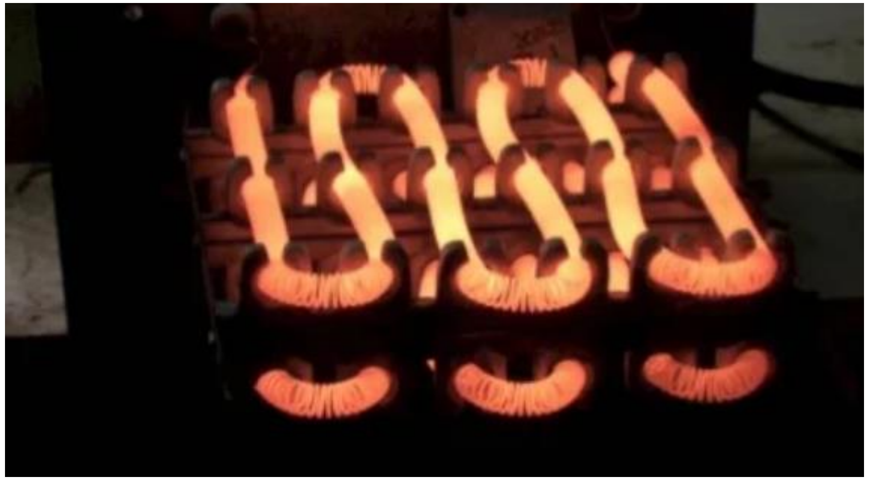


Unit-1: Electric Heating and Welding

2EEDE02: Electrical Power Utilization and Safety

Introduction

- Heat plays a major role in everyday life.
- All heating requirements in **domestic** purposes such as cooking, room heater, immersion water heaters, electric toasters.
- **Industrial** purposes such as welding, melting of metals, tempering, hardening, and drying can be melt easily by electric heating, over the other forms of conventional heating.
- Heat and electricity are interchangeable.
- Heat also can be produced by passing the current through material to be heated. This is called ***electric heating***;
- There are various methods of heating a material but *electric heating* is considered far **superior** compared to the heat produced by coal, oil, and natural gas.

- **Electric heating** is a process in which electrical energy is converted to heat.

1. When current is passed through a conductor, the conductor becomes hot (**resistance** heating).
2. When a magnetic material is brought in the vicinity of an alternating magnetic field, heat is produced in the magnetic material (**induction** heating).
3. When an electrically insulating material was subjected to electrical stresses; it too underwent a temperature rise (**dielectric** heating).

Advantages of Electric Heating

- Economical: Electric heating equipment is cheaper; they do not require much skilled persons; therefore, maintenance cost is less.
- Cleanliness: Since dust and ash are completely eliminated in the electric heating, it keeps surroundings clean.
- 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.
- Ease of control: In this heating, temperature can be controlled and regulated accurately either manually or automatically.
- Uniform heating: The substance can be heated uniformly throughout whether it may be conducting or non-conducting material.

- 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.
- Automatic protection: Protection against over current and overheating can be provided by using control devices.
- 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.
- Better working conditions: No irritating noise is produced with electric heating and also radiating losses are low.
- Less floor area: Due to the compactness of electric furnace, floor area required is less.
- High temperature: High temperature can be obtained by the electric heating except the ability of the material to withstand the heat.

Disadvantages

- The **cost** of electricity makes it expensive to use as a heating fuel.
- With space heaters, we can't easily provide central **filtration, humidification or cooling**.
- The electrical hazard of **shock** and **fire** caused by electricity is an issue.
- There are a cost associated with Electric heat requires a **larger electrical service** than normal.

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**

- One molecule of substance gets heated and transfers the heat to the adjacent one and so on.
- 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.
- Ex: Refractory heating, the heating of insulating materials, etc.

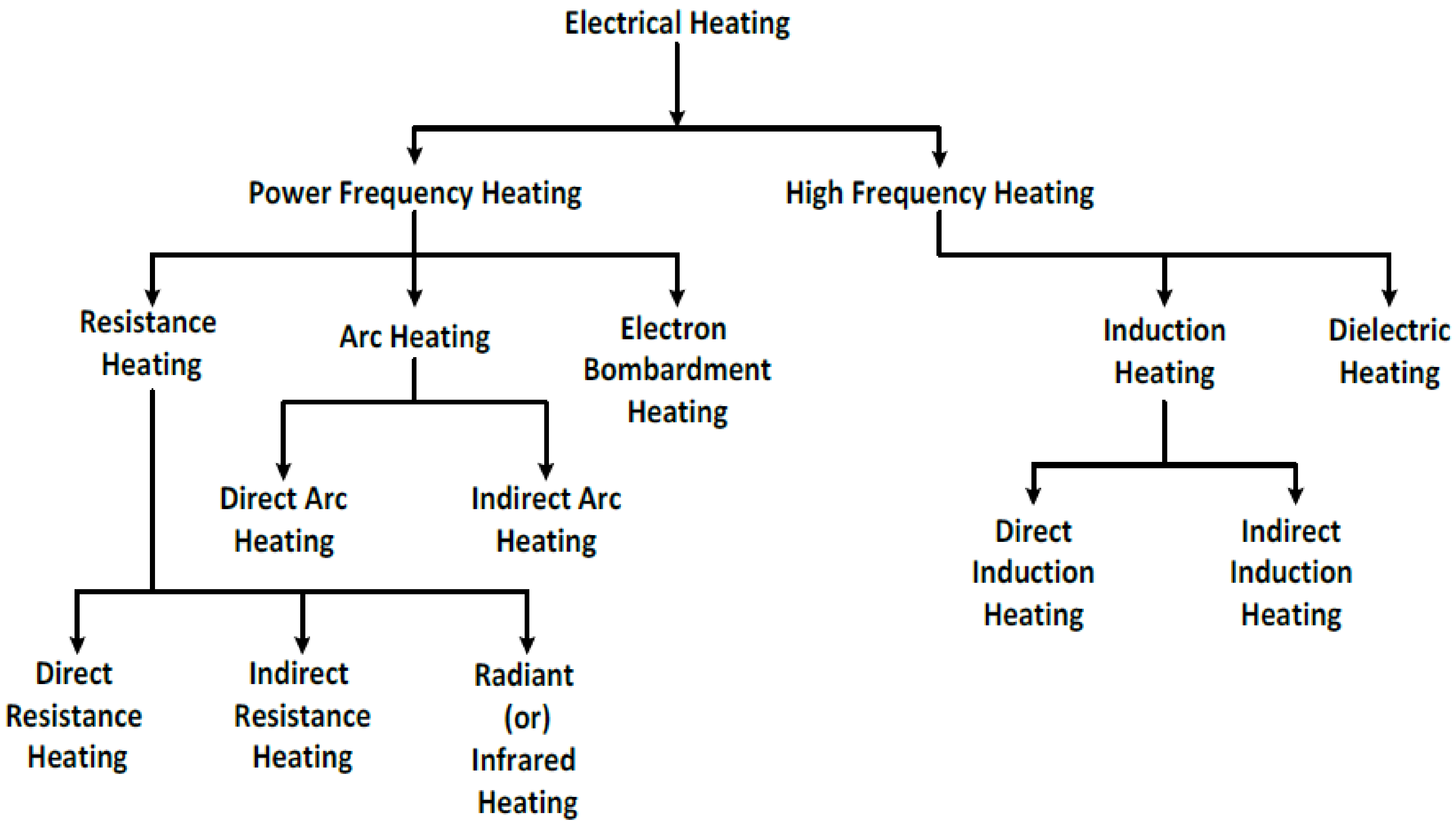
2. Convection

- 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 heat depends mainly on the difference in the fluid density at different temperatures.
- The quantity of heat absorbed from the heater by convection are depends on temperature of the heating element above the surrounding, size of surface of heater, on the position of heater.
- Ex: Immersion water heater.

3. Radiation

- In this mode, the heat transfers from source to the substance to be heated without heating the medium in between.
- It is dependent on surface.
- Rate of heat radiation is given by Stefan’s law.
- Ex: Solar heaters.

Classification of Electric Heating Method



HEATING ELEMENT MATERIALS

Indirect resistance furnaces use many different types of heating elements for producing heat. A good heating element should have the following properties :

1. **High Specific Resistance (or High Resistivity):** When specific resistance of the material of the wire is high, only short length of it will be required for a particular resistance (and hence heat) or for the same length of the wire and the current, heat produced will be more.

2. **High Melting Temperature:** If the melting temperature of the heating element is high, it would be possible to obtain higher operating temperatures.

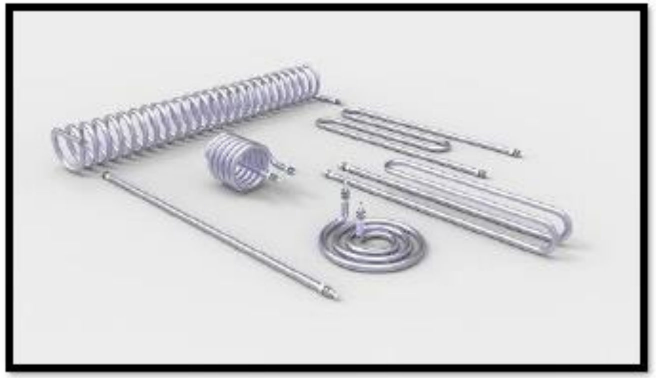
3. **Low Temperature Coefficient of Resistance**: In case the material has low temperature coefficient of resistance, there would be only small variations in its resistance over its normal range of temperature. Hence, the current drawn by the heating element when cold (i.e., at start) would be practically the same when it is hot.

4. **High Oxidising Temperature**: The element material should not be oxidized when it is subjected to high temperatures; otherwise the formation of oxidized layers will shorten its life.

5. **Positive Temperature Coefficient of Resistance:** If the temperature coefficient of the resistance of heating element is negative, its resistance will decrease with rise in temperature and it will draw more current which will produce more wattage and hence heat. With more heat, the resistance will decrease further resulting in instability of operation.

6. **Ductile:** Since the material of the heating elements has to have convenient shapes and sizes, it should have high ductility and flexibility.

7. **Mechanical Strength**. The material of the heating element should posses high mechanical strength of its own. Usually, different types of alloys are used to get different operating temperatures.



DESIGN OF HEATING ELEMENT

- Heating elements sound very simple and straightforward, but there are, many different factors that engineers have to consider in designing them.
- There are roughly 20 – 30 different factors that affect the performance of a typical heating element, including obvious things like the **voltage and current, the length and diameter of the element, the type of material, and the operating temperature.** There are also specific factors you need to consider for each different type of element.
- Normally, wires of circular cross-section or rectangular conducting ribbons are used as heating elements.
- **The size and length of wire can be obtained if the wattage of the heating element is known and if the operating voltage and ambient temperature and heating element temperatures are known.**

- Under steady-state conditions, a heating element dissipates as much heat from its surface as it receives the power from the electric supply. If **P** is the power input and **H** is the heat dissipated by radiation, then **P = H** under steady-state conditions.
- **Alternatively speaking**, initially when the heating element is switched on to supply, the temperature goes on increasing and finally a high a steady state temperature is reached when it can be assumed that practically all the heat is being transferred through radiations.

As per Stefan's law of radiation, heat radiated by a hot body is given by

$$H = 5.72\, eK\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \mathrm{W/m^2}$$

where T_1 is the temperature of hot body in °K and T_2 that of the cold body (or cold surroundings) in °K

Note:

T_K : Temperature in Kelvin (K)

T_C : Temperature in Celsius (°C)

$T_K = T_C + 273.15$

$T_C = T_K - 273.15$

K = radiant efficiency = 1 for single element

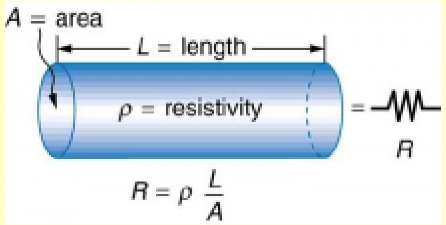
= 0.5 to 0.8 for more than element

e = emissivity = 1.0 for black body

= 0.9 for resistance heating element

Let V be the supply voltage of the system and R be the resistance of the element, then electric power input, $P = \dfrac{V^2}{R}$ W.

If ρ is the resistivity of the element, l is the length, a is the area, and d is the diameter of the element, then:



$$R = \rho \frac{l}{a} = \frac{\rho l}{\frac{\pi d^2}{4}}.$$

Therefore, power input, $P = \dfrac{V^2 \pi d^2}{4 \rho l}$. **(1)**

By rearranging the above equation, we get:

$$\frac{l}{d^2} = \frac{\pi V^2}{4P\ \rho}, \qquad \textbf{(2)}$$

where P is the electrical power input per phase (watt), V is the operating voltage per phase (volts), R is the resistance of the element (Ω), l is the length of the element (m), a is the area of cross-section (m^2), d is the diameter of the element (m), and ρ is the specific resistance (Ω-m).

