UNIT - III

ELECTRIC HEATING AND WELDING

Syllabus: Electric Heating: Advantages and methods of electric heating, resistance heating, induction heating and dielectric heating. Electric welding: resistance and arc welding, electric welding equipment, comparison between A.C. and D.C. Welding.

HEAT:

Heat is the form of energy that is transferred between two substances at different temperatures. The direction of energy flow is from the substance of higher temperature to the substance of lower temperature. Heat is measured in units of energy, usually calories or joules. Temperature is the measure of hotness or coldness of matter. Stated another way, temperature is the average kinetic energy per molecule of a substance.

MODES OF TRANSFER OF HEAT:

The transmission of the heat energy from one body to another because of the temperature gradient takes place by any of the following methods:

1. Conduction
2. Convection
3. Radiation

Conduction:

This phenomenon takes place in solid, liquid and gas. In this mode, the heat transfers from one part of substance to another part without the movement in the molecules of substance.

The rate of the conduction of heat along the substance depends upon the temperature gradient. Heat transfer is proportional to the difference of temperature between two faces.

The amount of heat passed through a cubic body with two parallel faces with thickness 't' meters, having the cross-sectional area of 'A' square meters and the temperature of its two faces T_1°C and T_2°C, during 'T' hours is given by

$$Q = \frac{kA}{t}(T_1 - T_2)\,T \text{ MJ}$$

Where k is the coefficient of the thermal conductivity for the material and it is measured in MJ/m3 /°C/hr.

Ex: Refractory heating, the heating of insulating materials, etc.

Convection:

This phenomenon takes place in liquid and gas. In this mode, the heat transfer takes place from one part to another part of substance or fluid due to the actual motion of the molecules. The rate of conduction of heat depends mainly on the difference in the fluid density at different temperatures.

Ex: Immersion water heater.

The amount of heat absorbed by the water from heater through convection depends mainly upon the temperature of heating element and also depends partly on the position of the heater. Heat dissipation is given by the following expression.

$$H = a\,(T_1 - T_2)^{\,b}\ W/m^2$$

Where ‘a’ and ‘b’ are the constants whose values are depend upon the heating surface and $T_1$and T_2 are the temperatures of heating element and fluid in °C, respectively.

Radiation:

This phenomenon is confined to surfaces. The complete process in which energy is emitted by one body, transmitted through an intervening medium or space, and absorbed by another body. It is dependent on surface. Ex: Solar heaters.

The rate of heat dissipation through radiation is given by Stefan's Law.

Heat dissipation $H = 5.72\times10^4\ ke\ \left[\left[\frac{1}{1000}\right]^4 - \left[\frac{2}{1000}\right]^4\ \right]/m^2$

Where

T_1 is the temperature of the source in Kelvin,

T_2 is the temperature of the substance to be heated in Kelvin,

k is the radiant efficiency = 1 for single element, 0.5-0.8 for several elements

e = emissivity = 1, for black body = 0.9 for resistance heating element.

From above Equation, the radiant heat is proportional to the difference of fourth power of the temperature, so it is very efficient heating at high temperature.

ELECTRIC HEATING:

Electric heating is a process in which electrical energy is converted in to “heat energy.” Electric heating works on the principle of “joule heating.” (An electric current through a resistor converts electrical energy in to heat energy).

Electric heating is based on the principle of that when electric current passes through a medium heat is produced. Let us take the case of solid material which as resistance R ohms and current flowing through it is I amps for t seconds than heat produced in the material will be $H = I^2Rt$ joules.

Domestic application of electric heating:

- Room heater for heating the building
- Immersion heater for water heating
- Hot plates for cooking
- Geysers
- Electric iron
- Electric kettles
- Electric oven for baking products
- Electric toasters etc…

Industrial applications of electric heating:

- Melting of metals
- Electric welding
- Molding of glass for making glass appliances
- Baking of insulators
- Molding of plastic components
- Heat treatment of pointed super passes
- Making of plywood

Advantages of electric heating:

The various advantages of electric heating over other types of heating

i. **Economical:** Electric heating equipment is cheaper; they do not require much skilled persons; therefore, maintenance cost is less.

ii. **Cleanliness:** Since dust and ash are completely eliminated in the electric heating, it keeps surroundings cleanly.

iii. **Pollution free:** As there are no flue gases in the electric heating, atmosphere around is pollution free; no need of providing space for their exit.

iv. **Ease of control**: In this heating, temperature can be controlled and regulated accurately either manually or automatically.

v. **Uniform heating**: With electric heating, the substance can be heated uniformly, throughout whether it may be conducting or non-conducting material.

vi. **High efficiency**: In non-electric heating, only 40–60% of heat is utilized but in electric heating 75–100% of heat can be successfully utilized. So, overall efficiency of electric heating is very high.

vii. **Automatic protection**: Protection against over current and overheating can be provided by using fast control devices.

viii. **Heating of non-conducting materials**: The heat developed in the non-conducting materials such as wood and porcelain is possible only through the electric heating.

ix. **Better working conditions**: No irritating noise is produced with electric heating and also radiating losses are low.

x. **Less floor area**: Due to the compactness of electric furnace, floor area required is less.

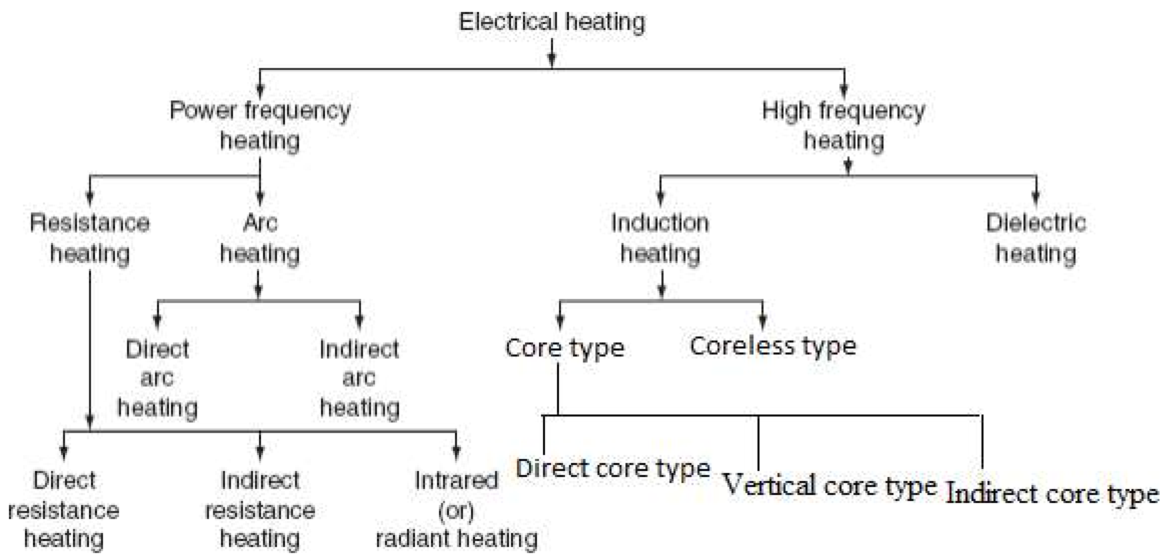
xi. **High temperature:** High temperature can be obtained by the electric heating except the ability of the material to withstand the heat.

xii. **Safety:** The electric heating is quite safe.

METHODS OF ELECTRIC HEATING:

Heat can be generated by passing the current through a resistance or induced currents. The initiation of an arc between two electrodes also develops heat. The bombardment by some heat energy particles such as α, γ, β, and x-rays or accelerating ion can produce heat on a surface.

Electric heating can be broadly classified as follows.



In general electric heating can be classified as power frequency heating and high frequency heating

POWER FREQUENCY HEATING:

Power frequency heating can be classified in to 2 type's i.e.

1. Resistance heating
2. Arc heating

1. Resistance heating:

When the electric current is made to pass through a high-resistive body (or) substance, a power loss takes place in it, which results in the form of heat energy, i.e., resistance heating is passed upon the I^2R effect. This method of heating has wide applications such as drying, baking of potteries, commercial and domestic cooking, and the heat treatment of metals such as annealing and hardening. In oven where wire resistances are employed for heating, temperature up to about 1,000°C can be obtained. The resistance heating is further classified as,

a) Direct resistance heating

b) Indirect resistance heating

c) Infrared (or) radiant heating.

a) Direct resistance heating:

In this type of heating electric current is passed directly through the body to be heated. Since the body has resistance, current causes heat generation in the body. Hence it raises the body temperature. (Or) In this method, the electric current is made to pass through the charge (or) substance to be heated.

