

Ch-1 Electrolytic Process

①

Electrolyte

- The substances which decompose when an electric current is passed through them are called electrolyte.
- The process of decomposition of electrolytic process or electrolysis.
- Electrolytes are generally in the liquid form.

Electroplating

The process of depositing a metal on the surface of some other metal by electrolysis is called electroplating.

Need of Electroplating

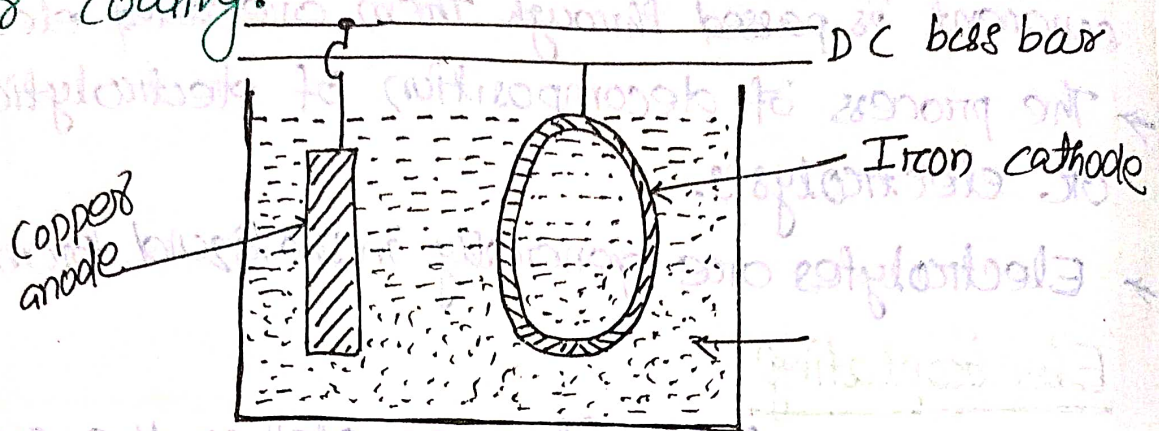
- (i) To protect the metal against corrosion.
- (ii) To give shining appearance to the articles.
- (iii) To give reflecting properties to the reflectors.
- (iv) To replace worn out material from a casting.

Basic Principle of Electrodeposition

- When two electrodes are dipped in an electrolyte and potential is applied across them, the electrodes are named as positive or anode and negative or cathode.
- The molecules of the substance dissolved are dissociated and broken down into +ve and -ve ions.
- The -ve ions appear at the anode and termed as anions, the +ve ions appear at the cathode and are termed as cations.

② Pure liquid like water do not suffer any decomposition when electricity is passed through them and are called as anions.

Q Discuss the process where a ring of iron is to be given a copper coating.

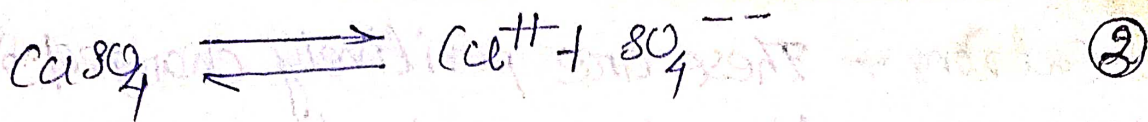


→ The sulphate solution readily breaks into positive ions Cu^{++} , which are deficit in two electrons per ion and SO_4^{--} negative ions having two surplus electrons per ion.

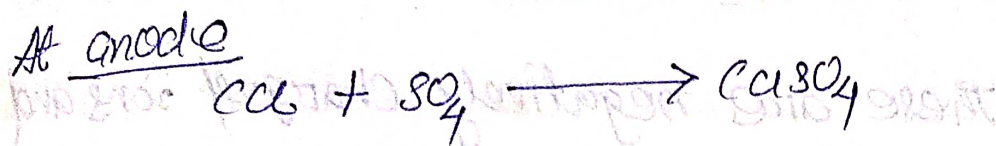
→ When a dc supply is given to both the electrodes then SO_4^{--} ions move towards the anode made of copper. Each SO_4^{--} ion after transferring two electrons to the anode becomes SO_4 radical.

→ It attacks the copper anode to form CuSO_4 molecule which dissolves once again in water to maintain the original electrolyte density.

→ The +ve copper ion reach the -ve electrode (cathode) and receives two electrons from the supply ckt to become Cu atoms this get deposited on the cathode is said to be copper plated.



At anode



At cathode

Cu^{++} plus two electron = metallic Cu atom to be deposited on the metallic cathode surface.

The phenomenon of deposition of a metallic coating on the surface of some other metal, through the process of electrolysis is called electroplating or electrodeposition.

Important Terms of Electrolysis :-

- (i) Electrolyte $\rightarrow$ The solution of a salt when used for electrolytic process is called an electrolyte.
- (ii) Electrodes $\rightarrow$ The plates or rods immersed in an electrolyte and connected to dc supply are called electrodes.
- (iii) Anode $\rightarrow$ The electrodes connected to the +ve terminal of the supply is called anode.
- (iv) Cathode $\rightarrow$ The electrodes connected to the -ve terminal of the supply is called cathode.
- (v) Ions $\rightarrow$ when a direct current is passed through an electrolyte it gets chemically decomposed into two parts known as +ve and -ve ions.

(vi) Cations $\rightarrow$ These are positively charged ions and they move towards the cathode. (4)

(vii) Anions $\rightarrow$ These are negatively charged ions and they move towards the anode.

(viii) Chemical equivalent weight $\rightarrow$ chemical equivalent weight of a substance may be defined as the ratio of its atomic weight and valency.

$$\text{Chemical Equivalent} = \frac{\text{Atomic weight}}{\text{valency}}$$

(ix) Electro chemical equivalent $\rightarrow$ Electro chemical equivalent of a substance is the amount deposited on passing a steady electric current of one ampere for one second through its solution.

(x) Atomic weight $\rightarrow$ The atomic weight of an element is a number which is the average of the masses of its various isotopes weight relative to their abundance or the atomic weight is the ratio of the weight of an atom of the element to the weight of an atom of hydrogen.

(xi) Valency $\rightarrow$ The valency of an atom or a group of atoms is the number of hydrogen atoms with which it will react chemically.

Application of Electrolysis : $\rightarrow$

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① Extraction of Metal from their Ores $\rightarrow$

① Ore + strong acid $\longrightarrow$ salt

salt solution $\xrightarrow{\text{Electrolysis}}$ metals

② Molten state ore $\xrightarrow[\text{in furnace}]{\text{Electrolysis}}$ Metals

② Extraction of zinc $\rightarrow$

zinc oxide + concⁿ sulphuric acid

roasted and $\longrightarrow$ zinc sulphate
passed through various

chemical process



impurities

cadmium copper

zinc sulphate solution $\xrightarrow{\text{Electrolysis}}$ zinc is deposited on the cathode.

Anode $\rightarrow$ Lead

cathode $\rightarrow$ Aluminium

The electrolysis process is takes place in wooden box with inner lining of lead.

③ Extraction of Aluminium $\rightarrow$

⑥

Ores of aluminium are

Chemical Process $\rightarrow$

bauxite, cryolite, barcuite

$\rightarrow$ Aluminium oxide.

Aluminium oxide + fused cryolite Electrolysed $\rightarrow$

aluminium deposited at the cathode

The furnace is lined with carbon. The temp of furnace is about 1000°C , requires a voltage of 8 volt and a current about 45000 Amp. Since electrolytic process requires a great amount of power, such plants are located near the hydro electric power station.

④ Refining of Metals $\rightarrow$

* The metal extracted from the ore not that much pure. Purity copper obtained 98% but the purity of copper for electrical applications should be 99.95%.

* The copper sulphide is taken as electrolyte anode as impure copper extracted and after electrolysis the pure copper is deposited on the cathode at regular interval the pure copper is remove from the cathode and anode replaced when ever required.

⑤ Production of chemicals → Many chemicals such as caustic soda, chlorine gas, ammonium sulphate, hydrogen, oxygen produced by electrolysis on large scale.

⑥ Separating Metals from their compounds → Metals are separated by their compound by means of electrolysis for example the ore of aluminium contains FeO , aluminium oxide, silica and Iron oxide. First pure aluminium oxide is obtained by suitable treatment and pure aluminium is obtained by electrolytic process.

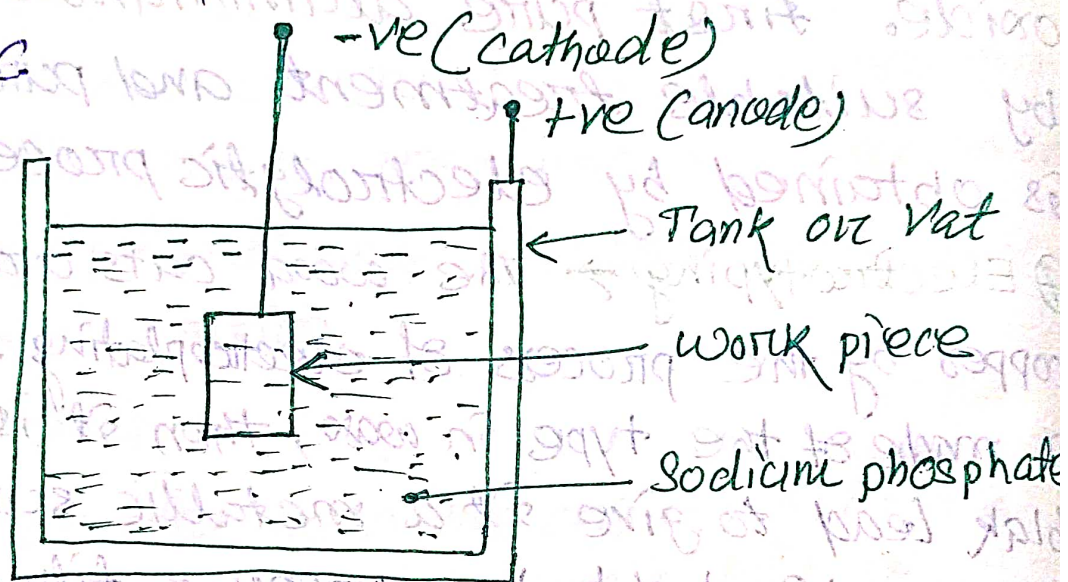
⑦ Electrotyping → The wood cuts are reproduced in copper by the process of electroplating. First the mould is made of the type in wax, then it is coated with black lead to give it a metallic surface and then it is subjected to the process a film of copper is formed on the prepared surface.

⑧ Electroforming → The production or reproduction of an article by electrodeposition is known as electroforming. In the production of coins, medals etc mould is first made by having an impression of point on wax surface which has exact impression of the object is coated with powdered graphite in order to make it conducting. The mould is then dipped in an electroforming cell as a cathode.

After obtaining coating of desired thickness the object is removed and the wax is melted out of the metal shell.

⑨ Electro deposition → Electrodeposition is the process of depositing a metal over another metal or nonmetal by electrolysis. An electroplating is a very common example of such a process.

⑩ Electro cleaning → The articles before electroplating should have a surface free from grease oil etc.



A solution of sodium phosphate is used as an electrolyte in the plating tank. The tank is connected to +ve terminal and the work piece to be cleaned is connected to the -ve terminal. Heavy current is passed through the solution and caustic soda is produced on the cathode which has a cleaning action. Hydrogen gas evolved at the cathode which removes the grease quickly. This process is called cathodic cleaning and is applicable to zinc and aluminium.

Faraday's Law's of Electrolysis : $\rightarrow$

⑨

1st Law $\rightarrow$ The weight of a substance liberated from an electrolyte in a given time is proportional to the total quantity of electricity passed in that time.

$$W \propto Q$$

$$W \propto I \cdot T$$

$$W = ZIT$$

$W \rightarrow$ weight of substance liberated in gm.

$Q \rightarrow$ Quantity of electricity passed,

$I \rightarrow$ Strength of current in ampere

$T \rightarrow$ Time of current flow in sec.

$Z \rightarrow$ A constant called electrochemical equivalent of substance

$$\text{If } I = 1A \quad T = 1\text{sec}$$

$$W = Z$$

Electrochemical equivalent of a substance is the amount of that substance by weight liberated in a unit time by the passage of unit current.

unit of ECE is mg/coulomb or gram/coulomb

$$Z = W \text{ mg/Coulomb}$$

(10)

$$= W \text{ mg/A. sec}$$

$$= W \times 10^{-3} \times 10^{-3} \times 3600 \times 10^3$$

$$= 3.6 W \text{ kg / 1000 A. Hr}$$

2nd Law → If the same current flows for a given time through several electrolytes, the weights of substance liberated are proportional to their chemical equivalents.

$$\text{Chemical equivalent} = \frac{\text{Atomic weight of substance}}{\text{valency}}$$

According to this law if we take two electrolytes of copper sulphate and nickel sulphate in which same current flows for the same time then

weight of copper deposited by given quantity of electricity

weight of nickel deposited by same quantity of electricity

Chemical equivalent of copper

Chemical equivalent of nickel

$W_{\text{copper}} \propto \text{Chemical equivalent of copper}$

$W_{\text{nickel}} \propto \text{Chemical equivalent of nickel}$

Current Efficiency : $\rightarrow$

(11)

Due to impurities which cause secondary reactions, the quantity of a substance liberated is less than that calculated from Faraday's law i.e.

$$\text{Current efficiency} = \frac{\text{Actual quantity of substance liberated}}{\text{Theoretical quantity}}$$

The current efficiency lies between 90 to 98%.

Energy Efficiency : $\rightarrow$

On account of secondary reactions the actual voltage required for the deposition or liberation of metal is higher than the theoretical value which increases the actual energy required.

Energy efficiency is defined as the ratio of theoretical energy required to the actual energy required.

$$\text{Energy Efficiency} = \frac{\text{Theoretical Energy}}{\text{Actual Energy Required}}$$

voltage : $\rightarrow$

The voltage required for the passage of the current through an electrolyte depends upon the potential drops of the electrodes and in the electrolyte.

$$W = ZQ$$

(12)

$$W = ZIT$$

$$\text{density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Volume of substance deposited} = \frac{\text{Weight}}{\text{Density}}$$

$$\text{Volume} = \text{Area} \times \text{Thickness}$$

Q. If a current of 10 amperes deposits 13.42 gm of silver from a silver nitrate solution in 20 minutes calculate the electro chemical equivalent of silver.

Ans $I = 10 \text{ Amp}$

$$T = 20 \times 60 = 1200 \text{ sec}$$

$$W = 13.42 \text{ gm}$$

$$W = ZIT$$

$$\Rightarrow Z = \frac{W}{IT}$$

$$= \frac{13.42}{10 \times 1200}$$

$$= 1.118 \times 10^{-3}$$

$$= 0.001118 \text{ gm/coulomb.}$$

Q. Calculate the quantity of electricity and the steady current required to deposit 5 gm. copper sulphate solution in one hour. Electrochemical equivalent of copper is 0.3294 mgm/coulomb. (13)

Ans $Z = 0.3294 \text{ mgm/coulomb} = 0.329 \times 10^{-3} \text{ gm/C}$

$W = 5 \text{ gm}$

$T = 1 \text{ hr} = 3600 \text{ sec}$

$W = ZQ$

$Q = \frac{W}{Z} = \frac{5}{0.329 \times 10^{-3}} = 15179.11 \text{ Coulomb}$

$Q = IT$

$I = \frac{Q}{T} = \frac{15179.11}{3600} = 4.21 \text{ Amp.}$

Q. Find the thickness of copper deposited on a plate of 2.25 cm^2 during electrolysis if a current of 1 ampere is passed for 100 minutes. Density of copper is 8.9 gm/cc and ECE of copper is $0.0003295 \text{ gm/coulomb}$.

Ans $A = 2.25 \text{ cm}^2$

$I = 1 \text{ A}$

$T = 100 \text{ min} = 6000 \text{ sec}$

density of copper = 8.9 gm/cc

ECE = $0.0003295 \text{ gm/coulomb}$

$W = ZIT$

$= 0.0003295 \times 1 \times 6000$

$= 1.977 \text{ gm.}$

$$\text{volume} = \frac{\text{weight}}{\text{density}}$$

$$= \frac{1.977}{8.9}$$

$$= 0.222 \text{ cm}^3$$

$$\text{thickness} = \frac{\text{volume}}{\text{Area}}$$

$$= \frac{0.222}{2.25}$$

$$= 0.098 \text{ cm}$$

Q. A rectangular metal plate having $5 \text{ cm} \times 4 \text{ cm} \times 1 \text{ cm}$ as its dimensions is to be electroplated with nickel. How long will it take to deposit a layer of 0.1 mm thickness, when a current of 4.3 amperes flows through the circuit?

Ans

Volume of the metal plate before electroplating

$$V = 5 \times 4 \times 1 = 20 \text{ cc.}$$

Final volume of metal plate after electroplating

$$= 5.02 \times 4.02 \times 1.02$$

$$= 20.584 \text{ cc}$$

volume of nickel deposited

$$= 20.584 - 20 = 0.584 \text{ cc}$$

$$w = \text{volume} \times \text{density}$$

$$= 0.58 \times 8.6 \text{ gm}$$

$$= 4.988 \text{ gm}$$

$$W = ZIT$$

(15)

$$\begin{aligned} \Rightarrow T &= \frac{W}{IZ} \\ &= \frac{4.988}{4.3 \times 0.000304} \\ &= 3815.78 \text{ CC} \end{aligned}$$

Electrodeposition : $\rightarrow$

The process of depositing metal over another metal or non metal by electrolysis is known as electrodeposition.
e.g:- Electroplating

Factor Effecting the amount of Electrodeposition :-

① Time :- Time $\propto$ Quantity of electrodeposition.

More mass will be deposited in more time and less mass will be deposited in less time for other conditions remain same.

② Efficiency :- Greater is the efficiency, greater is the quantity of metal deposited for a given time.

③ Current :- Current $\propto$ Mass of metal deposited

Greater is the current greater is the quantity of metal deposited while other conditions remain the same. But if the current is increased beyond a certain limit which is fixed for different metals separately, the metal deposited will be of different colours such as blackish which is called burnt metal.

④ Strength of solution:- If strength of solution is more then mass of metal deposited will be more (16) as compare to the dilute solⁿ of electrolyte if the other conditions remain the same.

Factors Governing the Better Electro Deposition:-

(i) Current Density:-

At low value ions are released at slow rate, deposit will be coarse and crystalline in nature.

At high value quantity of deposit becomes more uniform and fine grained.

If current density is so high that exceeds the limit then spongy and porous deposit is obtained.

Current density means current per unit area.

i.e.
$$\text{current density} = \frac{I}{A}$$

(ii) Electrolytic Concentration:-

Increase in concentration of electrolyte gives higher current density and get better deposit.

(iii) Temperature:-

The temperature of electrolyte is different for different metals to have better deposit.

Chromium plating the temperature is maintained at 35°C . In copper plating at 50°C and in nickel plating it is between 50°C to 60°C . (17)

(iv) Addition of Agents :-

Addition of agents like organic compounds such as gums, rubber, alkalines and sugar etc increases the quality of deposit, the additional agents are supposed to be absorbed by crystal nuclei and prevent their growth in to large crystals.

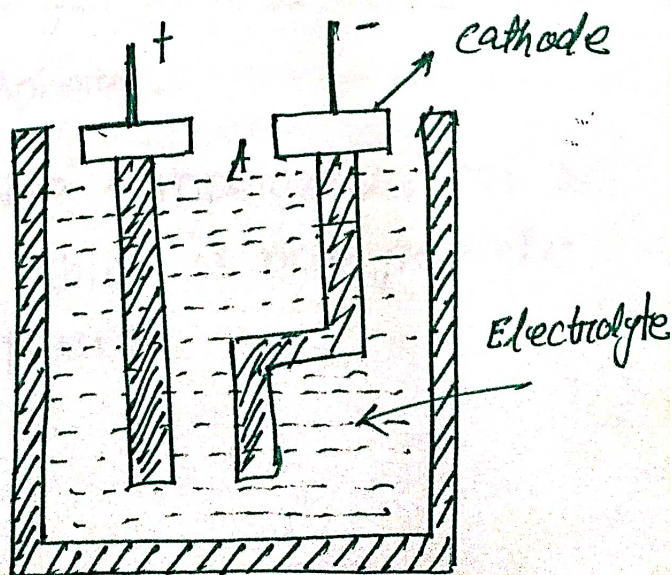
(v) Nature of Electrolyte :-

The smoothness of the deposit largely depends upon the nature of electrolyte. For example silver from silver nitrate solution forms a rough deposit while that from cyanide solution forms a smooth deposit.

(vi) Nature of the metal upon which deposit is to be made :-

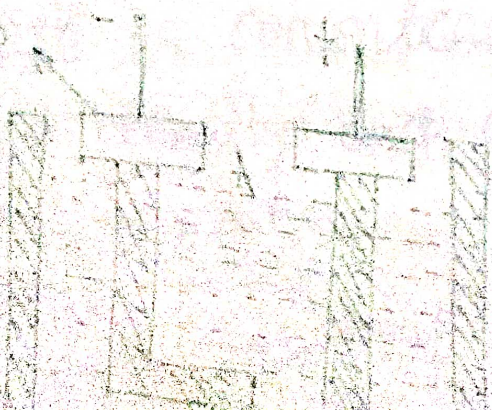
These factors influence the growth of crystal since it is believed that the operation of crystal is in continuation of these on the base metal.

(vii) Throwing Power :-



In the given diagram the surface of AB is far from the anode than the surface CD. Therefore resistance to ~~be~~ current path from anode to AB is more than that in case of CD hence the thickness of the deposit on the surface AB will be smaller. The throughing power can be improved by two methods

- (i) By increasing the distance between the object and the anode so that the relative variation in resistance between the anode and the different part on the object is reduced.
- (ii) By using some colloidal matter which results in the increase of current density.



Ch-20 Electrical Heating

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Electric heating is based on the principle that when electric current passed through a medium (solid, liquid and gas) heat is produced.

when current 'I' passes through any ckt having $R \Omega$ then power dissipated in that circuit is $I^2 R$ watts.

If the current flows for T sec then energy consumed is $I^2 R T$ joules/watt sec. This energy is being converted into heat and can be worked out as

$$H = \frac{I^2 R T}{4.2} \text{ Calories}$$

$$= 0.24 I^2 R T \text{ Calories}$$

when 4.2 is a constant called as mechanical equivalent of heat.

Advantages of Electrical Heating:

① Clean and Neat Atmosphere $\rightarrow$ Electrical heating is free from dust and smoke. The operator do not go black while operating an electrical heat appliance.

② No Pollution $\rightarrow$ No flue gas is there. Hence do not result in pollution of atmosphere.

③ Controlled Temperature $\rightarrow$ The temperature can be controlled within $\pm 5^\circ\text{C}$ which is not possible in non electrical heating process.

④ Ease of control → The heating can be started instantaneously or stopped at a required time keeping a time gap between switching off and cooling of the heating circuit. Automatic switching controls are possible.

⑤ Localised Application → A workpiece can be heated up to ~~particular~~ particular depth for heat treatment where as the piece as a whole receives heat in non electrical heating process.

⑥ Low Ambient Temperature → The temperature around an electrical furnace is much lower as compared to that around non electrical furnace which is ~~troublesome~~ troublesome for the workers.

⑦ Uniform Heating → Uniform heating can be generated through induction heating process.

⑧ Heating of bad conductor of Heat and Electricity → Wood, plastic and bakery items can uniformly and suitably heated with dielectric heating process.

⑨ Highest Efficiency of Utilisation → Heat produced electrically does not go waste through chimney or other by products. Most of the heat is utilised on heating the material hence results in high efficiency.

⑩ Cheap Furnance → Installation do not take big space, do not require any storage of coal and fire wood, no chimney needed, no extra heat insulation necessary.

⑪ Mobility of Job → Pieces undergoing heat treatment can be mounted on a conveyor passing through the heating cabinets making use of electric heaters.

Mode of Heat Transfer: →

(i) Conduction

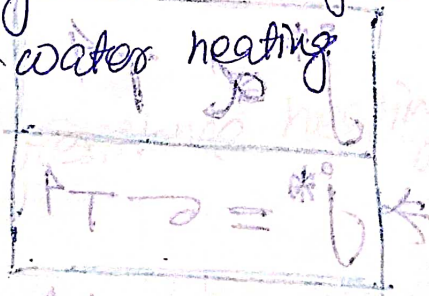
(ii) Convection

(iii) Radiation.

Liquids are heated by convection method solids by conduction method and distant objects are heated from the source of heat by radiation. Heat of sun reaches to us by radiation.

Domestic Application of Electric Heating: →

- ① Room heaters for heating the building
- ② Immersion heaters for water heating
- ③ Hot plates for cooking
- ④ Geyers
- ⑤ Electric kettles
- ⑥ Hot air driers
- ⑦ Electric Iron
- ⑧ Coffee percolators
- ⑨ Popcorn plant
- ⑩ Electric ovens for baking products
- ⑪ Electric Toasters



Industrial Applications of Electric Heating →

(22)

- ① Melting of metals
- ② Heat treatment of metals like annealing, tempering, soldering, Brazing and case hardening etc
- ③ Electric welding
- ④ Moulding of glass for making glass appliances
- ⑤ Enamelling of copper conductors
- ⑥ Heat treatment of painted surfaces
- ⑦ Making of plywood.

