**ELECTROMAGNETIC INDUCTION**

**Historical background:**

The discovery by H.Orested in 1819 that a current gives rise to magnetic field led to the search that a magnet might produce a current.In 1830 Joseph Henry in America and a few months later in 1831 Michael Faraday in England discovered such a phenomenon.t was found that if the magnetic flux through a closed loop of wire is changed a current is found to flow in the loop.The current remains only as long as the magnetic flux continues to change.Since current is caused to flow by a source of emf,the changing magnetic flux must be the cause of inducing emf in the loop and produce current in the current in the closed loop.This phenomenon is called electromagnetic induction.

**Definition:**

***“Whenever there is a change in magnetic flux through a closed loop there is an induced e m f in the in the loop is called electromagnetic induction.”***

**OR**

***“When an emf is induced in a conductor due to change in magnetic flux linking the conductor.”***

**Explanation:**

Let us explain:

(i)Faraday observed that a galvanometer connected to the ends of a coil deflected(current is produced)when a magnet is moved toward or away from coil as shown:

When the north pole is brought near the coil ,the current flows in one direction (as in above fig).If a south pole is brought toward the coil the deflection is in the same direction as when the north pole is withdrawn.Similar effects are produced when the coil is toward or away from the fixed magnet.

If the magnet is held stationary with respect to the coil, the galvanometer needle doses not deflect.This means that it is the relative motion of the magnet and the coil that causes the deflection of the galvanometer,now the question is what relative motion do in terms of flux.The relative motion changes the magnetic flux linking the coil.

(ii)Consider a current carrying primary coil placed near to another coil called secondary coil.When the primary coil is moved toward or away from the secondary coil,current is produced in the secondary coil,if the secondary coil is moved toward or away from the primary coil still current is produced in the secondary coil,in both the cases the only thing that is common is the relative motion,which In terms changes flux.

(iii)It is important to know that origin of electromagnetic induction is not the relative motion but it is the change of flux.For this purpose, the same primary and secondary coil if the current is switched on in the primary,the galvanometer is deflected and when the current is switched off,the galvanometer shows deflection.Thus current in the secondary is produced whenever current in the primary circuit is changed,stopped,started,increased or decreased.The rotation of current in primary coil changes the magnetic flux passing through the secondary coil.

**Conclusion:**

From the above experiment,we conclude that whenever the magnetic flux linking a closed loop is changed there is an induced em f in the loop that causes the flow of current in the loop.

**Note:**

The current produced as a result of electromagnetic induction is called induced current.The magnitude of induced emf is found proportional to time rate of change of flux.

**FARADAY’S LAW OF ELECTROMAGNETIC INDUCTION**

**Statement:**

***“The magnitude of induced emf is equal to the negative time rate of change of magnetic flux through the circuit”***

**OR**

***“The induced emf produced is directly proportional to the rate of change of flux, this is known as faraday law of electromagnetic induction.”***

**Mathematical form:**

ε = -N

**Explanation:**

Let us consider a current carrying loop placed in a magnetic field B.If ‘φi’ is the initial flux at time t=0,and ‘φf ’ is the final flux through the loop after time t,then:

Change in flux in on loop = Δφ = φf  ­- φi

Change in the flux in N loops = NΔφ= Nφf  - Nφi

Therefore,

Change in flux in time t=NΔφ

So, change in flux in unit time = NΔφ/At

From the faraday law the rate of change of flux is equal to induced emf so,

ε = N)

This equation shows that the magnitude of induced emf.

The induced emf gives rise to a current whose magnetic field opposes the original change in flux.To represent this, we put negative sign in equation

ε = - N ………………………………….(14.1)

The concept of the negative sign is explained by Lenz in Lenz’s Law.

**Lenz’s law:**

**Background:**

Lenz’s law is a convenient alternative method for determining the direction of an induced emf or current.

**Statement:**

***“ The direction of the induced e m f is in such a way that it opposes the cause producing it”***

**Explanation**:

To explain Lenz’s law, let us consider relative motion between a coil and a magnet as shown in fig above.If the N pole of the magnet is moved towards the coil, the flux through the coil increases.This will produce induced current.It is observed that the induced current is produced in such away that it will produce a magnetic field which will oppose the motion of magnet towards the coil. To oppose the leftward increase, the field produced by induced current must point rightward.Thus, using the right hand rule,lenz’s law tell us that the current must move counter clock wise as shown in the fig below. This makes the face of the coil facing the magnet N-pole.

