DESIGN AND FABRICATION OF 60V, 50A SCR BASED INVERTER WELDING MACHINE

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Certificate

This is to certify that the Major Project Report entitled "**Design and fabrication of 60V, 50A SCR based inverter welding machine**" submitted by **Mr. Johni Bhasha Shaik (04MEE015)**, towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Power Apparatus & Systems of Nirma University of Science and Technology is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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ABSTRACT

Welding Technology has obtained access virtually to every branch of manufacturing; to name a few bridges, ships, rail road equipments, building construction, boilers, pressure vessels, pipelines, auto mobiles, aircrafts, launch vehicles and nuclear power plants. In the developing countries like India, Welding Technology needs constant upgrading, particularly in the field of industrial and power generation boilers, high voltage generation equipment, transformers in nuclear and aerospace industry.

In the most common processes a high welding dc current is used with low voltage. Also an isolation transformer is needed for safety reasons because the work piece forms part of the electrical circuit. Due to equipment weight reasons it is desirable to utilize a high frequency transformer instead of the conventional transformer connected directly to the ac mains.

The SCR based inverter welding machine can be used for manual metal arc welding , gas tungsten arc welding and gas metal arc welding.

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CHAPTER 1

Introduction

Welding is a fabrication process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the work pieces and adding a filler material to form a pool of molten material that cools to become a strong joint, but sometimes pressure is used in conjunction with heat, or by itself, to produce the weld. This is in contrast with soldering and brazing, which involve melting a lower-melting point material between the work pieces to form a bond between them. Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding can be done in many different environments, including open air, underwater and in space. Regardless of location, however, welding remains dangerous, and precautions must be taken to avoid burns, electric shock, poisonous fumes, and overexposure to ultraviolet light.

Until the end of the 19th century, the only other welding process was forge welding, which blacksmiths had used for centuries to join metals by heating and pounding them. Arc welding and oxyfuel welding were among the first processes to develop during the 1800s, and resistance welding followed soon after. Welding technology advanced quickly during the early 20th century as World War I and World War II drove the demand for reliable and inexpensive joining methods. Following the wars, several modern welding techniques were developed, including manual methods like shielded metal arc welding, now one of the most popular welding methods, as well as semi-automatic and automatic processes such as gas metal arc welding, submerged arc welding and flux-cored arc welding. Later, developments continued, with the invention of laser beam welding and electron beam welding in the latter half of the century. Today, the science continues to advance. Robot welding is becoming more commonplace in industrial settings, and researchers continue to develop new welding methods and gain greater understanding of weld quality and properties.

CHAPTER 2

HISTORY OF WELDING

Fig 2.1.The Iron Pillar in New Delhi.

The history of joining metals goes back several millennia, with the earliest examples of welding from the Bronze Age and the Iron Age in Europe and the Middle East. Welding was used in the construction of the Iron Pillar in Delhi, India, erected about 310 and weighing 5.4 metric tons. The Middle Ages brought advancements in forge welding, in which blacksmiths pounded heated metal repeatedly until bonding occurred. In 1540, Vannoccio Biringuccio published *De la pirotechnia*, which includes descriptions of the forging operation. Renaissance craftsmen were skilled in the process, and the industry continued to grow during the following centuries. Welding, however, was transformed during the 19th century—in 1800, Sir Humphrey Davy discovered the electric arc, and advancements in arc welding continued with the inventions of metal electrodes by a Russian, N.G. Slavianoff, and an American, C.L. Coffin in the late 1800s, even as carbon arc welding, which used a carbon electrode, gained popularity. Around 1900, A. P. Strohmenger released a coated metal electrode in Britain, which gave a more stable arc, and in 1919, alternating current welding was invented by C.J. Holslag, but did not become popular for another decade.

Resistance welding was also developed during the final decades of the 19th century, with the first patents going to Elihu Thompson in 1885, and he produced further advancements over the next 15 years. Thermite welding was invented in 1893, and around that time, another process, oxyfuel welding, became well established as well. Acetylene was discovered in 1836 by Edmund Davy, but its use was not practical in welding until about 1900, when a suitable blowtorch was developed. At first, oxyfuel welding was one of the more popular welding methods due to its portability and relatively low cost. As the 20th century progressed, however, it fell out of favor for industrial applications. It was largely replaced with arc welding, as metal coverings (known as flux) for the electrode that stabilize the arc and shield the base material from impurities continued to be developed.

World War I caused a major surge in the use of welding processes, with the various military powers attempting to determine which of the several new welding processes would be best. The British primarily used arc welding, even constructing a ship, the *Fulagar*, with an entirely welded hull. The Americans were more hesitant, but began to recognize the benefits of arc welding when the process allowed them to repair their ships quickly after a German attack in the New York Harbor at the beginning of the war. Arc welding was first applied to aircraft during the war as well, as some German airplane fuselages were constructed using the process.

During the 1920s, major advances were made in welding technology, including the introduction of automatic welding in 1920, in which electrode wire was fed continuously. Shielding gas became a subject receiving much attention, as scientists attempted to protect welds from the effects of oxygen and nitrogen in the atmosphere. Porosity and brittleness were the primary problems, and the solutions that developed included the use of hydrogen, argon, and helium as welding atmospheres. During the following decade, further advances allowed for the welding of reactive metals like aluminum and magnesium. This, in conjunction with developments in automatic welding, alternating current, and fluxes fed a major expansion of arc welding during the 1930s and then during World War II.

Other recent developments in welding include the 1958 breakthrough of electron beam welding, making deep and narrow welding possible through the concentrated heat source. Following the invention of the laser in 1960, laser beam welding debuted several decades later, and has proved to be especially useful in high-speed, automated welding. Both of these processes, however, continue to be quite expensive due the high cost of the necessary equipment, and this has limited their applications.

Table.2.1: Some important dates in the development of welding

1836	Acetylene gas discovered
1856	The principle of resistance welding discovered by Joule.
1881	Earliest carbon arc welding machines invented.
1885	(1). First patent on resistance welding machine. (2). Carbon arc welding developed.
1889-1890	First arc welding with bare wire.
1895	LeChatelier credited with discovering the oxygen-acetylene flame.
C1900	Aluminothermic reactions discovered.
1900	First oxyacetylene torches made.
1907-1910	Coated electrodes developed.
1909	Plasma arc system using gas vortex stabilized arc invented.
1912	First all steel automobile body welded by RSW
C1920	Flux cored wires used for hardfacing. First patent for flux cored wire.
1926	Solid extruded coating for SMAW electrodes introduced. Development of arc welding using He as a shielding gas.
C1930	Atomic hydrogen welding developed.
1935	Submerged arc welding developed.
1941	Gas tungsten arc welding invented.
C1950	Electroslag welding introduced.

1950	First spray transfer patent for gas welding.
1953	Constricted plasma arc invented.
1954	Self-shielded FCAW introduced.
1955	Constricted arc introduced.
1956	Friction welding invented.
C1957	First use of CO_2 with GMAW
1960	First laser beam produced using a ruby crystal.
1960s	Pulsed power GMAW introduced.
1961	First public disclosure of EBW.
1962	Electrogas welding introduced.
1964	1. Hot-wire welding processes introduced. 2. "One knob" introduced for SMAW.
1969	Plasma arc hot-wire cladding introduced.
1970s	Transistor controlled inverter welding power introduced.
1980s	1. Vapor phase reflow soldering introduced. 2. Solid state electrodes used in control.
1990s	Inverter technology dominates power supplies.
1991	Friction stir welding introduced.

CHAPTER 3

METODS OF WELDING

3.1. Shielded Metal Arc Welding:

One of the most common types of arc welding is shielded metal arc welding (SMAW), which is also known as manual metal arc welding (MMA) or stick welding. Electric current is used to strike an arc between the base material and consumable electrode rod, which is made of steel and is covered with a flux that protects the weld area from oxidation and contamination by producing CO_2 gas during the welding process. The electrode core itself acts as filler material, making a separate filler unnecessary. The process is very versatile, requiring little operator training and inexpensive equipment. However, weld times are rather slow, since the consumable electrodes must be frequently replaced and because slag, the residue from the flux, must be chipped away after welding. Furthermore, the process is generally limited to welding ferrous materials, though speciality electrodes have made possible the welding of cast iron, nickel, aluminium, copper, and other metals. The versatility of the method make popular in a number of applications, including repair work and construction.

3.2. Gas Metal Arc Welding:

Gas metal arc welding (GMAW), also known as metal inert gas (MIG) welding, is a semi-automatic or automatic welding process that uses an continuous wire feed as an electrode and an inert or semi-inert gas mixture to protect the weld from contamination. Since the electrode is continuous, welding speeds are greater for GMAW than for SMAW. However, because of the additional equipment, the process is less portable and versatile, but still useful for industrial applications. The process can be applied to a wide variety of metals, both ferrous and non-ferrous. A related process, flux-cored arc welding (FCAW), uses similar equipment but uses wire consisting of a steel electrode surrounding a powder fill material. This cored wire is more expensive than the standard solid wire and can generate fumes and/or slag, but it permits higher welding speed and greater metal penetration.

3.3. Gas Tungsten Arc Welding:

Gas tungsten arc welding (GTAW), or tungsten inert gas (TIG) welding, is a manual welding process that uses a non-consumable electrode made of tungsten, an inert or semi-inert gas mixture, and a separate filler material. Especially useful for welding thin materials, this method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds. It can be used on nearly all weldable metals, though it is most often applied to stainless steel and light metals. It is often used when quality welds are extremely important, such as in bicycle, aircraft and naval applications. A related process, plasma arc welding, also uses a tungsten electrode but uses plasma gas to make the arc. The arc is more concentrated than the GTAW arc, making transverse control more critical and thus generally restricting the technique to a mechanized process. Because of its stable current, the method can be used on a wider range of material thicknesses than can the GTAW process, and furthermore, it is much faster. It can be applied to all of the same materials as GTAW except magnesium, and automated welding of stainless steel is one important application of the process. A variation of the process is plasma cutting, an efficient steel cutting process.

3.4. Submerged Arc Welding:

Submerged arc welding (SAW) is a high-productivity welding method in which the arc is struck beneath a covering layer of flux. This increases arc quality, since contaminants in the atmosphere are blocked by the flux. The slag that forms on the weld generally comes off by itself, and combined with the use of a continuous wire feed, the weld deposition rate is high. Working conditions are much improved over other arc welding processes, since the flux hides the arc and no smoke is produced. The process is commonly used in industry, especially for large products. Other arc welding processes include atomic hydrogen welding, carbon arc welding, electro slag welding, electro gas welding, and stud arc welding.

3.5. Gas welding:

The most common gas welding process is oxyfuel welding, also known as oxyacetylene welding. It is one of the oldest and most versatile welding processes, but in recent years it has become less popular in industrial applications. It is still widely used for welding pipes and tubes, as well as repair work. The equipment is relatively inexpensive and simple, generally employing the combustion of acetylene in oxygen to produce a welding flame temperature of more than 3000°C. The flame, since it is less concentrated than an electric arc, causes slower weld cooling, which can lead to greater residual stresses and weld distortion, though it eases the welding of high alloy steels. A similar process, generally called oxyfuel cutting, is used to cut metals. Other gas welding methods, such as air acetylene welding, oxygen hydrogen welding, and pressure gas welding are quite similar, generally differing only in the type of gases used. A water torch is sometimes used for precision welding of items such as jewelry. Gas welding is also used in plastic welding, though the heated substance is air, and the temperatures are much lower.

3.6. Resistance welding:

Resistance welding involves the generation of heat by passing current through the resistance caused by the contact between two or more metal surfaces. Small pools of molten metal are formed at the weld area as high amounts of current (1000–1,00,000A) is passed through the metal. In general, resistance welding methods are efficient and cause little pollution, but their applications are somewhat limited and the equipment cost can be high.

Spot welding is a popular resistance welding method used to join overlapping metal sheets of up to 3 mm thick. Two electrodes are simultaneously used to clamp the metal sheets together and to pass current through the sheets. The advantages of the method include efficient energy use, limited work piece deformation, high production rates, easy automation, and no required filler materials. Weld strength is significantly lower than with other welding methods, making the process suitable for only certain applications. It is used extensively in the automotive industry—ordinary cars can have several thousand spot welds. A specialized process, called shot welding, can be used to spot weld stainless steel.

Like spot welding, seam welding relies on two electrodes to apply pressure and current to join metal sheets. However, instead of pointed electrodes, wheel-shaped electrodes roll along and often feed the work piece, making it possible to make long continuous welds. In the past, this process was used in the manufacture of beverage cans, but now its uses are more limited. Other resistance welding methods include flash welding, projection welding, and upset welding.

3.7. Energy beam welding:

Energy beam welding methods, namely laser beam welding and electron beam welding, are relatively new processes that have become quite popular in high production applications. The two processes are quite similar, differing most notably in their source of power. Laser beam welding employs a highly focused laser beam, while electron beam welding is done in a vacuum and uses an electron beam. Both have a very high energy density, making deep weld penetration possible and minimizing the size of the weld area. Both processes are extremely fast, and are easily automated, making them highly productive. The primary disadvantages are their very high equipment costs (though these are decreasing) and a susceptibility to thermal cracking. Developments in this area include laser-hybrid welding, which uses principles from both laser beam welding and arc welding for even better weld properties.

3.8. Laser welding:

Laser welding uses an intense energy beam as its heat source. Laser welding is accomplished at very high speeds with low heat generation and little or no distortion. Since no filler material is required, laser welds are less bulky and more precise. Laser welds are also very repeatable because they eliminate the human error. No physical material such as electrodes or contacts is needed to apply heat to the part.

With their well defined beams, lasers are excellent tools for welding thin materials, hermetic welds or in close proximity to heat-sensitive components. Even hard to reach areas can be laser welded if a line-of-site exists.

All materials which are commonly welded can be easily laser welded. In addition, difficult to join materials such as high carbon stainless steels and titanium may be successfully laser welded. Lasers are also used to weld many dissimilar materials which may otherwise be incompatible.

Advantages:

- Low heat input/minimal heat affect
- Fine grain structure/excellent weld quality
- High energy density/high weld speeds
- No filler material
- Line of sight access for hard to reach areas

3.9. Robot welding: In industries for automation robotic welding is used. The diagram of robotic welding is shown below.

3.10. Solid-state welding:

Like the first welding process, forge welding, some modern welding methods do not involve the melting of the materials being joined. One of the most popular, ultrasonic welding, is used to connect thin sheets or wires made of metal or thermoplastic by vibrating them at high frequency and under high pressure. The equipment and methods involved are similar to that of resistance welding, but instead of electric current, vibration provides energy input. Welding metals with this process does not involve melting the materials; instead, the weld is formed by introducing mechanical vibrations horizontally under pressure. When welding plastics, the materials should have similar melting temperatures, and the vibrations are introduced vertically. Ultrasonic welding is commonly used for making electrical connections out of aluminum or copper, and it is also a very common polymer welding process.

