Applied Physics Unit IV

Electromagnetic induction:

* Oersted discovered the magnetic field around the current carrying conductor.

* Ampere derived the equation for the magnetic field intensity.

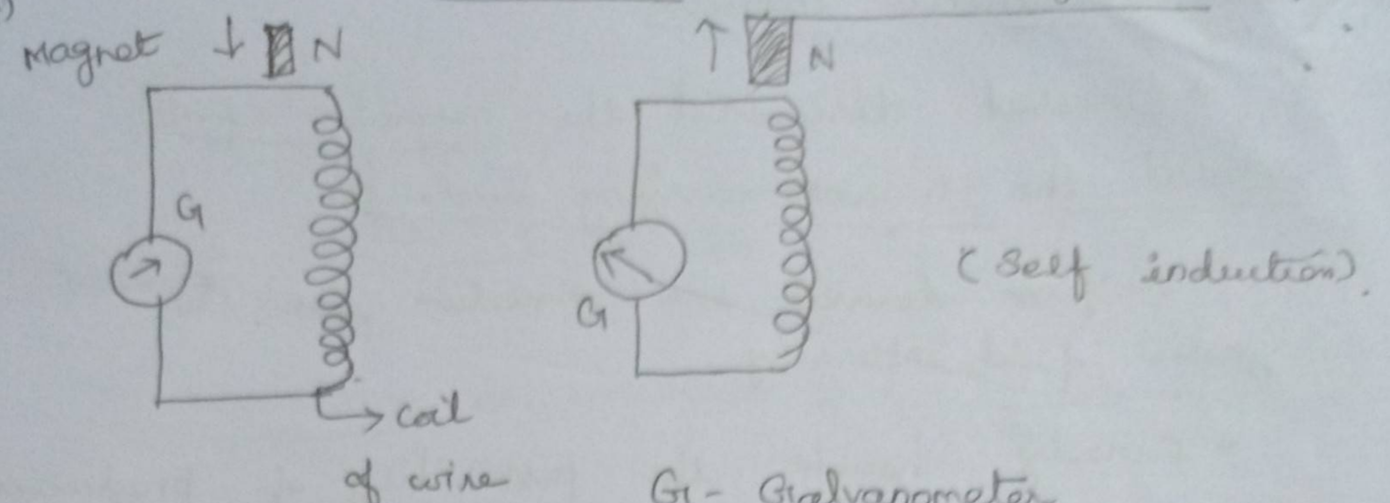
* Farady thought the possibility of producing an electric ~~field~~ current in changing magnetic field.

* Farady discovered that a current can be produced when a magnet brought near a closed circuit. The current produced in the conductor in this way is called induced current, and the e.m.f that causes this current is known as induced e.m.f. this phenomenon is known as electromagnetic induction.

* The working of transformer and dynamo is based on the principle of electromagnetic induction.

Experiment to demonestrate Electromagnetic induction

(9)



* If the magnet moved towards the coil, a momentoary deflection is observed in the galvanometer

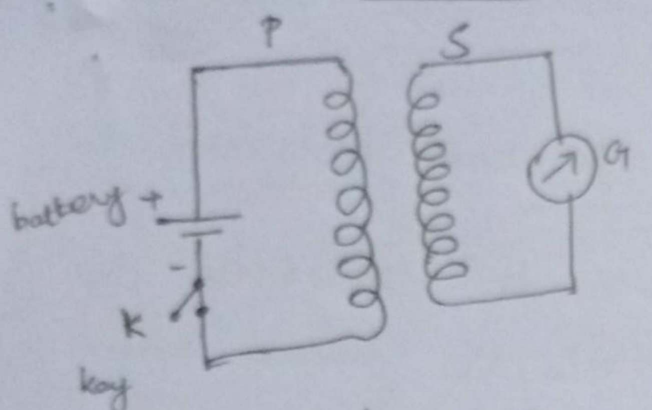
* If the magnet moved away from the coil, a momentary deflection observed in the coil, but is opposite direction. This indicates a momentary curren in the coil.

* If the same experiment is repeated with south pole, facing the coil, the deflection of the galvanometer is reversed.

*If the magnet is Stationary, there is no deflection.

* The same resuet is obtained, if the magnet is fixed and the coil is moved.

