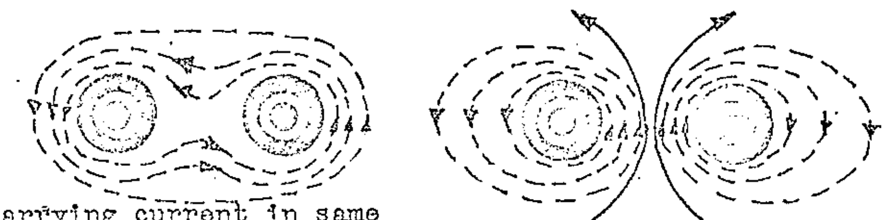
(c) The magnetic effect is proportional to the current in the conductor;



A. Carrying current in same direction

b. Carrying current in opposite direction

FLUX DUE TO TWO STRAIGHT CONDUCTORS

From these facts, it can be established that, to increase the magnet field strength -

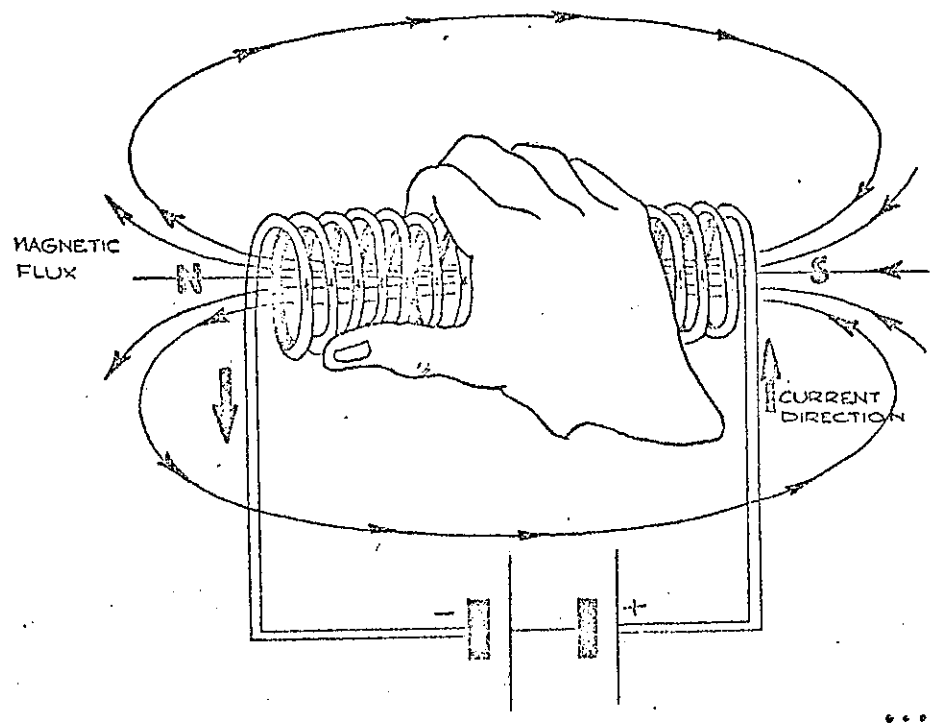
(1) Increase the current

(2) Increase the number of conductors

For practical use, coils (electro-magnets) are wound on formers with a pre-determined number of turns; the limiting factor on the amount of current, being the size of conductor.

Solenoid - a coil, or electromagnet, whose length is many times greater than its diameter is called a solenoid. To determine the polarity of a coil or solenoid, use the following rule:-

Right Hand Thumb Rule for Solenoids - grip the coil in the right hand so that the fingers point in the direction of current flow - extend the thumb at right angles to the fingers. The thumb points in the direction of the North Pole.



RIGHT-HAND RULE FOR SOLENOIDS

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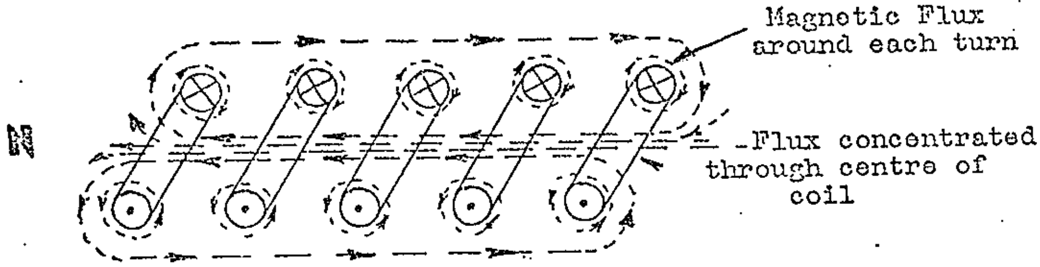


CROSS SECTION OF COIL

The cross-section view of a solenoid shows that the magnetic flux is more concentrated through the centre of the coil. Used in conjunction with a soft iron core, this is most desirable in electro-magnet equipment.

Electro-magnets have a distinct advantage over permanent magnets in that, depending on the magnetic material used, their field strength can be varied greatly, to suit any particular purpose.

M13/2/1

TITLE: LAWS OF MAGNETISM

LECTURER: STUART GARRY

DATE: 13/7/81

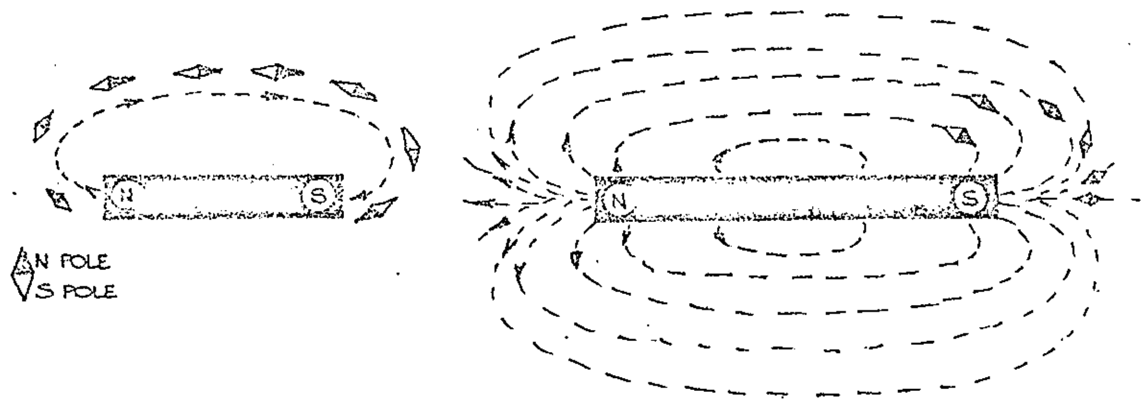
EQUIPMENT:

Introduction - from previous lectures, it has been established that when a magnetic field exists, there also exists, certain properties and characteristics relating to that field.

Magnetic Properties

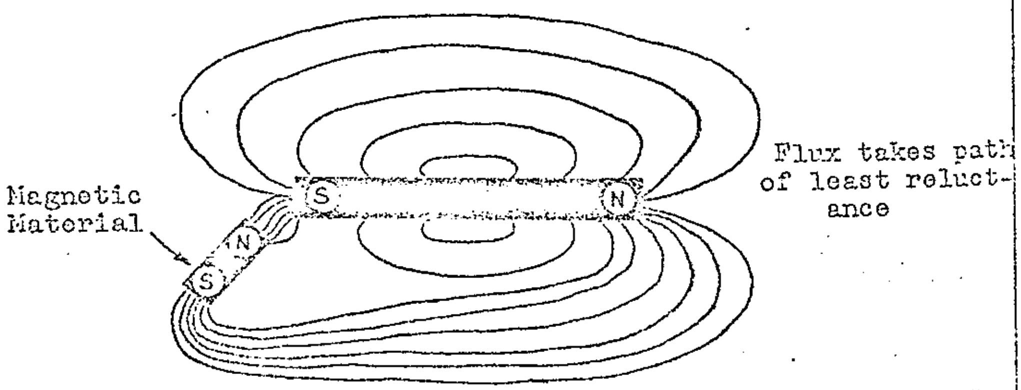
Magnetic Field - the region, or space, surrounding a magnet and, where magnetic forces can be detected, is called the magnetic field. A simple experiment with a bar magnet and iron filings will show the formation and extent of a magnetic field.

Lines of Force - each line of iron filings in the above experiment, represents a magnetic line of force. By moving a compass slowly along a line of force it can be seen that lines of force always act outwards at the North Pole and inwards at the South Pole.



LINES OF MAGNETIC FORCE

A magnetic line of force acts like an endless loop, which becomes longer as the magnetic force increases, and smaller as it decreases, but never losing its endless feature. Another property of lines of force is that they tend to take the path of least magnetic resistance (reluctance) - similar to electric current, which takes the path of least electrical resistance.



EFFECTS OF INCLUDING MAGNETIC MATERIAL IN A MAGNETIC FIELD

If a non-magnetic material is placed under the influence of a magnetic field, the lines of force are unaffected and tend to take the shortest route between their North and South Poles. However, if a magnetic material (low magnetic resistance or high "permeability") is placed in the field, the lines of force lengthen and distort, in order to pass through the material. This is the principle used for "magnetic screening".

Magnet Poles - all lines of force pass through its magnet and as a result, there is a concentration of lines of force at the magnet extremities. These concentrated areas are called the magnet poles and it is at these poles, that the greatest magnetic effect is obtained.

In the study of electron theory, it was found that like charges repelled each other and unlike charges were attracted. Similarly, in the study of magnetism it has been found that -

(1) Like poles repel;

(2) Unlike poles attract;

TITLE: SELF & MUTUAL INDUCTION
LECTURER: TREVOR GARRG
DATE: 13/7/81
EQUIPMENT: ELECTROMAGNET, SECONDARY COIL, GALVANOMETER

It has been determined from previous lectures that a current "flowing" in a conductor produces a magnetic field around that conductor. It is also a fact that a conductor passing through a magnetic field has an e.m.f. induced in it as it "cuts" the lines of force.