Another common process, explosion welding, involves the joining of materials by pushing them together under extremely high pressure. The energy from the impact plasticizes the materials, forming a weld, even though only a limited amount of heat is generated. The process is commonly used for welding dissimilar materials, such as the welding of aluminum with steel in ship hulls or compound plates. Other solid-state welding processes include co-extrusion welding, cold welding, diffusion welding, friction welding, high frequency welding, hot pressure welding, induction welding, and roll welding.

CHAPTER 4

GENERAL POWER SUPPLIES

Arc welding processes use a welding power supply to create an electric arc between an electrode and the base material to melt metals at the welding point. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. The welding region is sometimes protected by some type of inert or semi-inert gas, known as a shielding gas, and filler material is sometimes used as well.

To supply the electrical energy necessary for arc welding processes, a number of different power supplies can be used. The most common classification is constant current power supplies and constant voltage power supplies. In arc welding, the voltage is directly related to the length of the arc, and the current is related to the amount of heat input. Constant current power supplies are most often used for manual welding processes such as gas tungsten arc welding and shielded metal arc welding, because they maintain a relatively constant current even as the voltage varies. This is important because in manual welding, it can be difficult to hold the electrode perfectly steady, and as a result, the arc length and thus voltage tend to fluctuate. Constant voltage power supplies hold the voltage constant and vary the current, and as a result, are most often used for automated welding processes such as gas metal arc welding, flux cored arc welding, and submerged arc welding. In these processes, arc length is kept constant, since any fluctuation in the distance between the wire and the base material is quickly rectified by a large change in current. For example, if the wire and the base material get too close, the current will rapidly increase, which in turn causes the heat to increase and the tip of the wire to melt, returning it to its original separation distance.

The type of current used in arc welding also plays an important role in welding. Consumable electrode processes such as shielded metal arc welding and gas metal arc welding generally use direct current, but the electrode can be charged either positively or negatively. In welding, the positively charged anode will have a greater heat concentration, and as a result, changing the polarity of the electrode has an impact on weld properties. If the electrode is positively charged, it will melt more quickly, increasing weld penetration and welding speed. Alternatively, a negatively charged electrode results in more shallow welds. Non-consumable electrode processes, such as gas tungsten arc welding, can use either type of direct current, as well as alternating current. However, with direct current, because the electrode only creates the arc and does not provide filler material, a positively charged electrode causes shallow welds, while a negatively charged electrode makes deeper welds. Alternating current rapidly moves between these two, resulting in medium-penetration welds. One disadvantage of AC, the fact that the arc must be re-ignited after every zero crossing, has been addressed with the invention of special power units that produce a square wave pattern instead of the normal sine wave, making rapid zero crossings possible and minimizing the effects of the problem.

4.1. REQUIREMENTS FOR AN ARC WELDING POWER SOURCE:

For striking a welding arc it is essential to have the desired current in the welding circuit. Depending upon the type of current required it may be obtained from the following sources.

A welding transformer or a frequency changer (for AC welding).

1. A dc generator or a rectifier.

   The requirements which every welding power source is required to satisfy are:

   1. The no-load or open circuit voltage must be very high depending upon the type of current.
   2. The power of the welding source should be sufficient to provide the required welding current.
   3. The short circuit current must be within limits of safety for power source windings.

4.2. AC Welding Supply:

4.2.1. REQUIREMENTS OF WELDING TRANSFORMER:

A welding transformer should satisfy the following requirements.

1. It should have a drooping static volt-ampere characteristic.
2. To avoid spatter the surge of the welding current during a short circuit should be limited to the least possible above the normal arc current.
3. The open circuit voltage should not normally exceed 80v and in no case 100v.
4. The output current should be controllable continuously over the full available range.

4.2.2. BASIC TYPES OF WELDING TRANSFORMERS:

1. The high reactance type.
2. The external reactor type.
3. The integral reactor type
4. The saturable reactor type.

4.3. D.C WELDING POWER SOURCES:

D.C. welding power sources are of two types viz., dc welding generators and welding rectifiers.

A dc generator is usually coupled with an electric motor or an internal combustion engine to drive it. Such a combination is called a motor-generator welder or an engine driven welder or simply a dc arc welding set. It may be anyone of the following types.

1 The opposition series generator,
  a. separately excited
  b. self excited
2. a split pole generator
3. a cross field generator

The first two types are more commonly employed.

4.3.1. RECTIFIED D.C. WELDING POWER SOURCES:

This type of welding power source usually consists of a transformer and a bank of rectifying cells. A unit rectifying cell is called a diode and it allows the electrical current to pass only in one direction and thus helps in converting AC to DC.

The welding industry uses solid state devices like semi-conductors to rectifying cells. Earlier selenium was mainly used to make these cells but because of the demand for higher economy, reliability and efficiency most rectifying cells are now made of silicon.

In comparison with motor-generator welding set, a rectifier welding power source has the following advantages.

1. no rotating parts.
2. higher efficiency.
3. smaller weight.
4. smaller size and cost.

CHAPTER 5

BASIC INVERTER THEORY

The following discussion on high frequency inverter welding is geared toward its use in resistance welding small parts. However to understand its benefits, a quick review of the basics of resistance welding is necessary.

In resistance welding three factors are normally involved in making a weld; the amount of current passed, the pressure applied by the electrodes and the time the current flows through the pieces to be welded. The heat used for welding is generated by passing the current through the resistive circuit. The maximum amount of heat is generated at the point of maximum resistance. This normally at the surface of the two pieces to be welded. The high current generates enough heat between the two pieces that the metal reaches a molten state, and combined with the pressure and cooling after the current s flowing, the two parts are forged together.

The basic formula for resistance welding is $H=I^2 \times R \times T \times K$.

In this formula I= current flowing in the circuit

R= the resistance of the work in Ohms

T= time of current flow

K= the heat loss through radiation and conduction.

It is important to not that the welding heat is proportional to the square of the welding current. If the current is doubled, the heat generated is quadrupled. Welding heat is also proportional to the total time of current flow. Thus if the current is doubled, the current an be reduced. Normally a short weld time with high current would be preferred in order to minimize heat losses. Recognizing that the amount of current that flows are critical in generating the heat required to bring the metals to a molten state, it is also important to have a consistent welding current. Without consistent current in the secondary of the weld, especially in smaller, thinner parts, weld failure can occur.

Many of the inconsistencies in the secondary current in the resistance welding can be traced to inconsistent pressures, differences in part thickness and fit up, and variances in line voltage. Good weld heads and tooling can provide consistent pressures and part fit up. Control of the manufacturing process can minimize part differences. Line voltage fluctuations however, present another problem.

Most resistance welds are normally done with ac power supplies. These power supplies allow higher line voltage to be passed through a transformer. The transformer changes the high voltages and low currents into high currents, low voltages. Line voltages typically can vary from 3 t 30 percent. The line voltage fluctuations are amplified through the welding transformer. Thus, the welding currents that are generated can vary as much as 20 to 30 percent. This can result in poor welding conditions, especially when welding thin small parts. To compensate for the line voltage fluctuations, many control manufacturers developed feedback systems.

Feedback is a term used to describe a controls ability to start welding current flowing, look at the flow and then feedback to the control results. The control then compensates for variances to maintain consistency. There are different types of feedback. Current and voltage can be looked at and fed back before and after the transformer, or on both the primary and secondary sides of the welder. Some controls arts designed to look at power rather than current or voltage. However, power is current and voltage and the control calculates the power used and changes one of these variables to maintain constant power.

In the earliest types of power supply controls, line voltage was feedback to the control. The line voltage was looked at just prior to welding and the control compensated to maintain a consistent current output. However, the controls could not compensate for line voltage drops when the welding process began due to the large electrical demands of resistance welding. Also looking at the primary voltage does not compensate for the many variables involved in the secondary of the welder. Later controls, recognizing that compensating for the variances in the secondary on the welder were important in the making consistently repeatable welds, began to look in the secondary, where the weld actually was taking place. The high frequency inverter utilizes this type of secondary feedback, providing constant current, constant voltage or constant power modes.

5.1. AC VERSUS DC WELDING

AC welding, which uses AC line voltage to obtain the needed weld current, is limited to the time base of the incoming voltage. In AC resistance welding, the welding time is measured in cycles. In the US, the line voltage is normally at 60HZ or 60 cycles per second. A cycle as a unit of time. 60HZ is equal to 60 cycles per second. In seconds, one cycle is equal to 16.67ms.

In A welding a cycle consists of current starting at zero and gradually increasing to peak value, decreasing to zero, gradually decreasing to a negative peak value and then increasing again to zero. The current thus flows with positive and negative half cycles. The parts to be welded are heated on the positive half cycle and cooled on the negative half cycles. This is called cycling, and it can cause some undesirable effects in welding depending upon the materials and the thickness of the materials being welded.

Commonly in larger parts with longer weld times 30 to 60 cycles, the on- off cycles of heat are not as critical as in parts with weld times under three cycles. When welding smaller and thinner parts, where the weld time is typically under three cycles, after the first or second half cycle the materials being welded may be weakly bonded together. If the weld cools effectively between the half cycles, this bond can cause a loss of resistance required to make a good weld. In effect, the weld current no longer sees two pieces, but one thicker piece to heat and the heat is dissipated through out the entire two pieces as one. A longer weld time is required to obtain the proper strength because the weld current is no longer concentrated at the point of the weld, but is spread throughout the parts.

Another negative effect of cycling occurs if the heat is not applied consistently throughout the duration of the weld. The nugget growth can be irregular. Variations in the weld nugget are directly related to the quality and strength on a weld.

In order to overcome some of the negative effects of AC welding that are related to cycling, especially when considering smaller parts, direct current (DC), welding power supplies were developed. The most typical DC power supply is capacitor discharge type.

The capacitor discharge type of welder utilizes capacitors for the energy source. After charging, they are able to supply the necessary current to make a weld. A capacitor is like a battery in that it can hold a certain amount of energy.

Unlike a battery however, it releases all of its energy at once. Upon receiving a start signal from a welding head, the energy stored in the capacitors is dumped into a transformer that amplifies the current in order t supply the heat necessary to make the weld. One advantage of this type of welder is that, unlike the AC welder, the level of the line voltage can vary greatly without changing the amount of energy directed to the weld. Another advantage is that there is no cycling as in AC and the current is applied directly to the work pieces without any negative, or off, half cycle. Capacitor discharge type welders however, do have limitations.

One of the limitations is speed. The power supplies need time to raise the charge of the capacitors to the level at which they can supply the required energy to make the weld. In many automated systems, poor and inconsistent welds can occur if welding is attempted before the capacitors are fully charged. If this occurs, depending on the manufacturer of the supply, the supply will release any energy that has been stored, or the supply will not fire at all. The result can be weak welds or no welds at all.

Another of the limitations of capacitor discharge type welding is that the welding current waveform is limited to that of a capacitor discharging a high current for short amount of time, typically under two cycles. This release of energy over a short period of time can cause excessive weld splash, and can cause surface burning on many parts. Also, there is an inability of the power supply to control where the released energy goes and what it does. When the current from a capacitor discharge power supply is released, it is assumed that all of the energy stored is used to make a weld. However, in many instances where the resistance between the parts varies due to plating, part thicknesses, poor fit up, dirty electrodes, or varying pressures, energy is lost and the heat at the weld can vary. Capacitor discharge type welders can not compensate for these variances.

5.2. DC HIGH FREQUENCY WELDERS:

DC high frequency welding offers many advantages over AC of no off-time, thus eliminating the problems caused by cycling, as well as doubling the efficiency of the heat put into parts because it has no inductive losses. It is at higher frequency , thus the size and weight of the welding transformer can b smaller and lighter. There is no off time or charge time needed between weld as in the capacitor discharge type, and because of the speed and accuracy to its feedback system, it provides precise current waveform control. The accuracy and speed at which feedback can be used is one f its greatest advantages.

In AC welding, the time base is limited to that of the line voltage used. AC controls can compensate as often as every half cycle. This means that in a one cycle weld at 60 HZ, the control would flow one half cycle of current, measure the results of that half cycle and compensate to achieve the desired results in the second half cycle. For example, in a one cycle weld it would compensate one time. In a 10 cycle weld it would compensate 19 times. Obviously, the longer the AC welds the more accurate and consistent the control can be because it has more time and more compensation. In high frequency DC welding , at 2000HZ, the inverter feeds back four times per millisecond. Thus, in roughly in one cycle, the control would compensate 67 times. In a 10 cycle weld, the control would compensate 670 times. When welding smaller and thinner parts which require weld times less than two cycles, using the high frequency inverter provides the control to compensate almost immediately for minute changes in the resistance of the materials being welded. It enables consistent heat to be delivered throughout the weld, thus assuring better weld quality and consistency.

60HZ = 60 cycles/second

60 cycles = 1 second

16.7ms = 1 cycle

@ 2KHZ, cycle is repeated 2,000 times per second. There are 2 pulses or half cycles per cycle.

2 x 2,000 = 4,000/second

Divide 4,000/ second by 1002ms/second = 3.99(4)ms

4 x 17 (16.7) = 68 times- 1st half cycle =6

5.3. A Simple Welding Circuit:

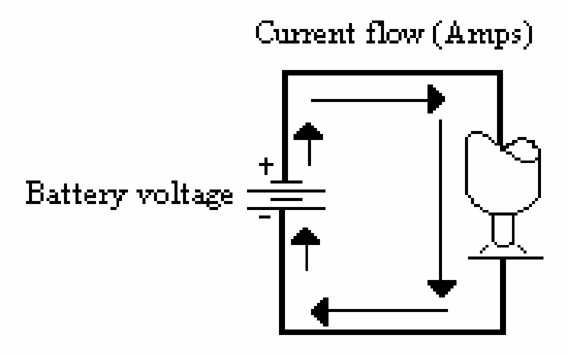


Fig.5.1: A simple welding circuit showing voltage source and current flow

The above figure shows a welding circuit using battery as a power source .the two most basic parameters we deal with a welding are the amount of current in the circuit, and the amount of voltage pushing it. Current and voltage are further defined as follows.

Current: The number of electrons flowing past a given point in one second and it is measured in amperes.

Voltage: The amount of pressure induced in the circuit to produce current flow. It is measured in volts.