The surface area of the circular heating element:

$$S = \pi dl.$$

$$\therefore \text{Total heat dissipated} = \text{surface area} \times H$$
$$= H\pi dl.$$

Under thermal equilibrium,

Power input = heat dissipated

$$P = H \times \pi dl.$$

Substituting P from Equation (1) in above equation:

$$\frac{V^2}{\rho\, l}\left(\frac{\pi\, d^2}{4}\right) = H \times \pi\, dl$$

$$\therefore \frac{d}{l^2} = \frac{4\,\rho\,H}{V^2}. \qquad \textbf{(3)}$$

By solving Equations (2) and (3), the length and diameter of the wire can be determined.

The above explanation is for circular type heating element.

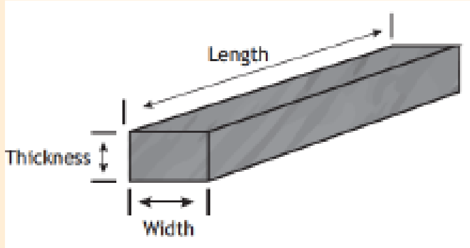
RIbbon-type element

Let w be the width and t be the thickness of the ribbon-type heating element.

Electrical power input $P = \frac{V^2}{R}$.

We know that, $R = \frac{\rho l}{a} = \frac{\rho l}{w \times t}$ (for ribbon or rectangular element, $a = w \times t$)

$$\therefore P = \frac{V^2}{\left(\frac{\rho\, l}{w \times t}\right)}$$



$$\therefore \frac{l}{w} = \frac{V^2\ t}{P\ \rho}. \qquad ..(1)$$

The surface area of the rectangular element $(S) = 2\,l \times w$.

(Neglecting the Side Area ***2tl*** as the thickness is negligible)

The surface area of the rectangular element $(S) = 2\, l \times w$.

$\therefore$ Total heat dissipated $= H \times S$

$$= H \times 2\, lw.$$

$\therefore$ Under the thermal equilibrium,

Electrical power input = heat dissipated

$$P = H \times 2\, lw$$

$$lw = \frac{P}{2\, H}. \qquad \text{.....(2)}$$

By solving Equations **(1)** and **(2)**, the length and width of the heating element can be determined.

Numericals Pertaining to Design of Heating Element

Ques: A resistance oven employing nichrome wire is to be operated from 220 V single-phase supply and is to be rated at 16 kW. If the temperature of the element is to be limited to 1,170°C and average temperature of the charge is 500°C, find the diameter and length of the element wire.

Radiating efficiency = 0.57, Emissivity=0.9, Specific resistance of nichrome wire = (109×10^{-8}) (Ω-m)/ ohm-m.

Solution. $P = 16\text{ kW} = 16{,}000\text{ W}$

As we know that, $$\frac{l}{d^2} = \frac{\pi V^2}{4\rho P} = \frac{\pi \times (220)^2}{4 \times 109 \times 10^{-8} \times 16{,}000} = 2{,}179{,}660 \quad \ldots (i)$$

Now, $$H = 5.72 eK\left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] W/\text{m}^2 = 5.72 \times 0.9 \times 0.57\left[\left(\frac{1443}{100}\right)^4 - \left(\frac{773}{100}\right)^4\right]$$

$= 116{,}752\text{ W/m}^2$

Now, total heat dissipated/s = electrical power input

$$\therefore \quad (\pi d) \times l \times 116{,}752 = 16{,}000; \quad \therefore \quad dl = 0.0436$$

or $\quad d^2 l^2 = 0.0019 \quad \ldots(ii)$

From Eqn. (*i*) and (*ii*), $l^3 = 2{,}179{,}660 \times 0.0019 = 4141$

$\therefore \quad l = \mathbf{16.05\ m}$ **Answer**

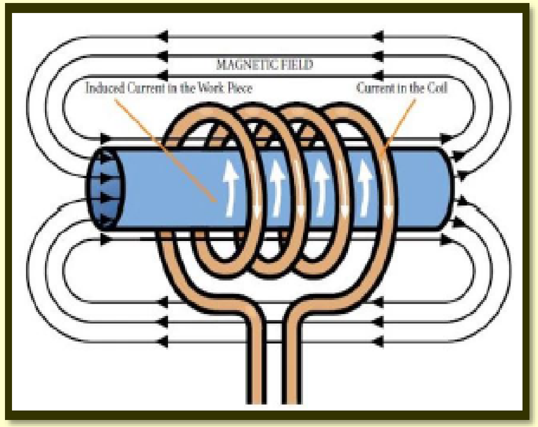
$d = 0.0436/16.05 = 2.716 \times 10^{-3}\ \text{m} = \mathbf{2.716\ mm}$ **Answer**

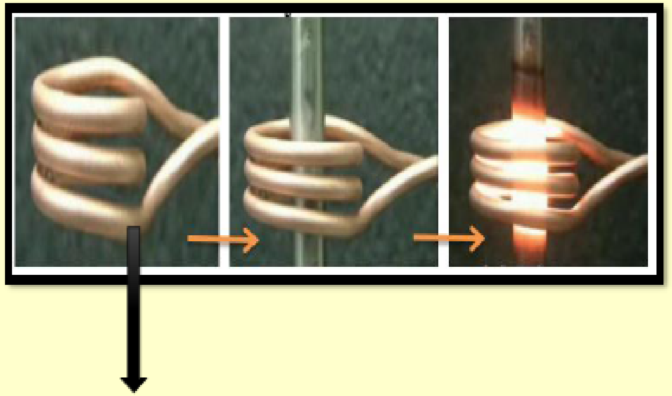
Ques (for Students' Practice): A 20-kW, 230-V, and single-phase resistance oven employs nickel - chrome **strip** 25-mm thick is used, for its heating elements. If the strip temperature is not to exceed 1,200 ^{0}C and the temperature of the charge is to be 700 ^{0}C. Calculate the width and length of the strip. Assume the radiating efficiency as 0.6 and emissivity as 0.9. Determine also the temperature of the strip when the charge is cold. Specific Resistance of the strip is taken as 1.106×10^{-6} (Ω-m) **(Answer: *l* = 7.435 m; *w* = 11.42 mm; T = 1124.9 ^{0}C)**

Ques (for Students' Practice): A 30-kW, 3-φ, 400-V resistance oven is to employ nickel-chrome strip 0.254 mm thick for the three star-connected heating elements. If the wire temperature is to be 1,100°C and that of the charge to be 700°C, estimate a suitable width for the strip. Assume emissivity = 0.9 and radiating efficiency to be 0.5 and resistivity of the strip material is 101.6×10^{-8} Ω - m. **(Answer: *w* = 7.4 mm; T = 1124.9 ^{0}C)**

INDUCTION HEATING / NON – CONTACT HEATING

- Induction heating systems are developed using electromagnetic induction that was first discovered by **Michael Faraday in 1831**.
- **Electromagnetic induction refers to the phenomenon by which electric current is generated in a closed circuit by the fluctuation of current in another circuit placed next to it.**
- **An induction heating system includes an induction power supply which converts line power to an alternating current, delivers it to a work coil creating an electromagnetic field within the coil. The work piece or charge or object (to be heated) is placed in the coil where this field induces a current in the work piece, which generates heat in the work piece. The work coil does not touch the work piece, and the heat is only generated by the induced current flowing in the work piece.**





Work Coil

Induction heating relies on two mechanisms of energy dissipation for the purpose of heating. These are energy losses due to Joule heating and energy losses associated with magnetic hysteresis.

INDUCTION HEATING

An induction-heating coil surrounding a conducting workpiece is fed with alternating current and the resulting magnetic flux couples with the workpiece. In accordance with Lenz's law, current is induced in the workpiece in such a direction that it attenuates the field of the coil. It is this current, flowing through the resistance of the workpiece, which generates heat.

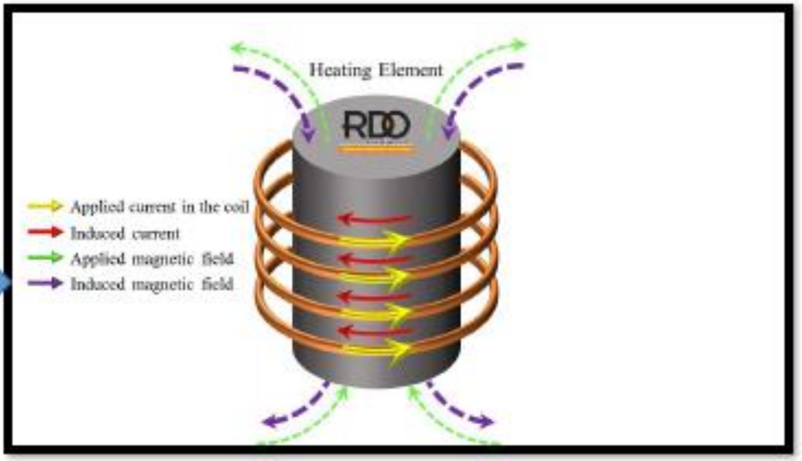
Direct Induction Heating

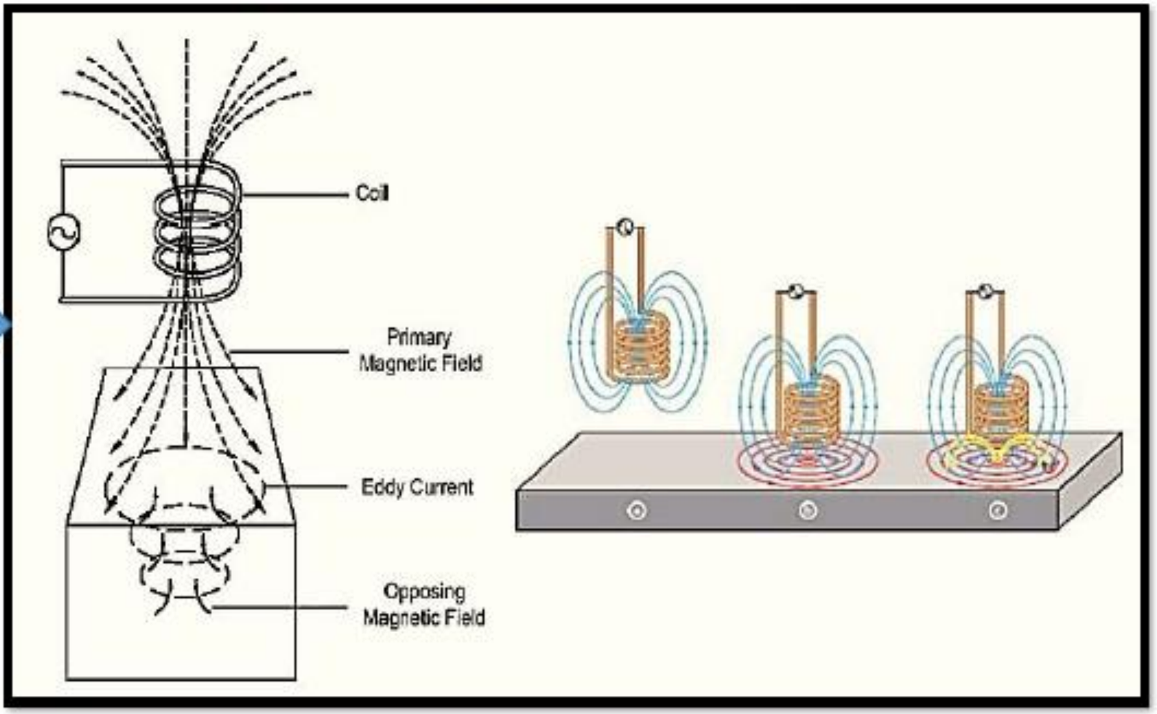
- In this method of heating, the currents are induced by electromagnetic action in the body to be heated. The induced currents when flowing through the resistance of the body to be heated develop the heat and thus raise the temperature.