Faraday's Law states:- Whenever the flux associated or linked with a circuit is changed, an e.m.f. is induced in the circuit, this e.m.f. lasting only so long as the change is taking place. The e.m.f. varies as the rate of change of flux.

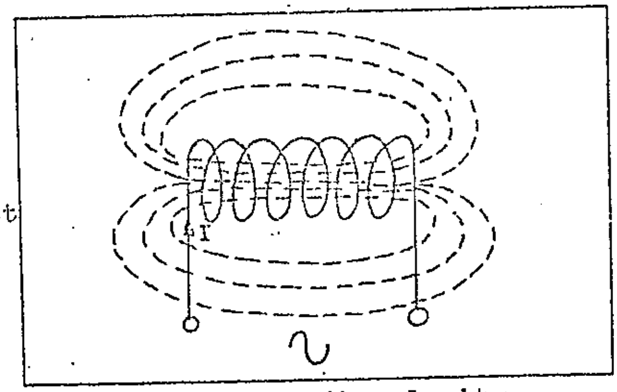
The important part of this Law has been underlined. The "change" of flux may be achieved in two ways.

1. Dynamically - by movement of the conductor.
2. Statically - by increasing or decreasing the strength of the magnetic field (by varying the magnitude of the current producing the magnetic field).

Both Self induced, and Mutually induced e.m.f.'s and currents are STATICALLY INDUCED.

Self Induction.

Consider the coil shown. A current I amperes flowing through the coil will produce magnetic lines of force around each turn of the coil. The nett result is one large magnetic field around the whole coil as shown.



Because an alternating current has been applied to the coil, the magnetic field will also be alternating, i.e. ih polarity will change as the direction of I changes.

The effect is that the magnetic field starts with zero lines of force when the "instantaneous" value of I is zero, and as the current builds up to maximum in either direction, then the lines of force will also build up to maximum and in doing so, they will be "cut" by the conductors of the coil.

This "cutting" of the lines of force by the conductors causes an e.m.f. to be induced in the conductors. In other words, the coil has induced in itself a second e.m.f. by SELF INDUCTION.

Lenz's Law states that when an e.m.f. is induced in a circuit, the current set up always opposes the motion, or change in current, which produces it. Therefore, the e.m.f. produced by self induction is in opposition to the applied e.m.f. It is often called a "BACK E.M.F."

Because the back e.m.f. is opposing the applied voltage, the value of current flow is decreased in the coil.

e.g. A coil having a resistance of 10 ohms has a voltage of 100 volts applied to its terminals. A back e.m.f. of 80 volts is produced by self induction. Calculate I.

...2/...

If, first, we ignore the effect of the back e.m.f., then by Ohm's Law.

$$I = \frac{V}{R} = \frac{100}{10} = 10 \text{ Amps}$$

Now re-calculating, include the back e.m.f. Eb.

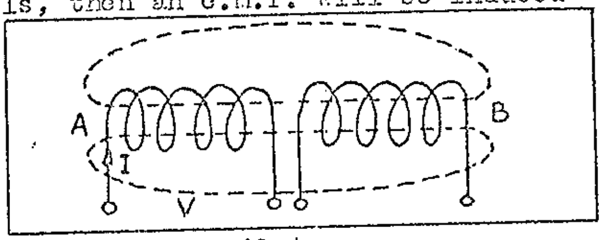
$$I = \frac{V - Eb}{R} = \frac{100 - 80}{10} = 2 \text{ Amps.}$$

It becomes obvious that I is reduced because of Self Induction.

Mutual Induction.

It has already been determined that the magnetic lines of force will induce an e.m.f. in the coil described above, as they cut the conductors.

If a second coil is positioned close to the first coil so that the same lines of force cut both coils, then an e.m.f. will be induced in both.



Coil A will have a voltage applied to it.

Current I will flow through coil A.

Magnetic lines of force will be produced by coil A.

The lines of force will be cut by conductors in coils A & B.

An e.m.f. E will be induced in both coils A & B.

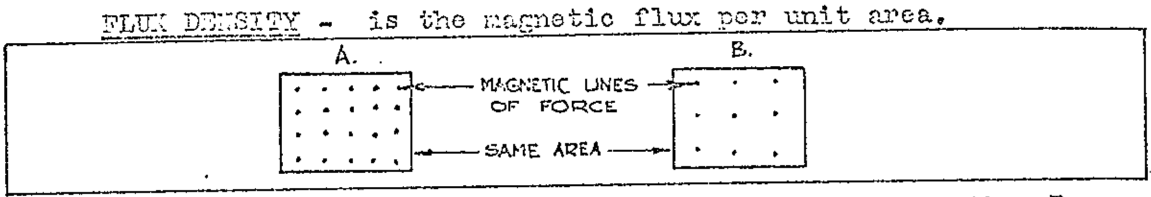
The e.m.f. in coil A being produced by self induction and the e.m.f. in coil B being produced by MUTUAL INDUCTION because the lines of force are common or MUTUAL to both coils.

The principle of mutual induction is that on which transformers and motors operate.

TITLE: MAGNETIC TERMS & RELATIONSHIPS
LECTURER: DAK, Hayse&, DARIO, Mark
DATE:
EQUIPMENT:

FLUX : is the combination of lines of force. It is the "flow of magnetism" - comparable to current in an electrical circuit. The unit for magnetic flux is the weber (1 Weber = 10^8 lines of force) and the symbol - $\emptyset$

FLUX DENSITY - is the magnetic flux per unit area.



In the above diagrams, A has a flux density greater than B, because there are more lines of force in the same cross-section area.

The symbol for flux density is B.

$B = \dfrac{\emptyset}{a}$ Where " $\emptyset$ " is in Webers and "a" in sq. metres.

Example: A laminated core carries a total flux ($\emptyset$) of .001 Webers. Cross-section dimensions of the core (a) are 2 cm x 3 cm. Calculate flux density (B).

$$\text{Area (a)} = \frac{2}{100} \times \frac{3}{100} \text{ sq. metres.}$$

$$\text{Flux Density (B)} = \frac{\emptyset}{a} = \frac{.001}{.02 \times .03}$$

$$= \frac{.001}{.0006}$$

$$= 1.67 \text{ Webers/sq.metre.}$$

MAGNETO MOTIVE FORCE: in an electrical circuit, it is necessary to have a force or pressure (voltage) to produce a current flow. Similarly, in a magnetic circuit, it is necessary to have a force to create a magnetic flux. The strength of this flux, or field, is dependant on 2 factors:-

(1) Amount of current.

(2) Number of turns.

Hence the magneto-motive force (MMF) = NI Where I = current
N = no. of turns.

Example: A contactor coil has 2,000 turns and takes $\frac{1}{2}$ Amp when switched on. Calculate MMF.

$$\text{MMF} = \text{NI amp/turns}$$

$$= 2{,}000 \times \tfrac{1}{2}$$

$$= \underline{1{,}000 \text{ amp/turns}}$$

RELUCTANCE: Symbol S is the opposition offered to magnetic Flux - similar to Resistance, which offers opposition to current flow.

The factors which affect Reluctance are:-

(1) Length of magnetic circuit - $S \propto$ Length (metres)

i.e. the longer the magnetic circuit, the greater the Reluctance.

(2) Cross-section area - $S \propto \frac{1}{a}$ (sq.metres)

i.e. the longer the corss-section area, the lower the Reluctance.

(3) Permeability - $S \propto \frac{1}{\mu}$

i.e. the higher the permeability, the lower the Reluctance.

Hence - $\text{Reluctance (S)} = \dfrac{\text{Length (L)}}{\text{Area(a)} \times \text{Permeability } (\mu)}$

PERMEABILITY: The ease with which a material will allow a magnetic flux to pass through it, is termed the "permeability" of that material. Ferro-magnetic materials allow magnetic flux to pass through them readily, therefore, they have a high permeability. Because the permeability of different materials vary, a standard is set, against which materials can be compared. This standard is the Actual Permeability of Free Space - Symbol uo. $u_o = 4\pi \times 10^{-7}$. (From this figure it can be seen that air has a very low permeability).

To compare the permeability of a given material against the standard (μ_o) a ratio is used. This ratio is called the Relative Permeability and is symbolised thus - μ_R. Therefore, the ratio of relative permeability against the absolute permeability is equated - $\mu = \mu_o\mu_R$ - and this is called the Actual Permeability (μ).

Actual Permeability is not constant for any given ferro-magnetic material, because the relative permeability (μ_R) varies with differing flux densities.

Example - the total mean length of a magnetic path through an iron core is 20 cm. The core dimensions are 1.5cm x 1 cm and has a permeability of 800. Calculate reluctance.

$$S = \frac{L}{\mu_o \mu_R\, a}$$

$$= \frac{.2 \text{ (metres)}}{800 \times 4\pi\, 10^{-7} \times .015 \times .01 \text{ (sq.metres)}}$$

$$= \underline{1,325,757 \text{ amp.turns/weber}}$$

To make calculation easier and simpler, Absolute Permeability (U_0) can be simplified from $\dfrac{1}{4\pi.10^{-7}}$ in thisequation to 800,000.

Therefore, the equation becomes $S = \dfrac{800,000 \times L}{\mu_R \times a}$

OHM'S LAW IN A MAGNETIC CIRCUIT - a comparison can be made between Ohm's Law for an Electrical Circuit and that of a Magnetic Circuit.

i.e. Flux ($\emptyset$) is comparable to Current (I)

Magneto-Motive Force (NI) is comparable to Voltage (V)

Reluctance (S) is comparable to Resistance (R)

Ohm's Law states $I = \frac{V}{R}$.

Therefore, Ohm's Law is a Magnetic Circuit is $\emptyset = \frac{NI}{S}$

MAGNETISING FORCE - the magneto-motive force required to magnetise a unit length of a magnetic path is termed the "magnetising force" for that portion.

Magnetising Force $H = \frac{NI}{L}$ where L is in metres.

Magnetising force can be compared with Voltage Drop in an electrical circuit.