Resistance in the welding circuit is represented mostly by the welding arc and to a lesser extent by the natural resistance of the cables, connections and other internal components. Even after alternating current AC became available for welding with the use f transformer power sources, welds produced were more difficult to accomplish and of lesser quality than those produced with direct current. Although these AC power transformers are greatly expanded the use of commercial power for SMAW. They could not be used for GTAW because as the current approached the zero value, the arc would go out. Motor generators followed quickly. These were machines that consisted of an AC motor that turned a generator that produced DC for welding. The output of these machines could be used for both SMAW and GTAW.

It was with a motor generator power source that GTAW was first accomplished in 1942 by V.H. Pavlecka and Russ Meredith while working for the Northrup aviation Company. Pavlecka and Meredith were searching for a means to join magnesium, aluminium and nickel which were coming into use in the military aircraft of that era.

Although the selenium rectifier had been around for some time, it was the early 1950s when rectifiers capable of handling current levels found in the welding circuit came about. The selenium rectifier had a profound effect on the welding industry. It allowed autotransformer power sources to produce DC and it meant that an A power source could now be used for GTAW welding as well as stick welding.

The realization is that high frequency added to the weld circuit would make AC power usable for TIG welding. The addition of this voltage to the circuit keeps the arc established as the weld power passes through zero. Thus stabilizing the GTAW arc, it also aids in arc starting without the risk of contamination. The later addition of remote current control, remote contactor control and gas solenoid control devices evolved into the modern GTAW power source. Further advances such as square wave and and advanced square wave power sources have further refined the capabilities of this already versatile process.

5.4. ALTERNATING CURRENT:

Alternating current (AC) is an electrical current that has both positive and negative half cycles. These components do not occur simultaneously, but alternately, thus the term alternating current. Current flows in one direction during one half of the cycle and reverses direction for the other half cycle. The half cycles are called the positive half and the negative half of the complete AC cycle.

FREQUENCY

The rate at which alternating current makes a complete cycle of reversals is termed frequency. Electrical power in the United States is delivered as 60cycles per second frequency, or to use its proper term 60 HZ. This means there are 120 reversals of current flow directions per second. The power input to an ac welding machine and other electrical equipment in the United States today is 60HZ. Outside of North America and United states, 50 HZ power is more commonly used. As this frequency goes up, the magnetic effects accelerate and become more efficient for use in transformers, motors and other electrical devices. This is the fundamental principle on how an inverter power source works. Frequency has major effect on welding arc performance. As frequencies goes up, the arc gets more stable, narrows and becomes stiffer and more directional. Figure represents some various frequencies.

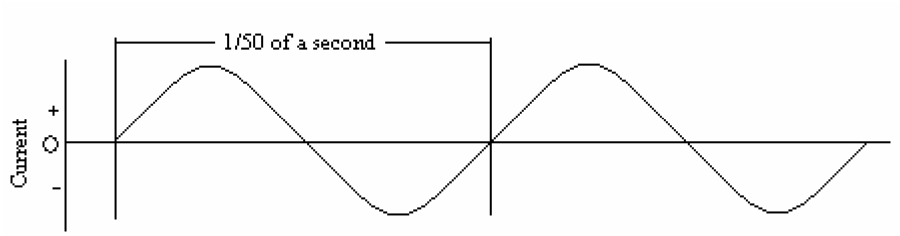


Fig.5.2: An oscilloscope representation of normal 50hz in relation to increased frequency rate

THE AC SINE WAVE

In some of the following sections we will be seeing alternating current waveforms which represent the current flow in a circuit. The drawing in the first part of the figure is what would be seen on an oscilloscope connected to a wall receptacle and shows the AC waveform known as a sine wave. The other two types of waveforms that will be discussed are square wave and advanced square wave. Figure 2.5 shows a comparison of these three waveforms. These waveforms represent the current flow as it builds in amount and time in the positive direction and then decreases in value and finally reaches zero. Then current changes direction and polarity reaching a maximum negative value before rising to zero value. This “hill” and “valley” together represent one cycle of alternating current. This is true no matter what the waveform is. Note however, the amount of time at each half cycle is not adjustable on the sine wave power sources. Also notice the reduced current high points with either of square wave type power sources.

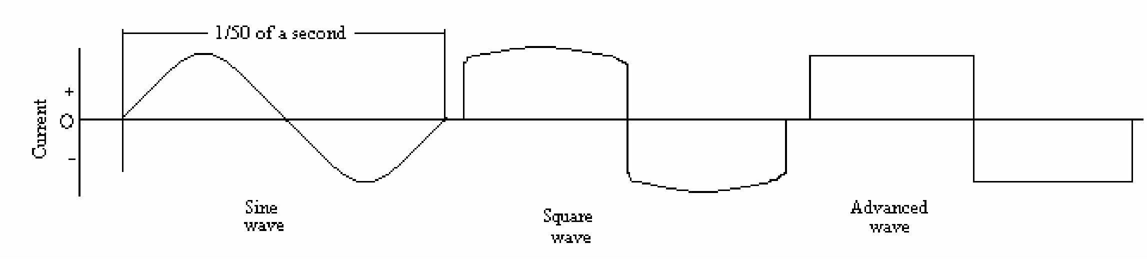


Fig.5.3: Comparison of the three different AC waveforms all representing a time balanced condition

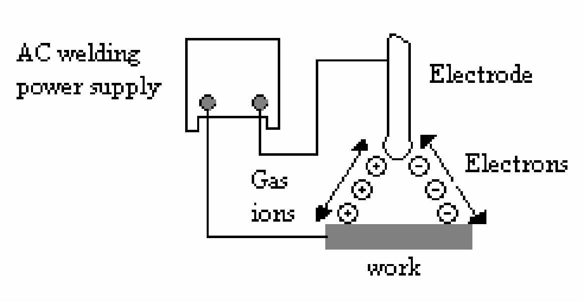


Fig.5.4: AC welding machine connection

SQUAREWAVE AC

Some GTAW power sources due refinements of electronics, have the ability to rapidly make the transition between the positive and negative half cycles of alternating current. It is obvious that when welding with AC, the faster you could transition between the two polarities (EN and EP) and the more time you spent at their maximum values, the more effective the machine you could be. Electronic circuitry makes it possible to make this transition almost instantaneously. Plus the effective use of the energy stored in magnetic fields results in waveforms that relatively square. They are not truly square due to electrical inefficiencies in the square wave power source. However, the advanced square wave GTAW power source has improved efficiencies and can produce a nearly square wave as accompanied in figure2.

ADVANCED SQUARE WAVE:

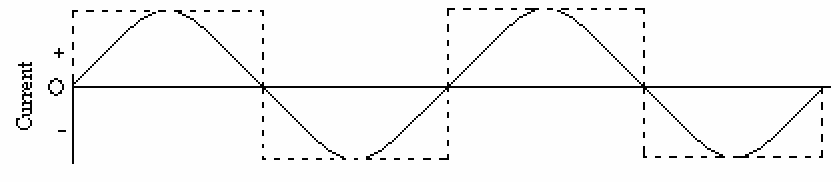


Fig.5.5: Advanced square wave super imposed over a sine wave

Advanced square wave allows additional control over the alternating current waveforms. Figure 6.5 shows an AC sine wave and an advanced square wave superimposed over it. Square wave machines allow us to change the amount of time within each cycle that the machine is outputting electrode positive or electrode negative current flow. This is known as balance control. They also reduce arc rectification and resultant tungsten spitting. With advanced square wave technology, AC power sources incorporate fast switching electronics capable of switching current up to 50,000 times per second, thus allowing the inverter type power source to be much more responsive to the needs of the welding arc. These electronic switches allow for the switching of direction the output welding current will be traveling. The output frequency of square wave or sine wave power sources is limited to 60 cycles per second, the same as the input power from the power company. With this technology and advancement in design, the positive and negative amplitude of the waveform can be controlled independently as well as the ability to change the no. of cycles per second. As is made up of DC electrode negative (DCEN) and direct current electrode positive (DCEP). To better understand all the implications this has on AC TIG welding, let us tale a closer look at DCEN and DCEP.

5.5. DIRECT CURRENT:

DC is an electrical current that flows in one direction only. DC can be compared to water flowing through a pipe in one direction. Most welding power sources are capable of welding with DC output. They can accomplish this with internal circuitry that changes or rectifies the AC into DC output. Figure5.5 shows that one cycle of AC sine wave power would look like after it has been rectified into DC power.

5.5.1. POLARITY:

Earlier in this section it was stated how the earliest welders used batteries for their welding power sources. These early welders found there were profound differences in the welding arc and the resultant welding beads when they changed the battery connections. This polarity is best described by what electrical charge the electrode is connected for, such as (DC) DCEN or DCEP. The work piece would obviously be connected to the opposite electrical charge in order to complete the circuit.

In GTAW welding, the welder has three electrodes of welding current type and polarity. They are DCEN, DCEP and AC. AC, as we are beginning to understand, is actually a combination of both DCEN and DCEP. Each of these current types has its applications, its advantages and disadvantages. A look at each type and its uses will help the welder select the best current type for the job.

5.5.2.DC ELECTRODE NEGATIVE: (Non standard term is straight polarity)

DC electrode negative is used for TIG welding of practically all metals. The torch is connected to the negative terminal of the power source and the work lead is connected to the positive. Power sources with polarity switches will have the output terminals marked electrode and work. Internally when the polarity switch is set for DCEN, this will be the connection. When the arc is established, electron flow is from the negative electrode to the positive work piece. In a DCEN arc, approximately 70% of the heat will be connected at the positive side of the arc and the greatest amount of heat is distributed into the work piece. This accounts for the deep penetration obtained when using DCEN for GTAW. The electrode receives a smaller portion of the heat energy and will operate at a lower temperature than when using AC or DC electrode positive polarity. This accounts for the higher current carrying capacity of given size tungsten electrode with DCEN than with DCEP or AC. At the same time the electrons are striking the work. The positively charged gas ions are attracted toward the negative electrode.

5.5.3. DIRECT CURRENT ELECTRODE POSITIVE:

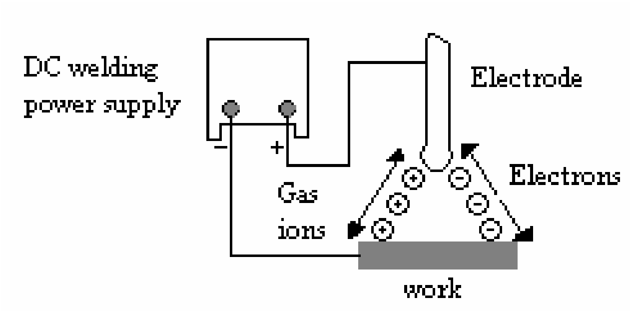


Fig.5.6: Connection for Direct current electrode positive

When welding with direct current electrode positive (DCEP), the torch is connected to the positive terminal on the welding power source and the ground or work lead is connected to the negative terminal. Power sources with polarity switches will have the output terminals marked electrode and work. Internally when the polarity switch is set for DCEP, this will be the connection. When using this polarity, the electron flow is still from negative to positive, however the electrode is now the positive side of the arc and the work is the negative side. The electrons are now leaving the work. Approximately 70% of the heat will be concentrated at the positive side of the arc; therefore the greatest amount of heat is distributed into the electrode. Since the electrode receives the greatest amount of heat and becomes very hot, the electrode must be very large even when the low amperages are used, to prevent over heating and possible melting. The work piece receives a smaller amount of the total heat resulting in shallow penetration. Another disadvantage of this polarity is that due to magnetic forces the arc sometimes wanders from side to side when making a fillet weld when two pieces of metal are at a close angle to one another. This phenomenon is similar to what is known as arc blow and can occur in DCEN but DCEP polarity is more susceptible.

At this point, one might wonder how this polarity could be of any use in GTAW. The answer lies in fact that some non-ferrous metals, such as aluminium and magnesium, quickly form an oxide coating when exposed to the atmosphere. This material is formed in the same way rust accumulates on iron. It's a result of the interaction of the material with oxygen. The oxide that forms on aluminium, however, is one of the hardest materials known to man. Before aluminium can be welded, this oxide because it has a much higher melting point than the base metal, must be removed. This oxide can be removed by mechanical means like wire brushing or with a chemical cleaner, but as soon as the cleaning is stopped the oxides begin forming again. It is advantageous to have cleaning done continuously while the welding is being done.

The oxide can be removed by the welding arc during the welding process when direct current electrode positive is used. The positively charged gas ions which were flowing from the work piece to the tungsten when welding with DCEN are now flowing from the tungsten to the negative work piece with DCEP. They strike the work piece with sufficient workforce to break up and chip away the brittle aluminium oxide and provide what is called a cleaning action. Because of this beneficial oxide removal, this polarity would seem to be excellent for welding aluminium and magnesium. There are however some disadvantages. For example to weld at 100 amperes it would take tungsten 1/4" in diameter. This large electrode would naturally produce a wide pool resulting in the heat being widely spread over the joint area. Because most of the heat is now being generated at the electrode rather than the work piece, the resulting penetration would probably prove to be insufficient. This smaller electrode would also concentrate the heat into a smaller area resulting in satisfactory penetration.

The good penetration of electrode negative plus the cleaning action of electrode positive would seem to be the best combination for welding aluminium. To obtain the advantages of both polarities, alternating current can be used.

WELDING WITH ALTERNATING CURRENT

When using alternating current sine waves for welding, the terms electrode positive and electrode negative which were applied to the work piece and electrode lose their significance. There is no control over the half cycles and you have to use what the power source provides. The current is now alternating or changing its direction of flow at a predetermined set frequency and with no control over time or independent amplitude. During a complete cycle of AC, there is theoretically one half cycle of electrode negative and one half cycle of electrode positive. Therefore during a cycle there is a time when the work is negative and the electrode is positive. In theory, the half cycles of alternating current sine wave arc are of equal time and magnitude.

BALANCED AND UNBALANCED WAVEFORMS:

Square wave AC power sources have front panel controls which allow the welder to alter the length of time the machine spends in either the electrode positive portion of the half cycle or electrode negative portion of the half cycle. Machines of this type are very common for TIG welding in industry today. Very few industrial GTAW AC sine wave power sources are being produced today.

Table5.1: Waveform Balance Control

	% time electrode negative	% time electrode positive
AC sine wave power source	Not applicable, control not available	Not applicable, control not available
Square wave	45- 68	32- 55
Advanced square wave	10- 90	10- 90

5.6. ADJUSTABLE FREQUENCY:

As stated earlier in this section, alternating current makes constant reversals in direction of current flow. One complete reversal is termed as cycle and is referred to as its frequency. As stated, in the United States the frequency of its delivery is 60 cycles per second, or to use the preferred term 60HZ. This means there are 120 reversals of current flow direction through the arc per second. The faster the current going through the changes the direction increases the arc pressure making the arc more stable and directional. This can be beneficial in automated welding by reducing the amount of deflection and wandering that occurs in the direction of travel when fillet welding.