In this method, electrodes are immersed in a material or charge to be heated. The charge may be in the form of powder, pieces, or liquid. The electrodes are connected to AC or DC supply. In case of DC or 1-φ AC, two electrodes are immersed and three electrodes are immersed in the charge and connected to supply in case of availability of 3-φsupply. When metal pieces are to be heated, the powder of lightly resistive is sprinkled over the surface of the charge (or) pieces to avoid direct short circuit. The current flows through the charge and heat is produced in the charge itself. So, this method has high efficiency. As the current in this case is not variable, so that automatic temperature control is not possible.

Applications:

- Electrode boiler for heating water
- Resistance welding
- salt bath furnace

Salt bath furnace:

This type of furnace consists of a bath and containing some salt such as molten sodium chloride and two electrodes immersed in it. Such salt have a fusing point of about 1,000–1,500°C depending upon the type of salt used. When the current is passed between the electrodes immersed in the salt, heat is developed and the temperature of the salt bath may be increased. Such an arrangement is known as a salt bath furnace.

In this bath, the material or job to be heated is dipped. The electrodes should be carefully immersed in the bath in such a way that the current flows through the salt and not through the job being heated. As DC will cause electrolysis so, low-voltage AC up to 20 V and current up to 3,000 A is adopted depending upon the type of furnaces.

The resistance of the salt decreases with increase in the temperature of the salt, therefore, in order to maintain the constant power input, the voltage can be controlled by providing a tap changing transformer. The control of power input is also affected by varying the depth of immersion and the distance between the electrodes.

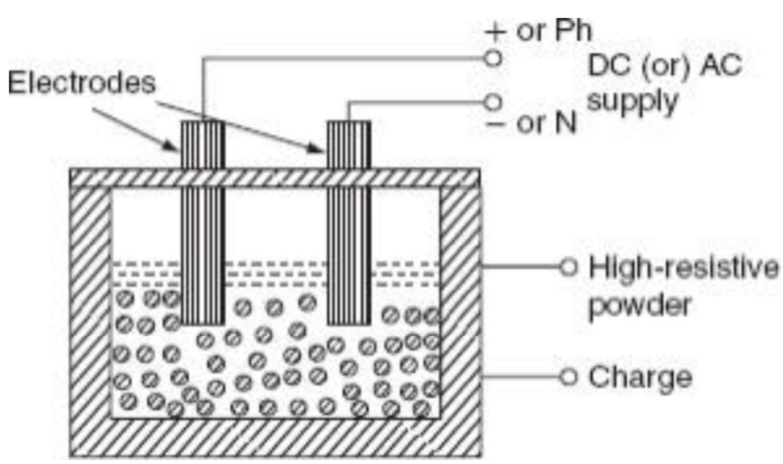


Fig.3.1. Salt bath furnace

Electrode boiler:

It is used to heat the water by immersing three electrodes in a tank as shown in the below Fig. This is based on the principle that when the electric current passed through the water produces heat due to the resistance offered by it. For DC supply, it results in a lot of evolution of H_2 at negative electrode and O_2 at positive electrode. Whereas AC supply hardly results in any evolution of gas, but heats the water. Electrode boiler tank is earthed solidly and connected to the ground. A circuit breaker is usually incorporated to make and break all poles simultaneously and an over current protective device is provided in each conductor feeding an electrode.

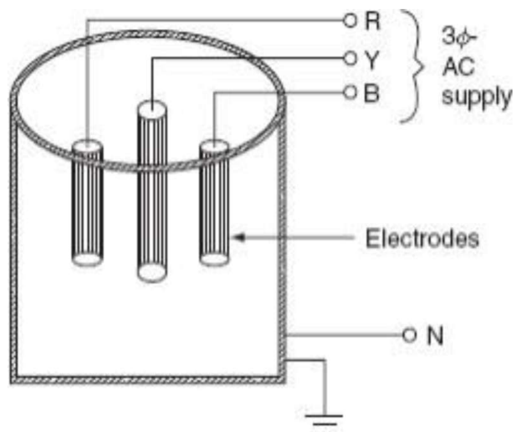


Fig.3.2. Electrode boiler

b) Indirect resistance heating:

In this method, the electric current is made to pass through a wire or high-resistance heating element, the heat so developed is transferred to charge from the heating element by convection or radiation.

In the indirect resistance heating method, high current is passed through the heating element. In case of industrial heating, sometimes the heating element is placed in a cylinder which is surrounded by the charge placed in a jacket is known as heating chamber is shown in the below fig. The heat is proportional to power loss produced in the heating element is delivered to the charge by one or more of the modes of the transfer of heat viz. conduction, convection, and radiation. This arrangement provides uniform temperature and automatic temperature control.

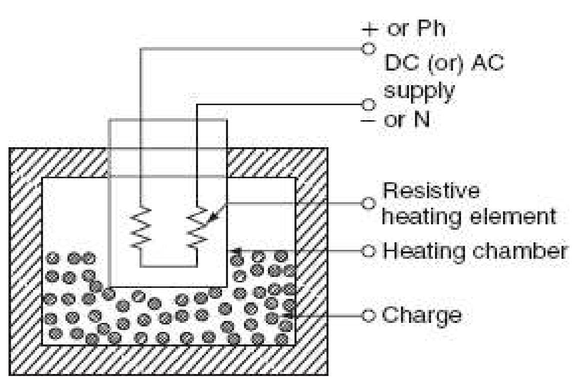


Fig.3.3. Indirect resistance heating

Applications:

- Resistance ovens
- Cooking
- Heat treatment of metals
- Immersion heaters or water heater
- Room heaters

Resistance ovens:

According to the operating temperatures, the resistance furnaces may be classified into various types. Low-temperature heating chamber with the provision for ventilation is called as oven. For drying varnish coating, the hardening of synthetic materials, and commercial land domestic heating, etc., the resistance ovens are employed. The operating temperature of medium temperature furnaces is between 300°C and 1,050°C. These are employed for the melting of nonferrous metals, stove (annealing), etc. Furnaces operating at temperature between 1,050°C and 1,350°C are known as high-temperature furnaces. These furnaces are employed for hardening applications. A simple resistance oven is shown in the below fig.

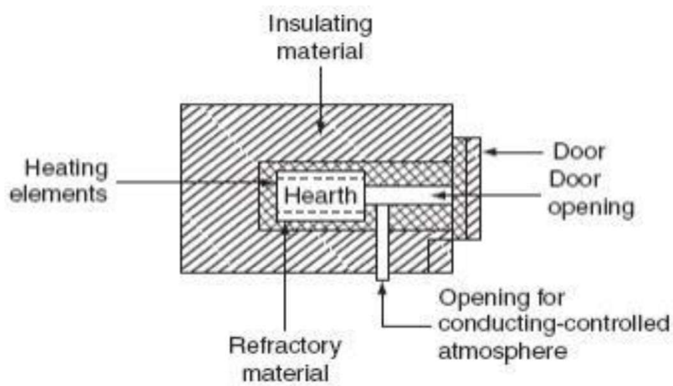


Fig.3.4. Resistance oven

Resistance oven consists of a heating chamber in which heating elements are placed as shown in the above fig. the inner surface of the heating chamber is made to suit the character of the charge and the type of furnace and oven. This type of insulation is used for heating chamber it is determined by the maximum temperature of the heating chamber.

Efficiency and losses of resistance ovens:

The heat produced in the heating elements, not only raises the temperature of the charge to desired value, but also used to overcome the losses occurring due to

1. **Heat used in raising the temperature of oven (or)furnace:** The heat required to raise the temperature of oven to desired value can be calculated by knowing the mass of refractory material (*M*), its specific heat (*S*), and raise of temperature (ΔT) and is given by

$$H_{oven} = MS\Delta TJ.$$

In case the oven is continuously used, this loss becomes negligible.

2. **Heat used in raising the temperature of containers (or)carriers:** Heat used in raising the temperature of containers (or) carriers can be calculated exactly same way as for oven or furnaces
3. **Heat conducted through the walls:** Heat loss conducted through the walls of the container can be calculated by knowing the area of the container (A) in square meters, the thickness of the walls (t) in meters, the inside and outside temperatures of the container T_1 and T_2 in °C, respectively, and the thermal conductivity of the container walls 'k' in m^3/°C/hr and is given by:

   Heat loss by conduction = $\frac{kA}{t}(T_1 - T_2)$ W
4. **Heat loss due to the opening of oven door:** Actually, there is no specific formula for the determination of loss occurring due to the opening of door for the periodic inspection of the charge so that this loss may be approximately taken as 0.58–1.15 MJ/m^2 of the door area, if the door is opened for a period of 2

Efficiency:

The efficiency of the oven is defined as the ratio the heat required to raise the temperature of the charge to the desired value to the heat required to raise the charge and losses.

$$\text{The efficiency of the oven} = \frac{\text{The heat required to raise the temperature of the charge}}{\text{The heat required to raise the temperature of the charge+Total losses}}$$

The efficiency of the resistance oven lies in between 60% and 80%.

c) Infrared (or) radiant heating:

In this method of heating, the heat energy is transferred from source (incandescent lamp) and focused upon the body to be heated up in the form of electromagnetic radiations, for low and medium temperature applications. Where as in resistance ovens, the heat transfers to the charge partly by convection and partly by radiation.

