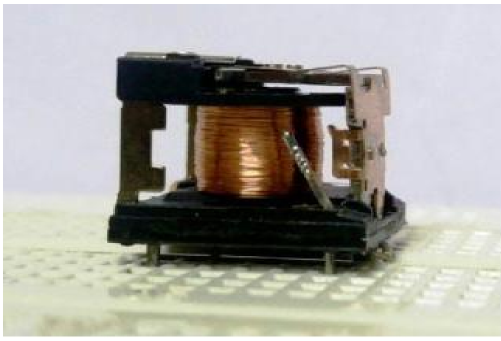
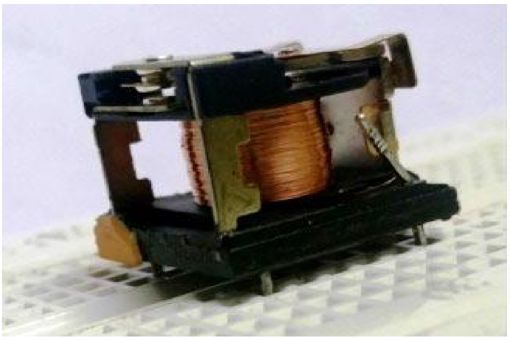
CHAPTER 5

5.1 RELAYS

The main usage of the **Relay** was seen in the history for transmitting and receiving the information, that was called as Morse code where the input signals used to be either 1 or 0, these change in signals were mechanically noted in terms of ON and OFF of a light bulb or a beep sound, it means those pulses of 1s and 0s are converted as mechanical ON and OFF using electromagnets. Later this was improvised and used in various applications. Let’s see how this electromagnet acts as a switch and why it is named as **RELAY**.

A relay is classified into many types, a standard and generally used relay is made up of electromagnets which in general used as a switch. Dictionary says that relay means **the act of passing something from one thing to another***,* the same meaning can be applied to this device because the signal received from one side of the device controls the switching operation on the other side. So relay is a switch which controls (open and close) circuits electromechanically. The main operation of this device is to make or break contact with the help of a signal without any human involvement in order to switch it ON or OFF. It is mainly used to control a high powered circuit using a low power signal. Generally a DC signal is used to control circuit which is driven by high voltage like controlling AC home appliances with DC signals from microcontrollers.

An electromechanical relay is basically designed using few mechanical parts like Electromagnet, a movable armature, contacts, yoke, and a spring/frame/stand, these parts are showing in the **internal pictures of Relay** below. All these are arranged logically to form into a relay.

Electromagnet:

An Electromagnet plays a major role in the **working of a relay**. It is a metal which doesn’t have magnetic property but it can be converted into a magnet with the help of an electrical signal. We know that when current passes through the conductor it acquires the properties of a magnet. So, when a metal winded with a copper wire and driven by the sufficient power supply, that metal can act as a magnet and can attract the metals within its range.

Movable Armature:

Movable armature is a simple metal piece which is balanced on a pivot or a stand. It helps in making or breaking the connection with the contacts connected to it.

Contacts:

These are the conductors that exist within the device and are connected to the terminals.

Yoke:

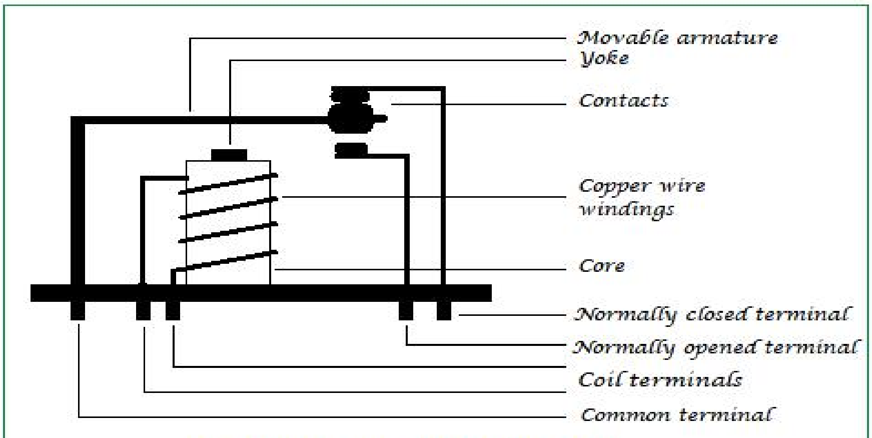
It is a small metal piece fixed on a core in order to attract and hold the armature when the coil is energized.

Spring (optional):

Few relays don't need any spring but if it is used, it is connected to one end of the armature to ensure its easy and free movement. Instead of a spring, a metal stand like structure can be used.

Construction of Relay and its operation:

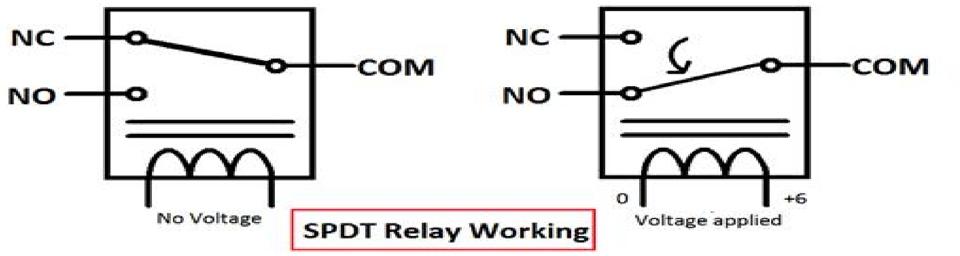
The following figure shows how a Relay looks internally and how it can be constructed,



An Electromagnetic Relay

On a casing, a core with copper windings (forms a coil) winded on it is placed. A movable armature consists of a spring support or stand like structure connected to one end, and a metal contact connected to another side, all these arrangements are placed over the core such that, when the coil is energized, it attracts the armature. The movable armature is generally considered as a common terminal which is to be connected to the external circuitry. The relay also has two pins namely **normally closed and normally opened (NC and NO),** the normally closed pin is connected to the armature or the common terminal whereas the normally opened pin is left free (when the coil is not energized). When the coil is energized the armature moves and is get connected to the normally opened contact till there exists flow of current through the coil. When it is de-energized it goes to its initial position.

The general **circuit representation of the relay** is as shown in the figure below



How Relay works?

Relay in NORMALLY CLOSED condition:

When no voltage is applied to the core, it cannot generate any magnetic field and it doesn't act as a magnet. Therefore, it cannot attract the movable armature. Thus, the initial position itself is the armature connected in normally closed position (NC).

Relay in NORMALLY OPENED condition:

When sufficient voltage is applied to the core it starts to create a magnetic field around it and acts as a magnet. Since the movable armature is placed within its range, it gets attracted to that magnetic field created by the core, thus the position of the armature is being altered. It is now connected to the normally opened pin of the relay and external circuit connected to it function in a different manner.

Note: The functionality of the external circuit depends upon the connection made to the relay pins.

So finally, we can say that when a coil is energized the armature is attracted and the switching action can be seen, if the coil is de-energized it loses its magnetic property and the armature goes back to its initial position.

Other than the Electromagnetic relay there are many other **types of relays** which work on different principles. Its classification is as follows

Types of Relay Based on the principle of operation

Electrothermal relay:

When two different materials are joined together it forms into a bimetallic strip. When this strip is energized it tends to bend, this property is used in such a way that the bending nature makes a connection with the contacts.

Electromechanical relay:

With the help of few mechanical parts and based on the property of an electromagnet a connection is made with the contacts.

Solid State relay:

Instead of using mechanical parts as in electrothermal and electromechanical relays, it uses semiconductor devices. So, the switching speed of the device can be made easier and faster. The main advantages of this relay are its more life span and faster switching operation compared to other relays.

Hybrid relay:

It is the combination of both electromechanical and solid state relays.

The most Common type of relay that is used in electronics is the electromechanical relay, however, in industrial applications there are other types of relays , such as solidstate relay,latching relay and timing relay.

Solid State Relay

Solid State Relays are semiconductor equivalents of the electromechanical relay and can be used to control electrical loads without the use of moving parts

Unlike electro-mechanical relays (EMR) which use coils, magnetic fields, springs and mechanical contacts to operate and switch a supply, the solid state relay, or SSR, has no moving parts but instead uses the electrical and optical properties of solid state semiconductors to perform its input to output isolation and switching functions.