Stefan's Law / Stefan Boltzman Law

It states that the total energy radiated per unit surface area of a black body across all wave lengths per unit time is directly proportional to the fourth power of black bodies thermodynamic temperature (T) .

$$\begin{array}{|c|} \hline j^* \propto T^4 \\ \hline j^* = \sigma T^4 \\ \hline \end{array}$$

σ = stefan boltzmann constant
or stefan constant

$$\sigma = \frac{2\pi^5 k^4}{15c^2 h^3} = 5.670373 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$$

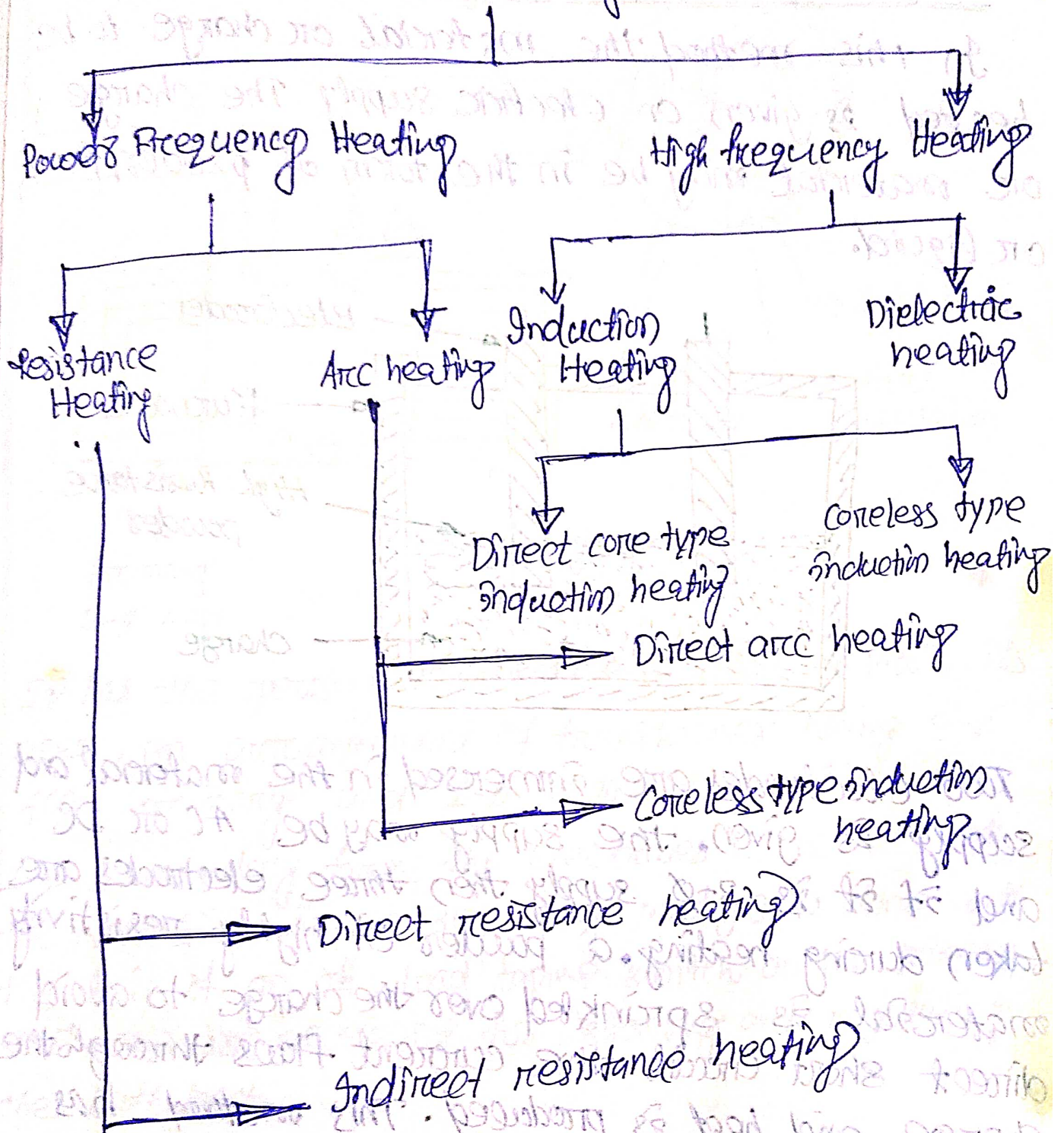
k = boltzmann constant

h = planck's constant

c = speed of light in vacuum.

Electric Heating

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Resistance Heating

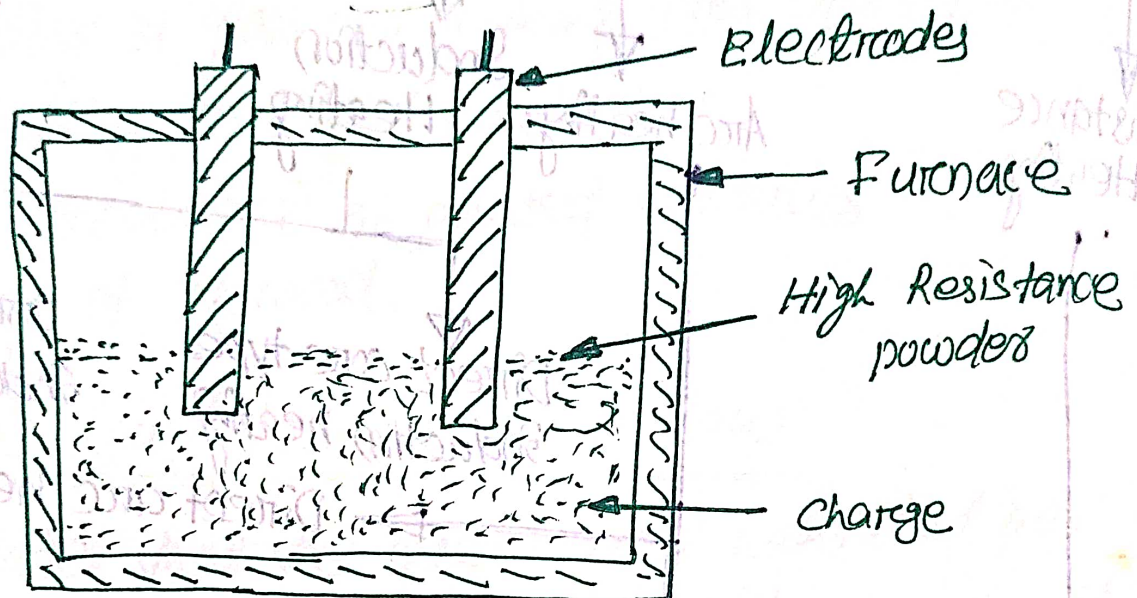
When a current is passed over any resistive material then heat is produced due to IR^2 loss.

- Two type
- (i) Direct Resistance Heating
 - (ii) Indirect Resistance Heating

* Direct Resistance Heating

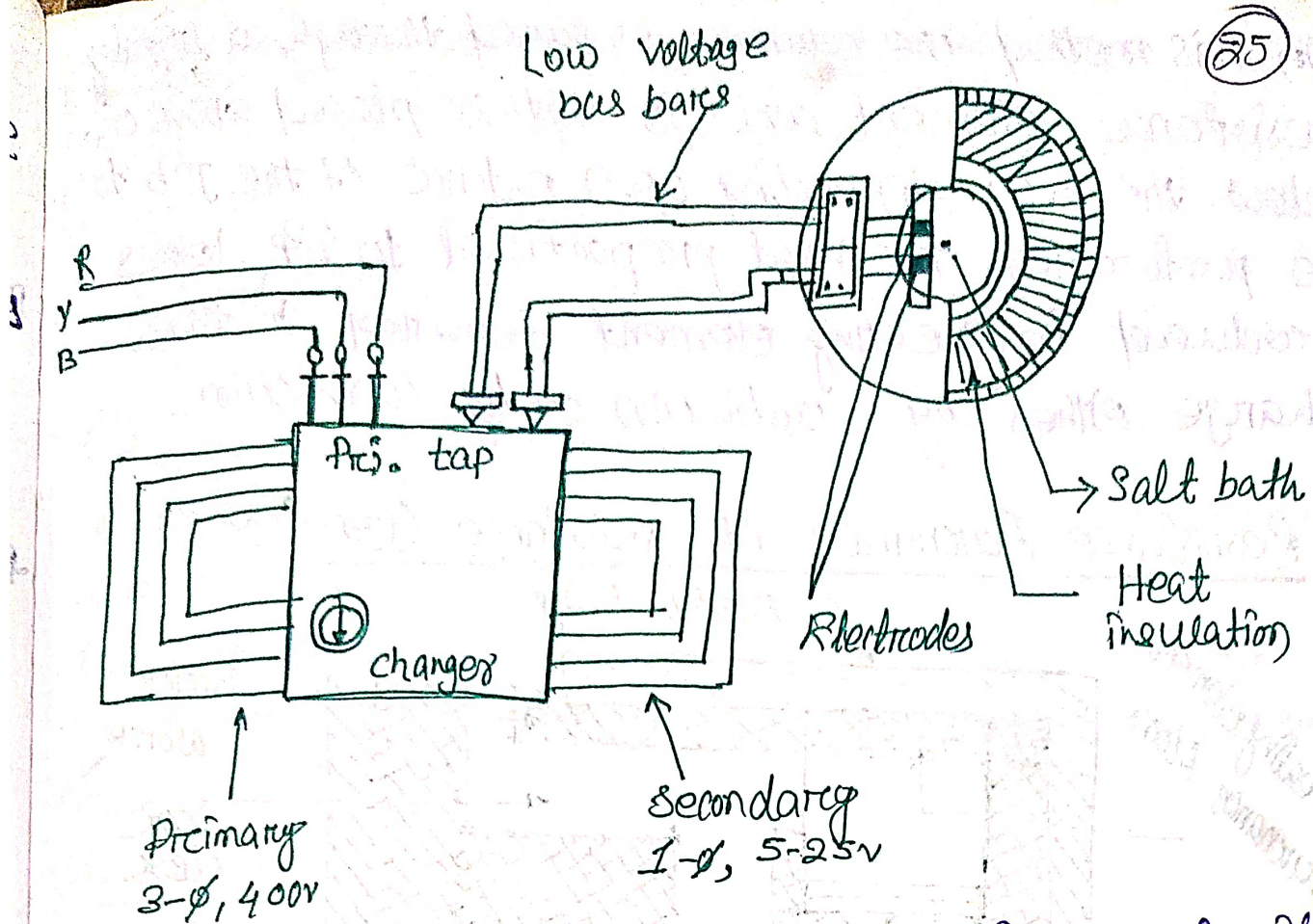
(24)

In this method the material or charge to be heated is given on electric supply. The charge or material may be in the form of powder, pieces or liquid.



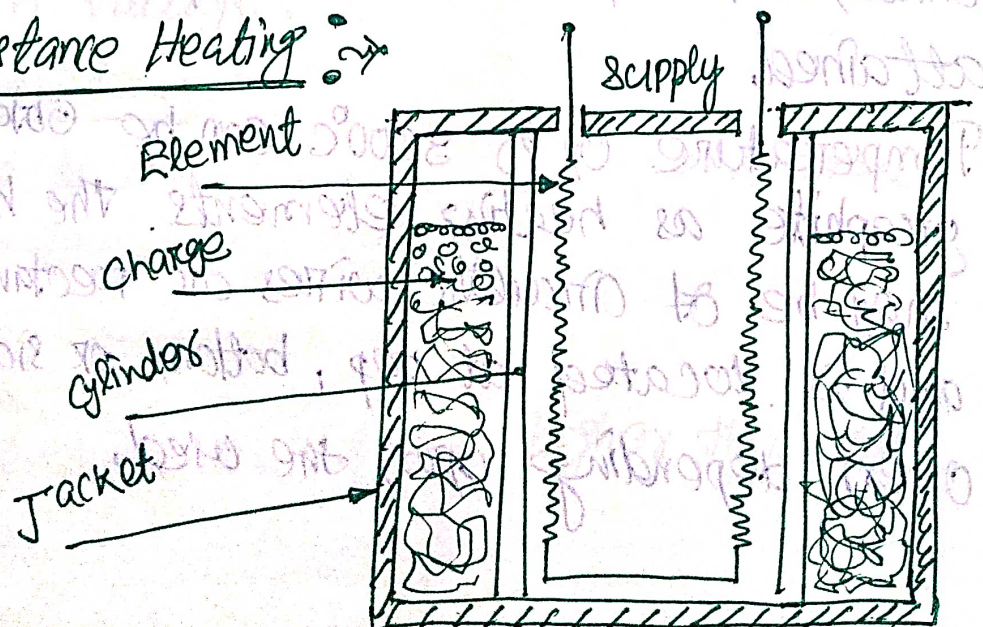
Two electrodes are immersed in the material and supply is given. The supply may be AC or DC and if it is 3- ϕ supply then three electrodes are taken during heating. A powder of highly resistivity material is sprinkled over the charge to avoid direct short circuit. The current flows through the charge and heat is produced. This method has high efficiency since heat is produced in the charge itself.

e.g. salt bath furnance



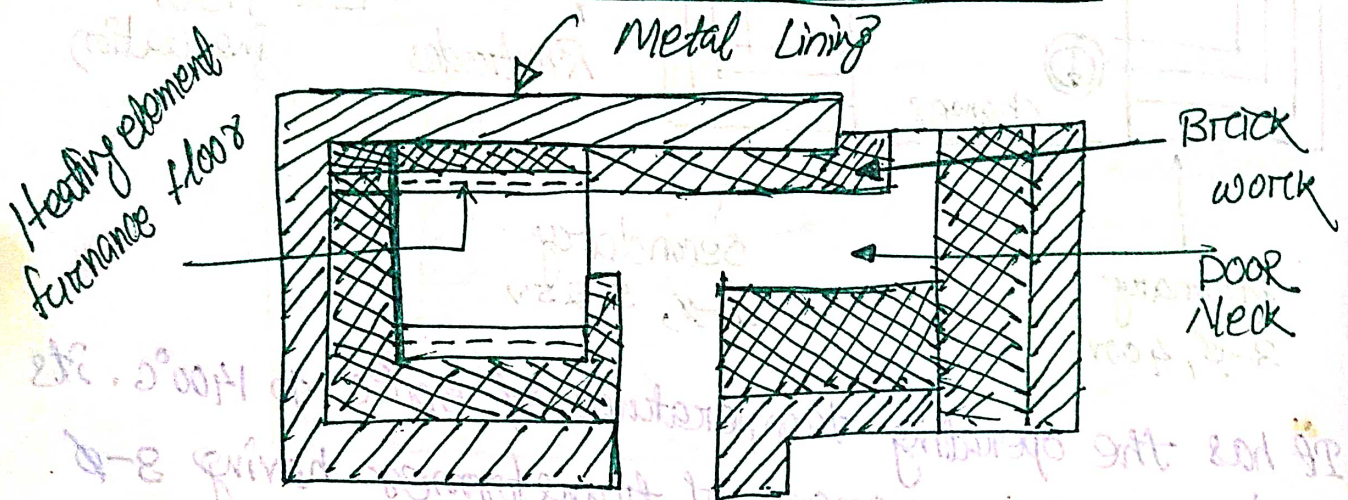
It has the operating temperature of 500°C to 1400°C . It needs an arrangement of transformer having 3-φ 400v primary and 1-φ 5 to 20v secondary. The 1-φ secondary forms the electrodes to the salt bath. The variation in the secondary voltage is done with the help of an off load tapping switch on the primary side. This is necessary for starting and regulating the bath load.

* Indirect Resistance Heating →



In this method the current is passed through a highly resistance element which is either placed above or below the oven depending upon nature of the job to be performed. The heat proportional to I^2R losses produced in heating element delivered to the charge either by radiation or by convection.

* Resistance Furnance or Resistance Oven :-



It is an enclosed chamber with ventilation provision used for drying and baking of pottery, commercial and domestic cooking, heat treatment of metal i.e. annealing, hardening etc. using high resistance heating wire element made up alloys of nickel, chromium and iron, the temp up to 1000°C can be attained.

Temperature up to 3000°C can be obtained by using graphite as heating elements. The heating elements may be of circular wires or rectangular ribbons and is located at top, bottom or sides of the oven depending upon the used.

Material Requirements for Element Making →

(27)

Indirect resistance furnace works on wide range of temperatures and different shapes, sizes and materials come to fulfill different requirement a good element material should have following properties.

(i) low temperature coefficient of resistance -

A resistance varies with temperature but it should not be in a wide range in case of element otherwise it will draw excessive current at initial stage and the resistance varies rapidly where the temperature rises from room temperature to 1200°C .

(ii) Resistance coefficient positive -

Resistance of negative coefficient material goes on decreasing for increase in temperature hence it draws heavy current at hot state and creates instability, so material with +ve coefficient are used in elements.

(iii) High Melting point -

The melting point of the element should be greater than operating temperature otherwise it will destroy in small raise in voltage.

(iv) High specific resistance -

Resistivity should be high so that it will require small lengths and give convenient size.

(v) High oxidizing temperature -

Oxidizing temperature should be higher than the operating temp.

(vi) Ductile -

(28)

To have convenient size and shape it should be highly ductile and flexible and should not be brittle and fragile. It should withstand vibration.

(vii) Anti corrosive -

The element should be anti corrosive withstand the corrosive heating atm.

(viii) Mechanical strength -

Material should have sufficient mechanical strength

Temperature Control of Resistance Furnaces →

If a constant voltage is given to an resistance furnace then it goes on increasing and may exceed the limits. Hence it need to be control by either decreasing the supply or cutting off momentarily in large furnace automatic control is given which may be electromagnetic or electronic involving servo mechanism operation.

The modes of control may be

(i) Two step → ON, OFF, High - low

(ii) Three step → low, Medium, High

(iii) continuous → continuous varying input energy depending upon the temperature inside the furnace

Basic control involves following adjustment (29)

- ① Intermittent switching i.e ON or OFF
- ② Variation of no. of heating element
- ③ Variation in ckt configuration.
- ④ change of applied voltage.

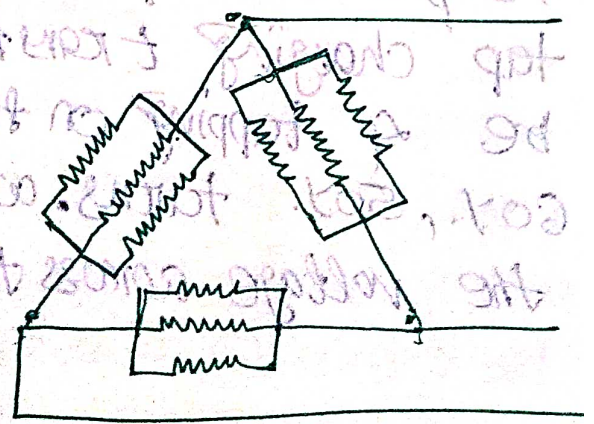
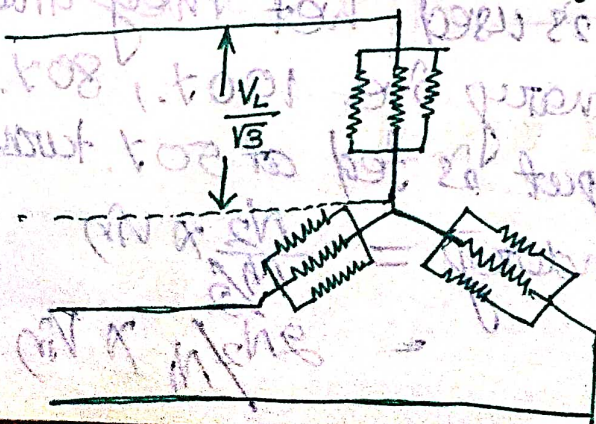
① Intermittent switching -

In this adjustment before the heat goes beyond a certain limit. the supply is turn off. Let it temp. decrease in close furnace the temp. still continuous to increase for some time after that it starts decreasing after decreasing a certain limit again the furnace is switch on to heat due to continuous switching ON or OFF there is lot of arcing at the switching contacts and hence this method is suitable only for small furnaces.

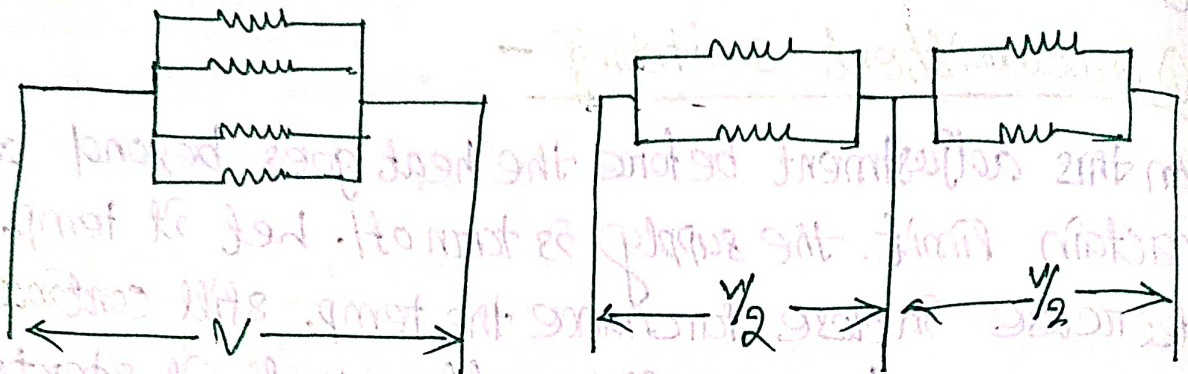
② Variation of no. of heating plates -

The no. of elements are changed instead of cutting the supply. more no. of heating plate means more heat and vice versa. However in case of 3- ϕ circuit equal no of elements should be removed for each phase to maintain the balance.

③ Variation in ckt configuration -

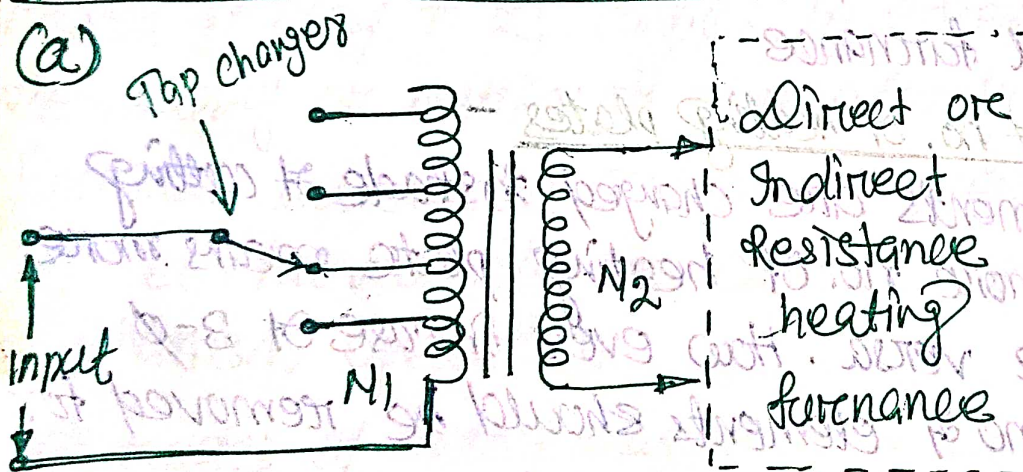


Since the power given by $\frac{V^2}{R}$ watts hence the heating will be more in case of Delta as compared to star. This is because each phase in a delta connection carries the same line voltage whereas in a star connection it is $\frac{1}{\sqrt{3}}$ times of the line voltage.



As the voltage reduced $\frac{V}{2}$ volts in the second case hence the power dissipated will be also $\frac{1}{4}$ th of the first one.

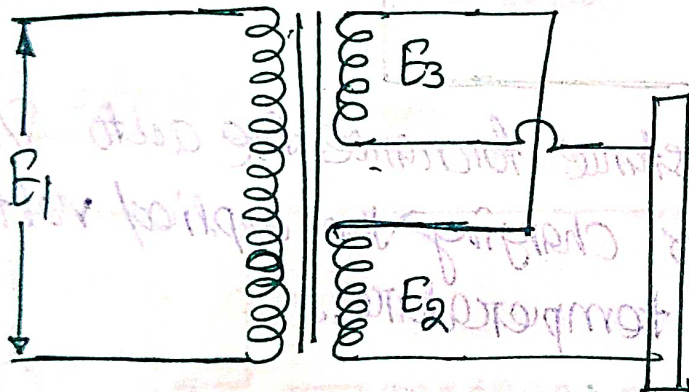
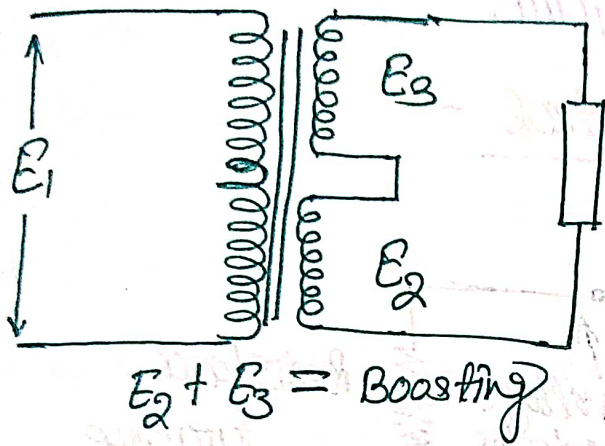
④ Change applied voltage —



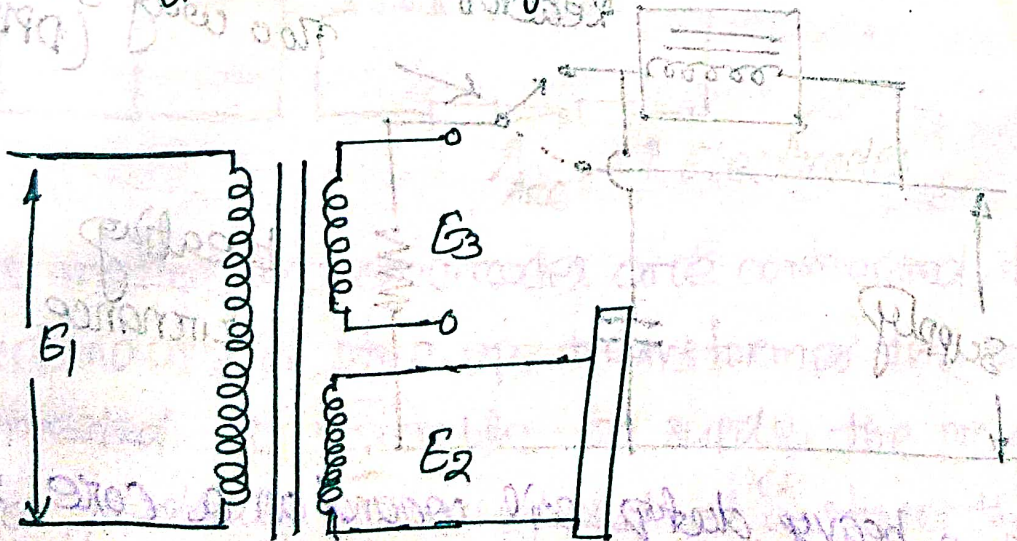
When applied voltage means less will be the temperature produced. In case of furnace tap changing transformer is used. Let there are 4 tapping on the primary i.e. 100%, 80%, 60%, 50%. turns. when input is fed at 50%, then the voltage across the secondary = $\frac{N_2}{N_1} \times V_{in}$
 $= \frac{2N_2}{N_1} \times V_{in}$

where as 100% primary is in the circuit the voltage across the secondary $= \frac{N_2}{N_1} \times V_m$ (81)

(b) Bucking boosting the secondary voltage —



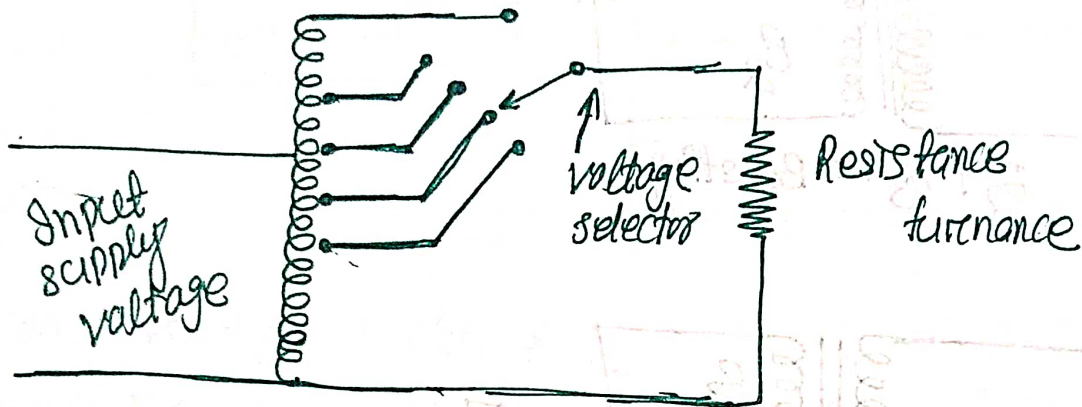
$E_2 - E_3 = \text{Bucking}$



Buck & Boost

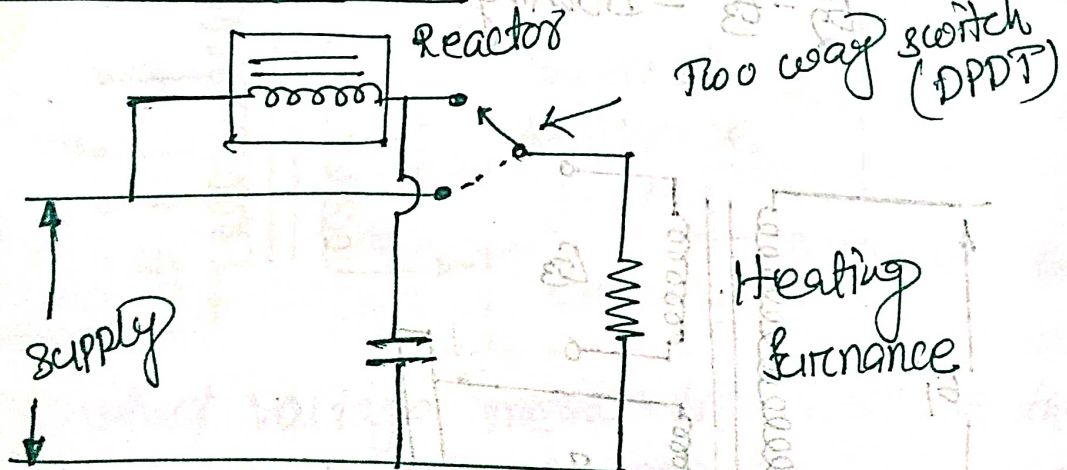
Here the secondary may have two windings one with less no of turns according to high or low voltage application boosting and bucking connection is done as shown in the figure.