In the radiant heating, the heating element consists of tungsten filament lamps together with reflector and to direct all the heat on the charge. Tungsten filament lamps are operating at 2,300°C instead of 3,000°C to give greater portion of infrared radiation and a longer life. The radiant heating is mainly used for drying enamel or painted surfaces. The high concentration of the radiant energy enables the heat to penetrate the coating of paint or enamel to a depth sufficient to dry it out without wasting energy in the body of the work piece

The main advantage of the radiant heating is that the heat absorption remains approximately constant whatever the charge temperature, whereas with the ordinary oven the heat absorption falls off very considerably as the temperature of the charge raises. The lamp ratings used are usually between 250 and 1,000 W and are operating at voltage of 115 V in order to ensure a robust filament.

Applications:

- Used for drying clothes in the textile industry
- Dry the wet paints on an object.

TEMPERATURE CONTROL OF RESISTANCE HEATING:

To control the temperature of a resistance heating at certain selected points in a furnace or oven, as per certain limits, such control may be required in order to hold the temperature constant or to vary it in accordance with a pre-determined cycle and it can be carried out by hand or automatically.

In resistance furnaces, the heat developed depends upon I^2Rt or $\frac{V^2}{Rt}$.

Therefore, the temperature of the furnaces can be controlled either by:

- Changing the resistance of elements.
- Changing the applied voltage to the elements (or) current passing through the elements.
- Changing the ratio of the on-and-off times of the supply.

Voltage across the furnace can be controlled by changing the transformer tapings. Auto transformer or induction regulator can also be used for variable voltage supply. In addition to the above, voltage can be controlled by using a series resistance so that some voltage dropped across this series resistor. But this method is not economical as the power is continuously wasted in controlling the resistance. Hence, this method is limited to small furnaces. An on-off switch can employed to control the temperature. The time for which the oven is connected to the supply and the time for which it is disconnected from supply will determine the temperature.

Temperature can be controlled by providing various combinations of groups of resistances used in the furnace and is given as follows:

- **Variable number of elements:** If '*R*' be the resistance of one element and '*n*' be the number of elements are connected in so that the equivalent resistance is R/n.
  Heat developed in the furnace is: H = $\frac{{}^{2}}{(R/n)} = \frac{V^2}{R} \times n$
  i.e., if the number of elements connected in parallel increases, the heat developed in the furnace also increased. This method does not provide uniform heating unless elements not in use are well distributed.
- **Series parallel (or) star delta arrangement of elements:** If the available supply is single phase, the heating elements can be connected in series for the low temperatures and connected in parallel for the high temperature by means of a series parallel switch.

  In case, if the available supply is three phase, the heating elements can be connected in star for the low temperature and in delta for the high temperatures by using star—delta switch.

2. ARC HEATING:

If the high voltage is applied across an air gap, the air in the gap gets ionized under the influence of electrostatic forces and becomes conducting medium, current flows in the form of a continuous spark, known as arc. A very high voltage is required to establish an arc but very small voltage is sufficient to maintain it, across the air gap. The high voltage required for striking an arc can be obtained by using a step-up transformer fed from a variable AC supply.

Another method of striking the arc by using low voltage is by short circuiting the two electrodes momentarily and with drawing them back. Electrodes made up of carbon or graphite and are used in the arc furnaces when the temperature obtained is in the range of 3000-3500 ^{0}C. There are two types of arc heating and they are

1. Direct arc heating
2. Indirect arc heating

Direct arc heating:

In this method, by striking the arc between the charge and the electrode or electrodes, the heat so developed is directly conducted and taken by the charge. The furnace operating on this principle is known as direct arc furnaces. The main application of this type of heating is production of steel.

Indirect arc heating:

In this method, arc is established between the two electrodes, the heat so developed is transferred to the charge (or) substance by radiation. The furnaces operating on this principle are known as indirect arc furnaces. This method is generally used in the melting of non-ferrous metals.

HIGH FREQUENCY HEATING:

The main difference between the power frequency heating and the high-frequency heating is that in the conventional methods, the heat is transferred either by conduction convection or by radiation, but in the high-frequency heating methods, the electromagnetic energy converted into the heat energy inside the material.

The high frequency heating can be applied to two types of materials. The heating of the conducting materials, such as Ferro-magnetic and non-Ferro-magnetic, is known as induction heating. The process of heating of the insulating materials is known as dielectric heating.

The heat transfer by the conventional method is very low of the order of 0.5–20 W/sq. cm. And, the heat transfer rate by the high-frequency heating either by induction or by dielectric heating is as much as 10,000 W/sq. cm. Thus, the high-frequency heating is most importance for tremendous speed of production

This high frequency heating can be classified in to two types

1. Induction heating.
2. Dielectric heating.

Advantages of high-frequency heating:

- Dielectric heating is appropriate for non-conducting materials such as plastic, wood, and synthetic compounds.
- When the heat is generated during the complete mass of material, then we get consistent heating. By using a conventional heating method, it is not achievable to get this.
- To complete this process very little time is necessary when contrasted to another method.

Disadvantages of high-frequency heating:

- This method is suitable for the highest dielectric loss materials
- The dielectric heating overall efficiency will be very low
- The radio interface can be caused due to high frequencies.
- The equipment used for dielectric heating is so costly so it is used only where other techniques are unfeasible.

Applications of High-Frequency Heating:

- There are many industries that use dielectric heating techniques like paper, textiles, food, chemicals, and plastic.
- There are many applications like baking, drying, welding, polymerization and defrosting.
- These come under the techniques of dielectric heating or high frequency.
- These two are electromagnetic wave energy forms.

1. INDUCTION HEATING:

The induction heating process makes use of the currents induced by the electromagnetic action in the material to be heated. To develop sufficient amount of heat, the resistance of the material must be low which is possible only with the metals, and the voltage must be higher, which can be obtained by employing higher flux and higher frequency. Therefore, the magnetic materials can be heated than non-magnetic materials due to their high permeability.

In order to analyze the factors affecting induction heating, let us consider a circular disc to be heated carrying a current of '*I*' amps at a frequency '*f*' Hz. As shown in below fig.

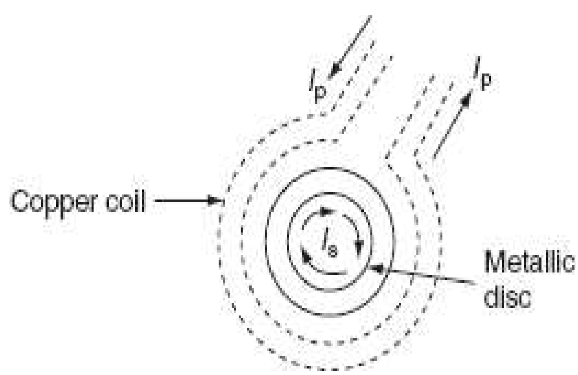


Fig.3.5. Induction heating

Heat developed in the disc is depending upon the following factors.

- Primary coil current.
- The number of the turns of the coil.
- Supply frequency.
- The magnetic coupling between the coil and the disc.
- The high electrical resistivity of the disc.

If the charge to be heated is non-magnetic, then the heat developed is due to eddy current loss, whereas if it is magnetic material, there will be hysteresis loss in addition to eddy current loss. Both hysteresis and eddy current loss are depended upon frequency, but at high-frequency hysteresis, loss is very small as compared to eddy currents.

The depth of penetration of induced currents into the disc is given by

$$d = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^9}{\mu f}} \text{ cm}$$

Where ρ is the specific resistance in Ω-cm, f is the frequency in Hz, and μ is the permeability of the charge

There are basically two types of induction furnaces and they are

a. Core type or low-frequency induction furnace.
b. Coreless type or high-frequency induction furnace

a. Core type or low-frequency induction furnace:

The operating principle of the core type furnace is the electromagnetic induction. This furnace is operating just like a transformer. It is further classified as,

- Direct core type.
- Vertical core type.
- Indirect core type

Direct core type induction furnace:

The core type furnace is essentially a transformer in which the charge to be heated forms single- turn secondary circuit and is magnetically coupled to the primary by an iron core as shown in below fig.