Just like a normal electro-mechanical relay, SSR's provide complete electrical isolation between their input and output contacts with its output acting like a conventional electrical switch in that it has very high, almost infinite resistance when nonconducting (open), and a very low resistance when conducting (closed). Solid state relays can be designed to switch both AC or DC currents by using an SCR, TRIAC, or switching transistor output instead of the usual mechanical normally-open (NO) contacts.

While the solid state relay and electro-mechanical relay are fundamentally similar in that their low voltage input is electrically isolated from the output that switches and controls a load, electro-mechanical relays have a limited contact life cycle, can take up a lot of room and have slower switch speeds, especially large power relays and contactors. Solid state relays have no such limitations.

Thus the main advantages solid state relays have over conventional electro-mechanical relays is that they have no moving parts to wear out, and therefore no contact bounce issues, are able to switch both “ON” and “OFF” much faster than a mechanical relays armature can move, as well as zero voltage turn-on and zero current turn-off eliminating electrical noise and transients.

Solid state relays can be bought in standard off-the-shelf packages ranging from just a few volts or amperes to many hundreds of volts and amperes of output switching capability. However, solid state relays with very high current ratings (150A plus) are still too expensive to buy due to their power semiconductor and heat sinking requirements, and as such, cheaper electro-mechanical contactors are still used.

Similar to an electro-mechanical relay, a small input voltage, typically 3 to 32 volts DC, can be used to control a much large output voltage, or current. For example 240V, 10Amps. This makes them ideal for microcontroller, PIC and Arduino interfacing as a low-current, 5-volt signal from say a micro-controller or logic gate can be used to control a particular circuit load, and this is achieved with the use of opto-isolators.

Solid State Relay Input

One of the main components of a solid state relay (SSR) is an opto-isolator (also called an optocoupler) which contains one (or more) infra-red light-emitting diode, or LED light source, and a photo sensitive device within a single case. The opto-isolator isolates the input from the output.

The LED light source is connected to the SSR's input drive section and provides optical coupling through a gap to an adjacent photo sensitive transistor, darlington pair or triac. When a current passes through the LED, it illuminates and its light is focused across the gap to a photo-transistor/photo-triac.

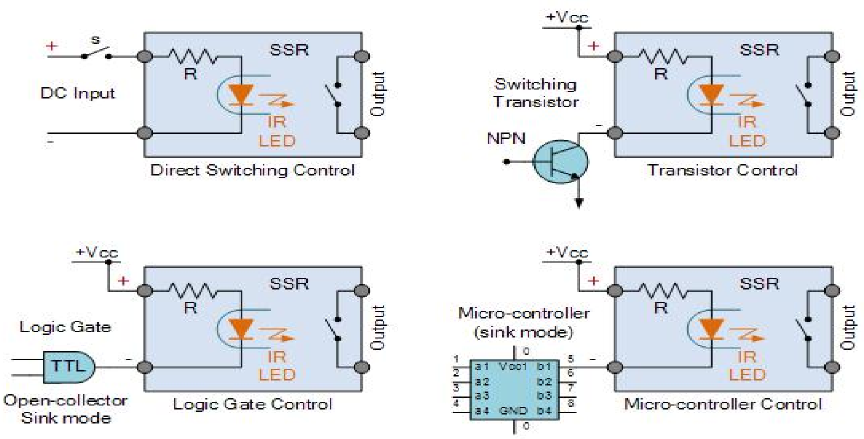
Thus the output of an opto-coupled SSR is turned "ON" by energising this LED, usually with low-voltage signal. As the only connection between the input and output is a beam of light, high voltage isolation (usually several thousand volts) is achieved by means of this internal opto-isolation.

Not only does the opto-isolator provide a higher degree of input/output isolation, it can also transmit dc and low-frequency signals. Also, the LED and photo-sensitive device could be totally separate from each other and optically coupled by means of an optical fibre.

The input circuitry of an SSR may consist of just a single current limiting resistor in series with the LED of the opto-isolator, or of a more complex circuit with rectification, current regulation, reverse polarity protection, filtering, etc.

To activate or turn "ON" a sold state relay into conduction, a voltage greater than its minimum value (usually 3 volts DC) must be applied to its input terminals (equivalent to the electro-mechanical relay coil). This DC signal may be derived from a mechanical switch, a logic gate or micro-controller, as shown.

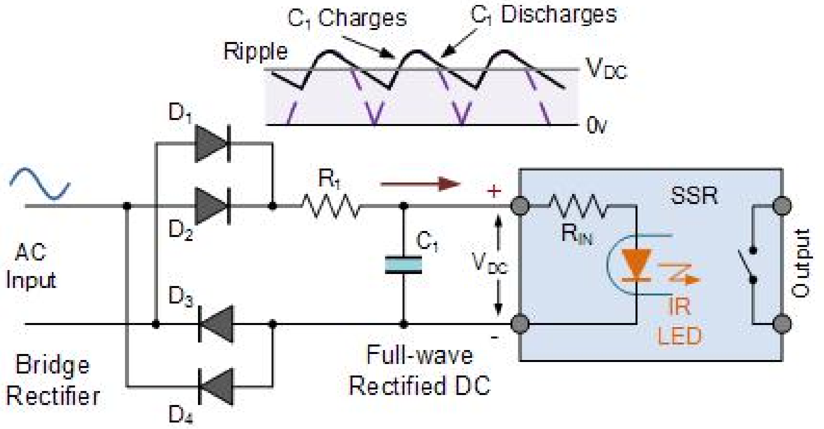
Solid State Relay DC Input Circuit



When using mechanical contacts, switches, push-buttons, other relay contacts, etc, as the activating signal, the supply voltage used can be equal to the SSR's minimum input voltage value, whereas when using solid state devices such as transistors, gates and micro-controllers, the minimum supply voltage needs to be one or two volts above the SSR's turn-on voltage to account for the switching devices internal voltage drop.

But as well as using a DC voltage, either sinking or sourcing, to switch the solid state relay into conduction, we can also use a sinusoidal waveform as well by adding a bridge rectifier for full-wave rectification and a filter circuit to the DC input as shown.

Solid State Relay AC Input Circuit



Bridge rectifiers convert a sinusoidal voltage into full-wave rectified pulses at twice the input frequency. The problem here is that these voltage pulses start and end from zero volts which means that they will fall below the minimum turn-on voltage requirements of the SSR’s input threshold causing the output to turn “on” and “off” every half cycle.

To overcome this erratic firing of the output, we can smooth out the rectified ripples by using a smoothing capacitor, (C1) on the output of the bridge rectifier. The charging and discharging effect of the capacitor will raise the the DC component of the rectified signal above the maximum turn-on voltage value of the solid state relays input. Then even though a constantly changing sinusoidal voltage waveform is used, the input of the SSR see’s a constant DC voltage.

The values of the voltage dropping resistor, R1 and the smoothing capacitor, C1 are chosen to suit the supply voltage, 120 volts AC or 240 volts AC as well as the input impedance of the solid state relay. But something around 40kΩ and 10uF would do.

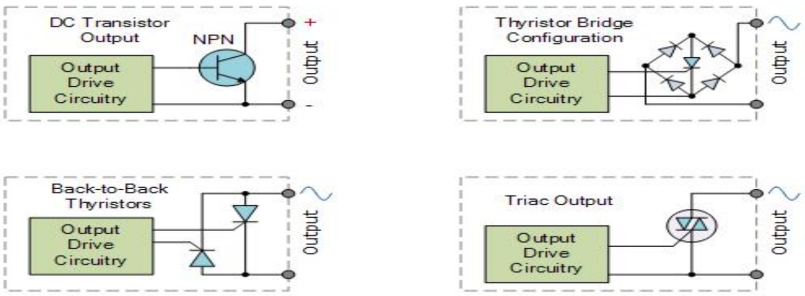
Then with this bridge rectifier and smoothing capacitor circuit added, a standard DC solid state relay can be controlled using either an AC or non-polarised DC supply. Of course, manufacturers produce and sell AC input solid state relays (usually 90 to 280 volts AC) already.

Solid State Relay Output

The output switching capabilities of a solid state relay can be either AC or DC similar to its input voltage requirements. The output circuit of most standard solid state relays are configured to perform only one type of switching action giving the equivalent of a normally-open, single-pole, single-throw (SPST-NO) operation of an electro-mechanical relay.