MAGNETIC CIRCUITS - as is the case with electrical circuits, there are 3 main types of magnetic circuits:-

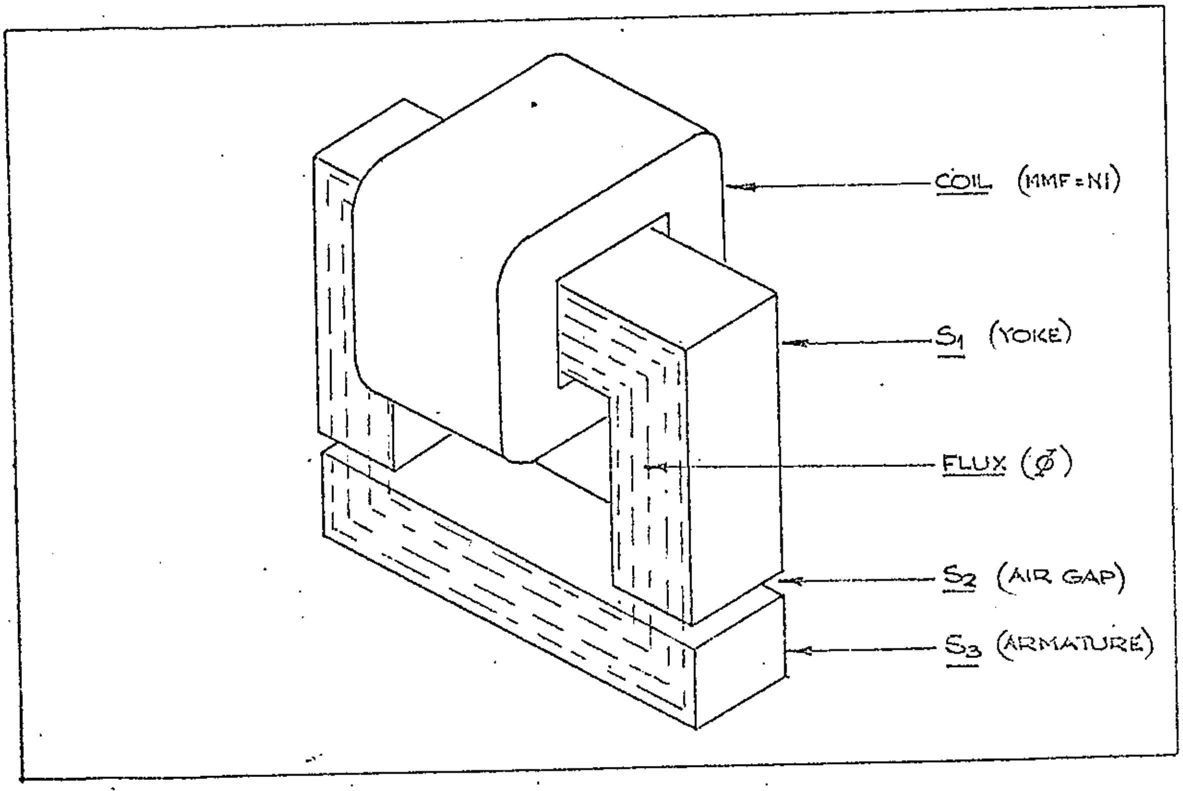
(1) Series
(2) Parallel
(3) Combined Series - Parallel

Similarly, the comparable magnetic units remain in the same relationship.

i.e. Series - (a) Total Reluctance $S_T = S_1 + S_2 + S_3 \ldots\ldots$

(b) Flux $\emptyset$ remains constant in the iron circuit.

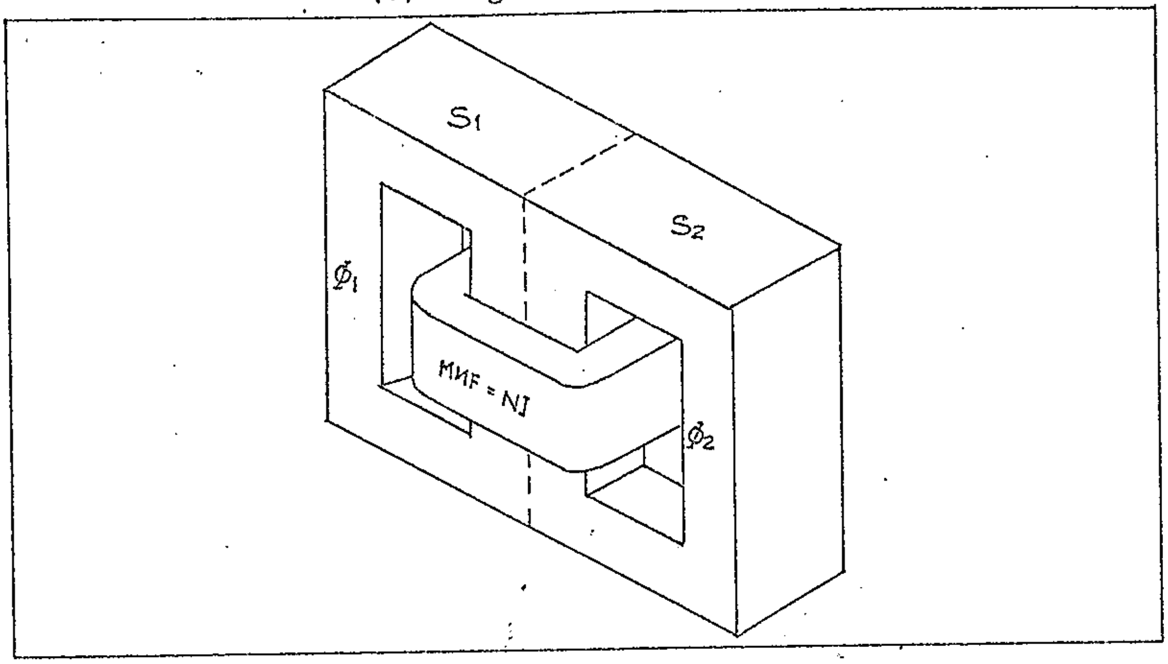
(c) Magneto-Motive Force $NI_T = NI_1 + NI_2 + NI_3 \ldots$



<u>Parallel</u> - (a) Total Reluctance $\frac{1}{S_T} = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3}$ .....

(b) Total Flux $\phi_T = \phi_1 + \phi_2 + \phi_3$ .....

(c) Magneto-Motive Force (NI) is constant.



<u>Series Parallel</u> - (a) Reluctance S_a for Path A

$S_a = S_1 + S_2 + S_3 + S_4$

(b) Total Reluctance ST

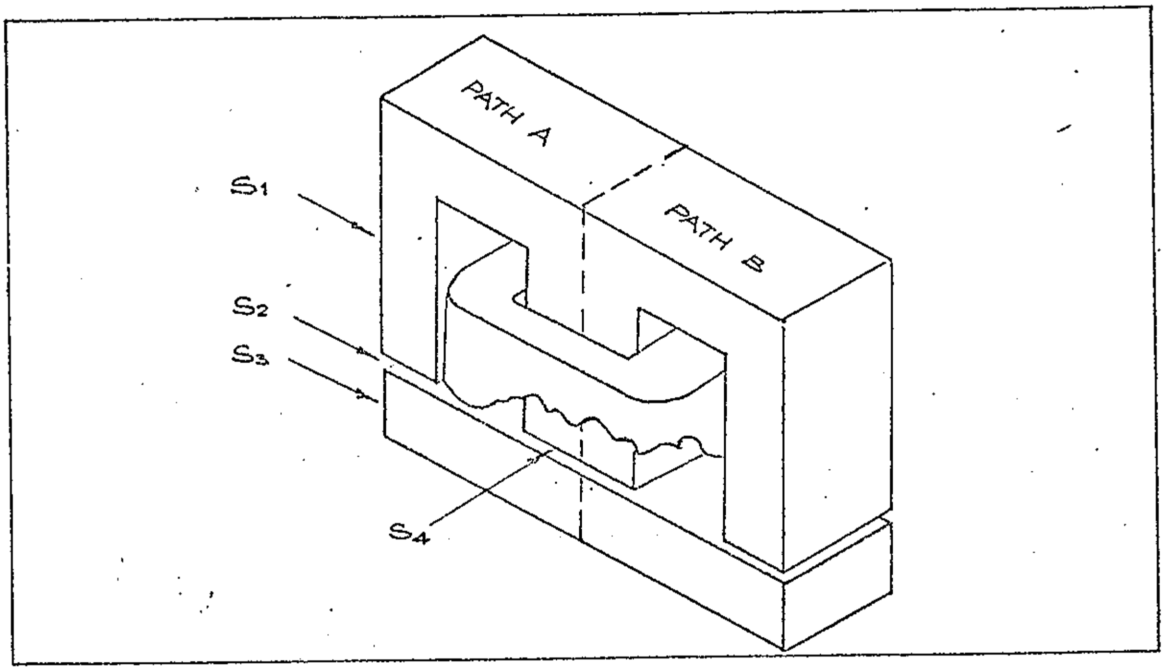
$$\frac{1}{S_T} = \frac{1}{S_a} + \frac{1}{S_b}$$

When Path A = Path B

$$S_T = \frac{S_a}{2} = \frac{S_b}{2}$$

(c) Air gap reluctance is calculated for ½ cross-section of iron in the centre limb.

(d) Calculate series section first.



MAGNETISATION CURVES:

Reluctance of non-magnetic materials and air is not affected by the flux density of those materials. Flux, therefore, varies directly as the M.M.F. and flux density (B) consequently varies directly as the Magnetising Force (H), providing the dimensions and area remains constant. A graph, plotting B against H, will be a straight line for non-magnetic materials.

For ferro-magnetic materials, the BH graph will appear as a curve. These BH curves are used to compare the magnetic characteristics of different ferro-magnetic materials.

MAGNETIC SATURATION:

By referring to a BH curve for any given ferro-magnetic material, it can be seen that a stage is reached, whereby an increase in H (magnetising force) will not give any appreciable increase in B (flux density). This effect is called "magnetic saturation".