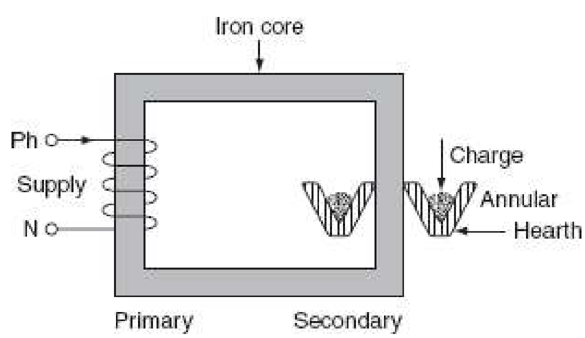


Fig.3.6. Direct core type induction furnace

It consists of an iron core, crucible (a ceramic or metal container in which metals or other substances may be melted) and primary winding connected to an A.C supply. The charge is kept in the crucible, which forms a single turn short circuited secondary circuit. The current in the charge is very high in the order of several thousand amperes. The charge is magnetically coupled to the primary winding. The charge is melted because of high current induced in it. When there is no molten metal, no current will flow in the secondary. To start the furnace molten metal is poured in the oven from the previous charge.

This type of furnace has the following drawbacks:

- This metal ring is quite large in diameter and is magnetically interlinked with primary winding, which is energized from an AC source. The magnetic coupling between primary and secondary is very weak; it results in high leakage reactance and low pf. To overcome the increase in leakage reactance, the furnace should be operated at low frequency of the order of 10HZ.
- Furnace is operating at normal frequency, which causes turbulence and severe stirring action in the molten metal to avoid this difficulty, it is also necessary to operate the furnace at low frequency.
- In order to obtain low-frequency supply, separate motor-generator set (or) frequency changer is to be provided, which involves the extra cost.
- If current density exceeds about 5 amps/mm^2, it will produce high-electromagnetic forces in the molten metal and hence adjacent molecules repel each other, as they are in the same direction. The repulsion may cause the interruption of secondary circuit (formation of bubbles and voids). This effect is called pinch effect. The pinch effect is also dependent on frequency; at low frequency, this effect is negligible, and so it is necessary to operate the furnace at low frequency.
- The crucible for the charge id of odd shape and inconvenient from the metallurgical point of view.
- The furnace cannot function if the secondary circuit is open. It must be closed. For starting the furnace either molten metal is poured into the crucible or sufficient molten metal is allowed to remain in the crucible from the previous operation. Such furnace is not suitable for intermittent services.

Vertical core type induction furnace:

It is an improvement over the direct core type furnace, to overcome some of the disadvantages mentioned above. This type of furnace consists of a vertical core instead of horizontal core as shown in below fig. It is also known as Ajax–Wyatt induction furnace.

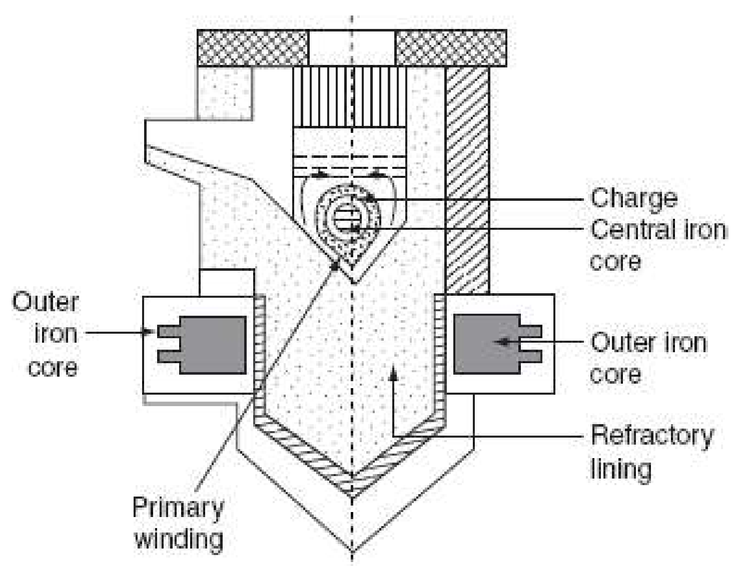


Fig.3.6. Vertical core type induction furnace

Vertical core avoids the pinch effect due to the weight of the charge in the main body of the crucible. The leakage reactance is comparatively low and the power factor is high as the magnetic coupling is high compared to direct core type.

There is a tendency of molten metal to accumulate at the bottom that keeps the secondary completed for a vertical core type furnace as it consists of narrow V-shaped channel. The inside layer of furnace is lined depending upon the type charge used. Clay lining is used for yellow brass and an alloy of magnesia and alumina is used for red brass. The top surface of the furnace is covered with insulating material, which can be removed for admitting the charge.

Necessary hydraulic arrangements are usually made for tilting the furnace to take out the molten metal. Even though it is having complicated construction, it is operating at power factor of the order of 0.8–0.83. This furnace is normally used for the melting and refining of brass and non-ferrous metals.

Advantages of vertical core type induction furnace:

- Accurate temperature control and reduced metal losses.
- Absence of crucibles.
- Consistent performance and simple control.
- It is operating at high power factor.
- Pinch effect can be avoided.

Indirect core type induction furnace:

This type of furnace is used for providing heat treatment to metal. A simple induction furnace with the absence of core is shown in below fig. In this type of furnace induction principle has been used for heating metals. In such furnace an inductively heated element is made to transfer its heat to the charge.

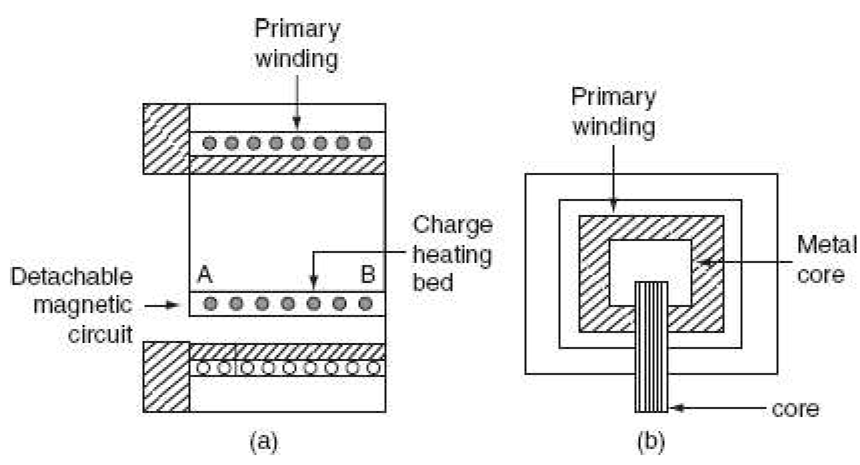


Fig.3.7. Indirect core type induction furnace

When the primary winding is connected to the supply, current is induced in the secondary of the metal container. The secondary winding itself forms the walls of the container or furnace and an iron core links both primary and secondary windings. The heat produced in the secondary winding is transmitted to the charge by radiation.

It consists of a magnetic circuit AB is made up of a special alloy and is kept inside the chamber of the furnace. The special alloy will lose its magnetic properties at certain temperature and regains them again when it is cooled to the same temperature. As soon as the furnace attains the critical temperature the reluctance of the magnetic circuit increases many times and the inductive effect correspondingly decreases thereby cutting off the heat supply.

The magnetic circuit 'AB' is detachable type that can be replaced by the other magnetic circuits having critical temperatures ranging between 400°C and 1,000°C. Thus the temperature of the furnace can be controlled very effectively. The furnace operates at a power factor of around 0.8.

The main advantage of such furnace is wide variation of temperature control is possible.

b. Coreless type or high-frequency induction furnace:

It is a simple furnace with the absence core is shown in below fig. Coreless induction furnace also operates on the principle of transformer.

