No Slag

There is no requirement for flux with this process; therefore, there is no slag to obscure the welder's vision of the molten weld pool. The finished weld will not have slag to remove between passes. Entrapment of slag in multiple pass welds is seldom seen. On occasion with materials like Inconel® this may present a concern.

No Sparks or Spatter

In the GTAW process there is no transfer of metal across the arc. There are no molten globules of spatter to contend with and no sparks produced if the material being welded is free of contaminants. Also under normal conditions the GTAW arc is quiet without the usual cracks, pops, and buzzing of Shielded Metal Arc Welding (SMAW or Stick) and Gas Metal Arc Welding (GMAW or MIG). Generally, the only time noise will be a factor is when a pulsed arc, or AC welding mode is being used.

No Smoke or Fumes

The process itself does not produce smoke or injurious fumes. If the base metal contains coatings or elements such as lead, zinc, nickel or copper that produce fumes, these must be contended with as in any fusion welding process on these materials. If the base metal contains oil, grease, paint or other contaminants, smoke and fumes will definitely be produced as the heat of the arc burns them away. The base material should be cleaned to make the conditions most desirable.

GTAW Disadvantages

The main disadvantage of the GTAW process is the low filler metal deposition rate. Another disadvantage is that the hand-eye coordination necessary to accomplish the weld is difficult to learn, and requires a great deal of practice to become proficient. The arc rays produced by the process tend to be brighter than those produced by SMAW and GMAW. This is primarily due to the absence of visible fumes and smoke. The increased amounts of ultraviolet rays from the arc also cause the formation of ozone and nitrous oxides. Care should be taken to protect skin with the proper clothing and protect eyes with the correct shade lens in the welding hood. When welding in confined areas, concentrations of shielding gas may build up and displace oxygen. Make sure that these areas are ventilated properly.

Process Summary

GTAW is a clean process. It is desirable from an operator point of view because of the reasons outlined. The welder must maintain good welding conditions by properly cleaning material, using clean filler metal and clean welding gloves, and by keeping oil, dirt and other contaminants away from the weld area. Cleanliness cannot be overemphasized, particularly on aluminum and magnesium. These metals are more susceptible to contaminants than are ferrous metals. Porosity in aluminum welds has been shown to be caused by hydrogen. Consequently, it is most important to eliminate all sources of hydrogen contamination such as moisture and hydrocarbons in the form of oils and paint.

II. GTAW Fundamentals

If you've ever had the experience of hooking up a car battery backwards, you were no doubt surprised at the amount of sparks and heat that can be generated by a 12 volt battery. In actual fact, a GTAW torch could be hooked directly to a battery and be used for welding.

When welding was first discovered in the early 1880s it was done with batteries. (Some batteries used in early welding experiments reached room size proportions.) The first welding machine, seen in Figure 2.1, was developed by N. Benardos and S. Olszewski of Great Britain and was issued a British patent in 1885. It used a carbon electrode and was powered by batteries, which were in turn charged with a dynamo, a machine that produces electric current by mechanical means.

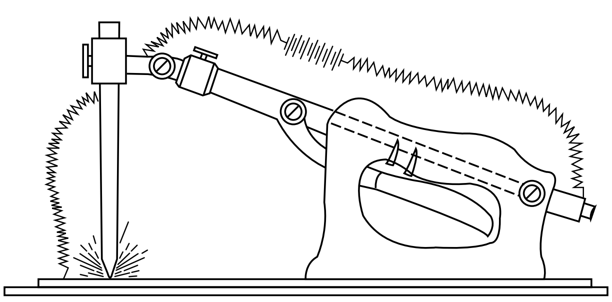


Figure 2.1 Original carbon electrode welding apparatus — 1885.

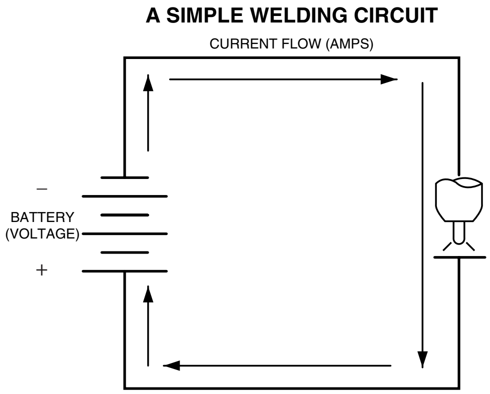


Figure 2.2 A simple welding circuit showing voltage source and current flow.

Figure 2.2 shows what a welding circuit using a battery as a power source would look like.

The two most basic parameters we deal with in 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. Measured in amperes (amps).

Voltage — The amount of pressure induced in the circuit to produce current flow. Measured in voltage (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.

Chapters could be written on the theory of current flow in an electrical circuit, but for the sake of simplicity just remember that current flow is from negative to positive. Early researchers were surprised at the results obtained when the battery leads were switched. We'll examine these differences in more detail later in the section when we discuss welding with alternating current.

Even after alternating current (AC) became available for welding with the use of transformer power sources, welds produced were more difficult to accomplish and of lesser quality than those produced with direct current (DC). Although these AC transformer power sources greatly expanded the use of commercial power for SMAW (Stick), they could not be used for GTAW because as the current approached the zero value, the arc would go out. (see Figure 2.4). 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, aluminum and nickel, which were coming into use in the military aircraft of that era.

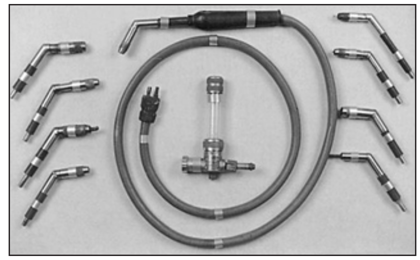


Figure 2.3 The original torch and some of the tips used by Pavlecka and Meredith to produce the first GTAW welds in 1942. *Note the torch still holds one of the original tungstens used in those experiments.*

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 AC transformer power sources to produce DC. And it meant that an AC 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 Squarewave, and Advanced Squarewave power sources have further refined the capabilities of this already versatile process.

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 60 cycles per second frequency, or to use its proper term 60 hertz (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 60 Hz power. Outside of North America and the 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 principal on how an "inverter power source works". Frequency has major effect on welding arc performance. As frequencies go up, the arc gets more stable, narrows, and becomes stiffer and more directional. Figure 2.4 represents some various frequencies.

