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NOTES ON DIRECT CURRENT FOR ELECTRICIAN'S MATE II.

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NOTES ON DIRECT CURRENT

for

ELECTRICIAN'S MATE II.

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The Electric Current.

Every atom is composed of a central nucleus of positive charge, around which revolve a number of negative electrons, termed planetary electrons. In many substances certain of these planetary electrons are not very firmly bound to their parent atoms and so are free to move from one atom to another. Such electrons are called free electrons.

In a substance containing many free electrons, copper for example, an interchange of electrons between the atoms is continually going on, in quite a haphazard manner. Under the influence of a certain force, called a Difference of Potential, however, the electrons are caused to move, no longer in all directions, but mainly in one particular direction, and this constitutes a current of electricity. Thus an electric current is merely a drift of electrons mainly in the same direction, and under the influence of a difference of potential. It is the difference of potential which determines both the strength and the direction of the current.

Current is denoted by the symbol I and is measured in Amperes (or amps.) by an Ammeter.

Note :- A current of 1 Amp. is a flow of electrons at the rate of 6.3×10^{18} per second.

Difference of Potential is denoted by the symbol V and is measured in Volts by a Voltmeter.

OHM'S LAW.

This law states that the ratio of the difference of potential between any two points in a circuit, to the current flowing, is constant, provided that the temperature remains the same. This constant is called the Resistance of that part of the circuit.

Resistance is denoted by the symbol R and is measured in Ohms by a Megger or by an Ohmmeter.

Ohm's Law can be expressed by the following three formulae :-

$$R = \frac{V}{I} \quad : \quad I = \frac{V}{R} \quad : \quad V = IR.$$

The three expressions can be obtained from the diagram (Fig. 1)

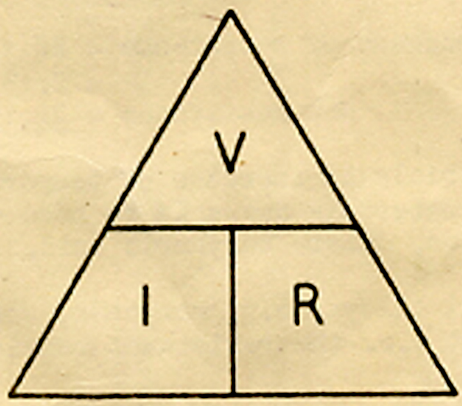


Fig. 1

Conductors are those materials which offer little opposition to the flow of electricity, e.g. metals, alloys, electrolytes, carbon.

Insulators are those materials which offer great opposition to the flow of electricity so that practically no current will flow through them, e.g. cotton, rubber, mica, bakelite, porcelain, asbestos.

Laws of Resistance

The resistance of a conductor depends on :-

(a) Its length.
(b) Its area of cross section.
(c) The material of which it is made, (the specific resistance).
(d) Its temperature.

Specific Resistance of a substance is the resistance of a piece of the material one inch long and one square inch in cross section. (Fig. 2) Sometimes centimetre units are used.

Neglecting the effect of (d) above we have :-

$$R = \frac{\rho l}{A}$$

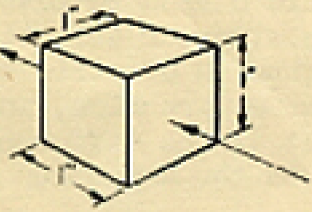


Fig. 2

Where R = resistance in ohms (Ω)
l = length in inches
ρ = specific resistance in ohms
A = cross section in square inches.

Example :- Calculate the resistance of a copper wire 1000 yds. long and 0.0012 sq. ins. in cross section. The specific resistance of copper is $\frac{0.7}{10^6}$ ohms per inch cube.

$$R = \frac{0.7 \times 1000 \times 36}{10^6 \times .0012} = \underline{21 \text{ ohms}}.$$

Effect of Temperature.

In general, the resistance (R) of a conductor increases with an increase of temperature.

The increase of resistance with rise of temperature is given by $R\alpha t$.

where α = the temperature coefficient.
t = the rise of temperature.

Example :- A conductor has a resistance of 20 ohms at 0°C. Find its resistance at a room temperature of 25°C., the temperature coefficient of copper being 0.0043.

$$\text{Increase of resistance} = 20 \times 0.0043 \times 25$$
$$= 2.15 \text{ ohms}$$
$$\text{New resistance} = \underline{22.15 \text{ ohms}}.$$

With some materials an increase of temperature produces a decrease of resistance. These materials are said to have a negative temperature coefficient, e.g. carbon, dilute sulphuric acid.

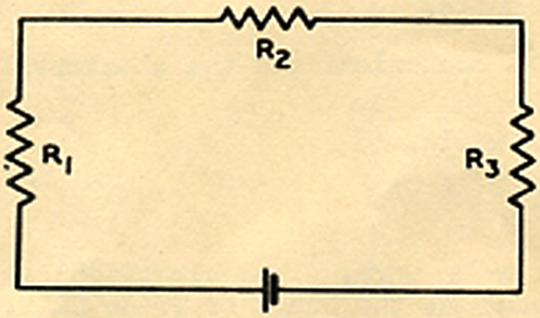
Certain special alloys, e.g. manganin, constantin, have no temperature coefficient i.e. the resistance remains constant over normal ranges of temperature.

Multiples and Sub-Multiples of Units.

Mega means	1,000,000 times,	e.g.	megohm (M).
Kilo "	1,000 "	e.g.	kilowatt (KW), kilovolt (KV).
Milli "	1/1000 of	e.g.	millivolt (mV), milliamp (mA).
Micro "	1/1,000,000 of	e.g.	microhm (μΩ), microvolt (μV).

Resistances in Series. (Fig. 3).

When several conductors are joined in series, that is, so that the whole current flows through each, their total resistance is the sum of the separate resistances.



Total Resistance = $R_1 + R_2 + R_3$

Fig.3

Resistances in Parallel. (Fig. 4).

When conductors are arranged so that each forms a separate path for a portion of the total current, they are said to be in parallel. Their combined or joint resistance (R) is found by the formula :-

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

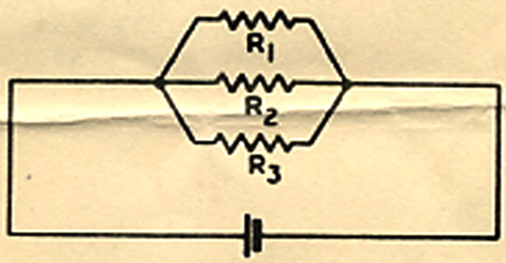


Fig.4

Example :- Find the total resistance when three conductors having 2Ω, 3Ω, and 5Ω resistance respectively are joined (a) in series (b) in parallel.

(a) $R = 2 + 3 + 5 = \underline{10 \text{ ohms}}$. (greatest)

(b) $\frac{1}{R} = \frac{1}{2} + \frac{1}{3} + \frac{1}{5} = \frac{31}{30}$ $R = \frac{30}{31}$ Ω (least possible)

If a number of resistances in parallel have the same value then :-

$$R = \frac{\text{Resistance of one}}{\text{Number in parallel}}$$

e.g. Find the resistance of 10 lamps joined in parallel if the resistance of each is 500 ohms.

$$R = \frac{500}{10} = 50 \text{ ohms.}$$

POWER.

Power is the rate of doing work. The mechanical unit is the Horse Power, equal to 33,000 ft. lbs. per min, e.g., a lift of 1000 lbs. through 33 ft. in 1 min.

The electrical unit of power is the WATT.

The power in an electrical circuit is given by the product of the current and the D.P.

$$P = IV \text{ watts.}$$

The relation between the mechanical and the electrical units is given by :-

$$1 \text{ H.P.} = 746 \text{ watts.}$$

ENERGY.

Energy is the capacity to do work. The electrical unit is the kilowatt-hour (KWH) also known as the Board of Trade Unit. 1 kilowatt-hour is the power expended when a power of 1 kilowatt is left on for 1 hour, or a power of 2 KW for ½ hour etc.

Example :- A radiator takes 10 amps. from 200 volt mains. What is its power and what would it cost to use it for 6 hours at a charge of 1¼d. per unit ?

Power = Current x D.P.
= 10 amps. x 200 volts
= 2000 watts or 2 KW.

Energy expended in 6 hours = 6 x 2 = 12 KWH or 12 units.
Cost = 12 x 1¼d. = 1s. 3d.

CELLS.

The simple cell most widely used where small currents are required for short periods is the Leclanche.
Positive plate - Carbon Negative plate - amalgamated Zinc.
Exciting liquid - solution of ammonium chloride.
Depolariser - Manganese Dioxide.

The voltage generated by chemical action is about 1.5 volts and is termed the E.M.F. of the cell.

Dry Cells are Leclanche cells in which the exciting liquid or electrolyte is absorbed in a paste. They are sealed to prevent the paste from drying up.

Inert Cells contain the same materials but require the addition of water prior to being brought into use.

Secondary Cells or Accumulators.

In the simple cells chemical substances are used up to provide a current but it is possible to store up electrical energy by changing it into chemical energy which can be reconverted as desired. Such a cell is the Lead-Acid Accumulator.
Positive plate - Lead peroxide Negative plate - Lead.
Electrolyte - dilute Sulphuric Acid. E.M.F. - 2 volts.