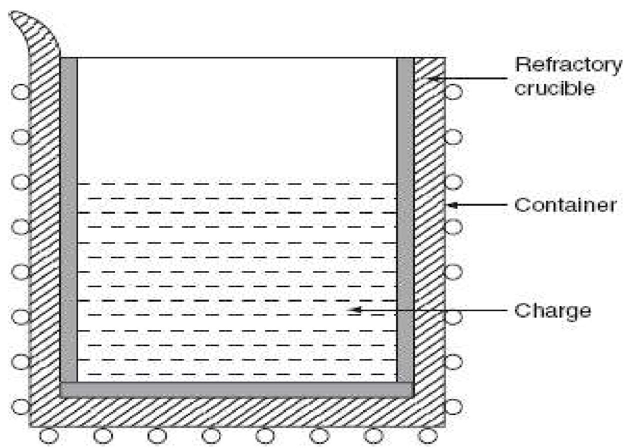


Fig.3.8. Coreless type induction furnace

The furnace consists of a refractory or ceramic crucible cylindrical in shape enclosed within a coil that forms primary of the transformer. The furnace also contains a conducting or non- conducting container that acts as secondary. If the container is made up of conducting material, charge can be conducting or non- conducting; whereas, if the container is made up of non-conducting material, charge taken should have conducting properties. In this furnace, heat developed in the charge due to eddy currents flowing through it.

When primary coils are excited by an alternating source, the flux set up by these coils induce the eddy currents in the charge. The direction of the resultant eddy current is in a direction opposite to the current in the primary coil. These currents heat the charge to melting point and they also set up electromagnetic forces that produce a stirring action to the charge.

The eddy currents developed in any magnetic circuit are given

$$W_e \propto B_m^2 f^2$$

Where B_m is the maximum flux density (tesla), f is the frequency in (Hz), and W_e is the eddy current loss (watts)

In coreless furnace, the flux density will be low as there is no core. Hence, the primary supply should have high frequency for compensating the low flux density. If it is operating at high frequency, due to the skin effect, it results copper loss, thereby increasing the temperature of the primary winding. This necessitates in artificial cooling.

The coil, therefore, is made of hollow copper tube through which cold water is circulated. Minimum stray magnetic field is maintained when designing coreless furnace, otherwise there will be considerable eddy current loss.

The selection of a suitable frequency of the primary current can be given by penetration formula. According to this

$$t = \frac{1}{2\pi}\sqrt{\frac{\rho \times 10^9}{\mu f}},$$

Where 't' is the thickness up to which current in the metal has penetrated, 'ρ' is the resistivity in Ω-cm, 'μ' is the permeability of the material, and 'f' is the frequency in HZ.

For the efficient operation, the ratio of the diameter of the charge (d) to the depth of the penetration of currents (t) should be more than '6', therefore let us take d/t = 8. Sub in the above equation.

$$f = \frac{16 \times \rho \times 10^9}{\pi^2 \mu d^2}$$

Advantages of coreless type induction furnace:

- Ease of control.
- Oxidation is reduced, as the time taken to reach the melting temperature is less.
- The eddy currents in the charge itself results in automatic stirring.
- The cost is less for the erection and operation.
- It can be used for heating and melting.
- Any shape of crucible can be used.
- It is suitable for intermittent operation.
- Absence of dirt, smoke, noise, etc.
- Accurate power control is possible

2. DIELECTRIC HEATING:

Introduction:

Whenever we hear the word 'fire' then the first thing that we understand from it is something related to 'heating'. So, basically, the fire was one of the major elements that were used in earlier days by human beings for purposes like cooking food, molding, or welding of metals, etc. However, with various technological advancements in recent years, so many alternatives have come into existence to perform such applications without the need for fire. Dielectric Heating is one of the valuable inventions relative to this field as through this a new way has evolved for such processes without the involvement of fire.

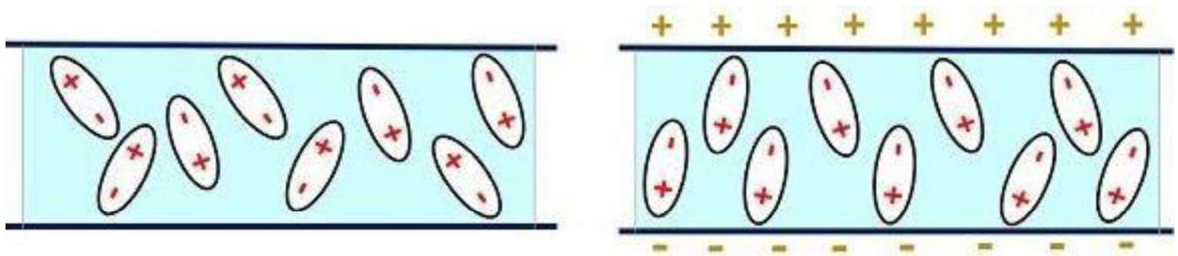
What is dielectric?

Dielectrics are basically insulators that possess very poor conducting ability relative to electric current. We know that every matter in this universe is composed of molecules whose elemental particle is an atom. When an external field is not present then the polar molecules within a material are randomly positioned within it. However, by applying an electric field, the material gets polarized; this is because the dipole moments of polar molecules get properly oriented.

Basically, in conductors, the loosely bounded electrons drift through the material when it is connected to the external electric field. However, this is not the case with dielectrics as they do not have loosely bounded electrons or free electrons for such actions. But here dielectric polarization occurs.

Dielectric Polarization:

It is nothing but the presence of polar molecules in the proper orientation. To understand this, consider the below fig.



(a) Unpolarized (b) Polarized with EF

Fig.3.9. Polarization

Here there are two conductive plates separated by dielectric material in both images. The first one is un polarized due to the absence of an electric field. However, in the second figure, it is seen that the arrangement is subjected to an electric field because of which there is a slight displacement of positive charges in the direction of the electric field and negative charges in the opposite direction of it. The minute charge separation within the dielectric is known as **polarization** and this leads to a reduction in the electric field within the dielectric.

Operating Principle of Dielectric Heating:

Dielectric Heating is a process of electric heating by which the temperature of a dielectric (non-conducting) material is raised by the application of an alternating electric field (high voltage ac signal). The increase in temperature results in heating the substance which is in contact with the external field.

Dielectric heating is sometimes called high frequency or radio-frequency heating, capacitive heating. This process allows uniform heating of non-metallic materials which are unable to conduct electricity.

The principle of operation of a dielectric heater is such that a non-conducting material is present between two electrodes and an external electric field is applied across these two electrodes. Basically, a wide range of frequency is provided to the electrodes.

The dielectric material which is present between the two electrodes can be anything such as wood, plastic, glass, etc. Though it is considered that a dielectric does not allow the flow of electric current through it, practically it is not possible. So, whenever these materials are provided with a high voltage alternating supply then even minute motion of charged particles results in the flow of current which leads to dielectric losses. This resultantly produces heat within the material.

Circuit Operation of Dielectric Heating:

Till now we have got the idea that the sole purpose of a dielectric heater is to heat up an insulating material. A dielectric heater is regarded as an electric heater as it transforms electrical energy into heat. We have already discussed induction heating (which is also a type of electric heating) in our previous content where the principle of electromagnetic induction is used to heat up the magnetic material without making direct contact with the source.

The below figure shows the circuit arrangement of a dielectric material and circuit diagram and phasor diagram which is formed by encapsulating an insulating material between two conducting plates forming a parallel plate capacitor arrangement.

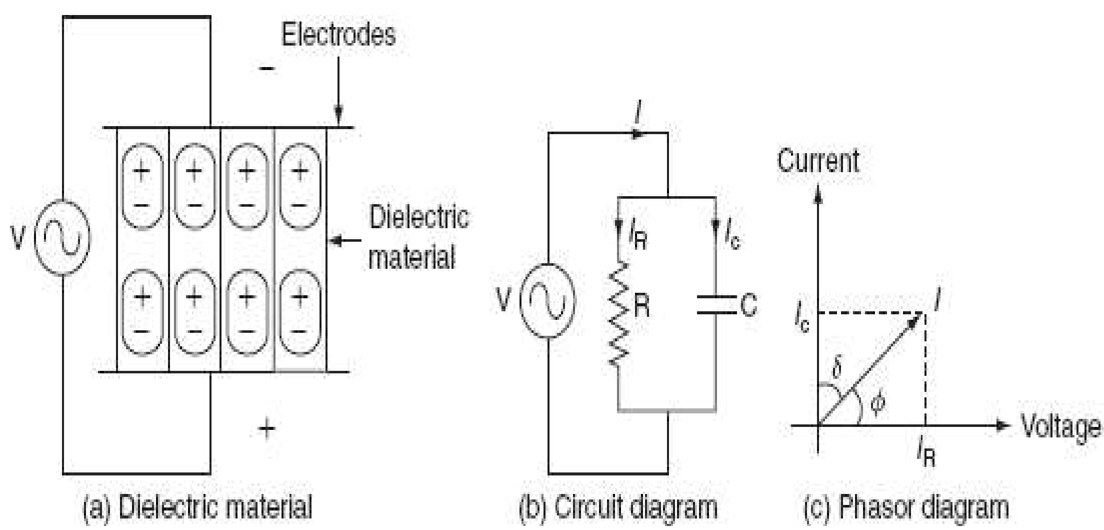


Fig.3.10. Dielectric heating

Here a very high-frequency ac voltage signal i.e., 20KV with frequency ranging between 10 to 50 MHz is provided across the whole capacitive arrangement. Dielectric loss results in the generation of heat. Now, the question arises. So, generally, when sinusoidal voltage is provided to the capacitor shown above then the capacitor draws some current. However, this current never leads the voltage by exactly 90°. This means that there exists some in-phase relationship between the supplied voltage and the flowing current. This resultantly produces power loss within the dielectric of the capacitive plates.