In practice, it is uneconomical to magnetise steel to a degree of flux density beyond "saturation", because of the wastage of power.

MAGNETIC HYSTERESIS:

The term "hysteresis" means "to lag". In electrical terminology, it is used to describe the lag between change in value or direction of the Magnetising Force and the resulting change in value or direction of Flux.

Mention has been made previously of Residual Magnetism, which is that portion of Flux which remains in a ferro-magnetic material after the Magnetising Force has been removed. It was also learnt that some materials retain magnetism to a greater degree than others. In order to remove residual magnetism it is necessary to use a force which acts in the opposite direction to the original magnetising force. This force is known as the Coercive Force and is measured in Reverse Ampere Turns. The amount of Coercive Force required to overcome residual magnetism depends on the type of material in use.

HYSTERESIS LOOP

If magnetisation curves are plotted to show the variation of Flux density in a ferro-magnetic material for both increasing and decreasing values of magnetising force, it is found that the curves do not coincide. This deviation between the curves is caused by hysteresis.

The accompanying graph illustrates the curves which result when a sample of ferro-magnetic material is subjected to a magnetising force which varies in both magnitude and direction.

Section AC shows the curve which results when a steadily increasing magnetising force (H+) is applied to the material which was initially in a completely de-magnetised state. Point C represents the value of flux density which occurs when H reaches a maximum value in the positive direction.

If H is now gradually decreased, then the magnetisation curve, CE, results. In point E, at which the curve intersects the vertical axis, indicates the value of residual flux density. This residual flux remains in the material when H is reduced to zero.

Application of a Coercive Force will reduce the residual flux to zero. The value of this Coercive Force is indicated by point F at which the curve intersects the horizontal axis.

By increasing H beyond point F in a negative direction, a resultant flux is set up in the opposite direction, reaching a maximum at point G.

If the magnetising force is again reversed, changing from maximum in the negative to maximum in the positive, the associated changes in flux density are represented by the portion of the curve G,K,L,C.

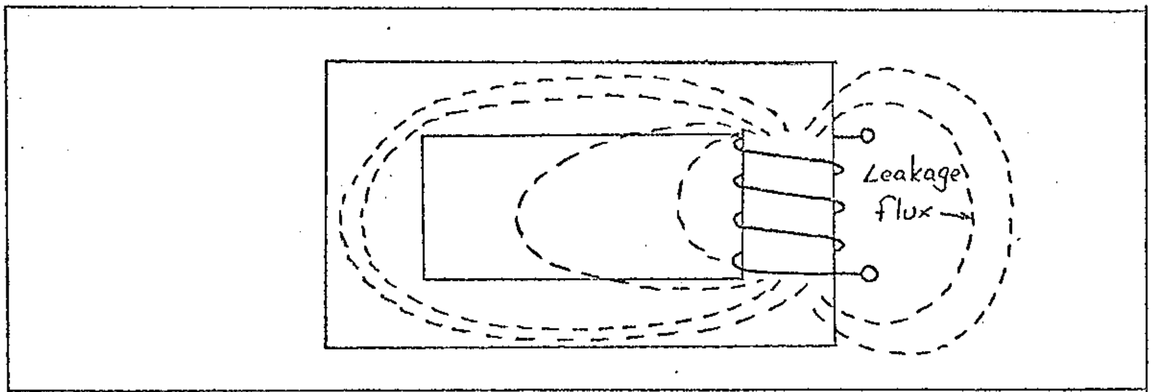
It is seen that the combined magnetisation curves form a closed loop - the Hysteresis Loop for ferro-magnetic material.

HYSTERESIS LOSS:

Changing magnetic flux causes changes in the alignment of molecules in a magnetic material, which results in the generation of heat within the material. Such heat generation results in a loss of energy which is known as Hysteresis Loss. The amount of hysteresis loss for a particular material varies directly as the area within the Hysteresis Loop for that material. Therefore, in equipment that is subjected to rapidly changing flux, it is important that the material used in the magnetic core should have a hysteresis loop of small area.

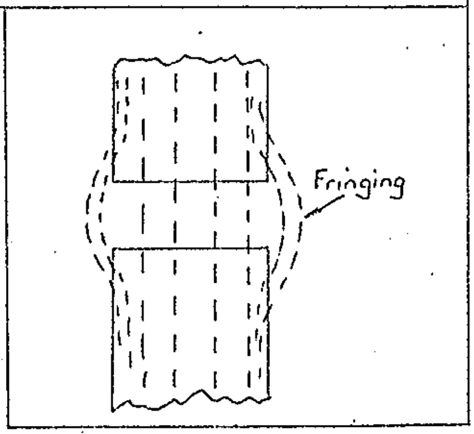
MAGNETIC LEAKAGE:

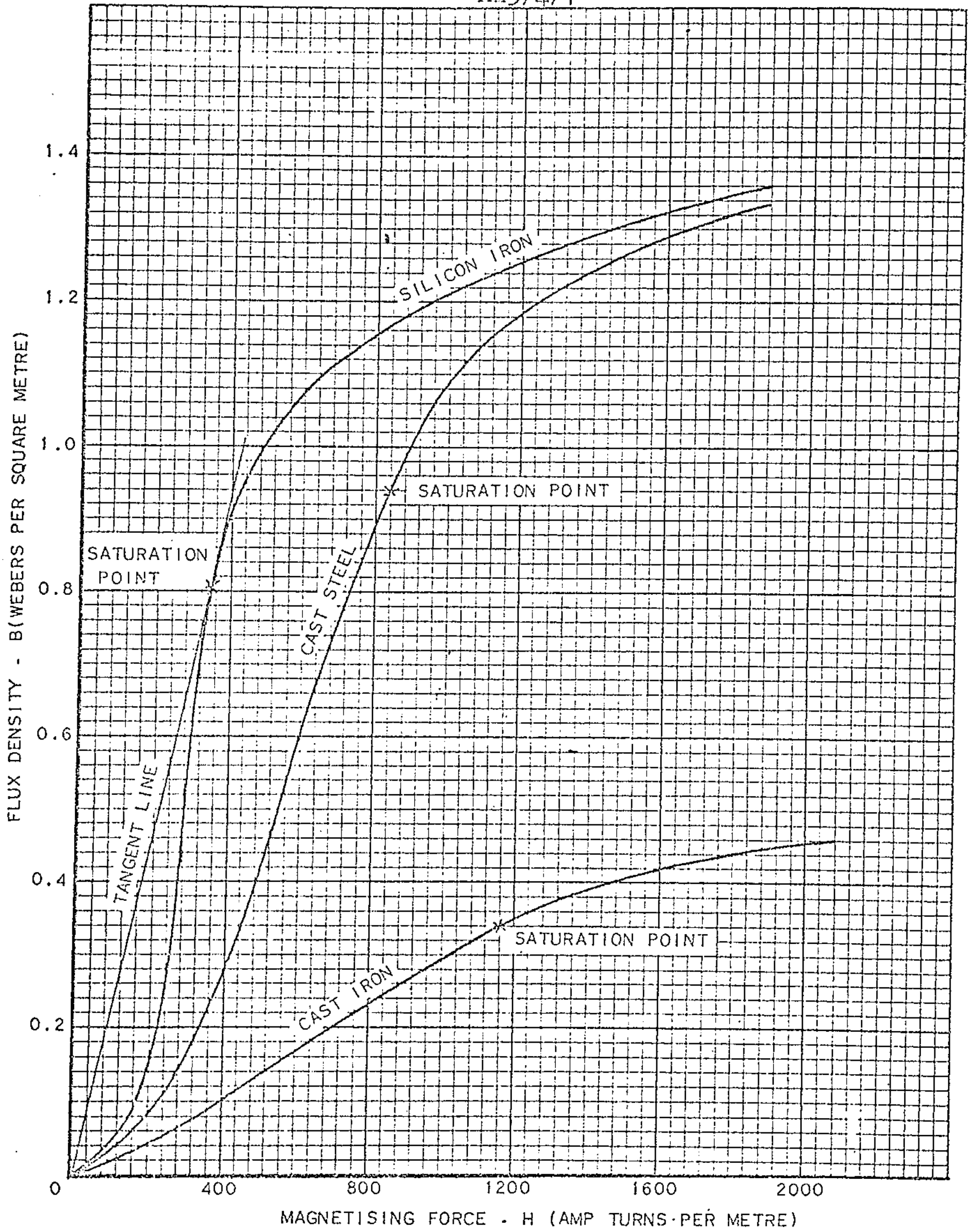
In many practical magnetic circuits it is desirable to have the maximum value of flux across a certain section of the circuit. However, the total flux produced by the source of M.M.F. (magneto-motive force) does not reach the air gap because a portion of it leaves the iron core and returns through the surrounding air. This portion of flux which leaves the main path is known as the "Leakage Flux".