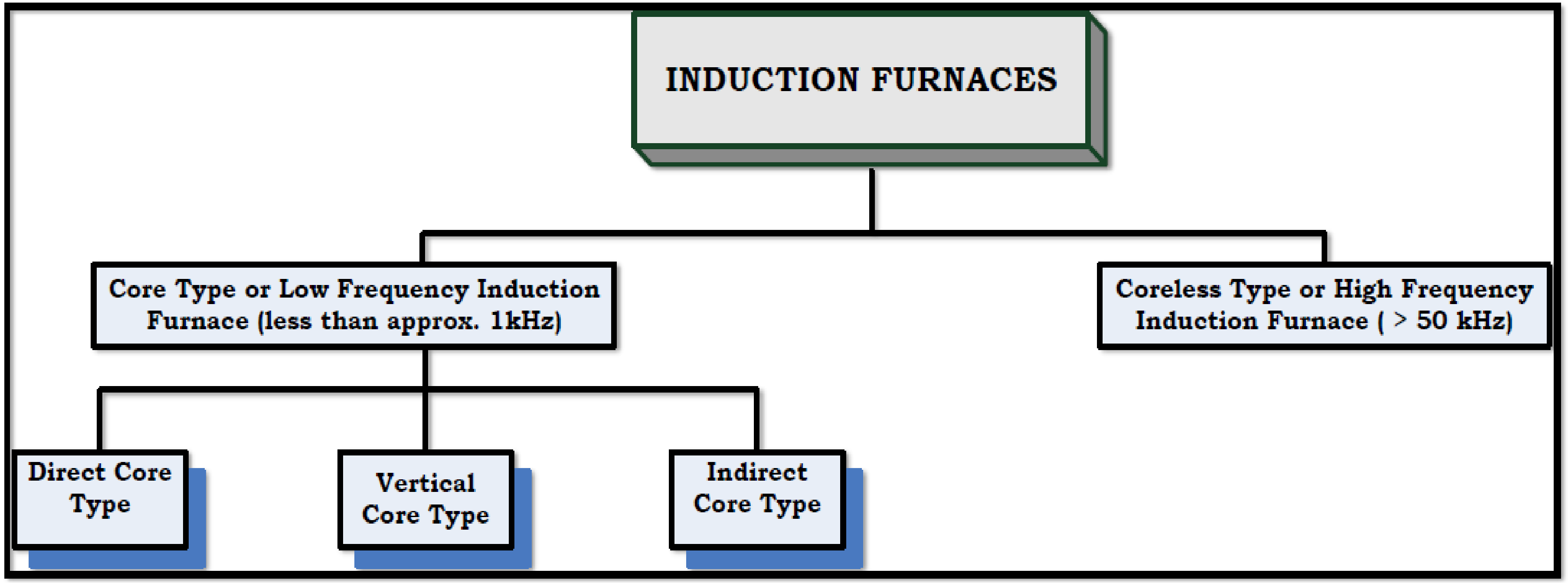
Indirect Induction Heating

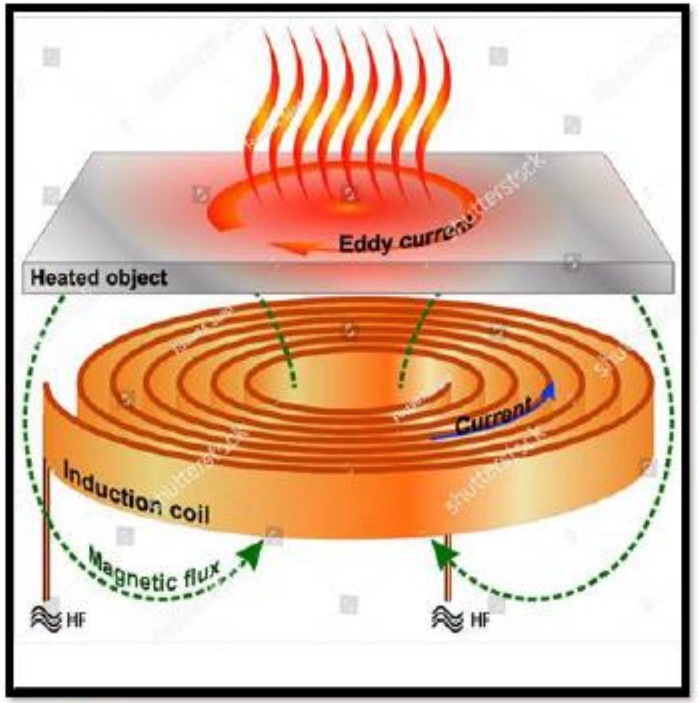
- In this method of heating, the eddy currents are induced in the heating element by electromagnetic action. Eddy currents set up in the heating element produce the heat which is transferred to the body to be heated up, by radiation and convection.

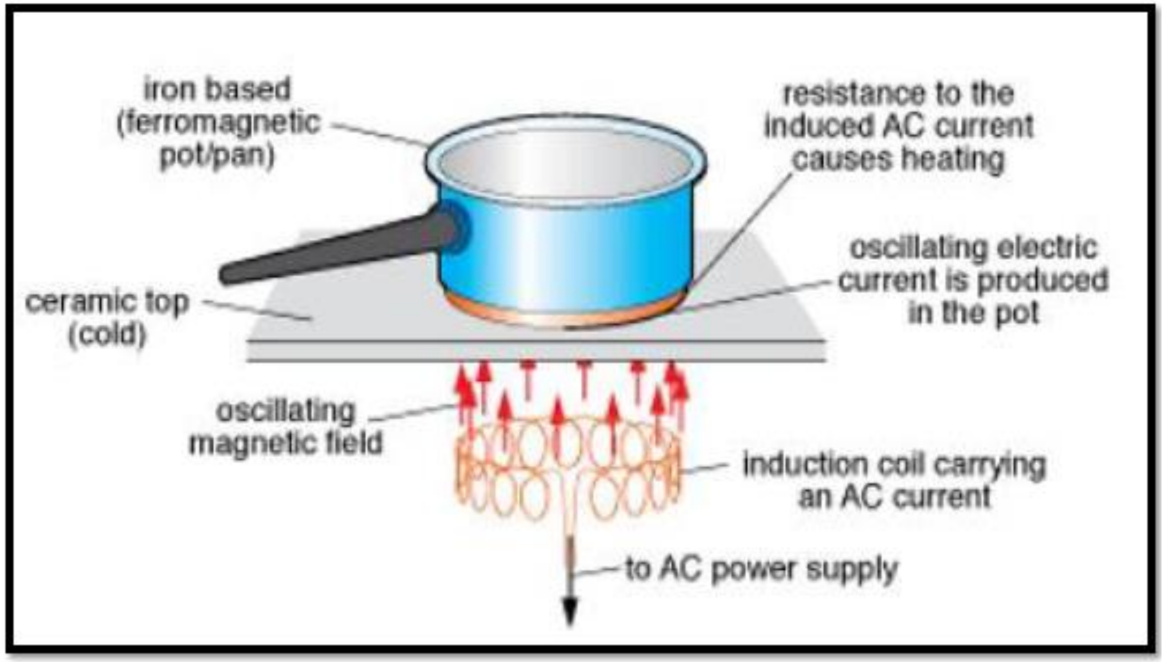
EDDY CURRENTS INDUCED IN THE WORKPIECE






INDUCTION FURNACES
Core Type or Low Frequency Induction Furnace (less than approx. 1kHz)
Coreless Type or High Frequency Induction Furnace (> 50 kHz)
Direct Core Type
Vertical Core Type
Indirect Core Type

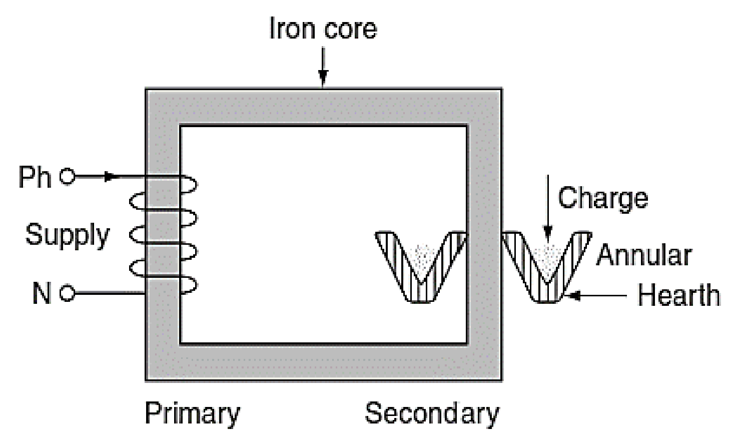




Induction Heating

Induction heating is generally used to heat the `work' directly, that is the induced currents flow in the electrically conducting object being heated.

DIRECT CORE TYPE INDUCTION FURNACE



If the transformer secondary current density exceeds **500 A/cm²** then, due to the interaction of secondary current with the alternating magnetic field, the molten metal is squeezed to the extent that secondary circuit is interrupted (due to constricting forces on the cross – section of the metal). This effect is known as **"pinch effect". The pinch effect is more pronounced at higher frequencies.**

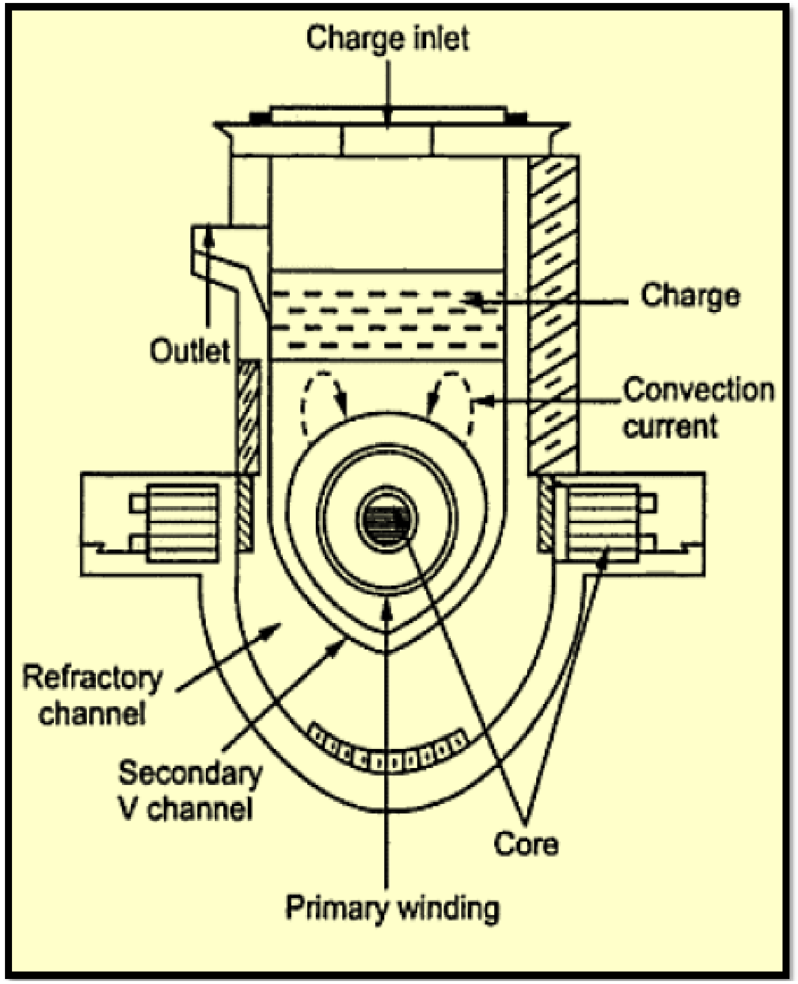
- It is essentially a transformer in which the charge to be heated forms a single-turn short-circuited secondary and is magnetically coupled to the primary by an iron core.
- The furnace consists of a circular hearth which contains the charge to be melted in the form of an annular ring.
- **When there is no molten metal in the ring, the secondary becomes open-circuited there-by cutting off the secondary current. Hence, to start the furnace, molten metal has to be poured in the annular hearth or sufficient molten metal is allowed to remain in the crucible rom the previous operation.**
- Since, magnetic coupling between the primary and secondary is very poor, it results in high leakage and low power factor. This difficulty, however, is overcome by employing supply frequencies as low as **10 Hz** for operation of such furnaces.

Drawbacks of Direct Core Type Induction Furnace:

- It has to be run on low-frequency supply which entails extra expenditure on motor-generator set or frequency convertor.
- It suffers from pinching effect.
- The crucible for charge is of odd shape and is very inconvenient for tapping the molten charge.
- It does not function if there is no molten metal in the hearth i.e. when the secondary is open. Every time molten metal has to be poured to start the furnace.
- It is not suitable for intermittent service.

However, in this furnace, melting is rapid and clean and temperature can be controlled easily. Moreover, inherent stirring action of the charge by electro-magnetic forces ensures greater uniformity of the end product.