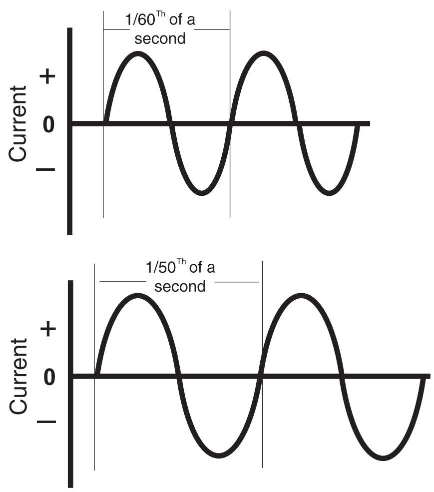


Figure 2.4 An oscilloscope representation of normal 50 and 60 Hz in relation to increased frequency rate.

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 Figure 2.5 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 Squarewave and Advanced Squarewave. 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 the zero value. This "hill" (positive half) and "valley" (negative half) 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 Squarewave type power sources.

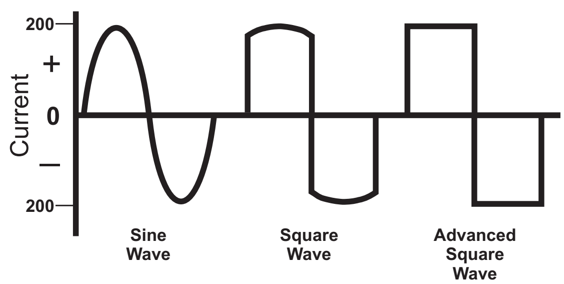


Figure 2.5 Comparison of the three different AC waveforms all representing a time balanced condition and operating at 200 amperes.

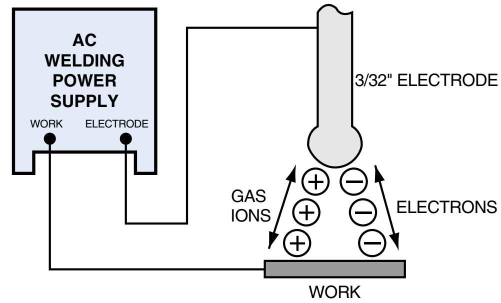


Figure 2.6 AC welding machine connection.

Squarewave AC

Some GTAW power sources, due to 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 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 are relatively square. They are not truly square due to electrical inefficiencies in the Squarewave power source. However, the Advanced Squarewave GTAW power source has improved efficiencies and can produce a nearly square wave as compared in Figure 2.5.

Advanced Squarewave

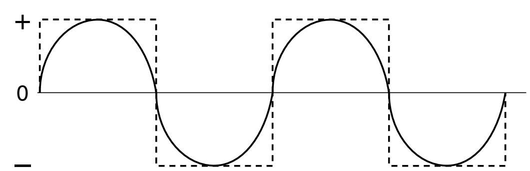


Figure 2.7 Advanced Squarewave superimposed over a sine wave.

Advanced Squarewave allows additional control over the alternating current waveforms. Figure 2.7 shows an AC sine wave and an Advanced Squarewave superimposed over it. Squarewave 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 Squarewave 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 the direction the output welding current will be traveling. The output frequency of Squarewave 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 advancements in design, the positive and negative amplitude of the waveform can be controlled independently as well as the ability to change the number of cycles per second. Alternating current is made up of direct current electrode negative (DCEN) and direct current electrode positive (DCEP). To better understand all the implications this has on AC TIG welding, let's take a closer look at DCEN and DCEP.

Direct Current

Direct current (DC) is an electrical current that flows in one direction only. Direct current can be compared to water flowing through a pipe in one direction. Most welding power sources are capable of welding with direct current output. They accomplish this with internal circuitry that changes or rectifies the AC into DC.

Figure 2.8 shows what one cycle of AC sine wave power would look like and what it would look like after it has been rectified into DC power.

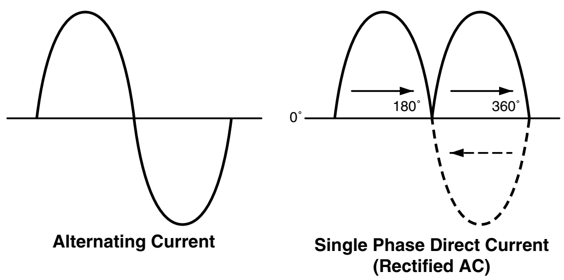


Figure 2.8 Single-phase AC — single-phase direct current (rectified AC).

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 resulting weld beads when they changed the battery connections. This polarity is best described by what electrical charge the electrode is connected for, such as direct current electrode negative (DCEN) or direct current electrode positive (DCEP). The workpiece would obviously be connected to the opposite electrical charge in order to complete the circuit. Review Figure 2.2.

When GTAW welding, the welder has three choices of welding current type and polarity. They are: direct current electrode negative, direct current electrode positive and alternating current. Alternating current, as we are beginning to understand, is actually a combination of both electrode negative and electrode positive polarity. Each of these current types has its applications, its advantages, and its disadvantages. A look at each type and its uses will help the welder select the best current type for the job. Figures 2.9 and 2.11 illustrate power supply connections for each current type in a typical 100 amp circuit.

Direct Current Electrode Negative
(Nonstandard Term is Straight Polarity)

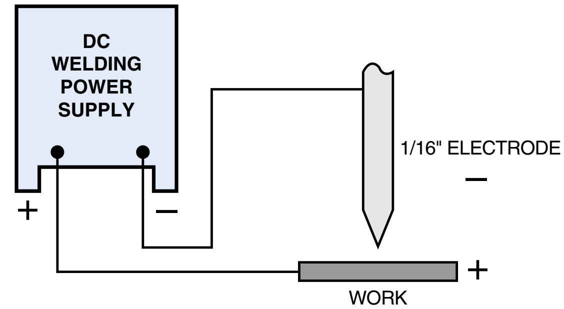


Figure 2.9 Direct current electrode negative.

Direct current 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 terminal. 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 workpiece. In a DCEN arc, approximately 70% of the heat will be concentrated at the positive side of the arc and the greatest amount of heat is distributed into the workpiece. 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 alternating current or direct current electrode positive polarity. This accounts for the higher current carrying capacity of a 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.

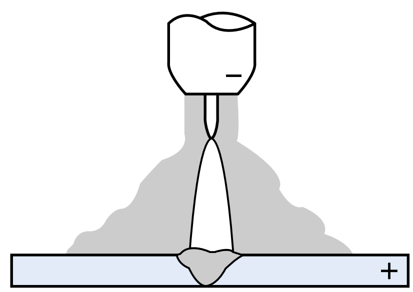


Figure 2.10 GTAW with DCEN produces deep penetration because it concentrates the heat in the joint area. No cleaning action occurs with this polarity. The heat generated by the arc using this polarity occurs in the workpiece, thus a smaller electrode can be used as well as a smaller gas cup and reduced gas flow. The more concentrated arc allows for faster travel speeds.