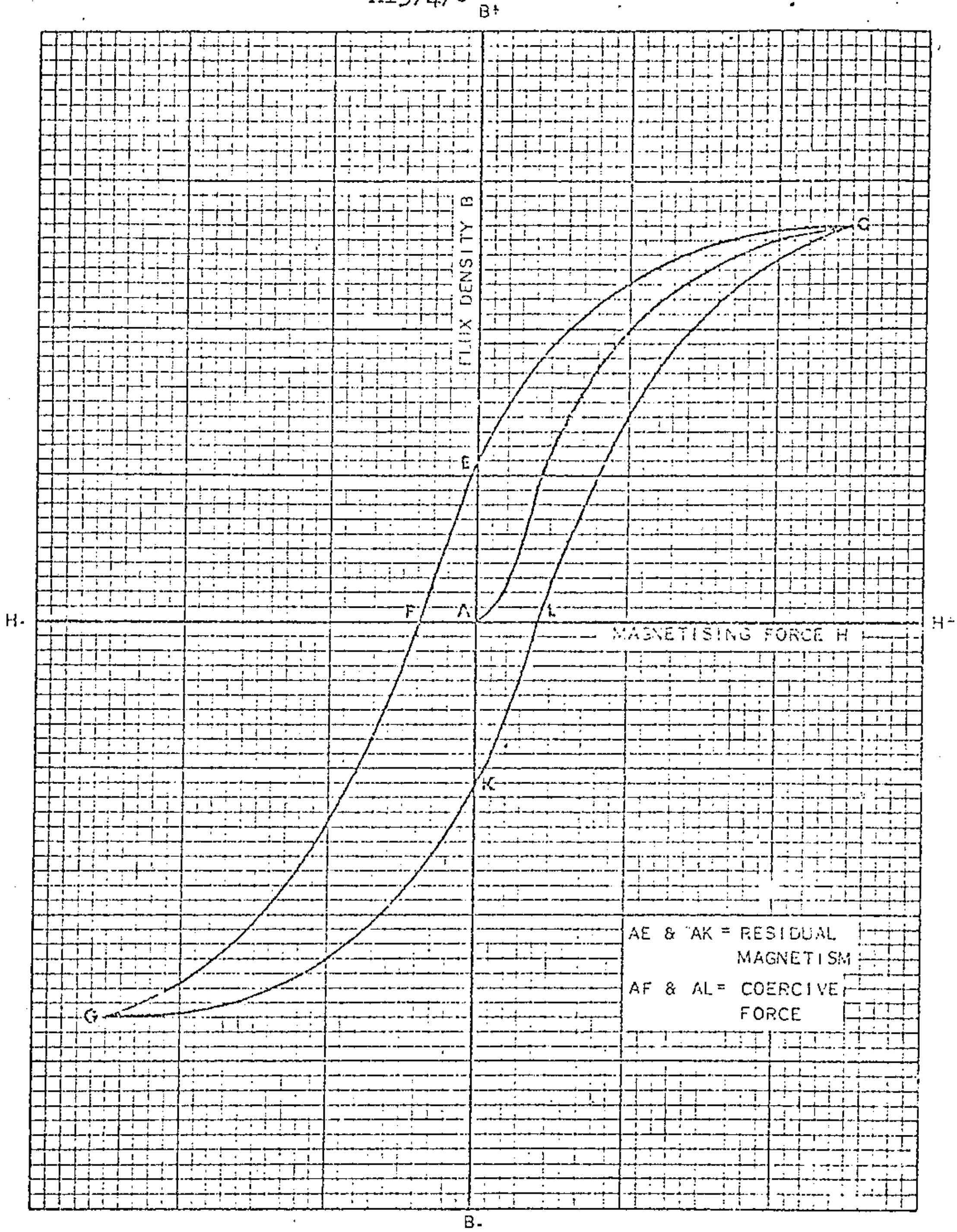
MAGNETIC FRINGING

In the accompanying diagram, which shows a magnetic field which exists across an air gap, it is seen that the lines of force near the centre are straight and those at the edges of the field curve outwards in the air gap. As a consequence, the flux density of the air gap is less than that of the material on either side of the gap.

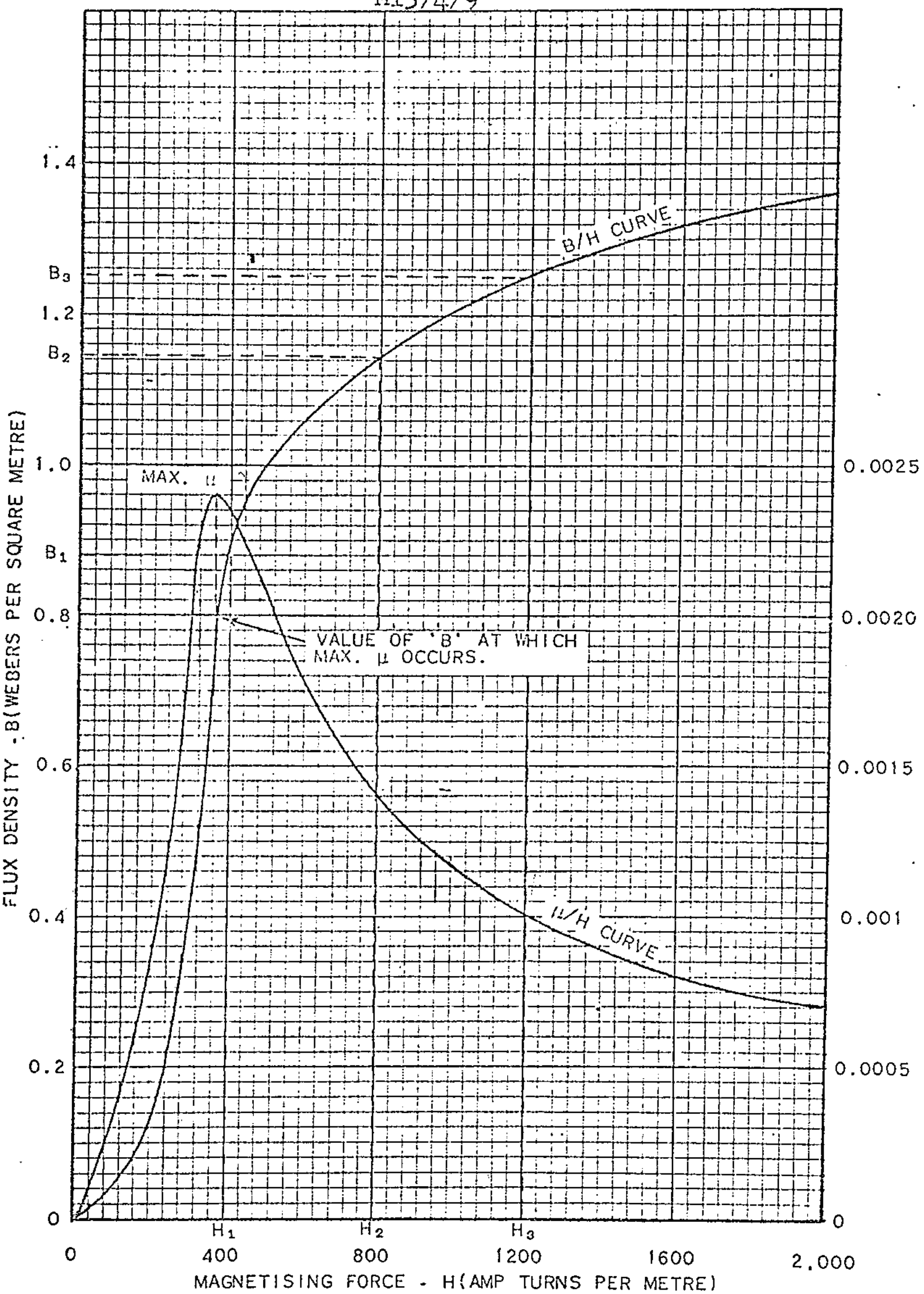




COMPARISON OF B-H CURVES FOR FERRO-MAGNETIC MATERIALS



HYSTERESIS LOOP FOR A FERRO-MAGNETIC MATERIAL



MAGNETISATION (B/H) & PERMEABILITY (μ/H) CURVES
FOR SILICON IRON

TITLE:- ELECTROMAGNETIC DEVICES

LECTURER:-

DATE:-

EQUIPMENT:-

In any electrical installation, magnetism plays a vital role. The majority of electrical equipment in use in industrial situations could not function without the use of magnetism.

Alternators in use at power stations use mutual induction to generate power using D.C. electromagnets and a network of armature windings.

D.C. generators run on a similar principle but use a commutor as a rectifier for the output and can be found in use in various specialised applications e.g. to supply power to the main alternator D.C. electromagnet (it then becomes known as an exciter).

Motors whether A.C. or D.C. run on the principle of attraction or repulsion between two unlike or like magnetic fields. Some types having both fields supplied from an external source, other types having only one field supplied, the second being created by mutual induction. Motors are used wherever motive power is required, whether rotating or linear.

Transformers use the principle of mutual induction between two windings on a common magnetic core. They can be found in use in a variety of sizes e.g. Large transformers at power stations raise the voltage as high as 275,000 volts prior to transmission over long distances to minimise the I^2R losses in the lines. Long distance transmission would not be practical at the alternator's output voltage since the losses would be a large portion of power transmitted. When the power reaches its destination, a network of distribution transformers brings the voltage back down to a level safe for use. These large types are usually oil immersed.

Small portable transformers are in common use in industrial situations for use with extra low voltage power tools and other portable equipment.

In general, transformers are found wherever a voltage change is necessary, the physical size being determined by the amount of power to be supplied by it i.e. its K.V.A. rating. Transformers can only operate on A.C.

Lifting magnets are in theory simply constructed. They usually consist of a coil of heavy wire enclosed in a heavy steel magnetic circuit. Power is supplied from a D.C. source. The two general shapes are circular and rectangular with circular the most popular for most classes of material, since it requires no positioning in relation to the load. The rectangular is usually used for handling regular shapes such as iron and steel billets, plates etc. They can be either permanently situated where the crane is used exclusively for this purpose, or removable so that the crane can be used for other lifting duties. Lifting magnets are normally found in steel mills, foundries, ship operations, strap yards, railroad yards etc.

Reactors are also, in theory, simply constructed. Generally used as a current limiting device, they consist of a coil of wire which can be either iron cored or air cored. Both types may be air cooled or immersed in oil. The reactor limits current by means of self-induction, i.e., a "back E.M.F." is produced in the coil which opposes the applied E.M.F. Reactors are used to restrict starting current with large types of motors because:- (1) They do not dissipate large amounts of heat as do resistors so their physical size can be smaller. (2) There is not a large power loss with reactors, therefore they are more economical to have in service than resistors. Reactors are also used to limit short circuit currents to reasonably safe values and to compensate for leading currents in cables or long transmission lines.