FREQUENCY ADJUSTABILITY

	Hz range
AC sine wave power source	Not adjustable, must use what the power company supplies
Square wave	Not adjustable, must use what the power company supplies
Advanced square wave	20 – 400

Table5.2: Frequency adjustment only available on the advanced square wave designed power source.

A lower than normal frequency can be selected on the advanced square wave power source, all the way down to 20Hz. This would have applications where a softer, less forceful arc may be required- build up, outside corner joints, or sections where a less penetrating, wider weld is required, as the frequency is increased, the arc cone narrows and becomes more directional. This can be beneficial for manual and automatic welding by reducing the amount of deflection and wandering that occurs in the direction of travel when making groove or fillet welds.

ADJUSTABLE FREQUENCY ADVANTAGES:

- Higher frequency yields narrower arc
- Higher frequency increases penetration
- Lower frequency widens arc
- Lower frequency produces a softer less forceful arc.

AC Versus DC Welding

AC WELDING	DC WELDING
1. The heat developed is not uniform as AC passes through zero twice during a cycle.	1. The heat developed is not uniform.
2. The energy consumption is low.	2. The energy consumption is high.
3. The equipment is comparatively cheap.	3. The equipment is costly as compared to that of AC welding.
4. As transformer is used, which has no rotating part; therefore wear and tear are small.	4. A MG set is used as both are rotating machines, wear and tear are more.
5. It needs more space.	5. The equipment needs less space.
6. As voltage required to strike the arc is high, danger of shock is more.	6. The voltage required is low. So danger of shock is less.
7. It's efficiency is high.	7. It's efficiency is low.
8. The system causes an imbalance of the supply.	8. It causes less imbalance of the supply.

Table5.3: Comparison of AC and DC welding

CHAPTER 6

INVERTER WELDING MACHINE

Inversion is the opposite of rectification. Rectification is the conversion of AC to DC and is achieved using rectifiers and diodes: four diodes in bridge connection for single phase and six diodes for three phase input. Inversion converts DC into AC. An inverter is not a simply a device like a diode, but a network of many components designed to achieve this conversion.

The great majority of arc welding today uses DC and since the mains are invariably AC, some method is required for changing from AC to DC. Inversion is only what happens within the inverter power source. Many other electronic and electrical conversions and transformations are required to convert the mains supply into one suitable for welding.. There is a great reduction in size and weight resulting from the inverter based design.

6.1. INVERTER DESIGN AND OPERATION:

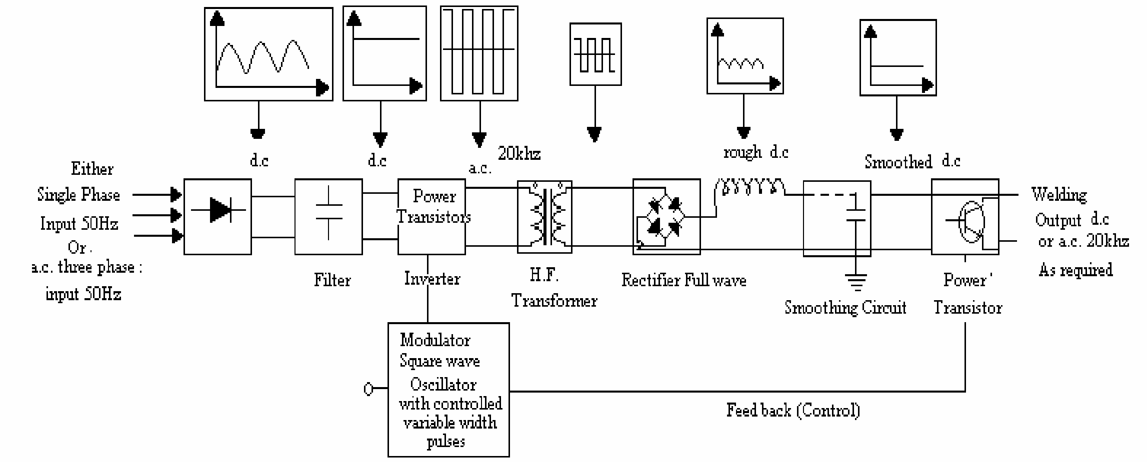


Fig.6.1: Block diagram of an inverter-welding machine

The inverter is an electronic network for converting dc to ac and the frequency of the current must be increased from that of the 50 HZ mains to up to 50KHZ. We have seen that increasing the frequency gives more controllable and adjustable qualities since it is easier to change electronic circuits than to vary large inductances made of iron and copper. The inverter circuit is the layout of the various instruments which are all contained within the framework of the inverter power source. First the incoming mains are passed into a rectifier which converts ac to dc. In order to improve the power factor of the power source a large filter capacitor immediately follows the rectifier stage. This has the advantage of providing a faster response energy store. Then the inverter circuit converts the incoming dc obtained from mains frequency to square wave ac again but at a much higher frequency than that of the mains supply, and usually within the range 5-50KHZ. This ac at high frequency is passed into a transformer bringing down the voltage and increasing the current to that used in a welding circuit. It is again rectified to DC and is passed through the filter inductor where, by Lenz's law, it is smoothed before passing to the welding terminals for connection to the electrode or TIG torch.

Many units today have a DC or AC (HF) output. This type of power source may have back to back or push-pull connection of more than one inverter. The high frequency AC output is used for aluminum welding.

6.2. Costs and trends

As an industrial process, the cost of welding plays a crucial role in manufacturing decisions. Many different variables affect the total cost, including equipment cost, labor cost, material cost, and energy cost. Depending on the process, equipment cost can vary, from inexpensive for methods like shielded metal arc welding and oxyfuel welding, to extremely expensive for methods like laser beam welding and electron beam welding. Because of their high cost, they are only used in high production operations. Similarly, because automation and robots increase equipment costs, they are only implemented when high production is necessary. Labor cost depends on the deposition rate (the rate of welding), the hourly wage, and the total operation time, including both time welding and handling the part. The cost of materials includes the cost of the base and filler material, and the cost of shielding gases. Finally, energy cost depends on arc time and welding power demand.

For manual welding methods, labor costs generally make up the vast majority of the total cost. As a result, many cost-savings measures are focused on minimizing the operation time. To do this, welding procedures with high deposition rates can be selected, and weld parameters can be fine-tuned to increase welding speed.

Mechanization and automatization are often implemented to reduce labor costs, but this frequently increases the cost of equipment and creates additional setup time. Material costs tend to increase when special properties are necessary, and energy costs normally do not amount to more than several percent of the total welding cost.

In recent years, in order to minimize labor costs in high production manufacturing, industrial welding has become increasingly more automated, most notably with the use of robots in resistance spot welding (especially in the automotive industry) and in arc welding. In robot welding, mechanized devices both hold the material and perform the weld, and at first, spot welding was its most common application. But robotic arc welding has been increasing in popularity as technology has advanced. Other key areas of research and development include the welding of dissimilar materials (such as steel and aluminum, for example) and new welding processes, such as friction stir, magnetic pulse, conductive heat seam, and laser-hybrid welding. Furthermore, progress is desired in making more specialized methods like laser beam welding practical for more applications, such as in the aerospace and automotive industries. Researchers also hope to better understand the often unpredictable properties of welds, especially microstructure, residual stresses, and a weld's tendency to crack or deform.

6.3. COMPARISON IN INPUT POWER COST:

Let us take 4mm arc welding electrode is being used.
It requires 160A welding current at approximately 24v.
Output power= 160x 24 =3.84Kw

Input voltage is 230v ac in the case of single phase and 415v ac in the case of three phase input power supply. While comparing in actual measurements the input voltage and output voltage has to accurately measured.

Parameter	Welding Transformer	Welding Rectifier	Welding Inverter
No load current	4 to 5A	4 to 5A	0.3 to 0.5A
No load power factor	0.2	0.2	0.99
No load power	400 to 500W	400 to 500W	50 to 100w
0utput power	3.84Kw	3.84Kw	3.84Kw
Efficiency	0.6	0.6	0.9
Input power	6.4Kw	6.4Kw	4.27Kw
Input power factor	0.5 to 0.6	0.6	0.95
Input KVA	12.8 to 10.66 at 230v, 1ph	10.66 at 415v,3ph	4.5 at 415v, 3ph
Input current	55A t0 46A	14.8	6.3A
Power consumption for 8hrs. a day	51.2 Kwh	51.2 Kwh	34.16Kwh
Power consumption for 250 days f a year	12,800Kwh	12,800Kwh	8540 Kwh
Cost of electricity Rs5 per KHH	Rs 64,000	Rs 64,000	Rs42,700
Excess in cost compared to inverter	Rs 21,300	Rs 21,300	…………
Excess input current from supply	48A	8.5A	………….
Saving in running cost as above	………..	…………	Rs 21,300
Saving in input current	………..	…………	8.5A to 48A
Saving in installed capacity	………..	…………	6.1 KVA to 11.0KVA

Table6.1: Comparison of different welding machines

Therefore there is a saving of Rs 21,300 per annum if a machine is used for one year for 250 days @ 8 hrs a day, that is 2000 hrs per annum. We can calculate the same for the given number machines and hours used which will substantially reduce the cost burden. Also we can calculate the saving in the installed capacity, which will also saves on electricity bill. This calculation is for 4mm electrode and for larger electrode sizes the savings will further increase.

CHAPTER 7

SCR BASED INVERTER WELDING MACHINE

7.1. Advantages of SCR Based Inverter Welding Machine:

- The weight of the machine is only 20Kgas as compared to conventional machines weight of 250Kgs.
- The machine becomes very compact and portable due to which it becomes suitable for site work.
- The machines are based on thyristor design due to which it becomes very rugged and maintenance free.
- The weld quality of inverter type welding machine is much superior as compared to conventional machine, because the DC output that we get is totally pure DC.
- Due to our advanced technology the current regulation which we can get is from 5A to 250A which is not possible with conventional machines.
- One of the main advantages of inverter type welding machine is the power consumption. The machines work on single phase supply and the input current is only 15A while the conventional machines work on 3 phase supply & draws the current of 40 Amps. Due to less power consumption the power will be drop down to 80%, which will naturally adds to profits of the company.
- Welding quality of our machine is much better because it gives porosity free, hydrogen free, splatter free welding.

7.2. Specialties of inverter welding machine:

- Totally indigenous machine.
- THYRISTOR based Inverter Welding Machine with feature essential
- For the Indian working conditions & protected against voltage fluctuations.
- Guaranteed X –Ray quality welding.
- Protection against over heating with indication
- Built in new generation of electronic high frequency unit
- Selection of MMA or TIG with toggle switch.
- Selection of high frequency mode or scratch start with toggle switch.
- Fine current control pot.

- Can weld the thickness of minimum .6mm with TIG.
- Automatic built in electronic soft start
- It gives easy arc striking
- Post flow adjustment pot
- Suitable for welding of 4mm electrode continuously.
- Illuminated ON/OFF switch for easy user feedback
- Designed to meet highest standards for safety & reliability
- Rugged reliable design
- Metallic body with epoxy powder coating for good look & long life

7.3. Principle of operation:

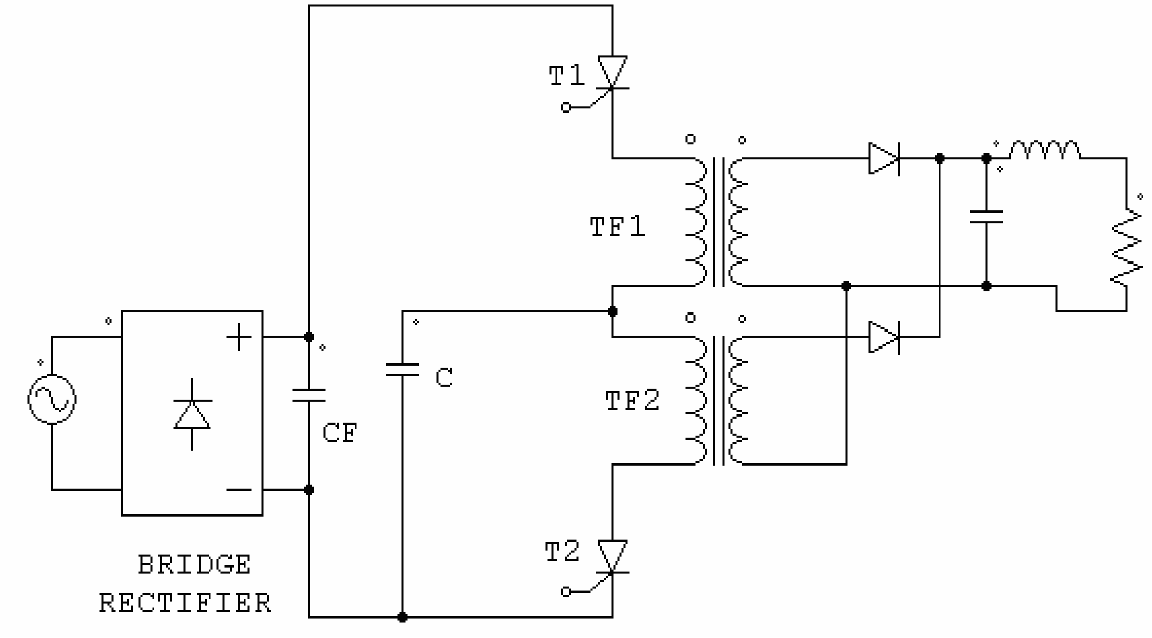


Fig.7.1: Circuit diagram of SCR based inverter welding machine

The circuit diagram of SCR based inverter welding power supply is shown in figure8.1. In the first stage the rectifier converts AC to DC which is pulsating.

To reduce the ripple content filter capacitor is used. The second stage consists of two thyristors and a transformer which consists of two primary and two secondary windings as shown in figure. To convert DC to AC the thyristors are triggered alternately.

To get first half cycle, thyristor T_1 is triggered and a resonant pulse of current i_1 flows through the thyristor T_1- transformer TF!- commutating capacitor C and the current falls to zero at t= t_{1m} and T_1 is self commutated. Firing of thyristor T_2 causes a reverse resonant current through the load and T_2 is also self commutated. The circuit operation can be divided into three modes and the equivalent circuits are shown below. The gating signals for the thyristors and the wave forms for the inverter supply current, DC load voltage and the voltage across the commutating capacitor are shown.