Now if the N-pole is with drawn from the coil, the flux through the coil decreases.According to lenz’s law the induced current will try to maintain constant flux.For this purpose,the induced current must be clockwise to make the face of the coil facing the magnet S-pole as shown:

In the same way,if the current in a current carrying primary coil is increased or decrease due to which induced current will be produced in secondary coil to oppose the increase or decrease,also if a coil is rotated in a magnetic field,induced current will flow in such a direction that the magnetic torque on the loop will oppose the rotation .

**Lenz’s law and law of consevation of energy:**

According to the law of conservation of energy,***“Energy can neither be created nor destroyed, rather it only changes its form”***

Changing magnetic field induces an emf and a conducting current,if there is a conducting path.Thus electrical energy appear as a result of this act.It is the work done against the opposing magnetic field,which is transformed into electrical energy.So if we are to generate electrical energy in a circuit by the method of electromagnetic induction,the agent performing the work must need some opposition from the circuit.

**If lenz’s law was not true:**

If lenz’s law was not true, the induced current in this pretend situation would produce in the same direction as the original change. The greater change in flux would produce an even larger current followed by a still greater change in flux, and so on. This would violate the law of conservation of energy. Such perpetual devices do not exist.

**Conclusion**:

We see that the violation of lenz’s law results in the violation of law of conservation of energy.Therefore,we conclude that lenz’s law is consistent with law of conservation of energy.

**Fleming’s Right Hand Rule:**

To find the direction of induced emf and hence current,fleming’s right hand rule is used.It states that:

***“Stretch out the forefinger,middle finger and thumb of your right hand at right angles mutually,if the forefinger points in the direction of magnetic field,thumb in the direction of the conductor,then the middle finger will point in the direction of induced current.”***

**Induced emf:**

***“When a conductor is placed in varying magnetic field,emf is induced in the conductor and this emf is called induced emf.”***

As the varying magnetic field can be brought about in two ways,therefore,induced emf is of two types:

(i)Dynamically induced emf

(ii)Statically induced emf

**(i)Dynamically induced emf:**

***“When a conductor is moved in a stationary magnetic field,in such away that the flux linking it changes, the e m f so induced is called dynamically induced emf.”***

e.g.The emf induced in an AC generator.

**(ii)Statically induced emf:**

***“When the conductor Is stationary and the magnetic field is changing, the emf so induced is called statically induced emf.”***

e.g.case of transformer.

**Motional emf:**

***“The emf produced due to motion of a conductor in a magnetic field is called motional emf.”***

**Explanation :**

To describe motional emf,let us consider a conducting rod of length‘l’.A galvanometer is connected between the end points‘S’ and ‘R’ of the rails,as shown:

A conducting loop is formed.A uniform magnetic field is applied perpendicular,directed in to the paper. When the rod is at rest, the galvanometer shows no deflection i.e current is not present in the loop. If the rod ispulled to the right or left with a velocity V, galvanometer shows deflection, indicating induced current through the loop.The emf so induced is called Induced emf.

**Mathematical derivation :**

Let us move the rod to the left with velocity ‘V’.Now,when the conductor is moved,an induced current is produced in the loop.When we move conductor to the right,the magnetic force also acts on the rod which tends to pull the rod to right (in a direction opposite to that of our applied force).If the conductor is moved with constant velocity,so the applied force must be equal to the magnetic force. So,

Fm = Fapp

Hence, ILB = Fapp………………………………………(14.2)

Now work is being done against the magnetic force i.e.the rate of work done will be given by

P = FappV

P = IlBV…………………………………………(14.3)

Now this power opposes as the electrical power in the circuit which is:

P=Iε (where ε is induced emf)…………………...(14.4)

Comparing equations (14.3) and (14.4) :

Iε = IlBV

**ε = BlV**…………………………………………….(14.5)

This is the mathematical form of emf induced.

Note that this is the case for which ‘B’,‘l’ and ‘V’ are mutually perpendicular.

**Case:**

If the magnetic field makes a certain angle ‘θ’ with the length ‘l’,then we will take the component of ‘B’ which is perpendicular to ‘l’ as shown;

So,

ε = (BSin)lV

**ε =BVlSinθ**.............................................(14.6)

**Mutual Induction:**

***“The phenomenon in which an induced emf is produced in the secondary coil when current is changing in the primary coil is known as mutual induction.”***

**Explanation:**

To understand mutual induction,let us consider two coils ‘A’ and ‘B’ lying close to each other as shown:

As from figure,coil ‘A’ is joined to a battery,wherever coil ‘B’ is connected to a sensitive galvanometer.If two coils of wire are placed near each other,a changing current in one will induce an emf in the other,thus starting,stopping or varying current in the primary coil ‘A’ will induce emf in the secondary coil ‘B’.The current in the coil ‘B’ lasts only as long as the current in the coil ‘A’ is changing.