At the ordinary frequency range of 50 Hz, this loss is not that significant that it can cause heat generation and so can be neglected. However, at larger frequencies i.e., in the megahertz range, the loss becomes quite large and this heats up the dielectric. This property of the whole configuration is utilized for the purpose of heating the dielectrics (insulating materials).

It is to be noted here that the amount of dielectric loss produced depends on the supply voltage and frequency. Therefore, in order to get the high heating effect, one must need to provide a very high-frequency voltage signal as this will give rise to high dielectric loss and so high heating effect.

The power dissipated within the dielectric material will be given as

$$P = VI_R$$

$$\text{Since, } I_C = I \sin\theta = I \cos\delta, \quad I_R = I \cos\theta = I \sin\delta \text{ Thus}$$

$$P = VI \cos\theta$$

And substituting the value of I from $I_C = I \sin\theta$ in the above equation, we will get,

$$P = V\frac{I_C}{\sin\theta}\cos\theta$$

Furthermore, the above equation will be written as

$$P = VI_C \cot\theta$$

From the phasor shown it is clear that, $\theta = 90° - \delta$

Therefore,

$$P = VI_C \cot(90^0 - \delta)$$

By trigonometric identity, $P = VI_C \tan(\delta)$

We know that, $$I_C = \frac{V}{X_C} \text{ and } X_C = \frac{1}{2\pi fc}$$

Therefore, on substituting, X_C value in I_C

$$I_C = \frac{V}{\frac{1}{2\pi fc}} = 2\pi fcV$$

Suppose, the dielectric slab is of width b (in m) with area A (in m^2) having permittivity ε (in farad/m), then its capacitance will be,

$$C = \frac{\varepsilon A}{b} \text{farad}$$

Now substitute above I_C value in equation $P = VI_C \tan(\delta)$

$$P = 2\pi fcv^2 \tan(\delta)$$

Now substitute C value in above equation

$$P = 2\pi f\left(\frac{\varepsilon A}{b}\right) v^2 \tan(\delta)$$

The volume of dielectric slab = Area * width = A * b (in m^3)

$$P = 2\pi f\, \varepsilon Ab\left(\frac{V}{b}\right)^2 \tan(\delta)$$

Thus, the power loss per unit volume will be, $P_0 = 2\pi f\left(\frac{V}{b}\right)^2 \tan(\delta)$ watts/m^3

Since, $\varepsilon = \varepsilon_0\varepsilon_r$

$$P_0 = 2\pi f \varepsilon_0 \left(\frac{V}{b}\right)^2 \tan(\delta) \text{ watts/m}^3$$

Where, ‘V’ is the applied voltage in volts,

‘f’ is the supply frequency in Hz,

ε_0 is the absolute permittivity of the medium = 8.854×10^{-12} F/m,

ε_r is the relative permittivity of the medium = 1for free space,

A is the area of the plate or electrode (m^2),

b is the thickness of the dielectric medium,

tan δ is the loss angle in radian.

Thus, from this equation, we can say that the power loss per unit volume of dielectric is directly proportional to

- The operating frequency,
- The square of voltage gradient and

Advantages:

- It is inexpensive.
- Unlike other electric heating techniques, it offers uniform heating.
- Dielectric heating provides the good heating ability to non-conducting materials like plastics.
- It takes moderate time for heating.
- Heat controllability is easy.
- The heat produced depends on the applied frequency.
- A fast-heating process causing an efficient rise in temperature by eliminating temperature difference within the non-conducting material.

Disadvantages:

- Its efficiency is only 50%, which is considered as its major drawback.
- Only the materials possessing high dielectric losses can be heated up.
- Sometimes radio interference exists because of high-frequency input.

Applications of Dielectric Heating:

The various applications of dielectric heating are as follows:

1. **Food processing**: In the field of food processing, it is used for various applications such as concentrating liquids within bottles, food cooking without outer shell removal, defrosting, dehydrating, germicidal heating, etc.
2. **Preheating of plastic preform**: It is one of the significant applications of dielectric heating as no other method can perform this in a uniform manner.

The raw plastic material in the form of biscuits or tablets are called plastic preform and to convert a bulk of these biscuits or tablets into a specific shape they are Kept inside the required mould Basically, to get them in desired shape uniform heating up to a certain level is required before putting them in the mould.

3. **Sterilization**: This process suits sterilizing medical equipment and aiding items like bandages, cotton, scissors, and other gauge instruments.
4. **Diathermy**: To generate a specific body temperature in order to cure certain kinds of pains or diseases, body tissues and bones are subjected to dielectric heating.
5. **Electronic Sewing**: It is the process by which the plastic sheets of umbrellas, raincoats, medicine containers can be sealed or joined. The materials with plastic films are not joined by ordinary stitching thus by the application of heat, sealing is provided to the material under the presence of mechanical pressure.
6. The preparation of thermo plastic resins.
7. The heating of bones and tissues.
8. The processing of rubber, synthetic materials, chemicals, etc.
9. The heating for the dehydration such as milk, cream, and vegetables.
10. The heating for the general processing such as coffee roasting and chocolate industry
11. The drying of paper, wood, etc.
12. The gluing of wood.
13. The heat-sealing of plastic sheets.

ELECTRIC WELDING:

INTRODUCTION:

In olden days, the process of metal welding can be done by heating the metals and pressed jointly which is known as forge welding method. But at present, the welding technology has been changed by the arrival of electricity. In the 19th century, different types of welding are used such as thermal welding, gas welding, and electric welding. After this, there are different types of welding technologies have been invented like friction, ultrasonic, plasma, laser, electron beam welding. Although, the applications of welding technology mainly involves in a variety of industries. Like automobile industry, pipe-line fabrication in thermal power plants, machine repair work, machine frames, etc.

Welding:

Welding is the process of joining two pieces of metal or non-metal together by heating them to their melting point. Filler metal may or may not be used to join two pieces. The physical and mechanical properties of a material to be welded such as melting temperature, density, thermal conductivity, and tensile strength take an important role in welding. Depending upon how the heat applied is created.

Advantages of welding:

- Welding is the most economical method to permanently join two metal parts.
- It provides design flexibility.
- Welding equipment is not so costly.
- It joins all the commercial metals.
- Both similar and dissimilar metals can be joined by welding.
- Portable welding equipment are available.

Disadvantages of welding:

- Welding gives out harmful radiations and fumes.
- Welding needs internal inspection.
- If welding is not done carefully, it may result in the distortion of work piece.
- Skilled welding is necessary to produce good welding.

ELECTRIC WELDING:

It is defined as the process of joining two metal pieces, in which the electrical energy is used to generate heat at the point of welding in order to melt the joint.

TYPES OF ELECTRIC WELDING:

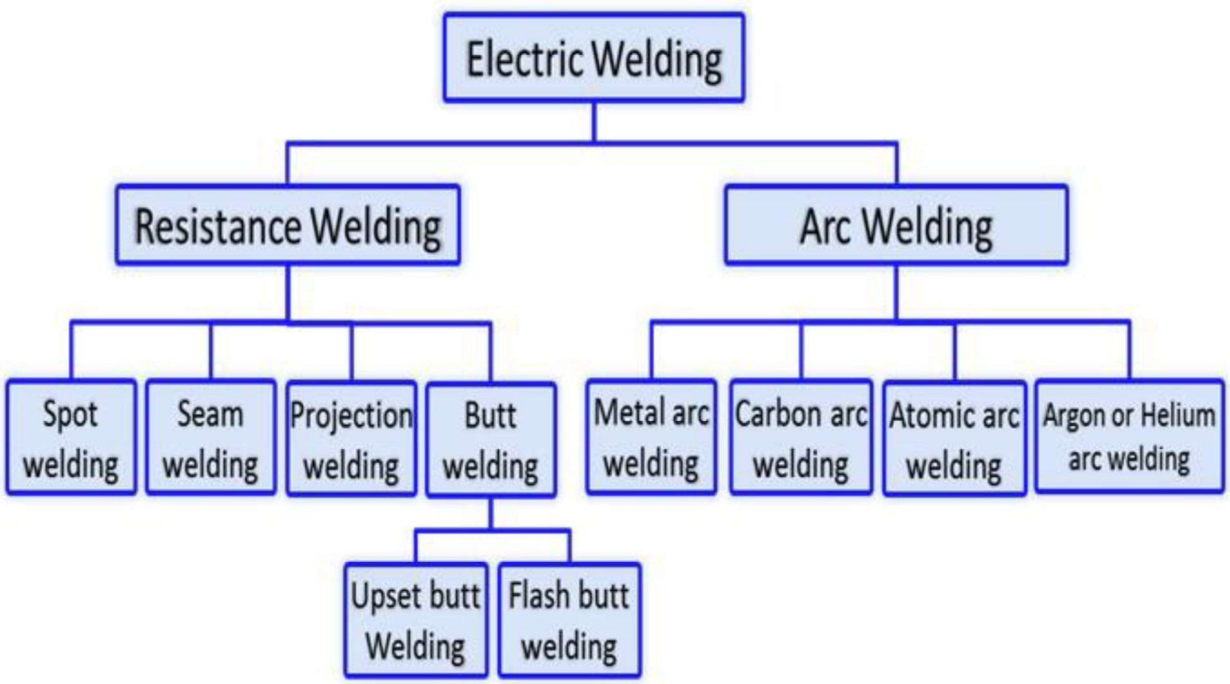


Fig.3.11. Classificationofelectricwelding

The selection of proper welding process depends on the following factors.

- The techniques of welding adopted.
- The cost of equipment used.
- The nature of products to be fabricated.

RESISTANCE WELDING:

Resistance welding is the process of joining two metals together by the heat produced due to the resistance offered to the flow of electric current at the junctions of two metals.

The heat produced by the resistance to the flow of current is given by:

$$H = I^2Rt$$

Where, H' is a generated Heat, and the unit of heat is a joule

I is the current through the electrodes and the unit of this is ampere

R is the contact resistance of the interface and the unit of this is Ohms

t is the time for which current flows and the unit of this is seconds

Here, the total resistance offered to the flow of current is made up of:

1. The resistance of current path in the work.
2. The resistance between the contact surfaces of the parts being welded.
3. The resistance between electrodes and the surface of parts being welded.

Working process of Resistance welding:

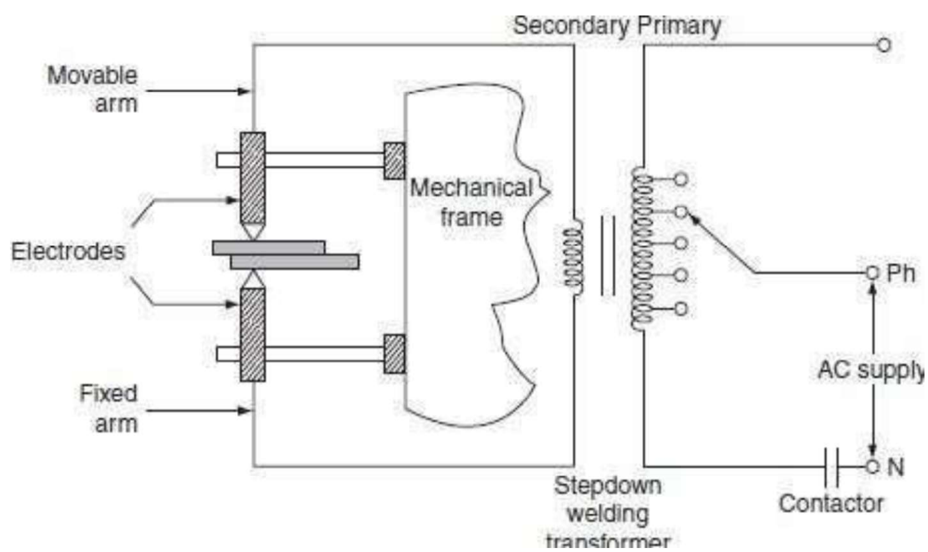


Fig.3.12. Electrical circuit for resistance welding

The electrical circuit diagram for resistance welding is shown in above fig. this method of welding consists of a tap changing transformer, a clamping device for holding the metal pieces, and some sort of mechanical arrangement for forcing the pieces to form a complete weld.

In this process of welding, the heat developed at the contact area between the pieces to be welded reduces the metal to plastic state or liquid state, and then the pieces are pressed under high mechanical pressure to complete the weld. The electrical voltage input to the welding varies in between 4 and 12 V depending upon area, thickness, composition, etc. and usually power ranges from about 60to 180 W for each sq. mm of area. Any desired combination of voltage and current can be obtained by means of a suitable transformer in AC; hence, AC is found to be most suitable for the resistance welding.

The magnitude of current is controlled by changing the primary voltage of the welding transformer, which can be done by using an auto-transformer or a tap-changing transformer. Automatic arrangements are provided to switch off the supply after a pre-determined time from applying the pressure, why because the duration of the current flow through the work is very important in the resistance welding.

Advantages:

- Welding process is rapid and simple.
- Localized heating is possible, if required.
- No need of using filler metal.
- Both similar and dissimilar metals can be welded.
- Comparatively lesser skill is required.
- Maintenance cost is less.
- It can be employed for mass production.

Disadvantages:

- Initial cost is very high.
- High maintenance cost.
- The work piece with heavier thickness cannot be welded, since it requires high input current.

Applications:

- It is used by many industries manufacturing products made up of thinner gauge metals.
- It is used for the manufacturing of tubes and smaller structural sections.

TYPES OF RESISTANCE WELDING:

Depending upon the method of weld obtained and the type of electrodes used, the resistance welding is classified as

1) Spot welding
2) Seam welding
3) Projection welding
4) Butt welding

1) Spot welding:

Spot welding means the joining of two metal sheets and fusing them together between copper electrode tips at suitably spaced intervals by means of heavy electric current passed through the electrodes as shown in below Fig.

This type of joint formed by the spot welding provides mechanical strength and not air or water tight, for such welding it is necessary to localize the welding current and to apply sufficient pressure on the sheet to be welded. The electrodes are made up of copper or copper alloy and are water cooled.

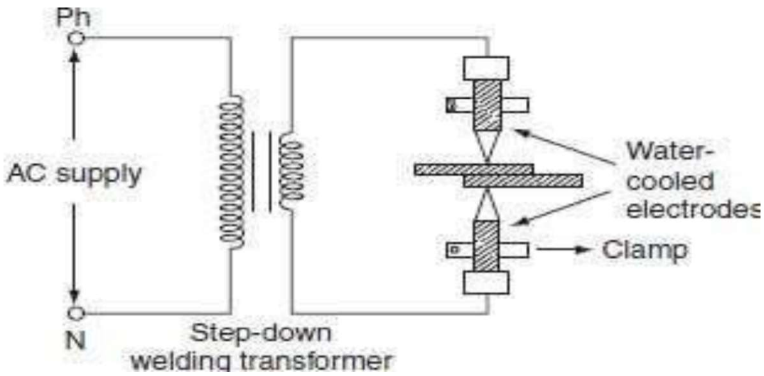


Fig.3.13. Spot welding

The welding current varies widely depending up on the thickness and composition of the plates. It varies from1,000 to 10,000 A, and voltage between the electrodes is usually less than 2 V. The period of the flow of current varies widely depending up on the thickness of sheets to be joined.

A step-down transformer is used to reduce a high-voltage and low-current supply to low-voltage and high-current supply required. Since the heat developed being proportional to the product of welding time and square of the current.

Good weld can be obtained by low currents for longer duration and high currents for shorter duration; longer welding time usually produces stronger weld but it involves high energy expenditure, electrode maintenance, and lot of distortion of work piece.

When voltage applied across the electrode, the flow of current will generate heat at the three junctions, i.e., heat developed, between the two electrode tips and work piece, between the two work pieces to be joined as shown in above Fig.

The generation of heat at junctions will effect electrode sticking and melt through holes; the prevention of electrode striking is achieved by

- Using water-cooled electrodes shown in below Fig. By avoiding the heating of junction electrodes in which cold water circulated continuously.
- The material used for electrode should have high electrical and thermal conductivity spot welding is widely used for automatic welding process, for joining automobile parts, joining and fabricating sheet metal structure, etc

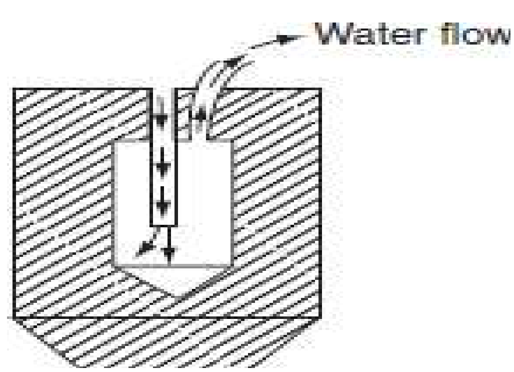


Fig.3.13. Water cooled electrode

2) **Seam welding:**

Seam welding is nothing but the series of continuous spot welding. If number spots obtained by spot welding are placed very closely that they can overlap, it gives rise to seam welding. In this welding, continuous spot welds can be formed by using wheel type or roller electrodes instead of tipped electrodes as shown in below Fig.