(ii) Mutual induction:



- Two coils placed closed to each other.
- Primary P is connected to a battery
- Secondary is connected to a galvanometer.

- When key is closed, a current flows through primary. The galvanometer gives momentary deflection; showing that an induced current in the secondary coil.

- When the current in P is steady, the galvanomet gives no deflection.

- When the primary is switched off, there is a momentary deflection, but in opposite direction.

- These two experiments show that whenever there is a change in the magnetic flux linked with the closed circuit, a current is induced. This phenomenon is called electromagnetic induction.

Laws of electromagnetic induction:

Farady's laws of electromagnetic induction:

(i) ~~Whatever~~ the magnetic flux associated with any closed circuit changes, an induced current flows through the circuit, which lasts only so long as the change lasts.

(ii) The magnitude of the induced e.m.f produced in a coil is directly proportional to rate of change of magnetic flux through the coil

$$\boxed{e \propto \frac{d\phi}{dt}}$$

Here ϕ - is the magnetic flux through the circuit.

$\therefore$ Induced e.m.f $\boxed{e = -\frac{d\phi}{dt}}$

The negative sign gives the direction of the induced emf.

Lenz's law: The direction of the induced e.m.f or induced current may be found by Lenz's law.

* "This law states that the direction of the induced e.m.f is such as to oppose the change in flux which induces it".

Fleming's Right Hard Rule:

The direction of the induced e.m.f and current can be determined by Fleming's right hard rule.

Stretch the thumb, the fore finger and the central finger mutually perpendicular to one another. If the thumb represents the direction of the motion of the conductor and the fore finger the direction of the magnetic field, then the central finger points the direction in which current is induced in the circuit.

f Induction.

When a current flows through a coil, a magnetic field is produced around the coil. If there is a charge in current flowing through the coil, then there is a charge in flux linked with coil. Due to this induced e.m.f is produced. Thus a varying current flowing through a coil, induces an e.m.f in the same coil. this phenomenon is known as self induction.

The magnetic flux ϕ linked with a coil is directly proportional to the current i flowing the coil.

$$\phi \propto i \rightarrow \text{current}$$

$$\phi = Li \rightarrow ①$$

where L is a const known as self inductance of the coil.

if $i = 1$ ampere, then $\phi = L$. from this we can define the self inductance.

The self inductance or coefficient of self induction of coil is defined as the magnetic flux linked

$$\phi = Li \longrightarrow ①$$

if $i = 1$ amp $\boxed{\phi = L}$

from ① $$\frac{d\phi}{dt} = L\frac{di}{dt}$$

but, $e = -\frac{d\phi}{dt}$ $\quad e = -L\frac{di}{dt}$

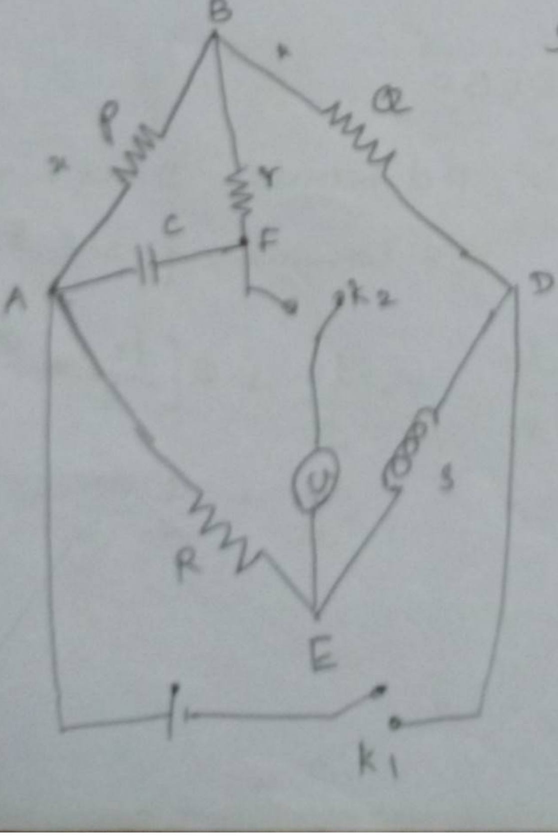
if $\frac{di}{dt} = 1$ amp/sec

$\boxed{e = -L}$ unit Henry

∴ volt/amp/~~sec~~ henry

1 Henry → if an e.m.f of 1 volt is induced in it due to the current flowing through itself changes at the rate of 1 amp/sec.

