mmf = flux x reluctance

$$= \phi \times S = \phi\,(l_1/\mu_0\mu_{r1}A_1 + l_2/\mu_0\mu_{r2}A_2 + l_3/\mu_0\mu_{r3}A_3 + l_g/\mu_0A_g)$$

$$= l_1\,\phi / A_1\mu_0\mu_{r1} + l_2\,\phi / A_2\mu_0\mu_{r2} + l_3\,\phi / A_3\mu_0\mu_{r3} + l_g\,\phi / A_g\mu_0$$

$$= l_1B_1/\mu_0\mu_{r1} + l_2\,B_2/\mu_0\mu_{r2} + l_3\,B_3/\mu_0\mu_{r3} + l_g\,B_g/\mu_0$$

Total mmf = $H_1l_1 + H_2l_2 + H_3l_3 + H_gl_g$

Note: The following formulae are used in the above expression

1. $\phi / A = B$
2. $B/\mu_0\mu_r = H$

Reluctance in Parallel (Parallel Magnetic Circuits)

If a magnetic circuit has 2 or more paths for the magnetic flux, it is called a parallel magnetic flux.

L_2

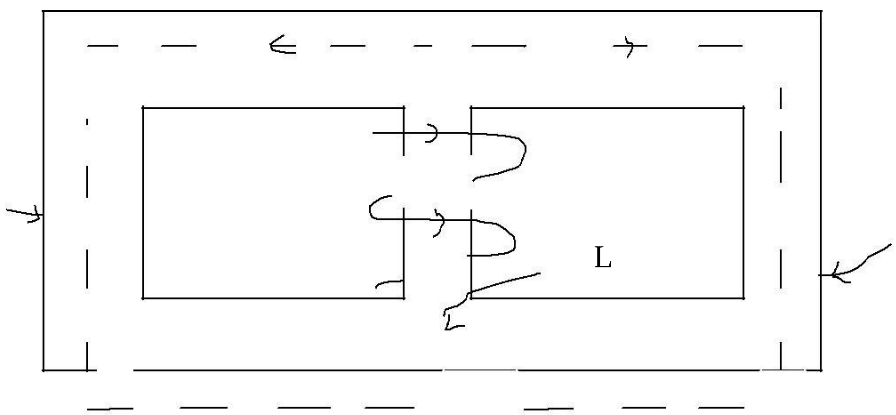


Figure 2.2 Reluctance in Parallel

On the central limb AB, a current carrying coil ia wound. The mmf in the coil sets up a magnetic flux ϕ_1 in the central limb. It is further divided in to 2 paths. They are

1. **The path ADCB which carries flux Φ_2 and**
2. **The path AFEB which carries flux Φ_3**

These 2 path are in parallel. The ampere turns (mmf) for this circuit is equal to the ampere turns required for any one of these paths.

$$Ø1 = Ø2 + Ø3$$

Reluctance of path BA = $S_1 = l_1/\mu_0\mu_{r1}A_1$

Reluctance of path ADCB = $S_2 = l_2/\mu_0\mu_{r2}A_2$

Reluctance of path AFEB = $S_3 = l_3/\mu_0\mu_{r3}A_3$

Mmf required for path ADCB = $Ø_2 \times S_2$

Mmf required for path AFEB = $Ø_3 \times S_3$

Mmf for parallel path = $Ø_2 \times S_2 = Ø_3 \times S_3$
Mmf required for path BA = $Ø_1 \times S_1$

Total mmf required = mmf for path BA + mmf required for path ADCB or path AFEB Total mmf (or) AT = $Ø_1 \times S_1 + Ø_2 \times S_2 = Ø_1 \times S_1 + Ø_3 \times S_3$

Worked Example

1. **Find the ampere turns required to produce a flux of 0.4 milliweber in the airgap of a circular magnetic circuit which has an airgap of 0.5mm. The iron ring has 4sq.cm cross section and 63cm mean length. The relative permeability of iron is 1800 and the leakage co-efficient is 1.15**