For most DC SSR’s the solid state switching device commonly used are power transistors, Darlington’s and MOSFETs, whereas for an AC SSR, the switching device is either a triac or back-to-back thyristors. Thyristors are preferred due to their high voltage and current capabilities. A single thyristor can also be used within a bridge rectifier circuit as shown.

Solid State Relay Output Circuit



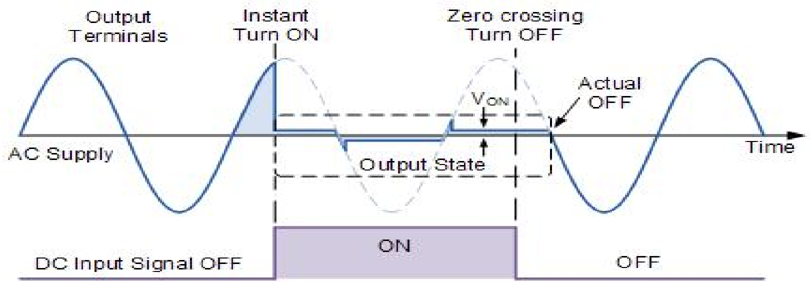
The most common application of solid state relays is in the switching of an AC load, whether that is to control the AC power for ON/OFF switching, light dimming, motor speed control or other such applications where power control is needed, these AC loads can be easily controlled with a low current DC voltage using a solid state relay providing long life and high switching speeds.

One of the biggest advantages of solid state relays over an electromechanical relay is its ability to switch "OFF" AC loads at the point of zero load current, thereby completely eliminating the arcing, electrical noise and contact bounce associated with conventional mechanical relays and inductive loads.

This is because AC switching solid state relays use SCR's and TRIAC's as their output switching device which continues conducting, once the input signal is removed, until the AC current flowing through the device falls below its threshold or holding current value. Then the output of an SSR can never switch OFF in the middle of a sine wave peak.

Zero current turn-off is a major advantage for using a solid state relay as it reduces electrical noise and the back-emf associated with the switching of inductive loads as seen as arcing by the contacts of an electro-mechanical relay. Consider the output waveform diagram below of a typical AC solid state relay.

Solid State Relay Output Waveform



With no input signal applied, no load current flows through the SSR as it is effectively OFF (open-circuited) and the output terminals see the full AC supply voltage. With the application of a DC input signal, no matter which part of the sinusoidal waveform, either positive or negative the cycle is going through, due to zero-voltage switching characteristics of the SSR, the output only turns-on when the waveform crosses over the zero point.

As the supply voltage increases in either a positive or negative direction, it reaches the minimum value required to turn the output thyristors or triac fully ON (usually less than about 15 volts). The voltage drop across the SSR's output terminals is that of the switching devices on-state voltage drop, VT (usually less than 2 volts). Thus any high inrush currents associated with reactive or lamp loads are greatly reduced.

When the DC input voltage signal is removed, the output does not suddenly turn-off as once triggered into conduction, the thyristor or triac used as the switching device stays ON for the remainder of the half cycle until the load currents drops below the devices holding current, at which point it switches OFF. Thus the high dv/dt back emf's associated with switching inductive loads in the middle of a sine wave is greatly reduced.

Then the main advantages of the AC solid state relay over the electro-mechanical relay are its zero crossing function which turns ON the SSR when the AC load voltage is close to zero volts, thus suppressing any high inrush currents as the load current will always start from a point close to 0V, and the inherent zero current turn-off characteristic of the thyristor or triac. Therefore there is a maximum possible turn-off delay (between the removal of the input signal and the removal of load current) of one half cycle.

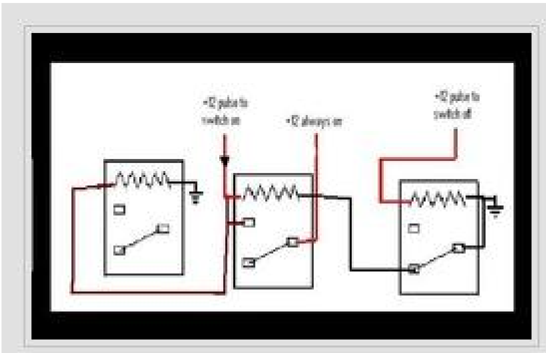
Phase Dimming Solid State Relay

While solid state relays can perform straight forward zero-crossing switching of a load, they can also perform much more complicated functions by means of digital logic circuits, microprocessors and memories. Another excellent application of a solid state relay is in lamp dimming applications, whether in the home or for a show or concert.

Non-zero (instant-on) switching solid state relays turn-on immediately after the application of the input control signal as opposed to the zero crossing SSR above which waits until the next zero-crossing point of the AC sine-wave. This random-fire switching is used in resistive applications such as lamp dimming and applications that require the load only to be energised for a small portion of the AC cycle.

Latching Relays

A latching relay is an electromechanical switch. Latching relays are electronic parts that are used to control large flow of electrical current with smaller flow of current. Relays are typically used when small continuous electrical currents must be used. A latching relay, however, is used to control large currents with smaller ones, using a pulse to move the switch that then stays in position, and this reduces the power requirement slightly.



Latching relays have a small metal strip that, in essence, revolves between two terminals. Solenoids, or small coils of wire, can be found on either side of a magnetized switch that has one input and two outputs at these terminals. The switch can be used to toggle one circuit on and off, or it can be used to switch power between two circuits. It's the coils that control the relay action. When an electrical flow goes into the coils, that current generates a magnetic field which turns off. The magnetic strip between the two coils is also exposed to the magnetic field, so that when the circuit causes a pulse of electrical current through these coils, it then pushes the switch mechanism from side to side. The metal strip remains in that position until it receives another magnetic pulse, but this time in the opposite direction. This action will push the switch back to the other terminal. This type of relay remains in the last position it was in when the current was removed.

Latching relays are 'bi-stable,' meaning they have two relaxed states. (These are also known as 'stay' relays.) When an electrical flow is turned off, the latching relay remains in the last state it was in. Latching relay is really a generic term that is used to describe the type of relay that maintains its position after the power is removed. The reason latching relays are used is because they allow control of a circuit by providing a single pulse to a relay control circuit. They are also used when it is necessary to have a relay that will maintain its contact position during power interruptions, when power must be conserved. There are many uses in today's electric devices for latching relays. These include industrial or commercial machines, such as car wash equipment that utilizes dryers and pumps. HVAC and refrigeration, anti-condensation equipment, industrial cleaning equipment are all excellent examples of equipment that utilizes latching relays. Commercial coffee machines and commercial cooking equipment also use latching relays.

There are three major types of latching relays, including mechanical, impulse sequencing, and magnetic. Mechanical latching relays use locking mechanisms to hold contacts in the last position until they receive information to change. This typically happens by energizing a second coil. Contacts then will remain locked in that position until the opposing coil has received energy. Impulse sequencing relays transfer contacts with each pulse. Typically, impulse relays are made up of a magnetic latch relay and a solid state circuit that will determine which position the relay is in when power is applied, and then the opposite coil will be energized. The contacts will hold this position when the power is removed, and when the coils again receive energy, the cycle will start again. A magnetic latching relay typically requires one pulse of coil power to move contacts in one direction, and then requires another pulse that is redirected to move the contacts back in the other direction. These types of relays can have either one or two coils. In a device that has only a single coil, the relay will move in one direction when an application of power occurs with one polarity. It will then reset when reversing the polarity. In a device with dual coils, when the polarized current is applied to a coil that is reset, the contacts will progress.

Some of the first applications of latching relays were in early computers that needed magnetic latching relays in order to store bits. Some of these computers in their earlier stages utilized other types of relays such as reed relays. Early computer memory that once used latching relays were replaced with something called 'delay line memory,' which was a form of memory used in the earlier models of digital computers.

TIMING RELAYS

Time delay relays can be divided into two general classifications: the on-delay relay, and the off-delay re lay. The on-delay relay is often referred to as DOE, which stands for "Delay On Energize." The off-delay relay is often referred to as DODE, which stands for "Delay on De-Energize." Timer relays are similar to other control relays in that they use a coil to control the operation of some number of contacts. The difference between a control relay and a timer relay is that the contacts of the timer relay delay changing their position when the coil is energized or de-energized. When power is connected to the coil of an on-delay timer, the contacts delay changing position for some period of time. For this example, assume that the timer has been set for a delay of 10 seconds. Also assume that the contact is normally open.