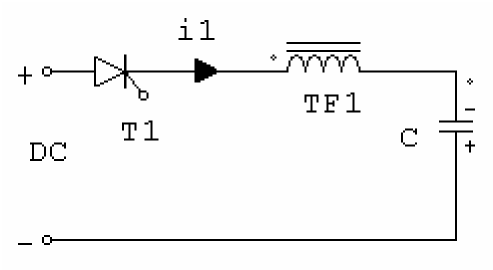
Mode1:

When T_1 is fired the primary current of TF1 flows through T_1-primary of TF1-C. The capacitor charges up to a maximum value of Vs + Vc. The time taken by the capacitor to reach its maximum value is given by

$t_m = (1/\omega_r) \tan^{-1}(\omega_r/\alpha)$ where

ω_r = resonant frequency

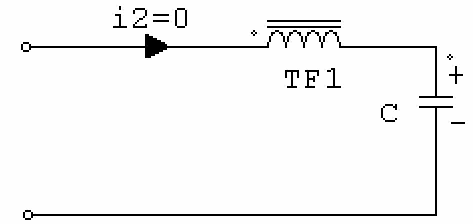
$\alpha = R/(2L)$



Mode1

Mode2:

During this mode, thyristors T1 and T2 are off. In this mode capacitor voltage remains the same.

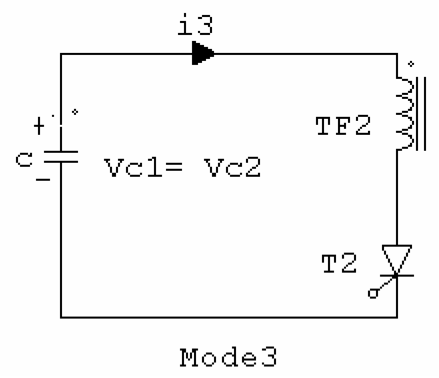


Mode2

Mode3:

This mode begins when T_2 is switched on and a reverse resonant current i_3 flows through the C- TF2- T_1 and a negative half cycle will appear across the secondary of transformer2.

The resonant pulse current $i_1(t)$ must be zero and T_1 must be turned off before T_2 is fired. Otherwise, a short circuit condition results through the thyristors and dc supply. Therefore, the available off time t_{off}, known as the dead zone, must be greater than the turn- off time of thyristors, t_q.



Waveforms:

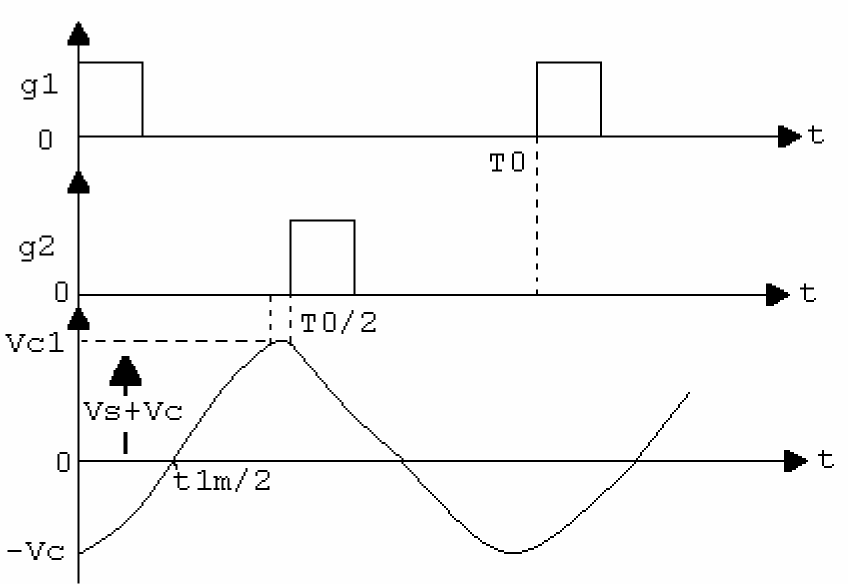


Fig.7.2. Waveforms across gates of thyristors and commutating capacitor

7.4. APPLICATION OF WELDING MACHINE:

Manual metal arc welding known as MMA welding for short, is one of the oldest welding processes still in use today. It goes back to research carried out by Slawjanow who in 1891 was the first to use a metal rod that was simultaneously the arc carrier and the welding additive, rather than the standard carbon electrode that had been used for arc welding until that point. The first stick electrodes were not coated and were therefore difficult to with. Later on the electrodes were coated with materials that made welding easier, protected the weld metal and had a metallurgic affect on the process. The first patent for coated stick electrode was created in 1908. Electrodes can be coated by dipping or by pressing on an extruder press. Today only electrodes with extruded coatings are used.

MMA welding is characterized by a relatively low level of investment and an universal application. The process can be used for wide range of materials and ensures high quality weld seams. In recent times, however, MMA welding has been superseded, frequently for economic reasons, by other welding techniques that can be mechanized.

MMA welding is a fusion welding process, and more precisely, a metal arc welding process. ISO 857-1 describes the welding processes in this group as follows:

Metal arc welding: Arc welding process using an electrode used during the procedure.

Metal arc welding without gas shielding: Metal arc welding process without the addition of external shielding gas and

Manual metal arc welding: Metal arc welding performed manually using a coated electrode.

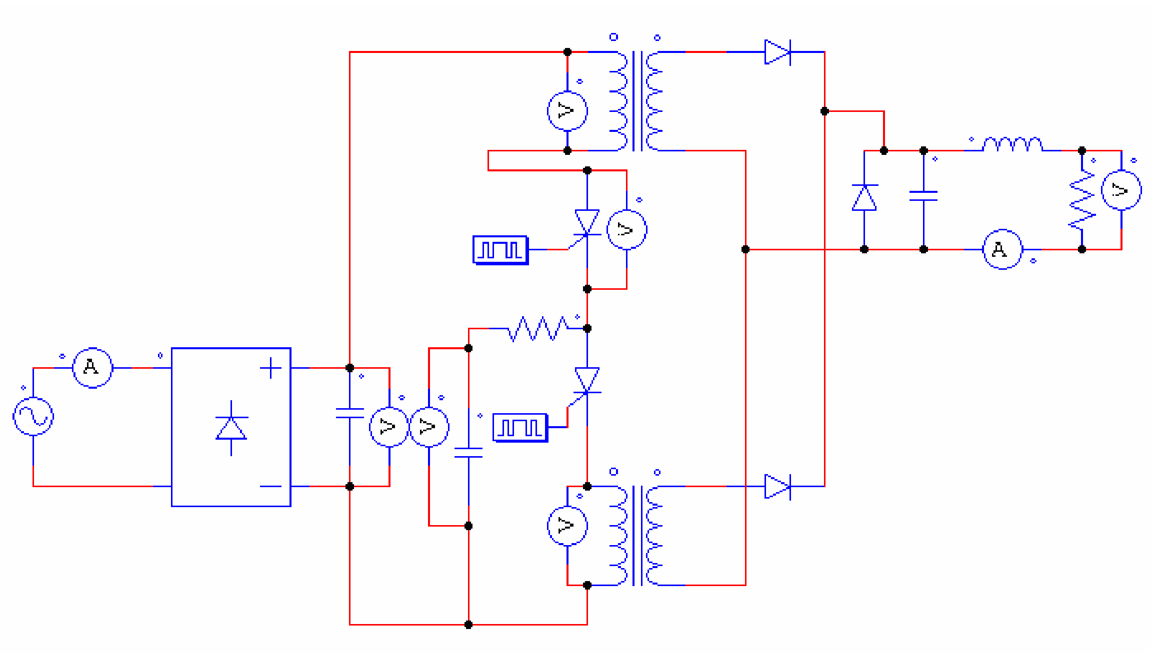
In Germany the last process mentioned is known as manual arc welding or MMA welding for short, and is characterized by the arcing between a melting electrode and the molten bath.

There is no external protection; any protection against the atmosphere comes from the electrode. In this case the electrode is both the arc carrier and the welding additive. The coating forms slag and/ or shielding gas, which among other things protects the drop being transferred and protects the molten pool against the ingress of the atmospheric gases oxygen, nitrogen and hydrogen.

CHAPTER 8

SIMULATION RESULTS

8.1. CIRCUIT DIAGRAM OF SCR BASED INVERTER WELDING MACHINE:



Simulation data used:

Filter Capacitor = 1500 µF

Commutating Capacitor = 4 µF

Transformer data: Ls=10µH Lm= 50µH

Primary turns = 40

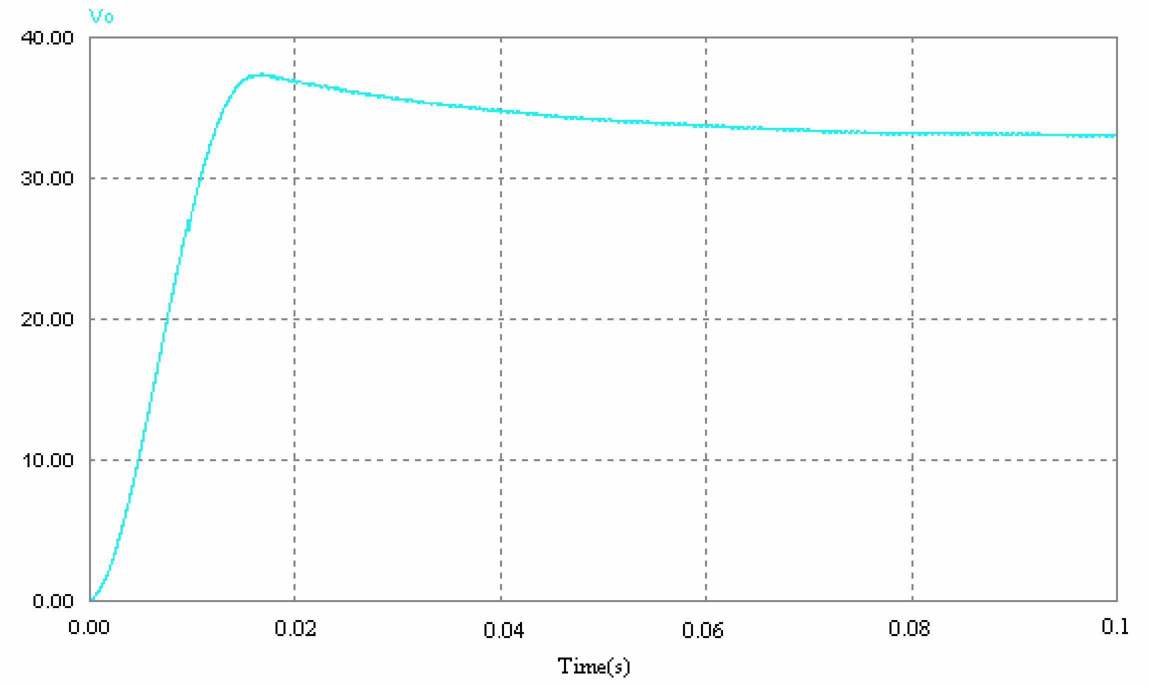
Secondary turns = 7

Output Filter Capacitor = 400µF

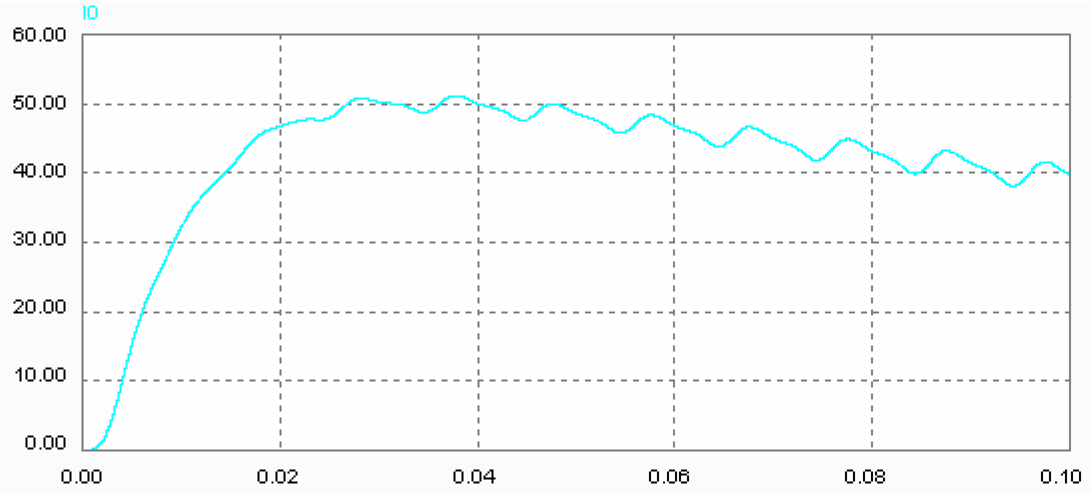
Smoothing reactor = 1mH

Output load resistance = 0.1Ohm

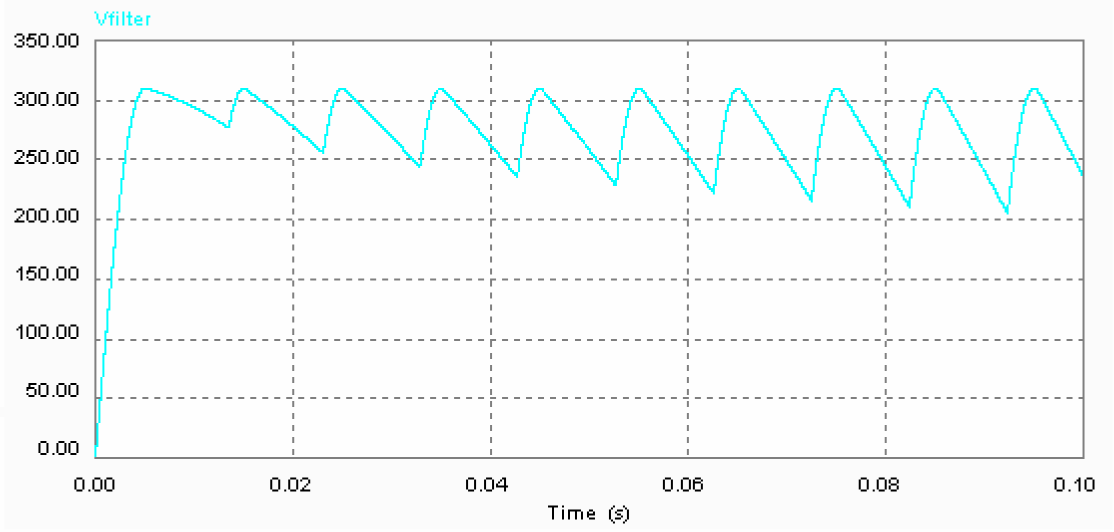
8.2. OUTPUT VOLTAGE:



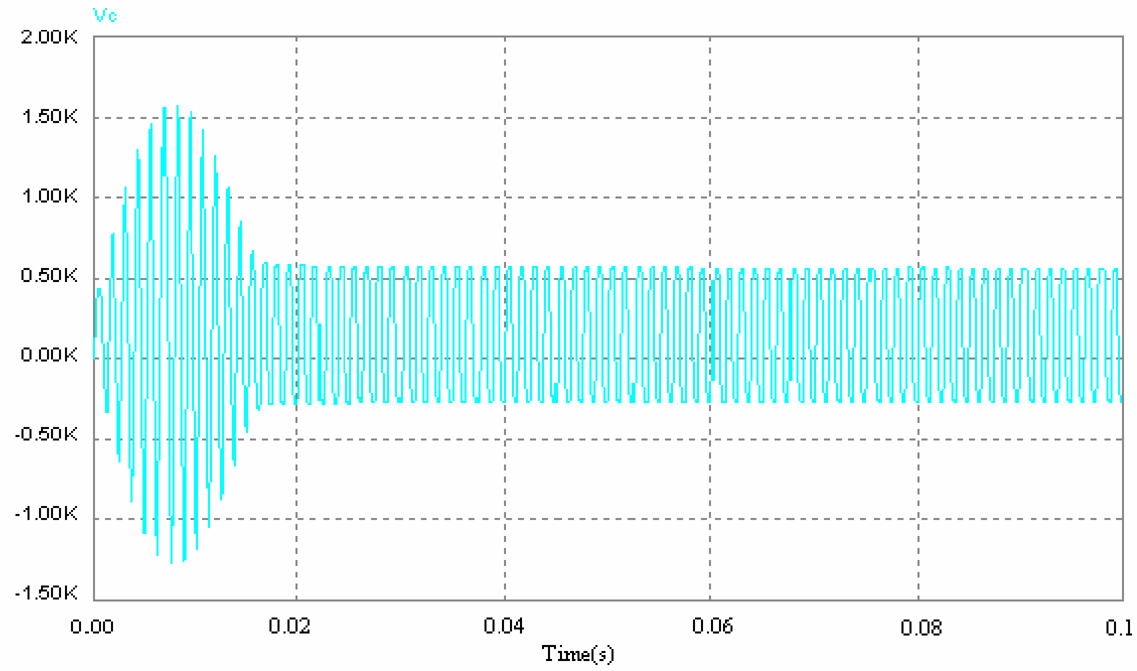
8.3. OUTPUT CURRENT:



8.4. VOLTAGE ACROSS FILTER CAPACITOR:



8.5. VOLTAGE ACROSS 4UF CAPACITOR:



CHAPTER 9

HARDWARE &TEST RESULTS

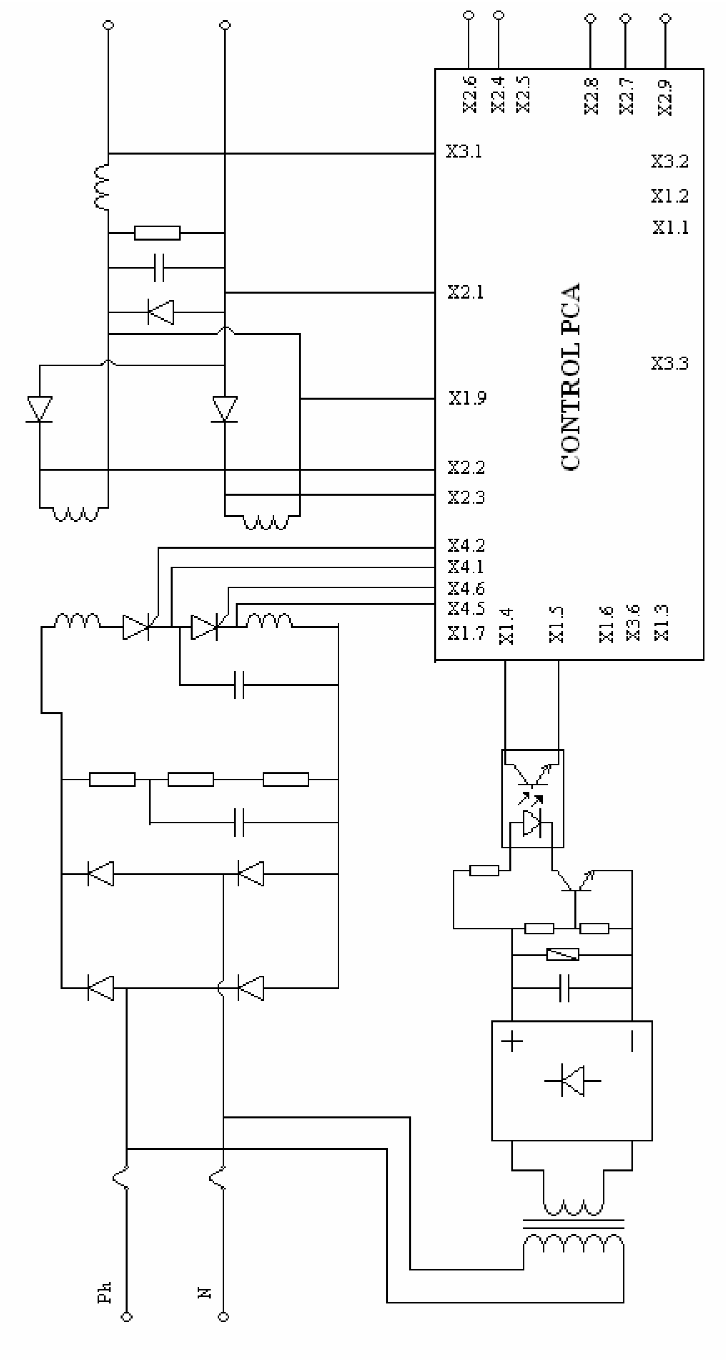


Fig. 9.1: Wiring diagram of welding machine

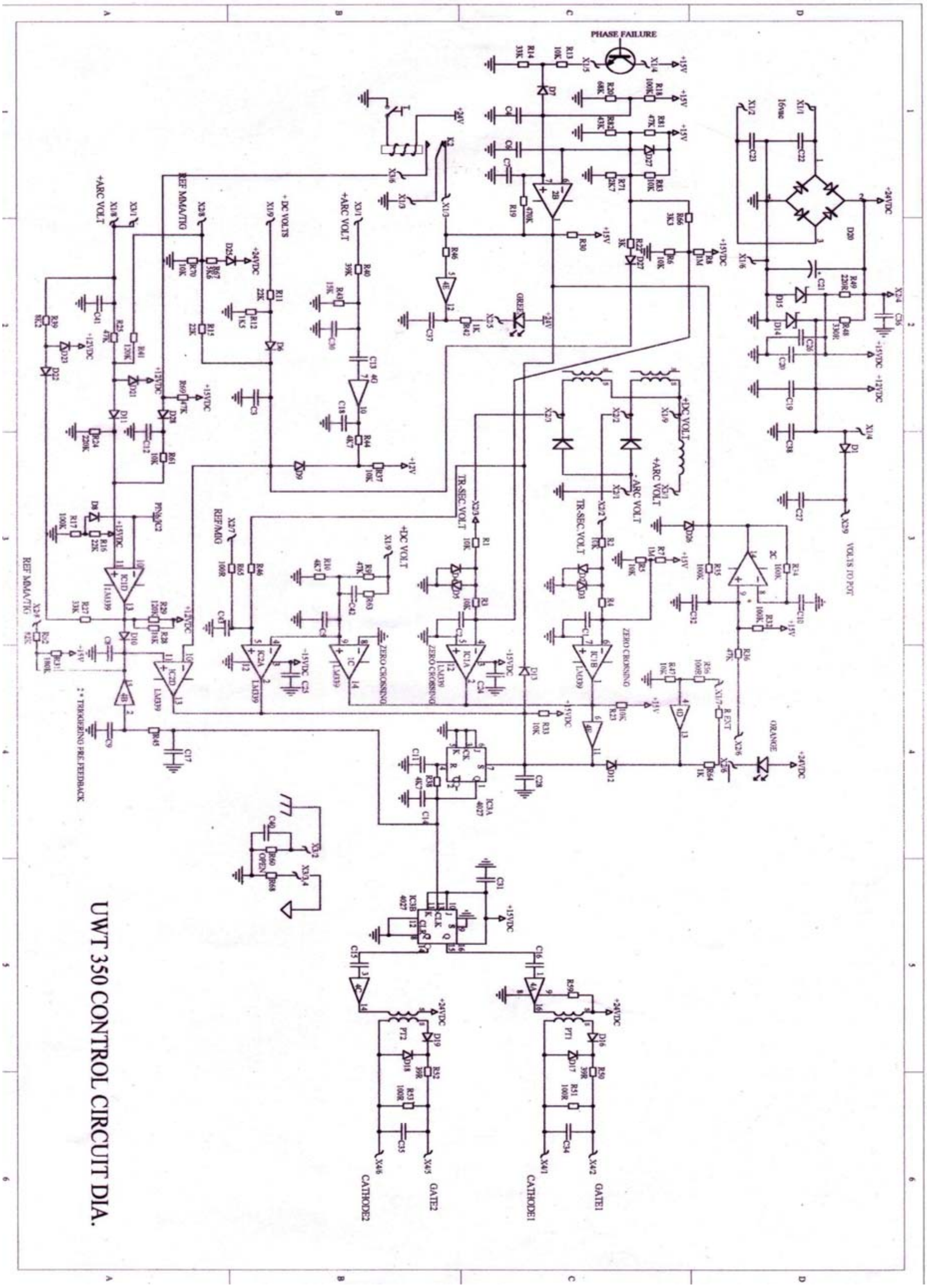


Fig.9.2: Control card of SCR based inverter welding machine

9.1. PCB LAYOUT OF SCR CONTROL CARD:

Fig. 9.3: Control card of SCR based inverter welding machine

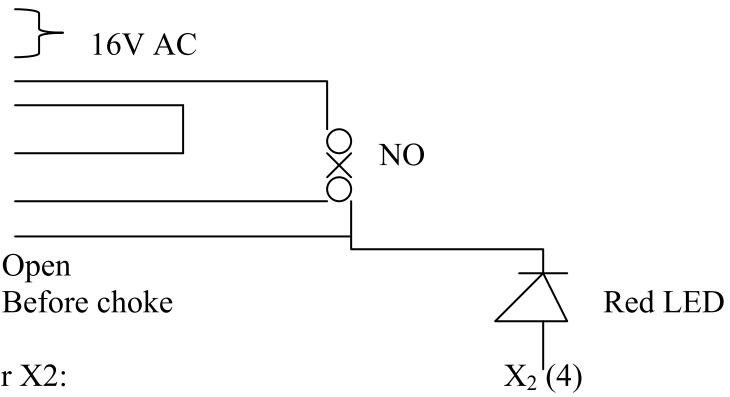
In the above layout X1, X2 and X3 are for external links, which are feedback inputs to the control card. Both X1 and X2 contain 9 pins and X3 contains 6 pins. A1, K1 and A2,K2 are pulse outputs.A1 s connected to the gate of SCR1 and A2 is connected to the gate of SCR2. Pin connections of X1, X2 and X3 are shown below.

When the potentiometer is varying from minimum to maximum the frequency is increasing. The pulse width (T_{on}) is 20microseconds.T_{on} remains constant irrespective of the frequency changes. The frequency is varying from 1000c/s to 2500c/s.

9.2. EXTERNAL LINK CONNECTIONS OF CONTROL CARD

For X1:

1-
2-
3-
4-
5-
6-
7-
8- Open
9- Before choke



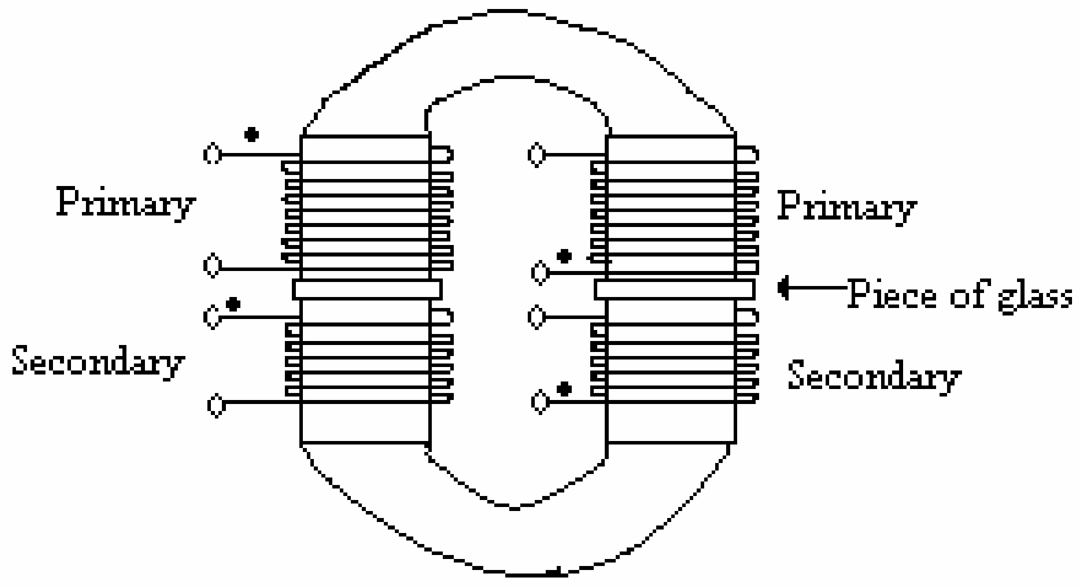
For X2:

1- Negative bus bar
2- Cathode of dode1
3- Cathode of diode2
4- +26v
5- Green LED
6- Red LED
7- Open
8- Wiper of potentiometer
9- End of potentiometer

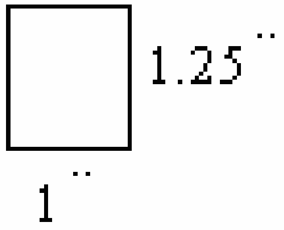
For X3:

1- After choke
2- Earth
3- End of potentiometer
4-
5-
6- Link to X_1 (6)