Direct Current Electrode Positive
(Nonstandard Term is Reverse Polarity)

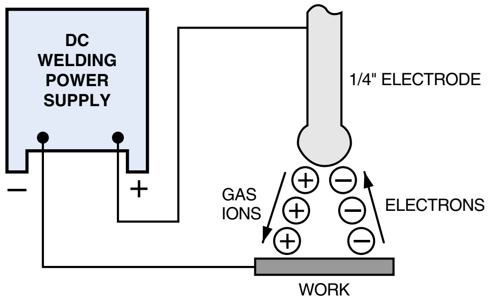


Figure 2.11 Direct current electrode positive.

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 low amperages are used, to prevent overheating and possible melting. The workpiece 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 will sometimes wander from side to side when making a fillet weld when two pieces of metal are at a close angle to one another. This phenomena 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 the fact that some non-ferrous metals, such as aluminum 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 aluminum, however, is one of the hardest materials known to man. Before aluminum can be welded, this oxide, because it has a much higher melting point than the base metal, must be removed. The 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 workpiece to the tungsten when welding with DCEN are now flowing from the tungsten to the negative workpiece with DCEP. They strike the workpiece with sufficient force to break up and chip away the brittle aluminum oxide, and provide what is called a cleaning action. Because of this beneficial oxide removal, this polarity would seem to be excellent for welding aluminum and magnesium. There are, however, some disadvantages.

For example, to weld at 100 amperes it would take a 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 workpiece, the resulting penetration would probably prove to be insufficient. If DCEN were being used at 100 amperes, a tungsten electrode of 1/16" would be sufficient. 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 aluminum. To obtain the advantages of both polarities, alternating current can be used.

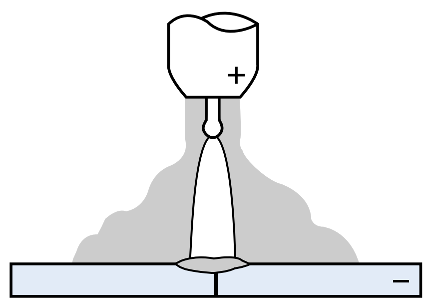


Figure 2.12 GTAW with DCEP produces good cleaning action as the argon gas ions flowing toward the work strike with sufficient force to break up oxides on the surface. Since the electrons flowing toward the electrode cause a heating effect at the electrode, weld penetration is shallow. Because of the lack of penetration and the required use of very large tungsten, continuous use of this polarity is rarely used for GTAW.

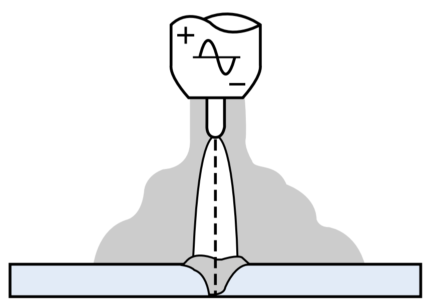


Figure 2.13 GTAW with AC combines the good weld penetration of DCEN with the desired cleaning action of DCEP. With certain types of AC waveforms high frequency helps re-establish the arc, which breaks each half cycle. Medium size tungstens are generally used with this process.

Welding with Alternating Current

When using alternating current sine waves for welding, the terms electrode positive (reverse polarity) and electrode negative (straight polarity) which were applied to the workpiece 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 alternating current, 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 positive and the electrode is negative. And there's 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 as seen in Figure 2.14.

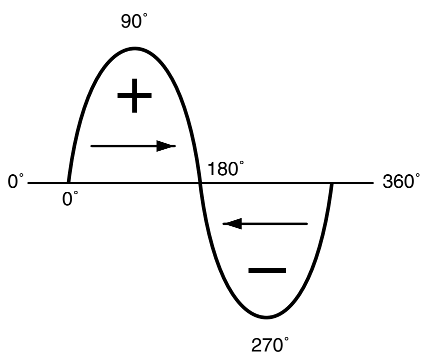


Figure 2.14 One complete cycle of AC sine wave showing reversal of current flow that occurs between the positive and negative half cycles. The degree symbol represents the electrical degrees. The arc goes out at 0˚, 180˚ and 360˚ and maximum amplitude is at 90˚ and 270˚.

Arc Rectification

When GTAW welding with alternating current, we find that the equal half cycle theory is not exactly true. An oscilloscope Figure 2.15 will show that the electrode positive half cycle is of much less magnitude than the electrode negative half cycle. There are two theories accounting for this. One is the oxide coating on nonferrous metals such as aluminum. The surface oxide acts as a rectifier, making it much more difficult for the electrons to flow from the work to the electrode, than from the electrode to the work. The other theory is that molten, hot, clean aluminum does not emit electrons as easily as hot tungsten. This results in more current being allowed to flow from the hot tungsten to the clean molten weld pool, with less current being allowed to flow from the clean molten weld pool to the electrode. This is referred to as "arc rectification" and must be understood and limited by the welder as indicated in Figure 2.16.

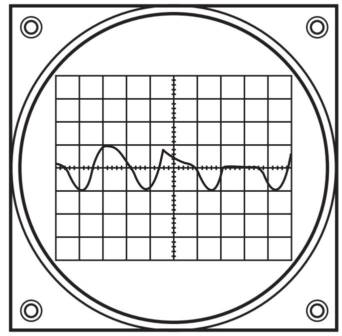


Figure 2.15 A reproduction of an actual unbalanced AC sine wave. *Note the positive half cycle is "clipped off". The missing portion was lost due to rectification of the arc. What can also be seen is a high current spike which can lead to tungsten breakdown and tungsten spitting.*

Arc Rectification

Indicators for the Welder	Results	Cures*
Arc noise	Tungsten inclusions	Don't dwell in the weld pool
Weld pool oscillation	Erratic arc	Add filler metal
Tungsten electrode breakdown	Lack of cleaning action	Keep arc moving along weld joint

*Power source of proper Advanced Squarewave design will eliminate this phenomenon.

Figure 2.16 Arc rectification.

Balanced and Unbalanced Waveforms

Squarewave 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 (cleaning) portion of the half cycle or electrode negative (penetration) 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.