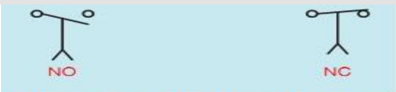
When voltage is connected to the coil of the on-delay timer, the contacts will remain in the open position for 10 seconds and then close. When voltage is removed and the coil is de-energized, the contact will immediately change back to its normally open position.

The operation of the off-delay timer is the opposite of the operation of the on-delay timer. For this example, again assume that the timer has been set for a delay of 10 seconds, and also assume that the contact is normally open. When voltage is applied to the coil of the off-delay timer, the contact will change immediately from open to closed. When the coil is de-energized, however, the contact will remain in the closed position for 10 seconds before it reopens. The contact symbols for an off-delay relay are shown in Fgr. 2. Time delay relays can have normally open, normally closed, or a combination of normally open and normally closed contacts.

Although the contact symbols shown in Fgrs 1 and 2 are standard NEMA symbols for on-delay and off-delay contacts, some control schematics may use a different method of indicating timed contacts. The abbreviations TO and TC are used with some control schematics to indicate a time-operated contact. TO stands for time opening, and TC stands for time closing. If these abbreviations are used with standard contact symbols, their meaning can be confusing.

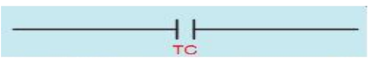
Fgr. 3 shows a standard normally open contact symbol with the abbreviation TC written beneath it.

This contact must be connected to an on-delay relay if it's to be time delayed when closing. ___ shows the same contact with the abbreviation TO beneath it. If this contact is to be time delayed when opening, it must be operated by an off-delay timer. These abbreviations can also be used with standard NEMA symbols.



Fgr. 1 On-delay normally open and normally closed contacts.

Fgr. 2 Off-delay normally open and normally closed contacts.



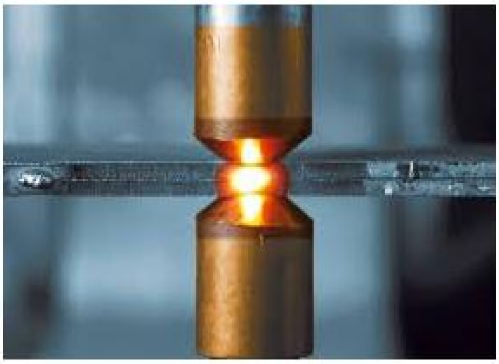
Fgr. 3 Time closing contact.

Fgr. 4 Time opening contact.

5.2 RESISTANCE WELDING

In older 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, resistance, gas and arc welding was invented. 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. This article discusses resistance welding, working principle, different types, advantages, disadvantages, and Applications.



What is Resistance Welding?

Resistance welding can be defined as; it is a liquid state welding method where the metal-to-metal joint can be formed within a liquid state otherwise molten state. This is a thermoelectric method where heat can be generated at the It is a thermo-electric process in which heat is generated at the edge planes of welding plates because of electric resistance and a weld joint can be created by applying low-pressure to these plates. This type of welding uses electric resistance to generate heat. This process is very efficient with pollution free but the applications are limited because of the features like equipment cost is high, and material thickness is limited.

The **working principle of resistance welding** is the generation of heat because of electric resistance. The resistance welding such as seam, spot, protection works on the same principle. Whenever the current flows through electric resistance, then heat will be generated. The same working principle can be used within the electric coil. The generated heat will depend on material's resistance, applied current, conditions of a surface, applied the current time period

This heat generation takes place because of the energy conversion from electric to thermal. The **resistance welding formula** for heat generation is

H = I2RT

Where 'H' is a generated Heat, and the unit of heat is a joule
'I' is an electric current, and the unit of this is ampere
'R' is an electric resistance, and the unit of this is Ohm
'T' is the time of current flow, and the unit of this is second

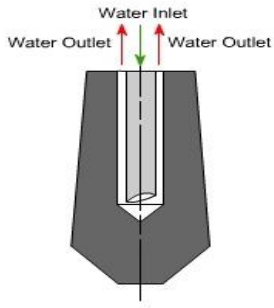
The generated heat can be used to soften the edge metal to shape a tough weld joint with fusion. This method generates weld with no application of any flux, filler material, and shielding gases.

Types of Resistance Welding

Different **types of resistance welding** are discussed below.

Spot Welding

Spot welding is the simplest type of welding where the work portions are held jointly below the force of anvil face. The copper (Cu) electrodes will make contact with the work portion & the flow of current through it. The work portion material applies a few resistances within current flow which will cause limited heat production. The resistance is high at the edge surfaces because of the air gap. The current begins to supply through it, then it will reduce the edge surface.

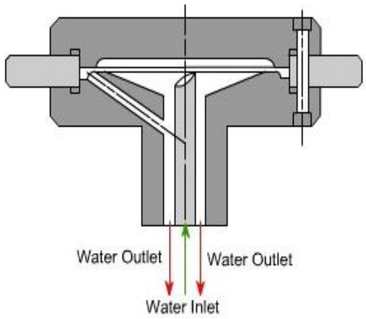


Spot Welding

The current supply & the time must be enough for the correct dissolving of edge faces. Now the flow of current will be stopped however the force applied with electrode continued for a second, whereas the weld quickly cooled. Later, the electrodes eliminate as well as get in touch with new spot to create a circular piece. The piece size mainly depends on electrode size (4-7 mm).

Seam Welding

This type of welding is also known as continuous spot welding where a roller form electrode can be utilized to supply current throughout work parts. Initially, the roller electrodes are getting in touch with the work part. High current can be supplied through these electrode rollers to melt the edge surfaces & shape a weld joint.

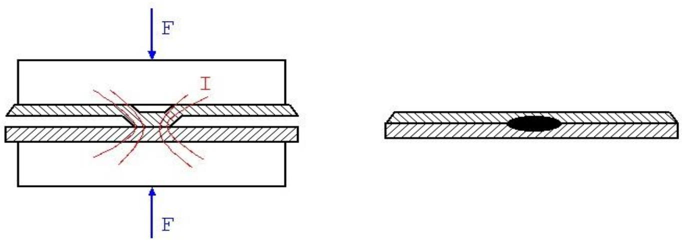


Seam Welding

At present, the electrode rollers will begin rolling on work plates to make a permanent weld joint. The weld timing & electrode movement can be controlled to guarantee that the weld overlap & work part doesn't acquire too warm. The speed of the welding can be about 60 in per min within seam welding, which is used to make airtight joints.

Projection Welding

Projection welding is similar to spot welding apart from a dimple can be generated on work parts at the place wherever weld is preferred. At present the work parts held among electrode as well as a huge quantity of current flow through it. A little quantity of pressure can be applied throughout the electrode on welding shields. The flow of current throughout dimple which dissolve it & the force reasons the dimple level & shape a weld.



Projection Welding

Flash butt Welding

The flash butt welding is a form of resistance welding, used for welding tubes as well as rods within steel industries. In this method, two work parts are welded which will be held tightly during the electrode holders as well as a high pulsed flow of current within the 1,00,000 ampere range can be supplied toward the work part material.


Flash Butt Welding

In the two electrode holders, one is permanent & other is changeable. At first, the flow of current can be supplied & changeable clamp will be forced against the permanent clamp because of the get in touch with the two work parts at high-current, the spark will be generated. Whenever the edge surface approaches into plastic shape, the flow of current will be stopped as well as axial force can be improved to create joint. In this method, the weld can be formed because of plastic deformation.

Resistance Welding Applications

The **applications of resistance welding** include the following.

- This type of welding can be widely used within automotive industries, making of nut as well as a bolt.
- Seam welding can be utilized to generate leak prove joint necessary within little tanks, boilers, etc.
- Flash welding can be used for welding tubes and pipes.