<u>Andersons</u> <u>method</u>:



S – resistance of the inductance coil

- k1 – pressed, P, Q and R are adjusted when k2 is pressed. Now the bridge in balanced for steady current.
- k1 – opened k2 pressed r is adjusted, so that no kick in the galvanometer now bridge is balanced for varying current.

Theory:

Let x, y be the charge measured in columbs passing through arms AB and AE and z the charge on the condensor plate. In the mesh ABFA,

$\boxed{V = IR}$ (ohm law) $V = Q/C$

In the mesh ABFA:

p.d b/w A&B = p.d b/w A&F + p.d across r,

$$P.\frac{dx}{dt} = \frac{z}{c} + r.\frac{dz}{dt}$$

$$\frac{dx}{dt} = \frac{z}{cP} + \frac{r}{P}.\frac{dz}{dt} \longrightarrow ①$$

In the mesh AEFA,

p.d between A & E = p.d b/w A and F + p.d b/w F.E

$$R.\frac{dy}{dt} = \frac{z}{c} + 0$$ (Since no current flows through galvanometer)

$$\frac{dy}{dt} = \frac{z}{cR} \longrightarrow ②$$

In the mesh DEBD,

P. d between D and E = p.d between D and B + p.d between B and E

$$L.\frac{d}{dt}\left(\frac{dy}{dt}\right) + S.\frac{dy}{dt} = r.\frac{dz}{dt} + Q\left[\frac{dx}{dt} + \frac{dz}{dt}\right]$$

$$L\frac{d^2y}{dt^2} + S.\frac{dy}{dt} = r.\frac{dz}{dt} + Q.\frac{dx}{dt} + Q.\frac{dz}{dt}$$

↳ ③

from (2) $$\frac{dy}{dt} = \frac{Z}{CR}$$

$$\frac{d^2y}{dt^2} = \frac{1}{CR} \cdot \frac{dz}{dt} \longrightarrow (4)$$

Substituting (4), (2) and (1) in eqn. (3) we get,

$$L \cdot \frac{d^2y}{dt^2} + S \cdot \frac{dy}{dt} = r \cdot \frac{dz}{dt} + Q \cdot \frac{dx}{dt} + Q \cdot \frac{dz}{dt} \rightarrow ③$$

$$\frac{L}{CR} \cdot \frac{dz}{dt} + S \cdot \frac{Z}{CR} = r \cdot \frac{dz}{dt} + \frac{Qz}{CP} + \frac{Qr}{P} \cdot \frac{dz}{dt} + Q \cdot \frac{dz}{dt}$$

$$\frac{dz}{dt}\left[\frac{L}{CR} - r - \frac{Qr}{P} - Q\right] = \frac{Qz}{CP} - \frac{Sz}{CR}$$

$$\frac{dz}{dt}\left[\frac{L}{CR} - r - \frac{Qr}{P} - Q\right] = \frac{z}{c}\left[\frac{Q}{P} - \frac{S}{R}\right] \longrightarrow ⑤$$

the bridge is balanced for steady current

$$\frac{Q}{P} = \frac{S}{R} \Rightarrow \frac{Q}{P} - \frac{S}{R} = 0 \rightarrow ⑥$$

Eqn. (5) becomes

$$\frac{dz}{dt}\left[\frac{L}{CR} - r - \frac{Qr}{P} - Q\right] = 0 \longrightarrow ⑦$$

$\frac{dz}{dt} \neq 0$ $$\frac{L}{CR} - r - \frac{Qr}{P} - Q = 0$$

$$\frac{L}{CR} = r + \frac{Qr}{P} + Q \Rightarrow L = CR\left[r - \frac{Qr}{P} + Q\right]$$

$$L = C\left[Rr - \frac{QRr}{P} + QR\right] \quad \left[\text{but } \frac{Q}{P} = \frac{R}{S}\right]$$

$$L = c\left[Rr + \frac{S}{\cancel{R}}\cancel{R}r + QR\right]$$

$$L = c\left[Rr + Sr + QR\right] \rightarrow (8)$$

from this eqn. co-efficient of self inducti
can be calculated.