Nickel-Iron Accumulator.

Much lighter than the lead-acid cell. Both plates are formed on steel grids, the positive containing nickel hydroxide and the negative, spongy iron. The electrolyte is caustic potash solution. E.M.F. - about 1.3 volts.

A similar cell used in the Service is the Nickel-Cadmium-iron accumulator. It is preferred to the nickel-iron for certain work because it maintains its output at low temperatures.

Internal Resistance of Cells. (Fig. 5)

The materials of a simple cell have an appreciable resistance and when current is flowing there is a loss of voltage through this resistance.

The terminal voltage (D.P.$_T$) is then less than the E.M.F. Consider a cell on open circuit. Connect a voltmeter to its terminals and take the reading (say 1.5 volts). This measures the E.M.F. of the cell. If now we connect an outside circuit the voltmeter reading will fall (to say 1.2 volts). This reading measures the terminal D.P. of the cell or the volts used in driving the current through the external circuit.

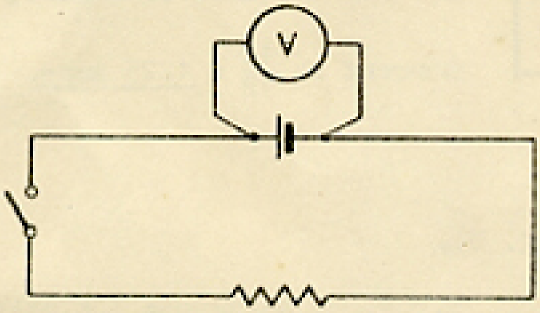


Fig 5

The other 0.3 volts is used in driving the current through the cell on account of its internal resistance. Accumulators have a very low internal resistance.

Capacity of an accumulator is measured in ampere-hours. Thus an accumulator of capacity 100-amp-hours should give a steady current of 20 amps. for 5 hours, but it is most unlikely to give 100 amps. for 1 hour.

Cells in Series. (Fig. 6)

The E.M.F. of a single cell is always small and therefore a number of cells are frequently connected together to form a battery. If cells are connected so that the positive terminal of one is joined to the negative terminal of the next and so on, they are said to be connected in series. Fig. 6 shows the circuit of a Service torch in which the battery is composed of three dry cells in series. It is usual to make a battery by joining similar cells and, if these be connected in series then :-

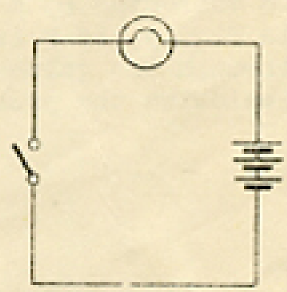


Fig 6

E.M.F. of battery = E.M.F. of one cell x number of cells. The E.M.F. of a single dry cell is 1.5 volts and therefore the E.M.F. of a Service torch is 4.5 volts.

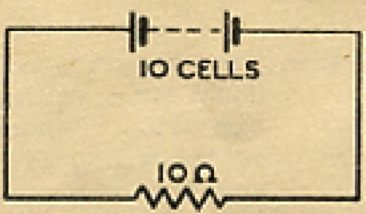
Cells in Parallel.

In this grouping all the positive plates are connected together forming as it were, one large positive plate. Similarly all the negative plates are joined. In this case :-

E.M.F. of battery = E.M.F. of one cell.

Example :- Find the strength of the current from ten cells, each having an E.M.F. of 1.5 volts and internal resistance 0.2 ohms, through an external resistance of 10 ohms when the cells are joined (a) in series (b) in parallel.

(a) Series Grouping (Fig. 7).

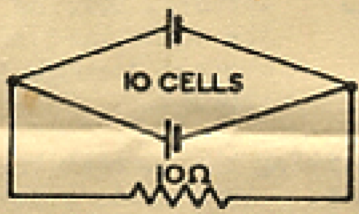


E.M.F. of battery = 10 x 1.5 = 15 volts.
Resistance of battery = 10 x 0.2 = 2 ohms.
Total resistance of circuit = 2 + 10
= 12 ohms.

Current = $\frac{15}{12}$ = 1.25 Amps.

Fig.7

(b) Parallel Grouping (Fig. 8).



E.M.F. of battery = 1.5 volts.
Resistance of battery = $\frac{0.2}{10}$ = 0.02 ohms.
Total resistance of circuit = 0.02 + 10
= 10.02 ohms.
Current = $\frac{1.5}{10.02}$ = 0.15 amps.

Fig. 8

Wheatstone's Bridge.

If two wires are connected in parallel and a current passed through them, then for each point in one wire, there exists a point in the other wire at the same electrical potential. If these two points be connected by a third wire, no current will flow between them. Thus in Fig. 9, if D is at the same potential as C, no current will flow through the galvanometer G. (A galvanometer is an instrument which indicates the presence of an electric current).

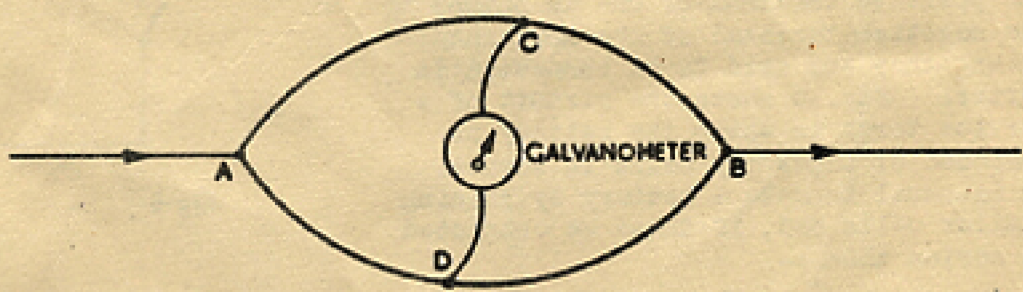


Fig.9

When this point of balance is obtained, then

$$\frac{\text{Resistance of AC}}{\text{Resistance of BC}} = \frac{\text{Resistance of AD}}{\text{Resistance of BD}}$$

This principle is used in the Foster Distance Thermometer, the Evershed Bearing Indicator, and the Bridge Megger.

MAGNETISM

Magnetic Substances such as iron, steel, nickel, cobalt, are capable of being attracted by a magnet.

Poles of a Magnet

These are the points near the ends of a magnet at which the magnetic force of the magnet appears to be most greatly concentrated. One is North-seeking (N), the other South-seeking (S). It is impossible to isolate either pole of a magnet.
Note :- Repulsion is the only test of a magnet.

Molecular Theory of Magnetism

According to this theory the molecules (the smallest particles capable of separate existence), not only of a magnet but also of unmagnetised iron or steel are complete magnets themselves. Before a piece of steel is magnetised these molecular magnets are assumed to be arranged in closed magnetic chains. No external signs of magnetism are shown (Fig. 10). The actual arrangement of the molecules in these chains is not known but it is possible that they arrange themselves in groups as shown in the diagram. When the steel is magnetised (by stroking with a magnet or by means of an electric current), the molecules are rotated until they are formed into parallel lines with their N poles all in the same direction (Fig. 11).

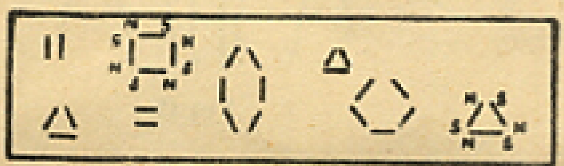


Fig 10

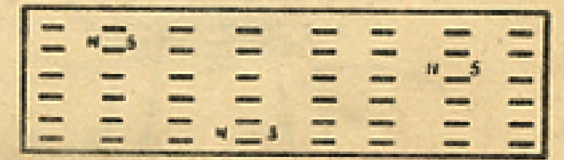


Fig. 11

Magnetic Saturation.

When a piece of steel is being magnetised there comes a time when, no matter how you may increase the magnetising force, you will be unable to make the steel a stronger magnet. When this point has been reached the steel is said to have reached a state of magnetic saturation.
Note :- From the theory above all the molecules have been turned into parallel lines.

Magnetic Induction.

By simple experiments we may show that a piece of iron will become magnetised in the presence of a magnet. It is said to be magnetised by induction.
Note :- 1. Induction precedes attraction.
2. The induced magnetism depends not only on the distance between magnet and iron but also on their relative positions.

Magnetic Fields.

The field of a magnet is the space surrounding it in which its influence can be detected.

A Line of Force is that line along which an imaginary isolated N pole would move if free to do so. (The direction in which such a pole would move gives its positive direction).

Diagrams of Magnetic Fields.

Typical diagrams of magnetic fields are shown in Figs. 12 to 16. Fig. 13 illustrates the distortion of the field of a straight bar magnet when a piece of soft iron is placed near it. (Note - magnetic induction).

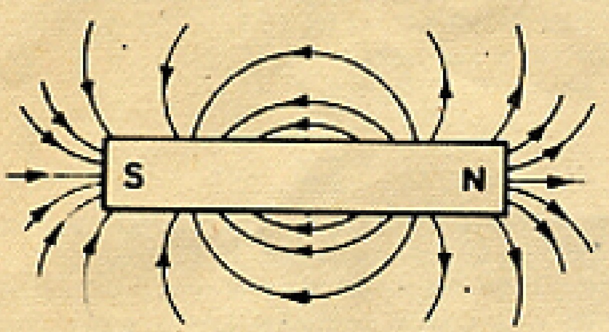


Fig 12.