Resistance Welding Advantages and Disadvantages

The **advantages & disadvantages of resistance welding** include the following

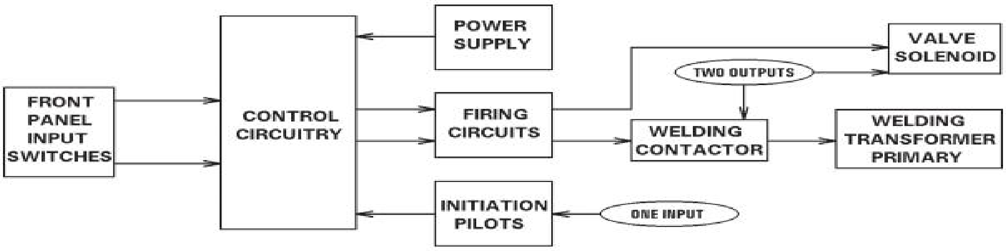
Advantages

- This method is simple and does not necessary high expert labor.
- The resistance welding metal thickness is 20mm, & thinness is 0.1 mm
- Automated simply
- The rate of production is high
- Both related, & different metals can be weld.
- Welding speed will be high
- It does not need any flux, filler metal & protecting gases.

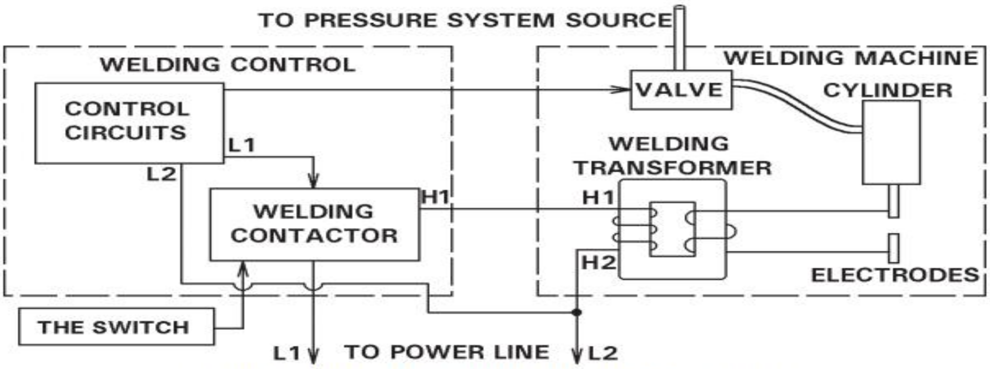
Disadvantages

- Tools cost will be high.
- The work section thickness is limited because of the current requirement.
- It is less proficient for high-conductive equipment.
- It consumes high electric-power.
- Weld joints contain small tensile & fatigue power.

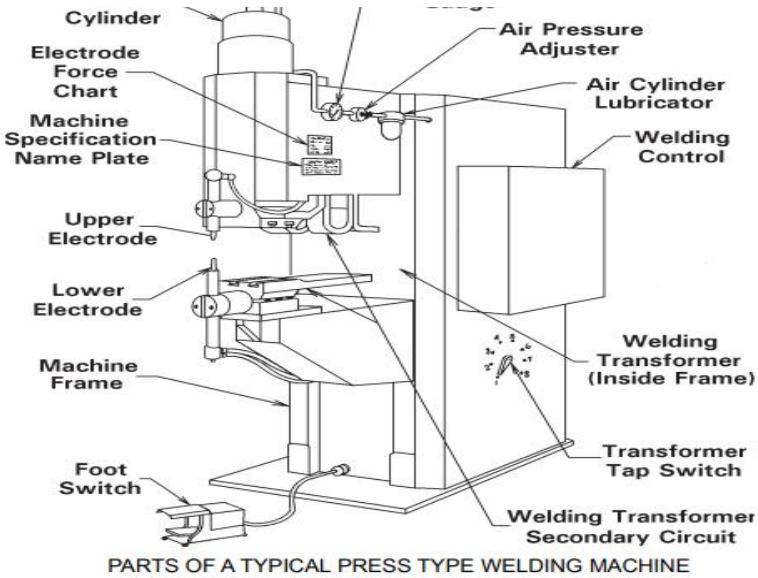
Thus, this is all about the resistance welding process, which is used for welding two metals. It includes a welding head used to hold the metal among its electrodes & applies a welding power supply & force to welding the metal. When the force is applied, the resistance produces heat, then resistance welding utilizes the heat. Likewise, whenever the flow of current attempts to move ahead throughout two metals, then heat can be generated because of the resistance of the metal. So finally this welding can be used to weld the metals using the pressure as well as heat.



BLOCK DIAGRAM. TYPICAL BASIC ELECTRONIC CONTROL CIRCUIT
Figure 6.



SIMPLIFIED DIAGRAM. MACHINE AND CONTROL HOOK-UP
Figure 9.



PARTS OF A TYPICAL PRESS TYPE WELDING MACHINE
Figure 10.

In order to obtain a good weld it is necessary to maintain the contact resistance uniform which depends upon the surface condition.

For welding thin materials the resistance of the current path in the work is kept minimum. For welding thick materials of low conductivity the resistances of the current path have a comparatively greater value and the control of contact resistance is not necessary. For welding thick materials of high conductivity either reduced pressure or high resistance electrodes having melting point higher than that of metal to be welded, can be used. For welding two dissimilar metals having different conductivity, low conductivity electrodes on high conductivity metal side and vice versa are used in order to prevent overheating on the low conductivity metal and to develop sufficient heat to melt high conductivity metal side.

The pressure which is to be applied on the weld is also an important factor. At high pressure, low temperature plastic welds can be obtained and where as if the pressure is lowered the resistance to the welding current is to be increased. There is a limit up to which the resistance can be increased and after that there will be surface burning. The pressure necessary to effect the weld varies from 2.5-5.5 kgf/mm2.

The magnitude of current is controlled by varying either the primary voltage of the welding transformer (by using auto- transformer between supply and the welding transformer) or changing the primary turns of the welding transformer. Alternative method of controlling the current to weld is to vary the magnitude and wave of the primary as well as secondary current by using Thyratron or Ignitron tubes in the primary circuit.

In resistance welding, the time for which current flows is very important. Usually automatic arrangements are devised which switch off the supply after a predetermined time from applying of pressure (starting of weld). The pressure may be applied manually, by air pressure, by springs or by hydraulic means. After switching off the supply, the pressure is maintained on the electrodes until the weld cools. In machines which are operated continuously, the electrodes are cooled by water circulating through hollow electrodes.

Electrical circuit diagram for resistance welding is shown in Fig. 6.1. The machine employed for resistance welding contains a transformer provided with necessary taps, a clamping device for holding the metal pieces, and a mechanical means for forcing the pieces to be welded, together to complete the weld.

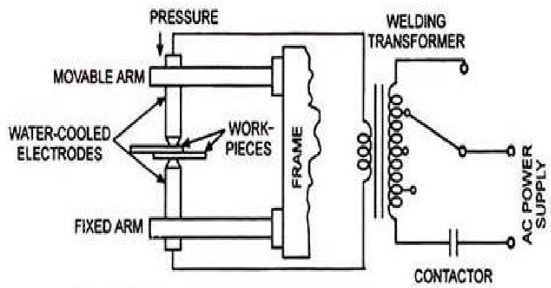


Fig. 6.1. *Electrical Circuit For Resistance Welding*

Resistance welding has the advantage of producing a large volume of work at high speeds that are reproducible with high quality. Resistance welds are made very quickly; however, each process has its own time cycle. Resistance welding operations are automatic. Good-quality welds do not depend on welding operator skill but more on proper set-up and adjustment of the equipment and adherence to weld schedules.

Resistance welding is employed mainly for mass production. It is easily adapted to those components which can be moved to the machine and are light. The operation is extremely rapid and simple. This is the only process where heat can be controlled and which permits a pressure action at the weld. Metals of medium and high resistance, such as steel, stainless steel, monel metal and silicon bronze are easy to weld. Special control gear is required, however, in the case of high- carbon steels and special equipment providing very high current impulses (stored energy welding) is used in case of materials of low electrical resistance.

The automotive industry is the major user followed by the appliance industry. It is used by many industries manufacturing a variety of products made of thinner-gauge metals and for manufacturing pipes, tubing, and smaller structural sections.

When specifying the material intended to be resistance welded, consideration must be given to the state in which this to be supplied to the welding shop. Whilst slight rust, mill scale etc., on the material may not affect the efficiency of arc welds to a considerable degree, lack of cleanliness will be fatal to resistance welded joints. Pickling or shot-blasting immediately prior to the resistance welding operation is essential for making this latter method a success.