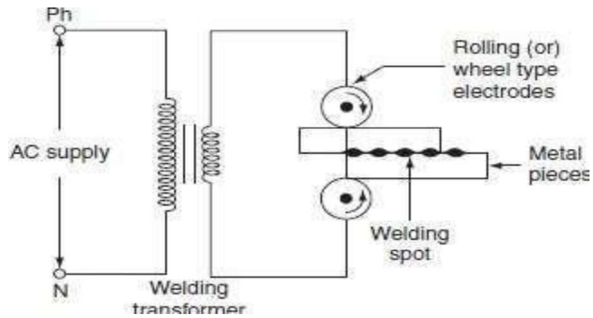


Fig.3.14. Seam welding

Seam welding is obtained by keeping the job under electrodes. When these wheel type electrodes travel over the metal pieces which are under pressure, the current passing between them heats the two metal pieces to the plastic state and results into continuous spot welds. In this welding, the contact area of electrodes should be small, which will localize the current pressure to the welding point. After forming weld at one point, the weld so obtained can be cooled by splashing water over the job by using cooling jets.

In general, it is not satisfactory to make a continuous weld, for which the flow of continuous current build up high heat that causes burning and wrapping of the metal piece. To avoid this difficulty, an interrupter is provided on the circuit which turns on supply for a period sufficient to heat the welding point. The series of weld spots depends up on the number of welding current pulses. The two forms of welding currents are shown in below Fig.

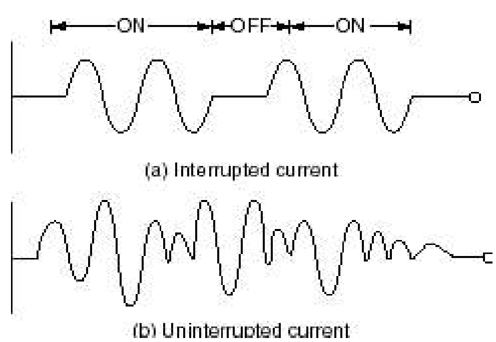


Fig.3.15. Welding current

Welding cannot be made satisfactorily by using uninterrupted or un-modulated current, which builds up high heat as the welding progress; this will over heat the work piece and cause builds up high heat as the welding progress; this will over heat the work piece and cause distortion. Seam welding is very important, as it provides leak proof joints. It is usually employed in welding of pressure tanks, transformers, condensers, evaporators, air craft tanks, refrigerators, varnish containers, etc.

3) **Projection welding:**

It is a modified form of the spot welding. In the projection welding, both current and pressure are localized to the welding points as in the spot welding. But the only difference in the projection welding is the high mechanical pressure applied on the metal pieces to be welded, after the formation of weld. The electrodes used for such welding are flat metal plates known as platens. The two pieces of base metal to be weld are held together in between the two platens, one is movable and the other is fixed, as shown in below Fig.

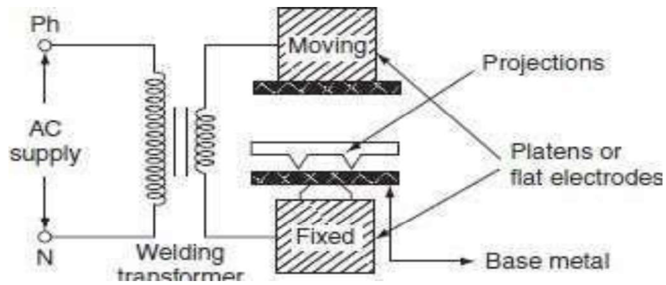


Fig.3.16.projection welding

One of the two pieces of metal is run through a machine that makes the bumps or projections of required shape and size in the metal. As current flows through the two metal parts to be welded, which heat up and melt? These weld points soon reach the plastic state, and the projection touches the metal then force applied by the two flat electrodes forms the complete weld. The projection welding needs no protective atmosphere as in the spot welding to produce successful results. This welding process reduces the amount of current and pressure in order to join two metal surfaces, so that there is less chance of distortion of the surrounding areas of the weld zone. Due to this reason, it has been incorporated into many manufacturing process. The projection welding has the following advantages over the spot welding.

- Simplicity in welding process.
- It is easy to weld some of the parts where the spot welding is not possible.
- It is possible to join several welding points.
- Welds are located automatically by the position of projection.

As the electrodes used in the projection welding are flat type, the contact area over the projection is sufficient. This type of welding is usually employed on punched, formed, or stamped parts where the projection automatically exists. The projection welding is particularly employed for mass production work, i.e., welding of refrigerators, condensers, crossed wire welding, refrigerator racks, grills, etc.

4) **Butt welding:**

Butt welding is similar to the spot welding; however, the only difference is, in butt welding, instead of electrodes the metal parts that are to be joined or butted together are connected to the supply. The two basic types of the butt welding process are,

a. Upset butt welding.
b. Flash butt welding.

a. Upset butt welding:

In upset welding, the two metal parts to be welded are joined end to end and are connected across the secondary of a welding transformer as shown in below Fig.

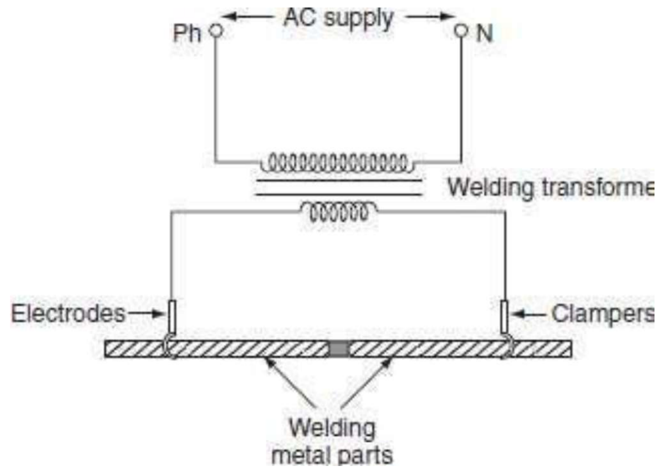


Fig.3.17. Upset butt welding

Due to the contact resistance of the metals to be welded, heating effect is generated in this welding. When current is made to flow through the two electrodes, heat will develop due to the contact resistance of the two pieces and then melts. By applying high mechanical pressure either manually or by toggle mechanism, the two metal pieces are pressed. When jaw-type electrodes are used that introduce the high currents without treating any hot spot on the job. This type of welding is usually employed for welding of rods, pipes, and wires and for joining metal parts end to end.

b. Flash butt welding:

Flash butt welding is a combination of resistance, arc, and pressure welding. This method of welding is mainly used in the production welding. A simple flash butt welding arrangement is shown in below Fig.

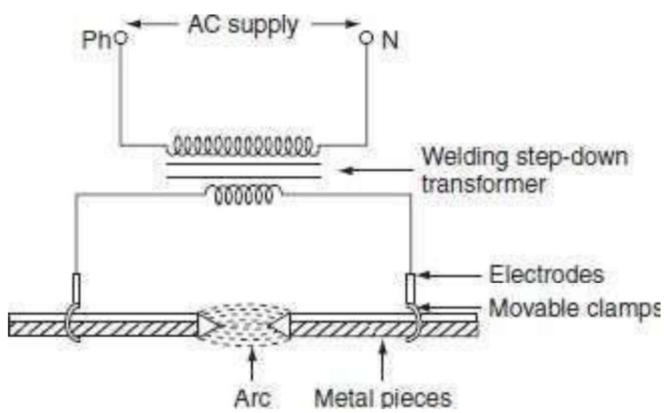


Fig.3.18. Flash butt welding

In this method of welding, the two pieces to be welded are brought very nearer to each other under light mechanical pressure. These two pieces are placed in a conducting movable clamps. When high current is passed through the two metal pieces and they are separated by some distance, then arc established between them. This arc or flashing is allowed till the ends of the work pieces reach melting temperature, the supply will be switched off and the pieces are rapidly brought together under light pressure.