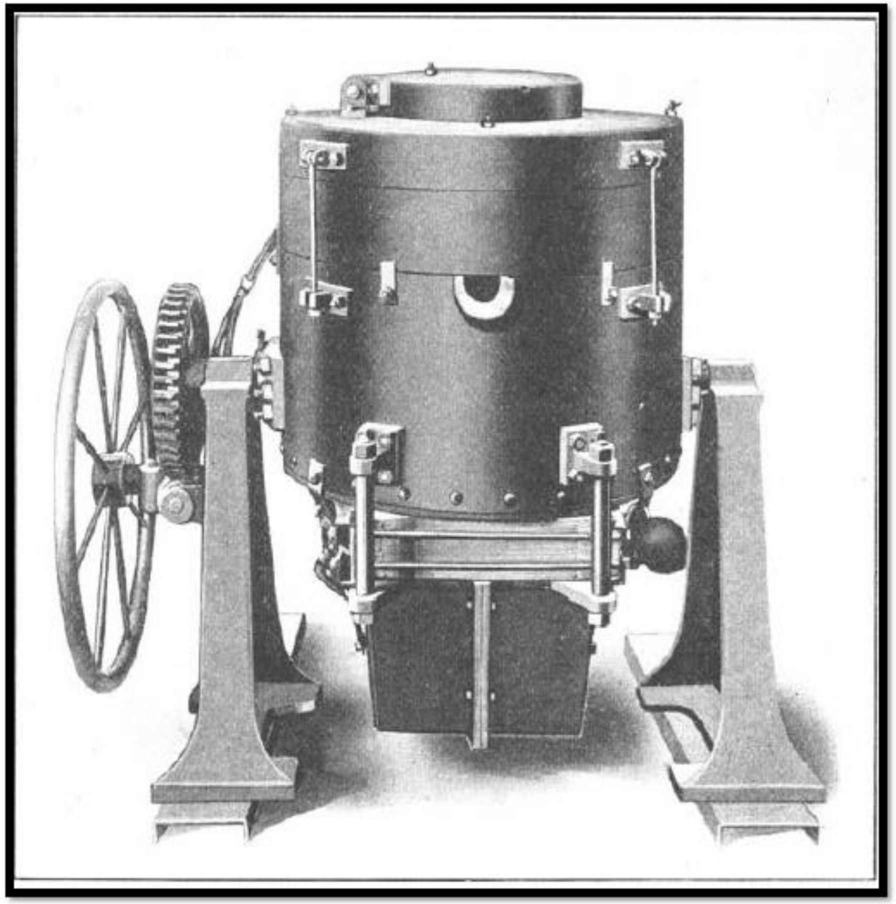
VERTICAL CORE TYPE INDUCTION FURNACE/ AJAX WYATT FURNACE

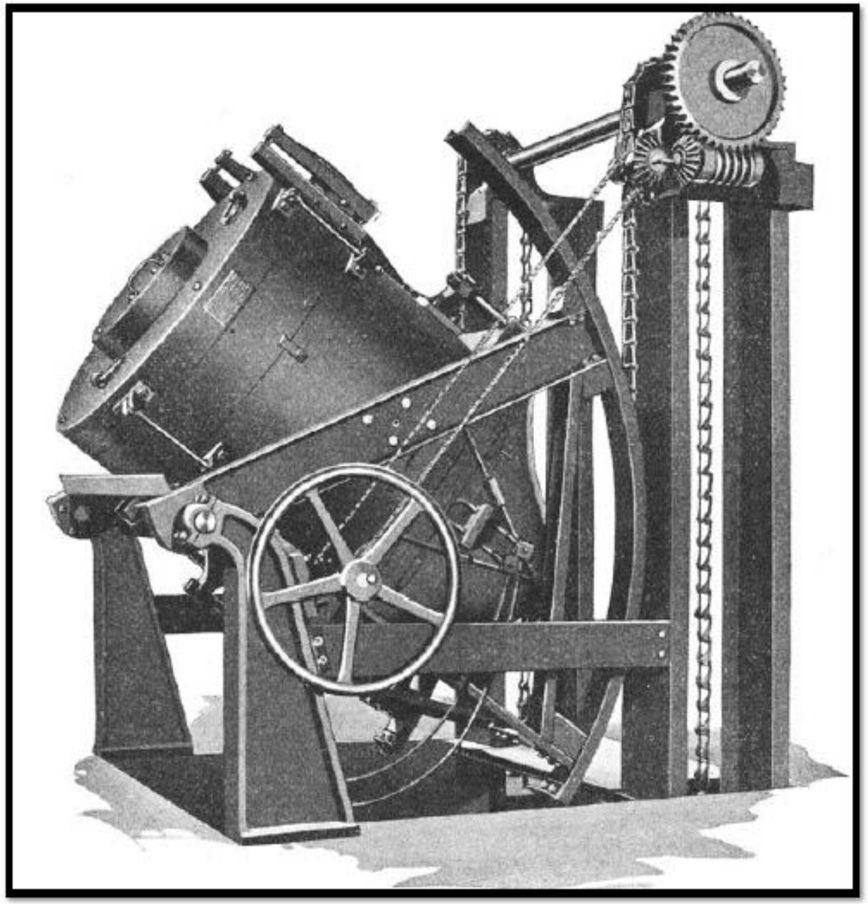


- In order to solve the problems (encountered in direct core type induction furnace i.e. pinch effect) practically, **an American Engineer, James R Wyatt**, employed by **Ajax Metal Corporation, proposed in 1915** to make V – shaped channel in a vertical plane below the hearth.
- **The magnetic coupling is better than Direct Core Induction Type Furnace, therefore leakage reactance is comparatively low and p.f. is high.**

- Since it is a Vertical Core Type Furnace, the tendency of the currents **to interrupt the secondary circuit due to Pinch Effect** is avoided due to weight of the charge in the main body of the crucible.
- The circulation of the molten metal is kept up round the Vee portion by convection currents and by the electromagnetic forces between currents in the two halves of the Vee.
- As the furnace is having a narrow Vee shape at the bottom, therefore tendency of the molten metal will be to accumulate at the bottom and even a small amount of charge will keep the secondary completed. Hence the chances of discontinuity of the circuit are less. For this reason, the Ajax – Wyatt Furnace is useful for continuous operation.
- **The power factor of the circuit is of the order of 0.8 to 0.83 pf, and it can be operated at power frequency.**
- **This furnace is used for melting non – ferrous metals such as brass, zinc and tin.**

AJAX – WYATT FURNACE





❑ MERITS OF AJAX - WYATT FURNACE:

1. Accurate control of temperature.
2. Uniform Castings.
3. Absence of Crucibles.
4. Consistent performance and simple control.
5. No combustion gases, thus eliminating the most common source of metal contamination.
6. Highly efficient heat, low running costs and improved performance.
7. Comparatively high power factor (0.8 – 0.85) with normal supply frequency since primary and secondary are both on the same central core.

INDIRECT CORE TYPE INDUCTION FURNACE

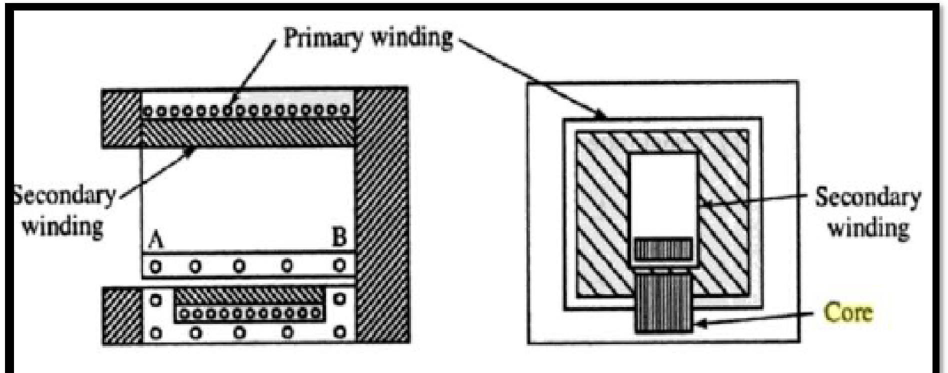


Fig. Indirect Core Type Induction Furnace.

- In this furnace, a suitable element is heated by induction which, in turn, transfers the heat to the charge by radiation.
- The secondary consists of a metal container which forms the walls of the furnace proper. The primary winding is magnetically coupled to this secondary by an iron core.
- When primary winding is connected to a.c. supply, secondary current is induced in the metal container by transformer action which heats up the container. The metal container transfers this heat to the charge.
- A special advantage of this furnace is that its temperature can be automatically controlled without the use of an external equipment.
- The part AB of the magnetic circuit situated inside the oven chamber consists of a special alloy which loses its magnetic properties at a particular temperature but regains them when cooled back to the same temperature. As soon as the chamber attains the critical temperature, reluctance of the magnetic circuit increases manifold thereby cutting off the heat supply. The bar AB is detachable and can be replaced by other bars (of different alloys) having different critical temperatures (400 ^{0}C and 1000 ^{0}C)

APPLICATIONS of INDUCTION HEATING

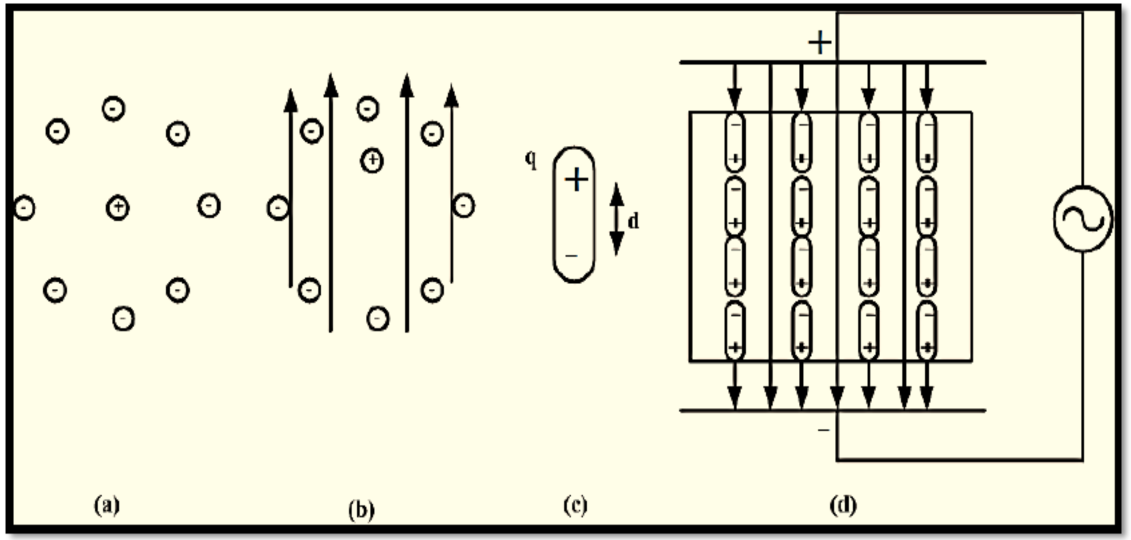
- The material of the work piece may be a metal such as steel, copper, aluminium or brass or it can be a semiconductor such as carbon, graphite or silicon carbide. To heat non-conductive materials such as plastics or glass, induction can heat an electrically-conductive susceptor, typically graphite, which then transfers the heat to the non-conducting material.
- Induction heating is used in processes where temperatures are as low as 100 ºC (212 °F) and as high as 3000 °C (5432 °F).
- Induction heating is used in domestic and commercial cooking, and in many industrial applications such as melting, heat treating, preheating for welding, brazing, soldering, curing, sealing, shrink fitting in industry, and in research and development.

Comparison Between High Frequency And Power Frequency Furnaces

S. No.	High Frequency	Power frequency
1	Frequency converter is necessary	Not required.
2	More energy required i.e, 20% to 30% for same rating.	Less energy required.
3	Maintenance cost is more	Less
4	Less turbulence and stirring effect	More
5	Large scrap melts with more oxidation loss.	Large scrap melts with less oxidation loss.
6	No special starting procedure is required	Special starting procedure is required.

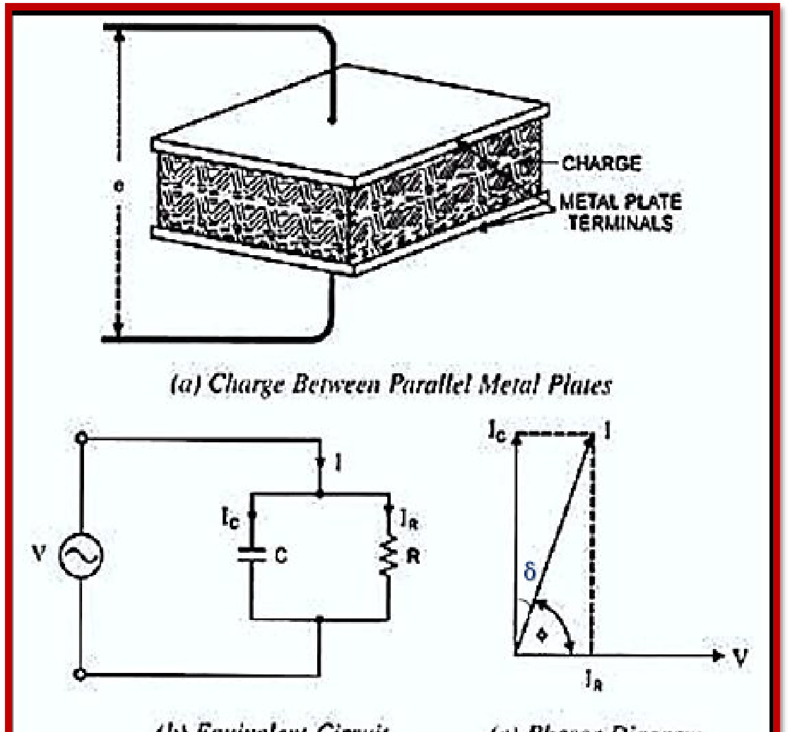
DIELECTRIC HEATING

- When an insulating material is subjected to an alternating electric field, the atoms get stressed and due to their interatomic friction, heat is produced. This heat loss is known as dielectric loss.
- When materials containing polar molecules having an electrical dipole moment is subjected to oscillating electric field, they will align themselves in rapidly oscillating electric field (these molecules rotate continuously by aligning with oscillating electric field). This is called **dipole rotation or dipolar polarization**. Rotating molecules push, pull, and collide with other molecules (through electrical forces), distributing the energy to adjacent molecules and atoms in the material. Once distributed, this energy appears as heat.