Mutual Induction

self induction

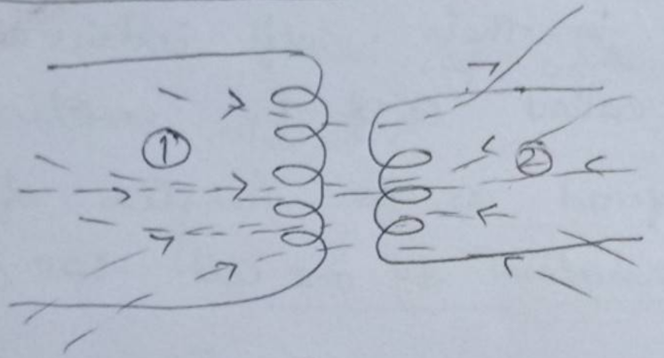
$$\phi \propto I \Rightarrow \boxed{\phi = LI}$$

L - co. eff of self inductance

I - current flows through the coil

ϕ - magnetic flux linked with the coil.

Mutual induction:



$$\phi \propto I \nearrow \text{current}$$

$$\phi = MI \longrightarrow ①$$

M - Coeff. mutual inductan

diff ①

$$\frac{d\phi}{dt} = M\frac{dI}{dt}$$

$$e = -\frac{d\phi}{dt} \Rightarrow \text{e.m.f} \quad -e = +M\frac{dI}{dt}$$

if $\frac{dI}{dt} = 1$ amp/sec $\quad e = -M$

the mutual inductance between a pair of coils is 1 Henry. If an emf 1 volts is induced in one coil when the current in the other coil changes at the rate of 1 ampere/sec.

Co-efficient of coupling:

* Coils used to obtain inductance for use in electrical circuits are called inductors.

* When two such coils are used together they get coupled to each other and in addition to their self inductances mutual inductive effects also come into play.

* The mutual inductances through between two coils is related to their self inductances through a a factor called Co.eff. of coupling

* It may be defined as the function of magnetic flux generated by one coil that gets linked up with the other.

Let us consider two coils having self inductances L1 and L2 and coupled together. Let I_1 be the current through C_1 produces flux ϕ_1. Therefore

$$\boxed{\phi_1 = L_1 I_1}$$

~~lly for the other &~~ Let a fraction k_1 of this flux gets linked up with coil C_2. So flux linked with C_2 will be.

$$\phi_2 = k_1 \phi_1 = k_1 L_1 I_1$$

The mutual inductance between the coils M then we can write

$$\phi_2 = M I_1$$

$$\therefore M \cancel{I_1} = k_1 L_1 \cancel{I_1}$$

(or) $\boxed{M = k_1 L_1} \longrightarrow$ ①

Similarly, if current I_2 flowing through C_2, produces flux ϕ_2 and a fraction k of it gets linked up with C_1 we can write for the flux through C_1 as