TRANSFORMER DESIGN



Turns ratio
Primary = 40 turns
Secondary = 7 turns



Cross Section Of CRGO core

Fig. 9.4: Diagram of inverter machine transformer

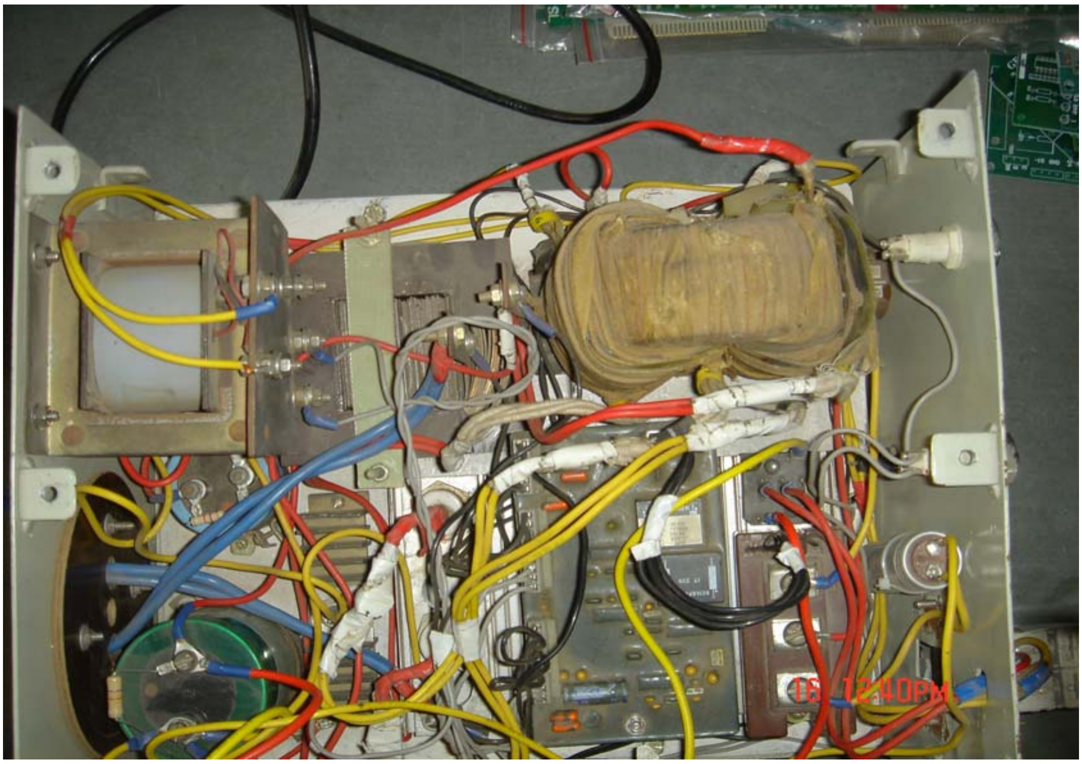


Fig. 9.5: Internal layout of the SCR based inverter welding machine

Fig. 9.6: Input side of the SCR based inverter welding machine

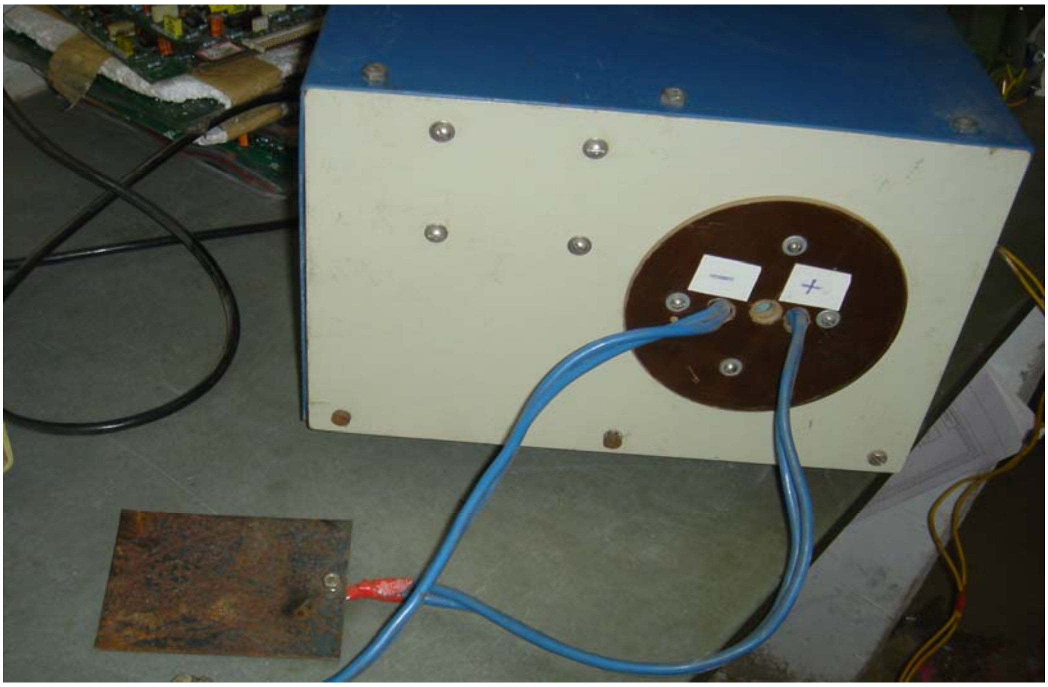


Fig.9.7: Output side of the SCR based inverter welding machine

Fig. 9.8: Top view of the SCR based inverter welding machine

Practical Result:

Fig.9.9: No- load output voltage of the SCR based inverter-welding machine

CHAPTER 10

CONCLUSION & FUTURE SCOPE

CONCLUSION

Owing to their small size and low weight, inverter welding machines are preferred over conventional welding machines. Inverter welding machines gives good quality welding and it is spatter free. Both simulation and practical results of SCR based inverter welding machine are shown. After comparison it is observed that both results are nearly matching. Because of the high frequency the size if the machine is drastically reduced.

FUTURE SCOPE

Welding machine in today’s engineering scenario is most necessary and important for all industries. In today’s globalized world people need the qualities with lower rate. The future plan is to go wide range in this SCR based inverter welding machines as SCRs are available in wide range of capacities, to build PWM converter – inverter arc welding machine which removes low order harmonics, which have a harmful effect on power distribution system and cause incorrect operation on the other equipments, in the input current of inverter arc welding machine. For higher frequencies the size of the machine drastically reduces. Because of this reason the future plan also extends to go for IGBT, MOSFET based inverter welding machines.

APPENDIX - A

NOTE ON WELDING ELECTRODES

An electrode is a piece of wire or a rod (of a metal or alloy), with or without flux covering, which carries current for welding. At one end it is gripped in a holder and an arc is set up at the other.

TYPES OF WELDING ELECTRODES:

Depending upon the material of the electrode, it may felt and supply filler metal; if it is non-consumable, a separate filler addition generally becomes necessary.

The composition of core wire depends upon the metal to be welded. For example, to weld mild steel, core wire of similar composition will be prepared, in order to get a homogeneous welded joint. The size or diameter of the core wire will depend upon the amount of weld metal to be deposited and on the type of joint or the gap to be bridged between the two plates to be welded. Higher currents will be required to weld with bigger diameter electrodes. The length of core wire is designed after considering rigidity, electrical resistance, the ease in welding and the diameter of the electrode. Generally thin and larger diameter electrodes are of shorter lengths and medium sized electrodes have bigger lengths. The reason is if thin electrodes are made longer they may bend and welding may not be carried out properly; and if bigger diameter electrodes are made long, their weight may increase too much to make welding operation inconvenient for the operator. In longer electrodes, electrical resistance and thus the heat generated in the electrode body increases, which may spoil the electrode covering. Diameter remaining the same, an electrode of higher resistance material is normally made smaller in length.

NON-CONSUMABLE OR REFRACTORY ELECTRODES:

They are made up of high melting point materials like carbon (MP 6700°F), pure tungsten (MP 6150°F) or alloy tungsten. These electrodes do not melt away during welding. They maintain the arc, which melts the base metal (as in TIG and carbon arc welding). Strictly speaking, these electrodes cannot be called non-consumable. The electrode length goes on decreasing with the passage of time, because of vaporization and oxidation of the electrode material during welding. In welding processes using refractory electrodes, filler metal addition may or may not be needed, depending upon the plate thickness and the type of joint.

First amongst the non-consumable electrodes are copper-coated carbon or graphite electrodes. Copper coating increases the electrode conductivity or current conducting capacity of the electrodes. A comparison of carbon and graphite electrodes is given below.

Carbon Electrodes	**Graphite Electrodes**
1. less expensive	1. comparatively costlier
2. Carry less current	2. Carry larger currents as compared to carbon electrodes.
3. Short life	3. Long life
4. Simpler arc control	4. Arc control is comparatively difficult
5. Soft material	5. Material is hard and brittle
6. Higher electrical resistance.	6. Lesser electrical resistance.

Table.A.1: Difference between carbon and graphite electrodes

Carbon or graphite electrodes ranging from 2mm to 15mm are employed for welding purposes.

Next amongst non-consumable electrodes are, those of pure tungsten, (1 or 2%) thoriated or (0.3 – 0.5%) zirconated tungsten electrodes. Alloying pure tungsten increases emissivity, resistance to contamination, arc stability, and electrode life. In addition, arc initiation is easier, electrode tip remains cooler (as compared to pure tungsten electrode), electrode consumption is less and there is a gain in current carrying capacity.

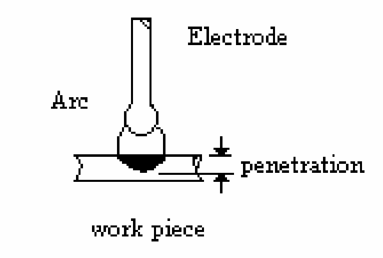
As compared to carbon electrodes, tungsten electrodes are much more expensive and alloy tungsten electrodes are still costlier. Tungsten/alloy tungsten electrodes ranging from 0.5mm to 6mm diameter are commonly available for welding purposes.

Tungsten and alloy tungsten electrodes should preferably be used on DCSP, and where it becomes essential to use the electrode on DCRP (as in the welding of aluminium) electrode over heating is minimized by keeping currents low. In certain cases, with ac welding, zirconated electrodes give better results.

ELECTRODE SHAPES, POLARITY AND ITS EFFECTS:

Correct electrode shape and polarity will decidedly produce better welds.

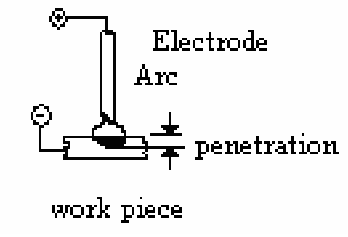
With AC:



Effects:

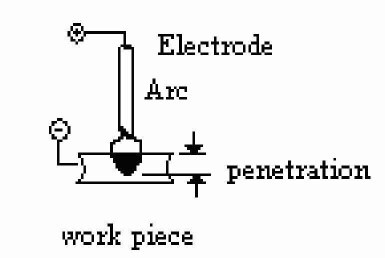
1. currents higher than those in DCRP can be employed. (400 to 500 amps. For 6mm diameter electrodes).
2. Arc cleaning of the base metal.
3. Normal penetration.
4. Equal heat distribution at electrode and job.
5. Electrode tip is colder as compared to that in DCRP.
6. Average arc voltage in argon atmosphere is 16v.

With DCRP:



1. Currents employed are generally less than 125amps (up to 6mm diameter electrodes) to avoid over heating.
2. 66.66% heat is generated at the electrode and 33.33% at the job.
3. least penetration
4. Average arc voltage in argon atmosphere is 19v.
5. Chances of electrode over heating, melting and losses.
6. Better arc cleaning action.

With DCSP:



1. Welding currents up to 1000 amps can be employed for 6mm diameter electrodes.
2. 33.33% heat is generated at the electrode and 66.66% at the job.
3. Deep penetration.
4. average arc voltage in argon atmosphere is 12v
5. Electrode runs colder as compared to AC or DCRP.
6. No arc cleaning of base metal.

CONSUMABLE ELECTRODES:

They are low melting point electrodes made up of different metals and their alloys. When the arc between the electrode and job is struck, the end of the electrode starts melting and transfers to the job in the form of the droplets. The electrode itself adds filler metal. Droplets transferring (from electrode end and through arc) to the work piece deposit there most of the heat generated as resistance heating in the electrode and of the arc. Because of this reason a consumable electrode welding system possesses higher thermal efficiency (about 85%) as compared to that of a non- consumable electrode welding arrangement (about 55%). Consumable electrodes may be of the following types.

Bare electrodes: They consist of a metal or alloy wire without any flux coating on them.

Lightly coated electrodes: Electrodes with a coating factor approximately 1.25 are termed as lightly coated electrodes

Medium coated electrodes: they are the electrodes with a coating factor about 1.45.

Because of unstable arc, irregular metal transfer and atmosphere contamination, bare electrodes do not produce sound and satisfactory welds but still they find application where weld strength is not a primary consideration and it is difficult to carry post cleaning of the joint.

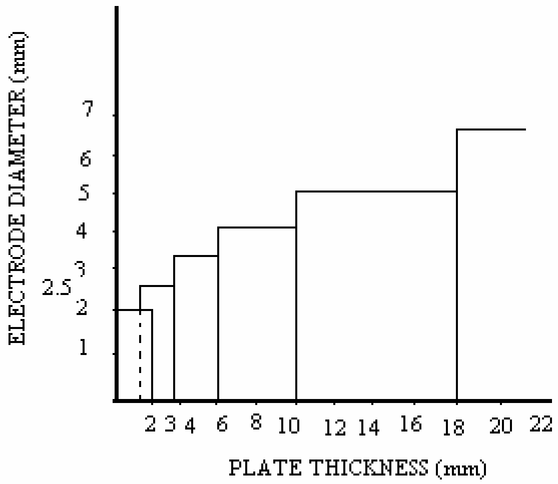
Covered Electrodes: They produce very good weld appearances, weld metal properties and defect free joints.

Certain electrodes give good results on DCRP and others work equally well on AC or DC, for example

(a) AWS E 6012, BS E 206 electrodes work well on both AC and DCSP.
(b) AWS E 6010, BS E 100 are operated on DCRP only.
(c) AWS E 7018, BS E 601 are used on AC or DCRP.

SELECTION OF ELECTRODES:

Selection of a right kind of electrode for a particular application is very important to achieve desired properties in the welded joints.



FigA.1: Relationship between plate thickness & Electrode diameter (manual metal arc Welding using covered electrodes)

The choice of an electrode depends on the following factors:

(a) Chemical composition of the base metal. In order to keep weld metal homogeneity the electrode should have chemical composition more or less similar to that if the plate to be welded.

(b) Thickness of work piece. The figure given below suggests the values of electrode diameters for welding steel plates of different thicknesses. Preferably, electrode diameter should be less than the plate thickness.

(c) Nature of electrode coating, arc behaviour and metal losses due to volatilization and spatter.

(d) Positions in which welding is to be carried out.

(e) Type of joint and number of runs.

(f) Type of power source available.

(g) Type of polarity.

(h) Weld bead geometry and the shape of the weld bead surface.