Dielectric heating (also known as electronic heating, RF heating and high frequency heating) involves the heating of electrically insulating materials by dielectric loss. A changing electric field across the material causes energy to be dissipated as the molecules attempt to line up with the continuously changing electric field.

All dielectric / insulating materials can be considered to be imperfect capacitor and can be represented by a parallel combination of a resistor ***R*** and a capacitor ***C.***



(a) Charge Between Parallel Metal Plates

(b) Equivalent Circuit

(c) Phasor Diagram

- The dielectric loss is directly proportional to the frequency of ac supply given to the two plates of the capacitor.
- In dielectric heating the heat is produced within the material itself. Because heat generation is uniform, the dielectric material is heated uniformly. This is the important property of dielectric heating.

$$Dielectric\ Loss\ (P) = \frac{V^2}{R}$$

$$From\ the\ phasor\ diagram\ \tan\delta = \frac{I_R}{I_C} = \frac{V/R}{V\omega C}$$

$$\frac{V}{R} = V\omega C \tan\delta$$

$$\frac{1}{R} = \omega C \tan\delta$$

$$\therefore\ P = \frac{V^2}{R} = V^2\omega C \tan\delta \quad (\tan\delta = dielectric\ loss\ tan\ gent\ /\ dissipation\ \ factor)$$

Normally δ *is small*

$$\therefore\ P = V^2\omega C\delta\ \ watt$$

Where **δ** is in radian and is known as the loss angle. It is an indication of the state of the dielectric whether it is healthy or unhealthy. The higher the value of **δ,** the less healthy is the state of the dielectric material.

$$\text{Current through the capacitor}, I_C = \frac{V}{X_C} = \frac{V}{1/2\pi fC} = V2\pi fC \text{ Amps}$$

where C is in farads and V is in volts

The current drawn from supply,

$$I \cong I_C \cong 2\pi fCV \text{ Amps}$$

$$\text{Power produced}, P = VI\cos\phi = V \times 2\pi fCV \times \cos\phi \text{ Watts}$$

$$= 2\pi fCV^2 \times \cos\phi \text{ Watts}$$

The capacitance of a parallel plate capacitor is given as

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

where ε_0 *is the permittivity constant*

ε_r = *relative permittivity of the medium*

A = *Area of the plate* (m^2)

d = *thickness of the medium* (m)

$$Therefore,\ dielectric\ loss,\ P = V^2 2\pi f \times \frac{\varepsilon_0 \varepsilon_r A\delta}{d}$$

$$So,\qquad P \propto V^2\ \ and\ \ P \propto f$$

- By varying one of these two quantities, the rate of dielectric heating can be varied. The insulation problem limits the voltage to be used; hence to achieve more heat, high frequency is used. However, there is a limit also, on the high frequency, imposed by cost involved in getting a circuit for obtaining very high frequencies and other difficulties.
- The product $\boldsymbol{\varepsilon_r \delta}$ is known as the loss factor. The **loss tangent tan $\boldsymbol{\delta}$** is a measure of how a material dissipates electrical energy as heat.
- Usual frequency used for dielectric heating is in the range of 1 to 30 MHz. Though higher frequencies between 50 – 200 MHz are also used but these power supplies are of low output.

APPLICATIONS OF DIELETRIC HEATING:

- The fact that water heats at a much more rapid rate than any other material when subjected to high frequency field, dielectric heating is most conveniently used for moisture removal especially when the moisture is disposed uniformally deep into the material and no other conventional heating method is available for its removal.
- Dielectric heating is also used for
  1. Heating thin films such as lacquers and paints applied to metallic surfaces,
  2. Preparation of thermo – plastic resins.
  3. Heat – sealing of plastic sheets,
  4. Bonding of laminated wood,
  5. Drying of textiles,
  6. Dehydration of food and tobacco,
  7. Sterilization of cereals, etc.

MERITS OF DIELETRIC HEATING:

1. If the material to be heated is homogeneous, and the alternating (or varying) electric field is uniform, heat is developed uniformly and simultaneously throughout the entire mass of the charge.

2. As materials heated by this process are non-conducting, so by other methods heat cannot be conducted to inside so easily.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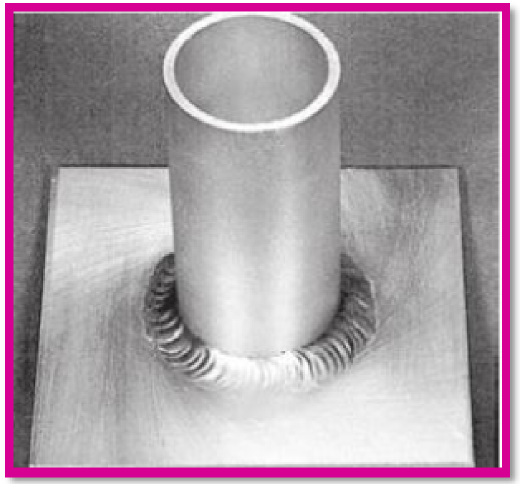
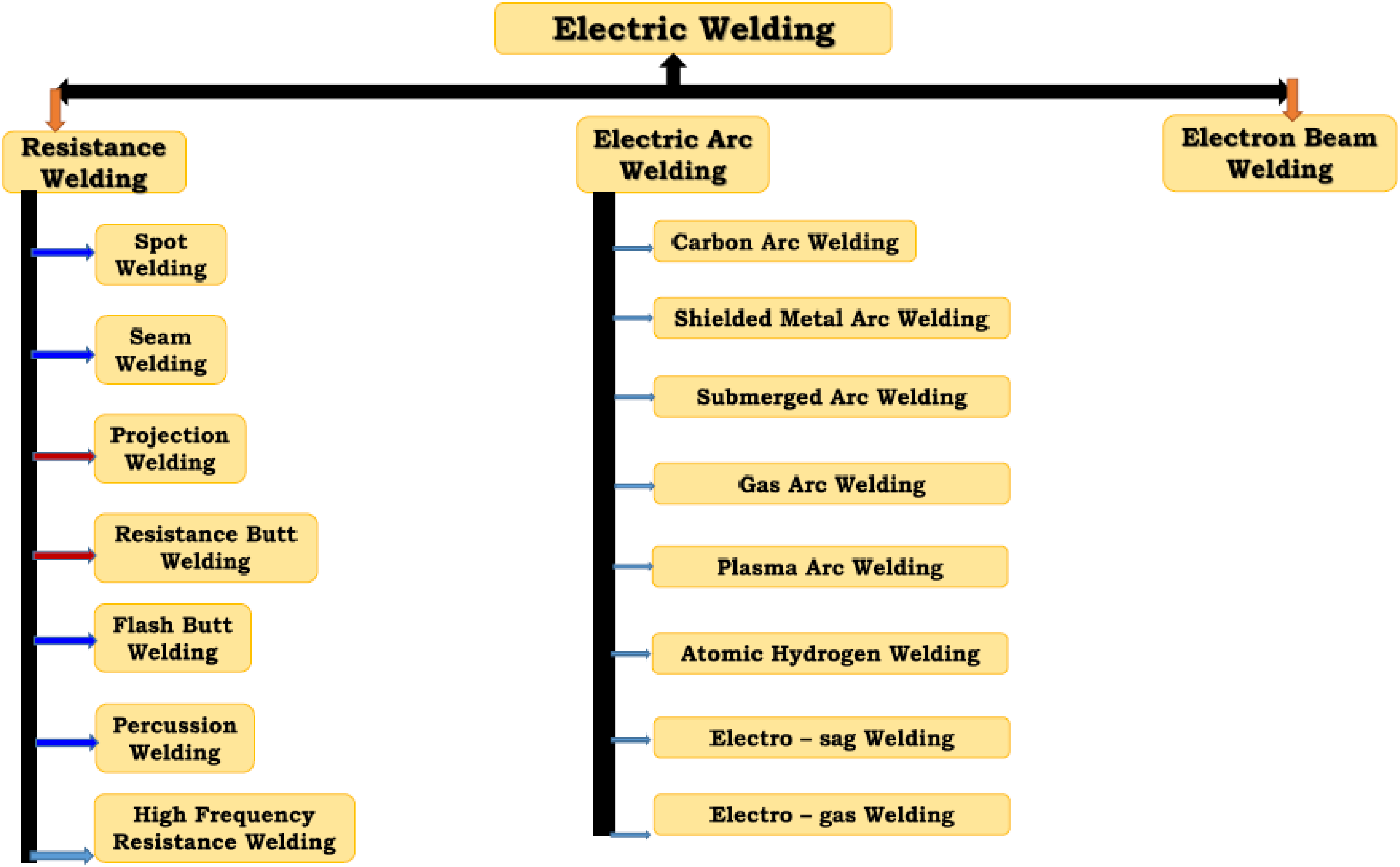
ELECTRIC WELDING

- Welding is defined as **“a joining process that produces coalescence of materials (the fusion or growing together of the grain structure of the materials being welded) by heating them to the welding temperature, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler material”**.
- Alternatively defined, **Welding is the joining together of two pieces of metal by heating to a temperature high enough to cause softening or melting, with or without the application of pressure, and with or without the use of filler material.**
- Any filler material used has either a melting point approximately the same as metals being joined or a melting point that is below these metals but above 800 degrees Fahrenheit.

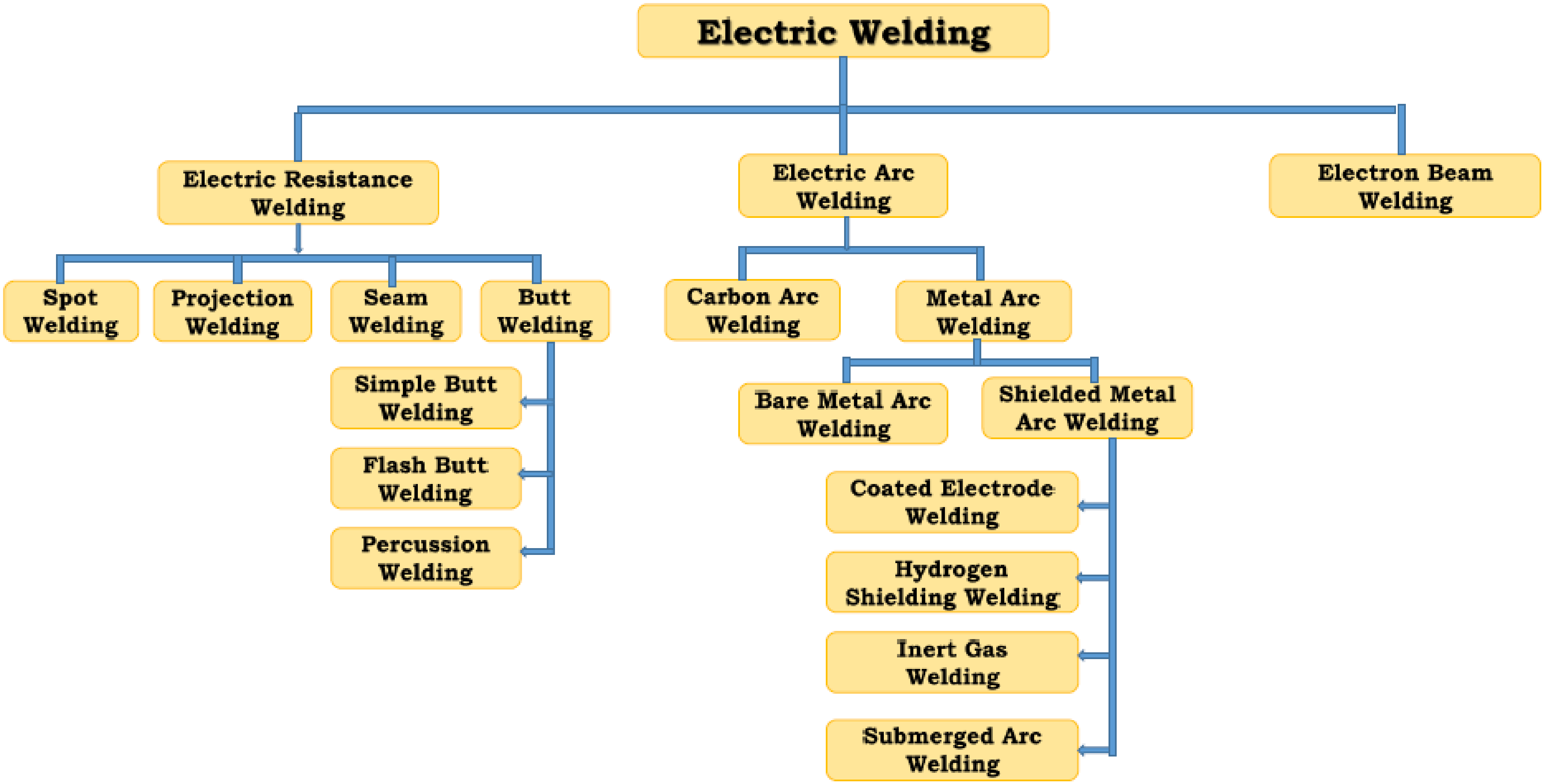


Welding is a process in *which materials of the same fundamental type or class are brought together and caused to join (and become one) through the formation of primary (and, occasionally, secondary) chemical bonds under the combined action of heat and pressure.*

Welding is the result of the combined action of heat and pressure.