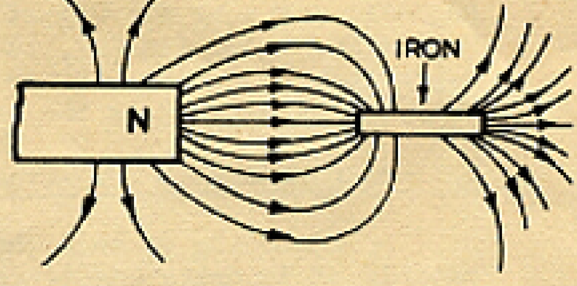


Fig. 13.

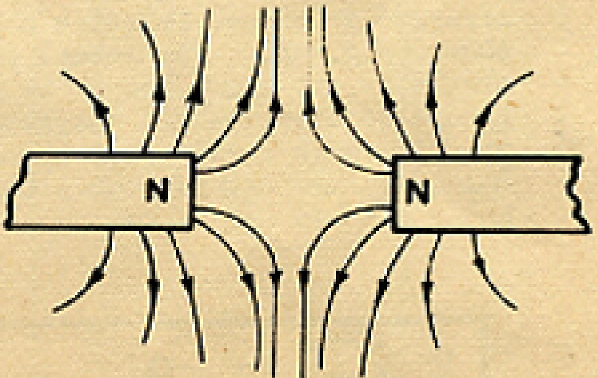


Fig. 15.

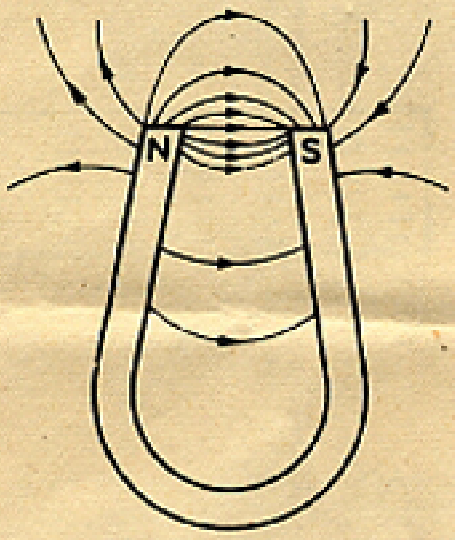


Fig. 14

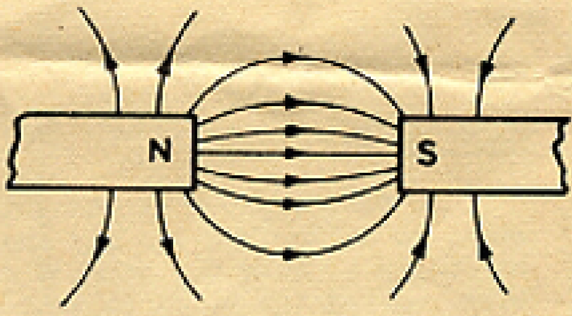


Fig 16

Magnetic Properties of Iron and Steel.

Soft Iron - Can be magnetised very easily and fully, but loses its magnetism quickly. It is suitable for temporary or electro-magnets.

Steel - Cannot be magnetised so quickly or so fully as soft iron, but retains its magnetism for a long time. It is suitable for permanent magnets.

Cobalt Steel or Tungsten Steel.

These are special magnet steels, which can be magnetised very strongly and retain their magnetic strength for a very long period. They are used to make strong permanent magnets for use in instruments and magnetos.

ELECTRO MAGNETISM.

If a compass needle be placed near a wire carrying a current, the needle is seen to be deflected from its normal N-S position. There must therefore be a magnetic field around the wire caused by the current. Experiment shows that the lines of force of this field are circular and their direction can be found by applying Maxwell's Corkscrew Rule which is as follows :-

"Imagine a corkscrew being screwed into the wire in the direction of the current. Then the motion of the thumb will indicate the positive direction of the lines of force".

Field due to a Straight Conductor carrying a Current.

This is shown in Fig. 17 (current away) and in Fig. 18 (current towards).

Field due to two Parallel Conductors carrying Current.

This is shown in Fig. 19 (currents in the same direction) and in Fig. 20 (currents in opposite directions).

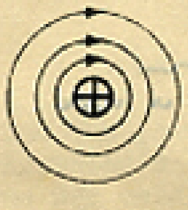


Fig 17

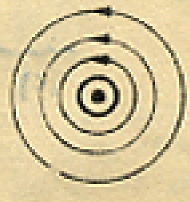


Fig 18

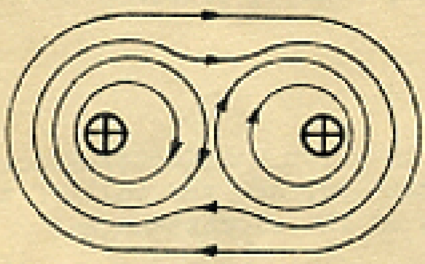


Fig 19

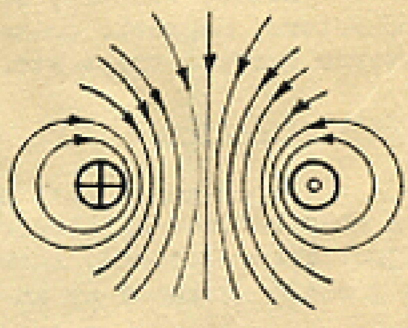


Fig 20

Magnetic Field due to a Solenoid.

Fig. 21 shows a solenoid and the field due to the current. The solenoid will have some of the properties of a bar magnet and the nature of its poles can be found by the Right-Hand Gripping Rule which states :-

"Grip the coil in the right hand, with fingers in the direction of the current and thumb at right angles to the fingers. Then the thumb will indicate the N pole of the solenoid".

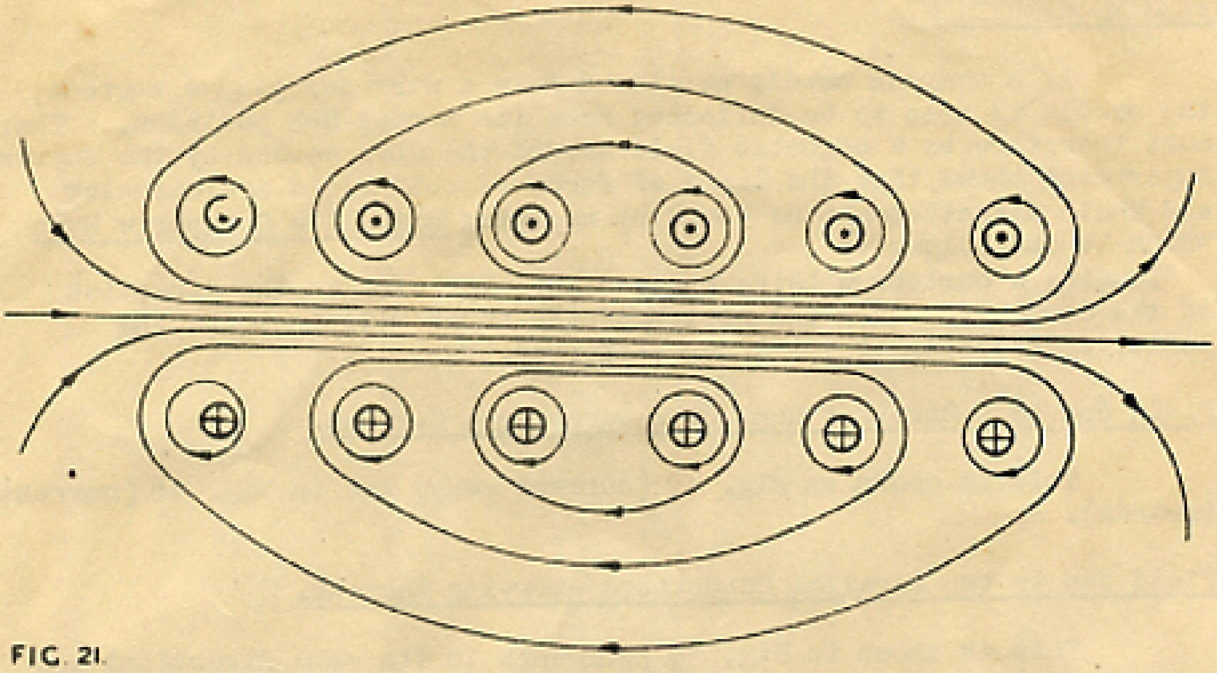


FIG. 21.

Magnetic Strength of a Solenoid depends on :-

(a) Strength of current
(b) Number of Turns
~~(c) The material of which it is made~~
(c) The material of which the core is made.

The two factors, current and number of turns, are multiplied together to give the number of ampere-turns. Thus a solenoid of 50 turns, carrying a current of 3 amps is said to have 150 ampere-turns.

If the core of a solenoid be composed of a magnetic material its magnetic strength is very much increased. This increase may be as much as 1000 times for the field of a dynamo where the core is made of special soft iron.