Sol. Given Data:

Flux in the airgap	**= Øg= Øuseful= o.4 weber**
Length of airgap lg	**= .5mm**
Cross-section of the iron ring A	**= $4x10^{-4}m^2$**

Mean length of iron ring = l = 63 cm

Relative permeability of iron = 1800

Leakage co-efficient λ = 1.15

This magnetic circuit has two materials airgap and iron

Total mmf = mmf in airgap + mmf in iron

Flux = mmf/reluctance

Mmf = flux x reluctance

a) For airgap: mmf = Øuseful x S_g

$$= 0.4\times10^{-4} \times (lg/\mu_0 A)$$

$$= 0.4\times10^{-4} ((0.5\times10^{-3})/(4\pi\times10^{-7}\times4\times10^{-4}))$$

$$= 397.88 \text{ AT}$$

b) For iron path flux = Øi = λ x Øuseful

$$= 1.15\times 0.4\times10^{-3}$$

$$= 0.46\times10^{-3}\text{wb}$$

Reluctance, Si = $(l/(\mu_0 \mu_r A))$

$$= 0.63/(4\pi\times10^{-7}\times1800\times4\times10^{-4})$$

$$= 696302.876 \text{ AT/Wb}$$

Mmf = $Ø_i$ x S_i

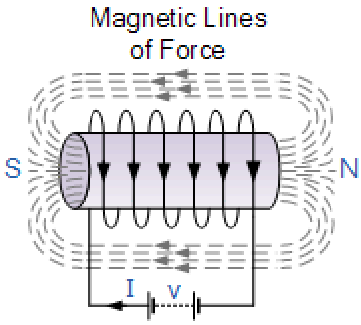
$$= 0.46\times10^{-3}\times696302.876$$

$$= 320.29\text{AT}$$

Total ampere turns required : 397.88+320.29 = 718 AT

Electromagnetic Induction

We have seen previously that when a DC current pass through a long straight conductor a magnetising force, H and a static magnetic field, B is developed around the wire. If the wire is then wound into a coil, the magnetic field is greatly intensified producing a static magnetic field around itself forming the shape of a bar magnet giving a distinct North and South pole.



Air-core Hollow Coil

The magnetic flux developed around the coil being proportional to the amount of current flowing in the coils windings as shown. If additional layers of wire are wound upon the same coil with the same current flowing through them, the static magnetic field strength would be increased.

Therefore, the [Magnetic Field Strength] of a coil is determined by the *ampere turns* of the coil. With more turns of wire within the coil, the greater the strength of the static magnetic field around it.

But what if we reversed this idea by disconnecting the electrical current from the coil and instead of a hollow core we placed a bar magnet inside the core of the coil of wire. By moving this bar magnet “in” and “out” of the coil a current would be induced into the coil by the physical movement of the magnetic flux inside it.

Likewise, if we kept the bar magnet stationary and moved the coil back and forth within the magnetic field an electric current would be induced in the coil. Then by either moving the wire or changing the magnetic field we can induce a voltage and current within the coil and this process is known as Electromagnetic Induction and is the basic principal of operation of transformers, motors and generators.

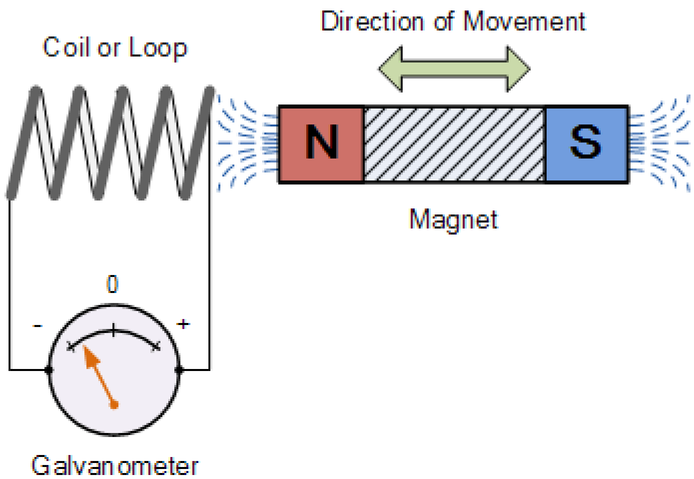
Electromagnetic Induction was first discovered way back in the 1830's by Michael Faraday. Faraday noticed that when he moved a permanent magnet in and out of a coil or a single loop of wire it induced an ElectroMotive Force or emf, in other words a Voltage, and therefore a current was produced.