Electric Welding
Resistance Welding
Electric Arc Welding
Electron Beam Welding
Spot Welding
Seam Welding
Projection Welding
Resistance Butt Welding
Flash Butt Welding
Percussion Welding
High Frequency Resistance Welding
Carbon Arc Welding
Shielded Metal Arc Welding
Submerged Arc Welding
Gas Arc Welding
Plasma Arc Welding
Atomic Hydrogen Welding
Electro – sag Welding
Electro – gas Welding


Electric Welding
Electric Resistance Welding
Electric Arc Welding
Electron Beam Welding
Spot Welding
Projection Welding
Seam Welding
Butt Welding
Carbon Arc Welding
Metal Arc Welding
Simple Butt Welding
Flash Butt Welding
Percussion Welding
Bare Metal Arc Welding
Shielded Metal Arc Welding
Coated Electrode Welding
Hydrogen Shielding Welding
Inert Gas Welding
Submerged Arc Welding

Resistance Welding

- Resistance welding is a process in which fusion between the **parts' surfaces occurs** as a result of the heat produced by the resistance between the parts' contacting surfaces.
- The welding current required to make a resistance weld must be at a very low voltage but at a high amperage. Pressure is constantly applied while the current is applied to ensure a continuous electrical circuit and to forge the heated parts together.
- By definition, a weld is a localized coalescence **(Fastening two pieces of metal together by softening with heat and applying pressure)** of metal heated to a suitable temperature.
- The rate at which the heat is generated is given by:

$$
\begin{aligned}
& W = I^2 R \\
\text{where } & W = \text{Electrical power in watts} \\
& I = \text{Current in Amps} \\
& R = \text{Resistance in Ohms}
\end{aligned}
$$

- If the power is applied over a time interval of t seconds, the heat energy developed in the resistance is:

$$
\begin{aligned}
& Q = I^2 Rt \\
\text{where } & Q = \text{Watt} - \text{sec or Joules}
\end{aligned}
$$

SPOT WELDING

- In this process overlapping sheets are joined by local fusion at one or more spots, by the concentration of current flowing between two electrodes. This is the most widely used resistance welding process.

OR

In this process, the weld is produced by the heat obtained at the interface between the workpieces. This heat is due to the resistance to the flow of electric current through the workpieces, which are held together by pressure from the electrode.

- The size and shape of the formed welds are controlled somewhat by the size and contour of the electrodes. The welding time is controlled by a timer built into the machine or by a computer program.

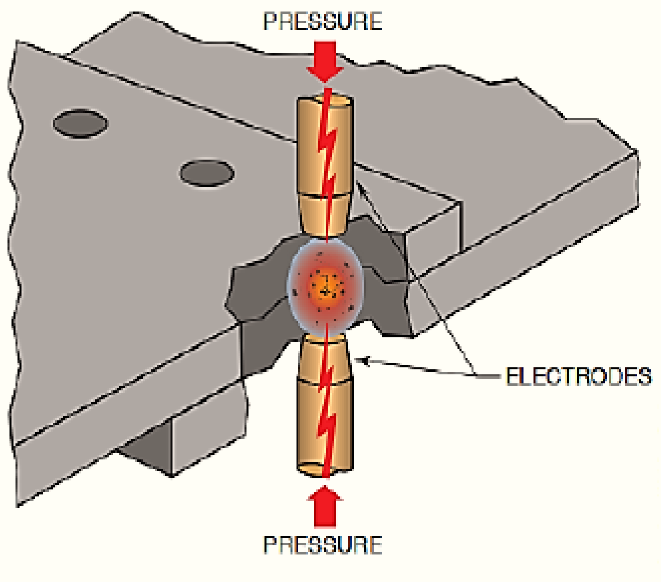


FIGURE : Heat resulting from resistance of the current through the metal held under pressure by the electrodes creates fusion of the two workpieces during spot welding.

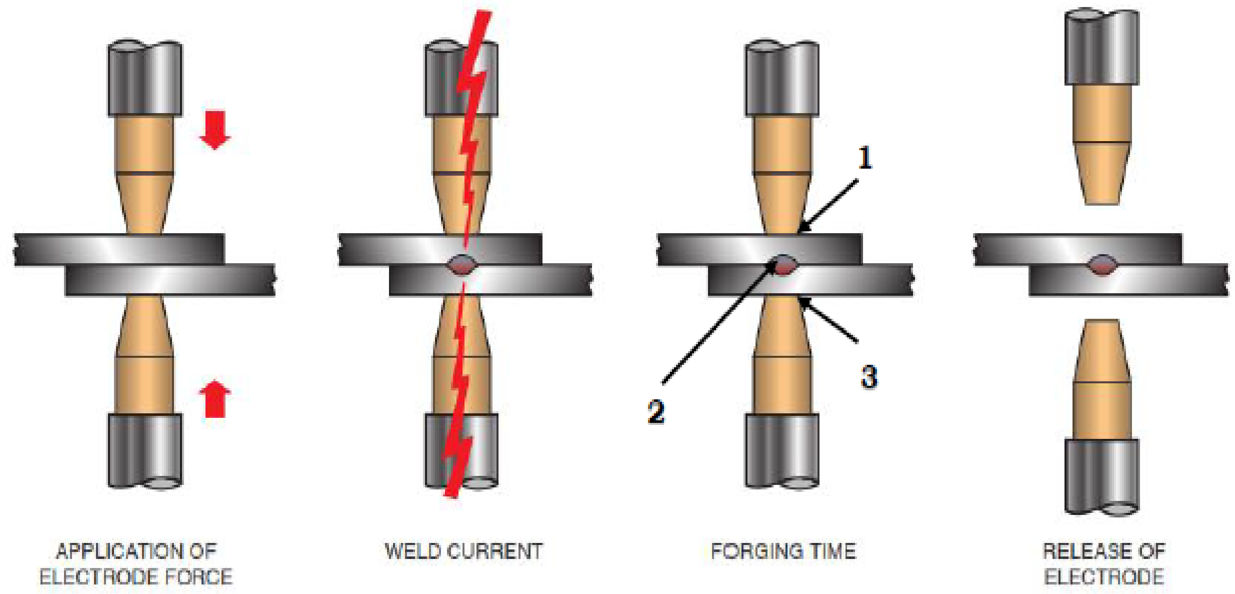
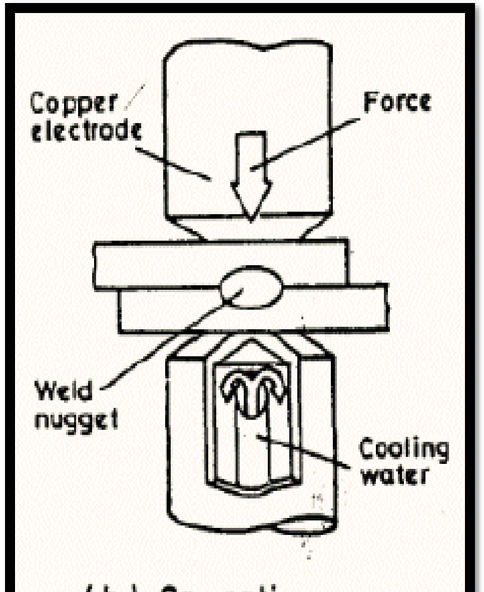


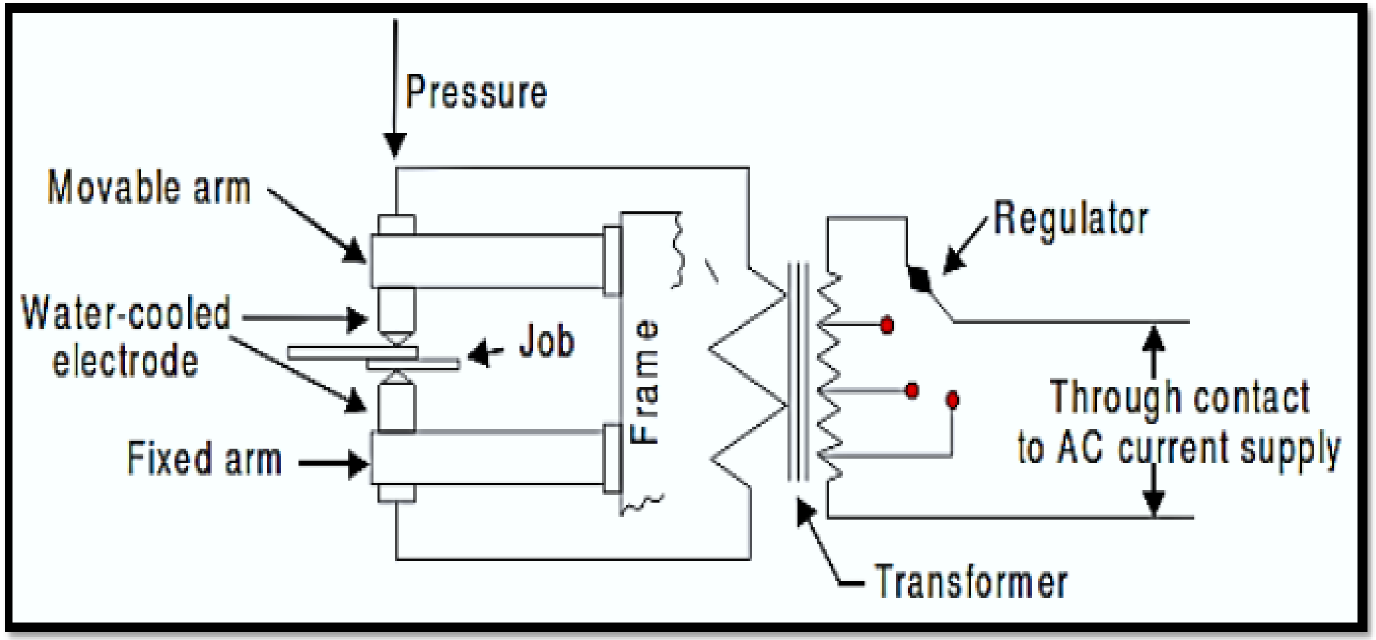
FIGURE Basic periods of spot welding.

- Heat generation at junctions at 1 and 3 will cause electrode sticking and melt through hole. As such heating of junctions 1 and 3 is to be avoided. This is achieved by taking following measures:

1. By water cooling the electrodes, junctions 1 and 3 are cooled.
2. Electrodes are made of materials (copper beryllium and copper tungsten) which have high electrical conductivity and high thermal conductivity so that heat developed at junctions 1 and 3 is minimum in the first instance. Secondly, whatever heat is developed is efficiently conducted away.