Uses of Electro-magnets. (Fig. 22).

Bells, buzzers, telephone receivers, field magnets of dynamos and motors, magnetic cranes, circuit breakers, relays, overload and reverse current trips etc.

Effect of Air-Gap

Experiments with suitable apparatus in which varying distances are made between an electro-magnet and an armature, and the pull of the magnet then measured, show that the strength of the electro-magnet is greatly weakened by an 'air-gap'.

With the apparatus shown in the following figure, the electro-magnet is allowed to attract the large piece of soft iron C which moves horizontally in the guides F. The pull necessary to draw the armature away is measured by the spring balance S, the pull being taken by the fixed peg D.

To demonstrate the effect of the air-gap, pieces of paper of varying thicknesses are placed between the pole pieces and the armature. The pull-off is then measured.

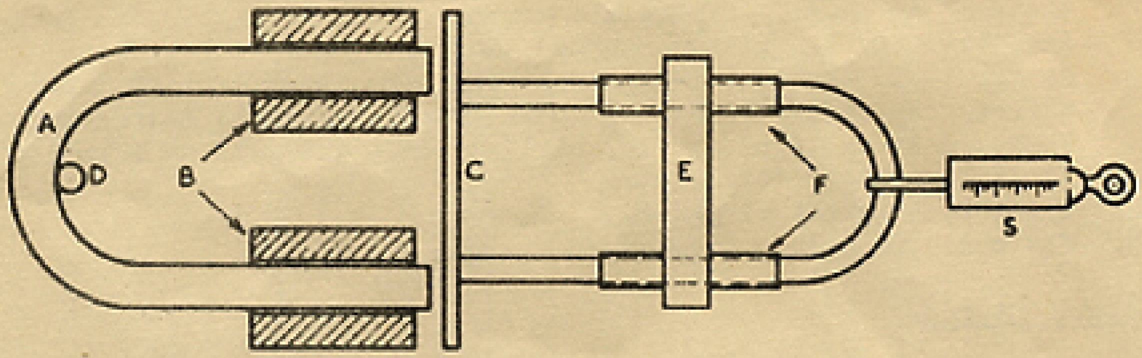


FIG 22.

A --- U shaped soft iron.
B --- Coils.
C --- Soft iron armature.
D --- Stop.
E --- Rigid Block.
F --- Guides.
S --- Spring Balance.

Results :-

Current in Coils	No. of pieces of Paper inserted.	Pull required.
2 amps.	None	32 lbs.
	1	24 "
	2	18 "
	3	11 "
	4	5 "
4 amps.	None	37 lbs.
	1	32 "
	2	25 "
	3	18 "
	4	10 "

Note :- A current of 2 amps gives a pull of 32 lbs. It might be expected that a current of 4 amps would give 64 lbs. instead of 37 as above, the number of turns in the coils remaining the same. This is explained by the fact that the electro-magnet reaches a state of magnetic saturation when an increase in current will not give an increased pull.

INSTRUMENTS.

The Moving Coil Instrument. (Fig. 23).

If a coil be suspended freely in the field of a permanent magnet and if now a current be passed through the coil there will be a turning effect exerted on the coil. This turning effect depends on the strength of the current in the coil and therefore this principle may be used to measure the current.

The magnet used is of the horse-shoe type with shaped pole pieces and an iron cylinder fixed between them. The coil moves around this cylinder and turns against a pair of hair-springs which also serve to lead the current to and from the coil.

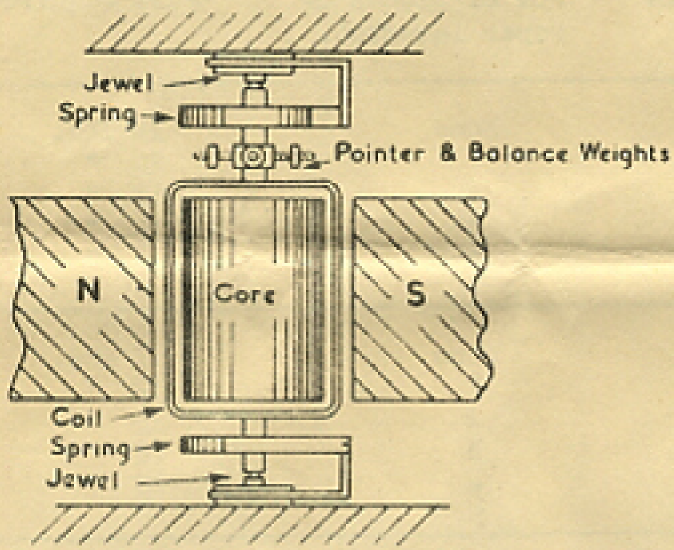
Advantages.

1. Owing to the intense magnetic field the number of turns required for the coil is small. Hence the moving parts are light, the instrument sensitive and the power absorbed small.
2. As the field in the air-gap is strong, the instrument is little affected by stray fields and in any case, the whole instrument is enclosed in an iron case to shield it from external magnetic fields.
3. It is remarkably dead-beat.
4. The action is not sluggish.
5. The scale is evenly divided.

Disadvantages.

1. Weakening of the springs and magnet with time.
2. Can only be connected in a circuit in one way - hence marked terminals - wrong usage bends pointer.
3. Despite precautions may be affected by change of temperature and by strong external magnetic fields.
4. Can be used only for D.C.

POINTER



ARRANGEMENT OF MOVEMENT OF M.C. INSTRUMENT.

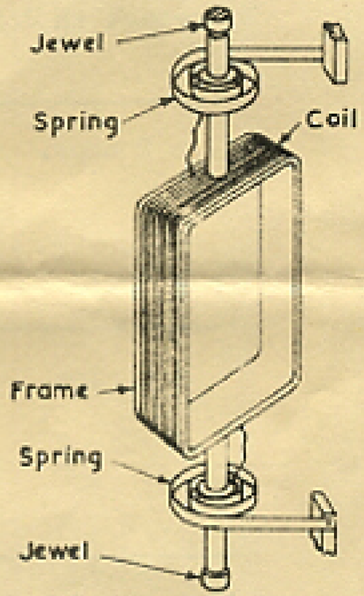
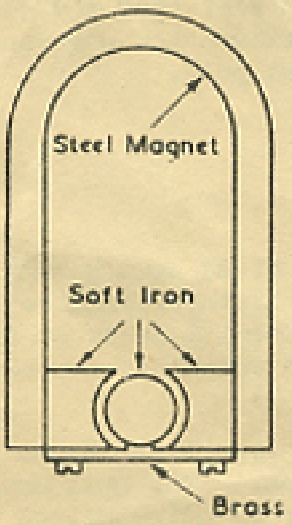


DIAGRAM OF MOVING COIL CONNECTIONS.



ARRANGEMENT OF MAGNET & CORE

DETAIL OF PIVOT

Fig 23

The Moving Iron Instrument.

(a) The Attraction Type (Fig. 24).

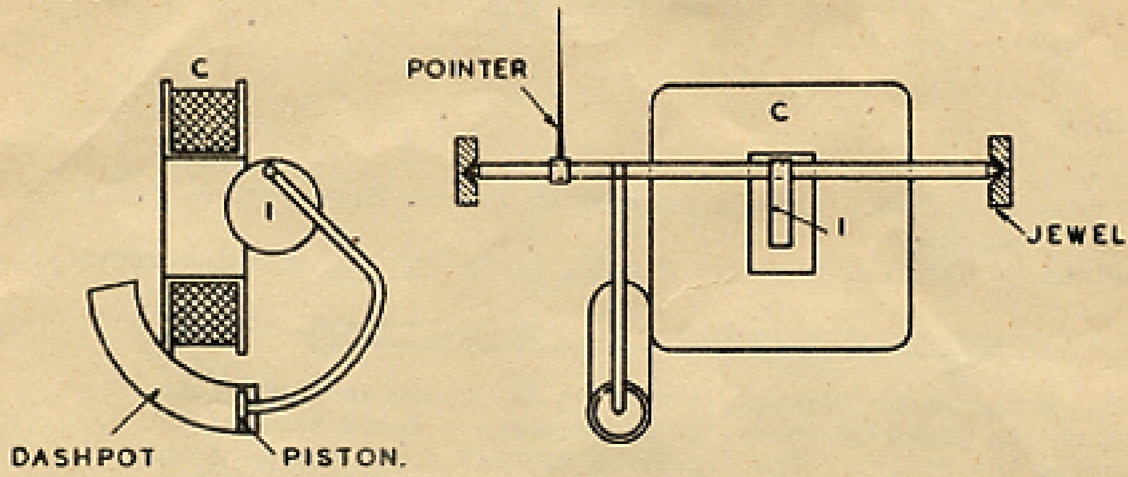


FIG.24. (3rd Angle Projection.)

The Attraction type depends on the principle that a piece of iron tends to move into the strongest part of a magnetic field in which it may be placed. In the Fig. above the coil C carries the current which is to be measured. The piece of iron I is mounted on a spindle which carries the pointer and a gravity control consisting of a bent arm to which is attached a piston moving in an air dash-pot. This device renders the instrument dead-beat.

(b)—The Repulsion Type (Fig. 25).