(i) Amount of weld metal to be deposited and deposition efficiency of the electrode.

(j) Surface finish and quality of weld metal.

(k) Mechanical and other properties required in the welded joint.

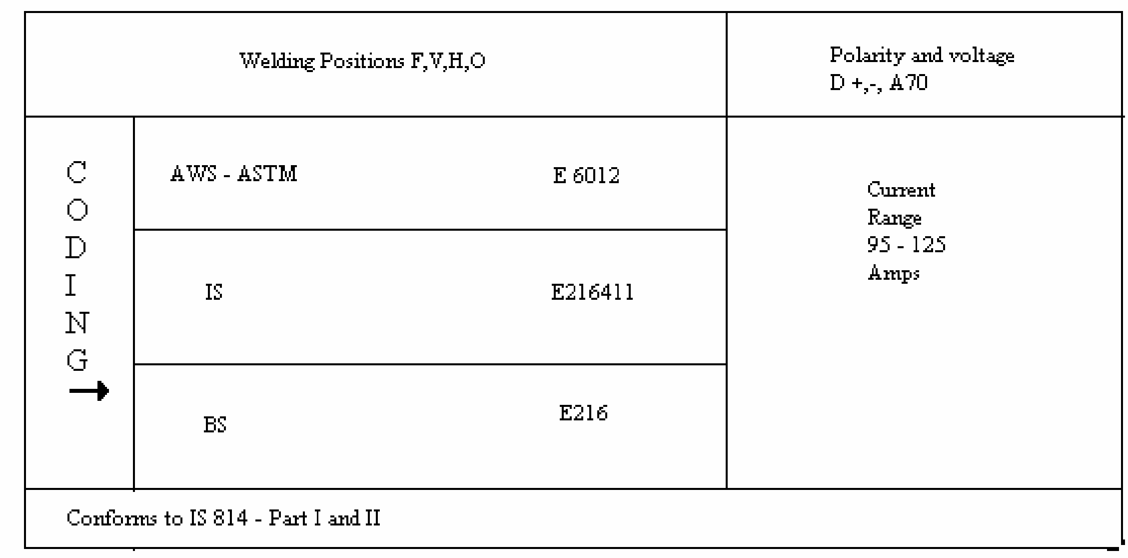
(l) Cost of the electrode.

CLASSIFICATION AND CODING OF MILD STEEL AND LOW ALLOY STEELS ELECTRODES

It seems essential that electrodes should have along with them some information about their properties and main features. Instead, every electrode manufacturer may give separate identification marks for his electrodes; it is much better if one classification and coding scheme is adhered to by all electrode manufacturers. With this logic in view, different societies developed and framed coding schemes in their countries.

Electrode classification provides information on constituents of flux coating, nature of slag, current and polarity, arc behaviour, welding position, appearance of weld deposit, quality of weld etc. and thus helps selecting most suitable electrode.

Electrode packets are marked with a code number which identifies an electrode and its main features.



Welding Positions F,V,H,O			Polarity and voltage D +,-, A70
C O D I N G →	AWS - ASTM	E 6012	Current Range 95 - 125 Amps
	IS	E216411	
	BS	E216	
Conforms to IS 814 - Part I and II			

Table.A.2: Electrode coding

Three systems of electrode classification and coding, namely American, British and Indian have been briefly discussed below:

(1)American (AWS-ASTM) System:

E XX XX or E 60 1 2
E XXX XX or E 100 1 5

Letter E signifies that electrode is suitable for metal (electric) arc welding.

XX/XXX(60/100) : First two or three digits indicate minimum tensile strength of weld metal in thousands of pounds per sq. inch, e.g. 60,000 and 100,000lbs/sq. inch. Other values of xx and xxx are 45, 70, 80, 90 and 120.

X(1) : Last but one digit indicates the welding position. It can be represented by numbers like 1,2 and 3 which indicate that welding can be carried out in any position, flat and horizontal positions, and flat position respectively.

X{2,5} : Last digit which may be 0,1,2,3,5 or 6 tells about power supply, type of covering, type of arc, penetration characteristics, etc.

(2) British (BS) System:

L	X	X	X	L
First letter	1st digit	2nd digit	3rd digit	last letter

Examples:

E 317 M

E 145 P

Various letters and digits indicate the following:

1st letter - it can be E, R or D. E indicates that it is a solid extruded electrode, R remains reinforced electrode and D indicates ‘Dipped electrode’, i.e. an electrode manufactured by dipping process.

1st digit - it indicates the class of covering. It can be 1, 2, 3, 4, 5,6 or 9

1 means high cellulose content.

2 means high titania content resulting in fairly viscous slag.

3 means appreciable titania content resulting in a fluid slag.

4 means high iron and/ or silicates content resulting in inflated slag.

5 means high iron oxides and/or silicates content resulting in a heavy solid slag.

6 means high calcium carbonate and fluoride content.

9 any other type of covering not mentioned above.

2nd digit - It indicates the position in which electrode can weld satisfactorily. Second digit can be represented by 1,2,3,4,5,6 or 9.

1. indicates welding positions like flat, horizontal, inclined, vertical, overhead(i.e. electrode is suitable for welding in all positions).
2. flat, horizontal.
3. flat only.
4. flat, horizontal, inclined.
5. flat, horizontal, vertical, overhead.
6. vertical, overhead.
9. not classified above.

3rd digit - It gives an idea of current, polarity and open circuit voltage of the welding power source. Any number like0,1,2,3,4,5,6,7 or 9 can be the third digit.

0 indicates D+, i.e. DCRP

1 D+, AA95, i.e. DCRP OR AC with OC voltage over 95 volts.

2 D-, A70, i.e. DCSP or AC with OCV over 70V.

3 D-, A45, i.e. DCSP or AC with OCV over 45V.

4 D+, A70, i.e. DCRP or AC with OCV over 70V.

5 D+, D-, A95, i.e. DCSP, DCRP, AC with OCV over 95V.

6 D+, D-, A70, i.e. DCSP, DCRP, AC with OCV over 70V.

7 D+,D-, A45, i.e. DCSP,DCRP, Ac with OCV over 45V.

9 Not classified above.

Last letter –

P indicates deep penetration electrode, and

M means a molybdenum bearing electrode.

Example : E 145 P means

(a). It is a solid extruded electrode,

(b). It has a high cellulose content,

©. It can weld in flat, horizontal and inclined positions,

(d). It can be operated on DCRP, DCSP or AC with a power source having OCV above 95 volts, and

(e). It is a deep penetration electrode.

(3) Indian (IS) System:

L	X	X	X	X	X	X	L
1st letter	1st	2nd	3rd	4th	5th	6th	last letter

Example : E307411

Various digits and letters indicate the following:

1st letter - It can be E or R. E indicates that electrode is solid extruded and R means an electrode extruded with reinforcement.

2nd digit - It indicates the positions in which electrode can weld satisfactorily. Second digit may be 0,1,2,3,4, or 9. 0 and 1 signify that the electrode can be used for welding in all positions, and in flat, horizontal, overhead and vertical positions respectively. 4 indicates flat and horizontal fillet positions. 2,3 and 9 have the same meaning as in British standard.

3rd digit - It has the same meaning as that of the third digit of British standard, except that the open circuit voltage is 90 in place 95 volts, and 50 instead of 45.

4th digit - They indicate range of tensile strength and value of minimum
5th digit - yield stress., e.g. 41 (fourth and fifth digits) and 51 mean that tensile strength ranges from 410-510 and 510- 610 N/mm^2 and minimum yields stress is 330 and 360 N/mm^2 respectively.

6th digit - It tells percentage elongation and impact value.

Last letter- P indicates deep penetration electrode, H hydrogen controlled electrode, and J, K, L indicate electrodes with iron powder coating and metal recovery 110-130%, 130-150% and above 150%, respectively.

Example: E 307411 means

(a) It has solid extruded electrode.
(b) Its covering contains appreciable amount of titania; a fluid slag.
(c) It is all position electrode,
(d) It can be operated on DCRP, DCSP or AC with a power source having, open circuit voltage 50 volts,
(e) Weld metal tensile strength ranges between 410 and 510 N/mm^2
(f) Minimum percentage elongation of weld metal (in tension) is 20% of $5.65\sqrt{S_o}$ and impact value of weld metal at 27^oc is 4.8 kgfm. Where S_o is the cross- section area of the specimen being tested.

SOME WELDING ELECTRODES OF Oerlikon - Fon:

(1) E – 725

Applications: Hard facing of parts subject to metal to metal wear and intense abrasion up to 500°c with moderate shock likely to be absorbed elastically. Wear resistance surfacing alloy, idea for clay extrudent screws, conveyor screws, mixer blades & scrapers. Blast furnace distributor cones, agitator blades etc.

Welding currents: (AC/DC+)

Size in mm	Amps
3.15	80 – 110
4	110 – 140
5	140 -180

(2) E – 1105

Applications: Low – alloy, hydrogen controlled basic coated, life prolonged consumable for all position welding of metal sheets X- ray, ultrasonic and ither code requirements.

Welding currents: (AC/DC+)

Size in mm	Amps
2.50	55 – 90
3.15	90 – 130
4	140 – 180
5	190 – 240

Properties: High deposition efficiency electrode, giving smooth and low spatter loss. Easy to operate in all positions and lend itself to easy slag removal

.

(3) E – 743S

Applications: For hard facing of parts subject to heavy abrasion and metal to metal wear with moderate impact up to 510oc, suitable for refractory press screws, palm nut press screws, cement press screws, conveyor screws, impellers, dredging bucket edge runner bottom, pug mill knife wing, boring bits, blast furnace bells and hoppers.

Welding currents: (AC/DC+)

Size in mm	Amps
3.15	120 – 155
4	140 – 200
5	160 – 210

APPENDIX -B

TYPES OF JOINTS NORMALLY USED

B.1. Geometry

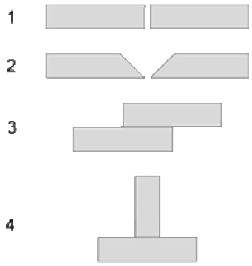


Fig.B.1: Common welding joint types – (1) is a square butt joint, (2) is a single-V preparation joint, (3) is a lap joint, and (4) is a T-joint.

Welds can be geometrically prepared in many different ways. The four most basic types of weld joints are the square butt joint, the single-V preparation joint, the lap joint, and the T-joint. Other variations exist as well, for example, double-V preparation joints are characterized by the two pieces of material each tapering to a single center point at one-half their height. Single-U and double-U preparation joints are also fairly common—instead of having straight edges like the single-V and double-V preparation joints, they are curved, forming the shape of a U. Lap joints are also commonly more than two pieces thick – depending on the process used and the thickness of the material, many pieces can be welded together in a lap joint geometry.

Often, particular joint designs are used exclusively or almost exclusively by certain welding processes. For example, resistance spot welding, laser beam welding, and electron beam welding are most frequently performed on lap joints. However, some welding methods, like shielded metal arc welding, are extremely versatile and can weld virtually any type of joint. Additionally, some processes can be used to make multipass welds, in which one weld is allowed to cool, and then another weld is performed on top of it. This allows for the welding of thick sections arranged in a single-V preparation joint, for example.

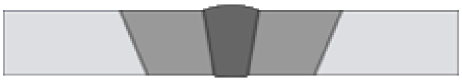


Fig.B.2. Welded butt joint

The cross-section of a welded butt joint, with the darkest gray representing the weld or fusion zone, the medium gray the heat-affected zone, and the lightest gray the base material.

After welding, a number of distinct regions can be identified in the weld area. The weld itself is called the fusion zone, more specifically; it is where the filler metal was laid during the welding process. The properties of the fusion zone depend primarily on the filler metal used, and its compatibility with the base materials. It is surrounded by the heat-affected zone, the area that had its microstructure and properties altered by the weld. These properties depend on the base material's behavior when subjected to heat. The metal in this area is often weaker than both the base material and the fusion zone, and is also where residual stresses are found.

B.2. Quality

Most often, the major metric used for judging the quality of a weld is its strength and the strength of the material around it. Many distinct factors influence this, including the welding method, the amount and concentration of heat input, the base material, the filler material, the flux material, the design of the joint, and the interactions between all these factors. To test the quality of a weld, either destructive or nondestructive testing methods are commonly used to verify that welds are defect-free, have acceptable levels of residual stresses and distortion, and have acceptable heat-affected zone (HAZ) properties. Welding codes and specifications exist to guide welders in proper welding technique and in how to judge the quality of welds.

B.3. Heat-affected zone

The effects of welding on the material surrounding the weld can be detrimental – depending on the materials used and the heat input of the welding process used, the HAZ can be of varying size and strength. The thermal diffusivity of the base material plays a large role—if the diffusivity is high, the material cooling rate is high and the HAZ is relatively small. Alternatively, a low diffusivity leads to slower cooling and a larger HAZ. The amount of heat inputted by the welding process plays an important role as well, as processes like oxyacetylene welding have an unconcentrated heat input and increase the size of the HAZ. Processes like laser beam welding give a highly concentrated, limited amount of heat, resulting in a small HAZ. Arc welding falls between these two extremes, with the individual processes varying somewhat in heat input. To calculate the heat input for arc welding procedures, the following formula can be used:

$$Q = \left(\frac{VXIX60}{SX100}\right)xEfficiency$$

where Q = heat input (kJ/mm), V = voltage (V), I = current (A), and S = welding speed (mm/min). The efficiency is dependent on the welding process used, with shielded metal arc welding having a value of 0.75, gas metal arc welding and submerged arc welding, 0.9, and gas tungsten arc welding, 0.8.

4.4. Distortion and cracking

Welding methods that involve the melting of metal at the site of the joint necessarily are prone to shrinkage as the heated metal cools. Shrinkage, in turn, can introduce residual stresses and both longitudinal and rotational distortion. Distortion can pose a major problem, since the final product is not the desired shape. To alleviate rotational distortion, the workpieces can be offset, so that the welding results in a correctly shaped piece. Other methods of limiting distortion, such as clamping the workpieces in place, cause the buildup of residual stress in the heat-affected zone of the base material. These stresses can reduce the strength of the base material, and can lead to catastrophic failure through cold cracking, as in the case of several of the Liberty ships. Cold cracking is limited to steels, and is associated with the formation of martensite as the weld cools. The cracking occurs in the heat-affected zone of the base material. To reduce the amount of distortion and residual stresses, the amount of heat input should be limited, and the welding sequence used should not be from one end directly to the other, but rather in segments. The other type of cracking, hot cracking or solidification cracking, can occur in all metals, and happens in the fusion zone of a weld. To diminish the probability of this type of cracking, excess material restraint should be avoided, and a proper filler material should be utilized.

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