TITLE:- GENERATION OF ALTERNATING CURRENT

LECTURER:-

DATE:-

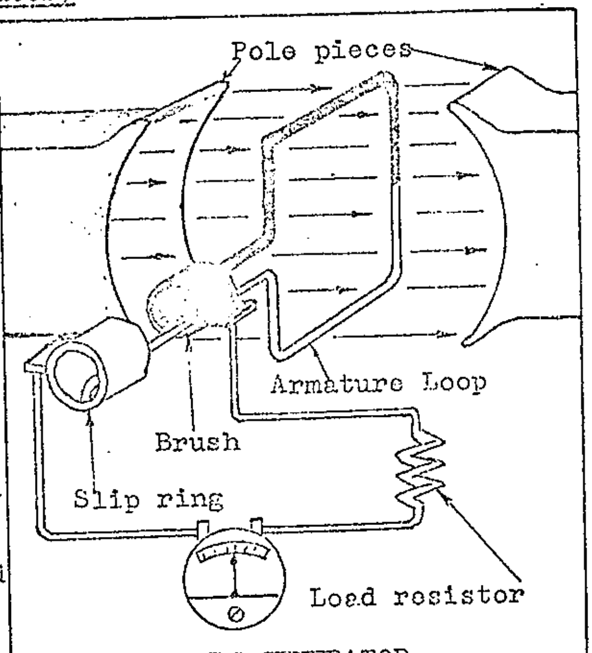
EQUIPMENT:-

If a piece of wire is connected across a very sensitive meter, and a magnet moved past the wire, the meter needle will deflect. This deflection indicates that electricity is produced in the wire.
If the magnet is placed near the wire and held still, no deflection results, however if the magnet is once again moved, being kept near the wire, the needle again deflects.

This demonstrates that magnetic flux and conductors are not enough on their own to generate an e.m.f. and since, if the wire is moved past the magnet the effect is the same, then it can be said that relative motion between the two is the third necessary factor.
For a continuous source of electricity a continuous motion has to be maintained by either the wire or the magnetic field. The most practical way to do this is to rotate the wire in a circle through the magnetic field.

Elementary A.C. Generator (Alternator)

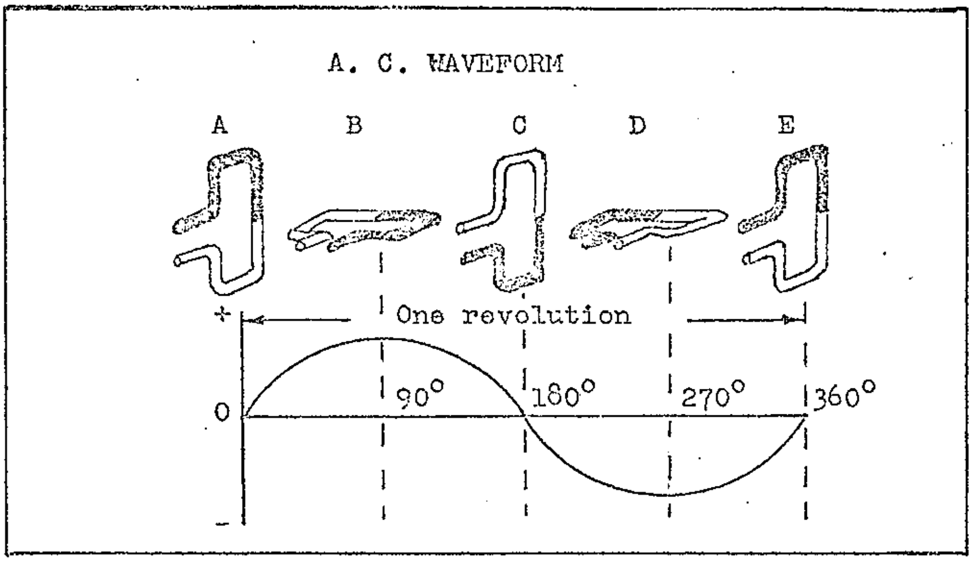
An elementary generator consists of a loop of wire placed so that it can be rotated in a uniform magnetic field to produce electricity in the loop. The ends of this "armature" loop are connected to rings called "slip rings". These rings, mounted on the shaft in a practical generator are insulated from the shaft and from each other. Current collectors called "brushes" ride on the slip rings to carry the electricity to the external circuit.



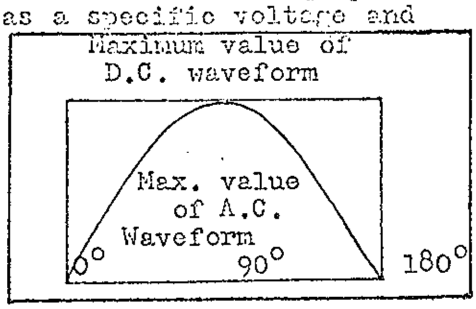
ELEMENTARY GENERATOR

Operation

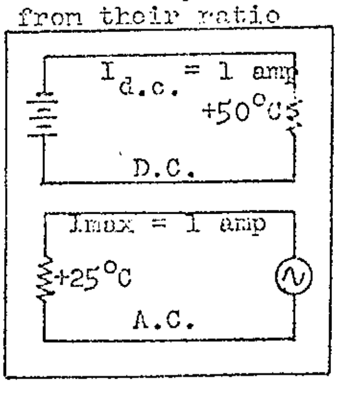
Assume loop is rotating in a clockwise direction and its initial position is A (Fig. 2). In position A, the loop is perpendicular to the magnetic field and the black and white conductors are moving parallel to the magnetic field. No lines of force are cut therefore no e.m.f. is generated. As the loop rotates from A to B, the conductors are cutting through more and more lines of force, until at 90 degrees (position B) they are cutting through a maximum number of lines of force. In other words between 0 degrees and 90 degrees, the e.m.f. generated in the conductors builds up from zero to a maximum. At this time, the black conductor is moving down through the field and the white conductor up through the field. The e.m.f.'s in both conductors are in series, therefore the resultant voltage across the two brushes will be the sum of the two e.m.f.'s.
The current will vary as the e.m.f. varies.
As the loop continues rotating from position B (90 degrees) to position C (180 degrees), the conductors which are cutting through a maximum number of lines of force at position B cut through fewer lines, until at position C they are moving parallel to the magnetic field and no longer cut any lines of force.
The generated e.m.f. therefore will decrease whilst the loop moves from position B to position C in the same manner as it increased from zero to 90 degrees.



From zero to 180 degrees, the conductors of the loop have been moving in a given direction through the magnetic field: therefore the polarity of the generated e.m.f. has remained the same. But beyond 180 degrees, the direction of the cutting action of the conductors through the magnetic field reverses.
In consequence, polarity of the e.m.f. and the current flow will reverse. While the loop is rotating from C to D and back to A, the current flow will be in the opposite direction to that in which it was flowing when the loop was rotating from A to C.
The rise and fall of generator terminal voltage will be the same as it was from A to C except for its reversed polarity. The alternator has now completed an output of one cycle of alternating current.
The shape of the graph of the generated e.m.f. and current is known as a sine wave.
Since one complete cycle of voltage and current is generated for one revolution of the elementary generator, if the loop is rotated at 50 revolutions per second, the generated e.m.f. will complete 50 cycles per second (50 HZ) and this will be said to be its frequency.
A.C. frequency is important since most a.c. electrical equipment requires a specific frequency as well as a specific voltage and current, for proper operation.



Effective value of A.C.
It will be clear that if an A.C. waveform with a certain maximum value is compared to a D.C. waveform with the same maximum value, the D.C. value is greater than the A.C. at all points except the point at which the A.C. sine wave passes through its peak.
The A.C. value therefore will have an effective value that is less than the D.C. value. A convenient way of finding the effective value is to compare the heating effect in a resistor of a given value when D.C. is passed through it for a given period of time, and when A.C. of an equal maximum value is passed through it for the same period of time. The two temperature increases are then compared with each other: and from their ratio the effective value of the A.C. is calculated.
Consider the two circuits alongside, both of which have a resistor R of the same resistance. In the D.C. circuit, a current of 1 amp raises the temperature of the resistor by (say) 50 degrees C. In the A.C. circuit, the current at its maximum value is 1, and the resistor is only raised by 25 degrees C.



The power loss, or energy consumed in a resistor is measured by the formula $P = I^2 R$.
The power loss in the D.C. circuit (I^2d.c.R) raised the temp. by 50 degrees C., while in the A.C. circuit, the power loss(I^2EFF x R) caused by I max. of 1, caused only half the D.C. loss.

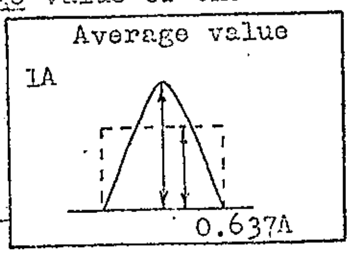
It follows that $I^2_{EFF} \times R = \frac{1}{2} I^2_{d.c.} \times R = \frac{1}{2} I^2_{Max.} \times R$

Simplifying $I^2_{EFF} \times \frac{1}{2} I^2_{Max.}$

$$I_{EFF} = \frac{1}{\sqrt{2}} I_{max.} \quad \text{or} \quad 0.707\ I\ max.$$

In other words, the effective current is only 0.707 of I maximum, therefore in the A.C. circuit, I maximum will have to be increased to IEFF x 2 (1.414) before it will produce the same heating effect as 1 amp of D.C.
The effective value of voltage or current is referred to as the R.M.S. (root mean square) values of voltage and current.
R.M.S. values are so called because of the method used to determine them:-
(a) A specific number of instantaneous values are taken from a complete cycle of the sine curve.
(b) Squaring these instantaneous values and finding the average of all the squared values - remember the heating effect of a current is proportional to the average value of the square of the current.
(c) Finding the square root of the average of the squared values - this is the 'root mean square' or r.m.s. value of the current or voltage.
When an A.C. current or voltage is specified, it is always the r.m.s value that is means unless otherwise stated.
All A.C. meters are graduated in R.M.S. values unless marked to the contrary.

Average values of waveforms
If an A.C. current is passed through a d.c. meter movement, the pointer would turn in one direction for a half cycle then, as the current reversed direction, the pointer would move in the opposite direction.
If the frequency of the A.C. was 50 c.p.s. the pointer would be unable to follow the reversal of current fast enough, and the pointer would vibrate back and forth at zero, the average value of a sine wave.
N.B. This vibration will soon damage a d.c. meter.
By using a rectifier in series with the d.c. meter, current flows only for half of each cycle, i.e. current flows in pulses which are all in the same direction. Each pulse causes a deflection of the pointer, which cannot move fast enough to return to zero between pulses and so continuously indicates the average value of the current pulses.



In a sine wave, the average value of a half cycle is 0.637 of the maximum or peak value. This value is obtained by averaging all the instantaneous values of the sine wave for a half cycle.
Although the deflection of the meter pointer depends on the half cycle average value of current, it is usual for meters to be calibrated to read R.M.S. values directly.

Phasor Diagrams
These are used to represent variable quantities such as current and voltages since they are much less laborious and time consuming to draw than sine waves.

With this method, all values are represented by straight lines which are drawn to scale. The time relationships are shown by the directions of these lines, which are considered to rotate in an anti-clockwise direction about a fixed point, with the 360 mechanical degrees representing 360 electrical degrees. Thus a 240 volt source with a current of 5 amps lagging by 30 degrees would be represented by the phasor diagram of fig. 1. It can be seen from the diagram that the voltage is represented by a line with an open arrowhead, whereas the current phasor has a closed arrowhead. This rule should be followed to avoid confusion. Another rule to observe is that whichever quantity is to be used as the reference, should be drawn horizontal, in this case the current.

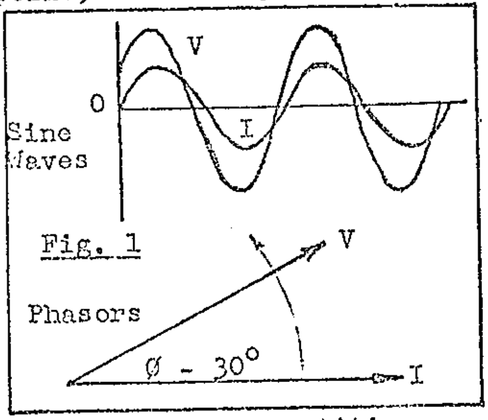


Fig. 1

Sometimes it is required to find the resultant of two quantities which are out of phase with each other, and this can easily be done with phasors.
If the reference and the individual quantities, (e.g. voltages) are drawn in, it will be found that if the two component voltages (Exc, ExL) are taken to be two sides of a parralelogram, the completed parallelogram would have phasor E as its diagonal (Fig. 2) i.e. The resultant e.m.f. would be represented in magnitude and phase by the diagonal of a parallelogram of which the two components formed the sides.

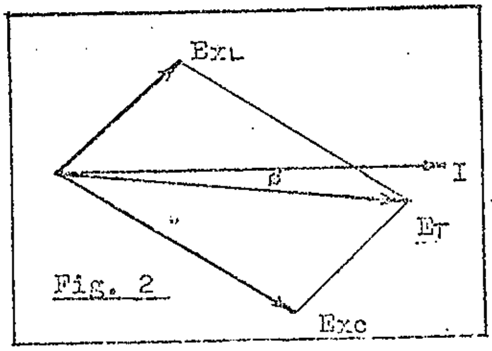


Fig. 2

To subtract one phasor from another when they are out of phase with each other, the phasor to be subtracted is rotated through 180 degrees, i.e. made negative, and then the resultant is found using the parallelogram method, e.g. if in Fig. 3, Exc is subtracted from ExL , the phasor diagram would take the form of Fig.3 with E_T the resultant.

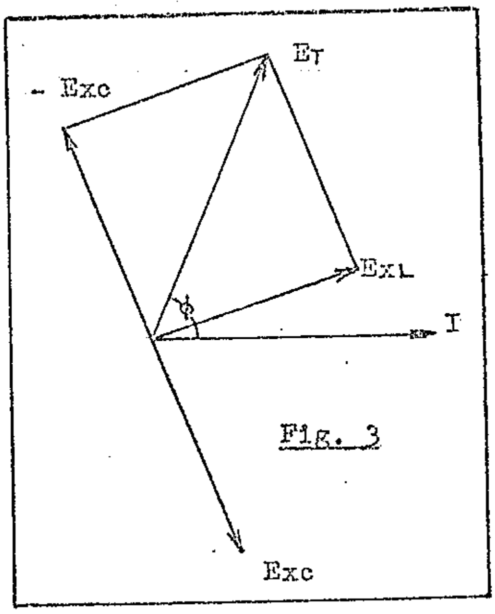
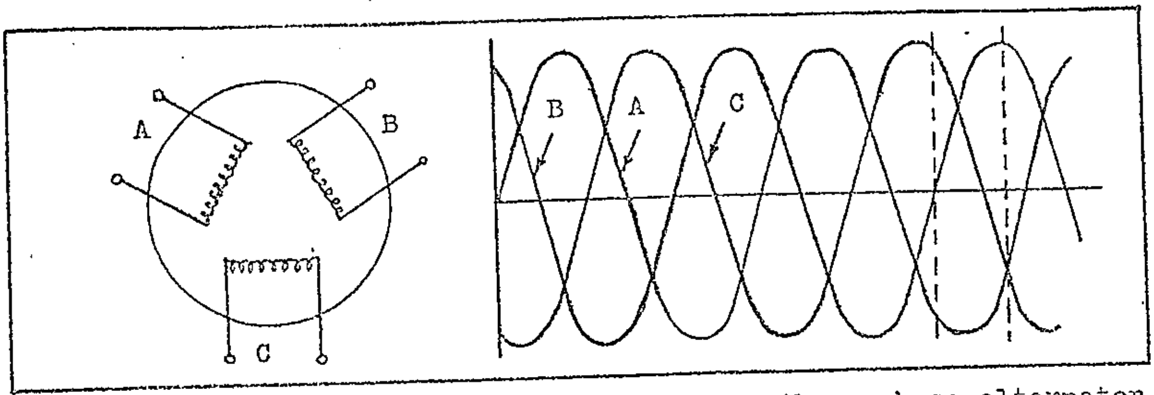


Fig. 3

Generation of 3 phase E.M.F.

The three phase alternator, as the name implies, has three single phase windings so spaced that the voltage induced in any one is phase displaced by 120 degrees from each of the other two. A schematic diagram of a three phase stator showing all the coils becomes complex, and it is difficult to see what is actually happening, so the simplified schematic illustrated shows the windings of each single phase lumped together as one winding.
The voltage waveforms generated across each phase are drawn on a graph, phase displaced 120 degrees from each other.

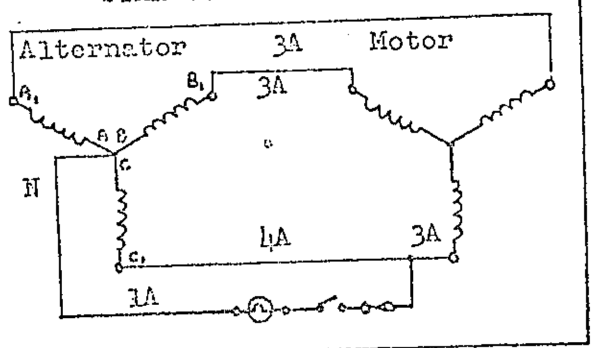


Instead of having six leads coming out of the three phase alternator from three separate phases, either of two special connections can be used so that only three leads are brought out from the alternator. Using these connections, power can be fed out to a three phase load through the leads as each in turn becomes positive, the lead(s) which at that moment are negative being used to complete the circuit. Thus in a 3 phase balanced system, no neutral is needed.

Star Connection In this system, the like ends are connected together to form a star point. (i.e. the three starts or the three finishes). This star point forms the neutral so that single phase loads can be connected with this system, the neutral wire returning the single phase current to the alternator.
The voltage from any of the line leads to the neutral is called the phase voltage. The voltage across any two of the line leads is the line voltage and is 1.73 times the phase voltage.

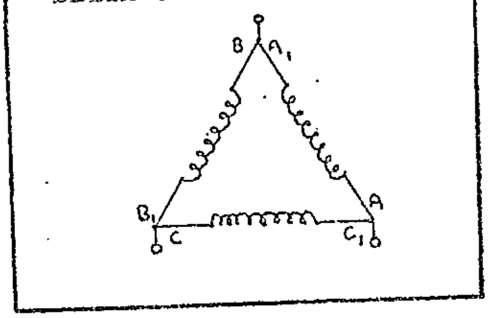
Line currents and phase currents in the windings are equal in a star connection.

STAR CONNECTIONS



Delta Connection With this connection the unlike ends are connected together (i.e. start to finish). In a delta system the line voltage and the phase voltage are equal, line current is 1.73 times the phase current. No neutral is available with a delta connection.
Both star and delta connections are used for three phase alternators and motors.

DELTA CONNECTION



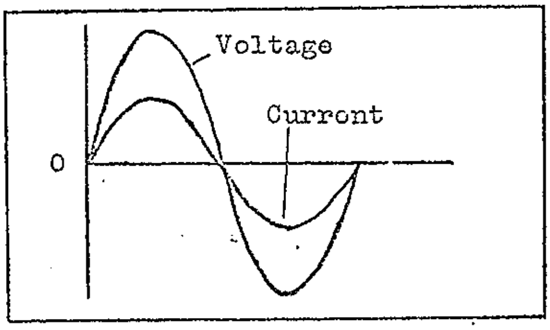
TITLE:- EFFECTS OF RESISTANCE, INDUCTANCE AND CAPACITANCE ON A.C.

LECTURER:-

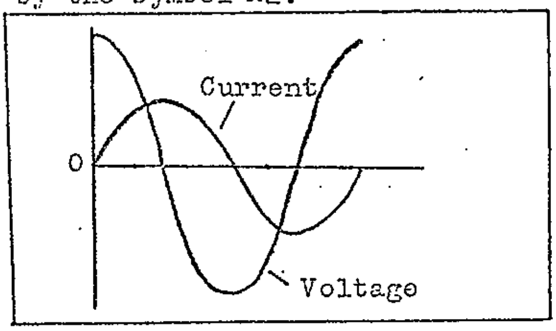
DATE:-

EQUIPMENT:-

Many A.C. circuits consist of "pure resistance" only, and for such circuits the same rules and laws apply as for D.C. circuits. These circuits contain devices which have no inductance or capacitance such as resistors, lamps and heating elements. When an A.C. circuit contains only such devices as these, Ohm's law, Kirchoff's laws, and the circuit rules for voltage, current and power can be used exactly as in d.c. circuits.
When an A.C. voltage is applied across a resistor, voltage increases to maximum in the +Ve direction, decreases to zero, increases to maximum in the -Ve direction and again decreases to zero to complete a cycle of voltage. The current flow follows the voltage: as voltage increases, current increases and current falls to zero along with the voltage i.e. voltage and current are "in phase".
Voltage and current are in "in phase" when they are the same frequency and pass through zero simultaneously, both going in the same direction.



Inductance in an A.C. circuit When a current flows in a conductor, a magnetic field is set up around that conductor, the magnitude of the field varying with the current. If the current is alternating, then the flux will also be alternating. This will induce an alternating e.m.f. in the conductor, the magnitude of which will at any instant be proportional to the rate of change of flux at that instant. This e.m.f. is called the e.m.f. of Self Induction.
By Lenz Law:- The direction of an induced current is such that the electromagnetic effects of the current oppose the change producing it. i.e. The induced e.m.f. is in opposition to the applied e.m.f. and is called a "back e.m.f.".
The back e.m.f. produces a choking effects on the current which is called inductive reactance, denoted by the symbol X_L.
If an A.C. circuit contains only pure inductance, the current is not in phase with the voltage. Instead, it rises to a maximum a quarter of a cycle later than does the voltage; and it remains a quarter of a cycle behind at all points in the cycle i.e. current lags voltage by 90°. Since all practical circuits contain resistance, however, the current never lags the voltage by as much as 90° but at a lesser angle depending upon the amounts of resistance and reactance in the circuit.