So what Michael Faraday discovered was a way of producing an electrical current in a circuit by using only the force of a magnetic field and not batteries. This then lead to a very important law linking electricity with magnetism, Faraday's Law of Electromagnetic Induction. So how does this work?.

When the magnet shown below is moved “towards” the coil, the pointer or needle of the Galvanometer, which is basically a very sensitive centre zero'ed moving-coil ammeter, will deflect away from its centre position in one direction only. When the magnet stops moving and is held stationary with regards to the coil the needle of the galvanometer returns back to zero as there is no physical movement of the magnetic field.

Likewise, when the magnet is moved ‑away‖ from the coil in the other direction, the needle of the galvanometer deflects in the opposite direction with regards to the first indicating a change in polarity. Then by moving the magnet back and forth towards the coil the needle of the galvanometer will deflect left or right, positive or negative, relative to the directional motion of the magnet.

Electromagnetic Induction by a Moving Magnet



Likewise, if the magnet is now held stationary and ONLY the coil is moved towards or away from the magnet the needle of the galvanometer will also deflect in either direction. Then the action of moving a coil or loop of wire through a magnetic field induces a voltage in the coil with the magnitude of this induced voltage being proportional to the speed or velocity of the movement.

Then we can see that the faster the movement of the magnetic field the greater will be the induced emf or voltage in the coil, so for Faraday‘s law to hold true there must be ‑relative motion‖ or movement between the coil and the magnetic field and either the magnetic field, the coil or both can move.

Faraday's Law of Induction

From the above description we can say that a relationship exists between an electrical voltage and a changing magnetic field to which Michael Faraday‘s famous law of electromagnetic induction states: ‑that a voltage is induced in a circuit whenever relative motion exists between a conductor and a magnetic field and that the magnitude of this voltage is proportional to the rate of change of the flux‖.

In other words, Electromagnetic Induction is the process of using magnetic fields to produce voltage, and in a closed circuit, a current.

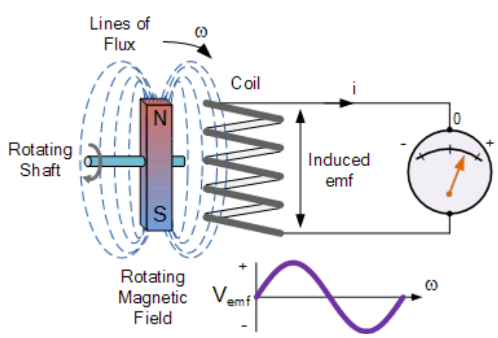
So how much voltage (emf) can be induced into the coil using just magnetism. Well this is determined by the following 3 different factors.

- **1). Increasing the number of turns of wire in the coil. – By increasing the amount of individual conductors cutting through the magnetic field, the amount of induced emf produced will be the sum of all the individual loops of the coil, so if there are 20 turns in the coil there will be 20 times more induced emf than in one piece of wire.**
- **2). Increasing the speed of the relative motion between the coil and the magnet. – If the same coil of wire passed through the same magnetic field but its speed or velocity is increased, the wire will cut the lines of flux at a faster rate so more induced emf would be produced.**
- **3). Increasing the strength of the magnetic field. – If the same coil of wire is moved at the same speed through a stronger magnetic field, there will be more emf produced because there are more lines of force to cut.**

If we were able to move the magnet in the diagram above in and out of the coil at a constant speed and distance without stopping we would generate a continuously induced voltage that would alternate between one positive polarity and a negative polarity producing an alternating or AC output voltage and this is the basic principal of how a Generator works similar to those used in dynamos and car alternators.