(C) Auto Transformer Control -



For very small resistance furnace the auto T/P control can work for changing the applied voltage and as such the temperature.

(d) Series Reactor control -



In case a heavy duty coil wound on a core is placed in series with the furnace when designed. A part of applied voltage drop across the impedance produced by the coil and the rest appears across the furnace thus by reducing the temperature

inside the furnace. The DPT switch makes the low or high temperature control (33)

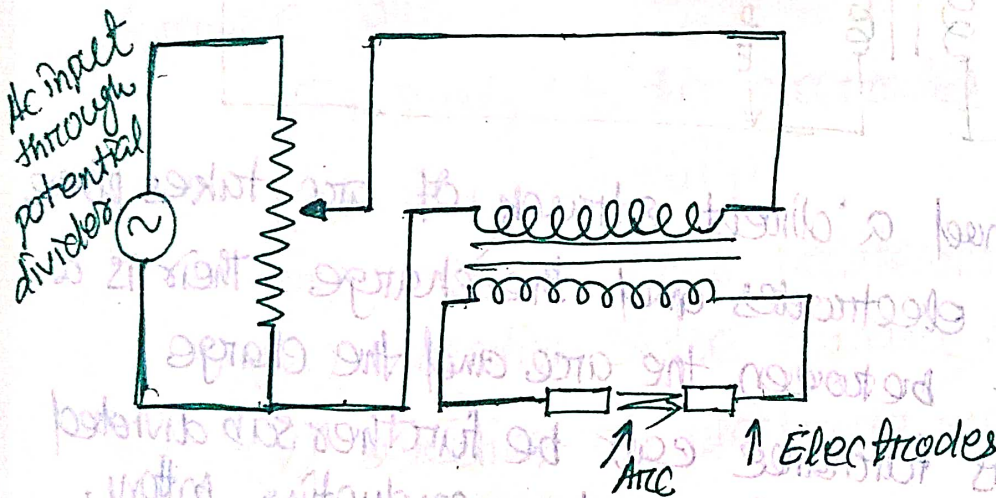
Arce Furnance

Melting or extraction of ferrous and non ferrous metal need high temp operation which is obtain through production of electric arc. it gives a temperature of 3000°C to 8500°C .

Methods of striking are

HT strike method
LT strike method

HT strike method



In this method two electrodes are connected to the HV secondary of step up transformer the primary is connected to variable ac supply the primary voltage gradually increased and at a stage the medium between the electrodes ionised and an arc is strucked it creates a very high temperature. The HT required is dependent upon the size and nature of the gap but runs in to thousands of volts.

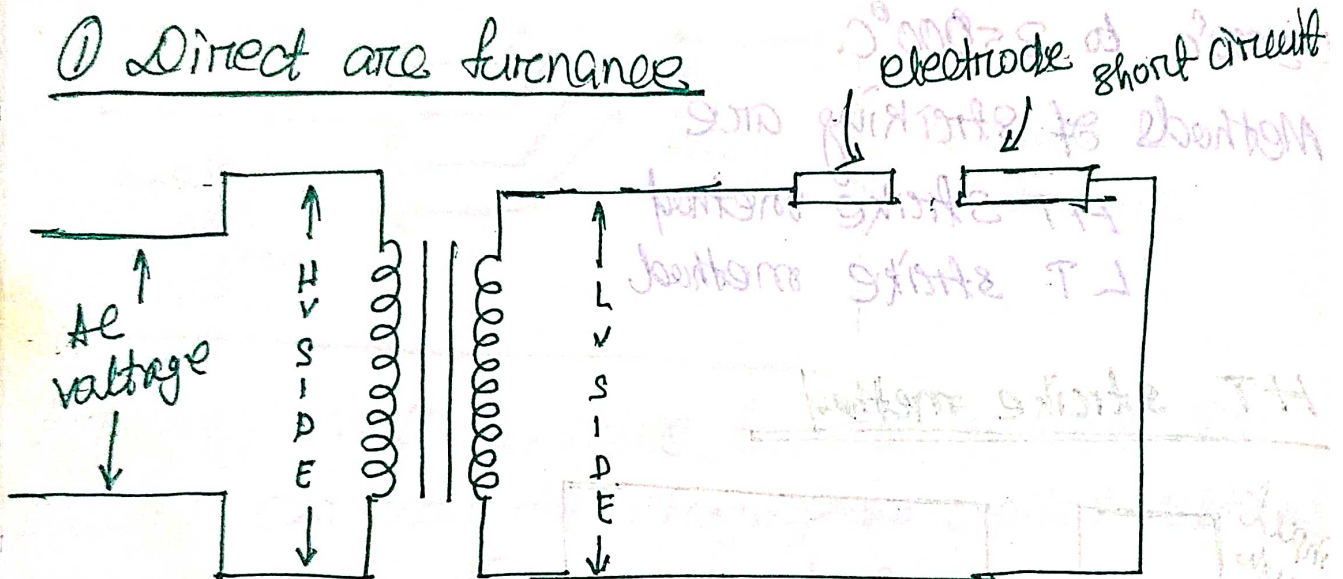
LT strike method

(31)

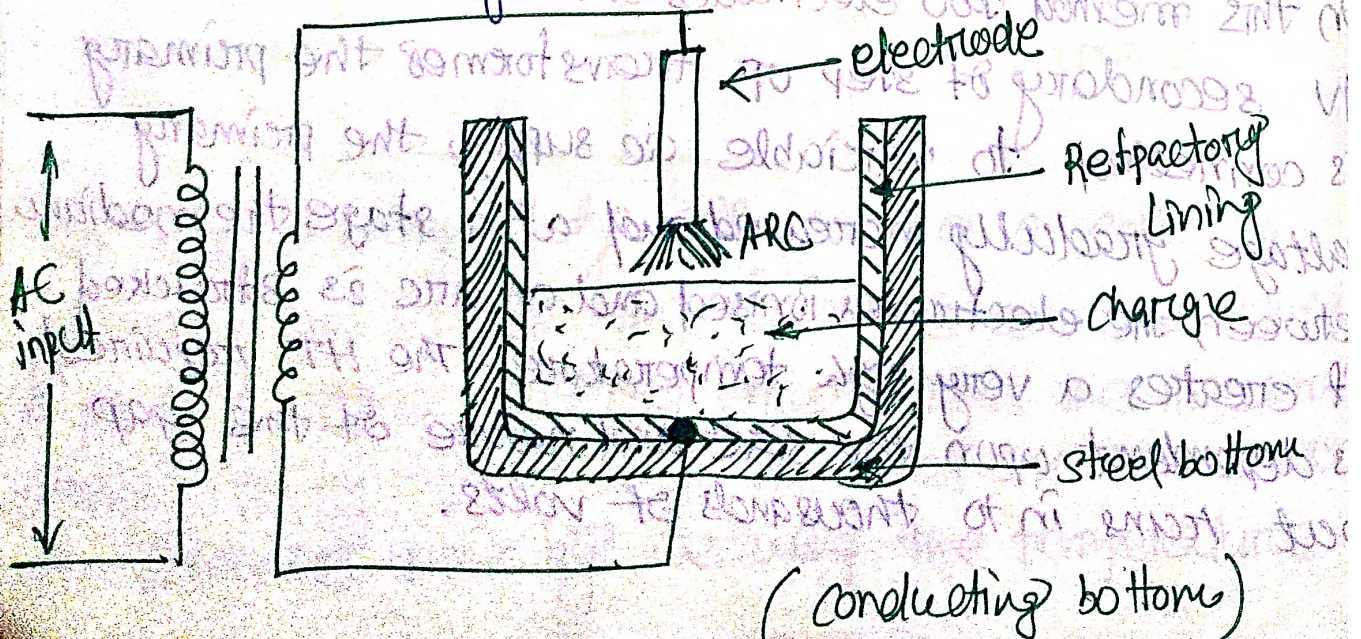
In this method the electrodes are connected to the low voltage side of the transformer this are momentarily short circuited and immediately separated resulting in production of an arc.

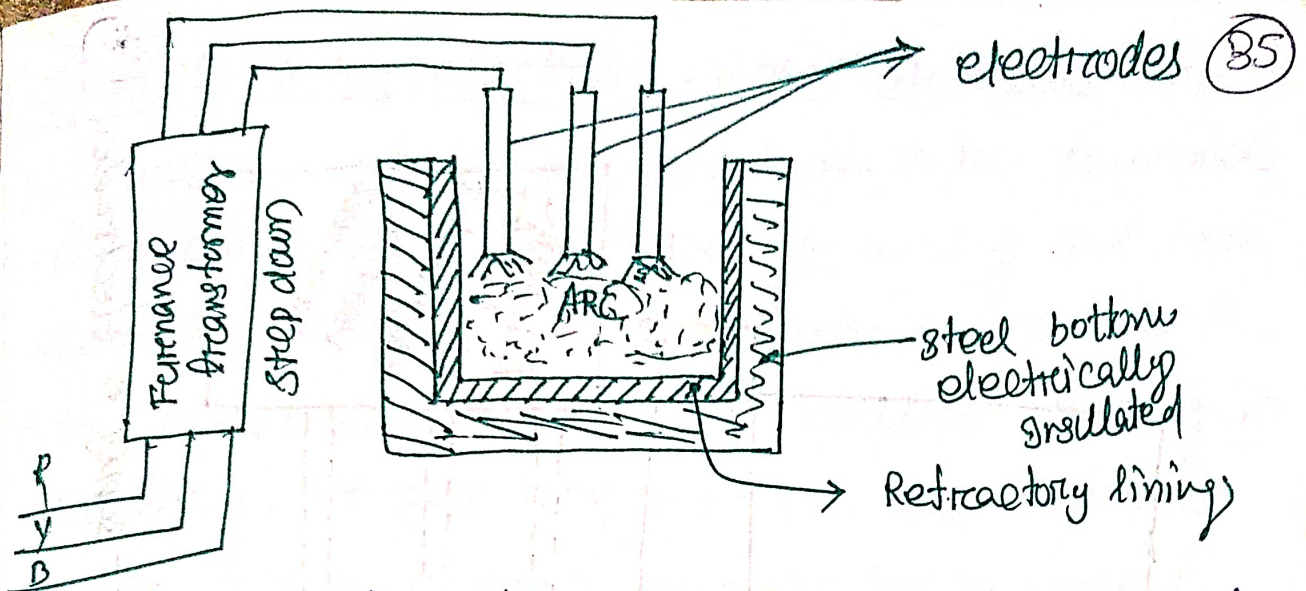
This furnace can be further subdivided into direct arc furnace and indirect arc furnace.

① Direct arc furnace



In this method a direct struck of arc takes place between the electrodes and the charge. There is a direct contact between the arc and the charge electrically this furnace can be further sub divided into conducting bottom and non conducting bottom.





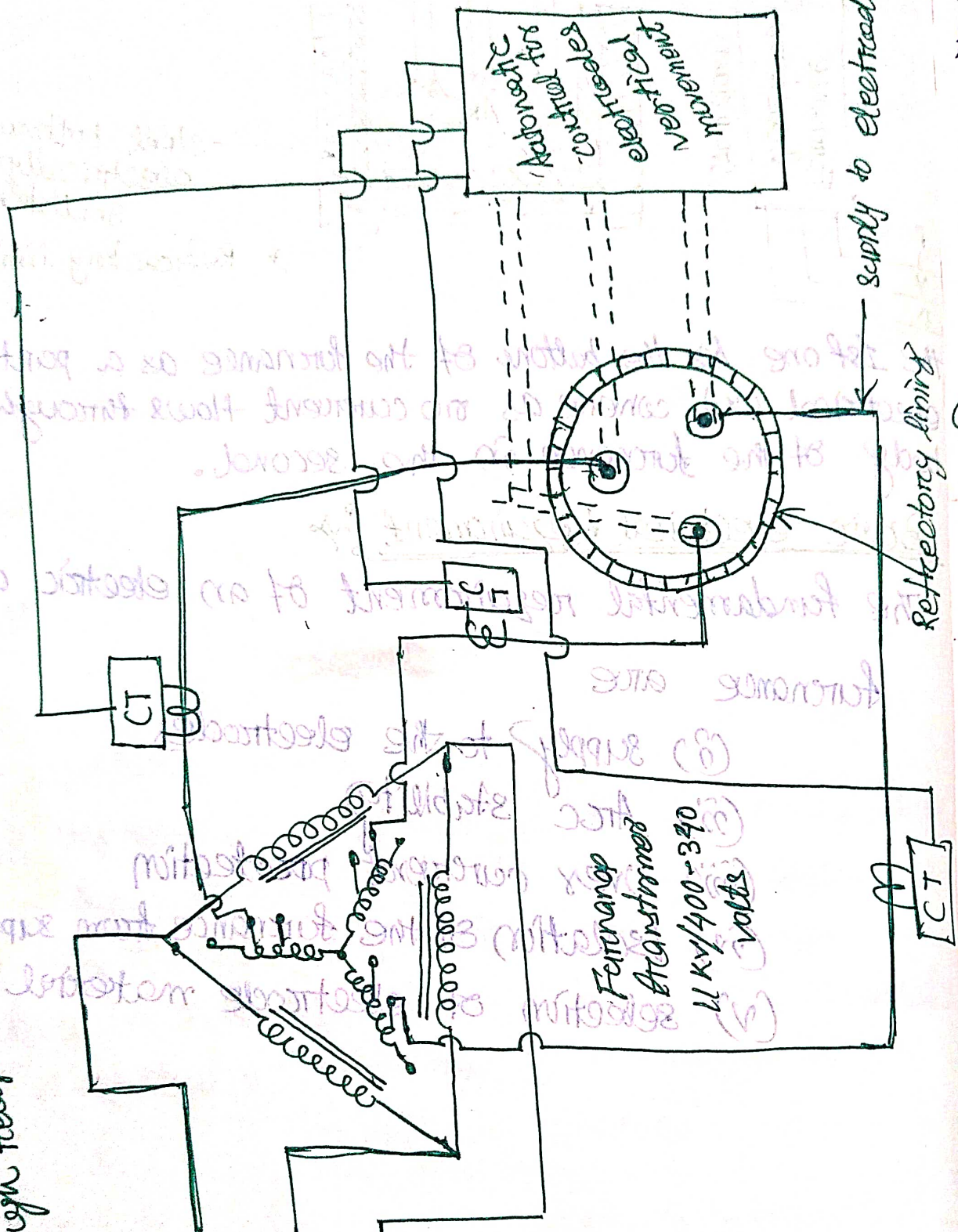
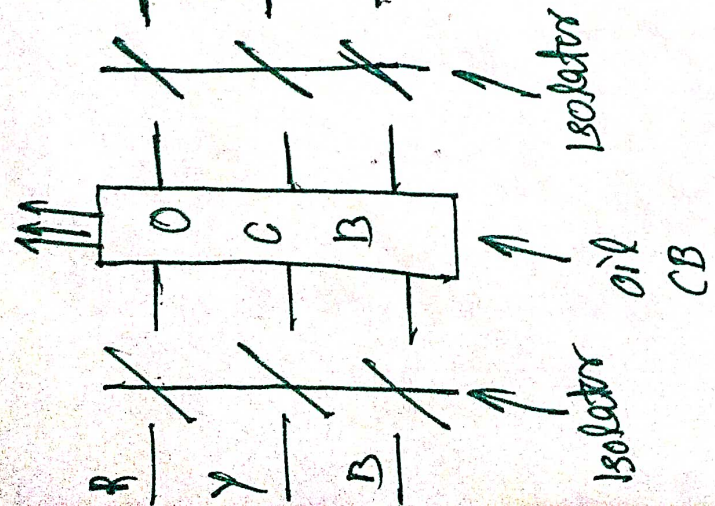
the 1st one has the bottom of the furnace as a part of electrical ckt where as no current flows through the body of the furnace in the second.

Basic electrical Requirement :-

The fundamental requirement of an electric arc furnace are

- (i) supply to the electrodes
- (ii) Arc stability
- (iii) Over current protection
- (iv) Isolation of the furnace from supply
- (v) selection of electrode material

TO CTs through relays



supply to electrodes

Reflector lining

Ferranti Argandrel
11 kV/400-340
volts

CT

CT

CT

(3F)
(i) supply to the electrodes → The electrodes are so created arcs and provided them to the furnace. It requires high reactance T/F winding and low secondary voltage hence the furnace T/F has a high reactance of 35%. and multiple tapping in secondary. It uses 11kV/340-400V and flexible cables which carries 100 to 1000 Amp of current.

(ii) Arc stability → Due to alter striking of arc the electrodes burned out which increase the length of arc so proper distance should be maintain between them. Again the material that arc to be metal under goes ~~increase in resistance~~ increase in resistance with increase in temperature. It also changes the magnitude of arc current. The effect is transmitted with the help of current transformer to an automatic regulator circuit which adjust the height of the electrodes during the ~~melting~~ melting process.

(iii) Over current protection → some time a shortcircuit happens in the furnace hence relay are used usually for the protection of over current which detects the current by the help of CTs and give it to circuit breakers.

(iv) Isolation of the furnace from supply → During the removal of the melt or slag from the furnace or providing charge to furnace. It need to isolate from the supply which is done by the use of isolator.

(v) selection of electrode material $\rightarrow$ usually ⁽³⁸⁾ carbon

or graphite electrodes are used

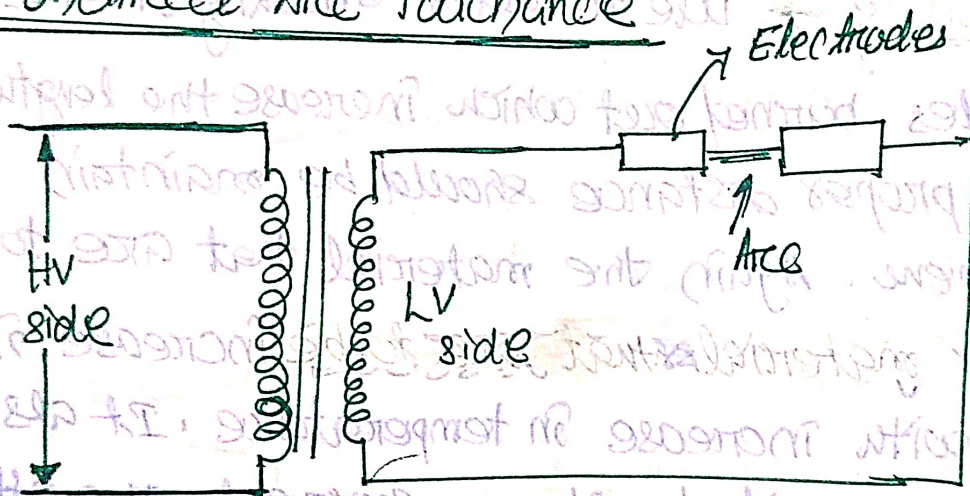
Basic Mechanical Requirement $\rightarrow$

1. Charging

2. Removal of melt & slag

3. Shell and lining structure

② Indirect Arc furnace

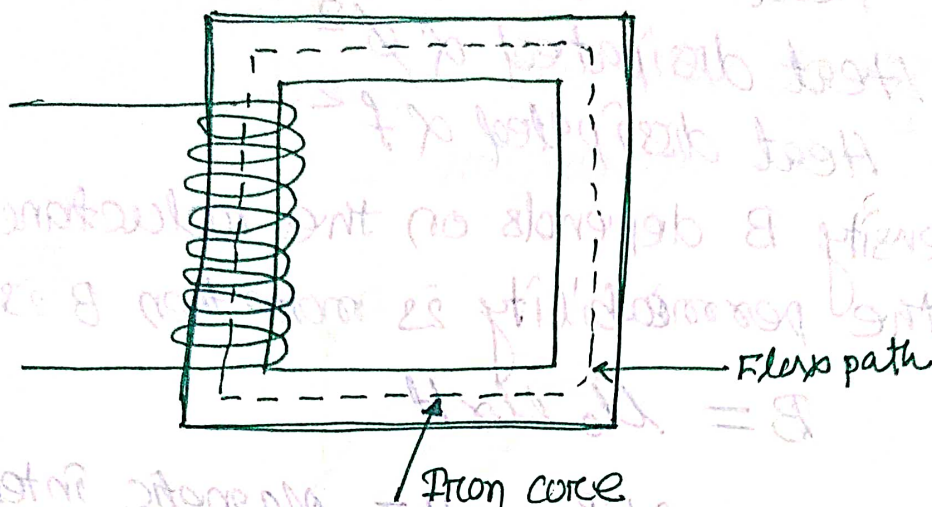


Here the heat produced by the arc set up between two electrodes thus the heating indirectly. The arc does not come in contact with the charge but heat is transferred through radiation from arc to top layer of charge and through conduction from top to bottom layers in the charge.

Induction Heating

(89)

Eddy Current



When a conductor cuts electromagnetic flux then electromagnetic EMF induced in it. If a coil is wound on an iron core and energised at source then alternating flux is produced which links both the coil as well as the core.

$$e = -N \frac{d\phi}{dt}$$

$$e = -L \frac{di}{dt} \text{ volts}$$

Since the core is a complete circuit single coil turns any induced emf will result in circulation of current through the core. This current is known as eddy current.

$$\text{Power dissipated from the core} = i^2 R$$

i = magnitude of current flowing in the coil

R = Resistance of the core material

The power dissipated will in the form of heat (4)

Power dissipated $\propto i^2$

Heat dissipated $\propto i^2$

Heat dissipated $\propto \phi^2$

Heat dissipated $\propto f^2$

Flux density B depends on the reluctance and hence the permeability is more then B is more

$$B = \mu_0 \mu_r H$$

$$H = \frac{NI}{L}$$

H = Magnetic intensity

B = Magnetic flux density
 $= \phi/A$

N = No of turns of the coil

I = current through the coil

L = length of magnetic ckt

μ_r = relative permeability

μ_0 = permeability of free space

$$B \propto H$$

$$\Rightarrow B \propto N$$

$$\Rightarrow \text{eddy current} \propto N$$

For large current flux will be large hence eddy current heating is a function of magnitude of the current. For less resistivity current flow will be more hence eddy current heating is a function of resistivity.

$$W_e = K B_{\max}^2 f^2$$

(41)

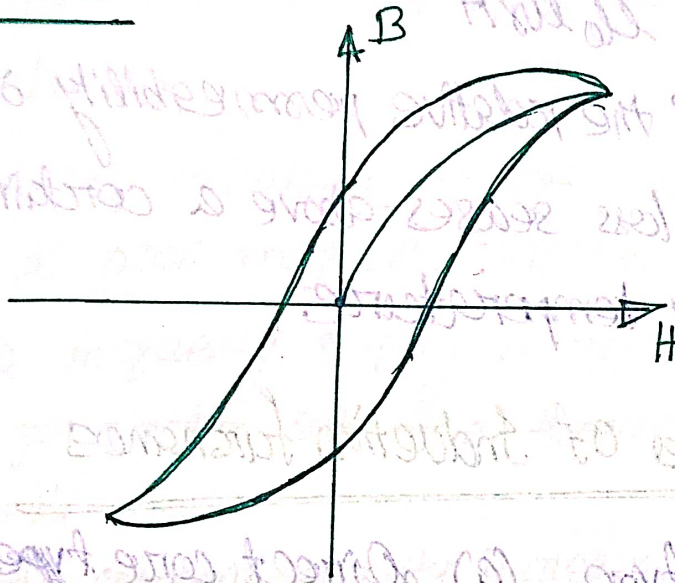
$K = \text{constant}$

$W_e = \text{eddy current loss}$

$B_{\max} = \text{Max. flux density}$

$f = \text{frequency}$

Hysteresis



If a material is magnetised, demagnetised and remagnetised again and again then there is also energy loss in the form of heat called hysteresis loss.

The curve shows the B-H curve or magnetisation curve. When the current is in its positive half cycle then the core is magnetised but when it goes zero, then the curve does not go to zero due to the residual magnetism in the core. Similarly it takes place in the reverse direction that is in the negative half cycle and a loop is formed called as hysteresis loop.

(a) Greater is the frequency of AC supply larger will be the no. of such loops traced per sec. and more will be heat produced.

(b) Hysteresis loss $= K_h B_{\max}^{1.6} f$
Hysteresis loss $\propto B_{\max}^{1.6}$

(c) As $B_{\max} = \mu_0 \mu_r H$

hence $B_{\max}$ $\propto$ the relative permeability of material

(d) the hysteresis loss ceases above a certain temp. called as curie temperature.