The formula used for finding the reactance in a circuit is:-

$$X_L = 2\pi fL$$

where f = frequency
L = inductance in henrys

e.g. Find the current which will flow through a coil of negligible resistance and an inductance of 0.04 henry when connected to a 200 volt, 50 Hz supply.

$$X_L = 2\pi FL = 2\pi 50 \frac{4}{100} = 4\pi \text{ ohms}$$

$$I = \frac{V}{X_L} = \frac{200}{4\pi} = \frac{50}{\pi}$$

$$\underline{I = 15.92 \text{ Amperes}}$$

The back e.m.f. can also be calculated:-

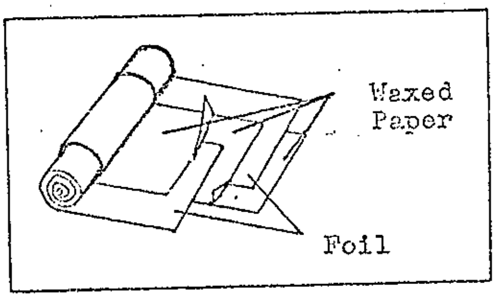
e.g. A 240 volt coil whose resistance is 8 Ω draws 3A when energised. Find the back e.m.f.

$$Eb = 240 - (3 \times 8) = 240 - 24$$

$$\underline{Eb = 216 \text{ volts}}$$

Capacitance in an A.C. circuit

Capacitance is the property of a circuit which opposes any change in circuit voltage. It exists in an electric circuit because certain parts of the circuit are able to store electric charges. Devices used to add capacitance to a circuit are called capacitors, sometimes called condensers. Basically, capacitors consist of two plates which can be charged - separated by an insulating material called the "dielectric". Most capacitors use metal foil for the plates. Common dielectric materials include air, mica, and waxed paper.

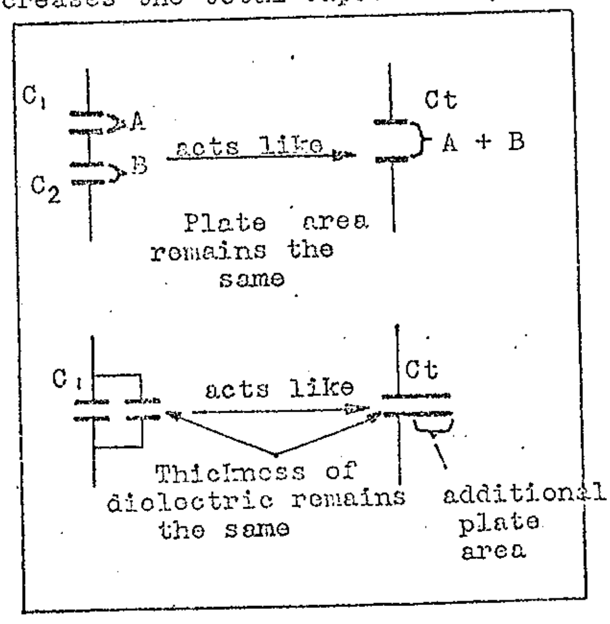


Three basic factors effect the capacitance of a capacitor:-

(1). Plate area - the larger the plates, the larger the capacitance.
(2) Distance between plates - the smaller the distance, the greater the capacitance.
(3) Dielectric material - the effect of different materials is measured against an air dielectric and will multiply the capacitance by an amount known as the "dielectric constant" e.g. a certain oiled paper has a dielectric constant of three; and if this is placed between the plates, the capacitance will be three times greater than if the dielectric was air.

When capacitors are connected in series or parallel, the effect on the total capacitance is opposite that for similarly connected resistor.

Connecting capacitors in series decreases the total capacitance, because it effectively increases the spacing between the plates. To find the total capacitance of series connected capacitors, a formula is used similar to the formula for parallel resistances. When capacitors are connected in parallel, the total capacitance increases because the plate area receiving the charge increases. The total capacitance for parallel connected capacitors is found by adding the values of the various capacitors connected in parallel.



Series Capacitance formula

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Parallel capacitance formula

$$C_T = C_1 + C_2 + C_3$$

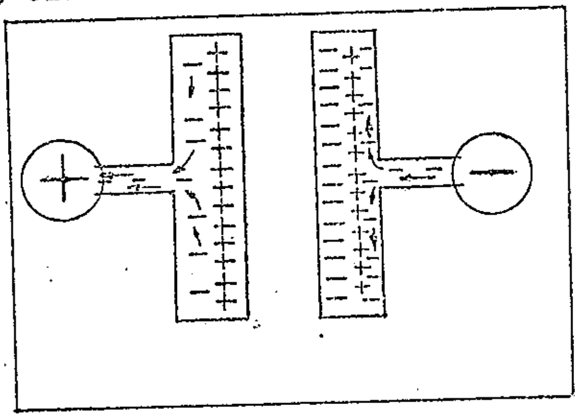
Units of Capacitance

The basic unit of capacitance is the farad. A capacitor has a capacitance of one farad when a charging current of one ampere flowing for one second causes a change of one volt in the potential between its plates.

The farad is much too great to use as the unit of capacitance for practical electrical circuits. Because of this, the units normally used are the microfarad (μF), equal to one millionth of a farad, and the picofarad (pF) equal to one million-millionth of a farad. Since electrical formulae use capacitance stated in farads, it is important to be able to change various units of capacitance to other units.

In order to charge a capacitor, an electrical force is required. Extra electrons forced onto one plate from a negative charge will charge the plate negatively. As these extra electrons build up on the plate, they repel or oppose the electrons trying to follow them. This slows the charging rate. When the repelling force equals the charging force, no more electrons flow.

Similarly, with the positive plate, electrons are removed by the attraction of a positive charge. The first electrons leave easily, but as the plate builds up a positive charge, it becomes increasingly difficult to pull electrons away. When the positive attracting force equals the plate's positive charge, no more electrons leave the plate. On discharge, the electrons move in the opposite direction.

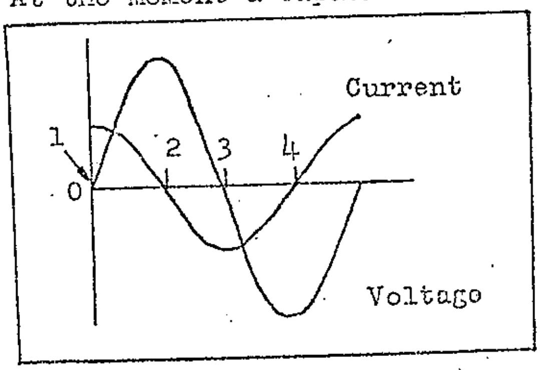


The action of the plates in opposing the movement of electrons is called "capacitance reactance" and is denoted by Xc.

Using the formula $Xc = \dfrac{1}{2\pi FC}$ where (F = frequency) (C = capacitance), capacitance reactance can be found.

If an A.C. voltage is applied to a capacitor, an ammeter in series with the capacitor will give a reading due to the electron movement, even although no electrical connection exists between the two plates.

If the capacitor is charged and the source removed, it will retain its charge. In a theoretical circuit of pure capacitance and no resistance, the voltage across the capacitor exists only after current flows to charge the plates. At the moment a capacitance starts to charge, the voltage across its plates is zero and the current flow is maximum (Point 1). When the capacitance reaches full charge, the current is zero and the voltage is maximum (Point 2). In discharging, the current rises to a maximum in the opposite direction while the voltage falls from maximum to zero (Point 3). Therefore it can be seen that in a purely capacitive circuit, the current leads the voltage by 90 degrees. In practice it will be less than 90 degrees because some resistance is always present.



Types of capacitor

Many different types of capacitors are used in electrical and electronic circuits, both fixed and variable.

Some of these types are as follows:-

(1) One type of variable capacitor uses air as a dielectric. One set of plates is mounted on a spindle so that the plates can be

moved in and out of the spaces between another fixed set of plates. The plate area, and hence, the capacity can be varied by turning the spindle.

(2) Another type, the variable mica capacitor, consists of two plates with a sheet of mica between them. A screw adjustment is used to force the plates together, and adjustment of this screw varies the capacitance of the capacitor. Several layers of mica and plates are used in larger capacitors of this type.

(3) Fixed mica capacitors consist of thin metal foil plates separated by sheet mica and moulded into a plastic cover. These capacitors are made in a capacity range between 10 pF and 0.01 μF.

(4) Paper capacitors use strips of metal foil as plates, separated by strips of waxed paper. Paper capacitors range in value from 250 μF to 1 μF, for most uses although larger paper capacitors are made for special applications.

Can be encased in either a cardboard cylinder or for wider temperature ranges, hard plastic or metal.

Paper capacitors used for high voltages (over 600 Volts) are impregnated with oil and oil filled.

Ceramic capacitors - extremely small type of capacitor - fixed or variable - use ceramic as dielectric and a film deposit of silver for the plates. They usually range in value from 1pF to 0.01 μF. The dielectric will insulate against voltages higher than 10,000 volts.

Electrolytic For value greater than 1 μF, the physical size of paper or mica capacitors becomes excessive and electrolytic capacitors are used for values of 1 μF to 1000 μF.

This type of capacitor is polarised, and if connected wrongly will break down and act as a short circuit $\therefore$ it is important to make sure of correct connections.

A "reversible" or non polarised type is sometimes used in A.C. circuits e.g. for motor starting.

TITLE:- SERIES AND PARALLEL IMPEDANCE AND RESONANCE

LECTURER:-

DATE:-

EQUIPMENT:-

SERIES

As has been previously explained, an alternating quantity can be represented in magnitude and phase relationship to other components by a straight line called a phasor.
If it was desired to find the voltage applied to two series connected resistors whose voltage drops were 10 volts and 25 volts respectively, they could be added numerically or drawn as phasors and added as in Fig. 1. All alternating quantities are not in phase however as numerical addition can not always be used.
If one of the above resistors (V1) was replaced with a pure inductance (X1), the phasor diagram would have to be redrawn as in Fig. 2. because in a purely inductive circuit the current lags the voltage by 90 degrees.
The applied voltage (VA) would now no longer equal the numerical sum of V1 + V2 but would equal their phasor sum which could be obtained by completing the parallelogram and measuring the diagonal O - VA (Fig. 3). This would be found to be larger than either V1 or V2 but always less than their numerical sum. If Fig. 3 is studied it will be noticed that the dotted line V2-VA is equal and parallel to O-V1 therefore a triangle could be drawn to represent these voltages (Fig. 4) and since this is a right angled triangle, Pythagoras theorem could be used to find VA. Thus $VA = \sqrt{V1^2 + V2^2}$.

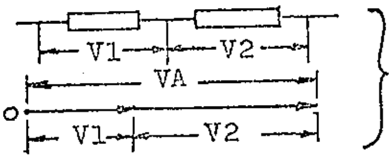


Fig. 1

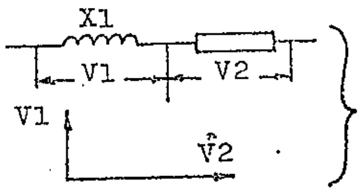


Fig. 2

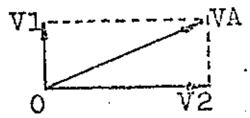


Fig. 3

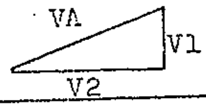
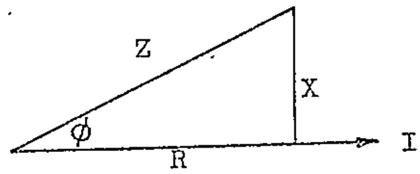


Fig. 4

Hence, in an A.C. series circuit, the numerical sum of voltage drops may be much greater than the applied voltage, the exception being when current and voltage are in phase, when numerical and phasor sums will be equal.
This voltage triangle can be used to obtain the total effective circuit resistance. The side $V1 = I x X$ and the side $V2 = I \times R$ (Resistance) and the side VA = I times the effective resistance of the series circuit.
Because the current I is the same in all parts of a series circuit, the resistance valves must have the same relationship as the voltage values.
Therefore values of resistance can be substituted for voltages V1, V2, and VA (Fig. 5).
Therefore $Z = \sqrt{R^2 + X^2}$.
The name given to the total effective circuit resistance, which is a combination of resistance and reactance is IMPEDANCE.



The triangle of Fig. 5 is known as an impedance triangle.
The angle Ø is important since this is the angle by which the current lags the applied voltage. (VA leads VR by Ø in Fig. 4. VR is in phase with the current).

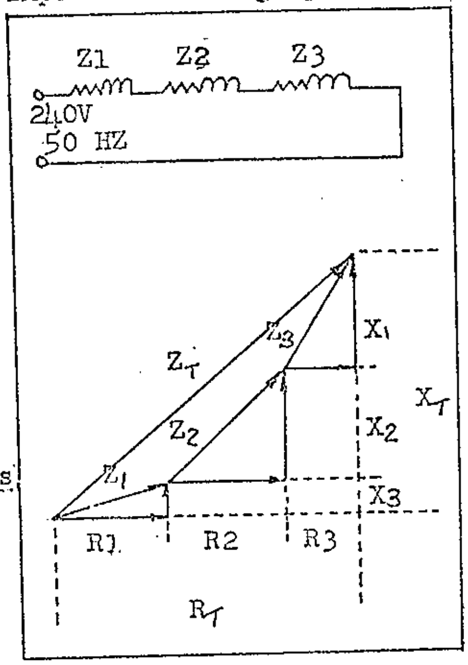
An impedance triangle can only be used to show the relationship between R, X, and Z in a series circuit. Other methods are used for parallel circuits.

IMPEDANCES IN SERIES

It is not possible to combine impedances to obtain a total impedance. To find the total impedance of a circuit it is necessary to add all the resistance components together and add them vectorially to the sum of all the reactance components.

Thus Z Total = $\sqrt{\text{sum of resistances}^2 + \text{sum of reactances}^2}$

The reason will be best seen if a set of impedances are graphically combined.



Example

Find the current flowing in the circuit opposite.

Where Z1 = 75 ohms resistance = R1
5 ohms reactance = X1

Z2 = 20 ohms resistance = R2
20 ohms reactance = X2

Z3 = 5 ohms resistance = R3
75 ohms reactance = X3

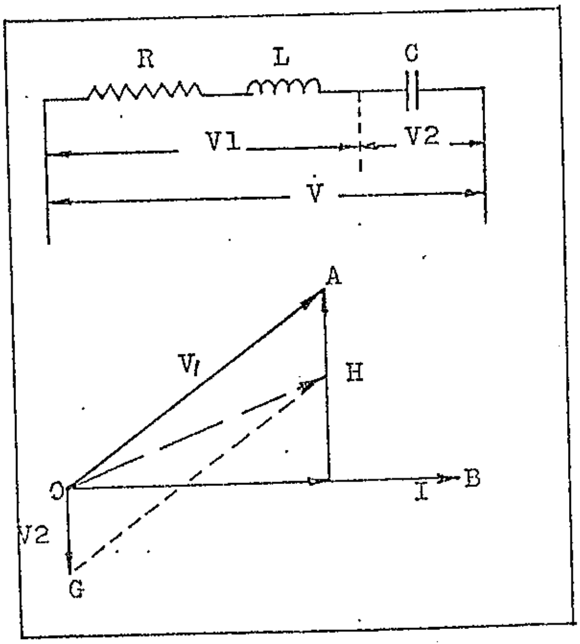
Answer from Phasors:- ______ Ohms

Using formula $ZT = \sqrt{RT^2 + XT^2}$ = ______ Ohms

The only time the impedances can be added is when all the phase angles are equal.

SERIES CIRCUIT CONTAINING RESISTANCE, INDUCTANCE AND CAPACITANCE.

In diagram: V1 = Voltage across L and R
V2 = Voltage across C



Then V is the phasor sum of V1 and V2.
Since current is common to all parts of a series circuit, it is used as the reference. In the phasor diagram let OB represent the current phasor.
V1 represented by OA is obtained as previously explained.
V2, the voltage acrsss the capacitor, is represented by OG drawn 90° behind the current vector since the capacitor has a leading current.
Complete the parallelogram OGHA.
Join OH. Then OH represents the applied voltage.

$$OH^2 = OC^2 + CH^2$$

$$OC = IR$$
$$CH = CA - AH$$
$$= IX_L - IX_c$$
$$= I\,(X_L - X_c)$$

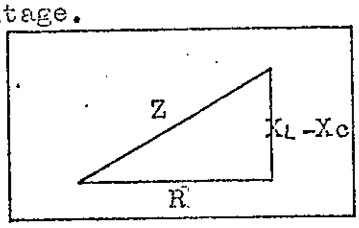
$$\therefore \quad E^2 = I^2R^2 + I^2\,(X_L - X_c)^2$$
$$E = I\sqrt{R^2 + (X_L - X_c)2}$$

$$I = \frac{V}{\sqrt{R^2 + (X_L - X_c)^2}} \quad \text{or} \quad I = \frac{V}{Z} \quad \text{since}$$

$R^2 + (X - X_c)^2$ is the impedance of the circuit, denoted Z.
The angle of lag $\varnothing$ is such that $\tan \varnothing = \frac{HC}{OC} = \frac{(X_L - X_c)}{R}$

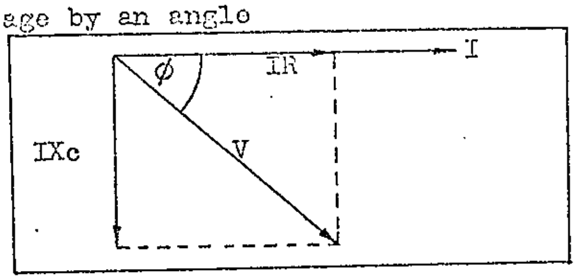
<u>If Xc is greater than X_L</u>, then OH falls on the other side of OB and the current is then leading the applied voltage.

The impedance triangle is obtained by dividing each side of voltage triangle by I.



A circuit containing resistance and capacitance only, is really only one in which X is zero.
Current is then given by $I = \frac{V}{\sqrt{R^2 + X_c^2}}$

The current leads the applied voltage by an angle $\varnothing$ such that $\tan \varnothing = \frac{X_c}{R}$



<u>IMPEDANCES IN SERIES</u>

$$Z_T = \sqrt{R_T^2 + X_T^2}$$

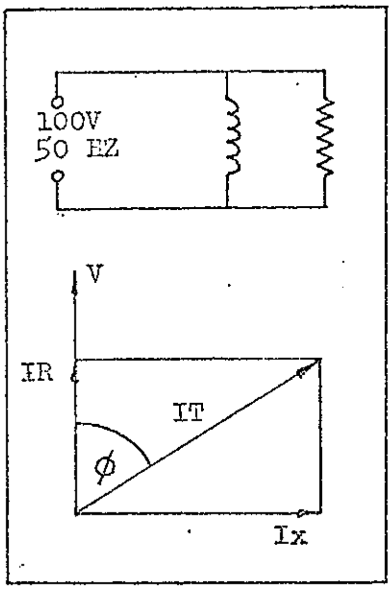
Where $R_T = R1 + R2 + R3$

$$X_T = 2\pi FL - \frac{1}{2\pi F C_T}$$

$$L_T = L1 + L2 + L3$$
$$\frac{1}{C_T} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

<u>CIRCUITS CONTAINING RESISTANCE AND REACTANCE IN PARALLEL</u>

The rules used to solve series circuits can be used to solve each individual branch of a parallel network.
However, the currents in each branch will not be in phase with each other and can not be added numerically to obtain total circuit current, therefore they must be added vectorially.
Considering the simple case of a pure inductance and a resistance connected in parallel.



Reactance of $L = 2\pi fL = 6.28 \times 50 \times .05 = 15.71$ ohms

Current through $L = \frac{V}{X} = \frac{100}{15.71} = 6.37$ amps

Current through $R = \frac{V}{R} = \frac{100}{12} = 8.33$ amps

The phasor of the diagram can now be drawn. Voltage is used as the reference when solving parallel circuits since it is the same in both branches.
From the phasor diagram it can be seen that

$$I = \sqrt{I^2 + Ix^2}$$

$$= \sqrt{8.33^2 + 6.37^2}$$

$$= \underline{\underline{10.5 \text{ Amps}}}$$

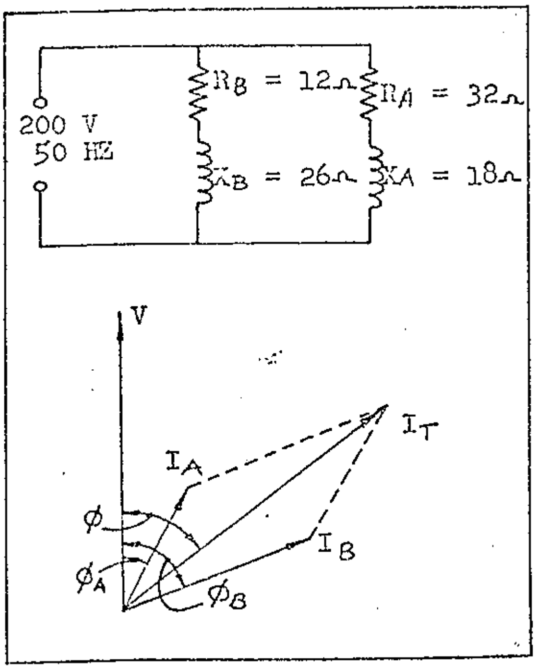
Knowing the total current and voltage, the impedance can be found

$$Z = \frac{V}{I} = \frac{100}{10.5} = \underline{9.52 \text{ ohms}}$$

Note The impedance is less than either the resistance or the reactance.
From phasor:- $\tan \phi = \frac{I_X}{I_R} = \frac{6.37}{8.33} = 0.7467$

$$\phi = 37.4^\circ$$

When each branch contains both resistance and reactance the current in each branch is found separately and the phasor sum of these currents equals the total current drawn from the mains.
Consider the circuit opposite.