In small generators such as a bicycle dynamo, a small permanent magnet is rotated by the action of the bicycle wheel inside a fixed coil. Alternatively, an electromagnet powered by a fixed DC voltage can be made to rotate inside a fixed coil, such as in large power generators producing in both cases an alternating current.

Simple Generator using Magnetic Induction



The simple dynamo type generator above consists of a permanent magnet which rotates around a central shaft with a coil of wire placed next to this rotating magnetic field. As the magnet spins, the magnetic field around the top and bottom of the coil constantly changes between a north and a south pole. This rotational movement of the magnetic field results in an alternating emf being induced into the coil as defined by Faraday's law of electromagnetic induction.

The magnitude of the electromagnetic induction is directly proportional to the flux density, β the number of loops giving a total length of the conductor, l in meters and the rate or velocity, ν at which the magnetic field changes within the conductor in meters/second or m/s, giving by the motional emf expression:

Faraday's Motional emf Expression

$$\varepsilon = -\beta.\ell.\upsilon \quad \text{volts}$$

If the conductor does not move at right angles (90°) to the magnetic field then the angle θ° will be added to the above expression giving a reduced output as the angle increases:

$$\varepsilon = -\beta.\ell.\upsilon\sin\theta \quad \text{volts}$$

Lenz's Law of Electromagnetic Induction

Faraday's Law tells us that inducing a voltage into a conductor can be done by either passing it through a magnetic field, or by moving the magnetic field past the conductor and that if this conductor is part of a closed circuit, an electric current will flow. This voltage is called an induced emf as it has been induced into the conductor by a changing magnetic field due to electromagnetic induction with the negative sign in Faraday's law telling us the direction of the induced current (or polarity of the induced emf).

But a changing magnetic flux produces a varying current through the coil which itself will produce its own magnetic field as we saw in the Electromagnets tutorial. This self- induced emf opposes the change that is causing it and the faster the rate of change of current the greater is the opposing emf. This self-induced emf will, by Lenz's law oppose the change in current in the coil and because of its direction this self-induced emf is generally called a back-emf.

Lenz's Law states that: ‖ the direction of an induced emf is such that it will always opposes the change that is causing it‖. In other words, an induced current will always OPPOSE the motion or change which started the induced current in the first place and this idea is found in the analysis of Inductance.

Likewise, if the magnetic flux is decreased then the induced emf will oppose this decrease by generating and induced magnetic flux that adds to the original flux.

Lenz's law is one of the basic laws in electromagnetic induction for determining the

direction of flow of induced currents and is related to the law of conservation of energy.

According to the law of conservation of energy which states that the total amount of energy in the universe will always remain constant as energy can not be created nor destroyed. Lenz's law is derived from Michael Faraday's law of induction.

One final comment about Lenz's Law regarding electromagnetic induction. We now know that when a relative motion exists between a conductor and a magnetic field, an emf is induced within the conductor.

But the conductor may not actually be part of the coils electrical circuit, but may be the coils iron core or some other metallic part of the system, for example, a transformer. The induced emf within this metallic part of the system causes a circulating current to flow around it and this type of core current is known as an Eddy Current.

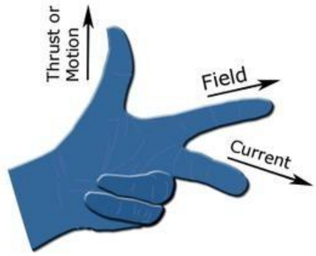
Eddy currents generated by electromagnetic induction circulate around the coils core or any connecting metallic components inside the magnetic field because for the magnetic flux they are acting like a single loop of wire. Eddy currents do not contribute anything towards the usefulness of the system but instead they oppose the flow of the induced current by acting like a negative force generating resistive heating and power loss within the core. However, there are electromagnetic induction furnace applications in which only eddy currents are used to heat and melt ferromagnetic metals.