Thus the e m f in the secondary coil is caused by the change in current in the primary. So,the emf induced in the secondary coil is directly propotional to the rate of change of current in the primary coil.In time t,if ΔIp is the change in current,then mutual induced emf in secondary coil will be:

ε ΔIp/t

ε = - MΔIp/ Δt …………………………………….

where ‘M’ is the constant of proportionality and is called ‘mutual inductance’ of the two coils.The negative sign is in accordance with Lenz’s law.

**Mutual inductance:**

M =

So,we can define mutual inductance as:

***“The ratio of the emf induced in the secondary to the time rate of change of current I the primary coil.”***

Also,

Ε= -NΔφ/ Δt …………………….(ίί)

Comparing (ί) and (ίί)

-NΔφ/At = MΔIp/At

M = -Δφ/ Δt

**Dependence:**

The value of ‘M’ depend upon the geometrical features of the two coil.The geometrical features include the cross sectional area of each coil.The number of turns in the two coils, the separation betweeen the coils and presence of iron in the coil,e.g.the closer the lines,the more lines of flux will passes through the secondary,so ‘M’ will be greater.

**Unit:**

The unit of ‘M’ is volt-sec/ ampere = Vs/ A called henry (H).

**One henry:-**

“The mutual induction is said to be one henry,when the current changing at the rate of 1 A/sec in one coil induces emf of 1 V in the other coil.”

**1 H = 1V/1A/sec**

**Self-induction:-**

***“The property of a coil due to which it opposes any change of current or flux through itself is known as self-induction.”***

OR

“The emf induced in a coil when magnetic flux linked with it,is changed by current flowing through it,is known as self-induced emf and the phenonenon is called self-induction.”

**Explanation:**

It is our common experience that when the conductor is stationary and the field is changing,then the emf induced is called statically induced emf,self-induced emf is an example of statically induced emf .

To understand self - induction consider a circuit as shown,

If the current in the coil changes, then the flux linking the coil will also change, hence an induced e m f is induced in the coil. This is known as self -induced e m f. the direction of this induced e m f (By Len’s Low) so that it opposes the cause producing it, namely the change of current in the

Coil. The self-induced e m f persists so long as the current in the coil is changing.

SELF INDUCTANCE:

‘’The property of a coil that opposes any change in the amount of current flowing through it is called ‘self-inductance’’

MATHEMATICAL FORM:-

In order to find an expression for self inductance and self induced e m f, consider a coil of N-turns carrying a current ‘I. when the current in the coil changes then flux linking the coil also changes, hence e m f is induced in the coil, so induced e m f will be;

ΔI/ Δ t

Ε = -L ΔI/Δ t ……………………………………… (1)

Where ‘L’ is constant of proportionality and is called self-inductance. The negative sign is in accordance with lens’s law.

SELF-INDUCTANCE DEF (MATHEMATICAL):-

Then (1)

L = ε/ΔI/Δ t

S o

‘’ The ratio of e m f induced in a coil to the rate of change of current in that coil is called self-inductance of that coil’

Also,

Ε = -N Δ φ/Δ t ……………………………………… (2)

From (1) and (2)

L = N φ/I

IMPORTANCE:-

The self inductance of many DC circuits is very small however, a coil with many turns and wound on an iron core or a large solenoid may have a large inductance. In A-C circuit inductance is of great importance since, the current is constantly changing.

UNIT:-

The unit of self-inductance is Henry.

ONE HENRY:-

‘’ The self-inductance of a coil is said to be one Henry if one volt e m f is produced due to change in current of 1A/s in that col.

SELF-INDUCTANCE OF A SOLENOID:-

Solenoid is a very popular specific geometry which has a variety of daily life application. Because of its specific shape, an expression can easily be obtained for its self inductance.

Let us consider a solenoid having current ‘I’ at t=o and it changes to ‘I + Δ I’ in time ‘d t’. If ‘n’ is the no of turns per unit length then,

Initial magnetic field = o n I …………………….. (ί)

Final magnetic field = o n (I + d I) ……………….. (ί ί)

As the area of solenoid is constant, so the change in magnetic flux is due to the change in magnetic field inside the solenoid i.e.

Δ φ = Δ BA = (Bf – Bi)A

Δ φ = o n (I + Δ ί) – oni)A

Δ φ = o n ΔI A ……………………………………… (iii)

From faraday law,

Ε = -N Δ φ/Δ t

Ε = - N o n ΔI A /Δ t …………………………..... (I v)

As, n = N/L N = n l so, the total no of turns is ‘N’ and ‘L’ is the length of solenoid so,

E = - l A Δ I/Δ t ………………………… (v)

E = - L /Δ t …………………………………………… (vi)

From formula it is clear that; inductance depends on

1. Permeability of material on which coil is wound.
2. Num of turns per unit length.
3. Geometry of solenoid.

ROLE OF INDUCTANCE IN CIRCUITS:-

Inductors play a great role in electronic, electrical etc circuits.