Brakes which are operated electromagnetically are generally band brakes and shoe brakes, the shoe type being the most common since it is ruggedly constructed, reliable, quick acting and reasonably trouble free. Brakes are spring operated and "fail safe", i.e. when de-energised, a stiff torque spring forces the shoes together so that they press against the wheel and prevent turning. When the

brake coil is energised, the armatures of the electromagnet are attracted to the core. This overcomes the spring force and the shoes move away from the wheel.
Typical examples of applications which require brakes are hoists, cranes, elevators and stockbridges.
Brakes are used not only to stop the drive but also to prevent motion under the influence of gravity, wind pressure etc. after the drive has come to rest.
Contactors and Relays are found in almost every industrial circuit in use today. They consist of a suitable coil of wire mounted on an iron circuit which has a movable armature. This armature can be hinged or "floating". Generally, the iron circuit is open when coil de-energised, i.e. there is a gap at a specific point in the iron circuit due to gravity. When power is applied to the coil circuit, the armature pulls in due to the magnetic forces set up in the iron circuit. Sets of contacts mounted on, and insulated from the armature, are used to open or close their respective circuits by using them in conjunction with sets of corresponding fixed contacts.
They can be either A.C. or D.C. types.
Contactors are devices used for repeatedly establishing or interrupting a main power circuit; they can however be fitted with auxiliary contacts connected in their own or another control circuit.
Relays are normally used in control circuits in such a way that a variation in conditions on one circuit effects the operation of other devices in the same or another circuit. Where power requirements are small enough, however, they can be used as contactors in the power circuit.
Using these contactors and relays, such functions as remote control, semi-automatic or automatic control, and sequence control are possible by careful arrangement of components.
Variations of this principle in common use are:-
(1) Timing relays can be used to time an automatically controlled circuit with a specific sequence with a high degree of accuracy.
(2) Magnetically operated circuit breakers which open their contacts due to increased magnetic forces when the circuit current rises above a pre-determined value.
Under normal circuit conditions, the armature in the iron circuit would not move since the magnetic forces would be insufficient.
Used to protect against short-circuit conditions.
(3) Overload relays which do not operate instantly as does the circuit breaker but have "inverse time characteristics", i.e. the larger the overload current, the smaller the operating time to open the circuit. Only used for overload protection, not short circuit protection.
(4) Solenoids, which generally use a centrally located plunger instead of an armature to operate valves etc.
Measuring instruments use magnetism, the most common types being the moving coil, in which two magnetic fields act upon each other to cause deflection of one which is free to pivot but under spring tension, and moving iron in which a magnetic field acts upon a movable vane to cause deflection. In both types the indicating needle is connected to the movable section.

TITLE:- TRANSFORMERS

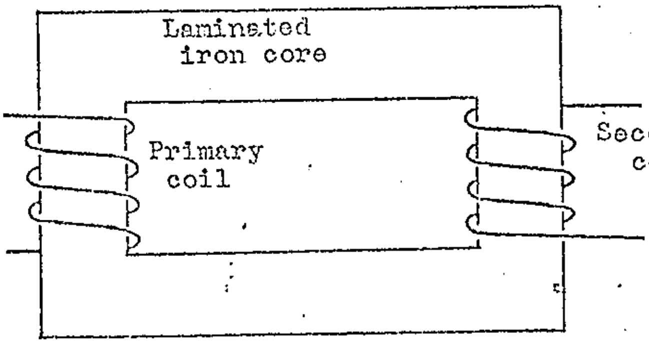
LECTURER:-

DATE:-

EQUIPMENT:-

Introduction - A transformer is a device which, by the principles of Magnetic Induction, is used to increase or decrease the voltage of an A.C. supply with a corresponding increase or decrease in current.

Construction: In its simplest form, a transformer consists of 2 separate coils of wire wound around a common laminated iron core. The coil connected to the supply voltage is called the PRIMARY COIL and the coil connected to the load is called the SECONDARY COIL.



Because of fairly high leakage in the above transformer, a more efficient transformer has been designed, with the Primary and Secondary coils being wound on the same leg of the iron core. One advantage of transformers over other apparatus, used for the same purpose, is that there are no moving parts.

Operation:- Transformers operate on the principle of Mutual Induction, which has been discussed previously. Suppose a primary winding has 100 turns and the secondary, 10 turns. If the primary coil is connected to 100 Volts A.C., it is found that the 100 volts is completely "dropped" across the primary, i.e. 1 volt dropped per turn. As the resistance of the winding is very low, it is obvious that most of the opposition to current flow will depend upon the "back e.m.f." of self induction in the winding. In fact, the "back e.m.f." is almost equal to the applied e.m.f. - the difference between the two being sufficient to force enough current through the winding, against the opposition of the resistance, to magnetise the core strongly enough to induce the required value of "counter e.m.f."

To this stage the transformer is merely acting as a choke coil and limiting the primary current. However, the same alternating flux, which cuts the primary winding and induces in it, a counter e.m.f., also links with the secondary, of 10 turns. Hence, an e.m.f. is induced in the secondary winding and its value will depend upon the number of flux linkages. If the flux linkages of the primary winding produced a back e.m.f. of one volt per turn, the same flux will obviously produce one volt per turn in the secondary windings. Therefore the secondary voltage in the above example will be 10 turns x 1 volt = 10 volts.

Ratio of Transformation - $\frac{\text{Primary Volts}(V_p)}{\text{Secondary Volts}(V_s)} = \frac{\text{Primary Turns}(N_p)}{\text{Secondary Turns}(N_s)}$

or $\frac{\text{Primary Volts}(V_p)}{\text{Primary Turns}(N_p)} = \frac{\text{Secondary Volts}(V_s)}{\text{Secondary Turns}(N_s)}$

Current Ratio:- the power taken from the secondary cannot exceed that taken by the primary.
Therefore - Primary Volts (V_p) x Primary Current (I_p) = Secondary Volts (V_s) x Secondary Current (I_s)

or $\frac{V_p}{V_s} = \frac{I_s}{I_p}$

The above ratio is for a perfect transformer. In actual fact -

Primary Power = Secondary Power + Losses

Transformer Losses - Losses in a transformer causes 2 disadvantages. Firstly, the loss of electric power increases the operating costs, and secondly, these losses are converted into heat, in both core and windings.
The 2 types of transformer losses are -

1. Copper losses
2. Iron losses

Copper, or I^2R, losses are due to the resistance of both windings and can be measured using the Short-Circuit Test. The secondary is short circuited and a low voltage is applied to the primary until the primary current is at full load. The power indicated by a watt-meter connected to the primary, is a measure of the copper losses.

Iron losses include Hysteresis and Eddy Current losses, and, since the core flux is independent of load, then these losses may be assumed constant. A wattmeter and ammeter connected to the primary of the transformer will read the power taken from the supply to supply iron losses if the secondary is Open Circuit. To overcome copper losses, larger copper conductors are used, whilst iron losses are kept at a minimum by constructing the core from thin laminations of Silicon Alloy steel.

$$\text{Transformer Efficiency} = \frac{\text{Output}}{\text{Output} + \text{Losses}}$$

Maximum efficiency occurs when Copper Losses = Iron Losses (most transformers are 92% - 98% efficient).

No-Load Current - this is the primary current taken from the supply when the secondary is not connected to a load. The current taken is used to supply iron losses (eddy currents and hysteresis). On open circuit E_p (back emf) is almost equal to V_p (applied voltage) and $E_s = V_s$ (secondary).

Transformer on Load - in previous discussion it was assumed that the flux in the core was entirely due to the primary current. If the secondary circuit is connected to a load, the secondary current will set up a flux in the core. The secondary current flux acts in opposition to the primary flux and so tends to lower the core flux density. This action lowers the value of induced e.m.f. and allows more current to flow in the primary winding. This increases the flux to such a value as will create a secondary induced e.m.f. high enough to force the secondary current through the load. This self-balancing action occurs whenever the load changes. It has been found that the core flux remains fairly constant at all loads, and that an increase in secondary current results in a decrease in the primary back e.m.f. and this, in turn, allows an increase in primary current to balance the increase in secondary current.

Regulation - as the secondary current rises, the secondary voltage falls, due to voltage drop in the windings. In practice this voltage decreases, compared to the secondary voltage at no load, should not exceed 5%.
It is calculated thus - $\frac{Es - Vs}{Es} \times 100$

Induced E.M.F. = the induced e.m.f. in a transformer can be calculated from the formula

$$E_{induced} = \frac{4.44 \times f \times 0 \times N}{10^8} \text{ volts RMS}$$

Where f = supply frequency
0 = maximum total flux in core = B x c.s.a.
N = number of turns
4.44 = a constant used to current value of induced e.m.f. to R.M.S. values.

Transformer Winding Formula

To determine turns required on the primary:-

$$\text{Prim. turns} = \frac{V \times 10^8}{4.44 \times F \times A \times \text{Flux Density}}$$

$$\text{Prim. Current} = \frac{W}{V} \times 1.09 \text{ (9\% magnetising current)}$$

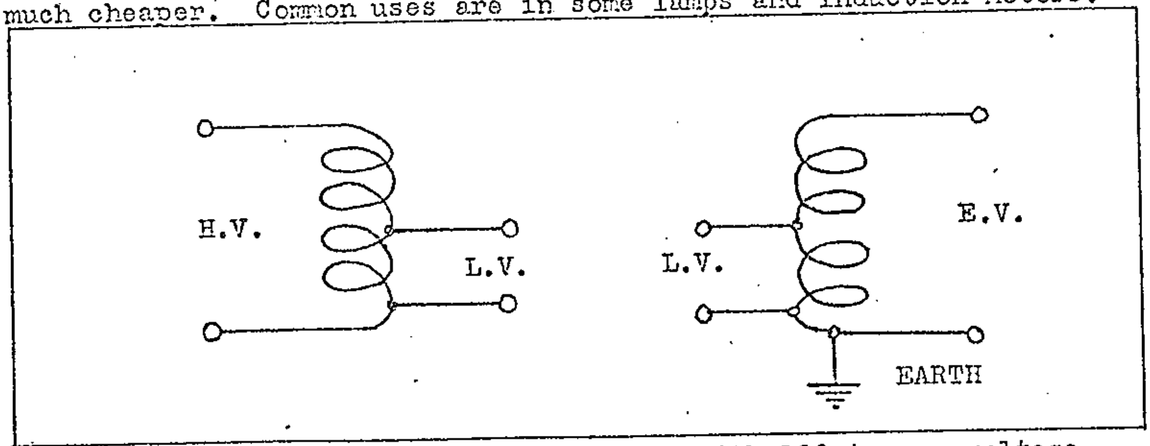
$$\text{Turns Secondary} = \left(\frac{\text{Primary Turns - Secondary V}}{\text{Primary V}}\right) \times 1.05 \text{ (5\% V drop)}$$

$$\text{Sec. Current} = \frac{W}{V}$$

Wire size is given in tables according to current carrying capacity

Where V = Primary Volts
F = Frequency
A = C.S.A. Iron Circuit
Flux D = C Cores 100000
Laminations 65000

Auto Transformers - this type of transformer has only one winding, with a tapping usually near the centre. They are used where the Ratio of Transformation is low, with the added advantage of being much cheaper. Common uses are in some lamps and induction motors.