In Branch A
the impedance $Z_A = \sqrt{R_A^2 + X_A^2}$

$$= \sqrt{32^2 + 18^2}$$

$$= \underline{36.7 \text{ ohms}}$$

and branch current

$$= \frac{V}{Z_A} = \frac{200}{36.7} = \underline{5.45 \text{ amps}}$$

The phase angle between applied voltage and branch current

$$= \tan \phi_A = \frac{X}{R} = \frac{18}{32} = .5625$$

therefore $\phi_A = \underline{29.4^\circ}$

In Branch B
the impedance $Z = \sqrt{R_B^2 + X_B^2}$

$$= \sqrt{12^2 + 26^2}$$

$$= \underline{28.6 \text{ ohms}}$$

and branch current

$$= \frac{V}{Z_b} = \frac{200}{28.6} = \underline{6.99 \text{ amps}}$$

The phase angle between applied voltage and branch current =

$$\tan \phi_B = \frac{X}{R} = \frac{26}{12} = 2.167$$

therefore $\phi_B = \underline{65.2^\circ}$

The phasor diagram is opposite.
When the graphical method is not suitable the resultant current I_T

can be calculated as follows:-

Determine the power component of I_A and I_B and add them numerically.

Do the same with the reactive components.

Thus:- $I_A \cos \phi_A = 5.45 \cos 29.4$ degrees

and $I_B \cos \phi_B = 6.99 \cos 65.2$ degrees

$= (5.45 \times 0.8712) + (6.99 \times 0.4195)$

$I = \underline{7.68 \text{ amps}}$ (In Phase)

$I_A \sin \phi_A = 5.45 \sin 29.4$ degrees

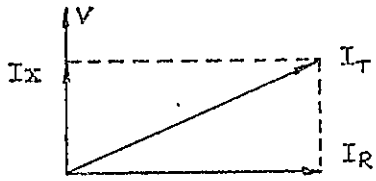
and $I_B \sin \phi_B = 6.99 \sin 65.2$ degrees

$= (5.45 \times 0.4909) + (6.99 \times 0.9078)$

$I_X = \underline{9.02 \text{ amps}}$ (Lagging 90 degrees)

The phasor diagram can now be drawn to scale to give the total current or by Pythagoras theorem

$$I_T = \sqrt{I_R^2 + I_X^2}$$
$$= \sqrt{7.68^2 + 9.02^2}$$
$$= \underline{11.85 \text{ amps}}$$



When solving parallel circuits the following procedure should be used.

1. Draw circuit layout.
2. Treating each branch as a separate series circuit, determine the impedance, current and phase angle of each branch.
3. Determine the power and reactive components of each branch current.
4. Add all the branch current power components.
5. Add all the branch current reactive components.
6. Add, by using phasors the total power and reactive currents to obtain the total current in the network.

<u>Series or Voltage Resonance</u>

Consider the circuit opposite which contains Resistance, Inductance and Capacitance in series.

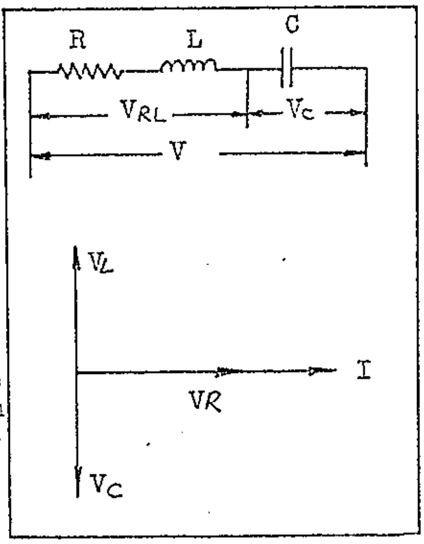
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

If $X_L = X_C$ the Z becomes equal to R and the current is given by $I = \frac{V}{R}$.

The circuit is now said to be in Series or Voltage resonance.

For a given circuit, this condition rises only at one particular frequency called the Resonant Frequency. The current is maximum and is in phase with the applied voltage as the phasor shows.

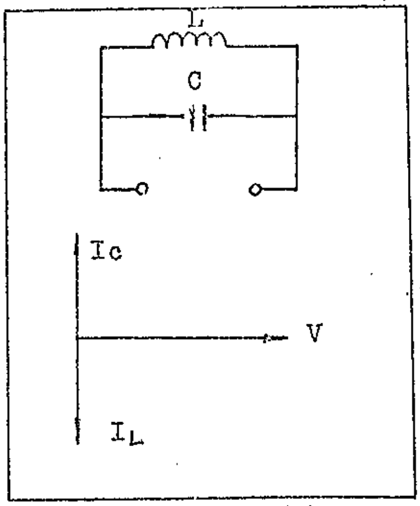
A circuit may be brought into resonance by altering the frequency until $X_L = X_C$ i.e.



$$2\pi f L = \frac{1}{2\pi f C}$$

$$\text{or } (2\pi f)^2 = \frac{1}{LC} \quad \therefore \quad 2\pi f = \frac{1}{\sqrt{LC}}$$

$$\text{Resonant frequency} \quad f = \frac{1}{2\pi\sqrt{LC}}$$



Parallel Resonance

Consider a pure inductor L in parallel with a capacitor C connected to a supply voltage V.

Current taken by inductor, $I_L = \frac{V}{X_L}$ lagging V by 90 degrees.
Current taken by capacitor, $I_C = \frac{V}{X_C}$ leading by 90 degrees.
The current I_T taken from the supply is equal to the difference between I_L and I_C.
If the frequency be gradually raised from zero, I_L will decrease from infinity and I_C will increase from zero. At a certain frequency I_L becomes equal to I_C and then I_T becomes zero. This condition is known as Parallel Resonance. Once again the frequency for this condition is known as resonant frequency.
An oscillating current which may assume large proportions is set up in the local circuit. Energy will surge between the capacitor and the inductor, electromagnetic energy becoming electrostatic energy and vice versa: no energy will be taken from the supply.
In practice, however, some resistance is always present hence these oscillations cannot be maintained without some energy being taken from the supply.

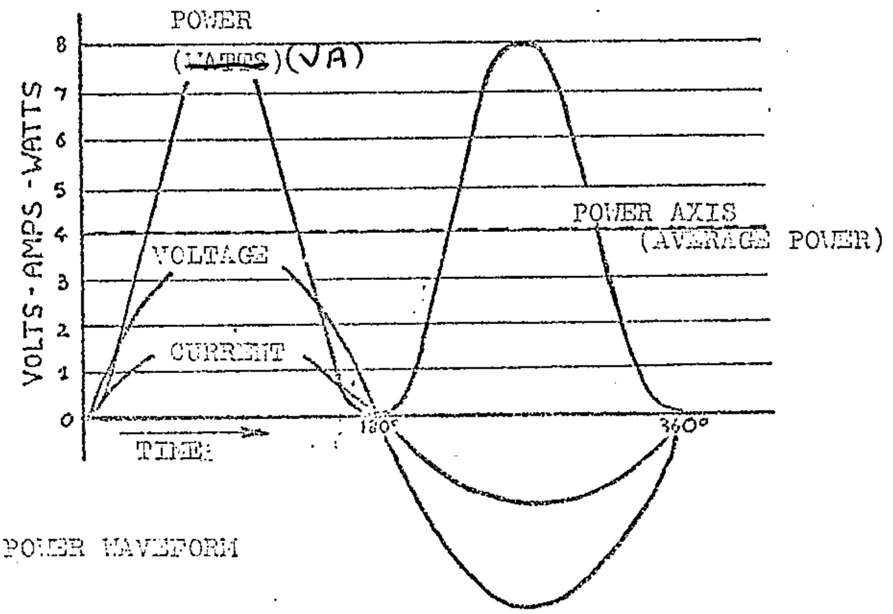
TITLE:- POWER IN A.C. CIRCUITS

LECTURER:

DATE:-

EQUIPMENT:-

The power used in an A.C. circuit is the average of all the instantaneous values of power or heating effect in a complete cycle. Instantaneous values of voltage and current are multiplied together to find the instantaneous values of power, which are then plotted to form a power curve. The average of this curve is the actual power used in the circuit.



A.C. POWER WAVEFORM

For "In phase" current and voltage waves the entire power curve is above the zero axis, (Fig. 1) even when current and voltage are negative since when two negatives are multiplied, the result is always positive. It should also be noted that when the power axis is drawn in, it can be seen that the power wave frequency is twice that of the voltage and current waves.

The power axis represents the average value of power in a resistive circuit, since the areas above the axis are exactly equal in area to those below it. Average power is the actual power used in any A.C. circuit.

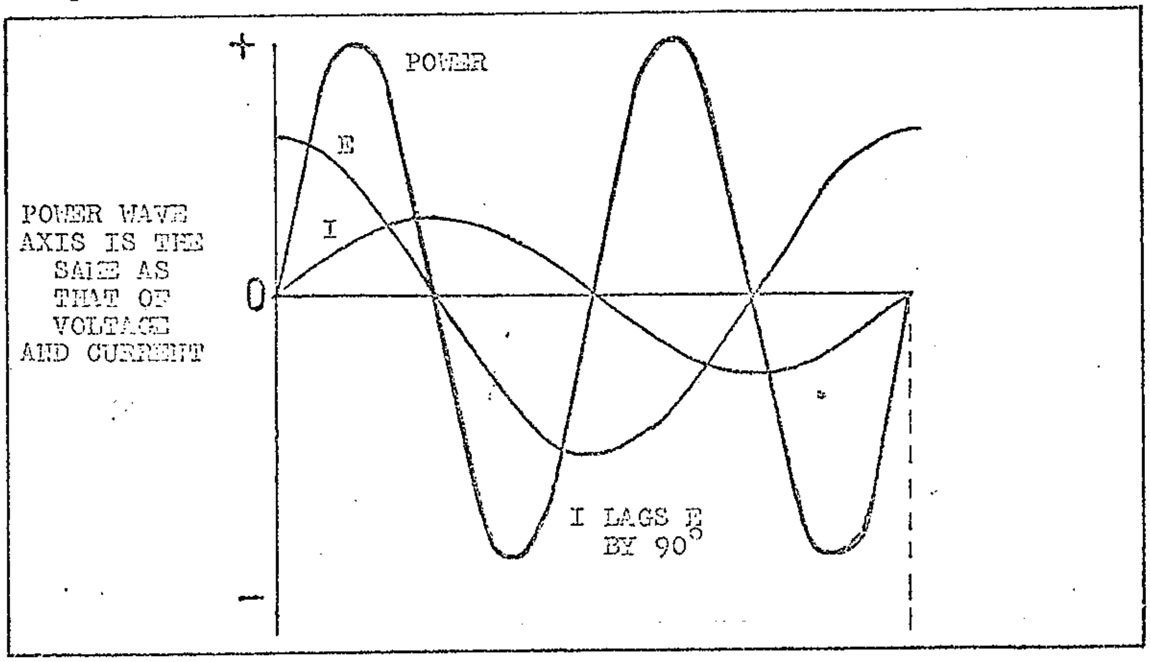
Since all values of power are positive for A.C. circuits consisting only of resistance, the average power for such circuits is equal to exactly one half the maximum, positive instantaneous power value. This value can also be found by multiplying the R.M.S. values of V and I together.
N.B. This rule only applies to A.C. circuits containing all resistance.

The R.M.S. values of V and I are:- $\frac{V_{max}}{\sqrt{2}}$ and $\frac{I_{max}}{\sqrt{2}}$

$$\text{average power} = \frac{E_{max}}{\sqrt{2}} \times \frac{I_{max}}{\sqrt{2}} = \frac{E_{max} \times I_{max}}{2}$$

$$= \frac{\text{Maximum power}}{2}$$

Power in inductive circuits
In a theoretical circuit containing only pure inductance, the current lags the voltage by 90 degrees. The power curve is found in the same way as for the purely resistive circuit, using instantaneous values of voltage and currents.
As was shown, the power curve for "in phase" voltages and currents is entirely above the zero axis since all the multiplications of instantaneous values gave positive answers. When a negative number is multiplied by a positive number, however, the result is a negative number. Thus, in calculating instantaneous values of power when the current and voltage are 90 degrees out of phase with each other, half the instantaneous values of power are positive and half are negative, as shown in Fig. 2. In such a circuit, the voltage and current axis is also the power wave axis, and the frequency of the power wave is twice that of the current and voltage waves.



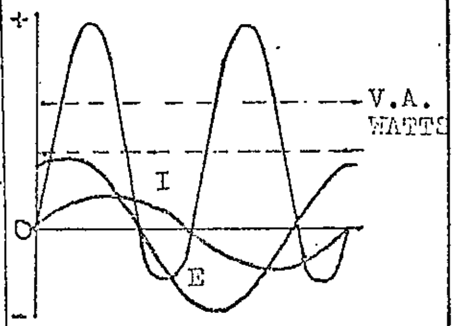
That portion of a power wave which is above the zero axis is called "positive power" and that which is below the axis is called "negative power".
In the case of a pure inductive circuit, the positive power furnished to the circuit causes a field to build up. When this collapses, it returns an equal amount of negative power to the power source. Since no power is used for heat or light in a circuit containing pure inductance (if such a circuit was possible) no actual power will be used even though the current flow is large.

Power Factor
When current and voltage are in phase, the product of their R.M.S. values is power in watts, as in D.C. circuits. If current and voltage are not in phase, the produce of their R.M.S. values is known as "volt-amps". The true power in watts then becomes I^2R or $\frac{E^2}{R}$, i.e. Power used in the resistive part of the circuit.

N.B. It is quite possible for a source to be producing many volt-amps while the true power dissipation of the circuit in watts, remains quite small. The ratio of true power to volt-amps of a circuit is called power factor.
In a pure resistive circuit, power in watts is equal to the product of the R.M.S. values of voltage and current so the power factor is unity (one).
When the power factor is less than unity it is expressed as a decimal. Any practical inductive circuit contains resistance and the phase angle is always less than 90 degrees. For phase angles of

less than 90 degrees, the amount of positive power always exceeds the amount of negative power, the difference between the two representing the actual power used in overcoming the circuit resistance. For example, if the circuit contains equal amounts of inductive reactance and resistance, the phase angle is 45 degrees and the positive power exceeds the negative power as shown in Fig. 3.

When apparent power is divided into true power, the resultant decimal is the Power factor i.e. $P.F. = \frac{I^2R}{\text{Volt-amps}}$.



VA - APPARENT POWER (EXI)

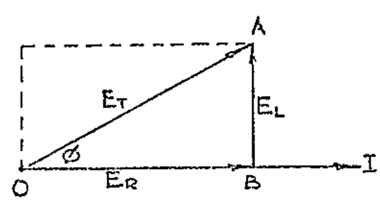
WATTS - TRUE POWER (I^2R)

The difference between apparent power and true power is sometimes called "wattless power" since it does not produce heat or light but does require a current flow in a circuit.

It can be seen that the current lags the voltage in an inductive circuit from the waveform diagrams, therefore inductive circuits are said to have a lagging power factor.

Consider the phasor diagram for the voltages in an R and L, A.C. series circuit.

It can be seen from Fig. 4 that E_R is the component of Et which is in phase with the current, and E_L is the component of Et which is 90 degrees out of phase with the current.



From the definitions of true power and apparent power: True power = $E_R I$

Apparent power = $E_t I$

$$\text{Power Factor} = \frac{\text{True Power}}{\text{Apparent Power}} = \frac{E_R I}{E_t I}$$

If top and bottom are both now divided by I

$$\text{Power Factor} = \frac{E_R}{E_T}$$

This ratio is the cosine of angle A.O.B. which is the phase angle.

So <u>power factor = Cos Ø</u>

Then true power (P) = Apparent power x Power factor

<u>P = EI cos Ø</u>

And since the voltage phasor has its sides in proportion to an impedance triangle for the same circuit, cos Ø also equals $\frac{R}{Z}$.

Consider the following example:

A 40 watt fluorescent tube in conjunction with its inductive ballast is connected to a 240V 50 HZ supply, the current being 0.4 amps and a wattmeter indicating 48 watts. Determine the Power Factor.

$$\text{Power Factor} = \cos Ø = \frac{\text{Watts}}{\text{Volt Amps}} = \frac{48}{240 \times 0.4} = \underline{0.5}$$

This power factor is low and it should be noted that the 48 watts could have been produced by 0.2 amps if the current had been in phase with the voltage.

To improve poor power factor is a vital requirement in the application of electricity to industry throughout the world.

It can be considered as a measure of calculating that portion of the current which is converted into useful work or power by a particular machine. The nearer the power factor approaches unity, the greater does this proportion become.

Apart from the loss of useful power which accompanies a low power factor, there are many other serious disadvantages among which are:-

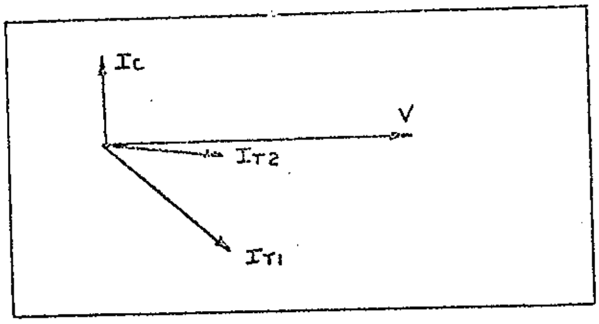
1. Increased power losses in the transmission system due to heavier currents.
2. Larger cables necessary to deal with heavier current without exceeding permissable voltage drop.
3. Control equipment etc. must be able to handle heavier current.
4. Increased size of generating plant necessary.
5. Extra fuel required in generating station because of increased losses.

Low power factor can be directly attributed to certain types of apparatus, among which are:-

(a) Induction motors
(b) Transformers
(c) A.C. welders
(d) Induction furnaces
(e) Vapour lighting.

In all these cases, a portion of the current is necessary to create a magnetic field and thus is not converted to useful power.

Power Factor Correction:- To counteract the large amount of "watt-less power" present when power factor is low, capacitors are placed in parallel with the individual loads. The current leads by 90 degrees in a purely capacitive circuit and with careful choice, the capacitor can bring the current close to unity power factor. In Fig. 5. the current I_{T1} lags by approx. 45° before insertion of capacitor in the circuit. With the capacitor in circuit however, the resultant I_{T2} shows a marked improvement in power factor is achieved.



Another method, usually used on a much larger scale, is to connect lightly loaded synchronous motors in parallel with suitable sections of the load. This has a similar effect to the capacitor but has the advantage that with this system it is possible to maintain the power factor at any required value within normal limits for all load conditions by adjusting the value of D.C. excitation.

Power in 3 phase circuits

Let I. be the current in the line
V. be the voltage between each pair of conductors
i,e, be the current and voltage respectively of each individual branch load.

First consider a non-inductive load.

The power given to each branch load circuit is i,e watts. Since there are three such branch circuits, the total power transmitted by the line to the branch circuits is 3 i.e. watts.

In the star connection $i = I$ and $e = \frac{E}{\sqrt{3}}$, hence in this case total

power $= 3i.e. = 3I\frac{E}{\sqrt{3}} = \underline{\sqrt{3}IE}$

In the delta connected system $i = \frac{I}{\sqrt{3}}$ and $E = e$, consequently

power of system $= 3i.e. = 3\frac{I}{\sqrt{3}}E = \underline{\sqrt{3}IE}$

Thus in either case the power is the same and equal to 3IE watts.

If the load is partly inductive the phase current and voltage will not be in phase with each other. In this case the power in each branch circuit will be e.i. cos Ø instead of i.e. watts. If the angle of lag in all the branch circuits is the same, the expression for the power in the line becomes

$$\text{Power} = 3\ \text{i.e.}\ \cos\phi \quad \text{or} \quad 3IE\cos\phi$$

which is the general expression for the power transmitted by a 3 phase line with equal loading on all phases i.e. a balanced load.

It is most important to remember that Ø is the phase angle between current and voltage in the branch circuits, and not between line current and line voltage. Also, the power factor of a 3 phase balanced circuit is the power factor of the three loads supplied.

TITLE:- RECTIFICATION

LECTURER:-

DATE:-

EQUIPMENT:-

Rectification means changing alternating current to direct current. Some equipment, both electrical and electronic, require D.C. for their operation, and since most power is supplied as an A.C. it has to be rectified before being fed to such equipment.
Rectifiers are devices which allow current to flow through them in one direction only, i.e. they act as an insulator against current flow in the other direction. Consequently, the current flow in a simple rectifier circuit is pulsating d.c. derived from the positive half cycles of A.C. rather than a steady d.c. current flow.

RECTIFIER TYPES

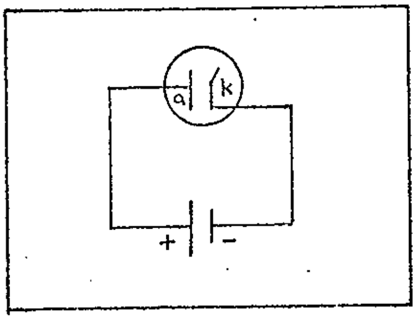
(1) Metal Rectifiers:- Largely replaced by more modern types, these can still, however, be found in use. They are generally made in the form of washers which are assembled on a mounting bolt in any desired series or parallel combination to form a rectifier unit. They are constructed by pressing certain metallic materials together to form a junction.
The combinations most often used are (1) copper and copper oxide and (2) cadmium alloy (or tin) and selenium.
Copper oxide rectifiers consist of discs of copper, coated on one side with a layer of copper oxide; and selenium rectifiers are constructed of discs made of metal (nickel, iron or aluminium) coated on one side with selenium, on top of which has been deposited a surface electrode in the form of a layer of cadmium alloy or tin.
No metal rectifier will stand more than a few volts across its terminals but by stacking in series, the voltage rating can be increased.
Similarly, no element can pass more than a limited amount of current. When greater current is required, several stacks are connected in parallel.