Waveform Balance Control

	% Time Electrode Negative*	% Time Electrode Positive
AC sine wave power source	Not applicable, control not available	Not applicable, control not available
Squarewave	45 – 68	32 – 55
Advanced Squarewave	10 – 90**	10 – 90

*This time controls the penetration and is most advantageous. Set to as high a percentage as possible without losing the cleaning. Very rare to set below 50%.

**Note the expanded electrode negative time available on the Advanced Squarewave machine.

Figure 2.17 Balance control time available from different types of machines.

Balance Wave Control Advantages

Max Penetration is when the balance control is set to produce the maximum time at electrode negative and minimum time at electrode positive.

- Can use higher currents with smaller electrodes
- Increased penetration at a given amperage and travel speed
- Use of smaller gas cup and reduced shielding gas flow rate
- Reduced heat input with resultant smaller heat affected zone and less distortion

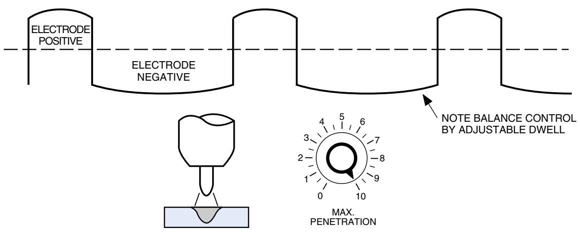


Figure 2.18 Maximum penetration balance control setting. The waveform has been set to an unbalanced condition, this allows more time in the negative half cycle where current flow is from the electrode to the work. (This produces more heat into the work and consequently deeper penetration.)

Balanced is when the balance control is set to produce equal amounts of time electrode negative and electrode positive. Thus on 60 Hz power, 1/120th of a second is spent electrode negative (penetration) heating the plate and 1/120th of a second is spent electrode positive (cleaning) removing oxides.

- Arc cleaning action is increased

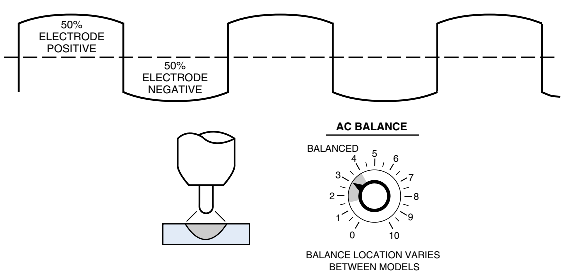


Figure 2.19 Balanced control setting. The waveform has been set to balanced. This allows equal time on each of the half cycles. *Note on this example balance occurs at a setting of 3 rather than at 5 as you might expect.* Other machines have digital read out that displays the exact % of time set. Whatever the method of setting, a plateau is reached where additional time in the positive half cycle is unproductive and will result in damage to the tungsten or torch. Therefore, most Squarewave machines will not permit settings that might cause damage to be made on the AC balance control.

Max Cleaning is when the balance control is set to produce the maximum time at electrode positive and minimum time at electrode negative.

- The most aggressive arc cleaning action is produced

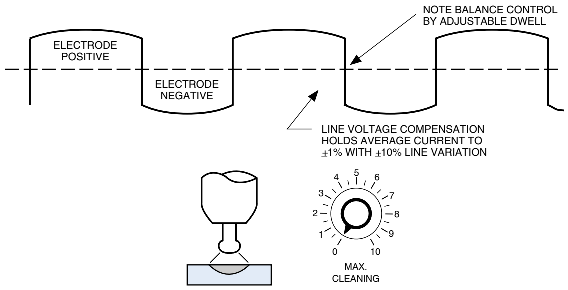


Figure 2.20 Maximum cleaning control setting. The waveform has been set to an unbalanced condition; this allows more time in the positive half-cycle where positive gas ions can bombard the work. Only a certain amount of total cleaning action is available, and increasing the time in the electrode positive half cycle will not provide more cleaning and may melt the tungsten, and damage the torch.

The benefits of the balance control should be well understood and applied in an appropriate manner. Figure 2.21 shows actual welds made at a given current and given travel speed with only the balance control being changed.

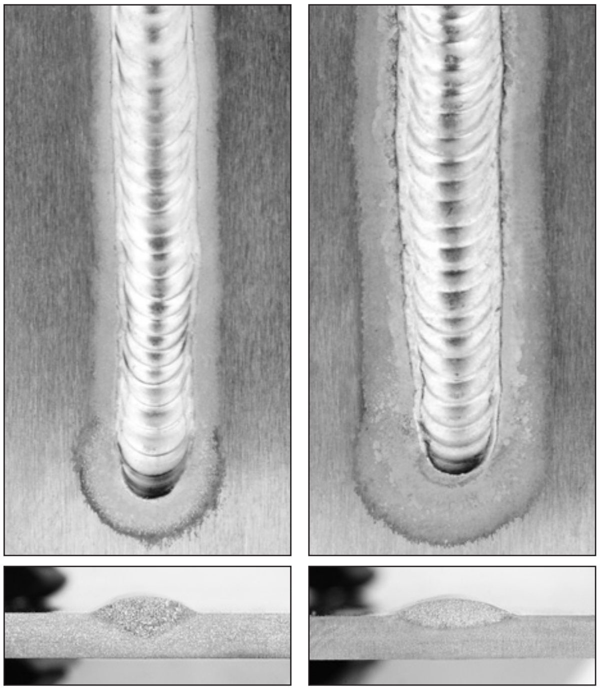


Figure 2.21 Note the variation in the cleaning band, and the weld profiles penetration pattern.

Adjustable Frequency (Hz)

As stated earlier in this section, alternating current makes constant reversals in direction of current flow. One complete reversal is termed a 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 60 Hz. This means there are 120 reversals of current flow direction through the arc per second. The faster the current going through the arc changes direction, increases the arc pressure making the arc more stable and directional.

Figure 2.22 shows an illustration of the frequency effects on a welding arc and the resultant weld profile.

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.