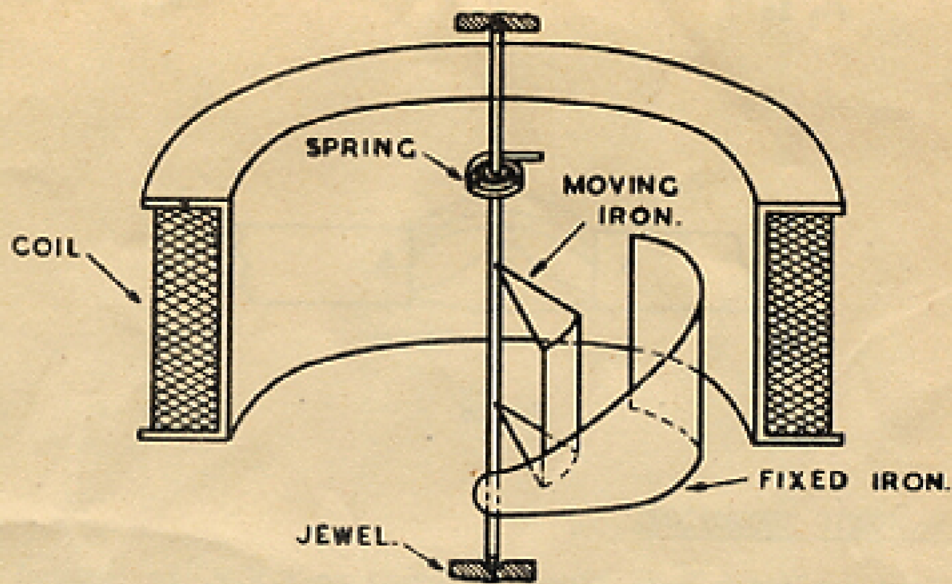


FIG. 25.

In the Repulsion type (above) two shaped pieces of soft iron are arranged inside the circular magnetising coil. One piece is attached to the spindle, the other is fixed. When current flows in the coil, both pieces of iron are similarly magnetised and the movable piece is repelled from the wide to the narrow end of the larger fixed piece. The movement is controlled by a flat hair-spring.

Advantages.

1. Robust construction, cheap.
2. No current in the moving parts, and therefore they can be built to carry the whole current in the fixed coil.
3. Can be used for A.C.

Disadvantages.

1. Tendency to read low.
2. Scale is not uniform - closely crowded at low readings - close again at upper readings.
3. Influenced by external magnetic fields, (iron case to minimise effect).

Effect of a Current-carrying Conductor in a Magnetic Field.

When a conductor carrying a current is placed in a magnetic field, across the lines of force, it experiences a force tending to move it across the field. The direction of this force can be found from field diagrams drawn as in Figs. 26, 27 and 28 or more simply by applying Fleming's Left Hand Rule.

"Extend the thumb, first and second fingers of the left hand at right angles to one another.

First finger - Field
SeCond finger - Current
ThuMb - Motion".

Fig. 26

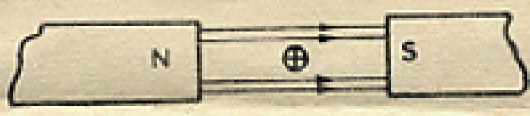


Fig. 27

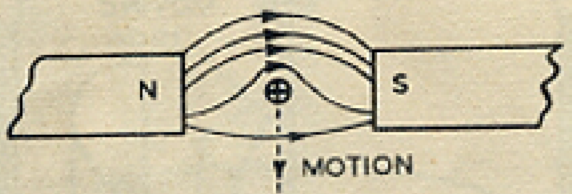


Fig. 28

ELECTRO MAGNETIC INDUCTION.

If a conductor cuts lines of force, an E.M.F. is induced in the conductor. (Faraday's Law).

The direction of this E.M.F. will be such as to oppose the change which produces it (Lenz's Law).

The direction can best be found by applying Fleming's Right Hand Rule.

If the conductor is part of a closed circuit, current will flow. There will be then a current-carrying conductor moving in a magnetic field and the conductor will experience a force, the direction of which can be found by using Fleming's Left Hand Rule. It will be seen that this force, called magnetic drag, is in the direction opposing motion. (Fig. 29). Thus an engine driving a dynamo must exert torque to overcome "drag". Dynamo and motor action occur at the same time.

Note :- Left Hand Rule for motor action - (motor cars keep to the left).
Right Hand Rule for induced E.M.F. (dynamo action).

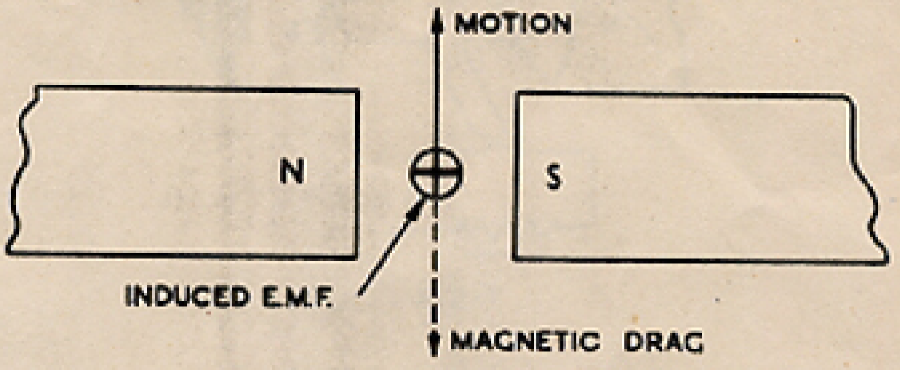


Fig.29

Parts of a Dynamo.

1. Stationary Field produced by self-exciting electro-magnets with cast steel cores and laminated soft iron pole shoes.
2. Rotating Conductors let into slots in an armature former which is built up of laminated soft iron stampings.
3. Commutator.

In practice the conductors are made to rotate between the poles of an electro-magnet. If the coil AB is rotated clockwise, the induced E.M.Fs. (by Fleming's Right Hand Rule) will be in the direction shown in Figs. 30 and 31 and the voltage at the terminals will follow the wave form of Fig. 32. This is an alternating E.M.F.

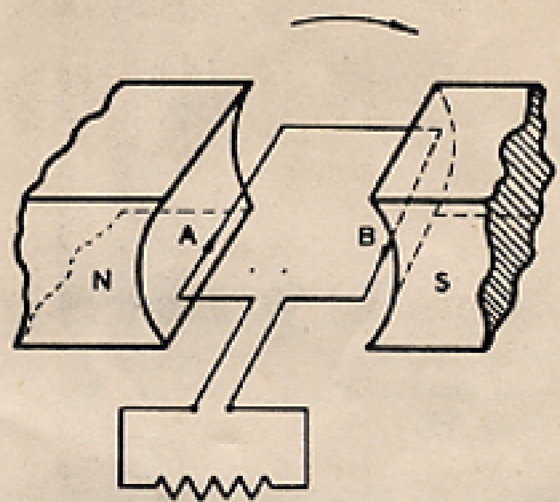


Fig 30.

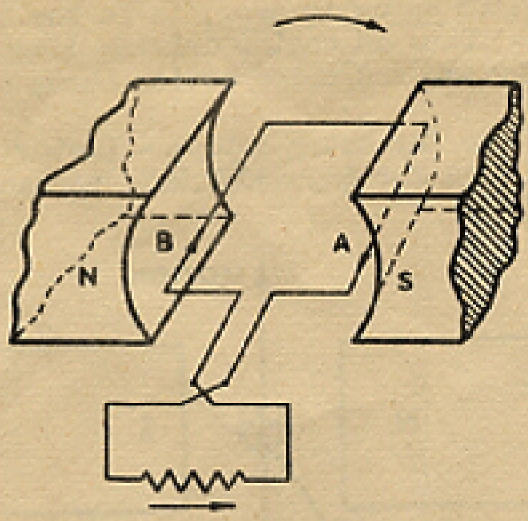


Fig.31.

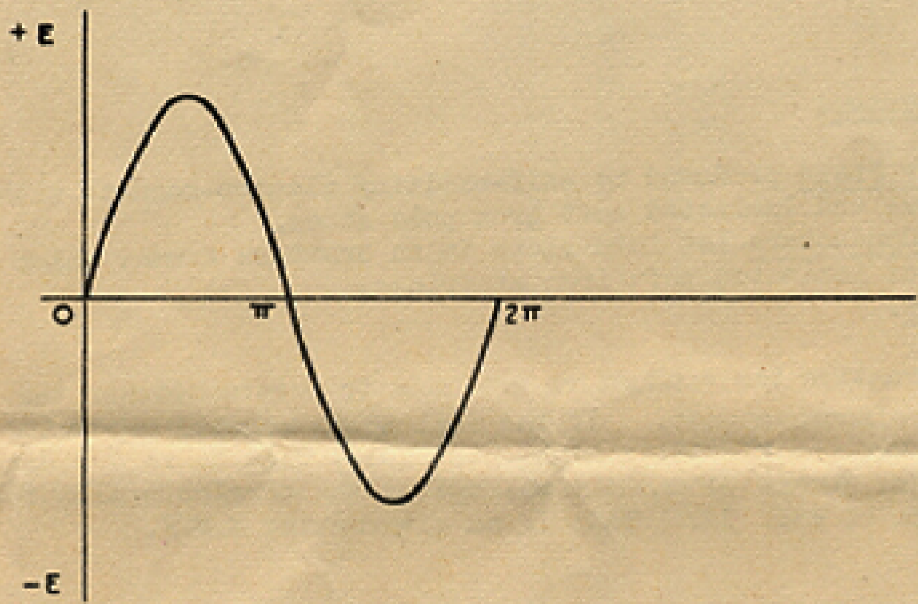


Fig. 32

If now the ends of the coil are soldered to two copper segments a and b, insulated from each other, which rotate with the coil, and brushes bear on these segments, it will be found that the current in the external circuit is unidirectional (Figs. 33 and 34) and the wave form is as shown in Fig. 35.