Different Types of Induction Furnance

① Core type (a) Direct core type

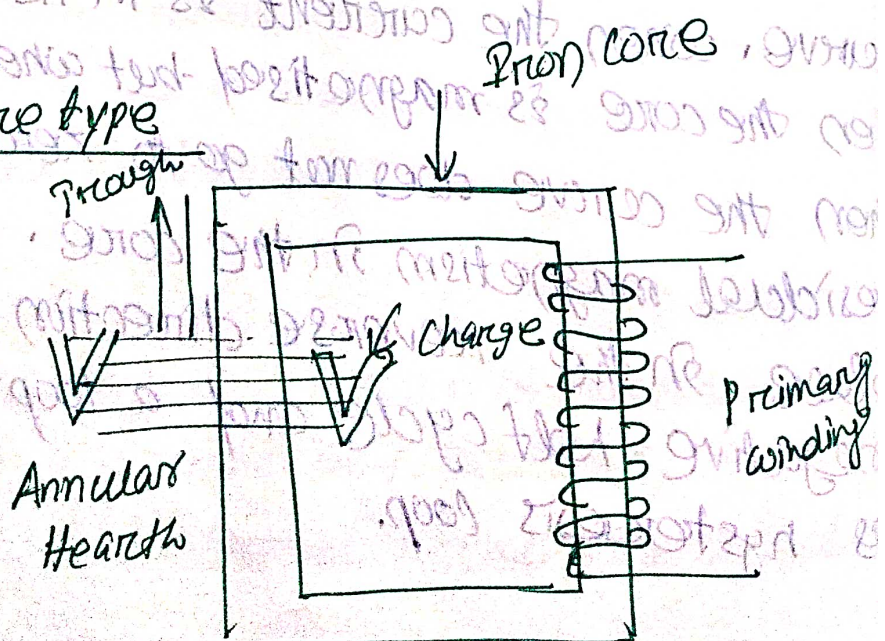
(b) Vertical core type

(c) Indirect core type

② Core less type

① Core Type

(a) Direct core type



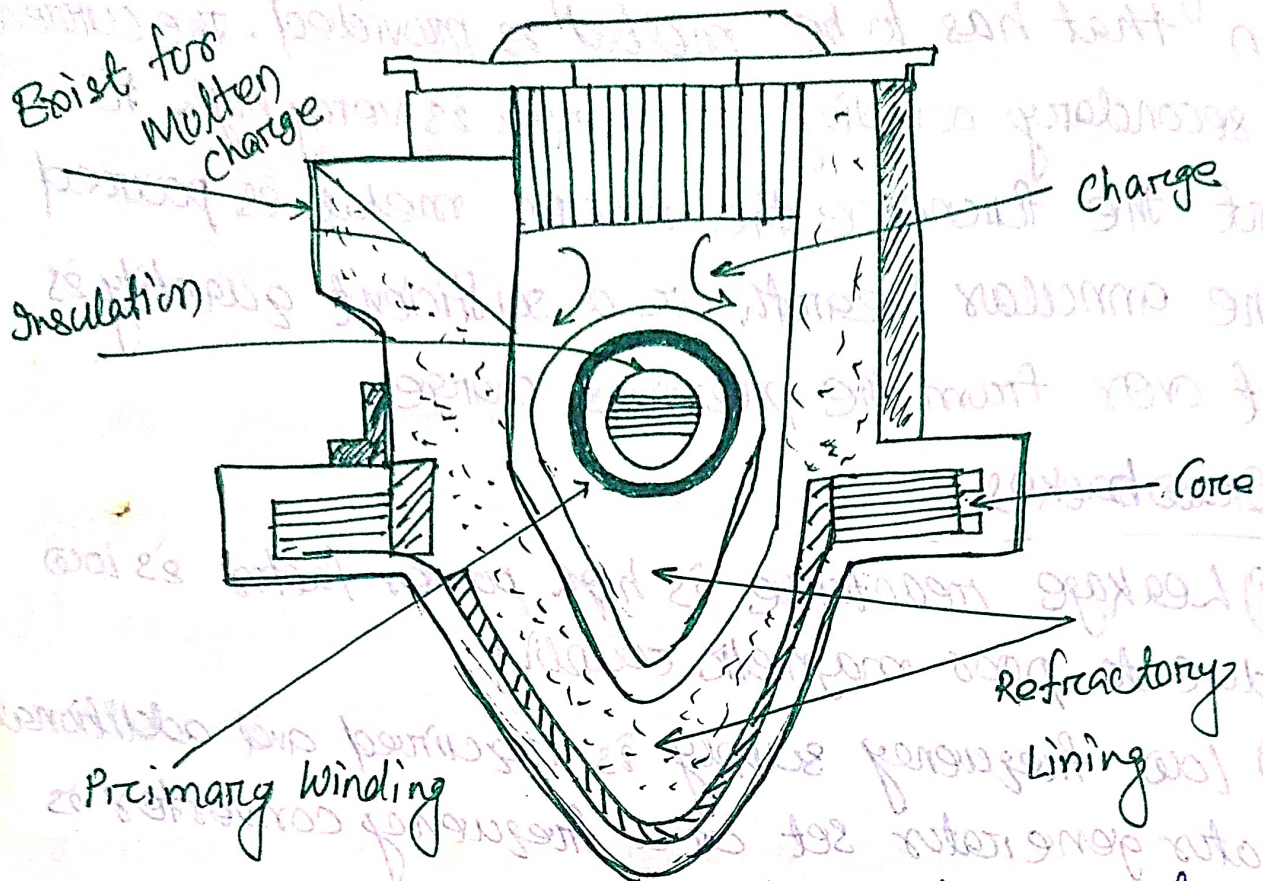
The function is like a transformer where a primary winding is there and a secondary winding with single turn that has to be melted is provided. The current in secondary winding or charge is very high to start the furnace the molten metal is poured in the annular hearth or a sufficient quantity is left over from the previous charge.

Drawbacks

- ① Leakage reactance is high power factor is low due to poor magnetic coupling.
- ② Low frequency supply is required and additional motor generator set or a frequency converter is required.
- ③ If the current density increases about 5 Amp/mm^2 then a complete interruption of secondary occurs.
- ④ Odd shape of crucibles are not convenient from metallurgical point of view.
- ⑤ Furnace can't be function if the secondary circuit is open so it must be closed.

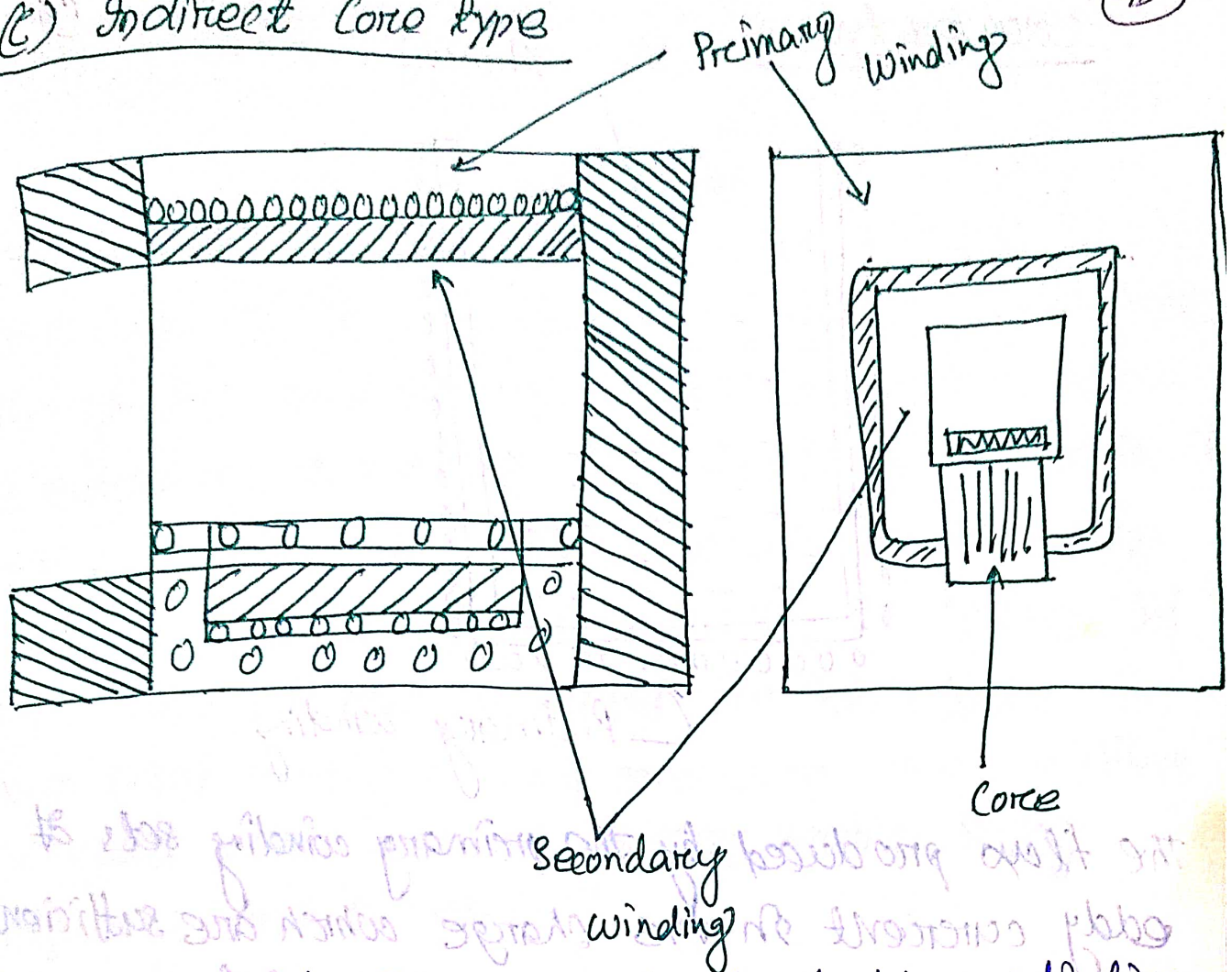
(b) Vertical core type

(44)



It is also called as Ajax Wyatt vertical core type furnace. It has better magnetic coupling than core type hence leakage reactance is comparatively low and power factor is high. The circulation of molten metal is kept up round the Vee portion by convection currents and by electromagnetic forces between the current in the lower halves of Vee. It is suitable for continuous operation as it is necessary to keep the Vee full of metal in order to maintain the continuity of secondary circuit.

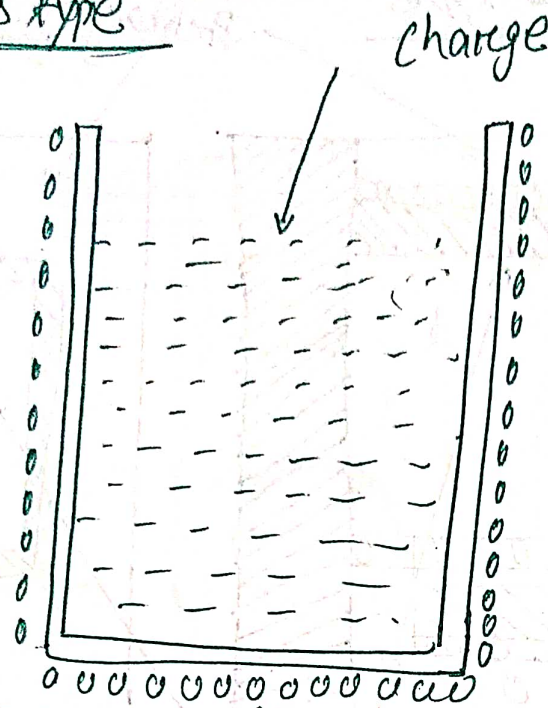
(c) Indirect Core type



In this method the charge is heated by radiation from an another hot metal which is heated inductively. In the figure the secondary winding forms the wall of a metal container and the iron core links the primary as well as secondary winding. A part of the magnetic ckt is situated in the oven chamber and made from a special alloy which loses its magnetic properties at a particular temperature and regains when cooled approximately to the same temperature. This part is made detached so that it can be replaced by other having different critical temperature ranging between 400°C to 1000°C .

Core less type

(46)



Primary winding.

The flux produced by the primary winding sets up eddy current in the charge which are sufficient to heat the charge to the melting point.

$$\text{Eddy current} \propto B^2 \times f^2$$

The furnace has a refractory lining.

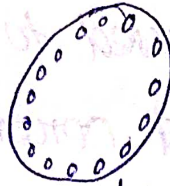
Advantages

- 1) Less time needed to reach the melting point
- 2) Control of power to charge is possible.
- 3) Charging and pouring is simple
- 4) No dust, smoke and noise produced
- 5) Automatic stirring in charge due to eddy current.

skin effect



dc

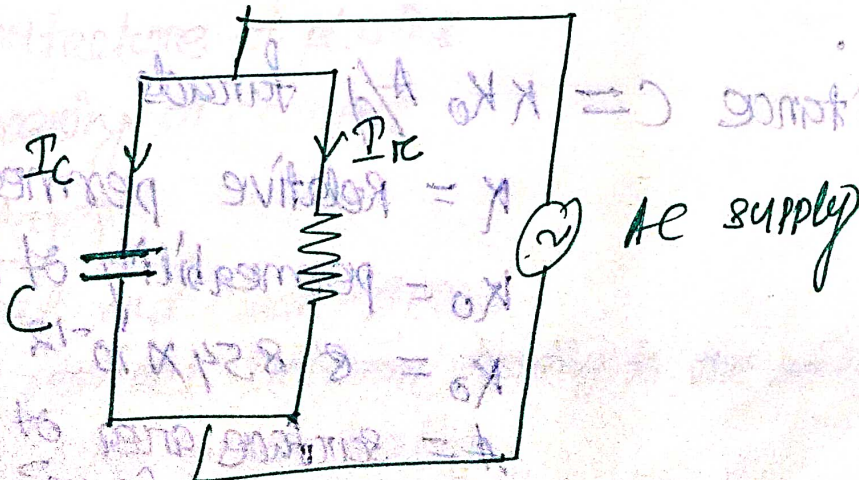
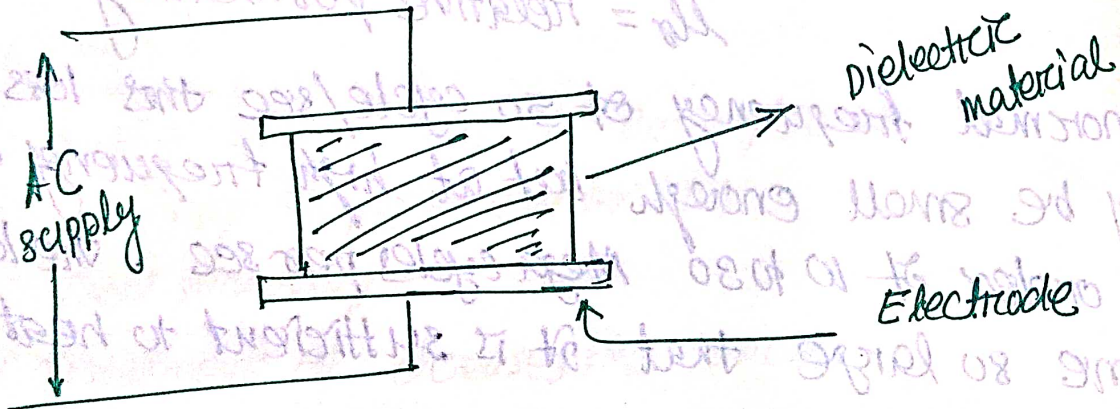


Ac

(47)

In AC the current tends to concentrate in the surface of the conductor and no current flows through the core of the conductor. This phenomenon is called as skin effect. It causes the resistance of the conductor to increase slightly particularly when diameter of the conductor is large. In stranded conductor ~~is large~~ the skin effect is much smaller than in solid conductors. The skin effect increases with increase of cross section, supply frequency and permeability.

Dielectric Heating / High frequency capacitive heating



→ This method is used to heat insulating materials like wood, plastic and ceramic etc. The supply frequency is 10 to 30 Mega cycles per sec and applied voltage up to 20 kV.

→ No capacitor in the world is perfectly capacitive so that the current will lead the voltage exactly by 90° . It has some resistive effect for which the current leads the voltage by some how an angle less than 90° . Hence there must be a resistive component of the current which is in phase with the voltage.

$$\delta = \frac{1}{2\pi} \frac{\sqrt{f \times 10^7}}{\rho \mu} m$$

f = resistivity

μ = relative permeability

At normal frequency of 50 cycle/sec the loss may be small enough but at high frequency of the order of 10 to 30 Mega cycles per sec. the loss become so large that it is sufficient to heat the dielectric.

capacitance $C = \frac{\kappa K_0 A}{d}$ farads

κ = Relative permeability

K_0 = permeability of air vacuum

$$K_0 = 8.854 \times 10^{-12}$$

A = surface area of electrodes in m^2

d = distance between electrodes

Application

- ▷ welding in manufacture of synthetic
- ▷ In wood processing industry
- ▷ For baking foundary cores
- ▷ food processing.

Microwave heating

Here the electricity is converted to electromagnetic waves i.e. high frequency radio waves. The wave length of this waves are very short for high frequency called as microwaves. Frequency is 2400 to 2500 MHz. The work of this waves are confined in a closed cavity or oven, used to absorb water or moisture from food.

Application

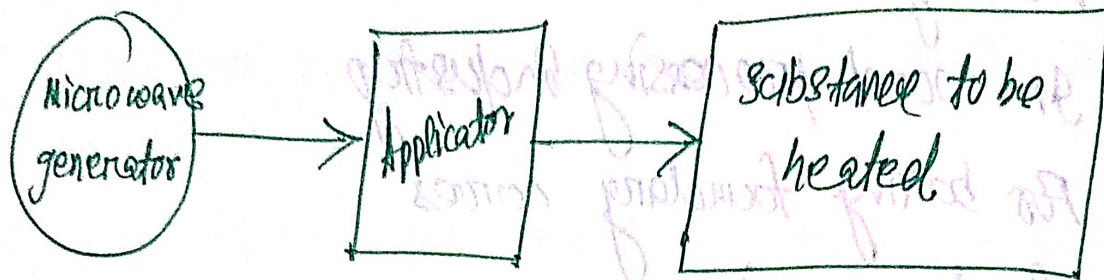
- (i) Baking manufacture of Bread/Toast
- (ii) Drying of paper and textiles.
- (iii) food processing
- (iv) Treatment of diseases like cancer
- (v) Manufacture of plastics
- (vi) Processing of cement.

Advantages

- (i) Neat and Clean system.
- (ii) It provides uniform heating to the substance
- (iii) provides quick heating.
- (iv) depth of penetration of heat is more.

Microwave Oven

50



Microwave Generator

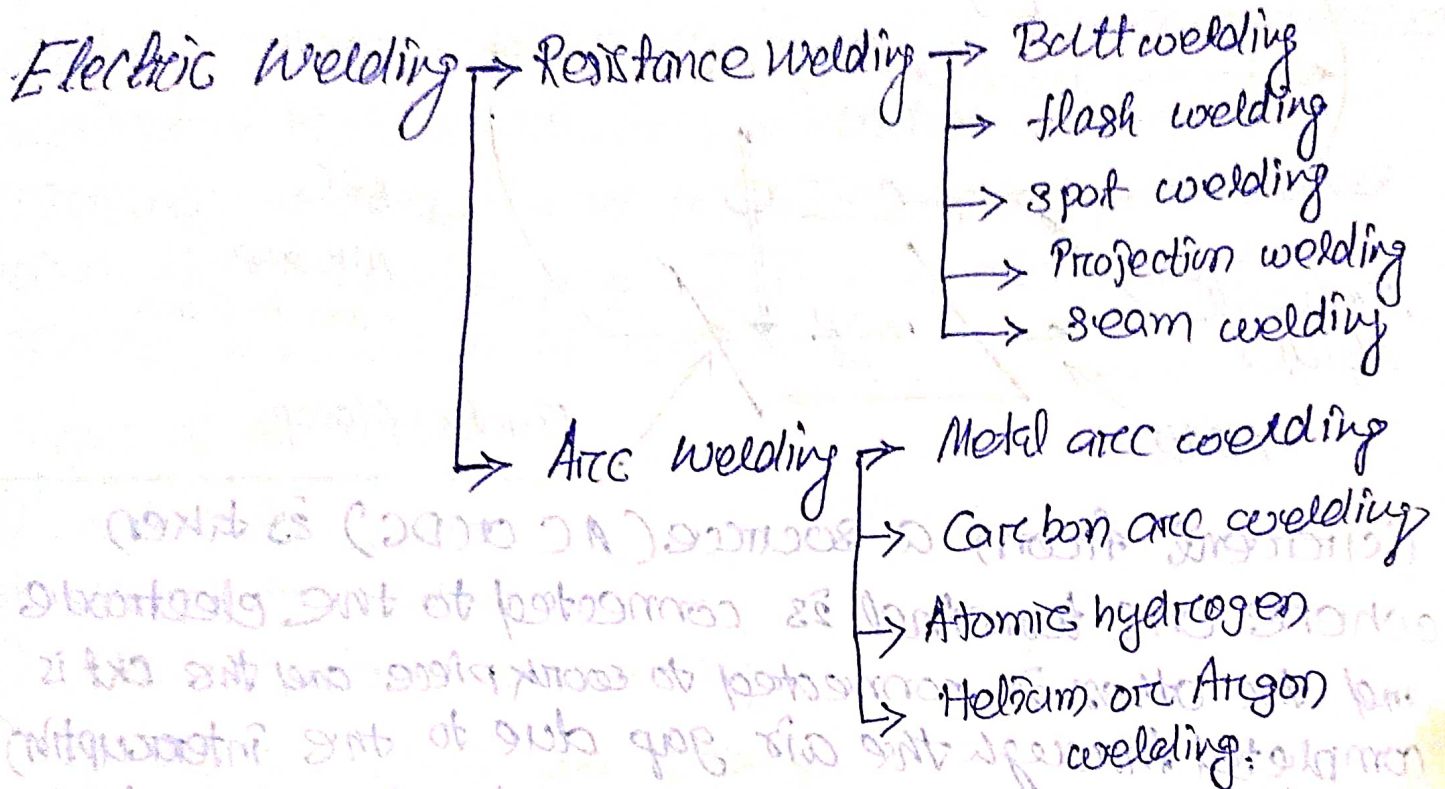
It generates microwave energy to be supplied to the substance to be heated.

Applicator

This is a link between microwave generator and the substance to be heated. It should be kept in mind that there should be proper impedance matching between the two for max^m power transfer to the substance and that too with out any leakage.

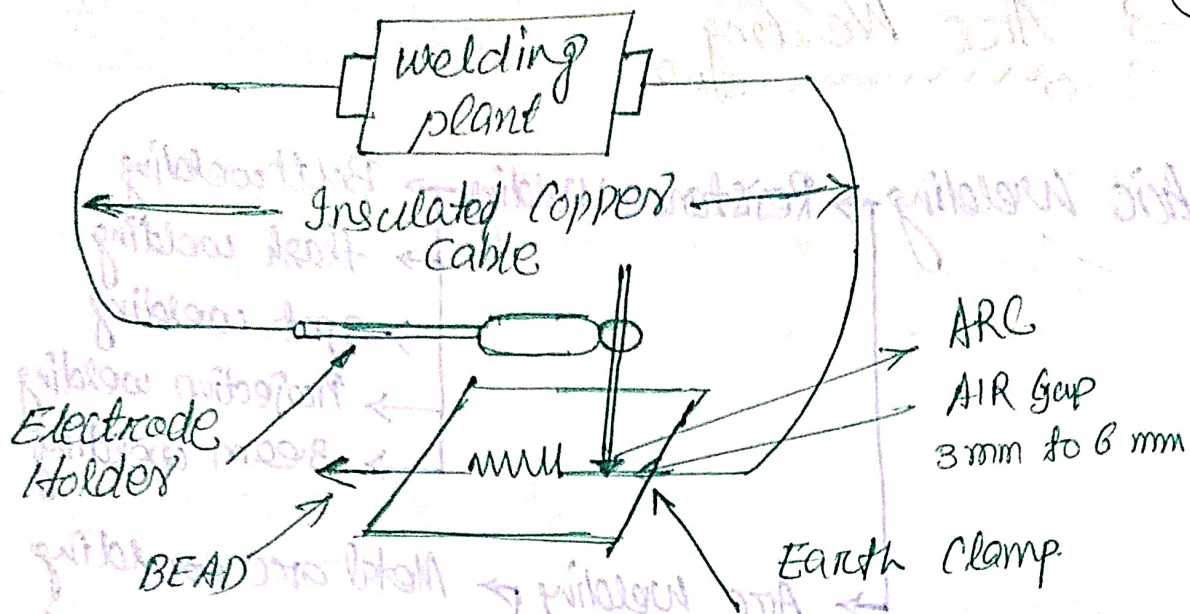
Ch-3 Arc Welding

(51)



An electric arc is produced when two electrodes with suitable electric current source comes in contact momentarily the current continuously to flow across the small gap and heat is produced for which the metal of the electrode and the work piece melts and forms the joint. The temperature is about 8000°C . Voltage is 100 volts and current ranges from 30 to 500 Amp (Manual operation) and 75 to 600 Amp (Automatic operation).

Principle of Arc Welding



Current from a source (AC or DC) is taken where one terminal is connected to the electrode and the other is connected to work piece and the ckt is completed through the air gap due to the interruption by the air gap or gas heat is produced and the temp attained varies from 3700°C to 4000°C near the electrical energy is converted to heat energy.

Electric Arc welding Equipment

① DC welding equipment

② AC welding equipment

DC welding Equipment

It consists of a set of squirrel cage induction motor and differential compound generator to give drooping characteristics. If supply from existing system is used for welding then a ballast resistance is put in series with the equipment which is suitable for multiple operators working at same time.

AC Welding Equipment

A transformer reduces the voltage of about 1000 volt. The regulate current and produce the dropping characteristics required a high resistance and reactance. when a reactance is used it must be designed to operate well below. The saturation point of its magnetic circuit to prevent introduction of harmonics.

Types of Arc welding

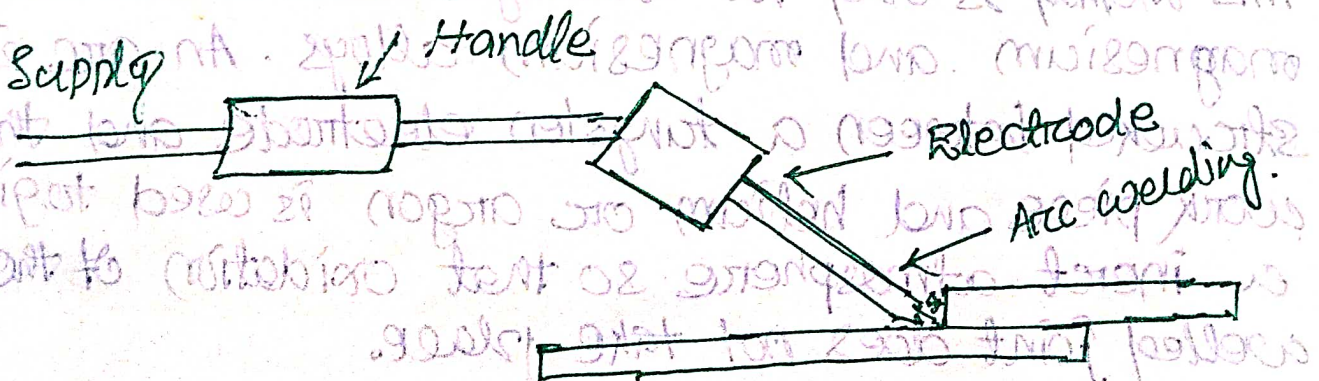
- ① Carbon Arc welding
- ② Metal Arc welding
- ③ Atomic hydrogen arc welding
- ④ Helium or argon arc welding.