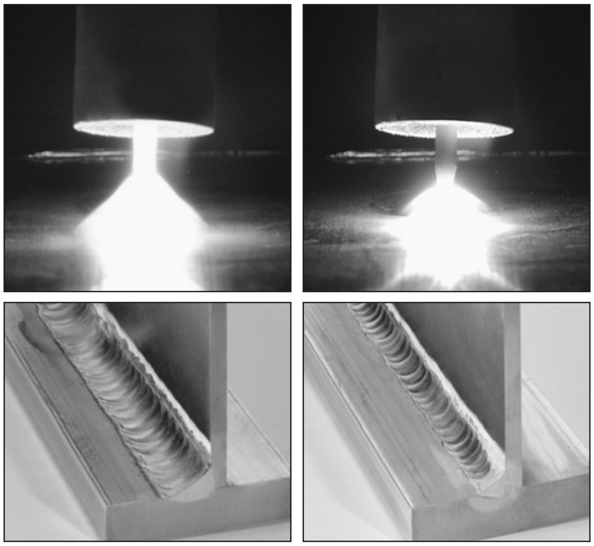


Figure 2.22 Normal 60 Hz arc compared to a 180 Hz arc. The current is changing direction 3 times faster than normal with a narrower arc cone and a stiffer more directional arc. The arc does not deflect but goes directly to where the electrode is pointed. This concentrates the arc in a smaller area and results in deeper penetration.

Frequency Adjustability

	Hz Range
AC sine wave power source	Not adjustable, must use what the power company supplies
Squarewave	Not adjustable, must use what the power company supplies
Advanced Squarewave	20 – 400

Figure 2.23 Frequency adjustment only available on the Advanced Squarewave designed power sources.

A lower than normal frequency (60 Hz) can be selected on the Advanced Squarewave power source, all the way down to 20 Hz, as indicated in Figure 2.23. 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. Figure 2.24 is an example of a high cycle arc on an aluminum fillet weld. Figure 2.25 is an example of an Advanced Squarewave power source capable of frequency adjustment and enhanced balance control.

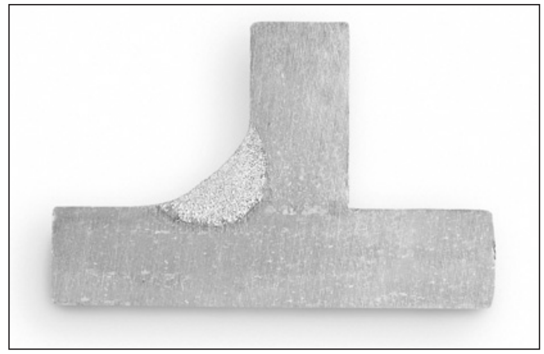


Figure 2.24 Advanced Squarewave arc at 180 Hz fillet weld on aluminum.

Figure 2.25 An Advanced Squarewave power source with arc frequency and enhanced balance control benefits.

Adjustable Frequency Advantages

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

Independent Current Control

The ability to control the amount of current in the negative and positive half cycle independently is the last item in the AC cycle that is controllable. Certain Advanced Squarewave power sources allow this control. These power sources provide separate and independent amperage control of the electrode negative (penetration) and electrode positive (cleaning) half cycles.

The four major independently controllable functions of the Advanced Squarewave AC power source are:

1. Balance (% of time electrode is negative)
2. Frequency in hertz (cycles per second)
3. Electrode negative current level in amps*
4. Electrode positive current level in amps*

*Specially designed Advanced Squarewave power sources only.

Figure 2.26 shows you what an Advanced Squarewave output might look like on an oscilloscope.

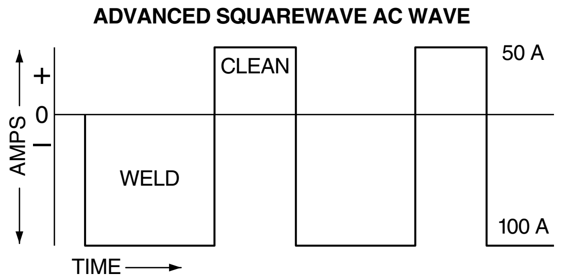


Figure 2.26 An Advanced Squarewave AC wave with independent current control.

The ability to control these separate functions with the Advanced Squarewave power source provides some unique advantages. A more efficient method of balancing heat input and cleaning action is available, which in turn, results in increased travel speeds.

The benefits of Advanced Squarewave forms go beyond increased travel speeds. This type of welding allows a narrower and deeper penetrating weld bead compared to that of Squarewave or sine wave machines. The Advanced Squarewave AC is capable of welding thicker material than Squarewave or sine wave power sources at a given amperage. Figure 2.27 shows an example of welds made with Squarewave and Advanced Squarewave power sources. Note with an extended balance control the etched cleaning zone can be narrowed or eliminated.

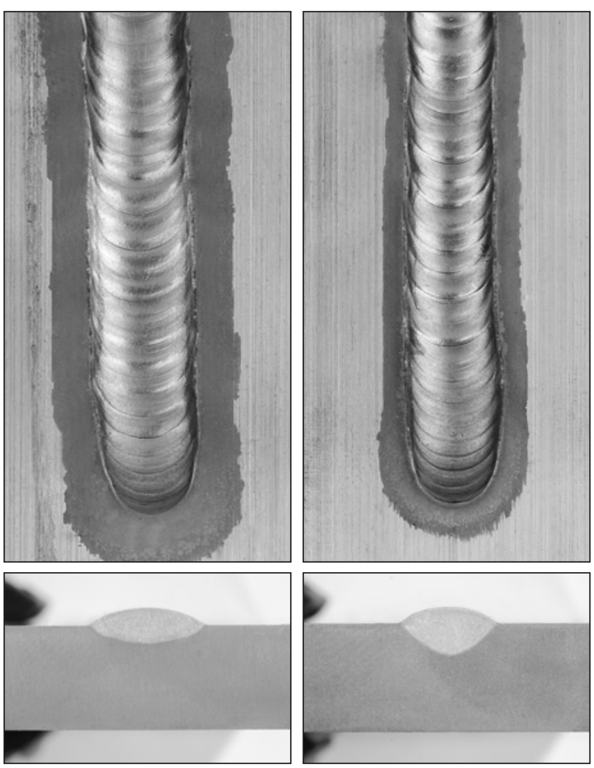


Figure 2.27 At 250 amps, note the weld profile comparison between the Squarewave and Advanced Squarewave on this 1/2" aluminum plate.

Figure 2.28 An Advanced Squarewave AC power source.

The transition through zero on Advanced Squarewave power sources is much quicker than Squarewave machines; therefore, no high frequency is required even at low amperages. High frequency is only used to start the arc and is not needed at all in touch start mode.