This arrangement of segments forms what is known as a Commutator.

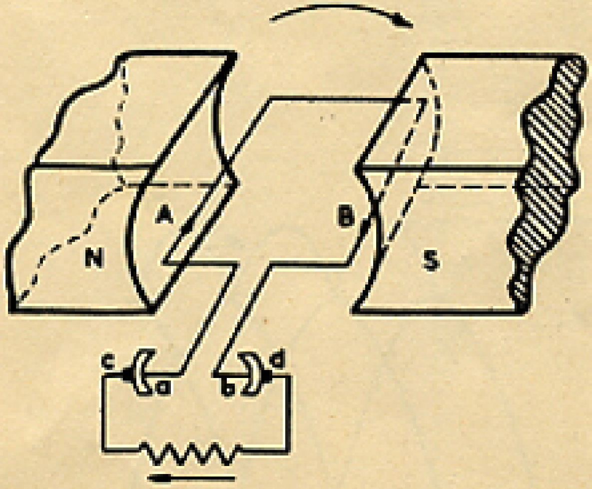


Fig.33.

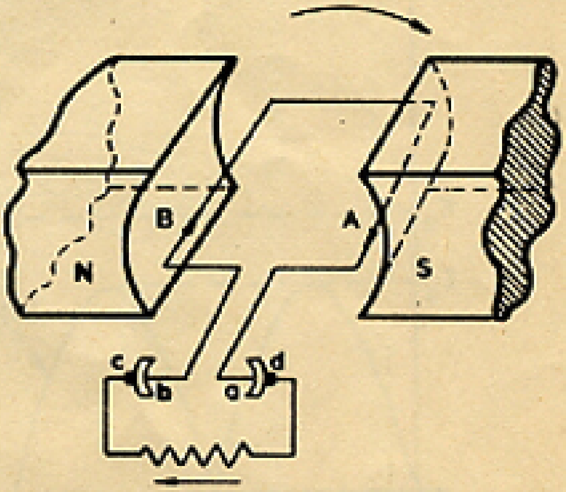


Fig.34.

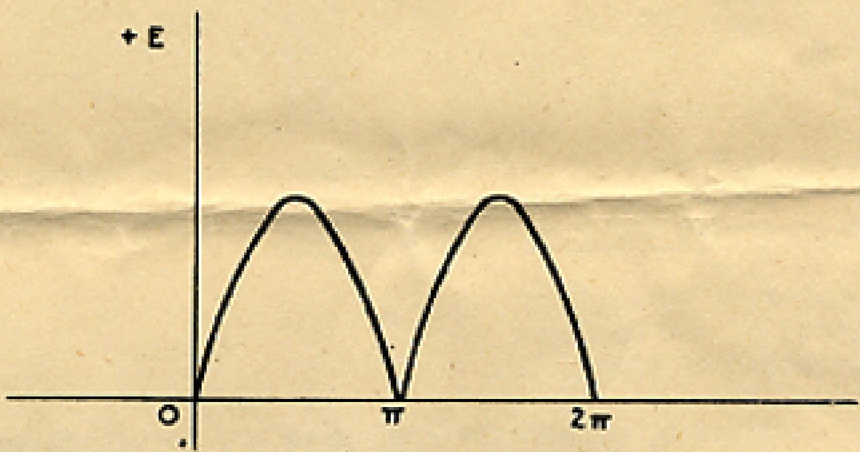


Fig 35

The E.M.F. obtained from a single coil would be rather small. It could be increased by having a coil of many turns, but this would cause a very big rise and fall in terminal voltage. A better method is to use a large number of conductors, equally spaced around the circumference and to connect each conductor in series with its neighbour by soldering the ends to adjacent commutator segments. Fig. 36 illustrates the effect of (a) a single coil (b) two coils at right angles (c) a large number of equally spaced conductors connected in series.

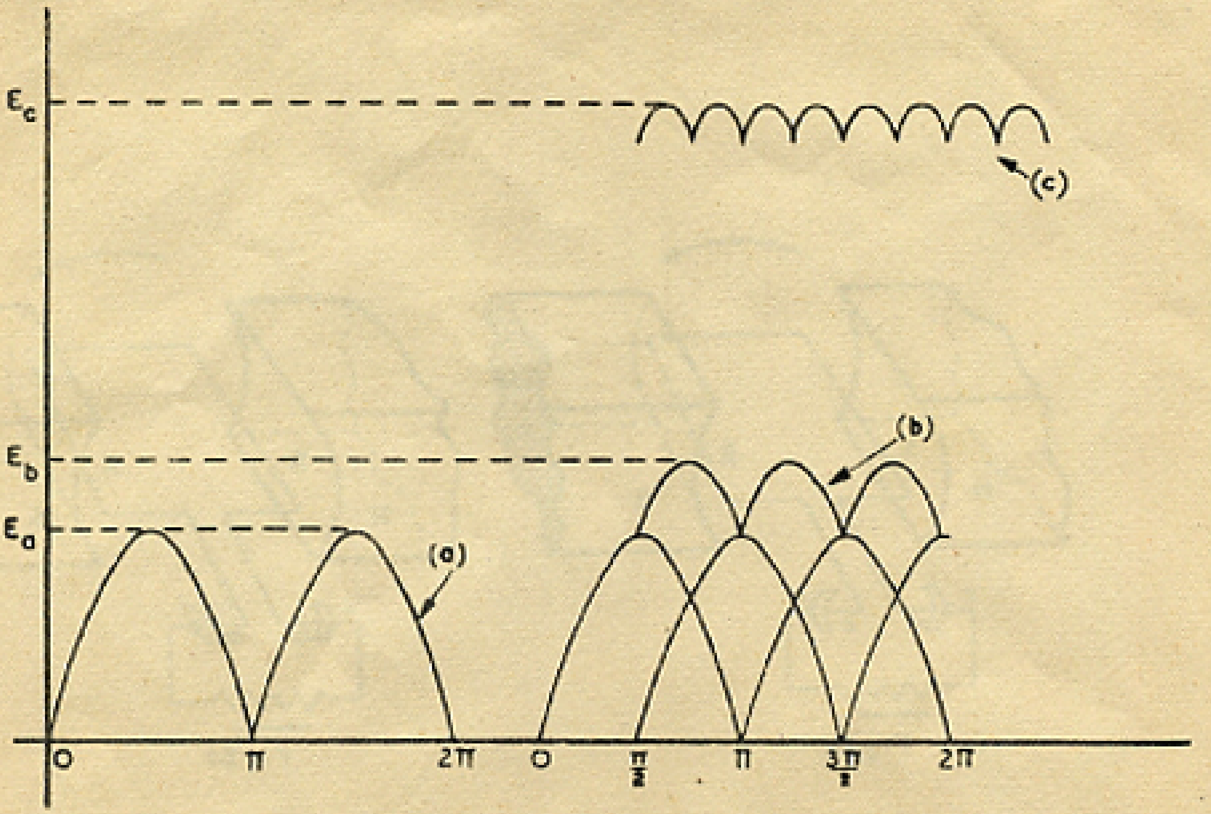


Fig. 36

The brushes are made of carbon to minimise the sparking of the machine.

Factors governing the E.M.F. of a Dynamo.

(1) Number of conductors.
(2) Speed of the machine.
(3) Strength of the Field.

Note :- Number of conductors and speed are incorporated in the design of the machine but the field strength can be varied by the use of a Field Regulator. This is the method used by the Switch Board Watchkeeper to keep a steady terminal voltage in H.M. Ships.

Types of Dynamo.

1. The Series Wound Dynamo.

This machine is not used in the Service because a big increase of load (current taken from the machine) produces a correspondingly big increase in terminal voltage.

2. The Shunt Wound Dynamo.

The field coils consist of many turns of fine wire connected across the armature, i.e. in parallel with the external circuit. As the load increases, the terminal voltage falls slightly, but this can be corrected by means of the Field Regulator which adjusts the field current. This is the method used in the Service and referred to above.

<u>The Shunt Protection Coil</u> consists of a high, non inductive resistance connected across the field regulator to provide an alternative path in case the regulator circuit is broken. All Service dynamos are fitted with shunt protection coils. (Fig. 37).