Carbon Arc Welding

This method is normally used for welding for copper and its alloy. The carbon electrodes is kept in negative terminal to prevent brittleness in welded joint.

Two type of carbon Arc welding are used one is where no flux is used and other where flux in the form of powder or past is used.

Metalic Arc welding



AC $\rightarrow$ 100V

DC $\rightarrow$ 50V

In the metallic arc system a metal rod is taken as electrode and arc is strucked on the work piece with the help of ac supply from an welding transformer or DC supply from the DC welding generator. The electrode is momentarily touched to the work piece to produce arc and make the joint. It creates a temperature of 3500°C .

Atomic Hydrogen Arc Welding

In this welding a DC or AC supply is given to two tungsten electrodes. Molecular hydrogen is blown through this arc and converted to atomic hydrogen. At a small distance away from the cathode the concentration of atomic hydrogen is decreased due to the relative decrease in heat takes place & a release of the heat is occurs for recombination. To strike and maintain the arc an open circuit voltage of 800 volt is required, current ranges up to 50 Amp and the temp is about 400°C .

Helium or Argon Arc Welding

This method is used for welding aluminium alloy, magnesium and magnesium alloys. An arc is strucked between a tungsten electrode and the work piece and helium or argon is used to give a inert atmosphere so that oxidation of the welded joint does not take place.

AC $\rightarrow$ 100V
DC $\rightarrow$ 70V.

Resistance Welding

(55)

The principle of resistance welding is the generation of heat in the joint by passing a heavy current through the parts and also mechanical pressure is applied which welds the plastic material and refine the grain structure.

$H = I^2 R t$ $H =$ Heat generated by passage of an electric current I through a resistance R for t second of time.

The temperature attained depends on the heat produced and is affected by heat loss. The amount of current necessary (AC) is 4400 to 5000 Amp per square centimeter of area to be welded. The pressure varies from 280 to 565 kg per square centimeter.

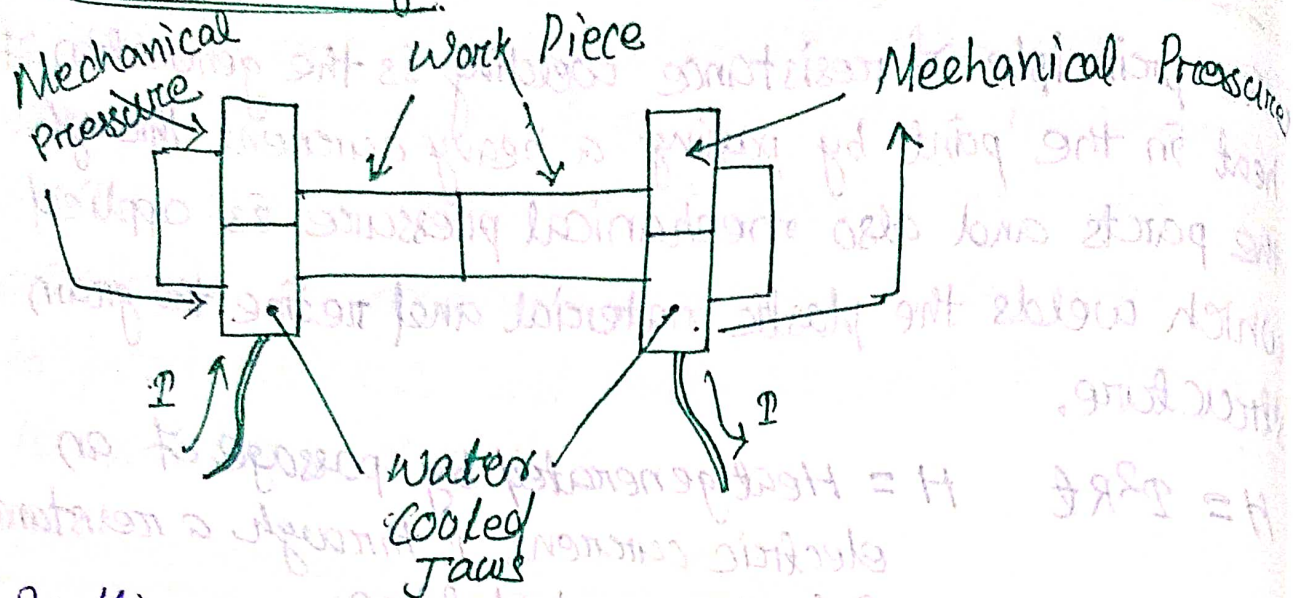
Advantages

- ① It is a quick method of joining two pieces.
- ② The wastage of metal is very less.
- ③ The process can be accurately control.

Types of Resistance welding

- ① Butt welding
- ② Flash welding
- ③ Spot welding
- ④ Seam welding
- ⑤ Projection welding

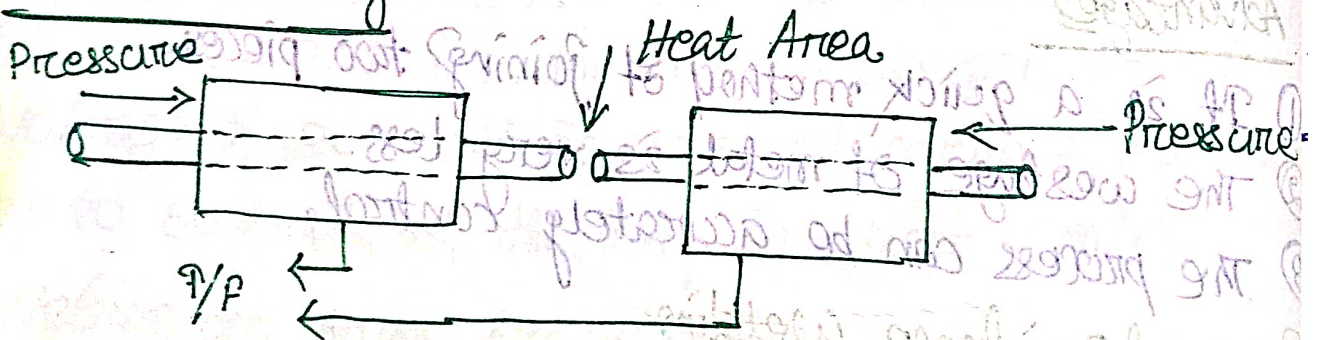
Butt Welding



In this process heat is generated by the resistance between two components. The two components are brought together, pressurised & a heavy current is passed from a welding transformer and forms joint.

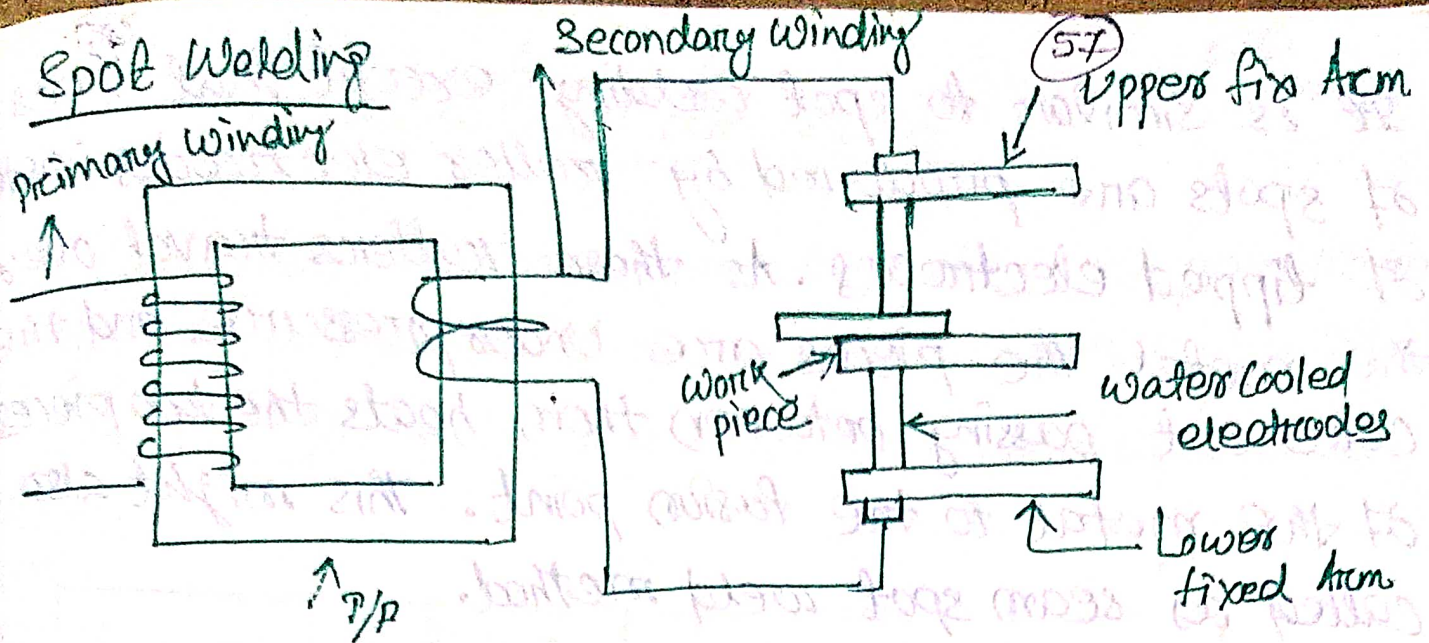
- Applied on end to end or edge to edge joint
- Used for welding of pipes, rods & wires.

Flash Welding



It is exactly similar to butt welding except for the difference that in this case current is applied to parts before they are brought together so that when they meet arcing or flashing takes place.

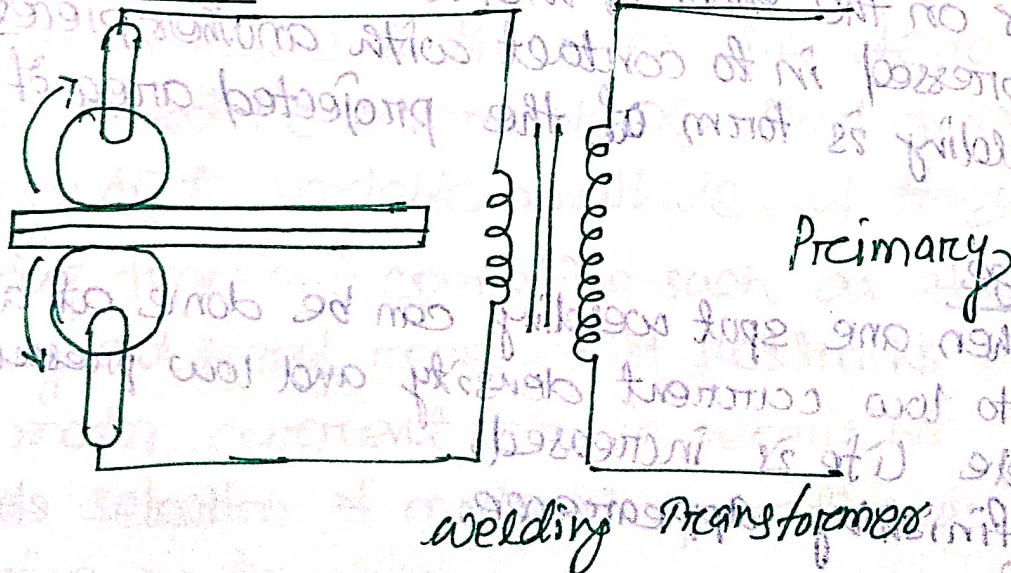
- ⇒ It is used to weld rods and pipes together.



A spot welding machine welds the metal in an area where the pressure made. It is the simplest and universally used method which consists of T/P, electrodes and electrical control switch. In the process both the material are overlapped and pressed between two water cooled electrodes and impulse of current around 5000 Amp is given the zone of pressure gets heated up to fusion.

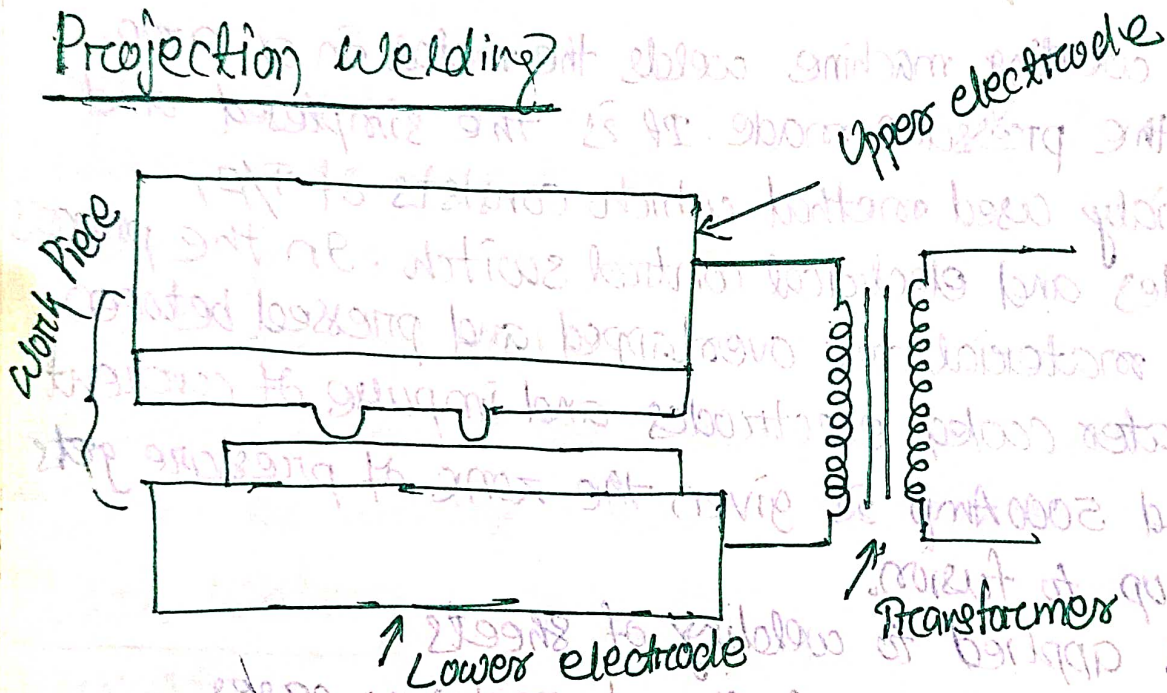
- It is applied to welding of sheets
- applied to boxes, cores and enclosing cases.

Seam welding



It is similar to spot welding except that series of spots are produced by roller electrodes instead of tipped electrodes. As these rollers travel over the metal the pieces are under pressure and the current passing between them heats the two pieces of the metal to the fusion point. This might also be called as seam spot weld method.

Projection Welding



It is modified form of spot welding where projection are there on the sheet of metal to be welded. One piece is pressed in to contact with another piece and the welding is form at the projected area of the sheet.

Advantage

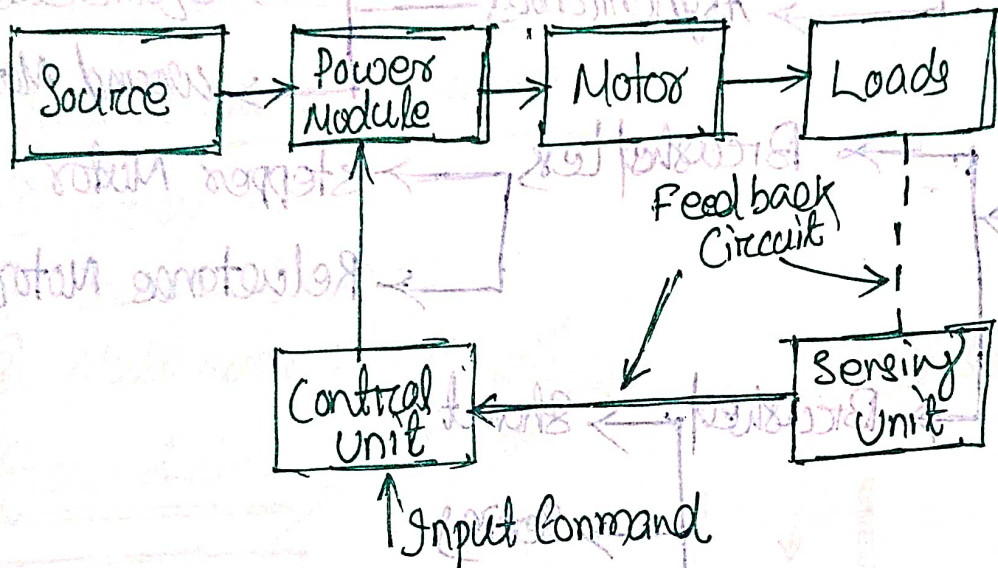
- ⇒ More than one spot welding can be done at a time.
- ⇒ Due to low current density and low pressure the electrode life is increased.
- ⇒ Good finishing appearance.

Application

- ⇒ Used in welding slots.
- ⇒ Nuts to plates.

Industrial Drives

The combination of motor or generator systems with prime mover containing a predefined control system comprise of a set of shafts, pulleys, belts, gears etc are called as electric drives.



Source

It is the electrical power supply AC or DC

Power Module

→ It converts the electrical energy from the source to a form suitable to the motor. i.e. AC to DC, DC to AC, fixed DC to variable DC, fixed amplitude and frequency AC to variable amplitude and frequency DC.

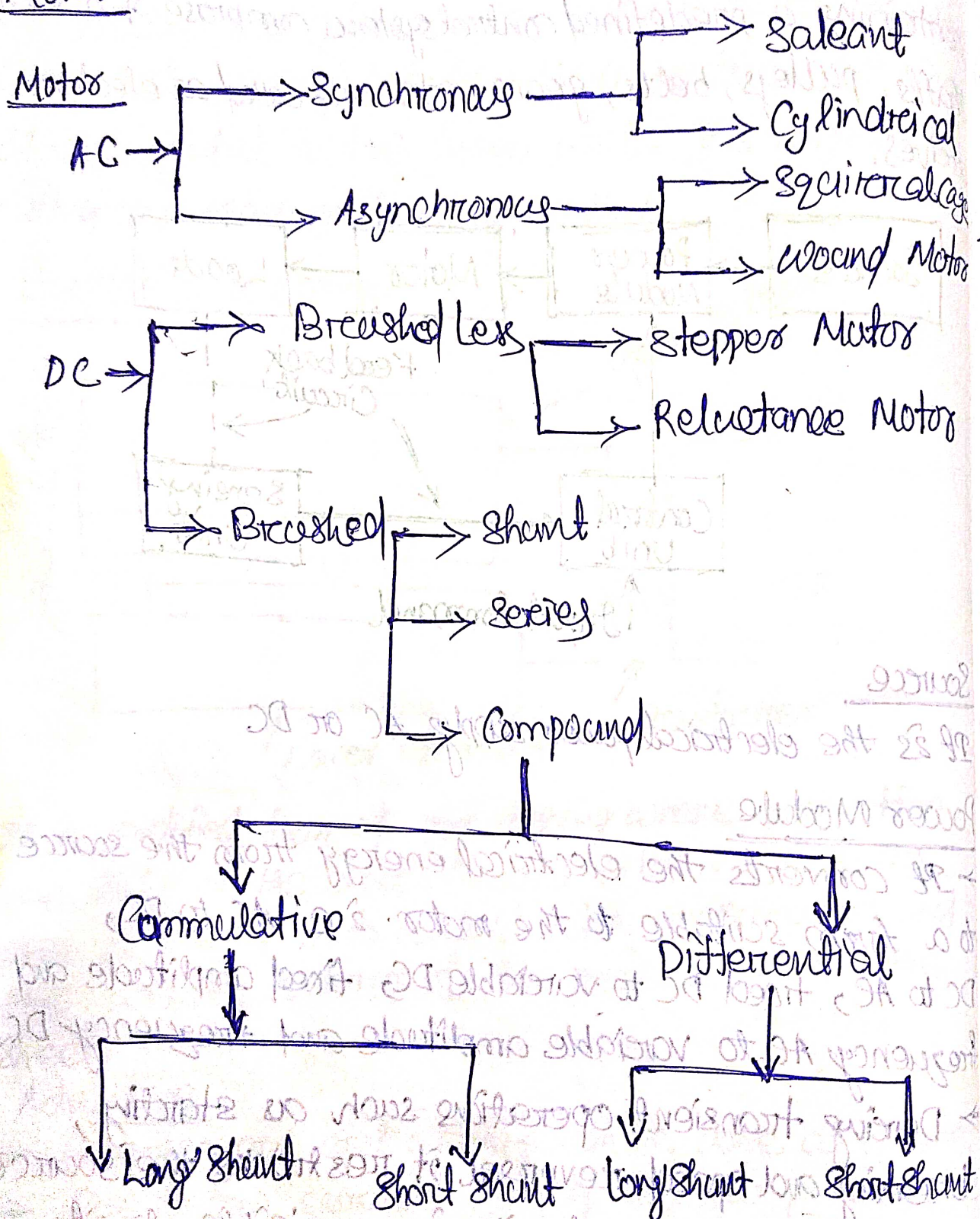
→ During transient operations such as starting, braking and speed reversal it restricts the source and motor current within permissible limits.

→ ~~mode~~ selection of mode of operation is done i.e. motoring or braking.

Load

Loads are usually the appliances such as fans, machines, domestic appliances, trains, pump etc

Motor



Sensing Unit

(62)

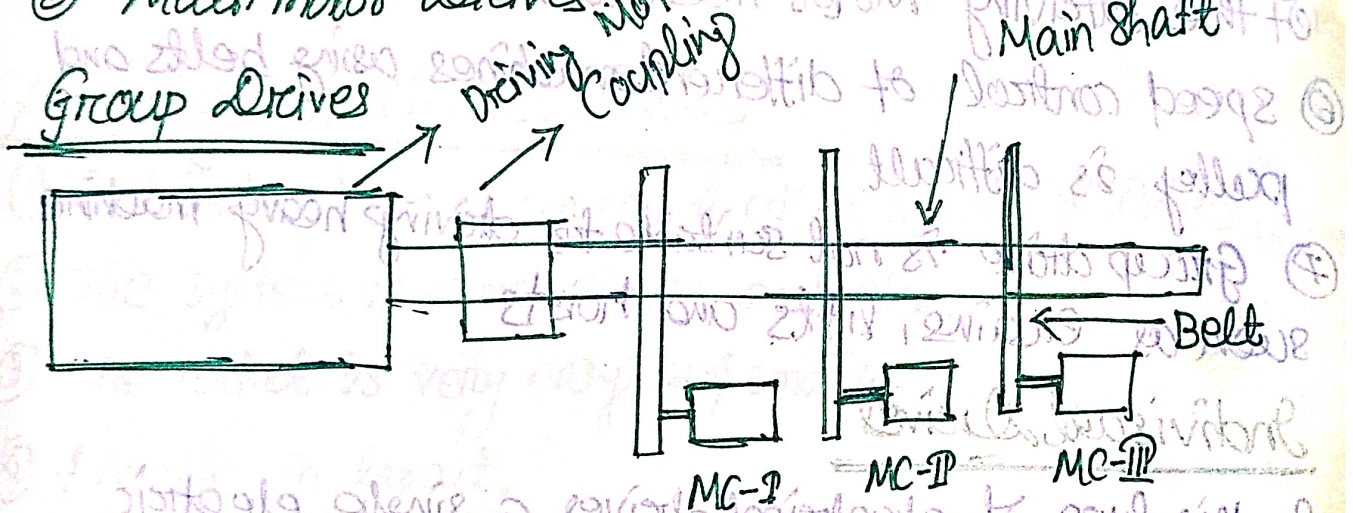
This are used to determine the drive parameters such as speed, motor current etc.

Control Unit

It controls the power modulator, decides generating commands for the protection of motor and power modulator. It usually operates at much lower voltage and power levels.

Types of Electrical Drives

- ① Group Drives
- ② Individual drives
- ③ Multimotor Drives



In this case one motor can be utilized for the driving of two or more than two machines. The motor is connected to a long shaft where different machine to be driven are connected by belt and pulley system.

Advantages

- ① Initial cost is less
- ② All the machine can start & stop simultaneously.
- ③ It requires less space
- ④ Maintenance cost is low.

Disadvantages

- ① Group drives has low power factor.
- ② efficiency $\Rightarrow$ Group drive system when used all the machines are not working together then the main motor shall work at very much reduced load.
- ③ If the main motor fails then the whole industries will shut down.
- ④ It is not possible to install a new machine at a far away distance.
- ⑤ If the no. of load unit is increased then the rating of the driving motor need to be increased.
- ⑥ speed control of different machines using belts and pulley is difficult.
- ⑦ Group drive is not suitable for driving heavy machine such as cranes, lifts and hoists.

Individual Drives

In this type of electrical drives a single electric motor is used to drive one individual machine. This type of drives cost more but the speed control, installation increase of unit and maintenance becomes very easy.

Advantages

- ① It gives desired operation as each machine is driven by its own individual motor.
- ② Individual motor works as good power factor.
- ③ Efficiency of the system is high.

- ④ More reliability
- ⑤ Machine can be installed at convenient location
- ⑥ useful when constant speed is required.
- ⑦ suitable for driving heavy machine such as lift & cranes.

Multimotor Drives

It consists of several individual drives which perform different functions and are a part of big complicated machinery. This type of drive has their application in paper making machines, cable manufacturing units, metal cutting machines, rolling mills etc.

Advantages of Electric Drives

- ① Cost is too low as compared to other systems of drives.
- ② The system is more simple and clean.
- ③ The control is very easy and smooth.
- ④ Flexible in layout.
- ⑤ Facility for remote control.
- ⑥ Transmission of power from one place to another with the help of cable instead of long shaft etc.
- ⑦ Its maintenance cost is quite low.
- ⑧ It can be started at any time without delay in time.

Disadvantage of Electric Drives

(65)

- ① Electric Drive system is tied only up to the electrified area.
- ② Accident may occur due to short circuit, leakage from conductors and breakdown of overhead conductor.
- ③ Failure of supply may paralyse the whole system.

Choice of Electrical Drive

- ① Requirement Related to the source →
Type of source, capacity of source, magnitude of voltage, voltage fluctuation, power factor, harmonics and their effect on other loads and ability to accept regeneration power.
- ② Steady state operation Requirements →
Nature of speed torque characteristics, speed regulation, speed range, efficiency, duty cycle, quadrant of operation, speed fluctuations and rating.
- ③ Transient Requirement →
starting, braking, values of acceleration and deceleration, reversing performance.
- ④ Capital and running cost, maintenance
- ⑤ Environment and location
- ⑥ Reliability.
- ⑦ Space and weight restriction.