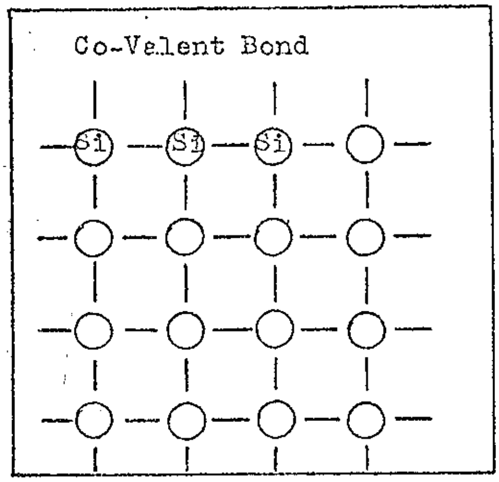
(2) Diode valves:- A diode valve is a glass tube, in which is placed two electrodes (anode and cathode) and a heating element, then the air is evacuated, leaving a partial vacuum.
Cathode - made of nickel with an oxide coating, to emit electrons freely.
Anode - the anode surrounds the cathode and is made of nickel plated steel.

OPERATION

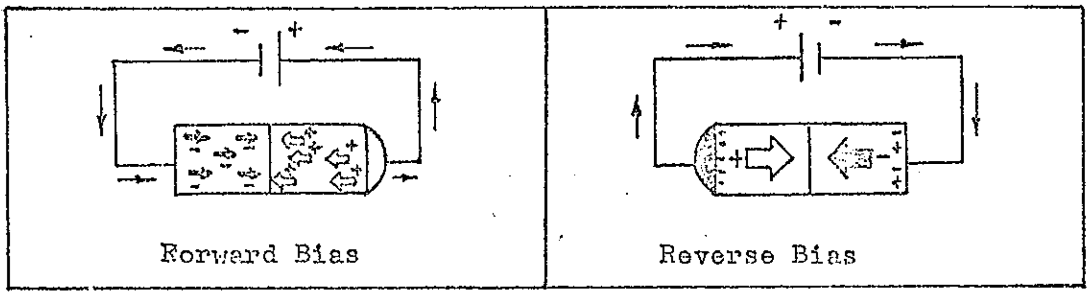
When the cathode is heated sufficiently, its electrons become excited and their velocity increases until they leave the parent body. Increased heat will form an electron "cloud", if a battery is now connected between anode and cathode with anode negative, the electrons are repelled back to the cathode. Reversal of polarity, will now encourage electrons to flow from the cathode to anode, while other electrons flow from battery to cathode.

Diode When silicon is "doped" with other materials which are either tri-valent or penta-valent, it forms either a positive (P) type material or an negative (N) type material respectively. The P type material is capable of accepting electrons and the N type material is capable of giving electrons up.



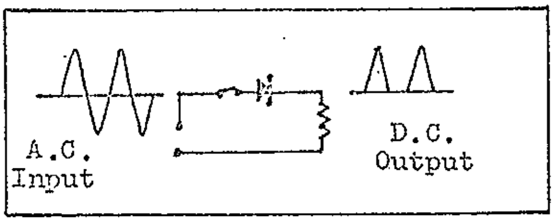


If a junction is formed of these two materials and a voltage applied to it with the N type material connected to +Ve and the P type material connected to -Ve, no current will flow due to the attraction - repulsion effect set up when a P.D is applied to a P.N junction. If, however, the P.D is reversed, current flows since the charged particles will attract and combine in the P.N junction. A diode, therefore, only allows current flow in one direction.



Symbol. Since rectifiers were being made before the electron theory was used to determine the direction of current flow, the arrow points in the direction of conventional current flow (+Ve to -Ve), this is in the opposite direction to electron flow. Thus the arrow points in the opposite direction to that of the current flow used in electronics:

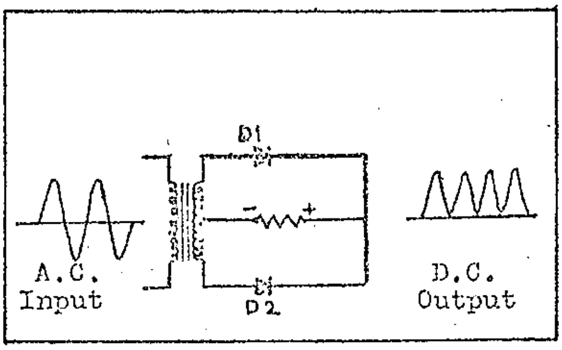
RECTIFIER CIRCUITS: The simplest form of rectifier circuit is called half wave. When the top half of the transformer becomes positive, the diode will conduct and current will flow for half a cycle through the load. When the polarity changes, (next half cycle), the diode blocks and no current flows.



Advantages (1) Cheap - uses only one diode.
(2) Does not require a centre tapped transformer.

Disadvantages (1) Not very good D.C. produced.
(2) Not very efficient - half wave not used.
(3) Diode has full supply voltage in both directions.

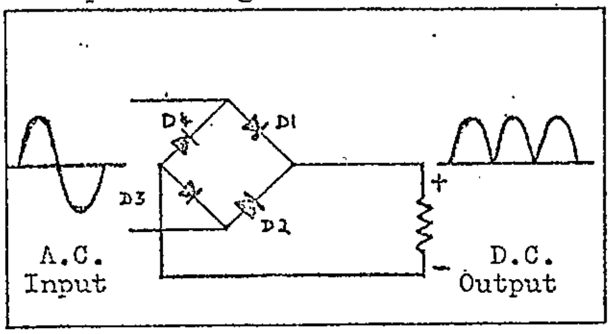
To overcome most disadvantages, the full wave rectifier is used. When the top side of the transformer is positive D1 conducts and current flows through the load as shown. When the next half cycle occurs, the polarities reverse and D2 conducts, and D1 blocks. Current flows again in same direction through load.



<u>Advantages</u> (1) Purer D.C. produced.
(2) No wasted power (both half cycles used).

<u>Disadvantages</u> (1) Centred tapped transformer needed, so twice supply voltage at terminals needed.
(2) Uses two diodes.

<u>Full wave bridge</u> - This commonly used type eliminates the need for a centre tapped transformer, yet still produces good D.C.

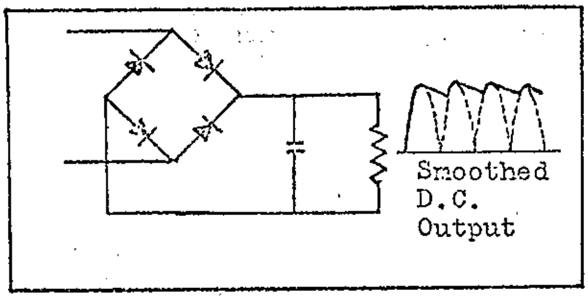


When the top of the transformer is positive, D1 conducts and D4 blocks, as does D2, so current flows through the load to the junction of D4 and D3, it flows through D3, because if it went through D4, it would be going back to the same potential. It will not flow through D2 for the same reason. When polarities are reversed, current flows through D2, while D3 and D1 block. Current then flows through the load in the same direction, until it reaches junction of D4 and D3. Current will flow through D4 because it is at a higher potential, then back through the transformer.

<u>Advantages</u> (1) No centre tapped transformer needed.
(2) Good D.C. produced.
(3) Efficient - all of cycle used.
(4) Diodes in series can be half rated supply voltage.

<u>Disadvantage</u> Cost - uses four diodes.

<u>Filtering (Smoothing)</u> The output from the rectifiers mentioned is a pulsating D.C. This is undesirable, especially in some electronic circuits. The filtering circuit smoothes out the ripples to give a steadier D.C. output.
The simplest way to give a smoothing effect is to connect a capacitor across the output.



<u>Operation</u> As the output voltage is rising, and current flowing through the load, the capacitor is being charged. After the peak is reached and the voltage starts falling away, the capacitor discharges across the load so that the voltage across the load does not fall to zero. As the capacitor is discharging, the next half cycle of voltage rises again and once again starts charging the capacitor as well as supplying the load.

TITLE: ELECTROMAGNETISM - PRODUCTION OF A MAGNETIC FIELD

LECTURER: SHANE / ALAN

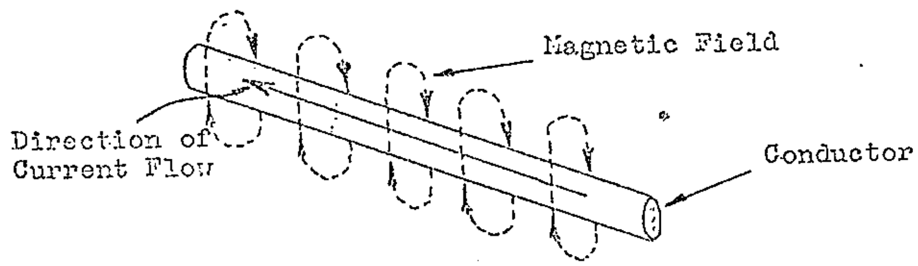
DATE: 13/7/81

EQUIPMENT:

Introduction - from previous study on Electron Theory, it is known that electric current is due to the movement of electrons in a conductor and that this current is always accompanied by a magnetic field, due to "electron spins" (similar to the Earth orbiting about the Sun and spinning on its own axis). It is reasonable to assume then, that any electron in motion will create a magnetic field, due to its motion. Thus, all matter possesses magnetic forces to some degree, because all matter is made up of atoms, which have one or more electrons in motion around their nucleus.

Magnetic Field due to Current Carrying Conductor.

A conductor carrying current is surrounded all along its length by a magnetic field, the lines of magnetic flux being concentric circles in planes at right angles to the conductor. (Magnetic lines of force are imaginary and cannot be seen.)



MAGNETIC FIELD - CURRENT CARRYING CONDUCTORS

The direction of the magnetic field can be found from either of the following 2 rules:-

(1) Right Hand Rule - place the outstretched right thumb along the conductor in the direction of the current flow, with the fingers wrapped around the conductor. The fingers point in the direction in which the magnetic field is acting round the conductor.

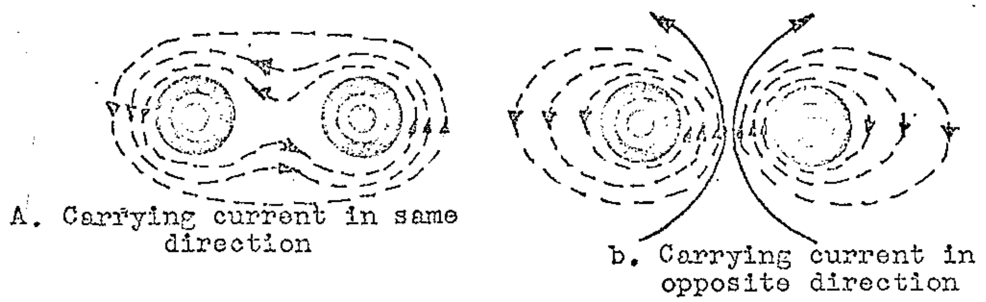
(2) Corkscrew Rule - the direction of the magnetic field is the direction of rotation of a corkscrew turned so as to advance along the wire in the direction of the current.

By experimentation, the following facts can be verified:-

(a) No magnetic effect is produced by two conductors laid side by side and carrying the same current in opposite directions;

(b) The magnetic effect produced by two conductors laid side by side and carrying the same current in the same direction is twice the magnetic effect due to one such conductor alone;

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



FLUX DUE TO TWO STRAIGHT CONDUCTORS

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

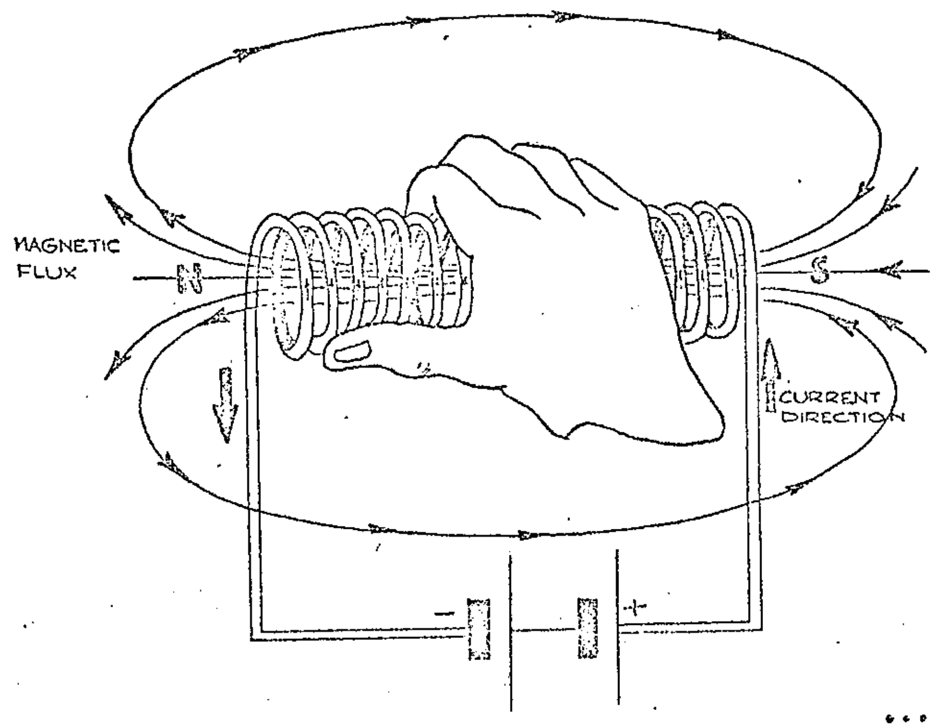
(1) Increase the current

(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.



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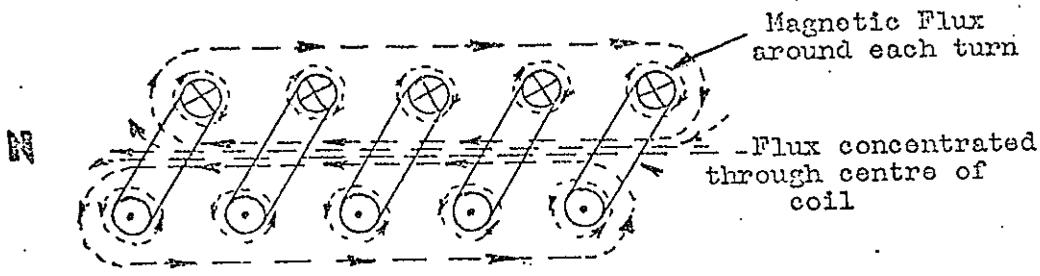
RIGHT-HAND RULE FOR SOLENOIDS



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

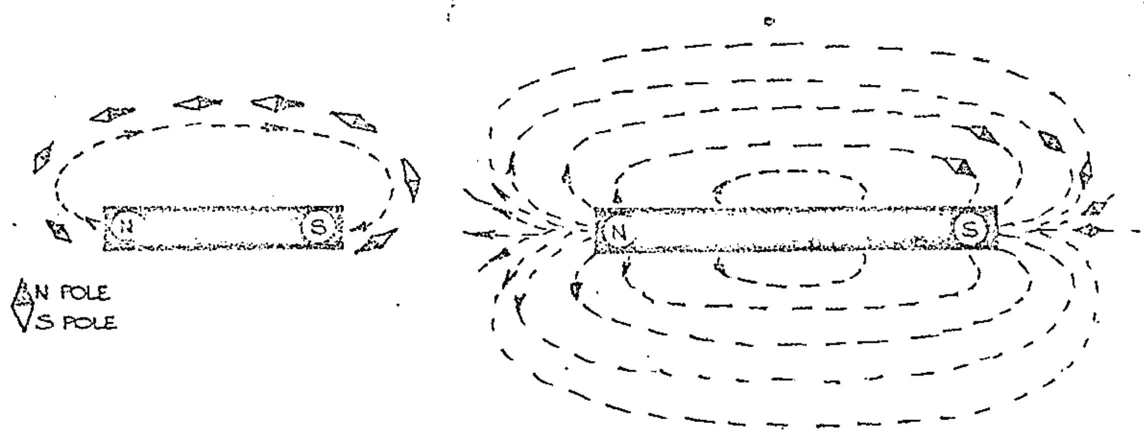
EQUIPMENT:

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

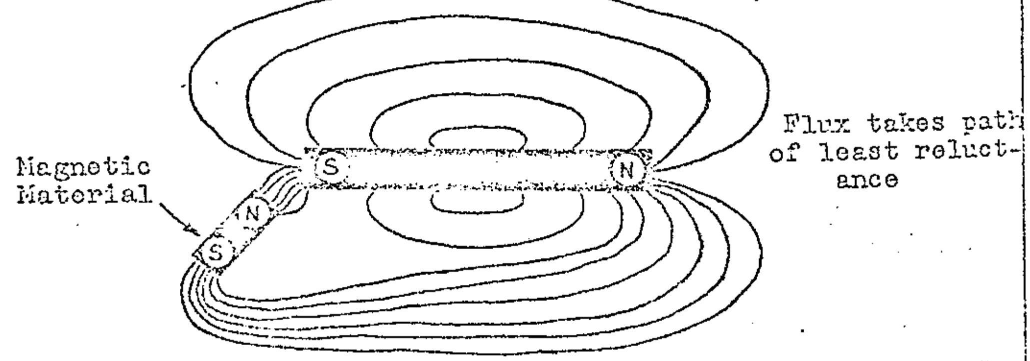
Magnetic Field - the region, or space, surrounding a magnet and, where magnetic forces can be detected, is called the magnetic field. A simple experiment with a bar magnet and iron filings will show the formation and extent of a magnetic field.

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

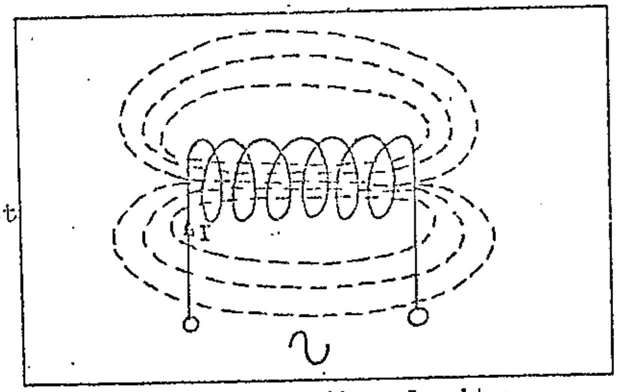
It has been determined from previous lectures that a current "flowing" in a conductor produces a magnetic field around that conductor. It is also a fact that a conductor passing through a magnetic field has an e.m.f. induced in it as it "cuts" the lines of force.

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.

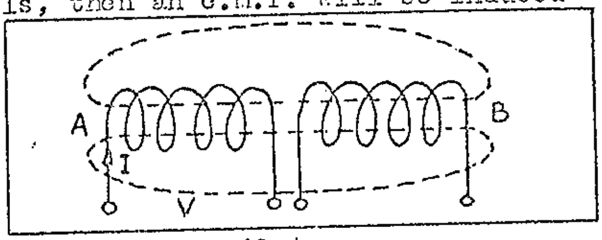
$$I = \frac{V - Eb}{R} = \frac{100 - 80}{10} = 2 \text{ Amps.}$$

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.

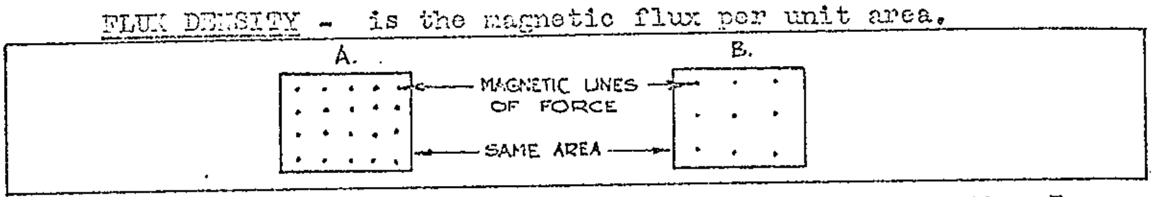
The e.m.f. in coil A being produced by self induction and the e.m.f. in coil B being produced by MUTUAL INDUCTION because the lines of force are common or MUTUAL to both coils.

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

TITLE: MAGNETIC TERMS & RELATIONSHIPS
LECTURER: DAK, Haysey, 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.

$B = \frac{\emptyset}{a}$ 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 - $\text{Reluctance (S)} = \dfrac{\text{Length (L)}}{\text{Area(a) x Permeability } (\mu)}$

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 $S = \dfrac{800,000 \times L}{\mu_R \times a}$

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

i.e. Flux (ϕ) 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 $\phi = \frac{NI}{S}$

<u>MAGNETISING FORCE</u> - 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.