$$\phi_1 = k_2 \cdot \phi_2 = \overset{M}{\boxed{k_2 L_2}} I_2$$

$$\phi_1 = M I_2$$

$\boxed{M = k_2 L_2} \longrightarrow$ ②

from ① and ②

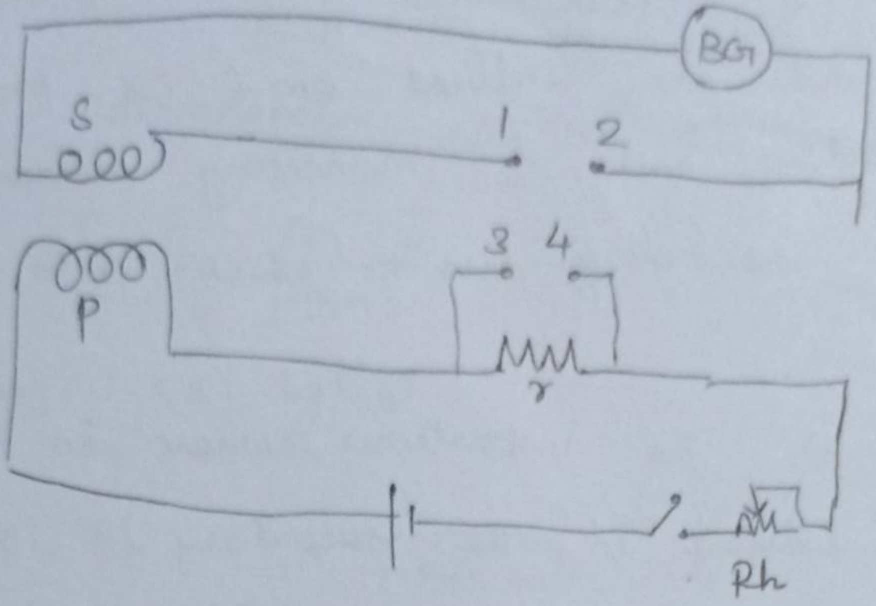
$$M^2 = k_1 k_2 L_1 L_2$$

$$M = k\sqrt{L_1 L_2} \qquad k = \sqrt{k_1 k_2}$$

$k = \sqrt{k_1 k_2}$ is called co-eff. of coupling between two coils. Its value ranges from zero to 1. It purely depends on the geometry of the coil and their relative positions. If whole flux generated by coil 1 gets linked up with second coil k = 1 and the coupling is perfect

⑦ If $k \leq 1$ the coils are are to close-coupled. on the otherhand. If k is much less than unity the coils are said to be loose-coupled.

Mutual Induction: Determination.



* It consists of two coils P and S as shown in fig.

* The primary P is connected to battery, Rheostat and a low resistance r and a key K.

* The Secondary S of the coil joined to the terminal of B.G through segment 1 and 2 of a quadrant key C. The ends of r are connected to 3 and 4 of the quadrant key.

First 1 and 2 are → connected so that B.G and the secondary coil S may form closed circuit. The segment 3 and 4 are connected together to short circuit resistance r. The rheostat is adjusted so that a suitable current passes through the primary on pressing key k.

* when key k is pressed, the current in the primary takes some time to reach maximum value. During this time, flux linked with the secondary coil changes, Hence an induced em.f is produced in the secondary, and a momentary current flows in the secondary due to which B G gives throw.

If i is the instanteous current in primary, the e.m. f iduced in the secondary is given by,

$$e = -M \cdot \frac{di}{dt} \rightarrow ①$$

If R is the total resistance of the secondary circuit, then instanteous current in the secondary is given by,

sub. e from ①

$$i' = \frac{e}{R} = -\frac{M}{R}\frac{di}{dt} \rightarrow ②$$

* This current flows through the B. G connected in the secondary circuit.

* This current in the primary grows from zero to steady value i_0. During this time interval t, total charge passes through B.G is by,

$$q = \int_0^{i_0} i' \, dt = \int_0^{i_0} \frac{M}{R} \cdot \frac{di}{dt} \cdot dt$$

$\frac{di}{dt} = i'$

$V = IR$

$e = iR$

$L = \frac{e}{R}$

The p.d across r is $= i_0 r$

$\boxed{V = IR}$

This extra p.d sends a steady current $i_0 r/R$ through the B.G. If θ_0 is the steady deflection of the galvanometer due to this current, then

$$\frac{i_0 r}{R} = \frac{c}{nBA} \cdot \theta_0 \longrightarrow ⑥$$

Dividing (5) by (6)

$$\frac{M i_0}{R} = \frac{T}{2\pi} \cdot \frac{c}{nBA} \theta_1 (1 + \lambda/2) \longrightarrow ⑤$$

$$\frac{M i_0}{\cancel{R}} \times \frac{\cancel{R}}{i_0 r} = \frac{T}{2\pi} \cdot \frac{c}{\cancel{nBA}} \theta_1 (1 + \lambda/2) \cdot \frac{\cancel{nBA}}{c} \cdot \frac{1}{\theta_0}$$

$$\frac{M}{r} = \frac{T}{2\pi} \cdot \frac{\theta_1}{\theta_0} (1 + \lambda/2)$$

$$M = \frac{Tr}{2\pi} \cdot \frac{\theta_1}{\theta_0} (1 + \lambda/2) \longrightarrow ⑦$$

using (7) mutual inductance M can be calculated

$$= \frac{M}{R} \cdot [i]_0^{i_0} = \frac{M i_0}{R}$$

$$\boxed{q = \frac{M i_0}{R}} \longrightarrow ③$$

Due to this charge, there is a throw in the B G, let it be θ_1.