Specification of commonly used Motor

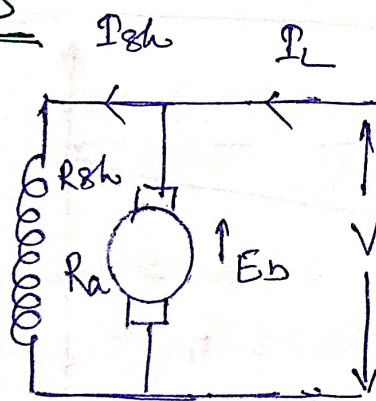
(66)

- ① Horse Power rating, Break Horse Power
- ② Type of supply DC or AC
- ③ whether 3- ϕ or 1- ϕ
- ④ frequency.
- ⑤ RPM
- ⑥ Enclosure.

Choice of Electric Motor

- ① Rating of the Motor
- ② Type of Motor $\rightarrow$ AC or DC
- ③ Type of bearings and enclosure to ~~stand~~ working condition.
- ④ Single or Multimachine system.
- ⑤ Type of Drive or transmission i.e. by direct or through gears, belt or chain.

DC Motors



$$E_b = V - I_a R_a$$

$$E_b = \frac{p \phi N Z}{60} \quad E_b \propto \phi N$$

p = no of pole

ϕ = flux per pole

N = speed

Z = no of conductors

A = no of parallel path

$$P = \frac{1}{\frac{2\pi N}{60}} R_b I_a$$

$$= \frac{60}{2\pi N} \frac{P \phi N Z}{60 A} I_a$$

$$P = \frac{P \phi Z I_a}{2\pi A} \quad \boxed{T \propto \phi I_a}$$

Shunt Motor $T \propto \phi I_a$

$$\boxed{T \propto I_a}$$

Series Motor

$$T \propto \phi I_a$$

$$\phi \propto I_f = I_a$$

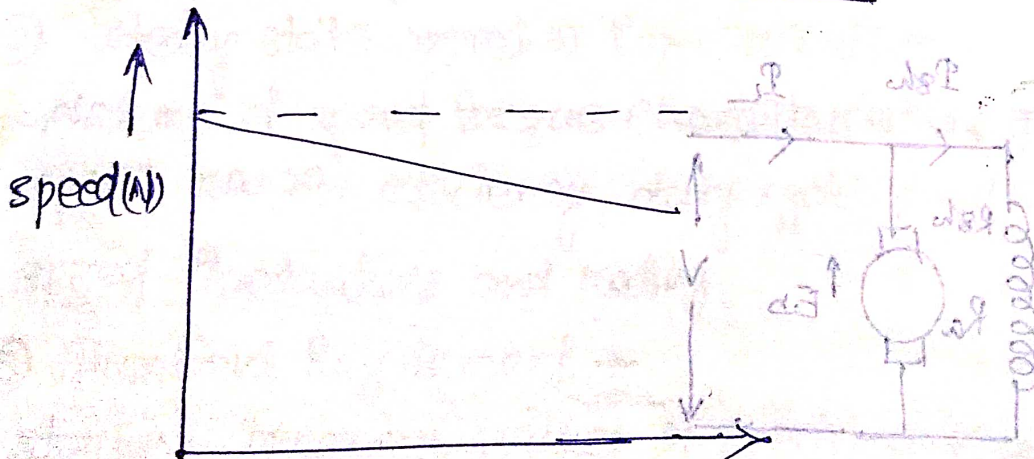
$$\phi \propto I_a \quad \boxed{T \propto I_a^2}$$

$$R_b = V - I_a R_a$$

$$\Rightarrow \frac{P \phi N Z}{60 A} = V - I_a R_a \Rightarrow N \propto \frac{V - I_a R_a}{\phi}$$

DC Shunt Motor characteristics

① speed - Current characteristics

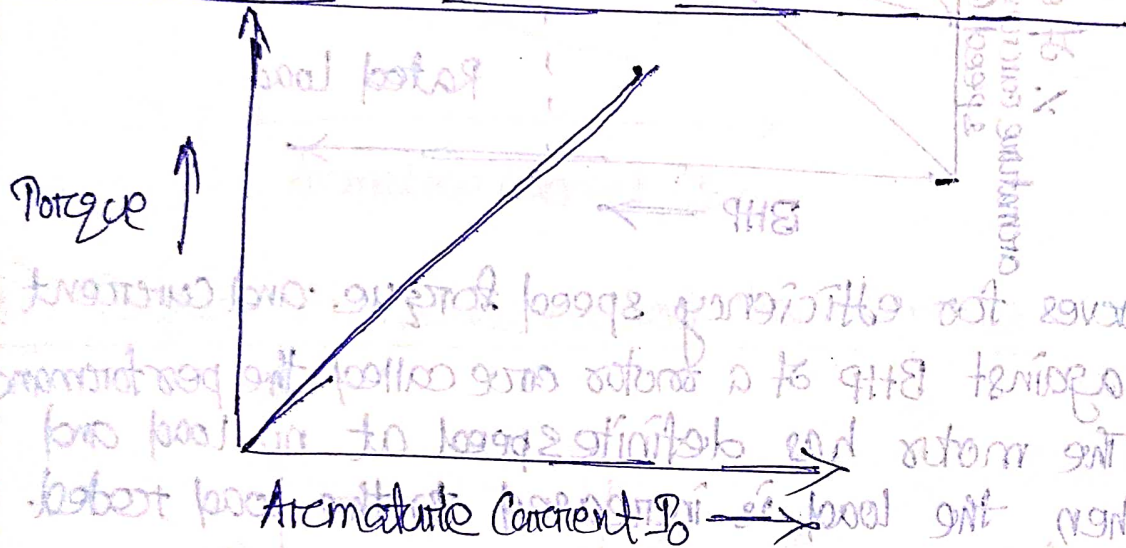


$$N \propto \frac{V - I_a R_a}{\phi}$$

$E_b = V - I_a R_a$
 $E_b = \frac{P \phi N Z}{60 A}$
 $N = \frac{60 A E_b}{P \phi Z}$
 $N \propto \frac{V - I_a R_a}{\phi}$

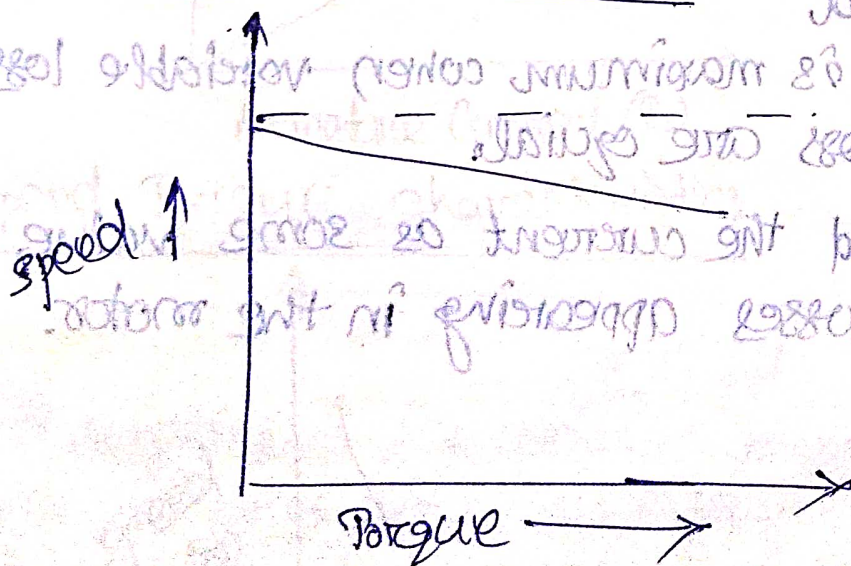
speed is directly proportional to the back emf and inversely proportional to flux ϕ . In shunt motor flux is constant hence if I_a is increased then $E_b = V - I_a R_a$ will decrease. So the speed decreases with increase in armature current.

③ Torque-Armature current characteristics



The $T \propto I_a$. Hence the characteristics is a ramp.

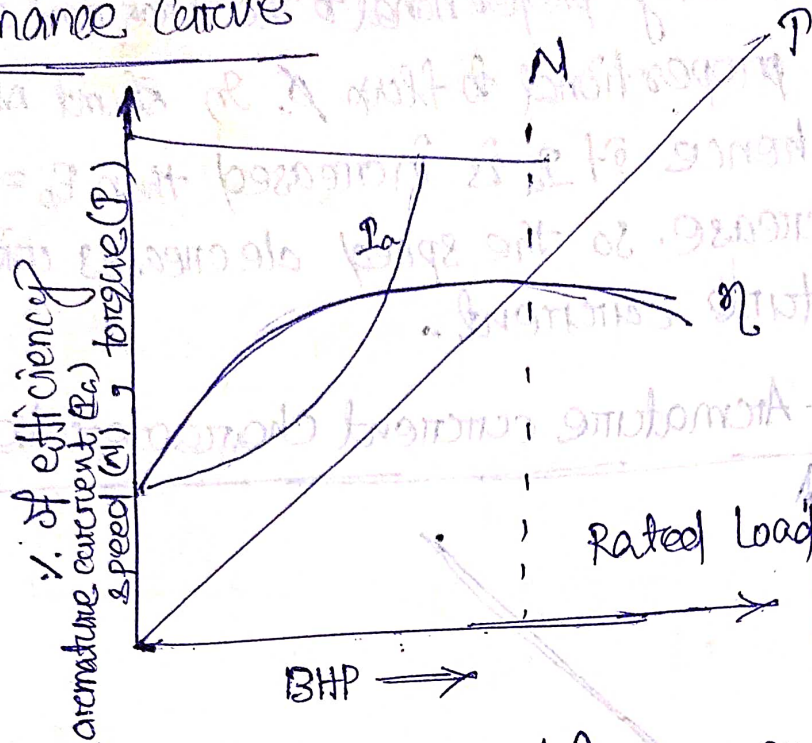
③ Torque speed characteristics



$$T \propto I_a$$

The speed decreases with increase in torque as the torque is directly proportional to the armature current.

performance curve



⇒ The curves for efficiency, speed, torque and current plotted against BHP of a motor are called the performance curve. The motor has definite speed at no load and falls when the load is increased to the load rated.

→ The efficiency of shunt motor increases rapidly in the begining, reaches its maximum value and fall at full load

→ The efficiency is maximum when variable loss and constant loss are equal.

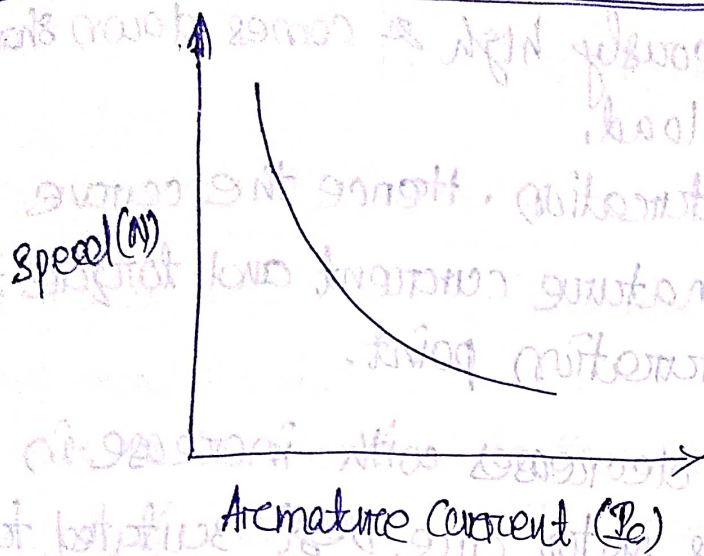
Even at no load the current is some value I_0 to meet the losses appearing in the motor.

← Super?

DC Series Motor Characteristics

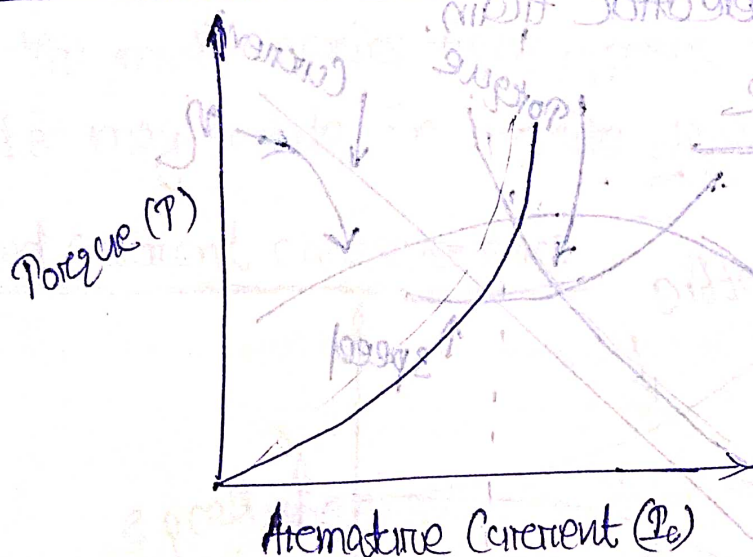
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① Speed Current characteristics



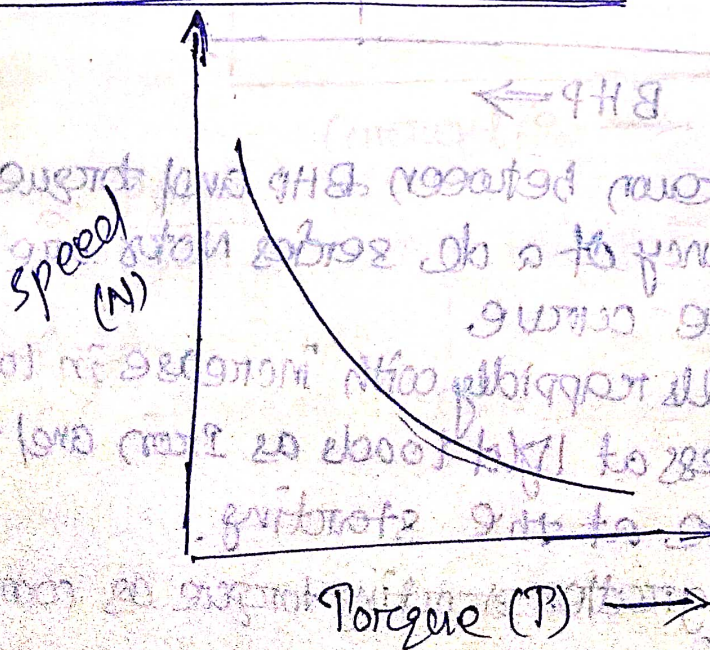
$$\begin{aligned} T &\propto I_a^2 \\ \phi &\propto I_a \end{aligned}$$

② Torque Armature current characteristics



For a given speed, torque is proportional to the square of the armature current.

③ Speed Torque characteristics

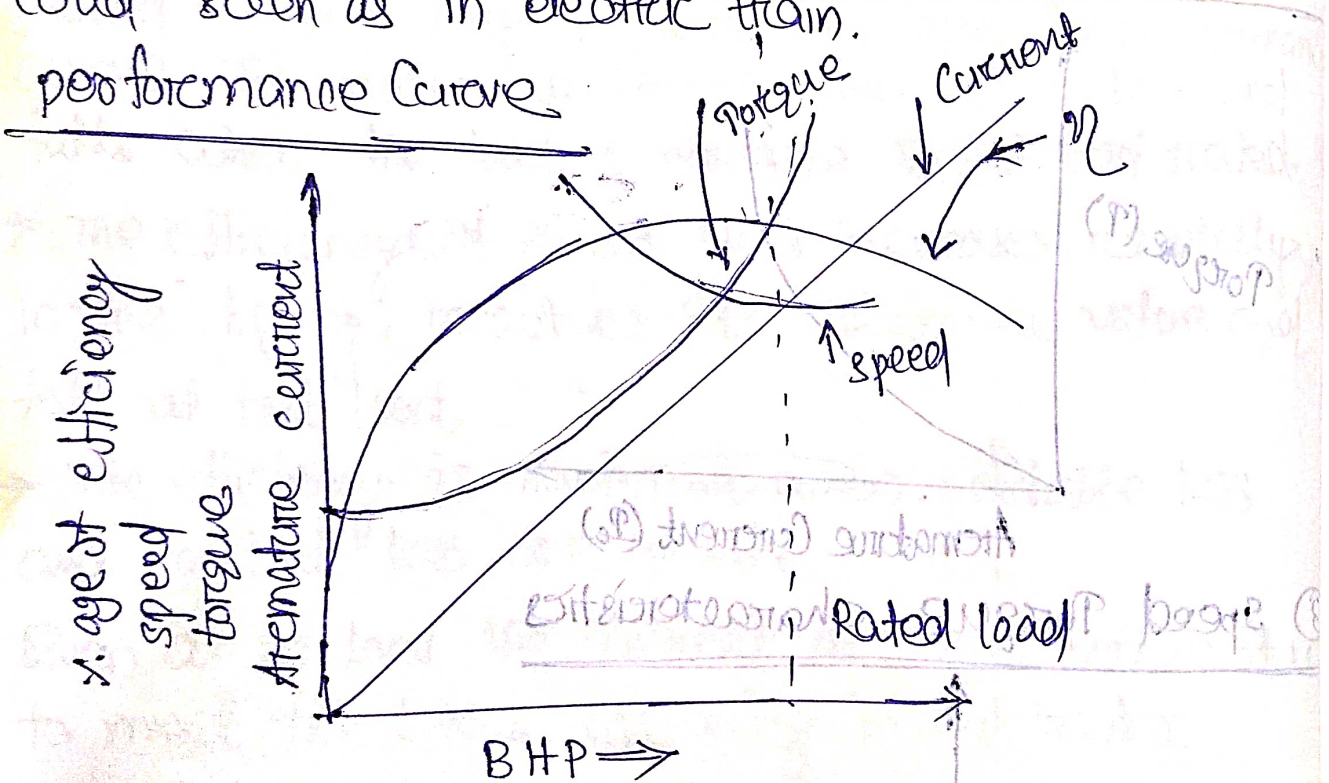


→ Speed is inversely proportional to I_a & flux ϕ directly proportional to I_a . Hence at light loads the speed is dangerously high & comes down sharply with the increase in load.

→ $T \propto I_a^2$ up to saturation. Hence the curve drawn between armature current and torque is parabola up to saturation point.

→ Speed of the motor decreases with increase in torque. Hence series motor are best suited for services where the motor is directly coupled to the load such as in electric train.

performance Curve



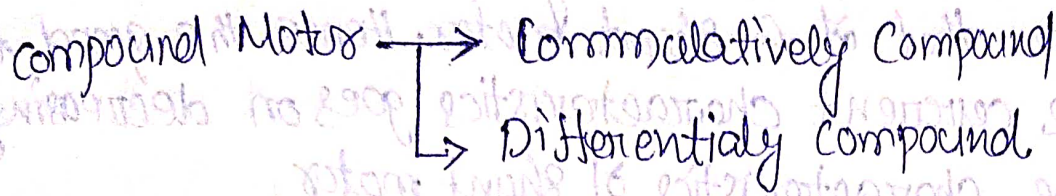
→ The curve drawn between BHP and torque, speed, current, efficiency of a dc series motor are known as performance curve.

→ The speed falls rapidly with increase in load the efficiency is less at light loads as iron and friction loss are large at the starting.

→ It develops a greater starting torque as compared to shunt motor.

DC Compound Motor characteristics

(72)



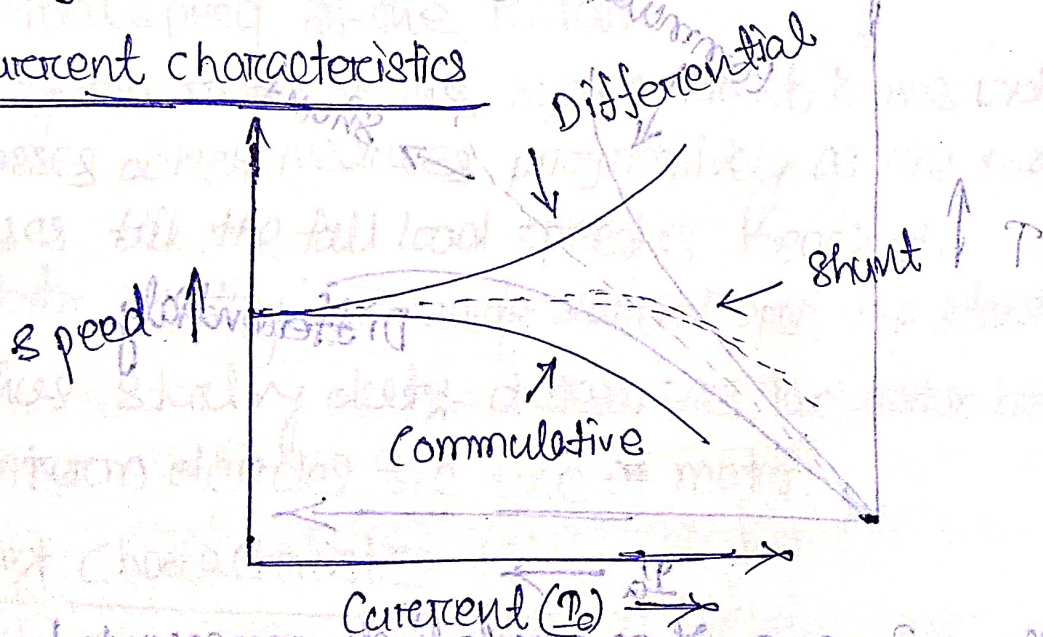
Commutatively Compound

- In this motor series field winding is connected to assist the shunt field.
- This motor are used in the application of sudden heavy load. i.e. rolling Mills, ~~seamless~~ etc.

Differentially Compound

In this motor series field opposes the shunt field. This motor may rotate in opposite direction at high load.

Speed Current characteristics



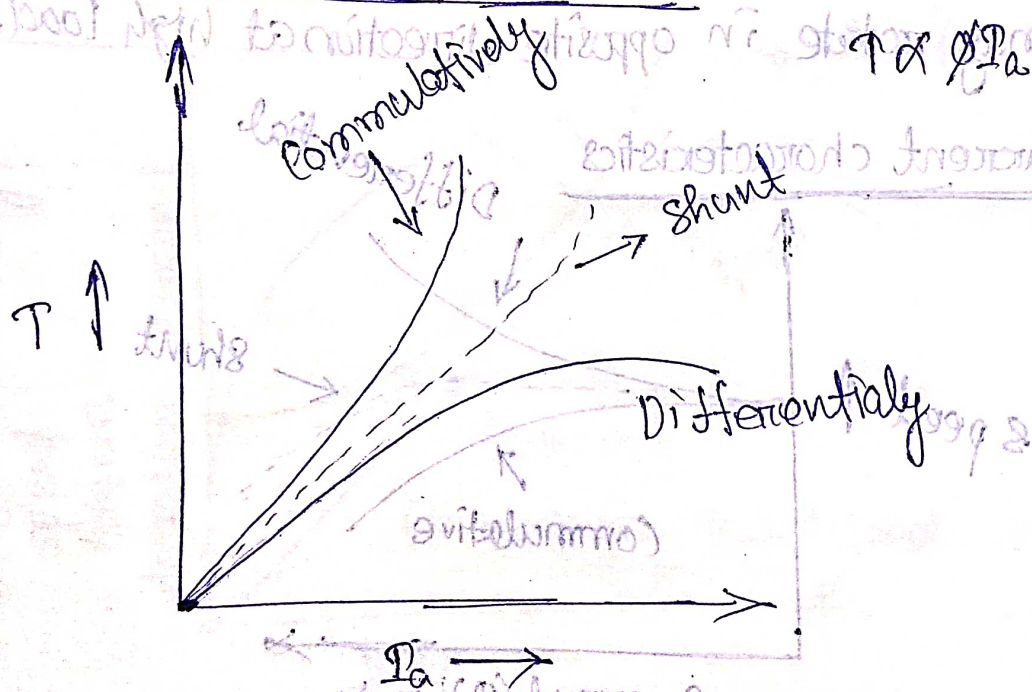
$$E_b \propto \frac{P \phi N Z}{60 A}$$

$$\Rightarrow N \propto \frac{E_b}{\phi}$$

The flux in case of cumulatively compound DC motor is greater than that of a shunt motor. Hence the speed-armature current characteristics goes on decreasing below the characteristics of shunt motor.

In case of differentially compound motor the series field opposes the shunt field as a result for the same value of armature current. The flux produced by differentially compound motor is lesser than that of shunt motor. Hence the speed is more than that of shunt motor.

Torque Current characteristics



→ Flux in case of cumulatively compounded motor is more than that of shunt motor. so torque develop in cumulatively compound motor is that of shunt motor for same armature current.

→ In case of differentially compounded motor flux is less than that of shunt motor hence the torque is less than that of shunt motor.

Starting characteristics

- The selection of motors in industrial case largely depends on the starting characteristics of the load. The size of the motor not only decided by the load torque but by the accelerating and breaking torque also.
- In case of induction motor which is largely used in industries, power transfer from stator to rotor through the rotating magnetic field hence the mechanical power develop by the motor depends on the actual speed of the rotor.
- Initially the motor draws high current, hence undergoes high losses which reduces progressively as the speed increases till the full load speed is reached. Thus rotor heating primarily depend upon the starting time thus starting duty determines the rotor heating which in turn decides the size of motor.

Running characteristics

- speed torque characteristics
- speed current characteristics
- torque current characteristics
- losses & efficiency.

Application of Motor

(75)

DC Shunt Motor

- This motor has nearly constant speed and torque varies proportional to the current.
- Starting torque and maintenance cost is medium.
- Continuous speed range of 4% is possible by usual ways.
- It can be used for driving constant speed line shaft lathes, vacuum cleaners, pressure blowers, centrifugal pumps, washing machines and printing press etc.

DC Series Motor

- It has very high starting torque, speed is dangerously high at light or no load.
- It is applied in electric traction rolling mills and cranes.

Commutatively Compound Motor

This are applied in driving compressors, stamping machines, door lifts, shearing machines, elevators.

Differential Compound Motor

Starting torque is low and has unstable operation, constant but dangerously high speed at no load. It is seldom used in practice.

Synchronous Induction Motor

It is a constant speed motor and starting torque is twice the full load torque. This are used for driving large fans, compressors, line shaft and pumps.

3- ϕ squirrel cage Induction Motor

It has nearly constant speed with poor starting torque. This are used in tubewell, leather, drilling machine saws, grinders, blowers etc.

Slipring Induction Motor

The speed is constant, starting torque is twice the full load torque has high overload capacity and speed can be controlled over a small range. This are used in lifts due to high starting torque, pumps windings machines, compressors etc.

3- ϕ series Motor

It has high starting torque of about 2.5 times of full load torque, speed control is possible over full range but maintenance cost is high. This are used in drives where load increases with speed, such as fans, centrifugal pumps, hoist work etc.

Scraper Motor

It has nearly constant speed high starting torque, wide range speed control and nearly unity power factor. This are applied in driving paper making machines, textile work etc.

1- ϕ Synchronous Motor

(77)

It has constant speed & speed control is not possible. Initial cost is more as compared to squirrel cage I.M. This one is used in teleprinters, clocks, sound recording etc.