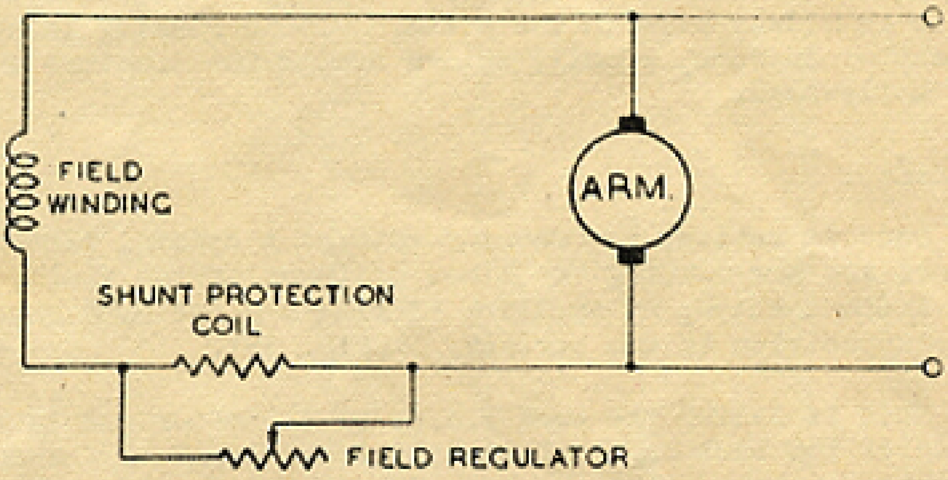


Fig 37

3. <u>The Compound Wound Dynamo.</u>

This is really a shunt wound dynamo with a few turns of thick wire in series with the armature and the external circuit, and wound to give a magnetic field in the same direction as that of the shunt windings. As the load increases, the series field increases and balances the drop in voltage found in the pure shunt machine. Such a machine gives an almost constant voltage over a wide range of loads without adjusting the field regulator (Fig. 38).

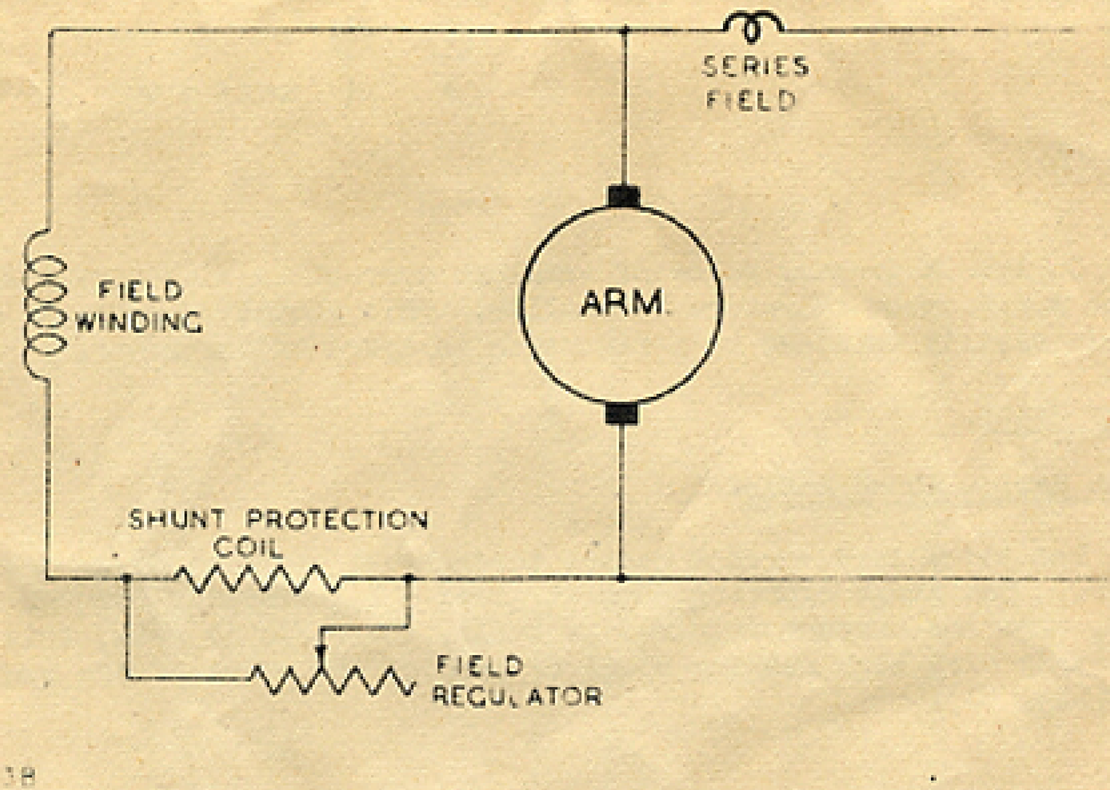


Fig 38

THE ELECTRIC MOTOR

Principle.

If a conductor carrying a current be placed in a magnetic field, across the lines of force, it experiences a force tending to move it across the field. The motor is a machine for converting electrical energy into mechanical energy. It is constructed similarly to the dynamo but is more robust. The conductors are carried in slots in the armature and the current changes direction by commutation when the conductor is midway between the poles. Smooth running is obtained by using many conductors, equally spaced around the armature which itself acts as a flywheel.

Back E.M.F.

Once in motion, the machine acts as a dynamo, since the armature conductors are now cutting the lines of force of the field, and an E.M.F. will be induced which, by applying Fleming's Right Hand Rule, is seen to be in opposition to the current. (Fig. 39).

This is called the back E.M.F. of the motor and it is the existence of the back E.M.F. that limits the value of the current taken by the motor. On no load the back E.M.F. is almost equal to the applied voltage and the current in the armature is very small.

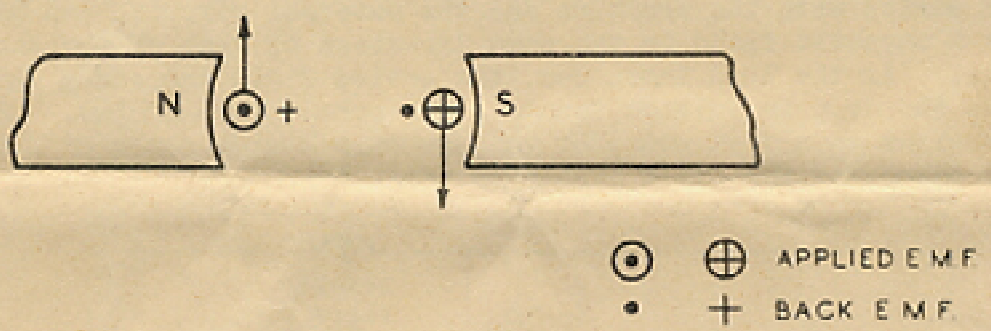


Fig 39

On load a greater value of armature current is necessary and the back E.M.F. must therefore be smaller. This reduction in back E.M.F. is usually obtained by a reduction in speed of the motor.

Types of Motor.

1. The Series Wound Motor.

The total load current passes through the field windings and the armature. The large starting current gives a big starting torque. On no load, when the current required is small, the field is weak, this results in a very high running speed to keep up the value of the back E.M.F. (Fig. 40).

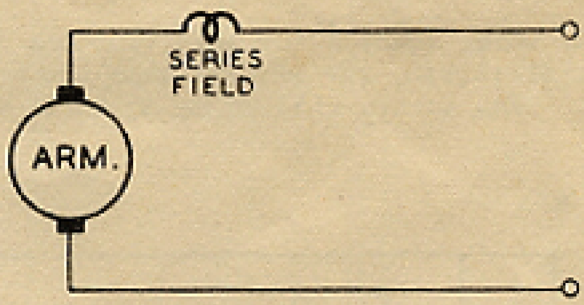


Fig 40.

Note :- (1) A series motor must be started always on load and must never be allowed to run light.
(2) Torque increases as field increases and as armature current increases.

2. The Shunt Wound Motor.

The shunt current is constant; armature current at start is greater than normal and this gives a fairly big starting torque and allows the motor to be started on load. It can also be started light, as it does not race badly under such conditions. The speed may fall by about 5% on full load. (Fig. 41).

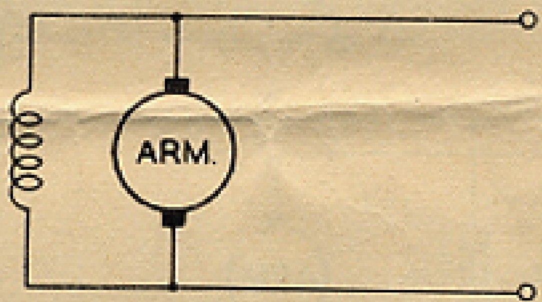


Fig 41

Note :- Under normal running conditions both series and shunt wound machines take a fairly heavy armature current. In the series motor this means that the field current is also large and therefore a small number of turns only is required for the field winding. In the shunt motor the field current is much smaller and many more turns are required in this case.

3. The Limiting Shunt Motor.

This is essentially a series wound motor with the addition of a small shunt winding which gives a field in the same direction as the series winding. The shunt turns provide sufficient field to prevent racing on no load (Fig. 42).