Fleming's Rule

Whenever a current carrying conductor comes under a magnetic field, there will be force acting on the conductor and on the other hand, if a conductor is forcefully brought under a magnetic field, there will be an induced current in that conductor. In both of the phenomenon, there is a relation between magnetic field, current and force. This relation is directionally determined by Fleming Left Hand rule and Fleming Right Hand rule respectively. 'Directionally' means these rules do not show the magnitude but show the direction of any of the three parameters (magnetic field, current, force) if the direction of other two are known. Fleming Left Hand rule is mainly applicable for electric motor and Fleming Right Hand rule is mainly applicable for electric generator. In late 19th century, John Ambrose Fleming introduced both these rules and as per his name, the rules are well known as Fleming left and right hand rule.

Fleming's Left Hand Rule

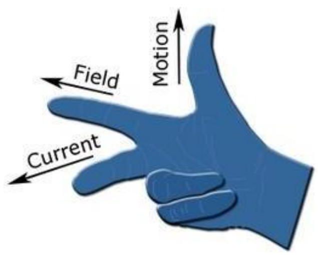
According to Fleming's left hand rule, if the thumb, fore-finger and middle finger of left hand are stretched perpendicular to each other as shown the figure above, and if fore finger represent the direction of magnetic field, the middle finger represents the direction of current, then the thumb represents the direction of force.



Fleming's left hand rule is applicable for electric motors. Whenever a current carrying conductor is placed in a magnetic field, the conductor experiences a force.

Fleming's Right Hand Rule

According to Fleming's right hand rule, the thumb, fore finger and middle finger of right hand are stretched perpendicular to each other as shown in the figure at right, and if thumb represents the direction of the movement of conductor, fore-finger represents direction of the magnetic field, then the middle finger represents direction of the induced current.



Fleming's right hand rule is applicable for electrical generators. As per [Faraday's law of electromagnetic induction](), whenever a conductor is moved in an electromagnetic field, and closed path is provided to the conductor, current gets induced in it.

Types of induced emf

There are two type of induced emf based on the nature, they are:-

- **Dynamically induced emf**
- **Statically induced emf:**

Further classified into:

- **Self induced emf**
- **Mutually induced emf**

Dynamically induced emf

An emf induced due to a physical movement of either conductor or flux. Here field is stationary and conductors cut across it. Either the coil or magnet moves. Magnitude of dynamically induced emf is as shown the conductor of length l is placed in the magnetic

field produced by a permanent magnet. The conductor moves in a plane which is parallel to the plane of the magnetic flux. Therefore induced emf is zero. Now if the plane of direction of motion of the conductor is perpendicular to the plane of magnetic flux then the induced emf is maximum. So the expression for magnitude of emf is given by: E =blv sin θ

2 Statically induced emf

Due to ac there is a change in the coil current with respect to time. This will result in alternating flux. Hence there will be change in flux w.r.t. time. This change in flux w.r.t. time will induce emf in this coil which is known as statically induced emf.

Self Induce E.M.F.

Consider a coil having N turns and carrying current I when Switch S is in closed position.The flux produced by the coil links with coil itself. The total flux linkages of coil will be NΦ Wb-turns. Now if the current I is changed with the help of variable resistance, then flux produced will also change, due to which flux linkages will also change.

Hence according to Faraday's law, due to rate of chang of flux linkages there will be induced emf in the coil. So without physically moving coil or flux there is induced emf in the coil. The phenomenon is called self induction

The emf induced in a coil due to the change of its own flux linked with it is called self induced emf.

Self Inductance

According to Lenz's law the direction of this induced emf will be so as to oppose the cause producing it. The cause is the current I hence the self induced emf will try to set up a current which is in opposite direction to that of current I. When current is increased, self induced emf reduces the current tries to keep it to its original value. If current is decreased, self induced emf increases the current and tries to maintain it back to its original value. So any change in current through coil is opposed by the coil.

This property of the coil which opposes any change in the current passing through it is called Self Inductance or only inductance.