1- ϕ Series Motor

It has high starting torque about 3 times the full load torque, speed control of full range is possible with the help of transformers. Maintenance cost is high. This one is applied in driving domestic appliances, vacuum cleaners, mixer grinders.

Repulsion Motor

High starting torque, wide range speed control is possible. This one is applied in services requiring large starting torque and adjustable but constant speed.

Capacitor start 1- ϕ induction Motor

It has high ~~start~~ starting about 1.5 times the full load torque. Speed control is not possible. Power factor is 0.7 to 0.9 Lagging. Mainly used for compressors, refrigerators and portable hoist.

Capacitor start capacitor run type Motor

High efficiency, power factor varies from 0.9 to 0.1 Lagging. Operation is quite and nearly constant speed. Application is in water coolers and large air conditioners.

Electric Traction

The system where driving force is obtained from electric motors are called electric traction.

e.g. → Electric Train, trolley buses etc

Ideal Traction System

The most important requirement of the driving equipment for traction service are follows.

- ① Maximum tractive effort should be exerted at starting in order that a rapid acceleration may be attained.
- ② The equipment should be capable of overloads for short periods.
- ③ The wear cost on tract. should be minimum.
- ④ The locomotive or train unit should be self contained and able to run on any road.
- ⑤ Braking should be possible with out excessive wear.

Advantages of Electric Traction

- ① Cheapness → Among all traction method this one is the cheapest.
- ② Acceleration & Braking → This one smooth & rapid.
- ③ Cleanliness → smoke, flue gas free hence it is most suitable for under ground & tubular railway traction system.

- ④ Maintenance cost $\Rightarrow$ Maintenance & repair cost of electric traction is about 50% than that of steam traction system.
- ⑤ Starting time $\Rightarrow$ It can be started in any instant without the loss of time where as steam engine need minimum 2 hr to get started.
- ⑥ High starting torque $\Rightarrow$ Electric traction uses series DC or AC Motors. hence the starting torque is very high & also makes acceleration rate very high.
- ⑦ Breaking $\Rightarrow$ In electric traction regenerative braking is used which feeds back about 40% of the energy.
- ⑧ Saving in high grade coal $\Rightarrow$ Steam locomotive requires high grade coal which is deficient in our country. the electric locomotives requires electric energy which is supplied either from hydropower plant or from a thermal power plant which run from low grade coal.
- ⑨ Better coefficient of adhesion $\Rightarrow$ In electric traction coefficient of adhesion is better due to absence of unbalanced forces produced by reciprocating masses. It reduces the wear and tear of the track.
- ⑩ It has greater passenger carry capacity at higher speed as compared to steam locomotive.

79. ① The fans and light in the trains can be connected directly to the supply lines and there is no need for providing extra generator and battery.

② Center of gravity $\rightarrow$ The height of electric traction trains are less as compared to steam engine trains. The lower height enables it to take curves even at higher speed.

Disadvantages of Electric Traction

- ① Higher initial expenditure is involved in electric traction.
- ② Failure of supply is a problem that can cause to stop the electric traction.
- ③ Electric locomotives have to move only on electric field track.
- ④ For electric braking and control additional equipment are required.
- ⑤ When AC energy is utilized for traction then precautions are to be taken to prevent the distribution network to interfere with adjacent telegraph or telephone line.

System of Traction

① Direct steam engine →

Reciprocating steam engine is most widely used for rail road operation. The system works by the application of the cylinder and driving wheels connection to produce the necessary motive power and easy speed control. The locomotive and trains are self contained and therefore it is not tied to a route.

Advantages

- Low initial investment as compared to electric drive.
- It has simple controls.
- It is cheap for low density, traffic areas and in initial stages of communication by rail.

Disadvantages

- Low efficiency (6 to 8%).
- Higher cost of Maintenance.
- Limited over load capacity.
- Greater wear of track because of oscillating parts atmospheric contamination, corrosion of steel structure and building due to smoke.

② Direct Internal combustion engine →

(82)

Internal combustion engine produces almost constant torque at all speeds to increase the starting torque & also for speed control a gear box as to be provided such an arrangement is only applied to small trolleys. The efficiency is 25%.

Advantages

- Initial investment required being only the cost vehicle and garage is very low.
- speed control and breaking system is very simple.

Disadvantages

- Its overload capacity is limited on account of speed torque characteristics of the engine.
- speed control is possible only by employing a gear box.
- Maintenance and running cost are high.
- It creates economic problems of the country as fuel oil are imported from other countries.
- It is not suitable for heavy railway work as the arrangement possible for speed control and utilizing the torque of engine to full capacity when running on full speed is not altogether satisfactory for it.

③ Internal combustion engine electric Drive → (88)

In this system a dc generator is coupled to a diesel engine drive at a constant speed. The dc generator supplies power to electric motors fitted with the wheels.

Advantages

- No modification of existing track is needed for the conversion of steam traction to diesel engine electric traction.
- Low capital cost as it does not involve the track electrification.
- Greater tractive effort as compared to steam engine as hence greater rate of acceleration at starting.
- Better riding quality.
- Absence of smoke and dirt. which is convenient for the passenger.
- Efficiency is greater than steam locomotives.

Disadvantages

- Maintenance and operating cost is high
- Overall load capacity is limited as diesel engine can not be overloaded.
- Life of diesel engine is comparatively shorter.
- special cooling system is needed for motor generator set.
- For same power diesel electric locomotive is costlier than steam or electric locomotive.

④ Battery Electric Drives →

(34)

In this drive the locomotive takes DC power from the secondary battery and give it to DC Motors. The DC motors are responsible for driving the vehicles. The capacity is very low and used for shunting railway yards, traction in mines, local delivery of goods in large industries and towns.

⑤ Electric Drives →

In this drive the vehicle draws electric energy from the distribution system fed at suitable point from any power station or substation.

Advantages

- Due to absence of smoke and dust it is very clean.
- Maintenance and repair cost is about 50% of that steam locomotives.
- It has rapid acceleration and braking system, hence reduces time and maintain the schedules.
- As hydroelectric power is cheap it saves fuel.
- Traction motor can withstand high overload for short time, where as steam and diesel locomotive can not.
- An electric train with multiple unit control can be operated from both ends and is ready from return trip with out much loss of time.
- Electric locomotive can be serviced immediately.

Disadvantages

- It causes interference to the telephone lines in some places.
- whole system become stands still in case of power failure.
- A very high capital cost is involve for initial installation.

DC & AC Traction Motors

- Motor used for traction purpose must have high starting torque & high starting acceleration to accelerate the heavy mass.
- Motor should have suitable speed torque characteristics.
- ⇒ In parallel operations of motors that should not be a large difference in the torque for a small speed variation i.e speed torque and speed current curves should not be flat.
- ⇒ During starting heavy current is drawn by the motor. Causing a considerable voltage fluctuation at supply line so traction motor should be so designed to withstand voltage fluctuation without on due effect on their performance.
- ⇒ Motors should in a position to withstand temporary interruption in power supply. occur while locomotive process from one supply section to another.
- ⇒ Motor used should in incorporated to simple speed control methods.

- Motor should be incorporated to easy and simple methods of rheostatic & regenerative braking mechanism
- During regenerative braking the distribution systems are subjected to higher voltage and hence the design of distribution system should be such made that it will account for this.
- The motor selection should be capable of taking heavy loads without flash over.
- Motor should be robust in constitution and high power output ratio which is achieved by employing high speed motors.
- Motor should be mechanically protected so as to prevent ingress of dirt, water, mud etc. in to it.
- Motor should have high mechanical & electrical efficiency.

Braking Characteristics

If an electric motor is to be stop the electric supply to it is disconnected. if the kinetic energy of the motor is large then it takes a long time to stop. so some extra braking system must be used so that it will stop before or within a predetermine time.

A good braking system must possess some important features like

- It should be fast and reliable
- The breaking force must be capable of being control.
- kinetic energy of the rotating parts of the motor and its driven machine must be suitable dissipated & suitable means must be provided.

Mechanical Breaking →

In mechanical breaking the stored energy of rotating part is dissipated in the form of heat by a break shoe or break lining which rubs on a wheel or break drum.

Electric breaking or Electrodynmamic Breaking →

In this type of breaking system the kinetic energy of the moving part of the system is converted into electrical energy which intern is dissipated as heat in a resistance or in certain cases may be return to the supply.

Advantages of Electric breaking over Mechanical breaking →

- ① Electric breaking is quite fast.
- ② It is cheaper than mechanical breaking as far as maintenance is concerned.
- ③ Due to fast operation & higher speed its capacity is quite high.
- ④ In some cases the energy required for the breaking is fed back to the source. Hence this results in saving in the operating cost.

⑤ Heat produced in electrical breaking is not harm but in mechanical breaking the heat produced due to mechanical breaks may lead to failure of the breaks.

⑥ Electrical breaking are more smooth and free from fire.

Disadvantages of Electric Breaking →

① Electric Breaking can stop the motor but it can not holds in stationary hence mechanical breaking is mandatory in addition with the electric breaking.

② Electric breaking can not be applied to all types of electric motors becomes limited choice of electric motor becomes limited.

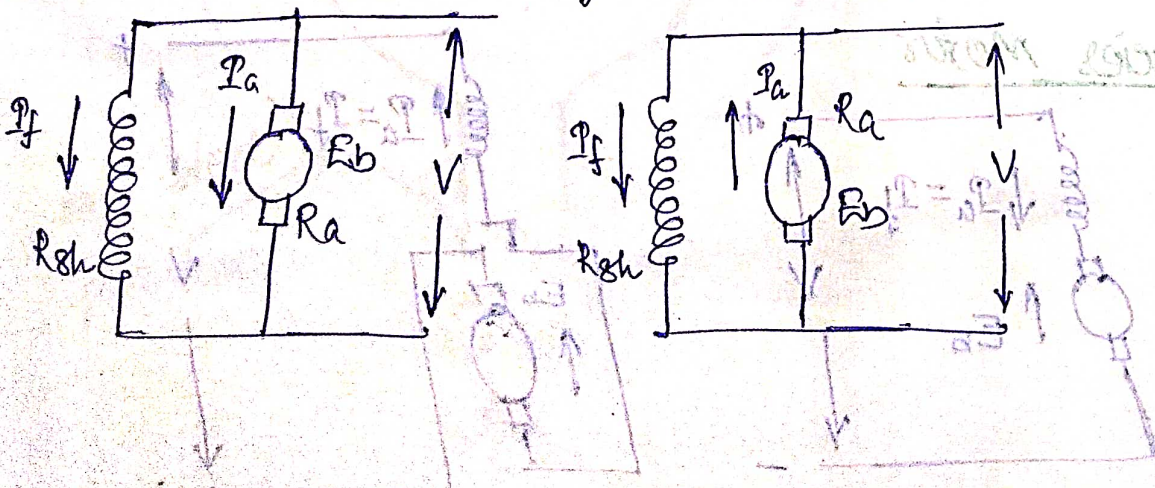
③ Its initial cost is very high.

Types of Electric Breaking

① Regenerative Breaking →

For shunt Motor

In regenerative breaking the motor is operated in a way that it generates energy and fed it back to the supply.



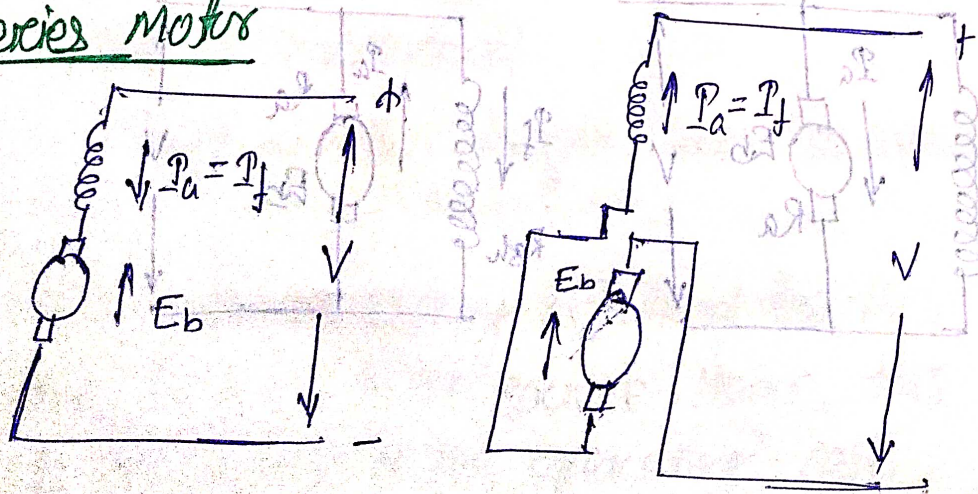
when back emf (E_b) becomes greater than the applied voltage ' V ' by keeping the flux unaltered then the power sends back to the supply, this can be achieved by

- (i) Supply voltage is reduced
- (ii) The field excitation is increased so that $E_b > V$
- (iii) The speed of the motor is increased beyond the no load speed of the motor so that $E_b > V$.

By doing this the torque produced in the opposite direction and the braking effect is produced.

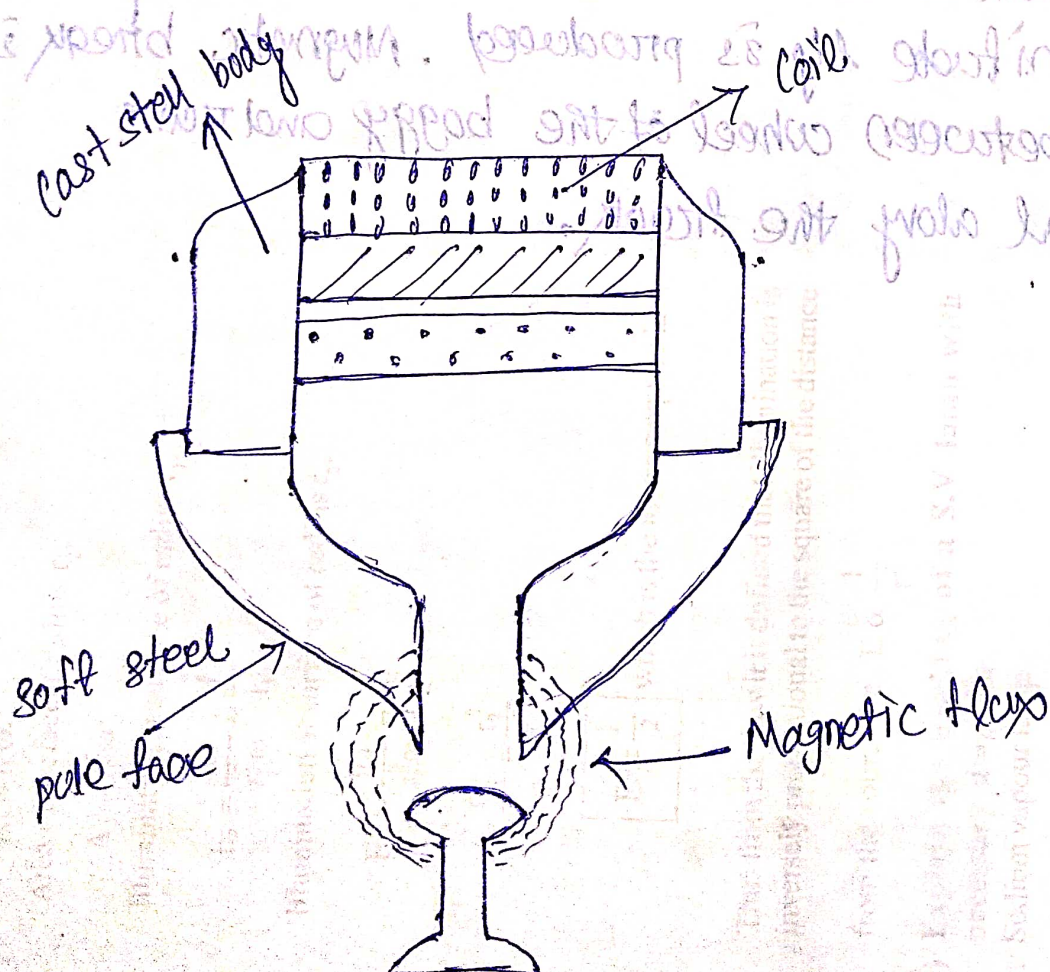
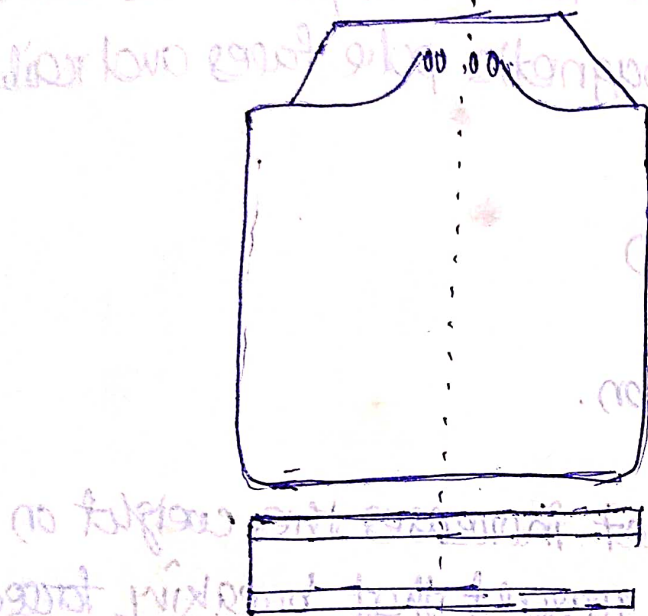
In normal working of dc shunt motor the applied voltage (V) is greater than the induced emf E_b and the motor drawing current from the supply. If due to overhauling loads the speed of the motor becomes greater than the normal. Then E_b becomes greater than ' V '. As a result the direction of armature current get reversed and feeds power to the source. This produces retarding torque and the speed of the comes down. E_b also can be increased by increasing the excitation or by increasing speed beyond its rated value.

For series motor



regenerative braking can not be applied to dc series motor because of the direction of armature current is reversed then the direction of field current also gets reversed. thus the series field connection must be reversed for regenerative braking as shown in the figure above.

② Magnetic Braking →



The figure shows the diagram of magnetic break consists of bipolar electromagnet with employed pole faces a short distance apart and along with rails. Its body is made up of cast steel and pole faces of soft steel. Pole faces are parallel to the rail. Passage of current through exciting coil produces magnetism which passes perpendicular to the rail face. This produces force of attraction between magnetic pole faces and rail given by the equation

$$F = \frac{B^2 a}{2 \mu_0} \text{ Newton}$$
$$= \frac{B^2 a}{8\pi \times 10^{-7}} \text{ Newton.}$$

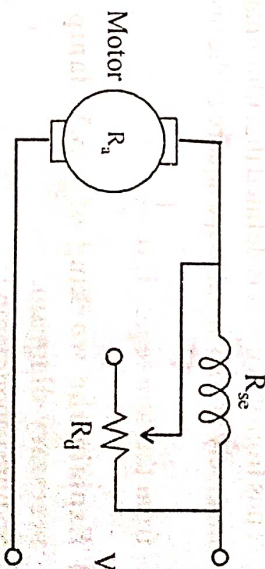
This magnetic force is effect increases the weight on breaking wheels with the result that breaking force of the magnitude μ_f is produced. Magnetic break is fitted in between wheel of the boggy and runs longitudinal along the track.

(g) Explain tapped field control of motor used for traction.

Ans. Tapped field control of dc series motor :

When traction motors have run up to speed an increase in speed is still possible to the extent of 15 to 30% by weakening the field strength. Since speed is inversely proportional to flux, by reducing the field strength the speed is increased. For reducing the strength of the field either a diverter is provided or the field is tapped.

The advantage of field control is that it makes the equipment very flexible. As for instance for city service low speeds with frequent starting & stopping are required. The equipment can operate with full field. When the same vehicle has to be used for suburban and inter urban lines where higher speeds are required, it would require a change in the gear ratio. So the provision of tapped field control eliminates the necessity of changing the gear ratio. Thus one type of equipment can operate various types of services at a reasonable energy consumption.



In this method the field resistance (R_{sc}) of the series motor is tapped by decreasing the no. of turns of the series field winding as shown in the figure. The resistance (R_d) will thus flux is decreased and speed turns are cut out, field flux is weakened and speed higher than normal speed is achieved.

Ans. Metadyne speed control of DC Traction motor :

The metadyne system of speed control estimates the energy loss and achieves a very smooth control during the acceleration period.

Consider a dc armature with two brushes and two poles. If current is supplied to the brushes A_1, A_2 the armature cure flux will be as shown and mainly confined the poles as shown in Fig.

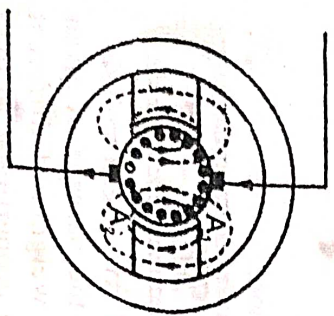


Fig. 1(a)

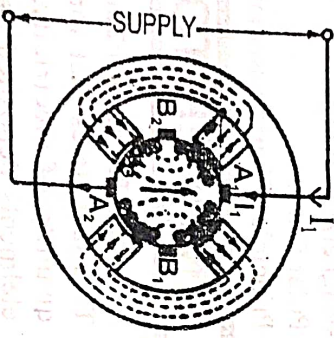


Fig. 1.(b)

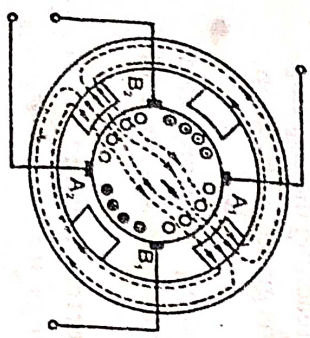


Fig. 1(c)

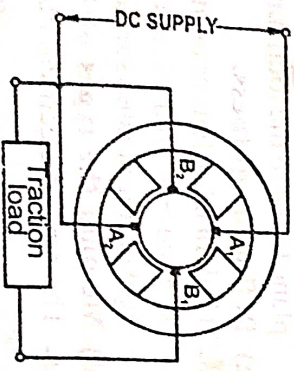


Fig. 1.(d)

in figure. If there are load four brushes, current is supplied to brushes A_1, A_2 and the armature cross flux will take up the path as shown in fig. If now the current is supplied to brushes B_1, B_2 as in figure, The armature cross flux takes up path as indicated. If the armature is rotated at constant speed and current ' I_1 ' is fed into brushes A_1, A_2 , an emf is induced in the wdg. between B_1, B_2 due to the flux produced by I_1 . No emf is induced between A_1, A_2 and the voltage between A_1, A_2 is on account of the voltage drop due to I_1 . Since an emf. is induced across B_1, B_2 a current I_2 will flow in a load connected between them. The resultant flux distribution on account of I_1 and I_2 as shown in Fig. The total flux (ϕ) may be assumed to be made up of two components ϕ_1 and ϕ_2 at right angles and directed along A_1, A_2 and B_1, B_2 . The rotation of the armature in ϕ_2 induces emf E_1 between A_1 and A_2 which opposes the supply voltage. Since the current is to be kept at its original value of the supply voltage must be induced to overcome E_2 . Under steady conditions

$$E_1 \propto \phi_2 = KI_2, E_2 \propto \phi_1 = KI_1$$

$$E_1 I_1 = E_2 I_2 \quad I_2 = KI_1 I_1$$

This shows that the m/c behaves like a dc Transformer only the rotational losses of the m/c need be supplied by the driving motor.

If the supply voltage ' E_1 ' remains constant, I_2 remains constant the arrangement is quite suitable for starting dc motors. The load current taken by dc motors remains constant. As the load resistance increases on account of the building up of back emf in dc motors I_2 remains constant, E_2 shall increase and since E_1 is constant, I_1 increases to supply the necessary power. After the motors have run up to speed, the current ' I_2 ' has to be reduced to the running value. For this purpose variator and regulator wdg are employed.

Illumination

(99)

Radiant energy is always emitted or absorbed in bundles. The valance electrons are responsible for the production of radiation in the visible region. Energy is emitted and absorbed only in discrete quanta of magnitude hf ,

$$h = \text{plank's constant} = 6.547 \times 10^{-27} \text{ erg sec}$$

f = frequency in Hz.

radiation is produced when even an electron falls from an outer stationary orbit to one nearer to the nucleus. whenever a such a transition occurs a single quantum or photon of radiation is emitted. Thus, the radiation from an atom is not continuous but is in the form of a quantum. whenever an electrons moves from one stationary orbit to another.

$$\text{velocity of light } v = \lambda f$$

λ = wave length

f = frequency of wave

Light spectrum consists of 7 colors denoted by

V $\rightarrow$ Violet

I $\rightarrow$ Indigo

B $\rightarrow$ Blue

G $\rightarrow$ Green

Y $\rightarrow$ Yellow

O $\rightarrow$ Orange

R $\rightarrow$ Red

Terms Used in Illumination

(95)

① Illumination →

when the light fall upon any surface the phenomenon is called illumination. It is defined as the number of lumens falling on the surface of unit area. denoted by E , Unit → lumens/m², lux, m. candle.

$$E = \frac{\phi}{A} \text{ lumen/m}^2 \text{ or lux or m. candle}$$

where ϕ is flux falling on the surface (lumen)

A is area of the surface (m²)

② Lumen →

Lumen is defined as the amount of luminous flux given out in space represented by one unit of solid angle by a source having an intensity of 1 candle power in all direction.

$$\begin{aligned} \text{Lumen} &= \text{candle power} \times \text{solid angle} \\ &= \text{CP} \times \omega \end{aligned}$$

Total lumen gives out by the source 1 candle is 4π lumens.

③ Luminous Flux →

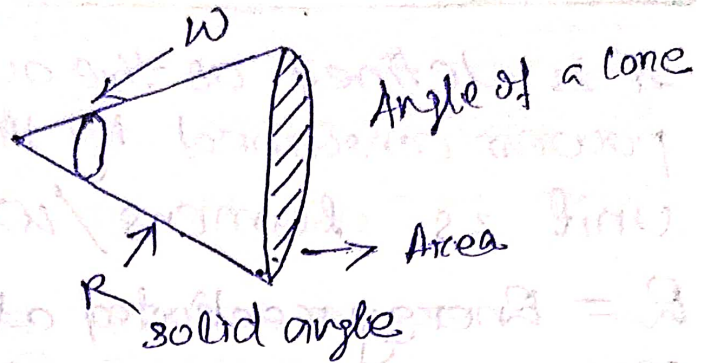
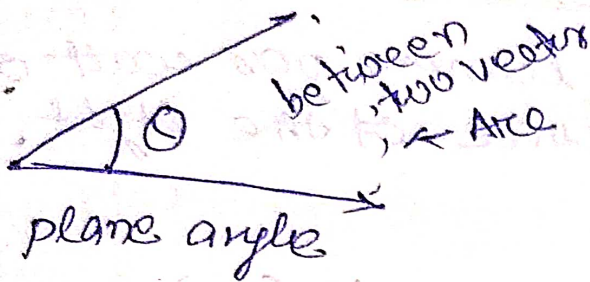
It is defined as the total quantity of Light energy radiated or emitted per sec from a luminous body in the form of light waves. Unit is lumens.

$$\phi = \frac{Q}{A}$$

Q = lumen hour
 t = time in hours.