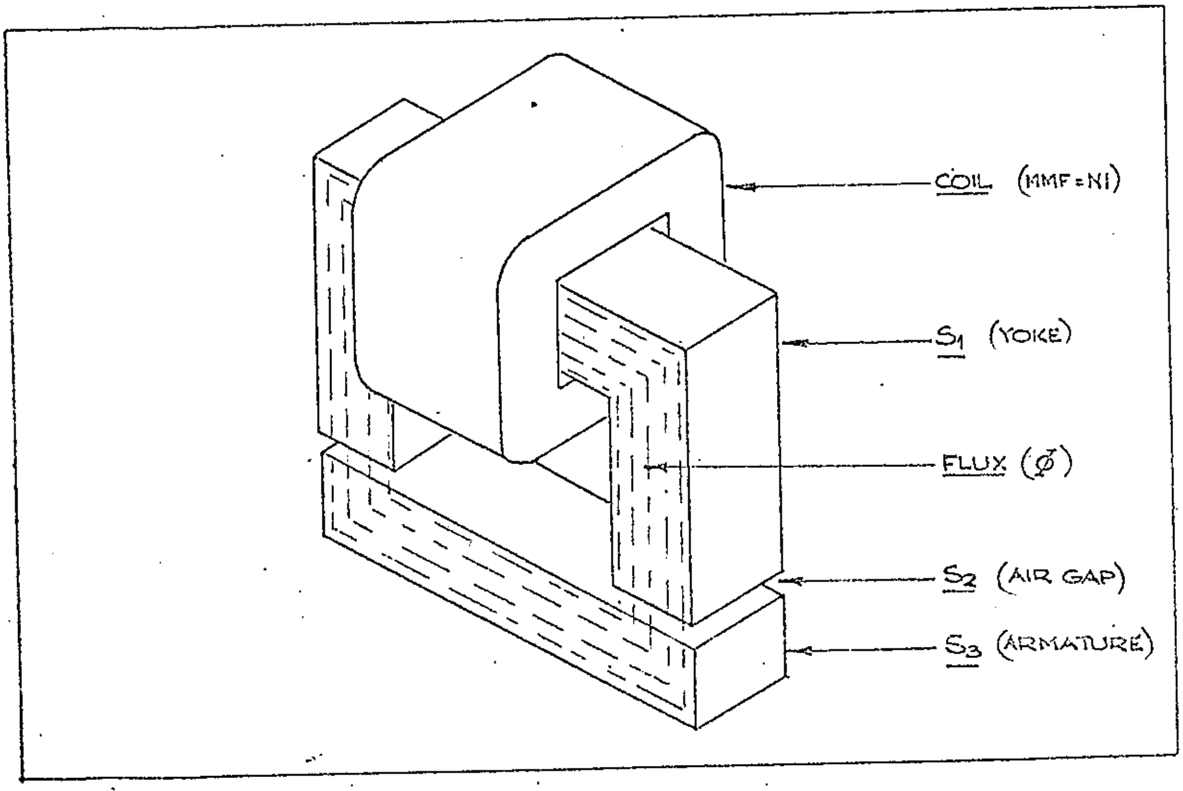
Magnetising force can be compared with Voltage Drop in an electrical circuit.

<u>MAGNETIC CIRCUITS</u> - 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.

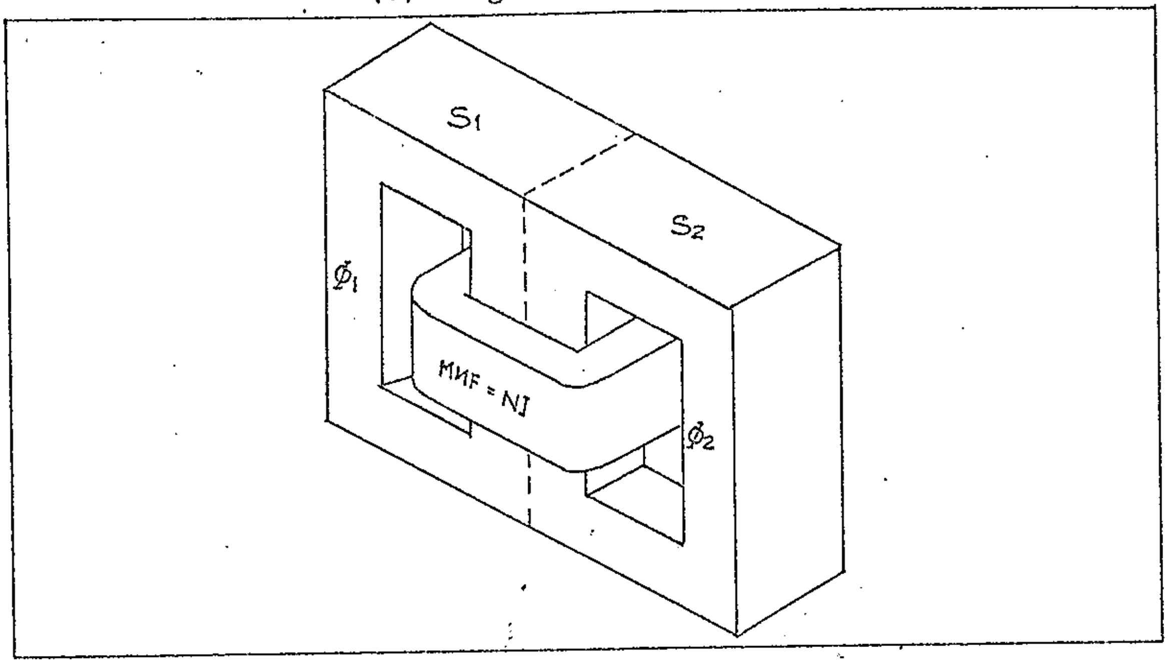
i.e. <u>Series</u> - (a) Total Reluctance $S_T = S_1 + S_2 + S_3 .....$
(b) Flux ϕ remains constant in the iron circuit.
(c) Magneto-Motive Force $NI_T = NI_1 + NI_2 + NI_3 ..$



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

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

(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 S_T

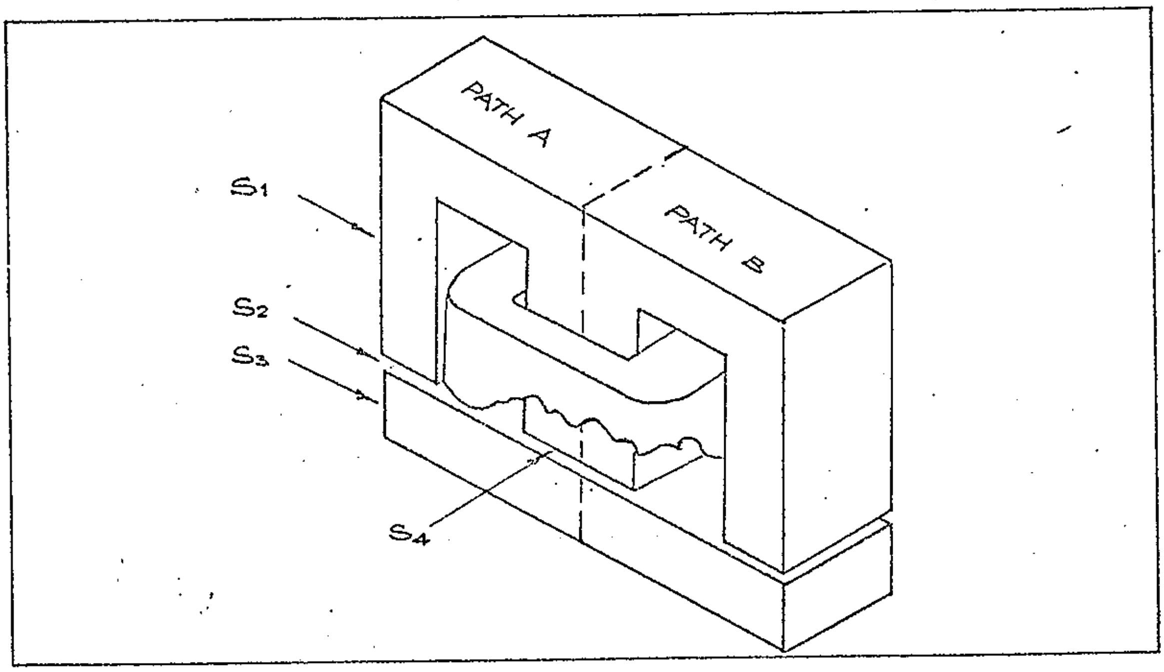
$\frac{1}{S_T} = \frac{1}{S_a} + \frac{1}{S_b}$

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.

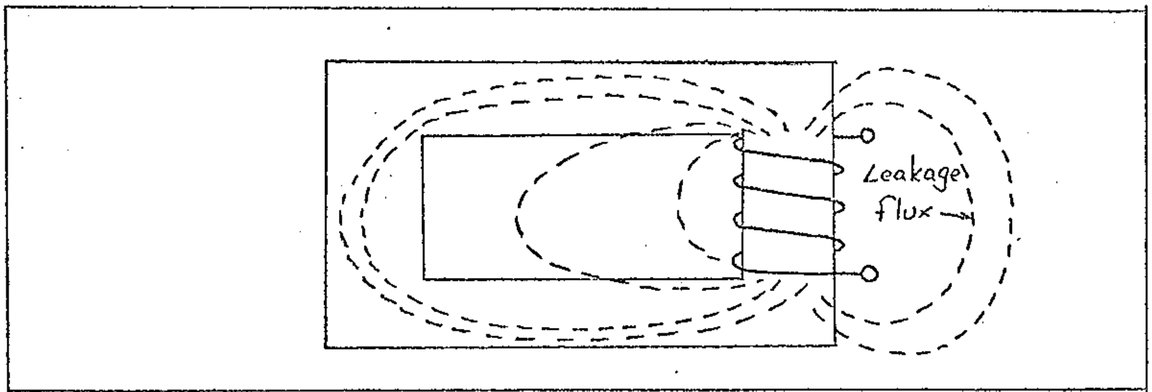
It is seen that the combined magnetisation curves form a closed loop - the Hysteresis Loop for ferro-magnetic material.

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.

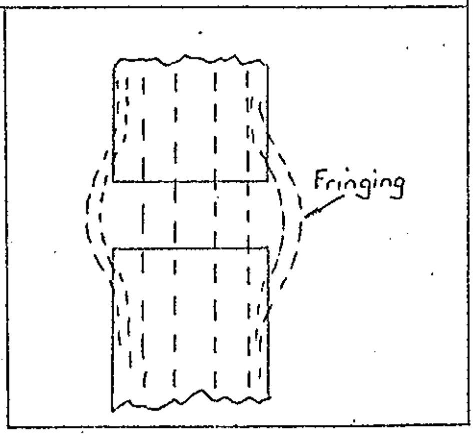
MAGNETIC LEAKAGE:

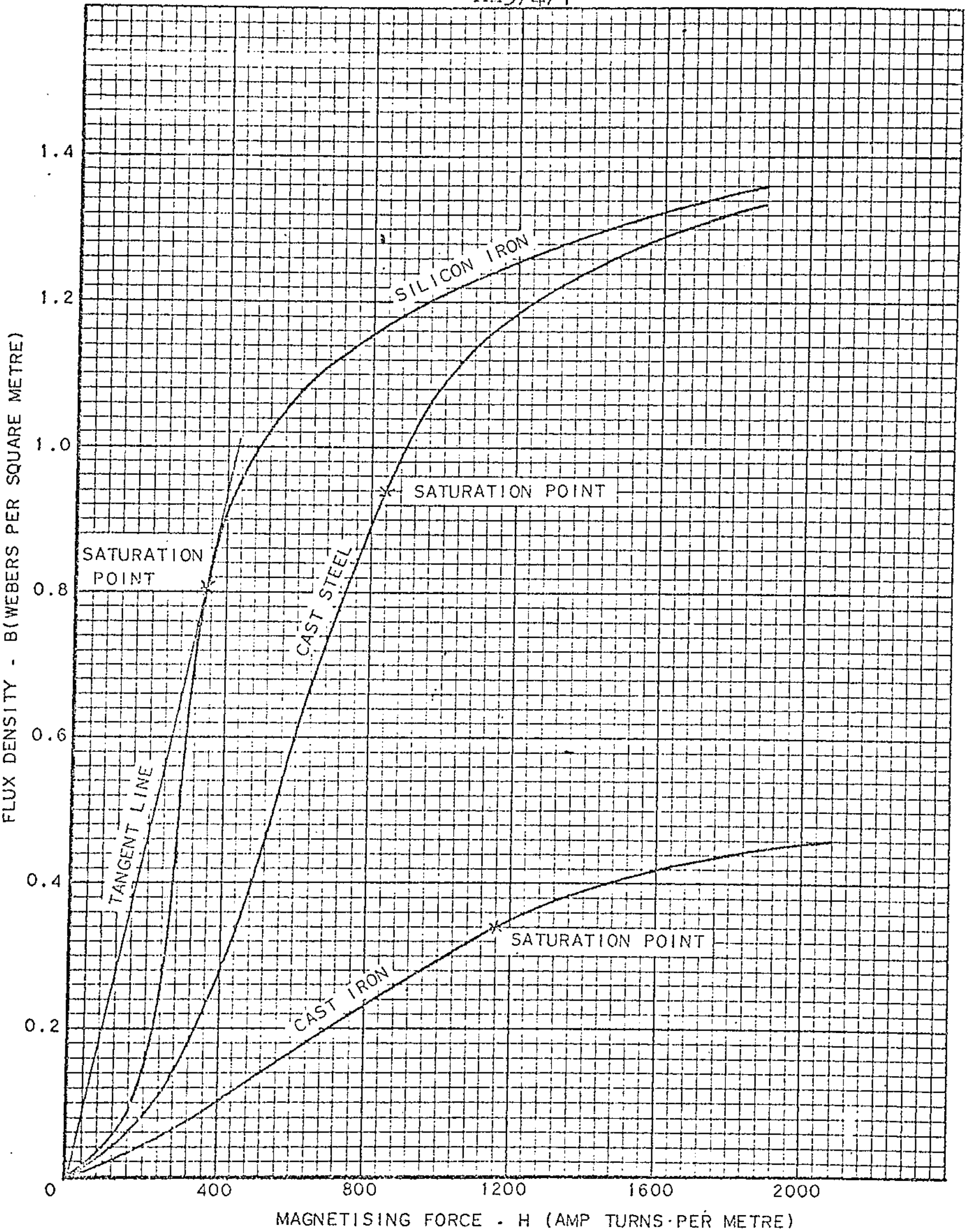
In many practical magnetic circuits it is desirable to have the maximum value of flux across a certain section of the circuit. However, the total flux produced by the source of M.M.F. (magneto-motive force) does not reach the air gap because a portion of it leaves the iron core and returns through the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



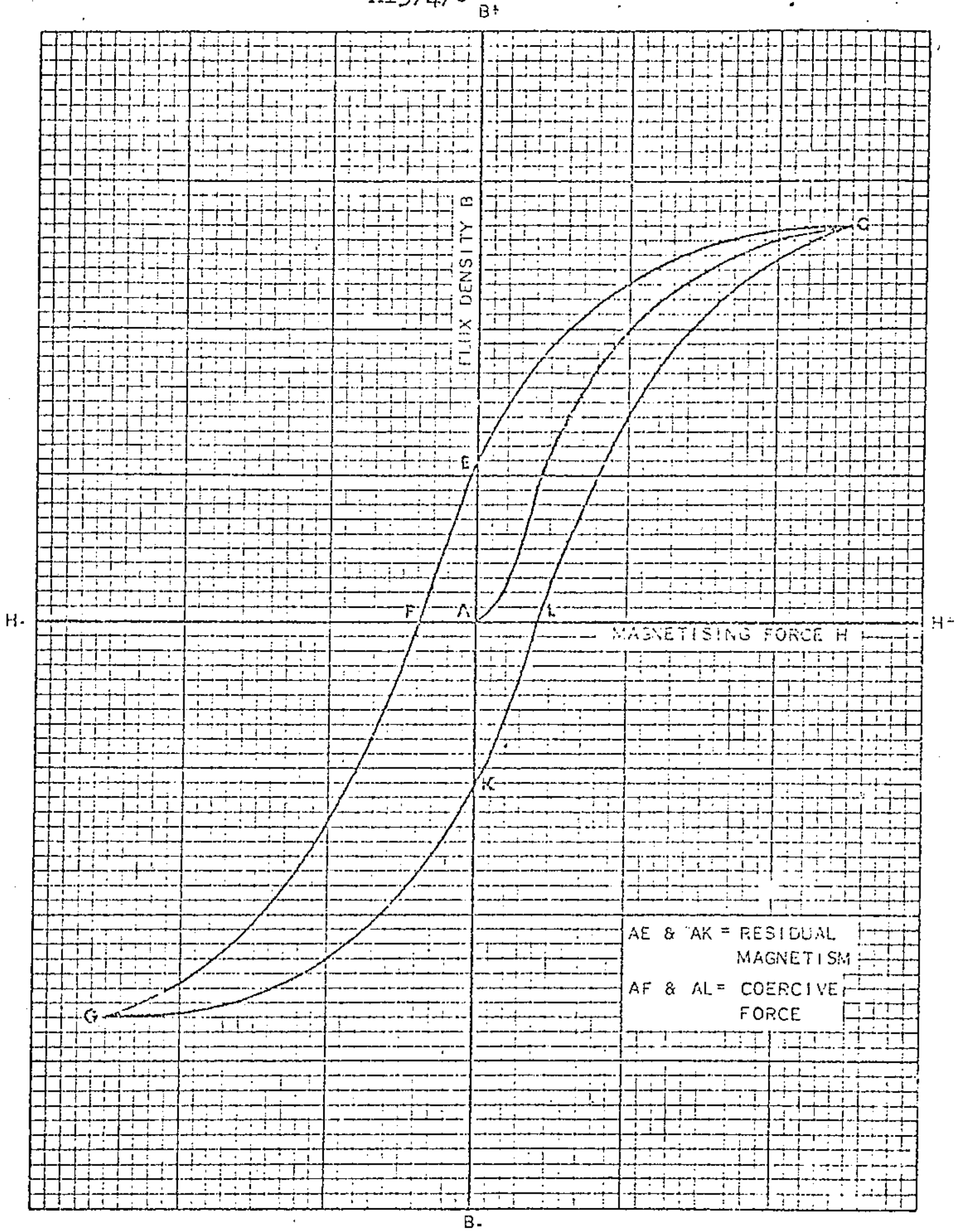
MAGNETIC FRINGING

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.

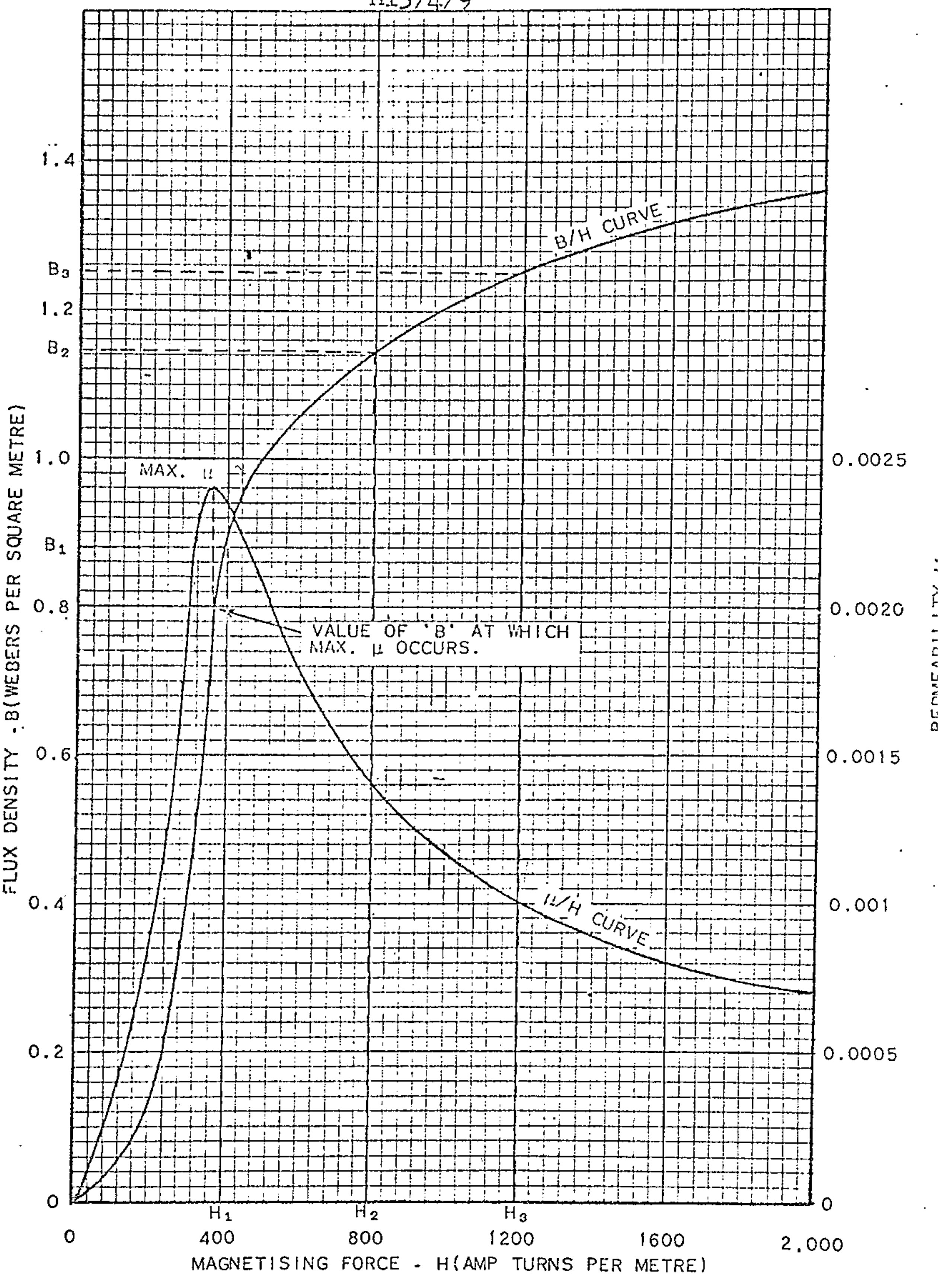




COMPARISON OF B-H CURVES FOR FERRO-MAGNETIC MATERIALS



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

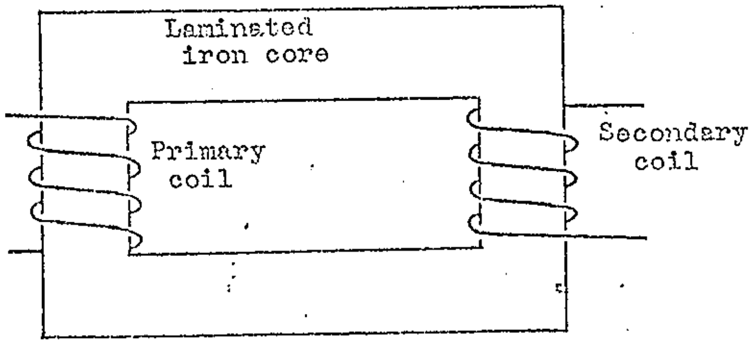
LECTURER:-

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 Ep (back emf) is almost equal to Vp (applied voltage) and Es = Vs (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:-

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

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

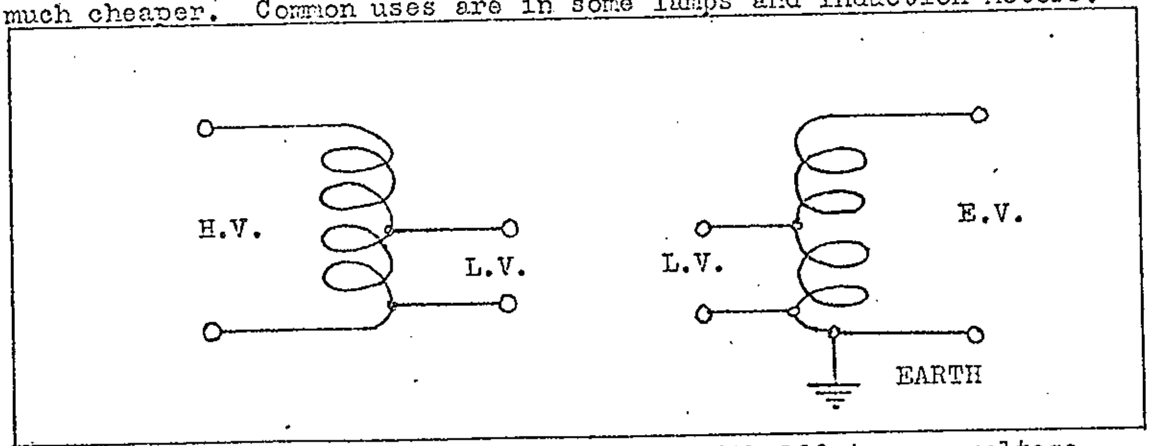
$$\text{Turns Secondary} = \left(\frac{\text{Primary Turns - Secondary V}}{\text{Primary V}}\right) \times 1.05 \text{ (5\% V drop)}$$

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

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.