When an induced e m f is produced in the coil due to increasing current, then its direction is always opposite to increasing current. i.e. The direction of self-induced e m f is opposite to that of applied voltage. On the other hand when an e m f is produced in coil due to decreasing current then the direction of self-induced e m f is always opposite to decreasing current i.e. its direction will be same as that of applied voltage. Thus by increasing the self-induced e m f, increases the opposition the changing current. So, they play a vital role in circuits.

A-C GGENERATOR:-

‘’A device which w/c converts mechanical energy into electrical energy (alternating voltage)is known as A-C generator’’.

BASIC PRINCIPLE:-

A C generator is based on faraday’s law of electromagnetic induction. An e m f is produced by changing the magnetic flux inside a coil using mechanical energy.

CONSTRUCTION:-

An A-C generator consists of following parts:-

1. ARMATURE:-

It consists of a rectangular coil (CDEF) of n turns, which are wound on cylindrical iron core. The assembly of coil plus cylinder is called armature. The armature can rotate about an axis, which is perpendicular to a uniform field of flux density B.

1. MAGNETIC FIELD:-

The magnetic field is provided by an electromagnet or by a permanent magnet.

1. SLIP RINGS:-

The terminals of the coil are connected to slip rings A1 an A2. A1 is connected to the side ‘CD’ of the coil and ‘A2’ is connected with ‘EF’ of the coil. The rings are concentric with the axis, rotate with the coil and are insulated from each other.

(I v) CARBON BRUSHES:-

Two carbon brushes ‘B1’ and ‘B2’ touching the rings connect the coil to the external load. ‘A1’ is always in contact with brush ‘B1’ and ‘A2’ is in c0ntact with ‘B2’.

All the arrangements are shown as;

WORKING THEORY:-

When the coil rotates b/w poles of magnet, an e m f is induced due to change in flux. The current flows through the external circuit by slip rings ‘A1’ and ‘A2’ w/h are made up of copper. When the side ‘CD’ moves upward then according to Fleming’s right hand rule, the current flows from ‘C’ to ‘D’ and ‘E’ to ‘F’. Thus the current enters the circuit at ‘B2. After half revolution, the side ‘FE’ will take the position of ‘CD’ and current direction is reversed. So, current flows from ‘F’ to ‘E’ and ‘D’ to ‘C’. Now the current enters the circuit at ‘B2’ and leaves it at ‘B1’. Thus an induced e m f and the current change in half revolution in magnitude and direction

The situation after half revolution is shown as;

EXPRESSION FOR INDUCED E M F:-

Suppose the coil is rotating with constant angular velocity ‘w ’ and completes one rotation in time period

T = 2 / w = 1/f,

Where ‘f’ is the frequency of relation. Let at any instant t, be the angle b/w the field ‘B’ and normal ‘n’ to the plane of the coil as shown;

Then the flux through coil of ‘N’ turns, each of area ‘A’ will be;

Φ = N ( )

Φ = N B A ……………….. (1)

Since,

So, (1) φ = N A B Cos wt ………………… (2)

Now induced e m f according to faraday’s law will be;-

E = - Δ φ/

Put value of

E = - Δ (N A B )/ Δ t

‘N’, ‘A’, ‘B’ are constant and do not change with time, and Δ Cos wt/Δ t = - w sin wt

So,

E = - (-N A B Sin w t )

E = NAB w Sin wt ………………………………………. (i)

When wt = 90

E = N A B w

So, (i)

E = E0 Sin wt ……………………………………………... (i i)

The e m f varies with Sin of the angle; this variation Is called sinusoidal variation

Also,

W = 2 f

E = E o Sin 2

E = E0 Sin 2 f t

GRAPH OF E M F VS TIME:-

The graph of current versus time has the same shape as that of e m f, against time but magnitude depends upon the resistance of the circuit. Now, we discuss the sinusoidal variation at various times.

STAGE (1)

At time t=o the angle = wt = 0, the n^ to plane of the coil is parallel to ‘B’, so

E = N A B w (0)

E = o

STAGE (2)

At t = T/4,

2

Sin 90 = 1

S0, E = N A B w

E = E max

This gives the peak value in positive direction.

At t = T/2,

, Sin = 0

So,

E = o

STAGE (4)

At time t =n 3T/4,