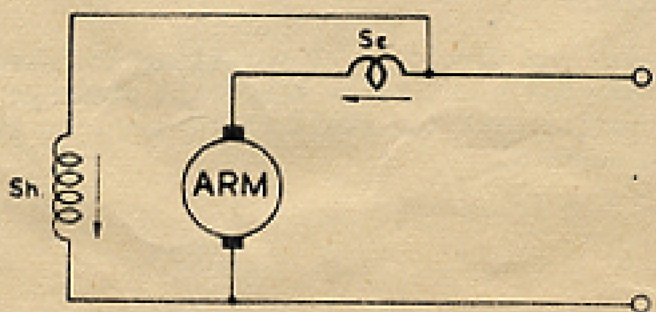


Fig 42

4. <u>The Cumulative Compound Motor.</u>

Like the limiting shunt motor this type has two windings giving fields in the same direction, but in this case the main field is that of the shunt winding. The series winding is added to improve the starting torque (Fig. 43).

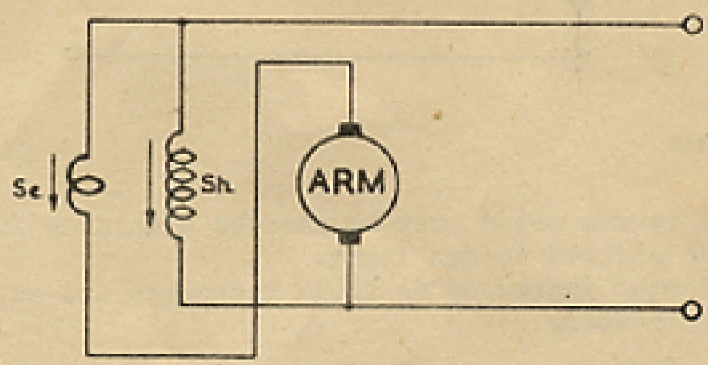


Fig 43

5. <u>The Differential Compound Motor.</u>

This type of motor, like the cumulative compound, has a main shunt field, but the series winding gives a field in the opposite direction to that of the shunt winding. This weakens the main field on heavy loads and thus counteracts the tendency of the shunt machine to drop off in speed as the load comes on. With careful compounding the speed remains almost constant at all loads (Fig. 44).

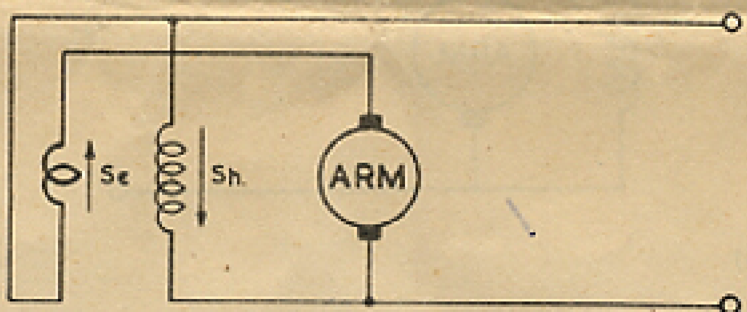


Fig 44

<u>Uses of Motors.</u>

(i) Series Type - electric traction, fan motors, cranes and variable speed jobs.
(ii) Shunt Type - workshop motors, pumps and small generators.
(iii) Limiting Shunt Type - capstan, boat hoist, ammunition hoist motors.
(iv) Cumulative Compound Type - trolley buses, heavy machinery.
(v) Differential Compound Type - bilge pump motors.

<u>Reversing of Motors.</u>

To reverse the direction of rotation, the direction of current is reversed in either the armature or the field windings, but not in both. Owing to difficulties with the field it is usual to reverse the direction of the armature current.

Speed Control of Motors.

Methods of speed control may be divided into three main groups :-

A. Methods depending on alterations in the field strength.
B. Insertion of resistance in the armature circuit.
C. Alterations in the supply voltage.

A. Alterations in the Field Strength.

(Note :- Speed increases as field is weakened and decreases as field is strengthened).

(1) Series Machines.

(a) By use of a Diverter.

This is a variable resistance connected across the field windings (Fig. 45). As the value of this resistance is decreased, more current passes through the resistance and less through the field windings. Thus the strength of the field is reduced and the motor speeds up.

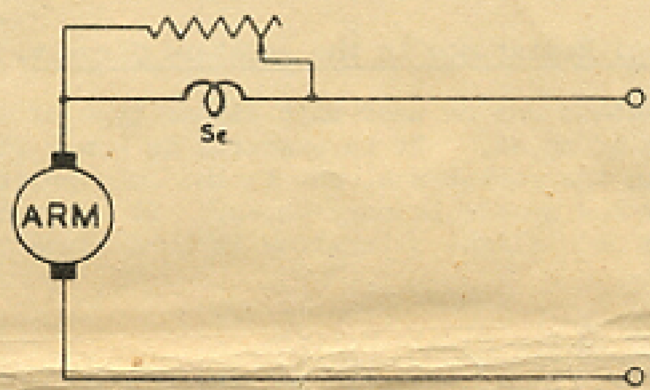


Fig 45

(b) By Re-grouping the Field Coils.

A four pole machine has four field coils and these can be connected (1) in series, (2) in series-parallel, (3) in parallel (Fig. 46). A diverter may be used with any one of these arrangements. Method (1) gives the strongest field and slowest speed, (3) gives the weakest field and the fastest speed.

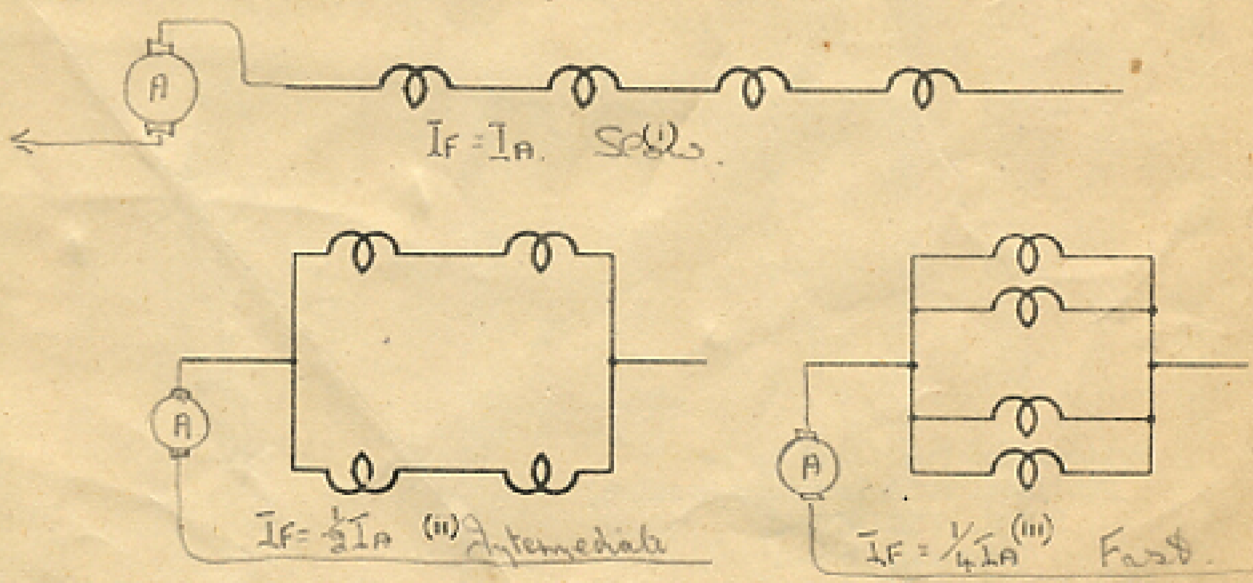


Fig 46

(2) Shunt Machines.

By use of a Field Regulator.

This is a variable resistance placed in series with the field coils. By increasing the value of this resistance the field current is reduced, the field weakened and the motor must speed up. (Fig. 47).

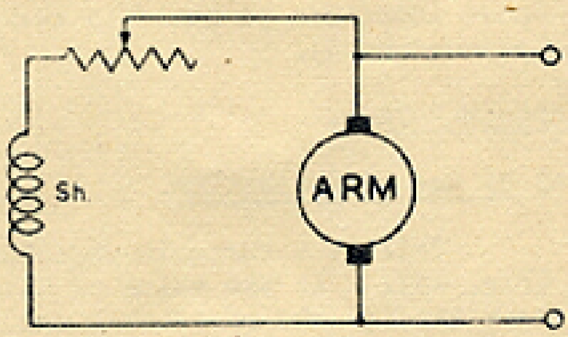


Fig 47

B. Insertion of Resistance in the Armature Circuit.

This method can be used with either type of motor and results in a reduction of speed. It is wasteful in power since there are large losses in the resistance, but is the only practicable way of obtaining very low speeds in many cases. It is unsatisfactory for shunt machines as a slight alteration in load leads to a big change in speed.

C. Alterations in the Supply Voltage.

In the Ward-Leonard system which is applied to forward capstan motors, a separate generator is used, driven from the ship's mains by a shunt wound motor. This generator supplies current to the armature of the actual capstan motor, the field of which is excited from the mains, and the voltage supplied can be varied by the use of the field regulator of the dynamo. This is a very flexible method of speed control, but the first cost is high, as three machines have to be used.
(Note :- The speed of such a motor is very nearly proportional to the applied voltage; hence the wide variation obtained by this method).

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