$$q = \frac{T}{2\pi} \cdot \frac{C}{nAB} \theta_1 (1 + \lambda/_2) \longrightarrow (4)$$

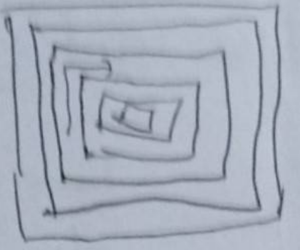
Comparing (3) and (4)

$$\frac{M i_0}{R} = \frac{T}{2\pi} \cdot \frac{C}{nBA} \cdot \theta_1 (1 + \lambda/2) \longrightarrow ⑤$$

To determine M, we have to Eliminate i_0 and $C/_{nBA}$ form eqn (5). For this cotact between 1 and 2 and 3 and 4 is broken and segements 1,3 and 2,4 are conated. Now resistance r is included in the primary. The same steady current i_0 is now passed through the primary ciruit. As the value of r is very small it does not affect appreciable current i_0 in the primary circuit.

Eddy current

A solid conductor like a sheet of copper ⟹ large no. of closed path

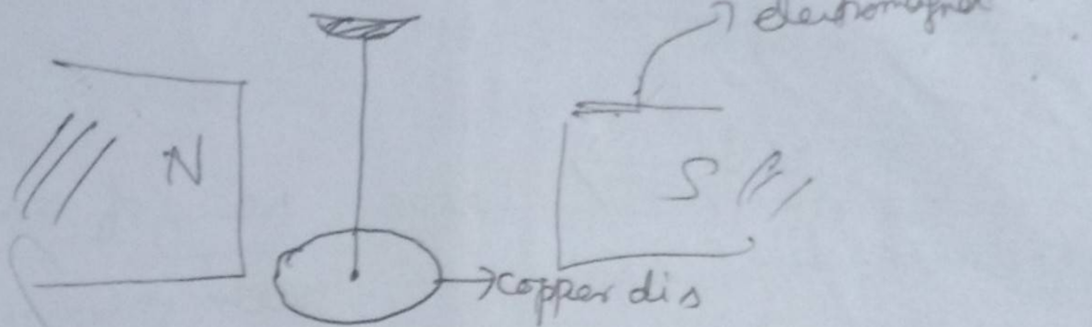


when the solid conductor moves across a magnetic field, the flux linked with the conductor changes. Hence induced currents are set up in the conductor. This was observed by focult in 1895. These induced current ~~flows~~ travel in the metal in a closed path in the form of eddies. These are known as eddy currents.

The direction of the current is determined by Lenz's law.

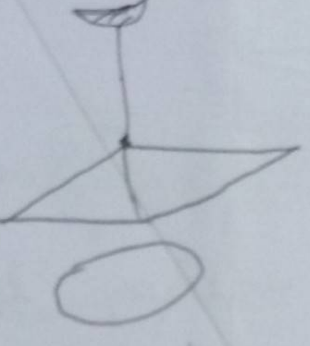
Demonstration

(I)



When there is a magnetic field, eddy currents are produced in disc and the speed of rotation decreases

(II)

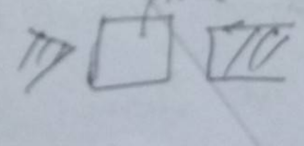


disc rotates needle also rotates.

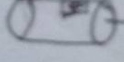
if disc rotate in opposite direction. needle also rotates in opposite direction

This rotation is due to eddy current

i) Induction furnace.



ii) Speedometer.

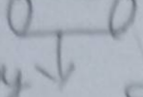


cylindrical drum attached to the magnet

* magnet is also attached if wheel rotates magnet also rotates, varying mag. field produces eddy current, and depending on the speed of the drum drag, a particular angle, the dragging angle given speed of automobile.

Speedometer:

using a two single phase current, rotating magnetic field is produced.



(placed in rotating magfield)

Due to eddy current the cylinder tends to rotate along magfield. Relative motion between cylinder and rotating magnetic field is reduced. So cylinder begins to rotate about the axis

iv) Energy meter:

when rotates eddy currents produced.

there is a deflection is proportional to the energy consumed.