Advanced Squarewave Advantages

- More efficient control results in higher travel speeds
- Narrower more deeply penetrating arc
- Able to narrow or eliminate etched zone
- Improved arc stability
- Reduced use of high frequency arc starts
- Improved arc starting (always starts EP independent of current type or polarity set)

Controlling the Advanced Squarewave Power Source

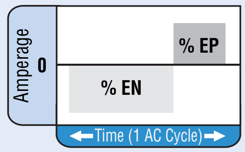
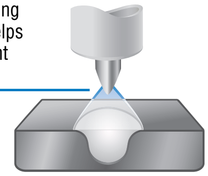
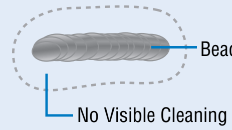
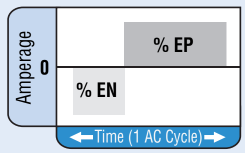
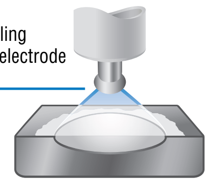
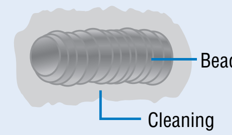
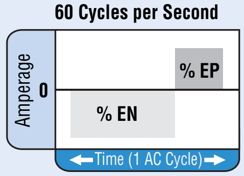
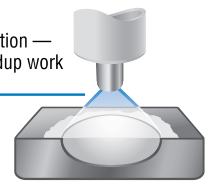
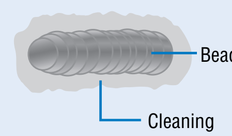
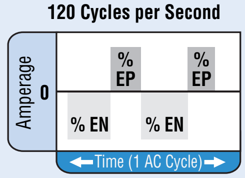
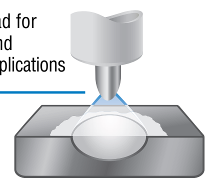
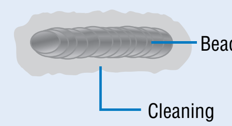
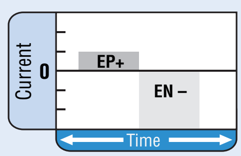
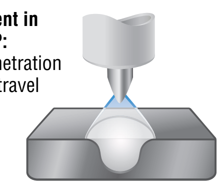
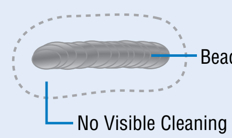
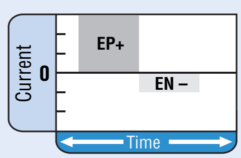
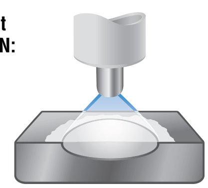
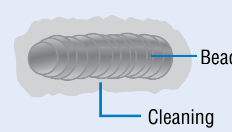
Feature	Waveform	Effect on Bead	Effect on Appearance
AC Balance Control Controls arc cleaning action. Adjusting the % EN of the AC wave controls the width of the etching zone surrounding the weld.	**51 – 99% EN** 	Reduces balling action and helps maintain point Deep, narrow penetration 	Narrow bead, with no visible cleaning 
	30 – 50% EN 	Increases balling action of the electrode Shallow penetration 	Wider bead and cleaning action 
AC Frequency Control Controls the width of the arc cone. Increasing the AC Frequency provides a more focused arc with increased directional control.	**60 Cycles per Second** 	Wider bead, good penetration — ideal for buildup work 	Wider bead and cleaning action 
	120 Cycles per Second 	Narrower bead for fillet welds and automated applications 	Narrower bead and cleaning action 
Independent AC Amperage Control Allows the EN and EP amperage values to be set independently. Adjusts the ratio of EN to EP to precisely control heat input to the work and the electrode.		**More current in EN than EP:** Deeper penetration and faster travel speeds 	Narrow bead, with no visible cleaning 
		**More current in EP than EN:** Shallower penetration 	Wider bead and cleaning action 

Figure 2.29 The Advanced Squarewave power source allows the operator to shape the arc and control the weld bead. Separately or in any combination, the user can adjust the balance control, frequency (Hz) and independent current control, to achieve the desired depth of penetration and bead characteristics for each application.

Note: All forms of AC create audible arc noise. Many Advanced Squarewave AC combinations, while greatly improving desired weld performance, create noise that may be objectionable to some persons. Hearing protection is always recommended.

Welding Fluxes for GTAW

As has been seen, the type of welding current and polarity has a big effect on welding penetration. Developments have been made in producing chemical fluxes that effect the surface tension of the weld pool molecules and allow improved penetration on certain metals. The flux is applied prior to welding and at a given amperage penetration will be increased. Figure 2.30 is an example of weld profiles with and without the use of this "Fast TIG Flux".

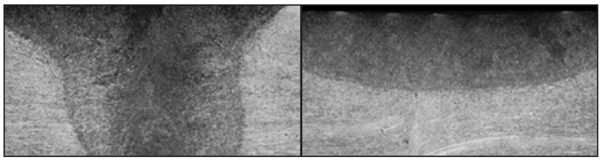


Figure 2.30 With and without use of FASTIG™ flux for enhanced penetration.

Arc Starting Methods

Gas Tungsten Arc Welding uses a non-consumable electrode. Since this tungsten electrode is not compatible with the metals being welded (unless you happen to be welding tungsten), it requires some unique arc starting and arc stabilizing methods.

Gas Ionization

Gas ionization is a fundamental requirement for starting and having a stable arc. An ionized gas, a gas that has been electrically charged, is a good conductor of electricity. There are two ways of charging this gas. Heat the gas to a high enough temperature and electrons will be dislodged from the gas atoms and the gas atoms will become positively charged gas ions. The heat of a welding arc is a good source for this thermal ionization. Unfortunately, when AC welding with conventional sine waves, as the current approaches zero there is not sufficient heat in the arc to keep the gas ionized and the arc goes out. The other ionization method is to apply enough voltage to the gas atom. The electrons will be dislodged from the gas atom and it is left as a positive gas ion.

High Frequency

This is a high voltage/low amperage generated at a very high cycle or frequency rate. Frequency rates of over 16,000 Hz and up to approximately 1 million Hz are typical. This high voltage allows for good arc starting and stability, while the high frequency it is generated at allows it to be relatively safe in the welding operation. Due to this high safe frequency, the high voltage ionizes the shielding gas, thus providing a good path for the current to follow. So the path between the electrode and the work becomes much more conducive to the flow of electrons, and the arc will literally jump the gap between the electrode and the workpiece. On materials sensitive to impurities, touching the tungsten to the work will contaminate it as well as the tungsten. This benefit of high frequency is used to start the arc without making contact with the work, eliminating this possible chance of contamination.