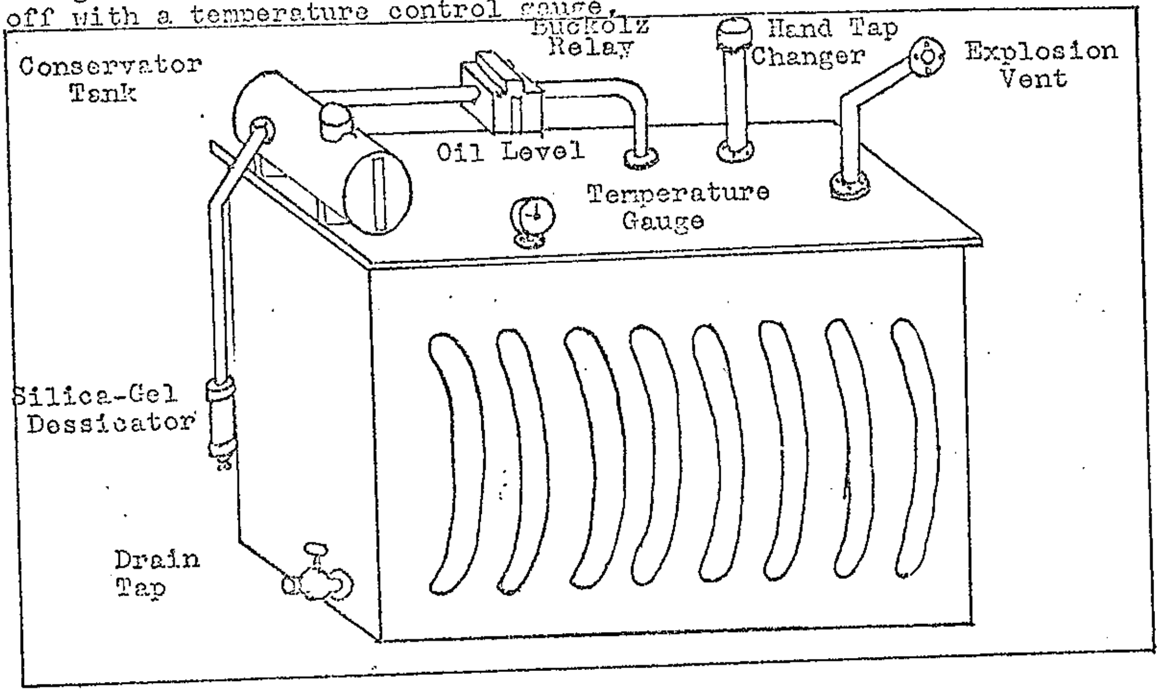


Operation - If 100V is applied to a coil with 100 turns, voltage drop will equal 1 volt/turn. Therefore, if the secondary is connected across half the winding it will have a voltage equal to half the primary back e.m.f. and 180° out of phase with the applied Primary e.m.f. As the primary and secondary 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.

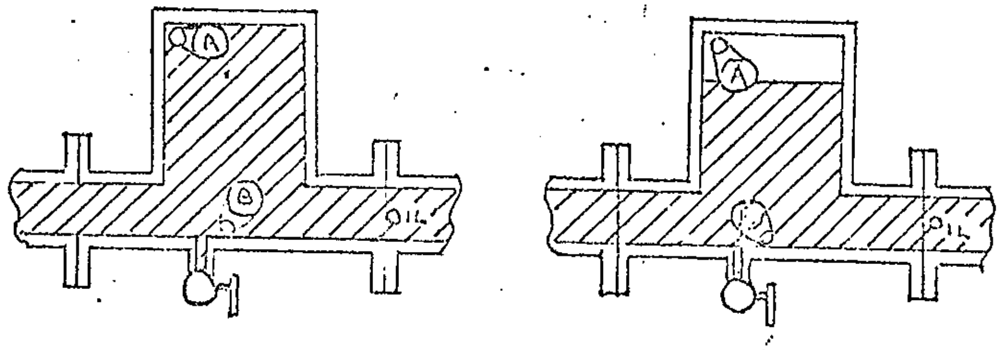
Temperature Gauge

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.

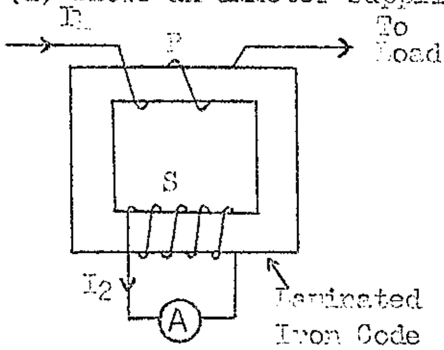


Fig. A. A Current Transformer

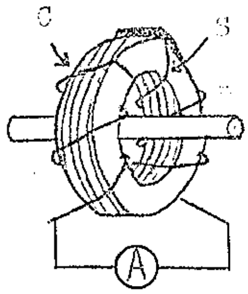


Fig. B. A Bar Primary Current Transformer

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:

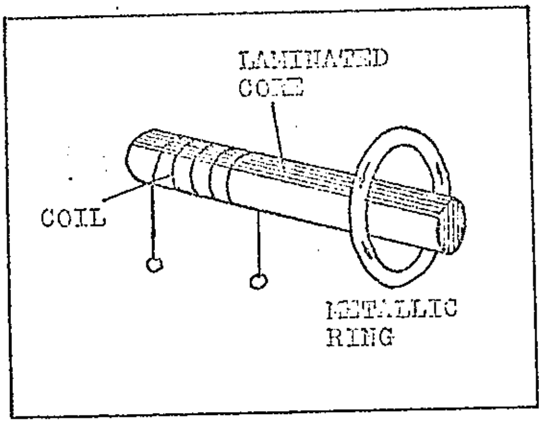
Although in most cases as with transformers, motors, contactors, relays etc., the effects of eddy currents are a nuisance which must be overcome by laminating the iron circuits, there are some areas where use is made of the heating effect of these eddy currents.

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.



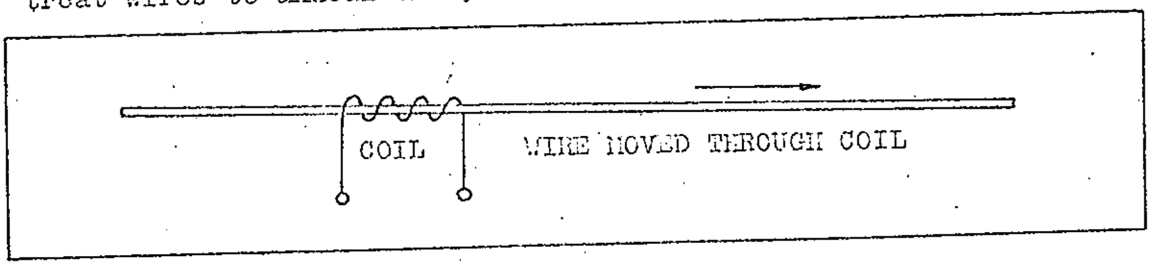
It can be seen in the diagram that the current flowing in the ring is at right angles to the lines of flux which are being produced by the coil. Measurement of this current is possible by using a Tong-Test Ammeter.

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.

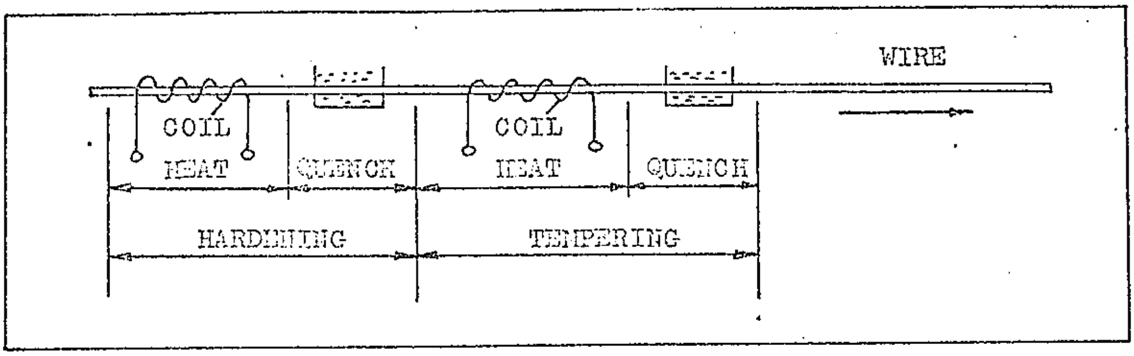
A practical application of the above arrangement would be a bearing heater where a bearing race is positioned in place of the ring.

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.

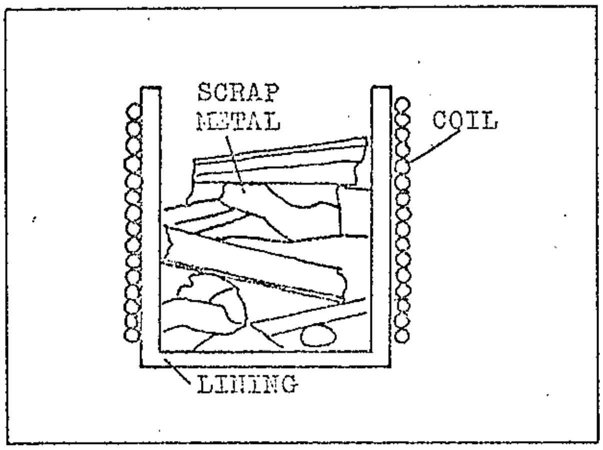
If the core were removed and a steel wire was fed through the coil, then it would heat the wire. This method is used to heat treat wires to anneal them, or harden them.



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:-

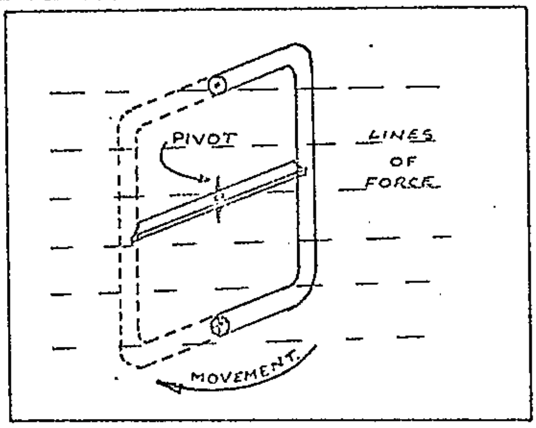
DATE:-

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.

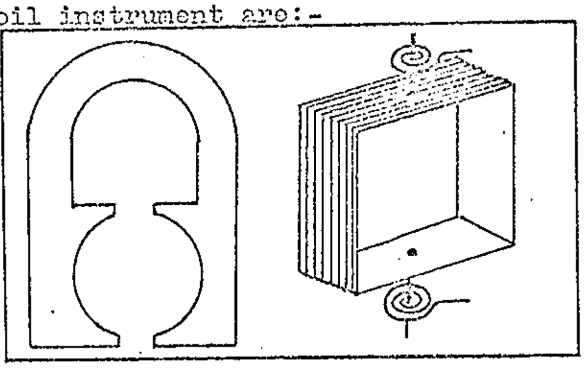
There are three main types, 1. Moving coil, 2. Moving iron, 3. Dynamometer. Other types are made for special purposes but will not be encountered in most electrical installations.

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:-

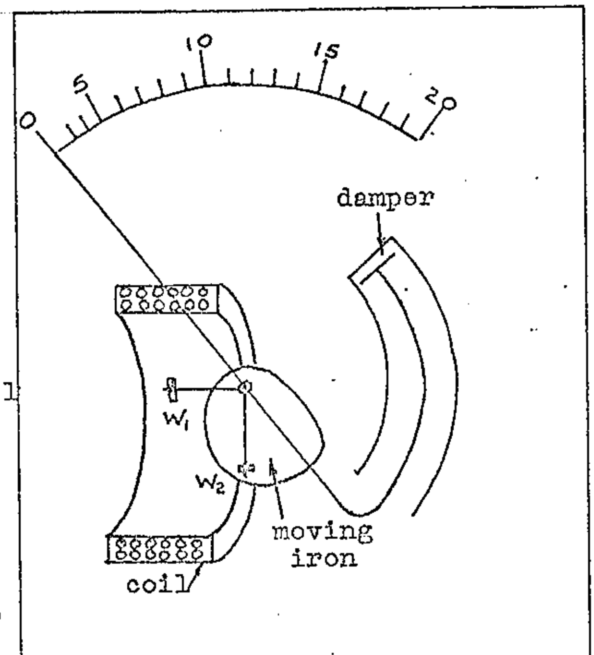


1. A permanent magnet with shaped pole pieces to provide a narrow air gap.
2. A rectangular shaped coil fitted with pivots and return or control springs.
The springs serve two purposes, i.e. to carry the current to and from the coil, and to cause the coil to return to its original position when there 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.

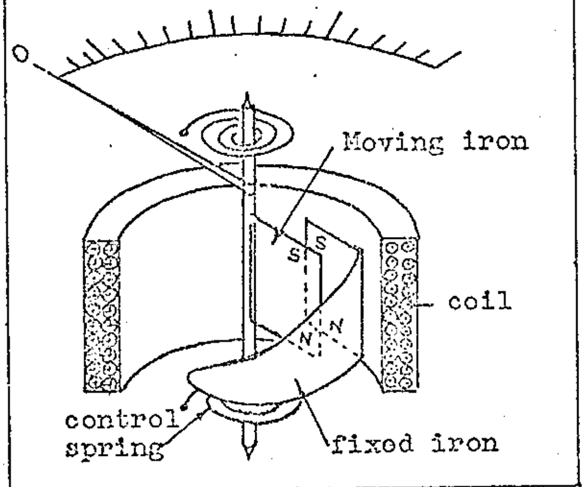
Moving Iron

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.

The damper is used to prevent oscillations caused by the control weights acting like a pendulum.
This type of movement produces a scale which is NON-UNIFORM.

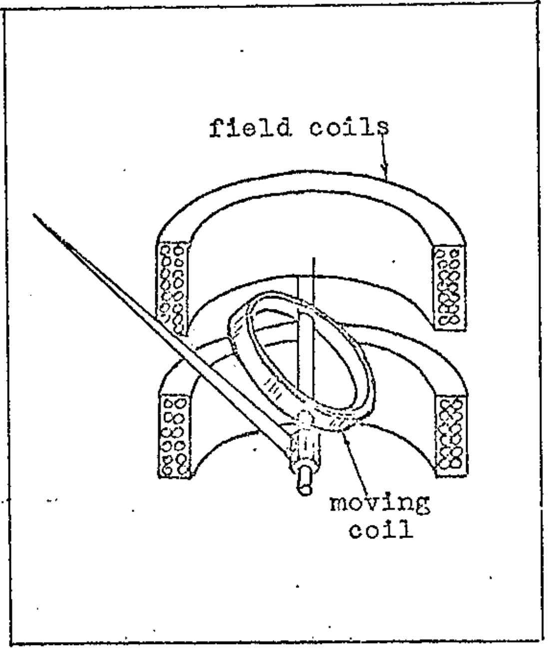


The repulsion type is more widely used as it is more accurate, reliable, and uniform.
A small soft iron plate is attached to the centre spindle which is free to rotate. Parallel to and almost touching this plate is a second, curved and tapered plate. When a current passes through the coil, both plates become magnetised to the same polarity. This causes repulsion between the two plates causing the smaller one to move. Because the larger plate is tapered, its effect is reduced as it becomes smaller.
This, together with the return or control springs, allow the scale to be graduated more uniformly.
Because the movement is independent of coil polarity, it is used for either AC or DC meters.



Dynamometer

Two identical fixed field coils arranged parallel to each other provide a magnetic field when a current passes through them.
A third moving coil is mounted on a spindle having control springs which is located inside the fixed field coils.
All three coils are connected in series, and each produces a magnetic field.
The fields produced by the two outer coils combine to create one stronger field.
The field produced by the moving coil is in opposition to the fixed coils, thus causing deflection.
The polarities of the coils remain related regardless of the direction of the current and is therefore suitable for AC or DC measurements.



All meter movements may be made as ammeters or voltmeters. Ammeters will have relatively FEW turns of HEAVY gauge wire except on the moving coils. A SHUNT is required for measuring higher current ranges. Voltmeters will have MORE turns of FINE gauge wire and will require a MULTIPLIER when used on higher voltage ranges.
Shunts and Multipliers are explained later.

TITLE:- MEASURING INSTRUMENTS

LECTURER:-

DATE:-

EQUIPMENT:- Voltmeter (a.c. d.c.) Ammeter (a.c., d.c.), Wattmeter, Watthour meter, power factor meter

It is often necessary to take accurate measurements of various electrical quantities. A number of instruments have been designed for this purpose, some of which are:-

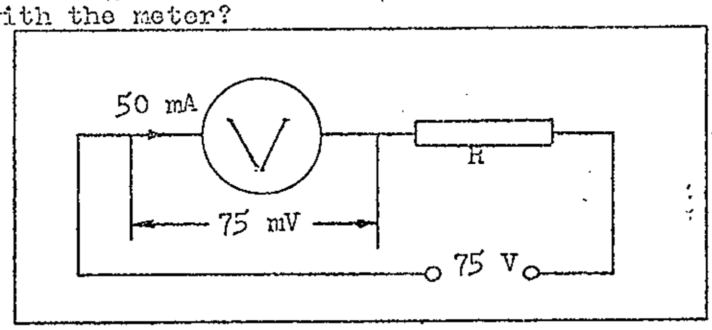
Voltmeter, ammeter, wattmeter, watthour meter, power factor meter, and maximum demand meter.

1. Voltmeter

A voltmeter may be either moving coil, moving iron, or dynamometer type. The moving coil may be used to measure d.c. voltages directly, or by adding a RECTIFIER, they may be used to measure a.c. The moving iron type and the dynamometer will both measure ac or dc directly. All will have windings of many turns of fine gauge wire.

The maximum voltage which may be applied to the actual meter movement is approximately 75 millivolt, i.e. 0.075 volts for full scale deflection. For use on higher voltages it is necessary to connect a MULTIPLIER in SERIES with the meter.

To determine the ohmic value of this multiplier or resistor, it is necessary to know the current and voltage for f.s.d.
e.g. A voltmeter has a f.s.d. of 50 mA at 75 mV. It is required to use the meter on 75 Volts. What value of resistance must be placed in SERIES with the meter?

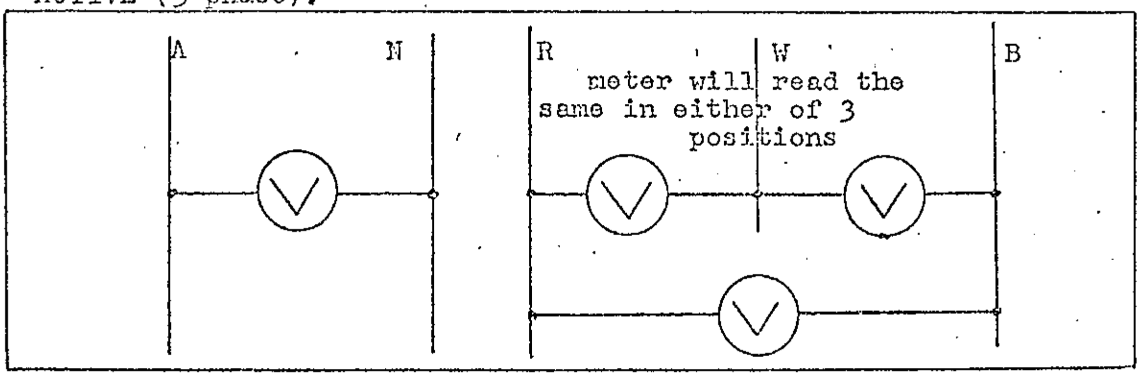


Current through Resistor R = 50 mA
Voltage across Resistor R = 75 - 0.075 = 74.925 Volts.
Resistor R $= \dfrac{74.925}{.05} = 1498.5$ ohms

Almost all voltmeters have a multiplier connected internally so that if the scale reads up to 250 volts, then that voltage will cause the pointer to deflect fully when applied to the external terminals.