Material up to 5 mm thickness which is to be used on resistance-welded jobs is usually purchased in a pickled and slightly oiled condition, and should be carefully stored in order to keep it clean. It can then be used without removing the oil film provided that the oil is clean. Material above 5 mm thickness should be shot-blasted before being taken to the resistance welding machines.

No long delay should occur between the shot blasting and the welding, in order to avoid new corrosion which might eliminate the advantage gained by the former. Sandblasting is not recommended, as particles of the siliceous material may be embedded in the steel surface and influence its electrical resistance.

High frequency resistance welding is done with 400 to 450 kHz current usually supplied by an oscillator. The high frequency current readily breaks through oxide film barriers and produces a thin heat-affected zone because it travels on the surface of the material.

However, resistance welding has got some limitations and drawbacks also, as enumerated below:

(i) The initial cost of equipment required is high.

(ii) Skilled persons are required for the maintenance of equipment and its controls.

(iii) In some materials, special surface preparation is required.

(iv) Certain resistance welding processes are limited to lap joints. A lap joint has an inherent device between the two metal pieces, which cause stress concentration in applications where fatigue is present. The device may also cause trouble when corrosion is present.

Machines for Resistance Welding:

The machine for resistance welding incorporates a transformer, suitable electrodes for supplying current to the weld and arrangement for controlling the mechanical pressure, and finally, means for controlling the duration of weld current flow. The mechanical pressure may be exerted through levers and clutch by an electric motor or by compressed air. The magnitude of pressure required depends upon the type of work and may vary from a few kg for thin sheets or wires up to a tonne or more for heavy work.

In the older type of welding machines, the electrodes were brought on to the work and the electrical circuit closed by the operation of a pedal. Thus application of pressure and the time duration of current flow used to be controlled by the operator and for this operator needs to be experienced and skilled. The modern practice is to pass heavy currents for shorter time durations (ranging from 10 ms to 100 ms). The equipment used for this purpose may be constant time, current-actuated, or energy-actuated types.

Constant time equipment is employed in high speed production where the work has a consistently clean surface. Constant time equipment may be provided with mechanical control or electrical control. In mechanical control providing up to 300 welds per minute, the device employed is a cam- operated switch, connected in the primary circuit of a welding transformer, driven from the welding machine.

For a large number of welds per minute the mechanical arrangement becomes unsuitable because it is not capable of providing consistently accurate timing, due to wear of the cam and operating mechanism, arcing and burning of the contacts and irregularities caused by closing of switch at different instants in the cycle.

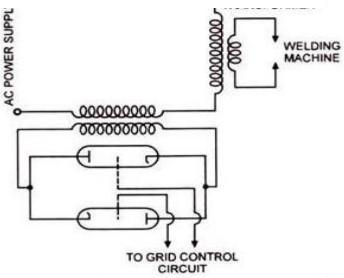


Fig. 6.18. *Valve Controlled Resistance Welding Circuit*

An alternative arrangement is to control the timing through grid controlled ignitrons or thyratrons. It is easier to build tubes for a high voltage and small current than with a low voltage and high current. An arrangement using valves in the secondary circuit of a series transformer is shown in Fig. 6.18. When the tubes conduct, the series transformer secondary is almost short- circuited, and whole of the supply voltage is available across the welding transformer primary.

But when the tubes are not conducting, the series transformer primary winding offers high impedance in the circuit of the welding transformer and the current is reduced to a negligible value. Auxiliary valves are employed for controlling the timing of the negative potential applied to the grids of the main tubes.

Constant-time method of control does not yield consistently good results when there may be variations in the conditions under which successive welds are made, due to variations in supply voltage or mechanical pressure, wearing of electrodes, surface irregularities etc. The energy-actuated control, wherein definite amount of energy is supplied to the weld, is used.

Constant-time method of control did not prove to be successful, particularly with modern high-speed welding. The energy- actuated control, which permits the current to flow until a predetermined amount of energy has been supplied to the weld, is theoretically an ideal method. However, the control equipment is quite complicated.

Power Supply for Resistance Welding:

AC supply is used for resistance welding because of the ease and convenience with which the required high current at a low voltage can be obtained by means of a transformer. The kVA required for resistance welding, when actually making a weld, ranges from a few kVA to as much as 1 MVA. The power factor will be about 0.25 or 0.3 lagging. The power factor is low mainly due to the high ratio of reactance to resistance of the loop formed by the jaws of the welding machine. Such heavy intermittent single-phase loads may cause serious voltage drop difficulties in the supply network.

Such problems can be overcome to some extent by connecting capacitors of suitable capacity in parallel with the welding transformer so as to improve the power factor. But with this arrangement the power factor will become leading when welding current is not being drawn. This problem can be avoided by connecting the capacitors in series with the welding transformer to neutralize the reactance drop in the supply circuit.

Electronic Control in Resistance Welding:

As there are several factors, i.e., current, pressure, heat, time, to be considered, manual control does not yield good results in case of resistance welding. For the precise control of these factors electronic control welding circuits are used.

Some of the electronic control circuits are given here:

i. Ignitron Contactor:

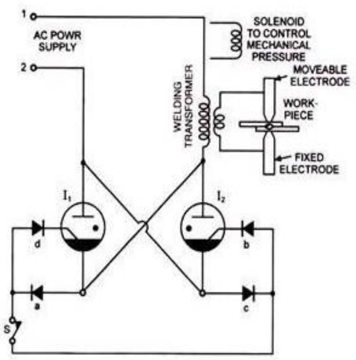


Fig. 6.19

We will now discuss the theory of ignitron contractor use as a contractor for controlling heavy currents.

A simple line contactor using two ignitrons is shown in Fig. 6.19. If the switch S is closed at the instant the line 1 is positive, current will rush through the primary of welding transformer, rectifier a, switch S, rectifier b, the ignitron I2 and back to the line 2. The current will strike an arc in ignitron I2 and the tube starts conducting. Now voltage drops across I2 to a low value, causing a voltage drop in the ignitron circuit. Therefore, the ignitron will conduct just long enough to strike an arc. Similarly, during next half cycle, the line 2 will be positive and the current will flow from line 2 through rectifier c, switch S, rectifier d to ignitron I1.

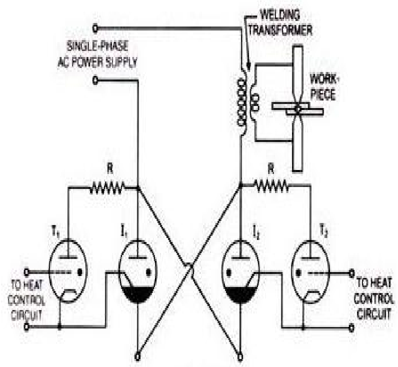


Fig. 6.20

During this half cycle, as the anode of ignitron I2 becomes – ve, it stops conducting. Metallic rectifiers are used in this circuit. They conduct the current in proper direction, thus, preventing the application of negative voltages to the electrodes and saving the ignitrons from inverse current damages. A solenoid is used to apply suitable pressure through the upper movable electrode. Manual control of the contactor switch is possible only if the welds are of long duration. But for the accurate time control of the welds of short duration, thyratrons are used to ignite the ignitrons, as shown in Fig. 6.20. The grid circuits of the thyratrons are controlled by a suitable timing control circuit.

Since very heavy current flows through the ignitrons, say 1,000 amperes, and arc drop be taken constant at 10 volts, therefore, losses to the tune of 10 kW will take place. So the ignitrons are always water cooled. In case of very heavy load, temperature of water becomes too high, normally closed thermostat contacts open and the ignitrons stop conducting.

ii. Heat Control Unit:

It is an electronic circuit which helps the delay in the firing of the ignitrons by a definite, predetermined angle in each cycle and operates in conjunction with the line contactor. A typical circuit employed for the heat control is shown in Fig. 6.21. This is essentially a phase shift control circuit and delays the firing of the ignitrons, thus reducing the magnitude of welding current as per requirements.

iii. AC Timer Circuit:

When the condenser C is discharged through a resistor R the voltage across the condenser falls exponentially as given by the expression-

From the above expression it is clear that greater the capacity of condenser and value of resistor, greater will be the time required for voltage to fall by given amount. In all timer circuits provision is, therefore, made for charging a condenser to a particular value of voltage and then discharge by short-circuiting switch till condenser is discharged to a particular value when relay will operate and particular contact will open or close.