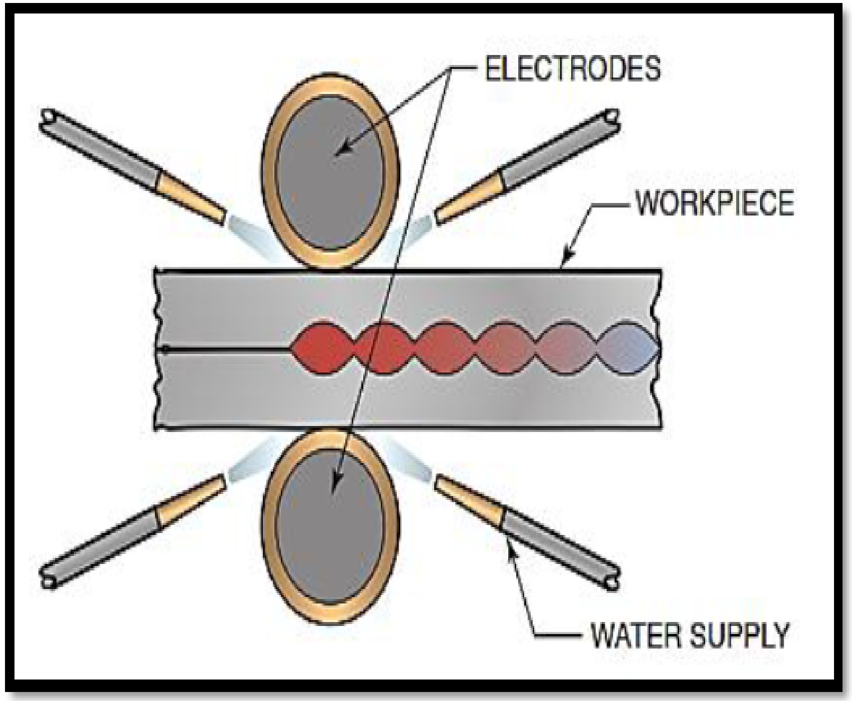
(b) Operation

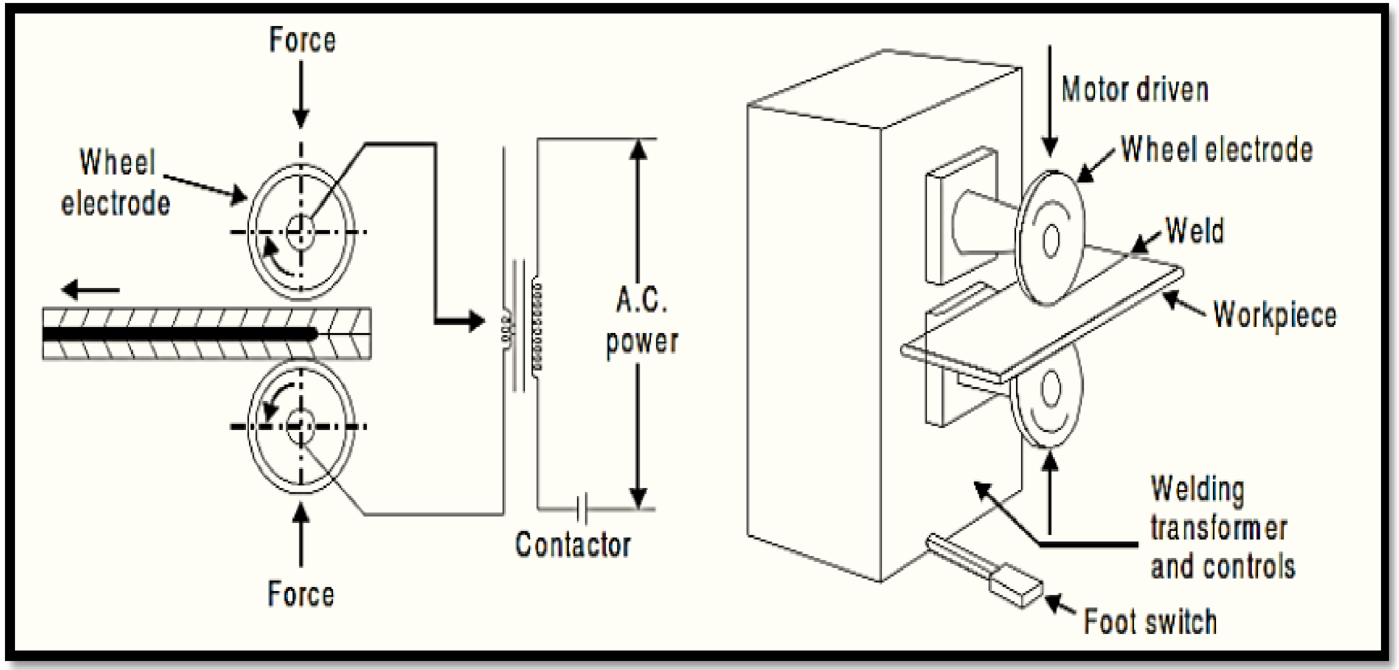


Applications: Spot welding is mainly used for lap welding of thin sheets particularly in the welding of automobile and refrigerator bodies, and high quality work in aircraft engines.

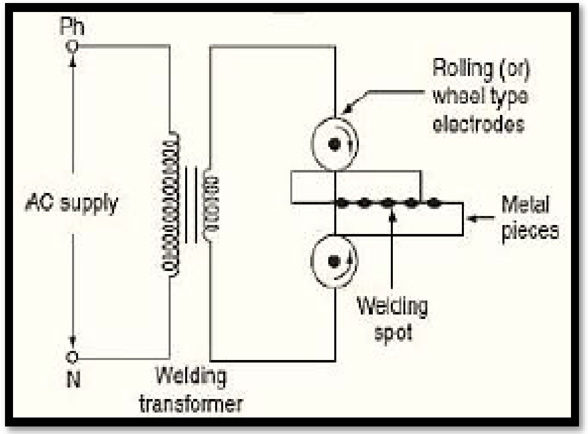
SEAM WELDING

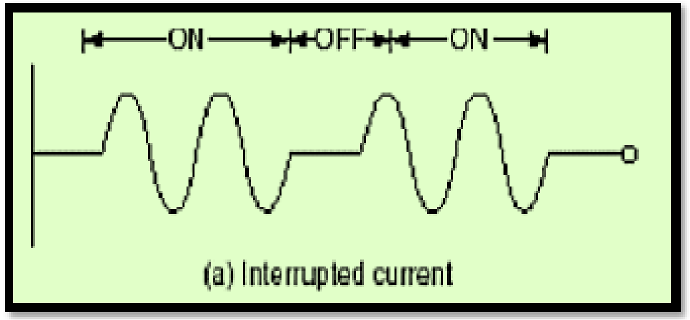
- Seam welding is similar in some ways to spot welding except that the spots are spaced so closely together that they actually overlap one another to make a continuous seam weld. Seam welding is accomplished by using roller-type electrodes in the form of wheels.
- In this welding process coalescence at the faying surfaces **(A faying surface is one of the surfaces that are in contact at a joint)** is produced by the heat obtained from the resistance to electric current (flow) through the work pieces held together under pressure by circular electrodes.
- Cooling is achieved by a constant stream of water directed to the electrode near the weld





- 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 upon the number of welding current pulses. Magnitude of welding current depends upon the thickness of the sheets to be welded.





(a) Interrupted current

S No.	Weld spots/inch	On off time in cycle	No. of cycles/inch weld	Supply frequency	Time in sec/inch weld	Welding speed in inch/sec
1	10	5	50	50	1	1"/sec
2	10	5	50	100	$\frac{1}{2}$	2"/sec
3	5	$1\frac{1}{2}$	15/2	50	3/20	$\frac{20}{3}$" /sec
4	15	$1\frac{1}{2}$	45/2	50	9/20	$\frac{10}{3}$" / sec

Applications

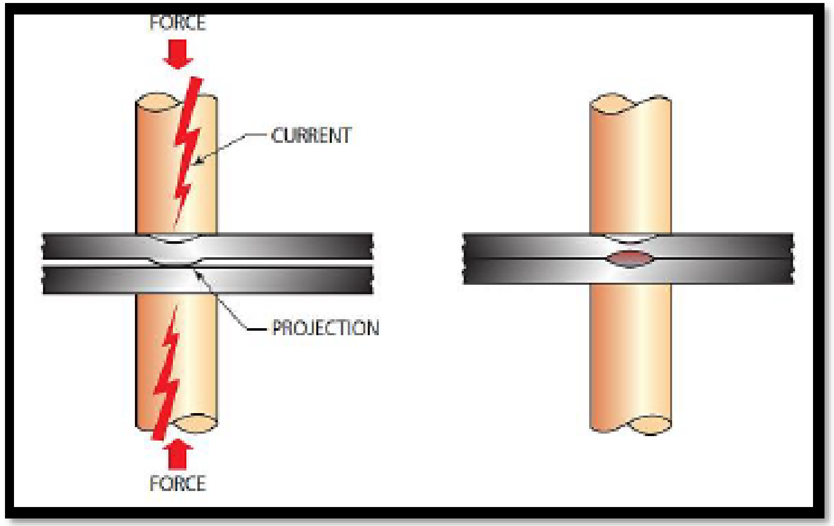
1. It is used for making leak proof joints in fuel tanks of automobiles.

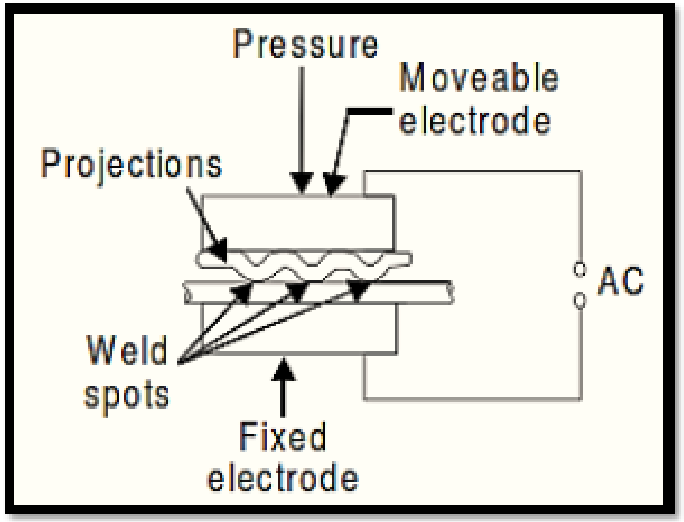
2. Except for copper and high copper alloys, most other metals can be seam welded.

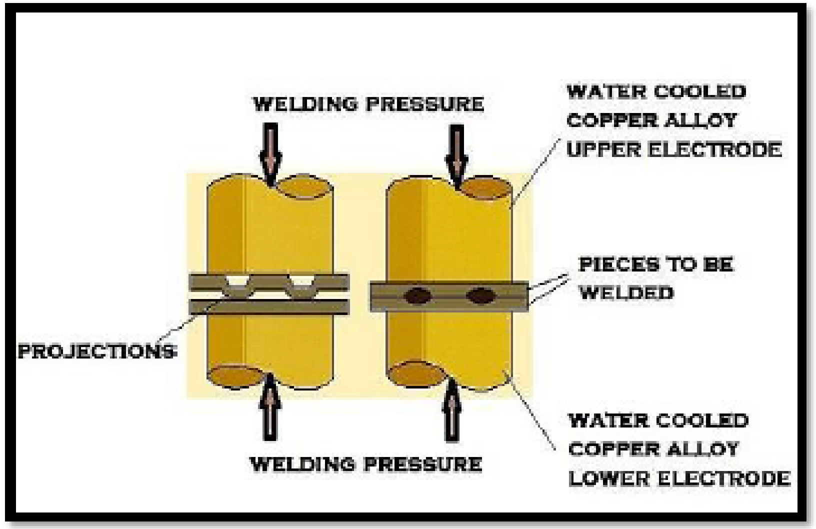
3. It is also used for making flange welds for use in watertight tanks.

PROJECTION WELDING

- This process is a resistance welding process in which **two or more than two spot welds are made simultaneously by making raised portions or projections on predetermined locations on one of the workpiece**. These projections act to localize the heat of the welding circuit.
- The pieces to be welded are held in position under pressure being maintained by electrodes.
- The **projections**—small, raised areas—can be any shape, such as round, oval, circular, oblong, or diamond. They can be formed by embossing, casting, stamping, or machining.
- The workpieces that have the projections and the other workpiece are placed between plain, large-area electrodes in the welding machine.