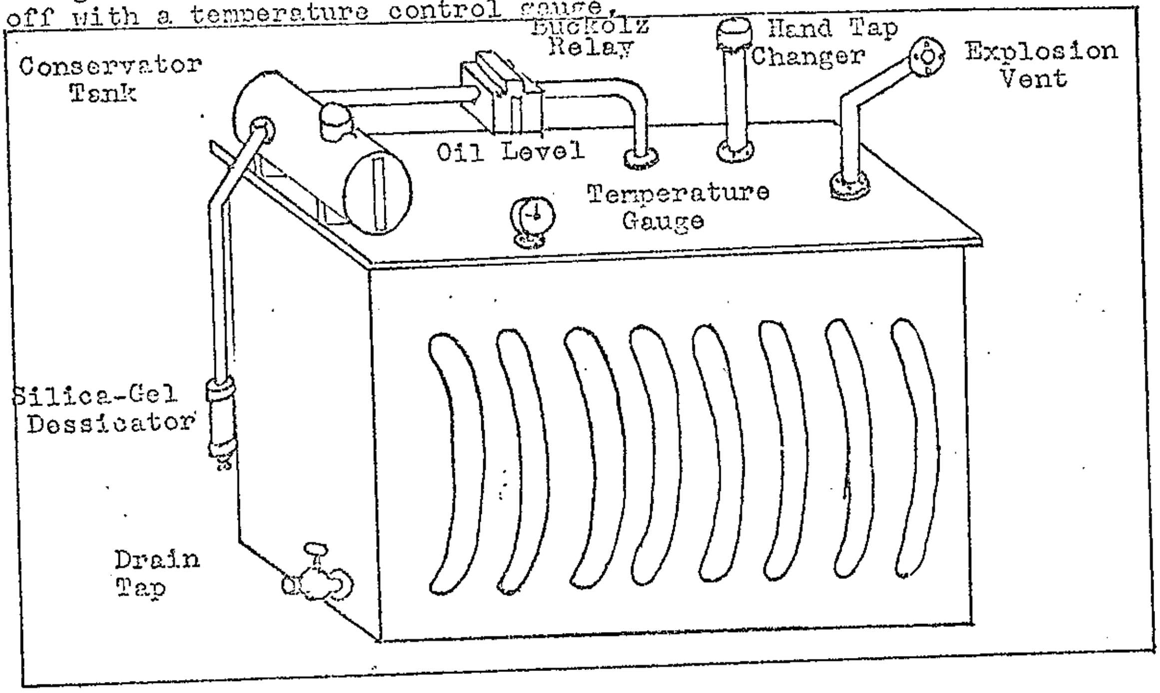


Operation - If 100V is applied to a coil with 100 turns, voltage drop will equal 1 volt/turn. Therefore, if the secondary is connected across half the winding it will have a voltage equal to half the primary back e.m.f. and 180° out of phase with the applied Primary e.m.f. As the primary and secondary currents are 180° out of phase, only the difference of their values will flow in the common part of the winding - 50 Volts.
One major disadvantage with auto-transformers, is the risk of a dangerously high potential existing in the low voltage secondary, should the Neutral become open circuit. To minimize this danger, it is necessary to connect one terminal of the low voltage circuit to

the earthed terminal of the high voltage circuit.
The S.A.A. wiring rules prohibit the use of auto-transformers, except in special cases, to raise or lower the voltage more than 25%.

Maintenance of Power Transformers

Below is a drawing of a typical power transformer, having most of the parts to be expected. Large transformers have a separate cooling radiator which cools the oil exactly the same as a car radiator cools a car's water system. On very large transformers, force draught fans are mounted under the radiator and are switched on and off with a temperature control gauge.



Silica Gel Dessicator

As the oil in the transformer expands and contracts due to rising and falling temperature either due to weather or load, air is drawn into or pushed out of the transformer. This breathing is done through the silica gel dessicator. The air entering the transformer must be completely dry, the silica gel extracts any moisture from the air. In doing so, the crystals turn from blue to pink, indicating they have extracted moisture. When this happens, the crystals must be exchanged for dry blue ones, and the pink crystals dried in an oven. It is no good assuming they will dry out when the weather improves, as the damp will evaporate into the transformer. There is also a small container at the bottom of the dessicator which contains a small amount of oil.

Drain Tap Samples

Periodically, a sample of the transformer oil is extracted to test its condition. To do this, two glass jars are used which are marked with the transformer title and the date. The bottles should be warmed lightly first, then a quarter filled with oil from the drain plug. Rinse the jar around with this oil then throw it away. Fill the jar to the top from the drain and replace the stopper immediately. Fill the second jar similarly, then close the drain and replace the drain valve cover. Only remove enough oil for the jars plus a rinse.

Conservator Tank Level

The highest point to which the transformer is filled in the conservator tank. Any topping up is done into this tank. Any oil added must be tested for condition first. On the end of the conservator tank there is usually a level indicator. If asked to check this, make sure it is the oil level that you are looking at and not a dirty mark on the glass. Oil temperature will effect the level, so give level at such and such a temperature of simply say with transformer either on or off.

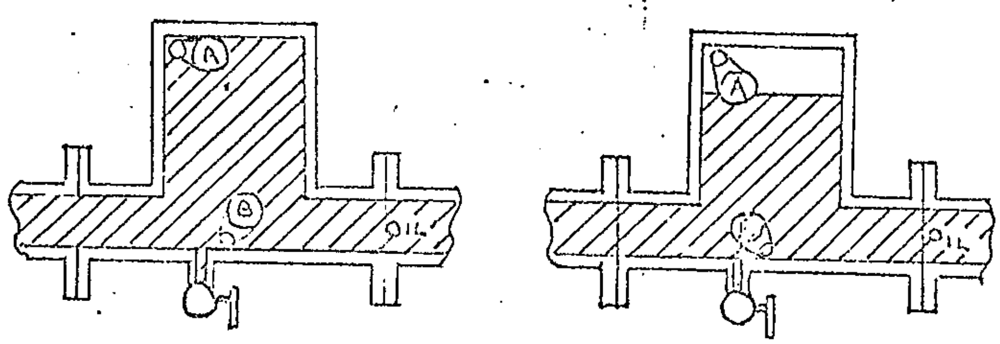
Temperature Gauge

There is a temperature gauge of the transformer which incorporates a switch. When the needle reaches an adjustable needle with a contact on it, this will open a contact or push one closed which will bring up an alarm or possibly trip the transformer.

Explosion Diaphragm

Transformers have been known to physically explode due to rapid heating and expansion of the oil under fault conditions. An explosion diaphragm is fitted, made of a relatively easily fractured plate, so that the potential pressures can be released in the event of an emergency.

Bucholz Relay



This device works has an overload warning and overload trip. Should a short circuit occur in or near the transformer, this will reflect as heat in the oil. A smallish short will result in the oil starting to gas. This gas will rise to the highest point it can and will actually be caught in the relay at "A", allowing the float "A" to fall and operate a switch. A large short circuit will reflect in the oil boiling and flowing quickly along the pipe pushing the float or flat "B" over and operating a switch.

Hand Tap Changer - This will vary the output over a small range or tapping i.e. if the secondary of the transformer is 415 Volts, there could probably be tappings at 405, 410, 415, 420 and 425. This position is usually set when the transformer is installed. The only time it is varied is if the load point should move, as in mines and quarries.

CURRENT TRANSFORMERS:-

It is difficult to construct ammeters, and the current coils of watt-meters, watt-hour meters and relays to carry alternating currents greater than about 100A. Furthermore, if the voltage of the system exceeds 500V, it is dangerous to connect such instruments directly to the high voltage conductors.

These difficulties are overcome by using current transformers. Figure (a) shows an ammeter supplied through a current transformer.

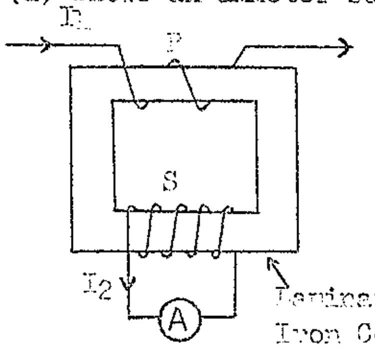


Fig. A. A Current Transformer

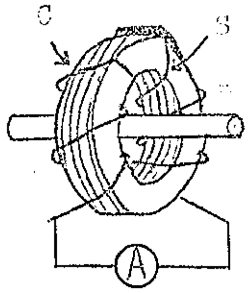


Fig. B. A Bar Primary Current Transformer

The ammeter is usually arranged to give full-scale deflection with 5A, and the ratio of the primary to secondary turns must be such that full-scale ammeter reading is obtained with full-load current in the primary. Thus, if the primary has 4 turns and the full-load primary current is 50A, the full-load primary ampere turns must be 200/5, namely 40. If the number of primary turns were reduced to one, and the secondary winding had 40 turns, the primary current to give full-scale reading of 5A on the ammeter would be 200A.