Dead beat galvanometer:

~~wooden~~ metalic frame, when coil rotats eddy currents are produced, It opposes the motion of the coil and make the galvanometer dead beat.

vi) Magnetic Brake:

when train moves, the axle of the wheel also rotates, A drum attached to the axle also rotates whenever the train is required to be stoped, magnetic field is applied to the rotating drum, The eddy current produced opposes the rotation of the wheel and train comes to stop.

Uses of Eddy currents:

(i) Induction furnace:

The induction furnace uses eddy current to produce heat. the metal which is to be heated is placed in a varying magnetic field. Due to production of eddy current heat is produced. This heat melts the metal. This method is used to seperate metals from their ore. This is also used to prepare alloys and also to melt them.

(ii) Speedometer:

In a speedometer, a cylindrical drum rotates with the speed of the wheel of the automobile. In a aluminium drum a magnet is placed. when the magnet rotates, an eddy current is produced in the cylindrical drum. Depending on the speed, the drum drags a particular angle. The dragging angle gives the speed of the automobile.

(iii) Induction motor:

In an induction ~~furnace~~ motor, using two single phase current, rotating field is produced. A metalic cylinder is placed in a rotating magnetic field. Due to eddy currents, the cylinder tends to rotate along with magnetic field. Hence the relative motion between the cylinder and rotating magnetic field is reduced. So the cylinder begins to rotate about its axis.

(iv) Energy meters:

In energy meters, the armature coil carries a metalic disc. It rotates between the pole pieces of a permanent magnet. When the armature rotates, eddy currents are produced in the disc. This tends to oppose the motion of the armature coil. Due to this breaking effect, the deflection is propotional to the energy consumed.

(v) Dead beat galvanometer:

In a moving coil galvanometer, the coil is wound on a metalic frame. When the coil rotates, eddy currents are produced in the frame. It opposses the motion of the coil and make the galvanometer dead beat.

(vi) Magnetic brakes:

When a train moves, the axle of the wheel also rotates. A drum attached to the axle also rotates. Whenever the train is required to be stopped, a magnetic field is applied to the rotating drum. The eddy current produced opposes the rotation of the wheel and the train comes to stop.

Transformer:

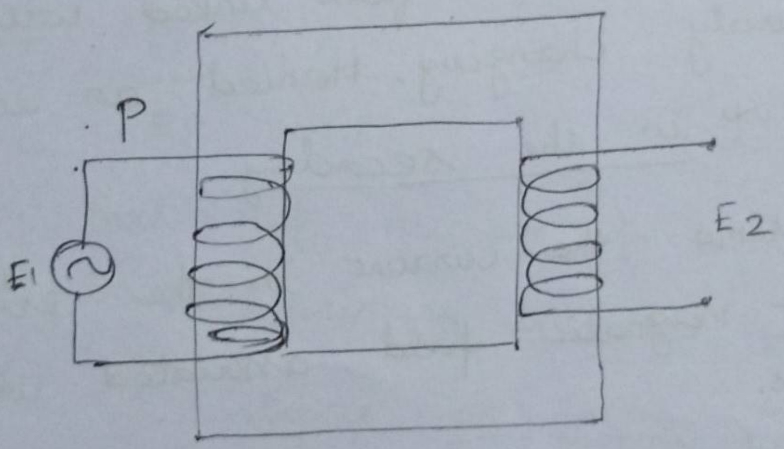
* The transformer is an electrical device based on the principle of electromagnetic induction.

* The transformer are off two types.

(i) Step down transformer - which converts high alternating voltage at low current into a low alternating voltage at high current.

(ii) Step up transformer - which converts ~~how~~ alternating voltage at high current into a high alternating voltage at low current.

Construction: Simple type transformer.



* It consists of two coils P and S wound seperately on a closed laminated core. The a.c which is to be converted is given between the ends of the coil P. It is called the primary.

- The output is taken across the ends of the coil S. This is called secondary.
- The core is made up of the sheets of a Stalloy which are insulated from one another to avoid eddy current losses.

Working:

- An alternating current is passed through the primary. As a results, an alternating current is induced in the secondary.
- Since the strength of alternating current in the primary is continuously charging, the magnetic flux linked with it also, continuously changing. Hence an induced e.m.f setup in the seconday.
- Every time the current in the primary reverses, the magnetic field associated with it also reverses.
- Since the secondary coil is close to the primary, the continuously reversing magnetic field associated with it will produce continuously reversing e.m.f in the secondary. If the secondary circuit is a closed one an alternating e.m.f will be set up in the secondary.