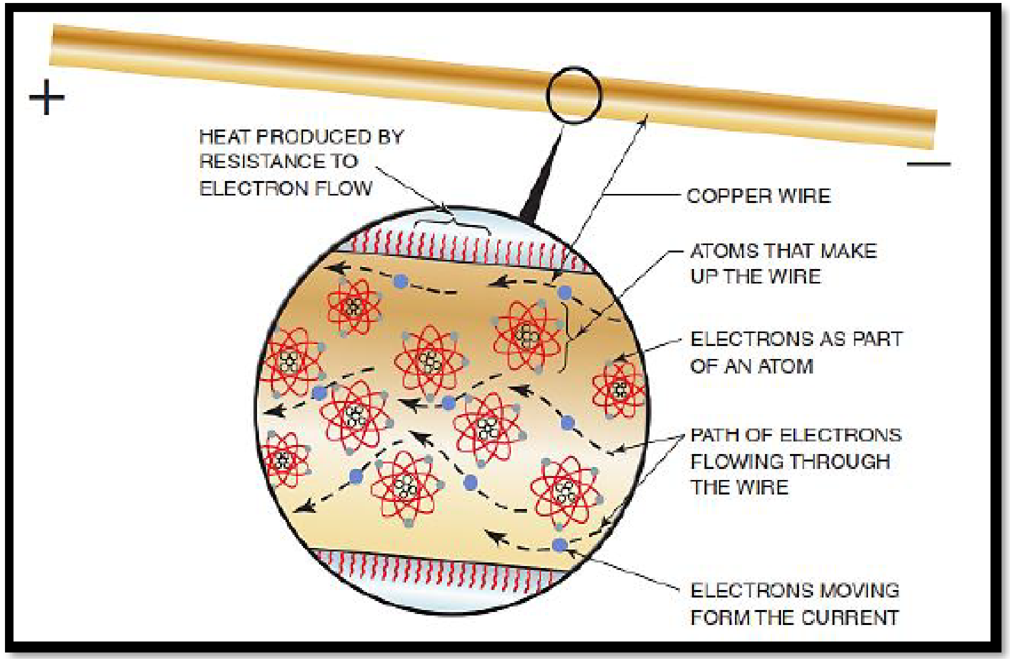


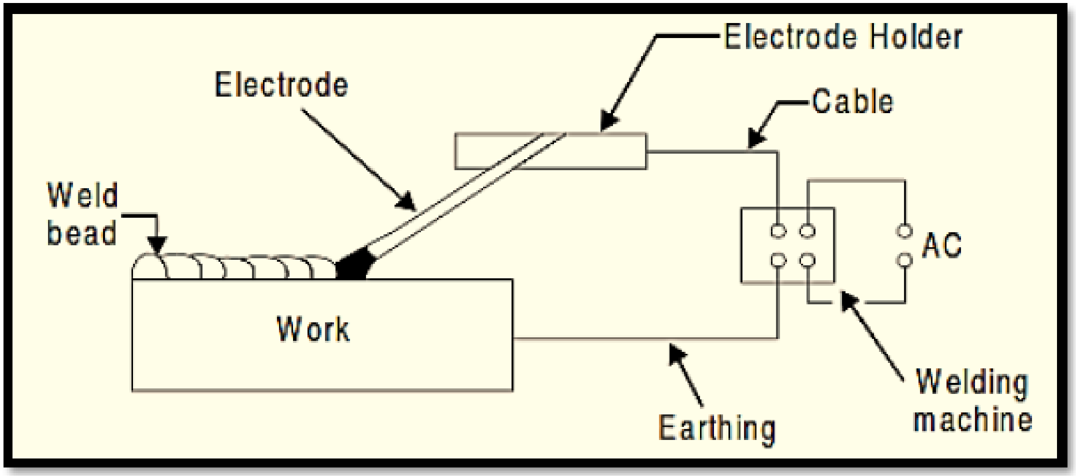




Applications: Steel plate, galvanized sheet steel, and stainless steels can be joined using projection welding.

ELECTRIC ARC WELDING



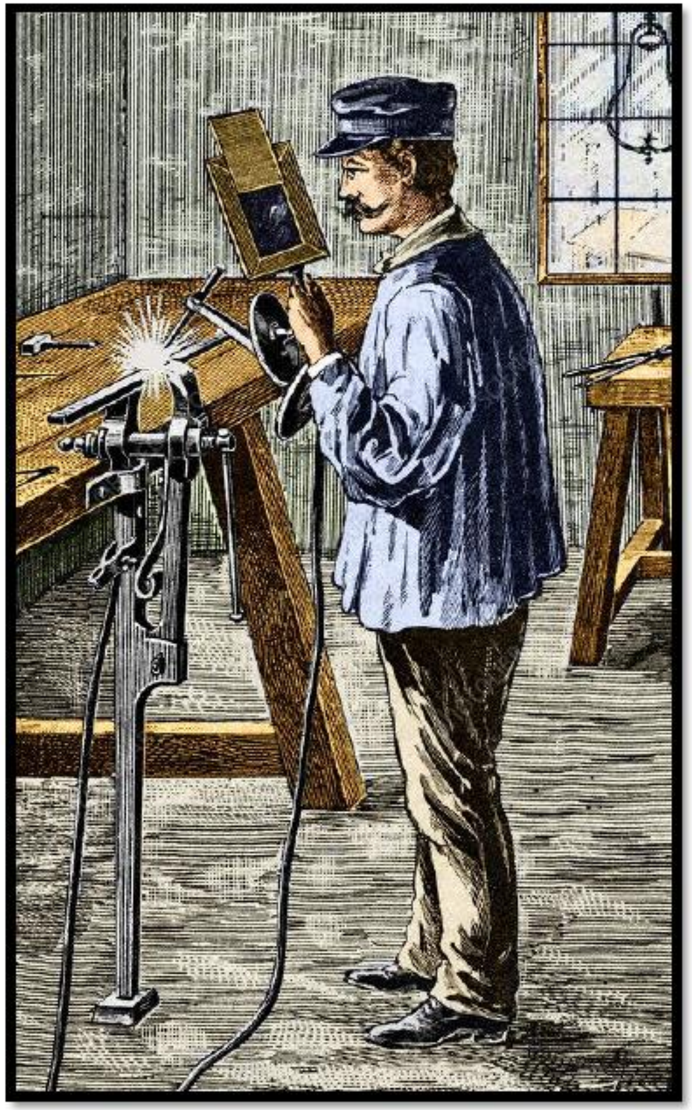


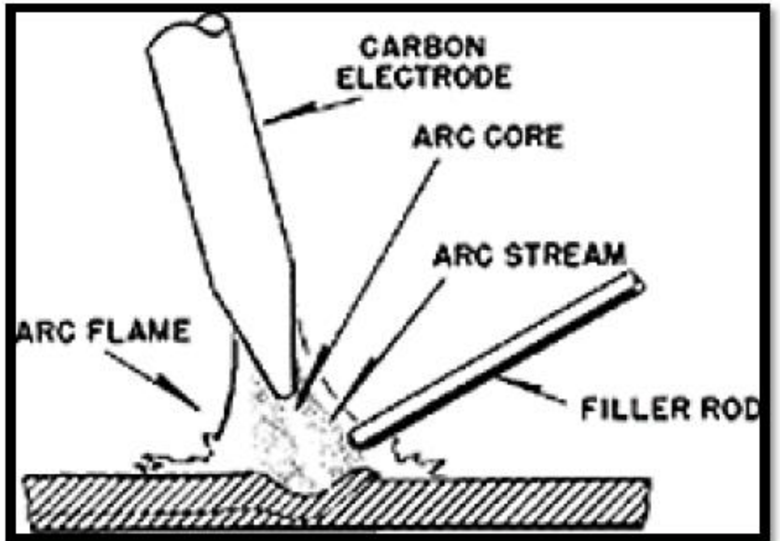
- The process, in which an electric arc between an electrode and a workpiece or between two electrodes is utilized to weld base metals, is called an arc welding process.

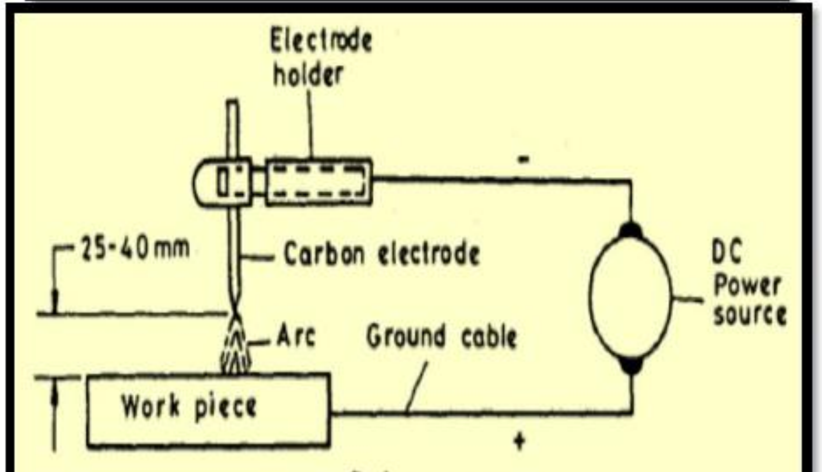
OR

- A welding process wherein heat required for welding or obtaining coalescence is produced with an electric arc with or without the application of pressure and with or without the use of filler material.
- The arc in arc welding is created between an electrode and a workpiece or a weldment, each at different polarities. The arc itself consists of thermally emitted electrons and positive ions from this electrode and the workpiece. These electrons and positive ions are accelerated by the potential field (voltage) between the source (one electrode) and the work (the opposite charged electrode), and produce heat when they convert their kinetic energy by collision with the opposite charged element.
- The electrode can be intended to be permanent, serving solely as a source of electrons or positive ions, or consumed, in which case it serves both as a source of energy for welding from these particles and as a filler to the weld joint.

CARBON ARC WELDING

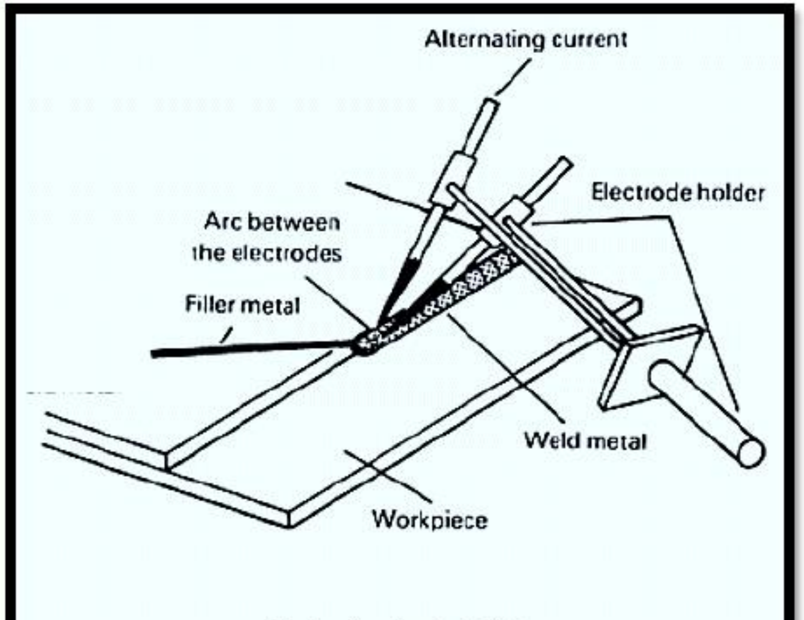






Carbon arc welding.

SINGLE ELECTRODE CAW



Twin-electrode CAW

CARBON ARC WELDING

- **CARBON ARC WELDING (CAW) utilizes what is considered to be a nonconsumable electrode, made of carbon or graphite, to establish an arc between itself and either the workpiece or another carbon electrode.**
- **Normally, no shielding gas is used.**
- **SINGLE ELECTRODE CAW: In this case the power supply for releasing the heat is DC. The electrode always acts as cathode (negative). The arc is created between the electrode and the workpiece which always act as anode (+ve). The arc is struck by touching the electrode with the job momentarily and then taking away by appropriate distance (generally 10 to 15 mm apart). The arc is allowed to impinge on the surface to be welded to form a pool of molten metal. The holder is steadily moved to complete the welding process.**
- **TWIN ELECTRODE CAW: The twin-electrode arrangement usually operates with alternating current (ac), generally with small ac power supplies. The arc is maintained between two carbon electrodes held in a special holder. The electric torch consists of two carbon electrodes that can be adjusted by means of a thumb – operated mechanism located on the handle of the electrode holder. The electrodes can be moved closer or further apart, making the arc of desired length.**

Applications: Used for welding steel, nickel, aluminium, copper and their alloys. It is also employed for brazing, pre – heating and post – heating of the welded joints.

Table Electric heating processes

Technique	*Frequency range*	*Power range*
Direct resistance	0–50 Hz	0.01–30 MW
Indirect resistance	50 Hz	0.5–5 kW
Oven, furnace	50 Hz	0.01–1 MW
Arc melting	50 Hz	1–100 MW
Induction heating	50 Hz–450 kHz	0.02–10 MW
Dielectric heating	1–100 MHz	1–5000 kW
Microwave heating	0.5–25 GHz	1–100 kW
Plasma torch	4 MHz	0.001–1 MW
Laser CO_2	30 THz	0.1–60 kW
Infra-red	30–400 THz	1–500 kW
Ultraviolet (mercury arc)	750–1500 THz	1 kW

Video Links

- https://www.youtube.com/watch?v=VpuNgEwExHE
- https://www.youtube.com/watch?v=zDsz_op-2ZE