Magnitude of Self induce EMF

From the Faraday's law of electromagnetic induction, self induced emf can be expressed as,

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

Negative sign indicates that direction of this emf is opposing change in current due to which it exists.

The flux can be expressed as,

$$\phi = (flux/ampere) \times ampere = \frac{\phi}{I} \times I$$

Now for a circuit, as long as permeability μ is constant, ratio of flux to current remains constant.

$$\therefore Rate\ of\ change\ of\ flux = \frac{\phi}{I} \times rate\ of\ change\ of\ current$$

$$\therefore \frac{d\phi}{dt} = \frac{\phi}{I} \cdot \frac{dI}{dt}$$

$$= -\left(\frac{N\phi}{I}\right)\frac{dI}{dt}$$

e

The constant $\frac{N\phi}{I}$ in this expression is nothing but the quantitative measure of the property due to which coil opposes any change in current. This constant is called coefficient of self inductance and denoted by ‗L'

$$\therefore L = \frac{N\phi}{I}$$

Expression for self inductance 'L'

$$L = \frac{N\phi}{I}$$

$$\phi = \frac{mmf}{Reluctance} = \frac{NI}{S}$$

$$L = \frac{N.NI}{I.S}$$

$$L = \frac{N^2}{s}\ henries$$

$$Now,\ S = \frac{l}{\mu a}$$

$$L = \frac{N^2}{\left(\frac{l}{\mu a}\right)}$$

$$L = \frac{N^2 \mu a}{l} = \frac{N^2 \mu_0 \mu_r a}{l}\ henries$$

Mutually induced EMF

If the flux produced by one coil is getting linked with another coil and due to change in this flux produced by first coil, there is induced emf in the second coil, and then such an emf is called mutually induced emf.

Magnitude of Mutually Induced EMF

Let

N_1 = Number of turns of coil A
N_2= Number of turns of coil B
I_1 = current flowing through coil A
Φ_1 = flux produce due to current I_1 in webers Φ_2
= flux linking with coil B

According to Faradays law , the induced emf in coil B is ,

$$e_2 = -N_2 \frac{d\phi_2}{dt}$$

Negative sign indicates that this emf will set up a current which will oppose the change of flux linking with it.

Now
$$\phi_2 = \frac{\phi_2}{I_1} \times I_1$$

If permeability of the surrounding is assumed constant then φ_2/I_1 is constant.

$$\therefore Rate of\ Change of\ \phi_2 = \frac{\phi_2}{I_1} \times Rate of\ \ change of\ \ current\ I_1$$

$$\therefore \frac{d\phi_2}{dt} = \frac{\phi_2}{I_1} \cdot \frac{dI_1}{dt}$$

$$e_2 = -N_2 \cdot \frac{\phi_2}{I_1} \cdot \frac{dI_1}{dt}$$

$$e_2 = -\left(\frac{N_2\phi_2}{I_1}\right) \cdot \frac{dI_1}{dt}$$

This $\left(\frac{N_2\phi_2}{I_1}\right)$ is called coefficient of mutual inductance denoted by M.

$$\therefore e_2 = -M \frac{dI_1}{dt}\ volts$$

Coefficient of mutual inductance is defined as the property by which emf gets induced in the second coil because of change in current through first coil.

Analogy of Electric and Magnetic Circuits

Electric Circuit	Magnetic Circuit
Path traced by the current is known as	Path traced by the magnetic flux is called
electric current.	as magnetic circuit.
EMF is the driving force in the electric circuit. The unit is Volts.	MMF is the driving force in the magnetic circuit. The unit is ampere turns.
There is a current I in the electric circuit which is measured in amperes.	There is flux φ in the magnetic circuit which is measured in the weber.
The flow of electrons decides the current in conductor.	The number of magnetic lines of force decides the flux.
Resistance (R) oppose the flow of the current. The unit is Ohm	Reluctance (S) is opposed by magnetic path to the flux. The Unit is ampere turn/weber.
$R = \rho.l/a$ Directly proportional to l. Inversely proportional to a. Depends on nature of material.	$S = l/(\mu_0\mu_r a)$. Directly proportional to l. Inversely proportional to $\mu = \mu_0\mu_r$. Inversely proportional to a
The current I = EMF/ Resistance	The Flux = MMF/ Reluctance
The current density	The flux density
Kirchhoff current law and voltage law is applicable to the electric circuit.	Kirchhoff mmf law and flux law is applicable to the magnetic flux.