Current transformers having a single-turn primary, are usually constructed as shown in figure (b) where "P" represents the primary conductor passing through the centre of a laminated iron ring "C". The secondary winding "S" is wound uniformly around the ring. The secondary circuit of a current must on no account be opened while the primary winding is carrying a current since all the primary ampere-turns would then be available to produce flux. The iron loss due to the high flux density would cause excessive heating of the core and windings, and a dangerously high e.m.f. might be induced in the secondary winding.

TITLE: INDUCTION HEATING

LECTURER:

DATE:

EQUIPMENT:

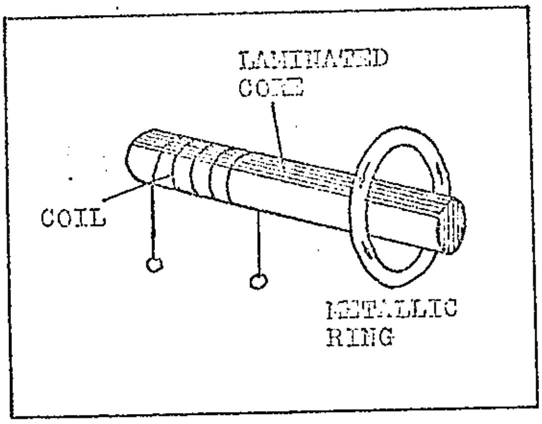
Although in most cases as with transformers, motors, contactors, relays etc., the effects of eddy currents are a nuisance which must be overcome by laminating the iron circuits, there are some areas where use is made of the heating effect of these eddy currents.

Heating by induction is quick, clean and more economical than using resistance type heaters.

Some of these applications are:- furnaces, brazing, welding, bearing heating, heat treatment.

PRINCIPLE OF OPERATION:

The basic principle behind induction heating is the same for all applications, i.e. the heat is produced by "Eddy Currents" circulating in the material being heated. This method will only work on materials which are electrical conductors.



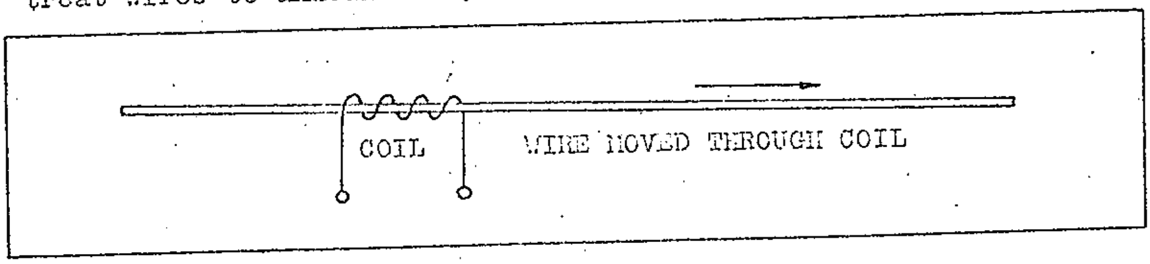
It can be seen in the diagram that the current flowing in the ring is at right angles to the lines of flux which are being produced by the coil. Measurement of this current is possible by using a Tong-Test Ammeter.

The effect can be related to the operation of a transformer. This has a primary coil, an iron circuit and a secondary coil. In the case shown, the secondary coil has been replaced by the conductive ring.

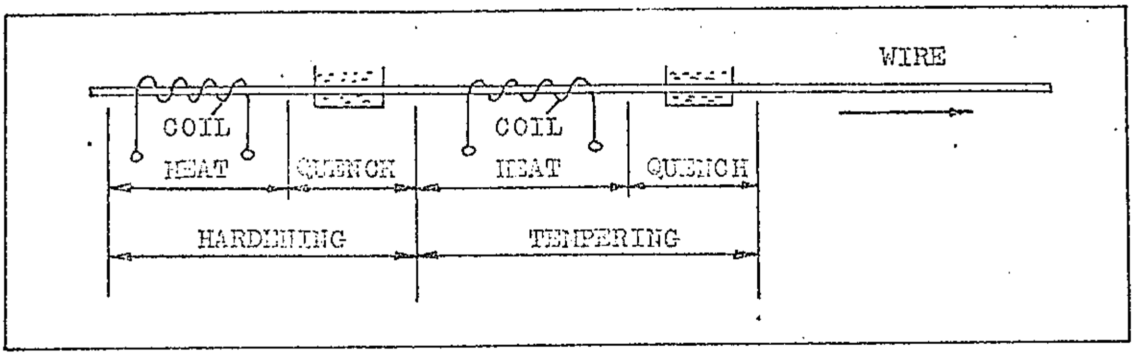
A practical application of the above arrangement would be a bearing heater where a bearing race is positioned in place of the ring.

If the core in the induction heater above were not laminated, then it too would become hot. This factor introduces a further method of heating.

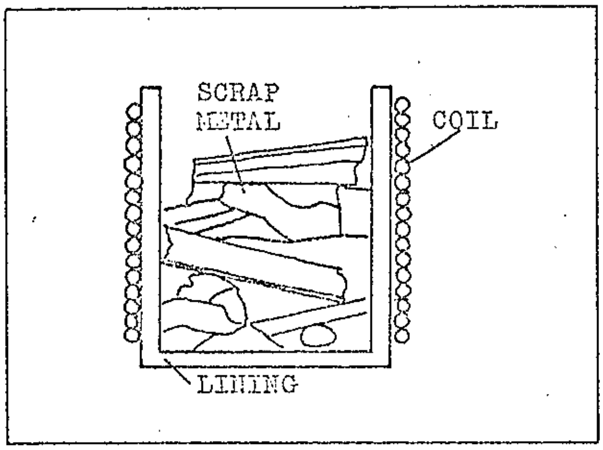
If the core were removed and a steel wire was fed through the coil, then it would heat the wire. This method is used to heat treat wires to anneal them, or harden them.



By using a number of coils, it is possible to perform several heat treatment processes simultaneously.



In a furnace, the coil is wound around a non-metallic container capable of withstanding high temperatures (Refractory Brick) and the metal to be heated is placed inside. When the coil is energised, the Eddy Currents flow in the metal causing it to heat and eventually melt. Once the metal is molten, the Eddy Currents cause a stirring effect in the furnace container ensuring equal heat distribution.



POWER SUPPLIES:

Because of the extremely highly inductive nature of this type of heating, the power factor is very low. It is usual to connect a bank of capacitors in aprallel with the coil to correct this power factor.

Frequency of the supply also affects the operation of an induction heater. The frequency may be anything from 50 Hz to several hundred kHz. As a general rule, the larger the furnace, the higher the frequency, and the greater degree of "stirring" required the lower the frequency.

TITLE:- METER MOVEMENTS

LECTURER:-

DATE:-

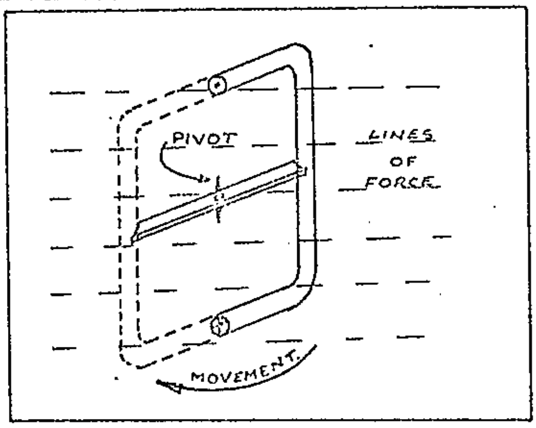
EQUIPMENT:- Moving coil, Moving iron, and Dynamometer movements.

A meter movement is the name given to the electrical and mechanical components used to move a pointer on a measuring instrument.

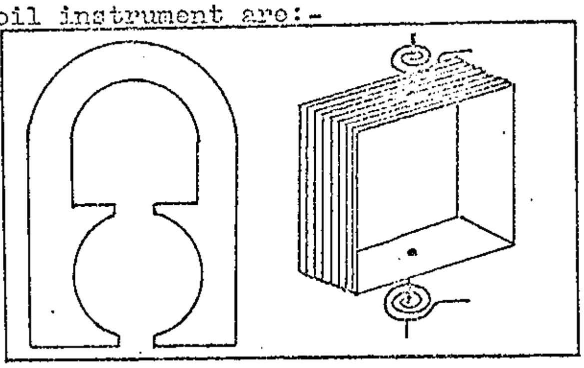
There are three main types, 1. Moving coil, 2. Moving iron, 3. Dynamometer. Other types are made for special purposes but will not be encountered in most electrical installations.

Moving Coil

When a current carrying conductor lies in a magnetic field, there is a force exerted on that conductor. Similarly, a coil placed in a magnetic field, as in the sketch, will have a force acting upon it, causing it to move. If the coil is suspended on a pivot as shown, it will turn. The direction in which it turns is dependent upon the polarity of the main field, and the direction of the current through the coil.



The distance which the coil will turn is directly proportional to the current flowing in the coil.
The essential parts of a moving coil instrument are:-



1. A permanent magnet with shaped pole pieces to provide a narrow air gap.
2. A rectangular shaped coil fitted with pivots and return or control springs.

The springs serve two purposes, i.e. to carry the current to and from the coil, and to cause the coil to return to its original position when there is no current flowing.
Because the direction of rotation is affected by current flow direction, the movement is said to be POLARISED and is therefore used only for D.C. measurements.
The coil must be made very light in weight, and can therefore only carry a small amount of wire of very thin gauge. This means that the current which actually passes through the coil will only be in the region of up to 100 milliamps.

Moving Iron

There are two types of moving iron instruments, 1. attractive iron type and 2. repulsion type.
A diagram of each type is shown.
Both have a cylindrical type coil through which a current is passed. In the first type, the soft iron disc is attracted towards the coil as the current is increased and deflects the pointer. The balance weights W_1 & W_2 are used to prevent the disc from being pulled into the coil fully. This would happen for every value of current in the coil. For this reason, the meter may only be used in a horizontal position.