① Solid Angle →

②



solid angle is the angle generated by the line passing through the point in space and the periphery of the area. A solid angle enclose a volume by an infinite number of lines lying on a surface and meeting at a point.

$$\omega = \frac{\text{Area}}{(\text{radius})^2} \quad \text{unit of } \omega = \text{steradian}$$

$$\text{plane angle } \theta = \frac{\text{Area}}{\text{radius}} = \frac{\text{Circumference}}{\text{radius}}$$

$$= \frac{2\pi r}{r} = 2\pi \text{ radian}$$

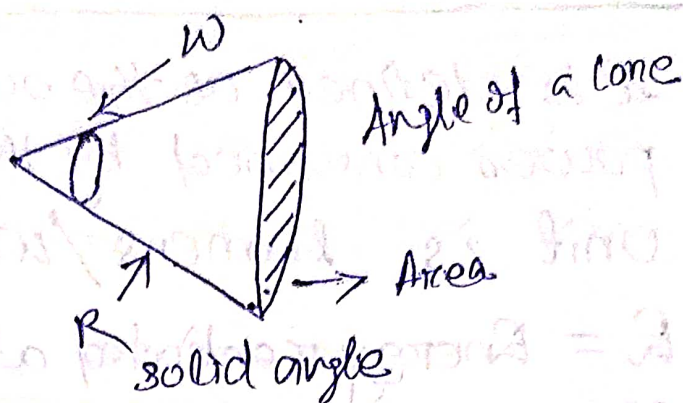
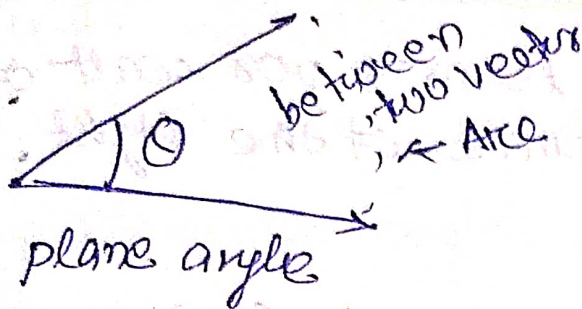
$$\text{solid angle } \omega = \frac{\text{Area of the sphere surface}}{(\text{radius of sphere})^2} = \frac{4\pi r^2}{r^2}$$

$$= 4\pi \text{ steradians}$$

$$\frac{\theta}{\omega} = \frac{r}{r} = 1$$

Solid Angle →

(B)



solid angle is the angle generated by the line passing through the point in space and the periphery of the area. A solid angle enclose a volume by an infinite number of lines lying on a surface end and meeting at a point.

$$\omega = \frac{\text{Area}}{(\text{radius})^2} \quad \text{unit of } \omega = \text{steradian}$$

$$\text{plane angle } \theta = \frac{\text{Area}}{\text{radius}} = \frac{\text{Circumference}}{\text{radius}}$$

$$= \frac{2\pi r}{r} = 2\pi \text{ radian}$$

$$\text{solid angle } \omega = \frac{\text{Area of the sphere surface}}{(\text{radius of sphere})^2}$$

$$= \frac{4\pi r^2}{r^2}$$

$$= 4\pi \text{ steradians}$$

$$\frac{\theta}{\omega} = \frac{r}{h} = \frac{r}{h}$$

⑤ Luminous efficiency or Radiant efficiency →

It is defined as the out in lumens per watt of the power consumed by the source of the light.
Unit is lumens/w.

E = Energy radiated at wave length (λ)

η = The relative sensitivity of eye at wave length

K = Maximum possible efficiency
= 680 lumens/watt

Efficiency at wave length $\lambda = \eta K$

total energy converted in visual effect

$$= K \int_{\lambda_1}^{\lambda_2} E \cdot \eta d\lambda$$

total energy radiated on all wave length

$$= \int_0^\infty E d\lambda$$

$$\text{Luminous efficiency} = \frac{K \int_{\lambda_1}^{\lambda_2} E \eta d\lambda}{\int_0^\infty E d\lambda}$$

⑥ Luminous intensity →

Luminous intensity in any particular direction in the luminous flux emitted by per unit solid angle by a point source. It is denoted by I .

$$I = \frac{F}{\omega} = \frac{\phi}{\omega}$$

Unit is lumens/steradian or Candela

Candela is defined as the luminous intensity in the particular direction of a surface of $\frac{1}{600,000}$ sq. m of a full radiator at the temperature of fusing platinum under a pressure of $101,325 \text{ N/m}^2$.

⑦ MSCP (Mean Spherical Candle Power) $\rightarrow$

It is defined as the average of candle power in all directions and in all planes from the source of light

$$\text{MSCP} = \frac{\text{Total flux in lumens}}{4\pi}$$

⑧ MHSCP (Mean Hemi-Spherical Candle Power) $\rightarrow$

It is defined as the average of candle powers in all directions above or below the horizontal plane passing through the source of light.

⑨ MHCP (Mean Horizontal Candle Power) $\rightarrow$

It is average of all candle power in all direction in the horizontal plane containing the source of light.

$$\text{⑩ Reduction factor} = \frac{\text{MSCP}}{\text{MHCP}}$$

$$\text{⑪ Reflection factor} = \frac{\text{reflected light}}{\text{Incident light}}$$

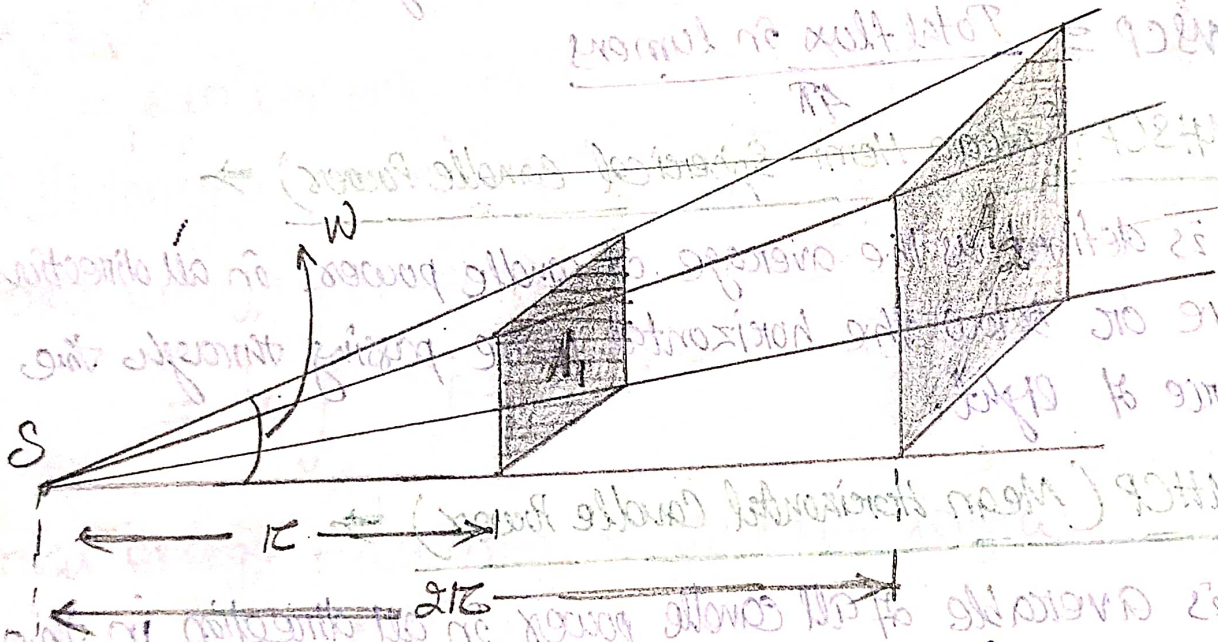
$$\text{⑫ Lamp efficiency} = \frac{\text{lumens emitted by source}}{\text{wattage of source of light}}$$

Laws of Illumination

1st law (Inverse Square law)

2nd law (Lambert's Cosine law)

Inverse Square law →



According to this law the illumination of a surface is inversely proportional to square of the distance between the source and surface provided that the distance between the surface & the source is sufficiently large so that the source can be regarded as a point source."

S = point source having an intensity I lumens/steradian

Two surfaces are there having area A_1 & A_2

A_1 is r metres away from source

A_2 is $2r$ " " " " "

Total flux $\phi = I \cdot \omega$ lumens

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i.e. flux on area $A_1 = I \cdot \omega$ lumens

$$\text{solid angle } \omega = \frac{\text{area}}{(\text{distance})^2} = \frac{A_1}{r^2} \text{ steradians}$$

Total flux on surface area = $I \cdot \frac{A_1}{r^2}$

illumination on surface of A_1 is E_1 , $E_1 = \frac{\phi}{A_1}$

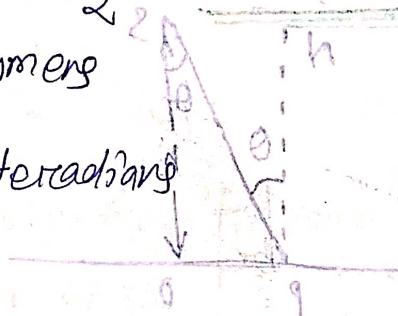
$$= I \cdot \frac{A_1}{r^2} \cdot \frac{1}{A_1}$$

$$= \frac{I}{r^2} \text{ lux or lumens/m}^2$$

Similarly for the surface A_2

Total flux = $I \cdot \omega$ lumens

$$\omega = \frac{A_2}{(2r)^2} = \frac{A_2}{4r^2} \text{ steradians}$$



$$\phi = I \cdot \frac{A_2}{4r^2}$$

$$E_2 = \frac{\phi}{A_2} = I \cdot \frac{A_2}{4r^2} \cdot \frac{1}{A_2} = \frac{I}{4r^2} \text{ lux or lumens/m}^2$$

$$E_1 : E_2 = \frac{1}{r^2} : \frac{1}{(2r)^2}$$

66 Illumination of a surface is inversely proportional to square of its distance from the source.

Lambert's Cosine Law →

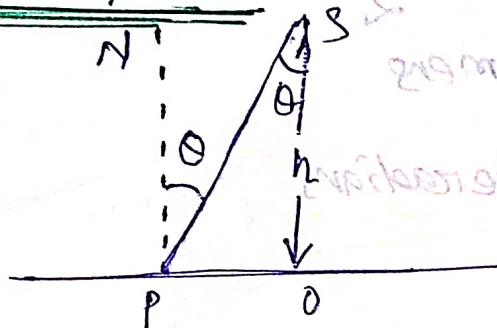
According to this law illumination of a surface varies directly as the cosine of the angle between the normal to the surface and direction of incident light.

$$E \propto \cos \theta$$

In the normal surface case $E = \frac{\phi}{\text{area}}$

In the inclined surface case $E = \frac{\phi}{\text{area}} \times \cos \theta$

Illumination at a point



Let p be the point on a plane surface at a distance of ' d ' metre from a source of light ' S '. ' h ' is the height of the source.

Let the source has I candle power

illumination point P is E_p

$$E_p \propto \frac{1}{d^2} \quad (\text{According to 1st law})$$

According to 2nd law

$$E_p \propto \cos \theta$$

$$E_p \propto \frac{\cos \theta}{d^2}$$

$$\Rightarrow E_p = \frac{I}{d^2} \cos \theta$$

where I is the luminous intensity of the source

$$\cos \theta = \frac{OS}{PS} = \frac{h}{d}$$

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$$\Rightarrow d = \frac{h}{\cos \theta}$$

$$E_p = \frac{P}{(h/\cos \theta)^2} \cdot \cos \theta$$

$$E_p = \frac{P}{h^2} \cos^3 \theta$$

Similarly Illumination at point 'O'

$$E_p = \frac{P}{h^2}$$

$$E_p \propto \cos^3 \theta = 1$$

$$E_p \propto \frac{P}{h^2}$$

Q. Calculate the total flux from the lamp having mean spherical candle power of 35.

$$\text{Total flux from the lamp} = 35 \times 4\pi = 439.82 \text{ lumens.}$$

Q. A 250 V has a total flux of 3000 lumens and takes a current of 0.8 Amp. Calculate (i) lumens/watt
(ii) MSCP/watt

$$\text{MSCP} = \frac{\text{Total flux}}{4\pi} = 238.73$$

$$P = 250 \times 0.8 = 200$$

$$\text{lumens/watt} = \frac{3000}{200} = 15$$

$$\text{MSCP/watt} = \frac{238.73}{200} = 1.19$$

Design of Lighting Scheme

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① Space height Ratio $\rightarrow$

It is defined as the ratio of horizontal distance between lamps.

$$\text{space height ratio} = \frac{\text{the horizontal distance between lamps}}{\text{Mounting height of the lamp}}$$

$$\text{② Utilization factor} = \frac{\text{Total lumens utilised on working plane}}{\text{Total lumens radiated by lamp.}}$$

the value of this coefficient depends upon the following conditions

- (a) The area to be illuminated
- (b) Height at which the lamps are fitted.
- (c) The colour of surrounding walls, ceiling, fittings etc.
- (d) The type of Lighting direct or indirect.

③ Depreciation factor

$$= \frac{\text{Illumination under normal working condition}}{\text{Illumination when everything is clean}}$$

avg. value = 0.8

$$= \frac{\text{Illumination when everything is clean}}{\text{Illumination under normal working condition.}}$$

④ Total lumens Required $\Rightarrow$

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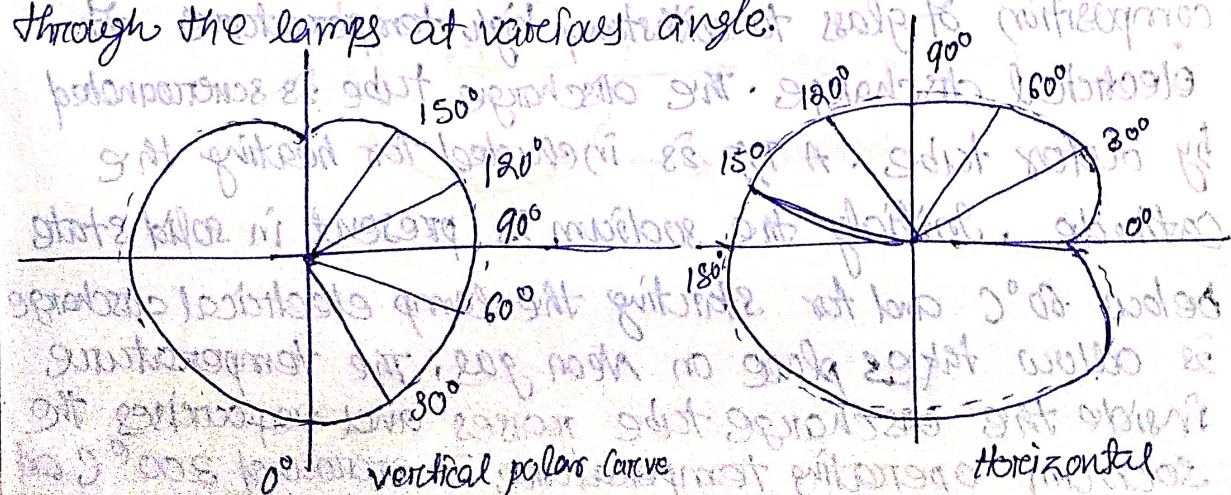
Total gross lumen o/p

$$= \frac{\text{Area (sq. ft)} \times \text{illumination (ft. Candles)}}{\text{Coefficient of utilization} \times \text{Depreciation factor (for value less than 1)}}$$

$$= \frac{\text{Area (sq. ft)} \times \text{illumination (ft. Candles)} \times \text{Depreciation factor (for value more than 1)}}{(\text{Coefficient of utilization}) \text{ utilization factor}}$$

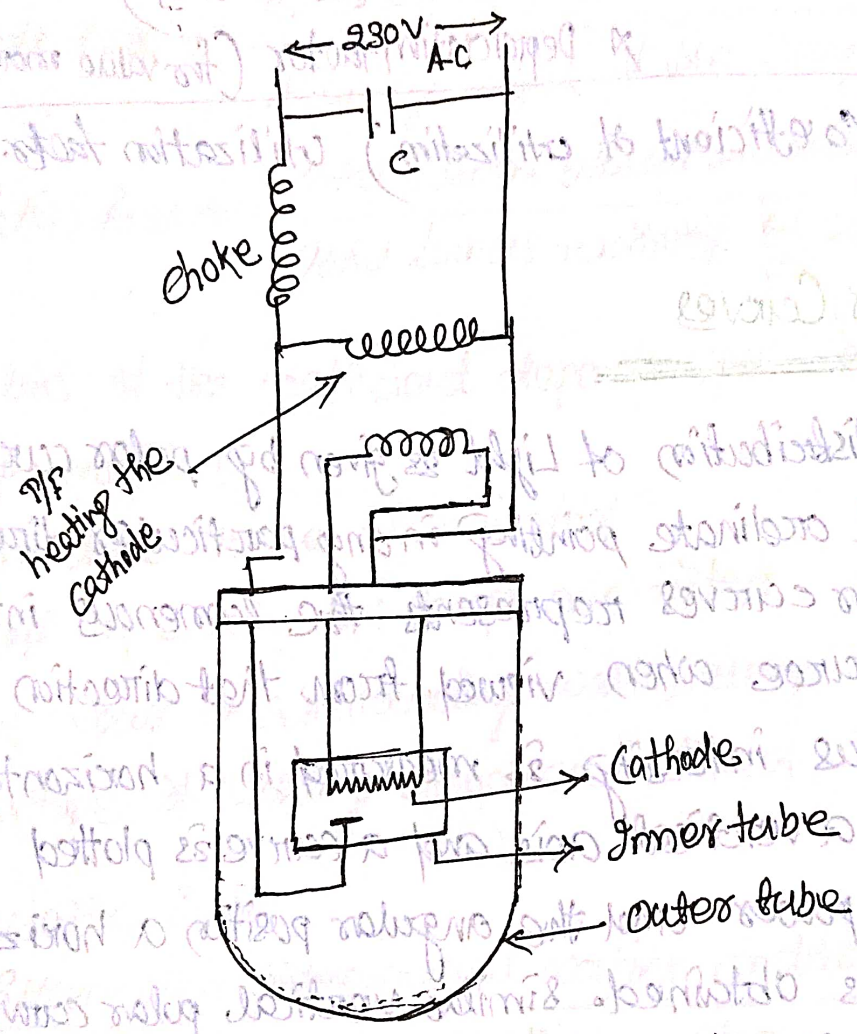
Polar Curves

The distribution of Light is given by polar curves. A radial ordinate pointing in any particular direction on a polar curves represents the luminous intensity of the source when viewed from that direction. If the luminous intensity is measured in a horizontal plane about a vertical axis and a curve is plotted between candle power and the angular position a horizontal polar curve is obtained. Similar vertical polar curve gives relationship of candle power in vertical plane passing through the lamp at various angle.



Brightness of the body
= $\frac{\text{Light emitted by the body}}{\text{Surface area of the body}}$

Sodium Vapour Lamp

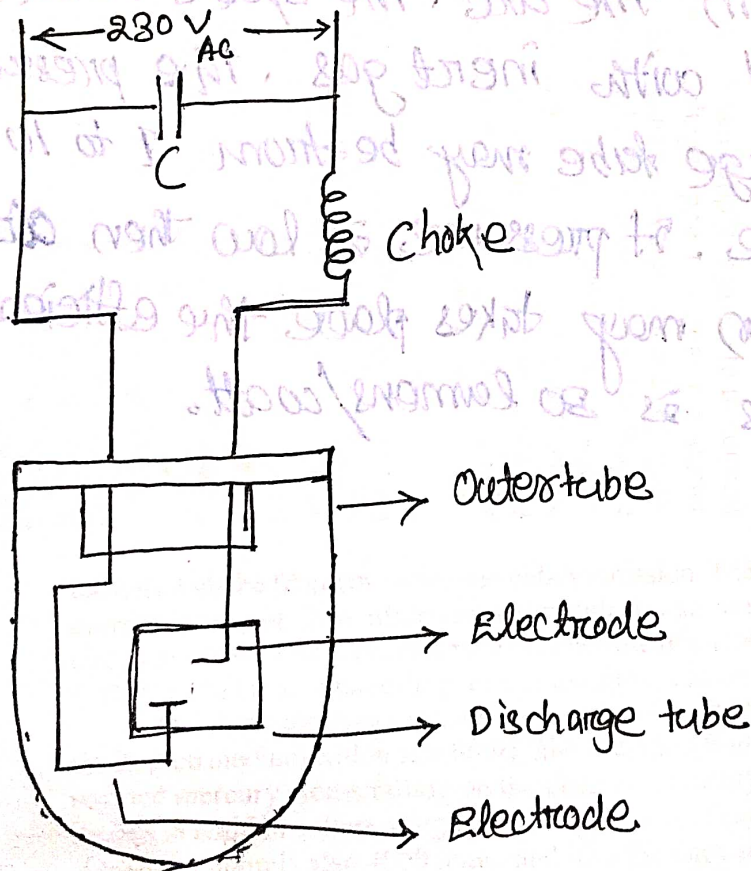


The lamp consists of a discharge tube having a special composition of glass to withstand high temperature of electrical discharge. The discharge tube is surrounded by outer tube. A T/P is included for heating the cathode. Initially the sodium is present in solid state below 60°C and for starting the lamp electrical discharge is allowed to take place on neon gas. The temperature inside the discharge tube rises and vaporises the sodium. Operating temperature is around 300°C and

It takes about 10 minutes for sodium to display ^(100%) red colour Neon by its own yellow colour. The lamp takes about $\frac{1}{2}$ hr to reach full output a choke is provided for stabilising the electrical discharge the light output is 80 to 50 lumens/watt.

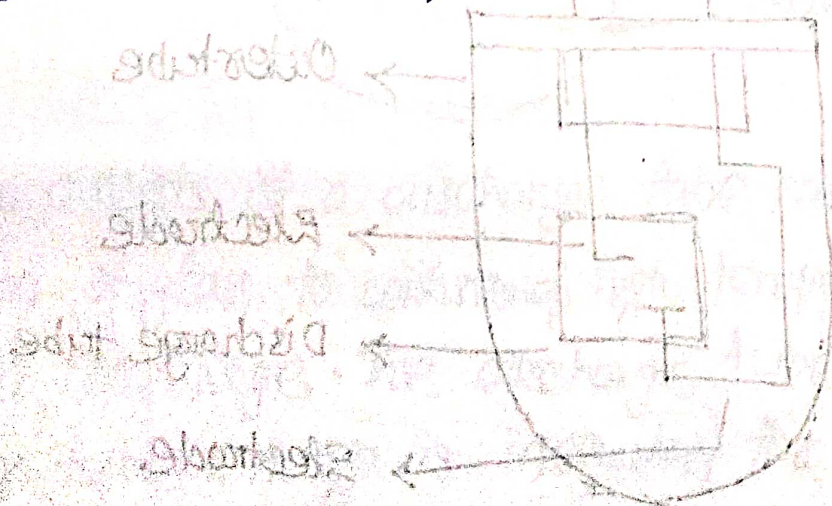
It has the highest theoretical luminous efficiency and gives monochromatic orange yellow light. The monochromatic light makes object appear grey. Such lamps are used for street and highway lighting.

High Pressure Mercury Vapour Lamps



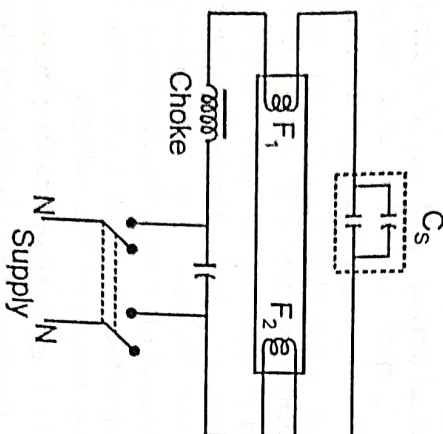
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High pressure mercury vapour lamp are similar to sodium vapour lamp. It has an outer tube and a discharge tube. The discharge tube containing the electrodes i.e. cathode and anode. The electrodes are made up of tungsten coils containing electron emitting material which may be a simple piece of thorium or an oxide. Argon is introduced which helps to start the lamp. The electrical discharge first takes place through argon and its vapour is the mercury drops inside the discharge tube. The electron emitting material supplies electron to maintain the arc. The space between two bulbs is filled with inert gas. The pressure inside the discharge tube may be from 1 to 10 atmosphere pressure. If pressure is low then ultraviolet radiation may take place the efficiency of this type of lamp is 30 lumens/watt.



(b) Explain with connection diagram the operation of fluorescent lamp with glow type starter.

Ans.



Construction : The fluorescent tube consists of a long tube with an electrode at each end which are in the form of coiled coil filament coated with an electron emitting material like oxide of barium and strontium. The inside of the tube is coated with fluorescent powder. A choke of high reactance is connected in series with the filament and starter as shown in the figure. A starter is connected in between two filament F_1 & F_2 as shown in the figure. There is also a capacitor is inside the starter. A capacitor C is connected across the supply terminal in order to improve power factor.

Operation : When supply is given to the circuit nearly full supply voltage appears across the starter terminals, due to low resistance of filament and negligible current through the choke. The starter is filled with some argon gas. At this high voltage the gas inside and a glow appears inside the starter. This warms up the bimetallic strip carrying moving contact and the strip bends and short circuited the starter terminal. This gives a circulation of strong current through the filament F_1 & F_2 and the choke coil.

As the filament is coated with oxides of barium and strontium, resulting in thermionic emission which can ionise the argon gas inside the tube. In the mean while the bimetallic strip of the starter cools down and breaks and pen the starter circuit. This sudden opening of starter contacts results in an about change of current linking with the choke coil and a high voltage surge is induced inside the choke coil which makes on filament F_1 at high potential w.r.t the other filament F_2 . This momentary high P.d is enough to ionise the gas medium i.e. mercury and argon present inside the tube. This results in passage of current between two electrodes inside the tube. As long as the ionisation presents collision between electrodes and mercury atoms continue. Further emission from filament is possible through the striking

the ions with the filament giving secondary emission. The current does not flow afterwards through the starter circuit due to the low resistance path between the filament F_1 & F_2 and a large voltage drop. across the choke circuit.

The choke also helps in keeping the current through the ionised medium within safe limits. The radiation from emitted mercury atoms falling on the phosphor coating results in whitish colour of light. The average life of the fluorescent lamp is also 4000 hours and its efficiency is about 40 lumens/watt.

The capacitor across the starter terminals is to avoid introduction of noise signals in the reception of a radio / transistor receiver being operated near the tube. the capacitor 'C' is connected across the supply in order to improve the power factor which becomes low due to the presence of high reactance choke coil.