When alternating current first became available for SMAW, researchers immediately began looking for a means to assist the re-ignition of the arc during the positive half of the AC cycle. Shielded Metal Arc Welding electrodes at this time did not have arc stabilizers in the coating for AC welding. It was found that the introduction of a high frequency/high voltage into the secondary welding circuit of the power source assured arc re-ignition. This high-frequency source is actually superimposed on the existing voltage of the power source. The high frequency is used to eliminate the effects of the arc outage. While the primary 60 cycle current is going through its zero point, the HF may go through many cycles, thus preventing the arc from stopping. A common misconception is that the high frequency itself is responsible for the cleaning action of the arc. But the high frequency only serves to re-ignite the arc which does the cleaning. Figure 2.31 shows the relationship of superimposed high frequency to the 60 cycle frequency of the primary current.

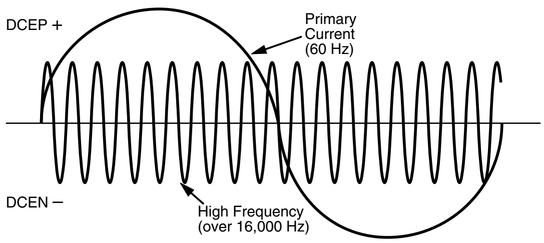


Figure 2.31 AC high frequency (not to scale).

With GTAW, high frequency is used to stabilize the arc. During the negative half of the AC cycle, electron flow is from the relatively small tungsten electrode to the much wider area of the pool on the workpiece. During the positive half cycle the flow is from the pool to the electrode. Aluminum and magnesium are poorer emitters of electrons when they are hot and molten than the hot tungsten. Plus the area of current flow on the molten weld pool is so much larger than the area on the end of the tungsten. The arc has a tendency to wander and become unstable. Because the high frequency provides an ionized path for the current to follow, arc re-ignition is much easier and the arc becomes more stable. Some power sources use high frequency for starting the arc only and some allow continuous high frequency to take advantage of its stabilizing characteristics.

High frequency has a tendency to get into places where it's not wanted and falls under control of the Federal Communication Commission (FCC). It can be a major interference problem with all types of electrical and electronic devices. See Figure 2.33 for installation information. The additional circuitry and parts required for the spark gap oscillator and its added expense is an additional drawback.

High-Frequency Usage

Control Setting	Effect	Application
OFF	Removes HF from the weld leads	For SMAW welding or where HF interference is a concern
Continuous	Imposes HF on the weld leads, all the time, when welding power is energized	For GTAW welding of the refractory oxide metals like aluminum and magnesium
Start only	Limit the time HF is imposed on the welding leads to when starting the arc	For GTAW DCEN welding of all metals that do not have refractory oxides (titanium, stainless steel, nickel, carbon steel, etc.)*

*Can also be used on aluminum and magnesium when welding with Advanced Squarewave power sources.

Figure 2.32 Explains proper use and applications.

1. Sources of Direct High Frequency Radiation
High frequency source (welding power source with built-in HF or separate HF unit), weld cables, torch, work clamp, workpiece, and work table.

2. Sources of Conduction of High Frequency
Input power cable, line disconnect switch, and input supply wiring.

3. Sources of Reradiation of High Frequency
Ungrounded metal objects, lighting, wiring, water pipe and fixtures, external phone and power lines.

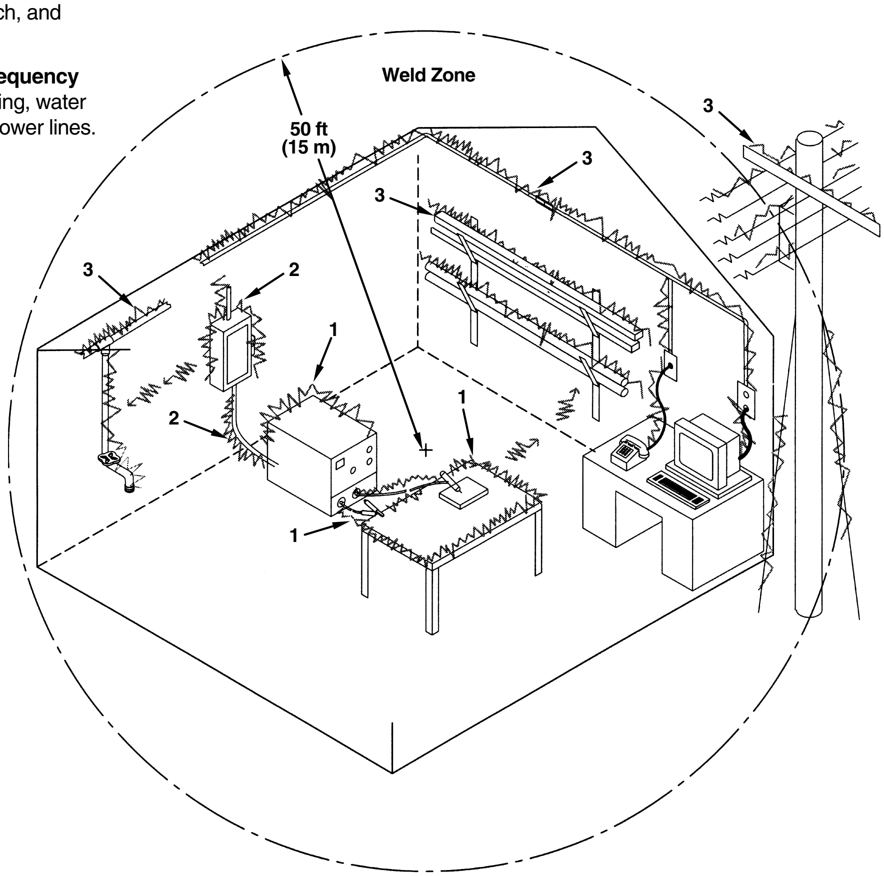


Figure 2.33 Illustrates sources of high-frequency radiation caused by an improper installation. The Federal Communications Commission has established guidelines for the maximum high-frequency radiation permissible.

Pulse Mode HF

These machines utilize special circuitry to impose a high intensity pulse on the output circuit when the voltage is at a specific value. Lets assume we have a machine that provides this pulse when voltage is 30 volts or more. When not welding, voltage (or pressure) is at maximum because no current is being allowed to flow and the pulsing circuitry is enabled. As the electrode is brought near the work, the pulses help jump start the arc and welding begins. Once the arc is started, weld circuit voltage typically drops to a value somewhere in the low teens to low twenties and the pulsing circuit senses this change and drops out. The pulse mode circuitry can also help stabilize the AC arc because it is enabled during times the voltage sine wave is transitioning through zero. The high intensity pulses do affect other electronic circuitry in the immediate vicinity, but the effect is not as pronounced as that of a high-frequency power source. You may find it necessary to move the electrode slightly closer to the workpiece to initiate the arc with pulse assist than you would with traditional high-frequency arc starting methods.