It will usually be found that moving iron instruments are encased in a steel or iron case to shield the components from the effects of stray magnetic fields.

A voltmeter is connected ACROSS (between) ACTIVE & NEUTRAL or ACTIVE - ACTIVE (3 phase).

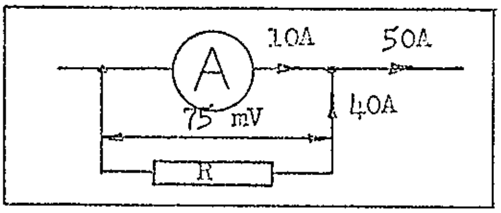


2. Ammeter

An ammeter is used to measure either a.c. or d.c. values of current. The fixed coils are wound of a heavier gauge of thicker wire, while the moving coils are the same as for voltmeters.

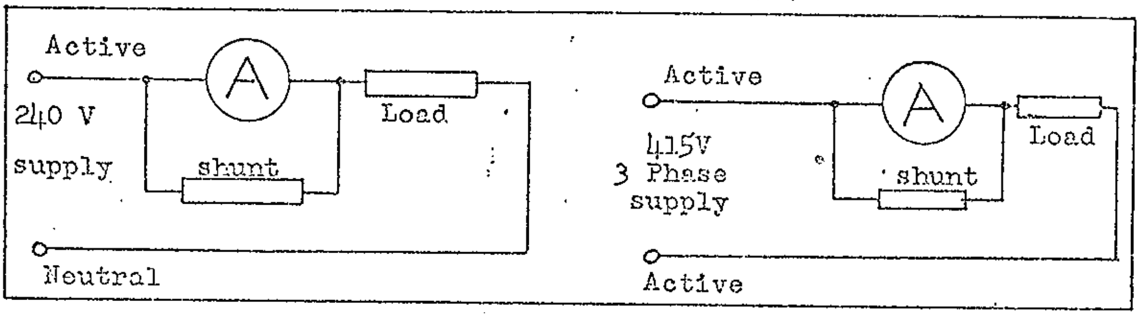
Again, the moving coil may only carry about 50 mA at 75 mV, and must be connected to a resistor. This resistor is connected in PARALLEL to the meter and is called a SHUNT. Its purpose is to bypass most of the current. It should be noted that the resistance will be a very LOW value, but it must be capable of carrying the total current being measured without becoming hot. It usually takes the form of a copper strap

e.g. An ammeter has an internal shunt to allow it to read 10 A. It has a voltage drop across it of 75 mV. What value of external shunt would be required to allow the meter to read 50 Amp.



Current through R = 40A
Voltage across R = 75 mV
Resistance of R = $\frac{.075}{40}$
= .00187 Ohms

An ammeter is connected in SERIES with the load.

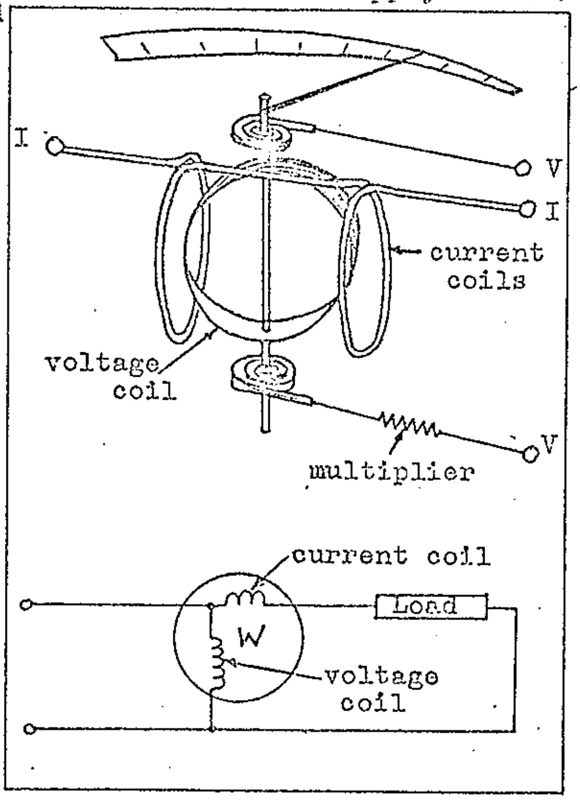


3. Wattmeter

A wattmeter measures the amount of power taken from a supply source. Electrical power can be calculated by multiplying current x voltage together, i.e. E x I = WATTS. This is what a wattmeter does using the dynamometer movement. Two sets of coils are used, 1. The fixed coils are heavy gauge wire with few turns and are connected in SERIES with the load (as an ammeter). 2. The moving coil is of fine gauge wire with many turns and is connected through a multiplier to the ACTIVE and NEUTRAL terminals (as a voltmeter).

When the current passing through the fixed coils is zero, then there is no magnetic field and hence no deflection. When a current flows, then the magnetic field set up by the fixed coil interacts with the field made by the moving coil thus causing a deflection.

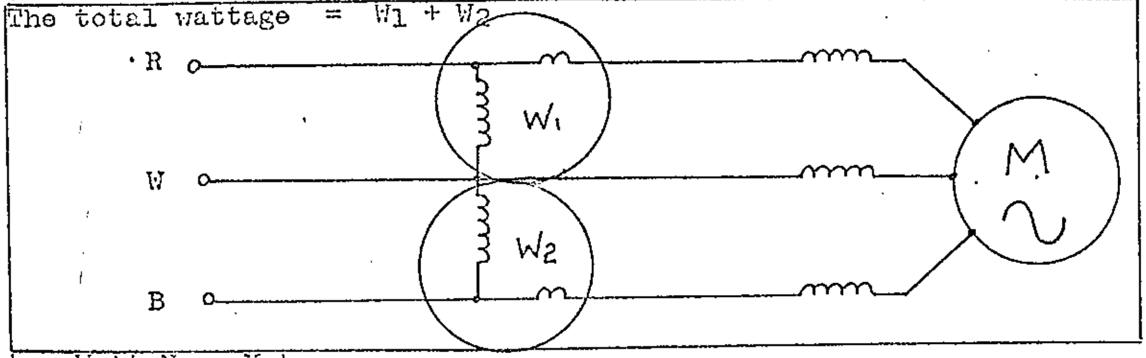
Power in a single phase supply may be measured using one wattmeter as shown.



To measure power in a BALANCED 3-phase supply requires the use of one wattmeter. The reading on the

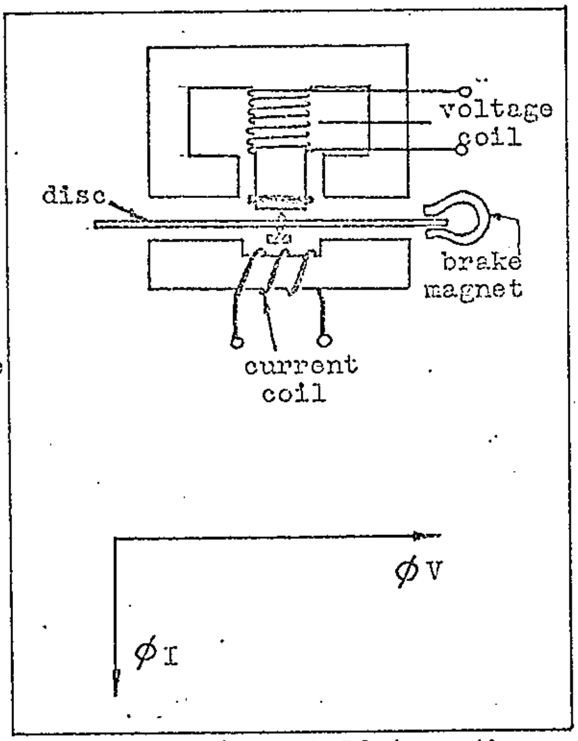
wattmeter must be multiplied by 3 to give the total power.
An unbalanced load may be measured by using two wattmeters connected as shown.

The total wattage = $W_1 + W_2$

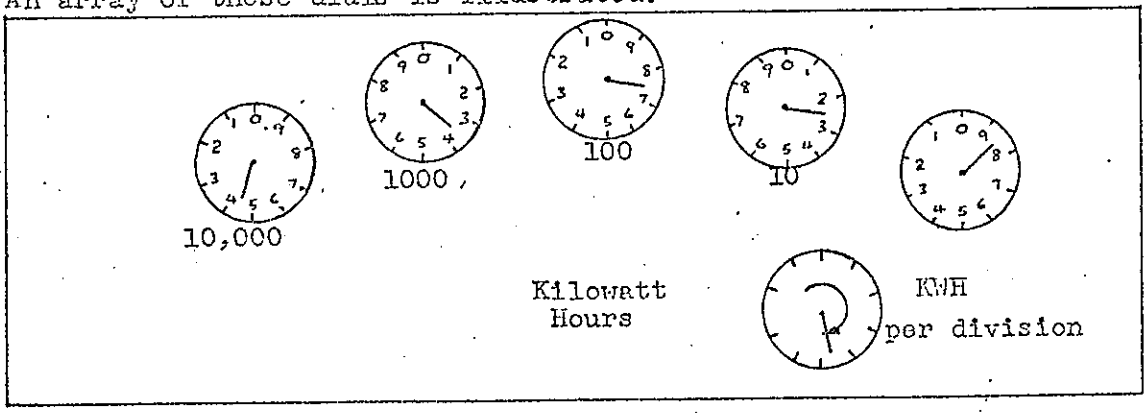


4. Watt Hour Meter

To enable generating authorities to recoup costs of generating electrical energy, each consumer has a watthour meter, or Kilowatt-hour meter to measure power consumed over a period of time i.e. Kilowatts per hour.
The Kwh meter performs this function.



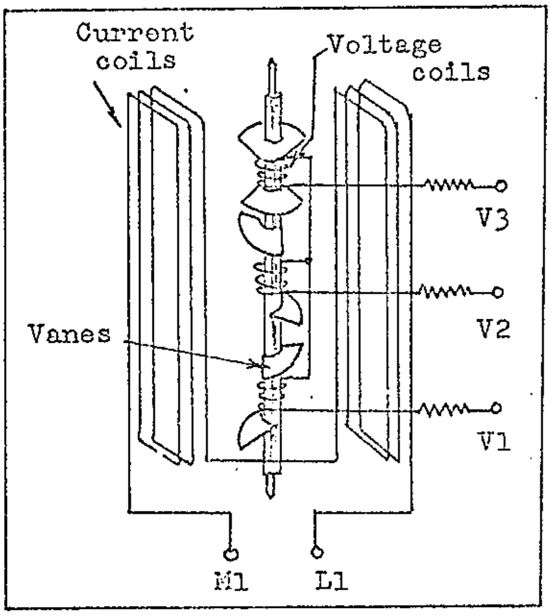
Construction & operation A laminated, 3 limb core is wound with many turns of very fine wire. A short circuited loop is placed around the centre limb. A voltage applied to this highly inductive arrangement produces a magnetic flux which acts on the aluminium disc.
A second laminated core is wound with few turns of heavy gauge wire through which is passed the load current. A second magnetic field is produced. The net result is that the two magnetic fields are displaced by 90° due to the large difference in their individual inductances, causing the flux from the voltage coil to LAG behind the flux of the current coil by 90°.
This resultant flux causes the disc to rotate at a uniform speed which is directly proportional to the current i.e. If the disc completes 10 revs/min.at 10 Amp, then it will rotate at 20 r.p.m. when the current is 20 Amps.
The fixed magnet has a braking effect on the disc to prevent "free running" of the disc when the current is zero.
The centre of the disc is attached to a spindle which passes through a train of gears to a number of dials which indicate energy consumption.
An array of these dials is illustrated.



When reading this type of meter, read from Left to Right.
Write down the number which each pointer has passed
i.e. the reading of the above meter would be 43728.4 Kwh.

5. Power Factor Meter

Because industrial circuits use loads such as motors, transformers etc. which are highly inductive, the current taken from the supply LAGS behind the voltage.
What this means is that the energy taken from the supply is greater that the energy used in performing work when the p.f. is large.
This excess energy must be paid for by the consumer and in the case of a large company can amount to many thousands of dollars per month.
It is of extreme importance that the p.f. be properly monitored to enable steps to be taken for its correction.
The meter illustrated is a 3 phase p.f. meter.
A centre spindle is fitted with vanes which come under the influence of the magnetic fields created by the coils. They are displaced by 120° per pair.
The coils wound around the centre spindle are connected to the supply voltages on each phase.
The two larger coils are current coils which are connected in series with one of the phases.
The meter illustrated is for measuring BALANCED 3 phase loads only. For measuring unbalanced loads, 3 current coils are required to measure the current taken in each phase.



5. Maximum Demand Meter

To enable supply authorities such as E.T.S.A. to plan their power distribution systems with respect to cable sizes, transformer sizes, they must know how much power is required by each consumer.
Because most consumers do not operate all their plant at the same time, the total power requirement is not equal to the total kw ratings of motors, lights, heaters etc. which a consumer has.
e.g. a consumer may have equipment with a total rating of 10,000 watts, but at any one time, he would not use more than, say, 5000 watts, i.e. 50%. This 50% is the demand factor.
The cost of buying electricity is greatly reduced if the consumer makes an agreement with the supply authority not to exceed this example of 5000 watts. This is the Maximum Demand that the consumer will make on the supply authority for electrical power. If this figure is exceeded, then additional costs are incurred to the consumer.
Measuring of this maximum demand is done by a Maximum Demand meter which operates over a 15 minute period.
Two pointers are used on the scale. One indicates the actual power being taken by the consumer per 15 minutes, while the other indicates the Maximum demand over the same time period.
If the first pointer passes the second pointer, then the Maximum demand has been passed and excess charges are incurred.
To prevent this happening, the substation operator switches off power to certain sections of the plant when the two pointers come close together.

TITLE:- TESTING INSTRUMENTS

LECTURER:

DATE:-

EQUIPMENT: Avo, Pocket multimeter, megger, Bridge Megger, Wheatstone's Bridge, Tong tester, Phase tester.

The electrician, in the course of his work, is required to carry out a number of tests to ensure that an installation is functioning properly and safely and to assist him in diagnosing faults. Common faults are short circuits, open circuits, earth faults, insulation failure, overload etc.
A variety of meters have been developed to make this job of fault finding easier and quicker. It is essential for the electrician to familiarise himself with the equipment available, and to fully understand its safe use and operation, and how to interpret the readings and results obtained.
Some of the common testing instruments covered in these notes are Avometer, "pocket"multimeter, megger, bridge megger, wheatstone Bridge, Tong tester, phase tester.

1. Avometer
The avometer is a multi purpose meter, capable of measuring Current (a.c. & d.c.) Voltage (a.c. & d.c.) Ohms, capacitance, power, decibels, power factor, and watts. Only the first 4 will be dealt with in these notes.
Before connecting the leads onto any piece of equipment ENSURE THAT THE METER IS SET ON THE PROPER RANGE otherwise serious damage or injury could result.
Place the meter on a flat horizontal surface, and take readings by viewing the pointer from directly overhead. A mirror is placed in the instrument to ensure accurate readings. The pointer and its reflection should coincide.

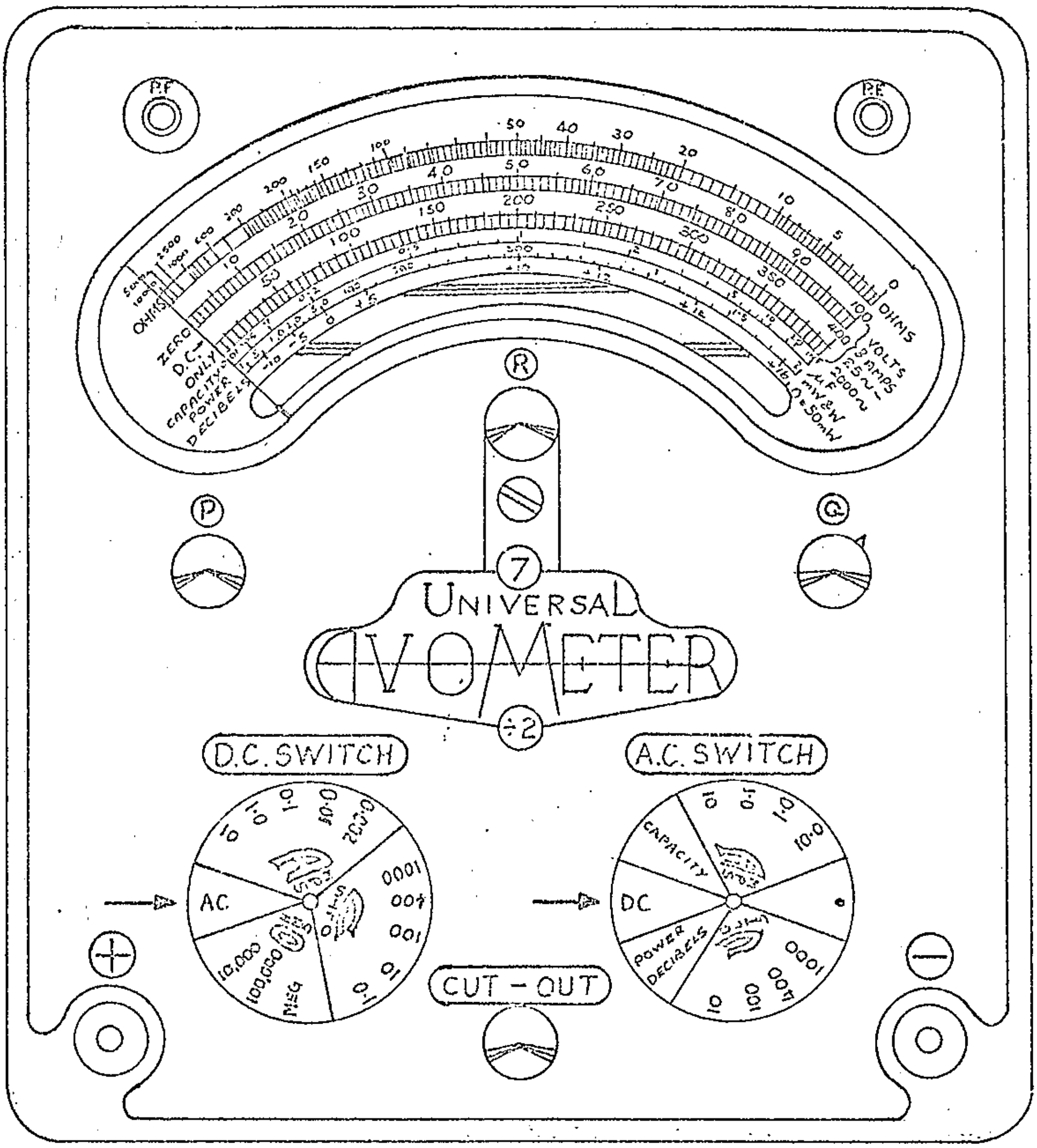
Ohm's Range
10,000 and 100,000 ohm ranges use a 1½ Volt cell, as the voltage in this cell gradually decreases with use, it may be compensated by adjusting knobs 'P' and 'R'.
Before commencing tests on these ranges, it is advisable to adjust these knobs as follows -

1. Connect the leads together.
2. Set D.C. switch to 100,000 ohms.
3. Adjust 'P' until pointer shows zero ohms.
4. Switch to 10,000 ohms range.
5. Adjust 'R' if necessary to zero ohms.
6. Switch to 100,000 ohms range again.
7. If necessary, re-adjust knob 'P'.

The objective is to make the pointer indicate Zero on both ranges.
When taking readings, switch to the scale which makes the pointer more to centre-scale area when this is possible.
Megohm range uses 2 x 4½ Volt cells in series. Before using this range, the meter must be "set" to zero in the following manner:-

1. Connect the leads together.
2. Set D.C. switch to the 1 megohm range.
3. Raise and turn knob Q and rotate clockwise until the pointer indicates zero.

Do not hold the resistance terminals or meter lead ends during this test or body resistance will cause errors.
Return knob Q to its normal position after this test.
If it is impossible to obtain zero on either of the above tests, replace the relevant batteries.
Do not allow discharged batteries to remain in the meter, and ensure that the D.C. switch is returned to the A.C. position after use to prevent drain on the batteries.
Do not connect the meter to ANY external source of voltage whilst set on any of the OHMS ranges as the meter movement may become damaged.



MODEL 7 UNIVERSAL AVOMETER

+	Connection for RED lead
-	Connection for BLACK lead
P	Potentiometer adjustment for Ohms scale
R	Potentiometer adjustment for Ohms scale
Q	Potentiometer adjustment for Megohm's scale, and for infinity adjustment on CAPACITY scale
P.F.	Connection to "Power factor and Wattage" unit
÷2	To increase meter range on AMPS or VOLTS only

D.C. SWITCH - Selector for measuring d.c. values or resistance values.

A.C. SWITCH - Selector for measuring all a.c. values

Current measurement

1. Set the instrument to the required range - AC or DC, and preferably to the highest value, i.e. 10 Amps AC or DC.
2. SWITCH OFF the circuit to be tested.
3. Connect the meter in SERIES with the load.
4. Switch on the power to the circuit.
5. Adjust the appropriate switch to allow the pointer to indicate as close to centre scale as possible.