Theory:-

Let n_p and n_s be the number of turns of the primary and the secondary respectively. Let ϕ be the flux linked with each turn of the primary and the secondary. The rate of change of flux is $d\phi/dt$. Hence the emf induced in the primary is given by,

$$E_p = -n_p \frac{d\phi}{dt} \longrightarrow (1)$$

The e.m.f induced in the secondary is,

$$E_s = -n_s \frac{d\phi}{dt} \longrightarrow (2)$$

$$\therefore \frac{E_s}{E_p} = \frac{n_s}{n_p} \longrightarrow (3)$$

The ratio of number of turns in the secondary to that in the primary is called transformer ratio.

* In a stepup transformer $E_s > E_p$. Hence $n_s > n_p$. Therefore the transformer ratio is greater than one. In a stepdown transfomer $E_s < E_p$. Hence $n_p > n_s$. Therefore, the transformer ratio is less than one.

Assuming no energy losses in the transforme the energy drawn from secondary is equal to that fed into the primary or in otherw

Power output = power input

If I_p and I_s are the values of the current in the primary and secondary coils respectively, we have.

$$E_s I_s = E_p I_p$$

$$\frac{E_s}{E_p} = \frac{I_p}{I_s} \rightarrow (4) \quad \text{But} \quad \frac{E_s}{E_p} = \frac{n_s}{n_p}$$

$$\boxed{\therefore \frac{E_s}{E_p} = \frac{I_p}{I_s} = \frac{n_s}{n_p}} \rightarrow (5)$$

In Stepup transformer, $I_p > I_s$

In Stepdown transformer $I_s > I_p$.

*In stepup transformer, the primary coil consists of small ~~turn~~ number of turns ~~and~~ of thick insulated wire wound on iron core.

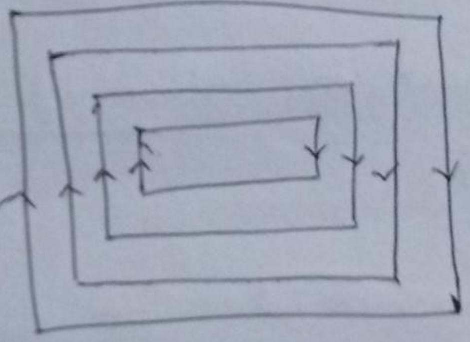
* while ~~the~~ ~~stepdown transformer~~, the secondary consists of large number of turns of thin insulated wire. In step down transformer, the opposite is the case.

* The efficiency of the transformer is ~~upto~~ 98%.

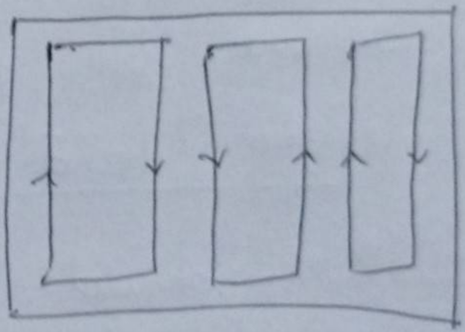
Eddy currents:

- In general, the current resulting from from the induced EMF flows in the conductor or coil only if the circuit is complete and the current flows in a definite path. In many cases, however, the induced currents circulate in a mass of metal when the metal is moving in a magnetic field or metal is placed in a changing magnetic field. Such currents induced in the mass of metal are known as Eddy currents.

Demonstration for Eddy current



(i) Solid core



(ii) Laminated core.

* Eddy current loses may be decreased by the using laminated core as shown in fig (ii)

Experiment:

Take a copper bar pendulum and allow it to swing between the pale pieces of an electromagnet. As long as the magnet is unexcited the pendulum swings freely and the amplitude diminishes slowly due to friction of air.

When the magnet is excited the pendulum moves through the strong magnetic ~~ma~~ field and an EMF is induced in the mass of the metal. As the resistance is small, eddy currents flow through the metal produce a force opposing the motion of the pendulum. Thus the pendulum comes to rest immediately. The direction of eddy current is produced is given by Fleming's right hand rule.

* It should be rombered that the original mechanical energy is converted into electrical energy and the electrical energy is converted into heat. Thus, due to the production of eddy current, heat is produced in the metal.