Typical ac timer circuit is shown in Fig. 6.22. Such a timer circuit is used to control the number of cycles for which power may be supplied into the weld. The action of such a timer circuit is explained as- when switch S is open and supply terminal 1 is positive w.r.t. terminal 2, the cathode and anode of thyratron are at the same potential, and grid is – ve w.r.t. cathode, and, therefore no current flow between cathode and grid. When terminal 1 is negative w.r.t. terminal 2, the potential at a is positive, grid becomes positive w.r.t. cathode and anode and electronic current flows through R2, R1 from grid to cathode, through R3 and to terminal 1.

In a few cycles the capacitor C2 will get charged to the maximum voltage between a and 1. This is due to the large value of time constant. The capacitor does not discharge much during the negative half cycle of the grid voltage. Resistance R, limits the grid-cathode circuit current to a safe value and also determines the number of cycles in which C2 will be fully charged. So long switch S remains open, capacitor C2 remains charged by the grid rectification action.

As soon as switch S is closed, the grid becomes very much negative w.r.t. cathode and there is no capacitor charging current through grid rectification. Capacitor will, therefore, start discharging through R2 and -ve bias of the grid will gradually decrease depending upon the time constant R2C2 of the discharge circuit. Conduction in thyratron tube will start during positive half cycle of anode voltage when the grid voltage instantaneously rises to critical grid voltage. Current through relay coil is rectified half waves. As such to avoid relay terminals chatter, a capacitor C1 is connected across relay coil.

iv. Energy Storage Welding Processes:

To meet the demand of heavy current of very high conductivity metals such as aluminium and magnesium energy storage welding circuits are used. There are basically two such circuits namely electrostatically stored energy circuits and electromagnetically stored energy circuits.

1. Capacitor Discharge Welding Circuit:

As shown in Fig. 6.23, condenser C (capacitor bank of capacity of 2,000 to 3,000 μF) is charged to about 3,000 volts from grid controlled rectifier. When the condenser is connected to the primary of welding transformer by ignitron contactor, it will discharge and thus high transient current will be produced in the secondary to weld the material.

The noteworthy points in connection with this circuit are:

(i) As the voltage of condenser approaches the voltage of the source of supply, charging rate becomes lower, therefore to charge condenser to about 3,000 V at high charging rate voltage of about 5,000 V to 6,000 V will be required. A voltage regulating circuit cuts off the rectifier from the bank when the voltage of the bank becomes 3,000 V.

(ii) If there is residual magnetism near saturation, it will result in low rate of change of flux linkages in the secondary and, therefore, in production of low heat. Hence in the welding transformer core flux should not be present.

2. Magnetic Energy Storage Welding Circuit:

In this type of welding, energy stored in magnetic circuit is used in the welding operation. The dc voltage of the rectifier is suitably controlled so that the current in the primary of the transformer rises gradually without inducing large current in the secondary. This is necessary to avoid preheating of metals at the weld joint. Preheating in aluminium, magnesium etc. is undesirable as it causes deformation.

When sufficient energy has been stored up in the transformer core, the contactor opens, dc flow ceases and there is a rapid collapse of magnetic field. The decay of flux induces heavy currents in the secondary of the transformer for welding.

The kVA demand on the line in magnetic energy storage welding is higher as compared to that in capacitor discharge welding but a high voltage rectifier and costly capacitor bank are not required.

5.3 HEATING CONTROL

5.3.1 Resistance Heating:

This method is based upon the I^2R loss. Whenever current is passed through a resistive material heat is produced because of I^2R loss.

There are two methods of resistance heating. They are

a. Direct Resistance Heating

b. Indirect Resistance Heating

a. Direct Resistance Heating:

In this method of heating the material or change to be heated is taken as a resistance and current is passed through it.

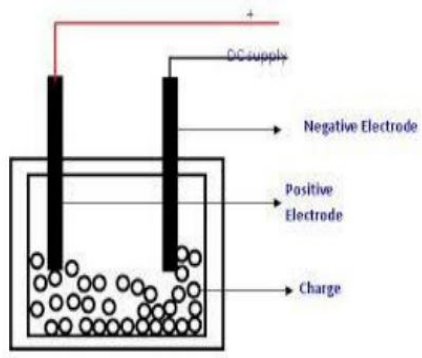
The charge may be in the form of powder pieces or liquid. The two electrodes are immersed in the charge and connected to the supply.

In case of D.C or single phase A.C two electrodes are required but there will be three electrodes in case of three phase supply.

When metal pieces are to be heated a powder of high resistivity material is sprinkled over the surface of the charge to avoid direct short circuit.

But it gives uniform heat and high temperature. One of the major applications of the process is salt bath furnaces having an operating temperature between 500˚C to 1400˚C.

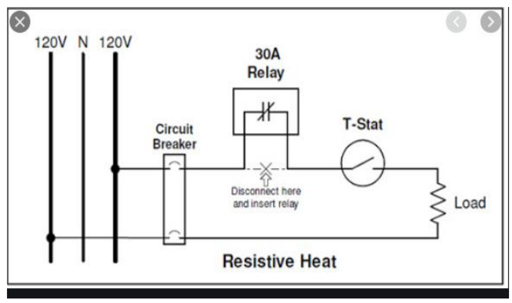
An immersed electrode type medium temperature salt bath furnace is shown in figure



The bath makes use of supply voltage across two electrodes varying between 5 to 20 volts.

For this purpose a special double wound transformer is required which makes use of 3Φ primary and single phase secondary. This speaks of an unbalanced load.

The variation in the secondary voltage is done with the help of an off load tapping switch of the primary side. This is necessary for starting and regulating the bath load.



Advantages:

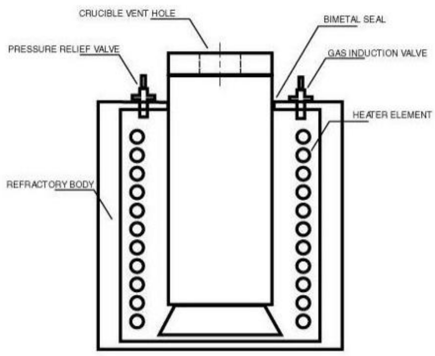
High efficiency.

It gives uniform heat and high temperature.

Application:

It is mainly used in salt bath furnace and water heaters.

b. Indirect Resistance Heating:



In this method the current is passed through a highly resistance element which is either placed above or below the over depending upon the nature of the job to be performed.

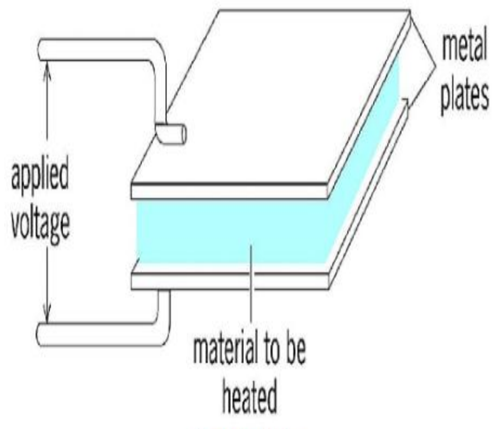
The heat proportional to I2R losses produced in heating element delivered to the charge either by radiation or by convection.

Sometimes in case of industrial heating the resistance is placed in a cylinder which is surrounded by the charge placed in the jackes.The arrangement provides as uniform temperature.

Automatic temperature control can be provided in this case

This method is used in room heater, in bimetallic strip used in starters, immersion water heaters and in various types of resistance ovens used in domestic and commercial cooking.

5.3.2 DIELECTRIC HEATING



Dielectric Heating

The definition of dielectric heating can be stated as – 'the process of heating up material by causing dielectric motion in its molecules using alternating electric fields". All materials are made up of molecules that are composed of atoms. The Dielectric Heating circuit diagram is shown below.