DO NOT TOUCH EXPOSED CONNECTIONS DURING THIS TEST.
Do not switch the meter to any other position during this test, whilst the power is ON or the leads connected, otherwise damage could result to the switch contacts or meter movement.
The "÷2" button may be used during this test. This button provides intermediate ranges between those indicated on the switches, i.e. it HALVES the value shown on the switch e.g. When the switch is set on the 10A range, by pressing the "÷2" button, that range becomes 5A.
If over half scale deflection is shown, DO NOT PRESS the 2 button, as this effectively doubles the pointer deflection.

Voltage measurement

1. Set the meter to the appropriate range. If the voltage value is unknown, set to the highest range (1000V).
2. SWITCH OFF the supply if possible.
3. Connect the meter leads.
4. Switch on the power - DO NOT TOUCH ANY EXPOSED LIVE CONNECTIONS.
5. Adjust the appropriate switch to allow the pointer to indicate as close to centre scale as possible.

The "÷2" button may also be used in a similar manner as explained previously.
Do not switch the meter to any other position whilst the power is on or the leads connected.
If it is possible to avoid measuring voltages to determine the required data, it is advisable to do so as this test is the most hazardous of all.

Capacitance test

When it is required to determine the value in microfarads of an unknown capacitor, carry out the following steps:-

1. Set A.C. switch to "CAPACITY".
2. Connect meter leads to 50 c.p.s. supply (from 65 to 250 Volts).
3. Switch on the supply.
4. Raise and turn knob 'Q' until meter indicates infinity (INF).
5. Switch off the supply.
6. Connect capacitor in series with meter.
7. Switch on the supply.
8. Meter will indicate capacitor value in microfarads.

DO NOT TOUCH EXPOSED LIVE CONNECTIONS.
On completion of this test, the supply should be switched OFF and the capacitor DISCHARGED before disconnecting.
Return the 'Q' knob to its normal position.

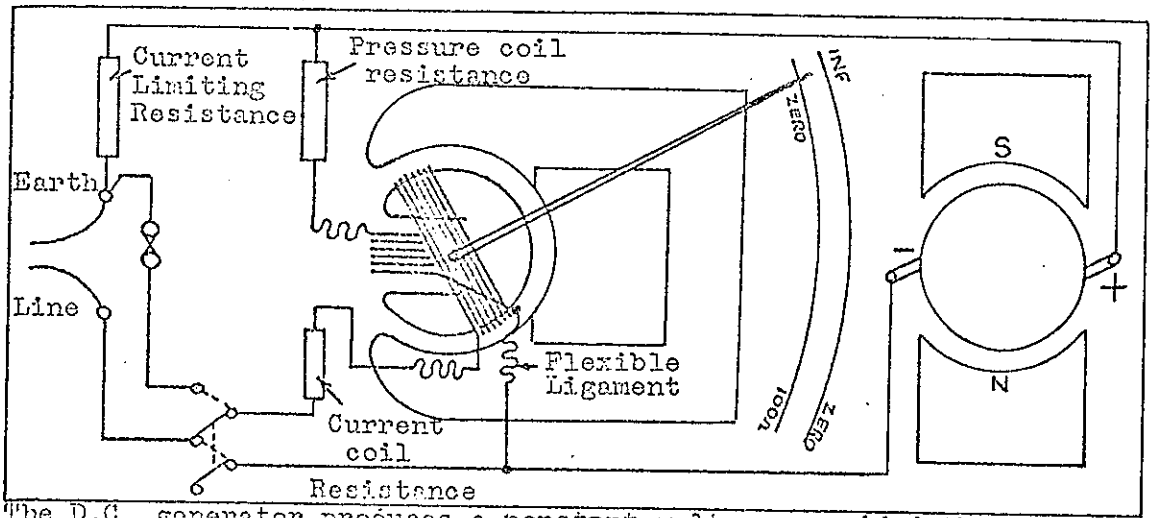
2. "Pocket" Multimeter

This type of multimeter is widely used and preferred by the electrician as it is small and compact and is easily carried in the toolbox. It does not have the wide range that the AVO has but for everyday checking it is most suitable.
Connection to AC and DC current and voltage and to the OHMS range is done by re-positioning the leads into various sockets. It is imperative that the leads be correctly connected before use.
Place the meter on a flat horizontal surface to ensure maximum accuracy.
Use the "0Ω" knob to zero the pointer when using the ohm ranges.
Observe the same precautions described in the previous section on the AVO when making current or voltage tests.
Remove the leads from the ohms sockets when not in use to prevent drain on the internal battery.

3. Megger

Insulation failure is a common occurence in electrical equipment. To check the "soundness" or otherwise of insulation, it is necessary to apply a voltage "across" it of at least twice the normal voltage.

A megger is a device which produces voltages between 250 Volts and 5000 Volts, in a series of steps. This may be done electronically or more commonly, by a generator, the construction of which is illustrated below.



The D.C. generator produces a constant voltage provided that the cranking speed is greater than that required to cause the integral clutch to slip. The voltage produced appears on the meter (reduced by the pressure coil resistance to a safe value) and is unaffected by the external resistance being measured. The current coil is in series with the generator and the resistance under test, i.e. the value of current is inversely proportional to the resistance under test.

The resultant forces from the two magnetic fields so produced cause the pointer to deflect by an amount which is proportional to the current flowing through the resistance under test.

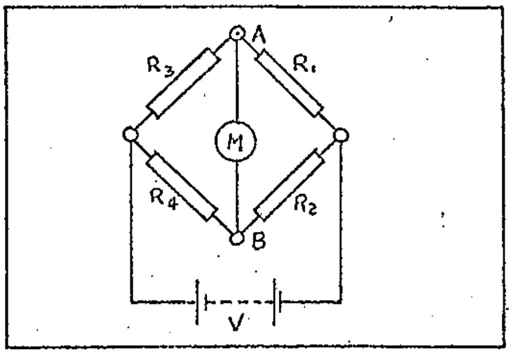
To test the insulation of electrical equipment, follow the procedure below:-

1. Switch OFF the supply to the equipment and attach the necessary tags.
2. Connect the EARTH lead from the megger to a suitable earth connection on the equipment to be tested. TEST EARTH
3. Connect the LINE lead of the megger to the active part of the circuit.
4. Crank the handle to a speed where the clutch slips.
5. Maintain this speed for 30 secs or more.
6. Observe the readings.
7. Cease cranking and leave the megger connected for 2-3 minutes when testing long cables or inductive loads as energy may be stored within the equipment.

Ideally, the readings obtained should be infinity, this in many cases may not be achieved. There is no set value on the megohm scale where it can be said that the test results obtained change from good to poor. Each item tested must be assessed individually, from the results obtained. Obviously, if the tests show readings in the lower half of the scale, then steps should be taken to locate the cause of the low tests. These causes may be due to dirt, moisture, dust etc. and should be rectified as soon as possible. Remember that insulation failure may cause FIRE or SHOCK.

4. Bridge Megger

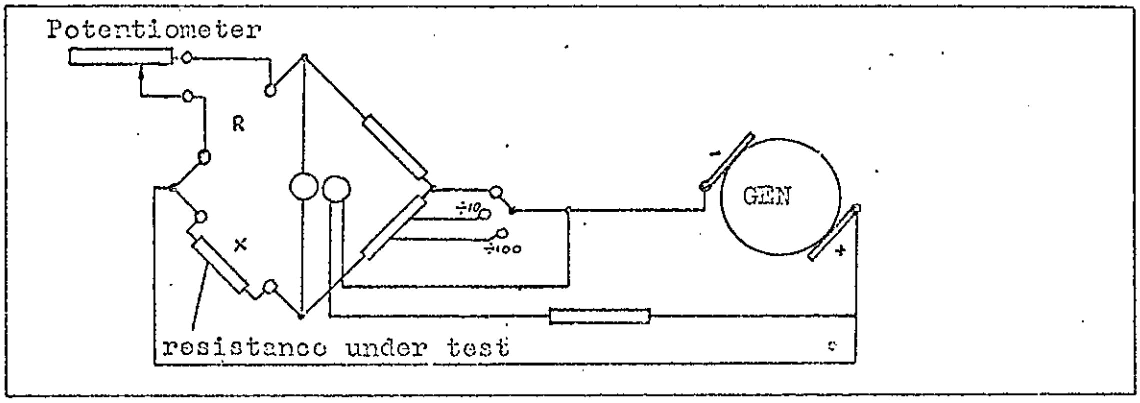
This instrument has a dual purpose. It may be used as a Megger as previously described, or it may be used as a resistance tester to measure accurately values between 0.01 ohms and 100,000 ohms using the principle of the Wheatstone Bridge.



Principle of Wheatstone Bridge

If $R1 = R2$
and $R3 = R4$
Then potential at A & B will be the same.
If one of the resistance values is changed, then the potentials at A or B change causing meter M to deflect.

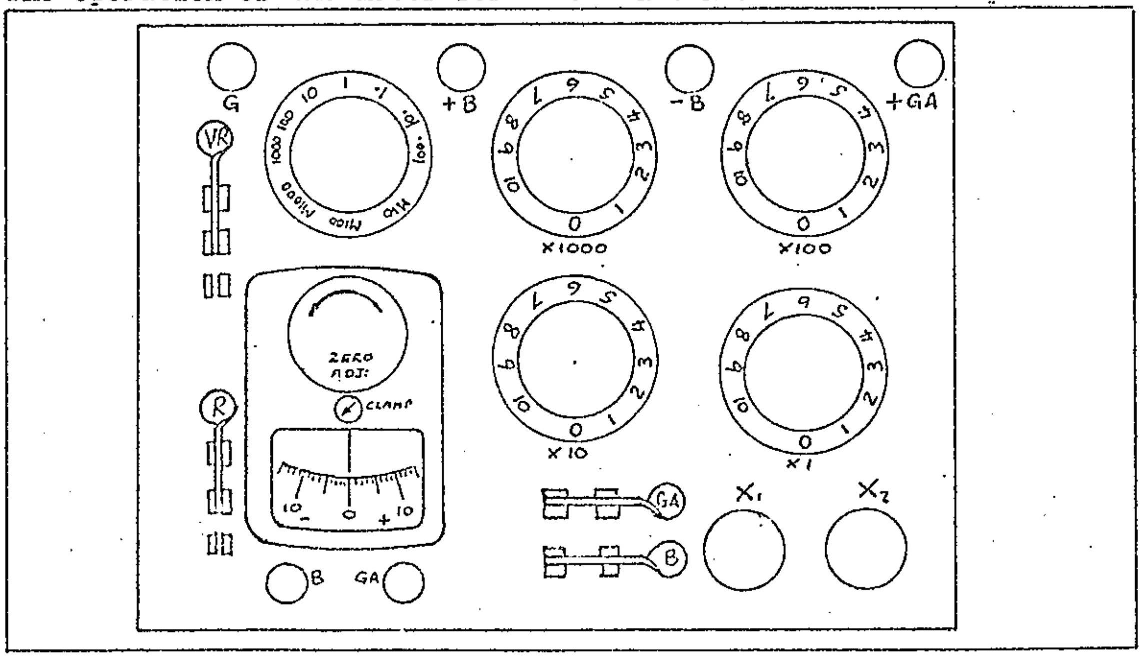
The circuit illustrated below is that of the bridge megger showing how two of the resistors in the above circuit have been replaced, one by an unknown resistor, the other by a potentiometer. The potentiometer is moved until the deflection on the meter is NIL. At this point, the potentiometer's resistance is equal to the resistance of the unknown resistor.



The actual adjustment of the potentiometer is by a series of switches which connect or disconnect fixed values of resistance. A further switch extends the range of the meter. When this switch is set to one of the values indicated (x10, x100, ÷10, ÷100) then the results of the test obtained must be multiplied or divided accordingly.

5. Wheatstone Bridge

This meter employs the principle of the Wheatstone Bridge and may be used for measuring resistance and locating faults by the VARLEY or MURRAY testing method. The carrying out of the latter two tests is explained later.
The operation of the meter for resistance measurement is explained.



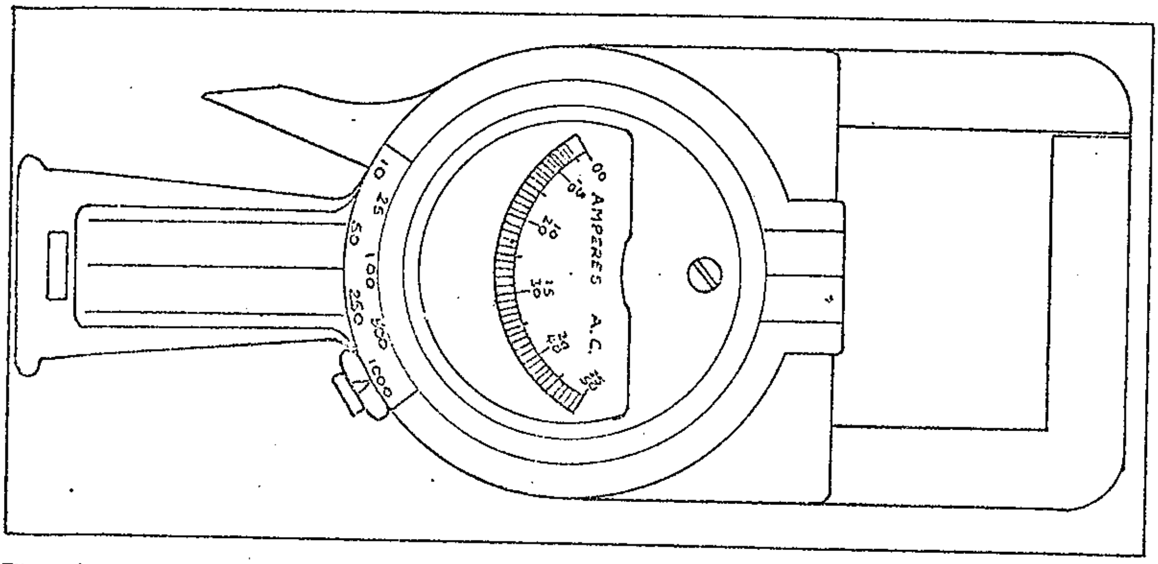
1. Close S, switch to VR side and S2 to R side.
2. Connect resistance under test to X1 and X2 terminals.
3. Unlock galvanometer movement.
4. Depress B and GA buttons.
5. Adjust MULTIPLY knob and the four resistance knobs until galvo reads zero.

The actual resistance is determined by multiplying the value obtained from the resistance control knobs by the MULTIPLY value indicated.

Extremely accurate readings may be obtained with this instrument, and care should be taken to ensure good solid connections. If connecting leads are used, the resistance of the leads should be subtracted from the total resistance calculated.

6. Tong test ammeter

When it is necessary to check currents flowing in a conductor without disconnecting the conductor, a Tong-test ammeter may be used. The principle of this meter is that a current carrying conductor produces a magnetic field.



The iron circuit is opened and placed around the INSULATED conductor and then closed.

The current range selector is gradually reduced from its maximum current position to a position where the meter pointer is close to centre scale.

Extreme care is required when using this meter as it is used in close proximity to live equipment.

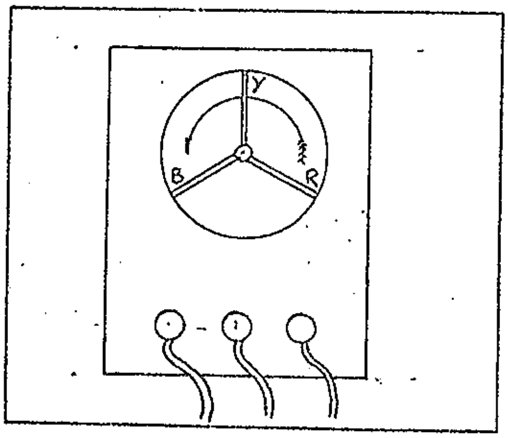
The meter will only indicate accurately when it is clamped around ONE conductor.

Phase tester

When a 3-phase motor has been disconnected from the supply, and it is required to re-connect it, there is a possibility of wrong connection causing the motor to turn in the wrong direction.

In most cases, this is not serious as the direction can easily be changed after the motor has been run, but in some cases, reversal of the motor may cause serious damage. To check that the polarities of the 3 phase supply are correct, a phase tester is required. This is a 3 phase synchronous motor driving a disc. The disc rotates indicating whether polarity and therefore direction of rotation is correct or not.

Reversal of a 3 phase motor is achieved by interchanging any pair of leads.

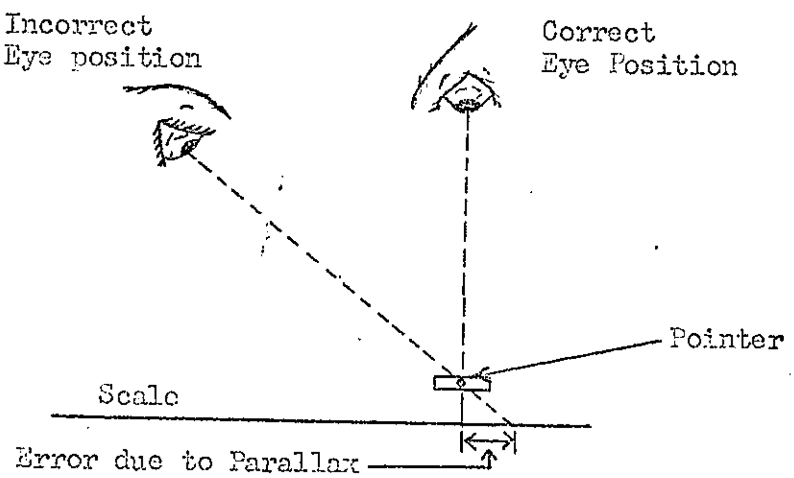


USE OF METERS

The selection of the best meter range to use depends upon two things. First, the range of the meter must be greater than the value to be measured and secondly the deflection of the meter pointer should be as large as possible. Any error due to zero correction, reading of scale, bearing friction, balance, etc., is of less importance with a large movemene of the pointer than with a small deflection. In general, meter readings should not be relied on for deflection of the lowest quarter of the scale.

Meters are expensive to repair or replace so always handle them with care. Do not drop or bump them about and place them in positions free from vibration.

Meters are of little value unless they are reading correctly. To read a meter correctly, the eye should be directly in front of the pointer, never to one side or the other. Fig. 1a, below shows how an error can be introduced by not following this rule.



A further point which must be noted is that since every line on the scale is not numbered, care must be taken in estimating the values of the unmarked intervals. The interval between two lines may be five volts on one scale and one tenth of a volt on another.

The range of the meter must also be considered. By "range" is meant the highest value which can be read on it. By the "scale" is meant the marked divisions for reading the meter. Meters may be made with a single range and scale or may be of the multi-range type. The multi-range type may be used for several ranges of measurements by the proper choice of switch settings or plug or terminal posts.

A multi-range meter may have one scale in which the true value is obtained by multiplying the scale reading by the proper number, or it may have a separate scale for each range.

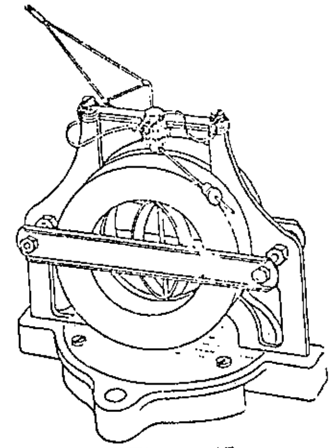


Figure 15.
Dynamometer Coils.

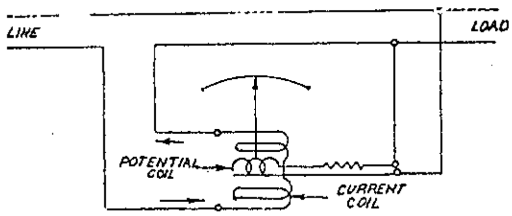


Figure 16.
Wattmeter Circuit.

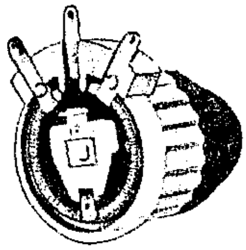


Figure 23.

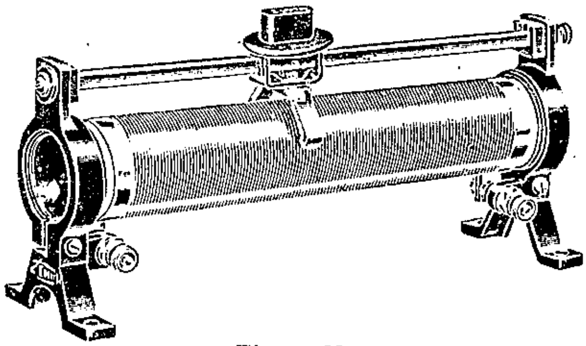


Figure 22.
Zenith Rheostat.

Figure 18.
Avometer.

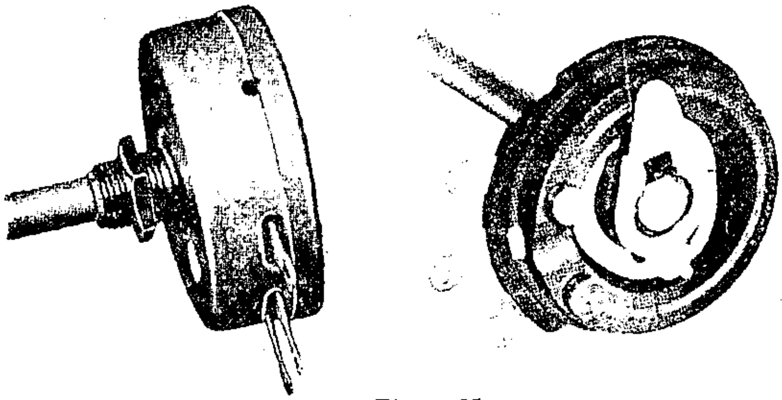


Figure 25.
Carbon Potentiometer.