Lift-Arc™

Lift-Arc™ allows the tungsten to be placed in direct contact with the metal to be welded. As the tungsten is lifted off the part, the arc is established. This is sometimes referred to as touch start. Little if any chance of contamination is possible due to special power source circuitry. When the Lift-Arc switch is activated, lower power level is supplied to the tungsten electrode. This low power allows some preheating of the tungsten when it is in initial contact with the part. Remember hot tungsten is a good emitter of electrons. This power level is low enough not to overheat the tungsten or melt the work thus eliminating the possibility of contamination. Once the arc is established the power source circuitry switches from the Lift-Arc mode to the weld power mode and welding can commence. Figure 2.34 illustrates the proper techniques to use with the Lift-Arc starting method.

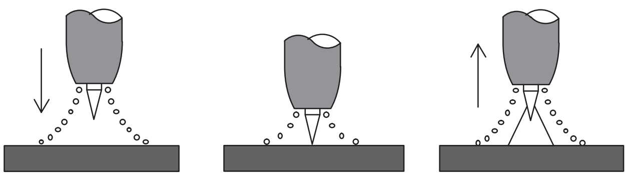


Figure 2.34 Proper arc starting procedure when using the Lift-Arc method.

Scratch Start

Scratch start is not generally considered an appropriate arc starting method as it can easily lead to contamination in the weld area. It is usually preformed when doing GTAW DC welding on a power source designed for SMAW only. These machines are not equipped with an arc starter so the only way to start the arc is with direct contact of the tungsten electrode with the metal. This is done at full weld power level and generally results in contamination of the electrode and or weld pool. This method as the name implies is accomplished much like scratching or striking the arc as would be done for Shielded Metal Arc Welding.

Capacitive Discharge

These machines produce a high voltage discharge from a bank of capacitors to establish the arc. The momentary spark created by these machines is not unlike a static discharge. Although capacitive discharge machines have good arc starting capability, they do not have the arc stabilization properties of high-frequency machines. They are typically used only for DC welding and not usable on AC welding.

Arc Starting

Methods	Alternating Current	Direct Current Electrode Neg.
High frequency	In continuous mode*	In start only mode
Pulse HF	In continuous mode*	In start only mode
Lift-Arc	Only with Advanced Squarewave power source**	Usable on any DC welding with appropriately equipped power source
Scratch start	Not recommended	Not recommended for x-ray quality welding due to tungsten inclusions possibility
Capacitor discharge	Not recommended	Usable on any DC welding with appropriately equipped power source

*With specially designed Squarewave power sources and Advanced Squarewave power sources it can be done in start mode as well.

**With specially designed Squarewave power sources appropriately equipped with Lift-Arc circuitry.

Figure 2.35 The various arc starting methods and applications of each.

Figure 2.36 A Squarewave GTAW welding power source.

Pulsed GTAW

Some of the advantages of Pulsed GTAW are:

- Good penetration with less heat input
- Less distortion
- Good control of the pool when welding out of position
- Ease of welding thin materials
- Ease of welding materials of dissimilar thickness

The main advantage of the Pulsed GTAW welding arc is that the process produces the same weld as a standard arc, but with considerably less heat input. As peak amperage is reached, penetration is quickly achieved. Before the workpiece can become heat saturated, the amperage is reduced to the point where the pool is allowed to cool but current is sufficient to keep the arc established. The pulsed arc greatly reduces the need to adjust heat input as the weld progresses. This gives the welder much greater pool control when welding out of position and in situations where joints are of differing thicknesses.

The basic controls for setting pulse parameters are:

Peak Amperage — This value is usually set somewhat higher than it would be set for a non-pulsed GTAW weld.

Background Amperage — This of course would be set lower than peak amperage.

Pulses Per Second — Is the number of times per second that the weld current achieves peak amperage.

% On Time — Is the pulse peak duration as a percentage of total time. It controls how long the peak amperage level is maintained before it drops to the background value.

Refer to Figure 2.37 to see what effect each of these settings has on the pulsed waveform.

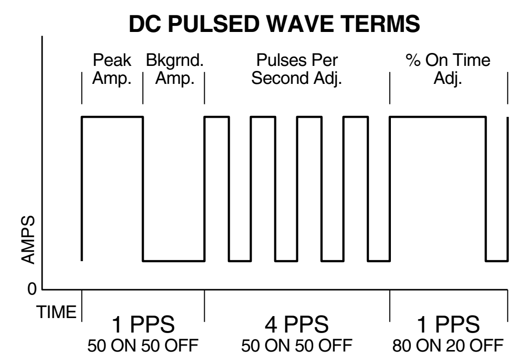


Figure 2.37 DC pulsed wave terms.

The pulsed waveform is often confused with the AC sine, or Squarewave. The AC sine wave represents direction of current flow in the welding circuit, while the pulsed waveform represents the amount and duration of two different output levels of the power source. The pulse waveform is not a sine wave at all. Note in Figure 2.37 that the actual output being displayed is direct current, and the signal does not switch between plus and minus values as it does in the AC sine wave. This is not to say that AC cannot be pulsed between two different output levels, as there are applications and power sources capable of doing just this.

High-Frequency Pulsed Welding

Although the majority of Pulsed GTAW welding is done in a frequency range of .5 to 20 pulses per second, there are applications where much higher frequencies are utilized. The advantage of high-frequency pulsing (200 to 500 pulses per second) is that the high-frequency pulse provides a much "stiffer" arc. Arc stiffness is a measure of arc pressure. As pressure increases, the arc is less subject to wandering caused by magnetic fields (arc blow). Welding with higher frequencies has also proven beneficial by producing better agitation of the weld pool which helps to float impurities to the surface resulting in a weld with better metallurgical properties. High-frequency pulsing is used in precision mechanized and automated applications where an arc with exceptional directional properties and stability is required. It is also used where a stable arc is required at very low amperages.

Since the electronic SCR and inverter type power sources have inherently very fast response time they can easily be pulsed. The SCR machines are somewhat limited in speed as compared to the inverters. However pulse controls are available for both types. They can be add-on controls like seen in Figure 2.38 or built directly into the power source.

Figure 2.38 An add-on pulse control for the SCR and inverter power sources.