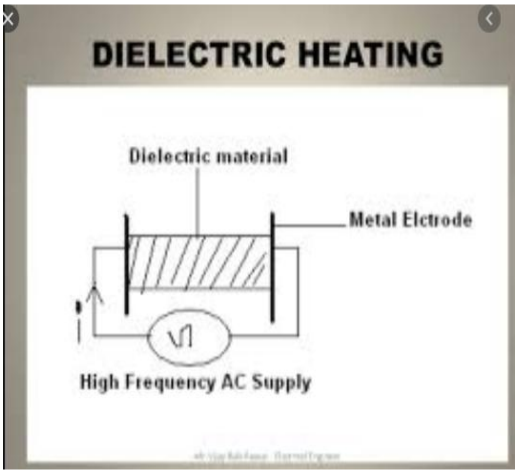
Polar molecules contain electric dipole moments. When such molecules are exposed to the electric field, they try to align themselves in the direction of the field. When the applied field oscillates, these molecules of the material undergo rotations in order to keep themselves aligned with the field. When the field changes direction, these molecules also reverse their direction. This process is called "Dielectric Rotation"

The temperature of the molecules is related to the kinetic energy of the molecules. In the dielectric rotation of the molecules, as the kinetic energy of the molecules increases, the temperature of the molecules increases. When the molecules collide or come in contact with other molecules, this energy gets transferred to all parts of the material thus heating up the material.

Thus dielectric rotation in the material is often referred to as Dielectric heating of the material. This heating is done using either electric fields of RF frequencies or electromagnetic fields. The applied field should be oscillating for dielectric rotation to take place. The frequency and wavelength of the applied field also affect the functioning of the system.

Dielectric Heating Working

As described below, the circuit diagram of the dielectric heating system consists of two metals plates to which the electric field is applied. The material to be heated is placed in between these two metals. There are two types of ways in which material are heating using the heating process.



Heating using low-frequency waves, as a near – field effect and heating with high-frequency waves using electromagnetic waves. The type of materials heated using these different types of waves is also different.

Low-frequency waves have higher wavelengths. Thus they can penetrate through non-conductive materials more deeply than electromagnetic waves. The systems using low-frequency fields should have the distance between the radiator and absorber to be less than 1/2π of the wavelength. So, the process of heating using a low-frequency electric field is near – contact process.

Higher frequency systems have lower wavelengths. Electromagnetic waves and microwaves are used for these systems. In these systems, the distance between metal plates is larger than the wavelength of the applied field. In these systems, conventional far-field electromagnetic waves are formed between the metal plates.

Applications of Dielectric Heating

Dielectric heating principle using high-frequency electric fields was proposed in the 1930s at Bell Telephone Laboratories. By varying the frequency of electric fields the Dielectric systems are designed for many types of applications.

Microwave Oven

When Microwaves are Used

In this dielectric heating, the 2.45GHz of the microwave of frequency is used. Microwave ovens used in homes are an example of this type of applications. These systems provide less penetrative and highly efficient heating system. Microwave volumetric heating provides a larger penetration depth. Thus this heating is used for heating liquids, suspensions, and solids on an industrial scale.

Microwave volumetric heating is applied for pasteurization, Flash pasteurization, microwave chemistry, sterilization, food preservation, biofuel production, etc.

When Radio Frequencies are Used

- RF dielectric often finds applications in the crop production area.
- This type of heating is used to kill some pests in food after harvest of the crop.

- This type of heating can heat materials uniformly.
- This type of heating can process food quickly.
- Diathermy, the process of RF heating of muscle for muscle therapy uses this type of heating.
- The process called Hyperthermia therapy, in which higher temperatures are used to kill cancer and tumor tissues, heating with RF frequencies is applied

Food Processing

In post-baking of biscuits in the production line, RF dielectric heating will reduce the baking time. Right size, shape and color biscuits can be produced with oven but RF heating can remove the remaining moisture from already dried parts of the biscuits.

- RF heating can increase the capacity of the oven, used in food production factories, up to 50%.
- Cereal-based baby products and breakfast cereals use the post-baking by RF dielectric heating.
- In the drying of food, dielectric baking is used along with conventional baking.
- When an electromagnetic dielectric is used for the baking better quality of food is achieved.
- Nutritional and sensory properties of food can be preserved during food processing when electromagnetic dielectric heating is used, as higher processing temperatures can be achieved in a shorter amount of time.

Right from the period of its invention, dielectric heating is being used in various forms. From an amazing food processor to a precise Electro surgery method, dielectric had found its application in almost every field of science.
Dielectric heating mechanism setup can be viewed as similar to the structure of the capacitor. In capacitor dielectric is placed in between two conducting plates and electricity is produced in a dielectric. Whereas in a dielectric heating system, the material to be heated is placed in between two conducting plates, to which electric field is applied and heat is generated inside the material.

Now a day's dielectric heating has found many applications in the agriculture industry, for implementation of many pest control methods.

5.3.3 INDUCTION HEATING

Induction heating is a process which is used to bond, harden or soften metals or other conductive materials. For many modern manufacturing processes, induction heating offers an attractive combination of speed, consistency and control.

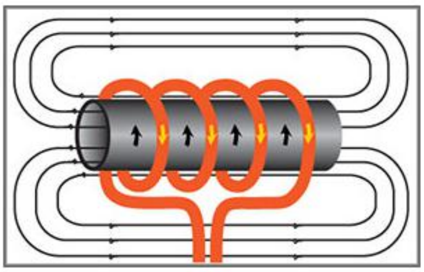


Fig. 3: The eddy currents flow against the electrical resistivity of the metal

The basic principles of induction heating have been understood and applied to manufacturing since the 1920s. During World War II, the technology developed rapidly to meet urgent wartime requirements for a fast, reliable process to harden metal engine parts. More recently, the focus on lean manufacturing techniques and emphasis on improved quality control have led to a rediscovery of induction technology, along with the development of precisely controlled, all solid state induction power supplies.

What makes this heating method so unique? In the most common heating methods, a torch or open flame is directly applied to the metal part. But with induction heating, heat is actually "induced" within the part itself by circulating electrical currents.

Induction heating relies on the unique characteristics of radio frequency (RF) energy - that portion of the electromagnetic spectrum below infrared and microwave energy. Since heat is transferred to the product via electromagnetic waves, the part never comes into direct contact with any flame, the inductor itself does not get hot (see Figure 1), and there is no product contamination. When properly set up, the process becomes very repeatable and controllable.

How Induction Heating Works

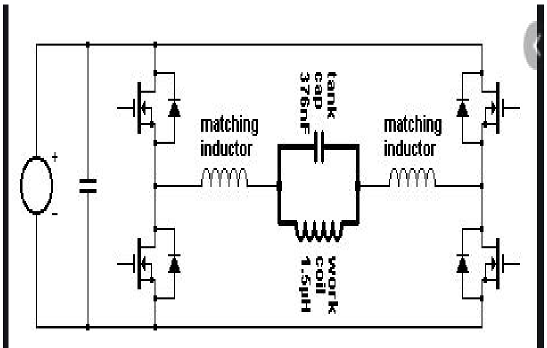
How exactly does induction heating work? It helps to have a basic understanding of the principles of electricity. When an alternating electrical current is applied to the primary of a transformer, an alternating magnetic field is created. According to Faraday's Law, if the secondary of the transformer is located within the magnetic field, an electric current will be induced.

In a basic induction heating setup shown in Figure 2, a solid state RF power supply sends an AC current through an inductor (often a copper coil),and the part to be heated (the workpiece) is placed inside the inductor. The inductor serves as the transformer primary and the part to be heated becomes a short circuit secondary. When a metal part is placed within the inductor and enters the magnetic field, circulating eddy currents are induced within the part.

As shown in Figure 3, these eddy currents flow against the electrical resistivity of the metal, generating precise and localized heat without any direct contact between the part and the inductor. This heating occurs with both magnetic and non-magnetic parts, and is often referred to as the "Joule effect", referring to Joule's first law – a scientific formula expressing the relationship between heat produced by electrical current passed through a conductor.

Secondarily, additional heat is produced within magnetic parts through hysteresis – internal friction that is created when magnetic parts pass through the inductor. Magnetic materials naturally offer electrical resistance to the rapidly changing magnetic fields within the inductor. This resistance produces internal friction which in turn produces heat.

In the process of heating the material, there is therefore no contact between the inductor and the part, and neither are there any combustion gases. The material to be heated can be located in a setting isolated from the power supply; submerged in a liquid, covered by isolated substances, in gaseous atmospheres or even in a vacuum.



FULL BRIDGE INDUCTION HEATER USING "LCLR" WORK COIL

Important Factors to Consider

The efficiency of an induction heating system for a specific application depends on several factors: the characteristics of the part itself, the design of the inductor, the capacity of the power supply, and the amount of temperature change required for the application.

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