Questions

PART A

1. What is a Series Magnetic circuit?
2. What is a parallel magnetic circuit?
3. Give the expression for the Total MMF of a composite magnetic circuit.
4. Give the expression for the Total MMF of a parallel magnetic circuit.
5. What is reluctance?
6. Define magneto motive force.
7. Define magnetic flux
8. What is leakage factor?
9. Give the correlation between flux, mmf and reluctance.
10. Write the correlation between magnetic flux density and magnetic field intensity.
11. Define magnetic flux density.
12. State Faraday‘s law of Electromagnetic induction.
13. State Fleming right hand rule.

14. **State Lenz's law.**
15. **What is Self inductance and Mutual inductance?**
16. **Reluctance and flux density are the two terms in magnetic circuits. What are the corresponding analogous terms in an electrical circuit?**
17. **A conductor of length 1m moves at right angles to a uniform magnetic field of flux density 1.5 wb/m^2, with a velocity of 50 m/sec. calculate the emf induced in it.**
18. **Write the expression for energy stored in magnetic field.**

PART B

1. **Explain in detail the analysis of simple and composite magnetic circuits.**

2. **a) Compare Magnetic circuits & Electric circuits.**
   b) An iron ring has a cross-sectional area of 400mm^2 and a mean diameter of 20 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 480 ohms and the supply voltage is 240 V.

3. **A coil is wound uniformly with 300 turns over a steel ring of relative permeability 900 having a mean circumference of 40 cm and a cross- sectional area of 5cm^2. If the coil has a resistance of 100 ohms and is connected to a 250 V dc supply, calculate (i) the coil mmf (ii) the magnetic field intensity (iii) total flux (iv) permeance of the ring.**

4. **A no of turns in a coil is 250. When a current of 20A flows in this coil, the flux in the coil is**
   milliwebers. When this current is reduced to zero in 2 milliseconds, the voltage induced in the coil lying in the vicinity of coil is 63.75V. If the co-efficient of coupling between the coil is 0.75 Find (i) Self inductance of the two coils
   (ii) Mutual inductance
   (iii) Number of turns in the second coil

5. **a) A mild steel ring having a cross-sectional area of 500mm^2 and a mean circumference of 400mm has a coil of 200 turns wound uniformly around it. Calculate (a) reluctance of the ring and (b) the current required to produce a flux of 800μwb in the ring. Assume relative permeability of mild steel to be 380.**

6. **(a) Derive the expression for self and mutual inductance**
   (b) Explain the types of induced emfs.

7. **An iron ring 30 cm mean diameter is made of square iron of 2 cm x 2 cm across section**

and is uniformly wound with 400 turns of wire of 2mm2 cross section. Calculate the value of the
self inductance of the coil. Assume μ_r = 800.

8. **A ring shaped electromagnet has an air gap of 6mm long and 20cm2 in area, the mean length of the core being 50cm and its cross-section is 10cm2. Calculate the ampere turns required to produce a flux density of 0.5Wb/m2 in the air gap. Assume the permeability of iron as 1800.**

9. **A circular iron ring, having a cross – sectional area Of 10cm2 and a length of 4 cm in iron, has an air gap of 0.4 mm made by a saw-cut. The relative permeability of iron is 1000 and permeability of free space is 4 x 10-7 H/m. The ring is wound with a coil of 2000 turns and carries 2mA current. Determine the air gap flux neglecting leakage and fringing.**

10. **State and explain the Faraday's laws of electromagnetic induction. Also give the Fleming's Right hand and Left hand rules.**