

Gas Metal Arc Welding

HISTORY OF GMAW

Gas Metal Arc Welding (GMAW) is an arc welding process that joins metals. It does this by heating the metals to their melting point with an electric arc. The arc is between a continuous, consumable electrode wire and the metal being welded. The arc is shielded from contaminants in the atmosphere by a shielding gas.

GMAW had its beginning in the late 1940's. It was developed as a means to speed up welding being done by the Gas Tungsten Arc Welding (GTAW) process. GTAW is also an arc welding process shielded by a shielding gas, but GTAW uses a nonconsumable tungsten electrode. The filler rod for GTAW is generally added manually at a much slower rate.



GTAW worked very well on thin gauge material thickness. GMAW developed when GTAW proved to be too slow a process to weld thick sections of aluminum. GMAW became much more efficient and profitable for welding thicker materials. GMAW was therefore developed to make welding a faster, more profitable process.

During its early days, GMAW was generally accomplished with small diameter aluminum electrode wires, high amperage, and shielding gases that were inert (non-reactive). Because an inert gas was used, the term Metal Inert Gas, or MIG welding was used to refer to this process. This term is still a very common reference for the welding process, even though technically incorrect. The development and use of reactive shielding gases for carbon steels gave rise to the term Gas Metal Arc Welding, or GMAW.

Since its development there have been many advances in the GMAW process. These have included advances in power source and wire feeder technology along with new developments in electrode filler wire and shielding gases. In the 1960's it was found that there was a new way to weld with spray transfer GMAW, and not be limited to the flat and horizontal fillet weld joint positions. It was found that this variation of GMAW-spray transfer (pulsed spray transfer) would provide all position welding capability. Developments in pulsed spray transfer and the various power sources and controls, have increased the flexibility and use of this spray transfer variations.

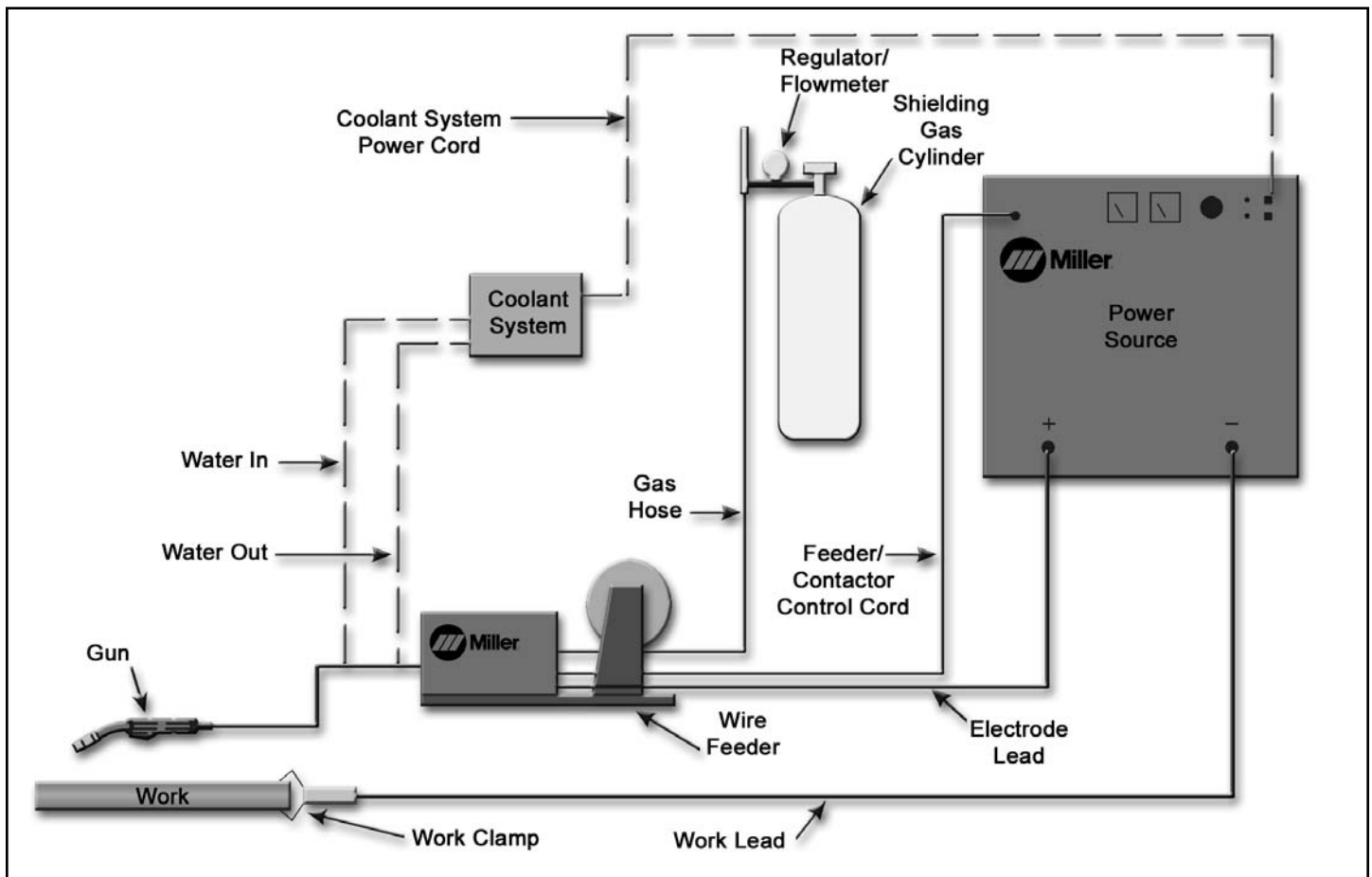
INTRODUCTION OF GMAW FUNDAMENTALS

TYPES OF GMAW

GMAW can be done in basically three different ways. Semiautomatic welding means that the equipment controls only the electrode wire feeding. The movement of the welding gun is controlled by hand. This is sometimes called hand held welding. Machine welding uses a gun that is connected to a manipulator of some kind (not hand held). An operator has to constantly set and adjust controls that move the manipulator. Automatic welding uses equipment that welds without the constant adjusting of controls by a welder or operator. On some equipment, automatic sensing devices control the correct gun alignment in a weld joint.

GMAW EQUIPMENT SETUP

A GMAW semiautomatic set-up may include a constant voltage welding power source with a constant speed wire feeder or a voltage sensing wire feeder, or a constant current welding power source may be used with a voltage sensing wire feeder. The choice of what type of welding power source and feeder to use will be determined by the mode of GMAW transfer desired. The welding machine provides welding electrical power, the wire feeder controls the supply of wire to the welding gun. The welding gun directs the electrode wire into the weld joint. The shielding gas provides arc area protection and helps determine weld arc characteristics.



Basic GMAW Equipment

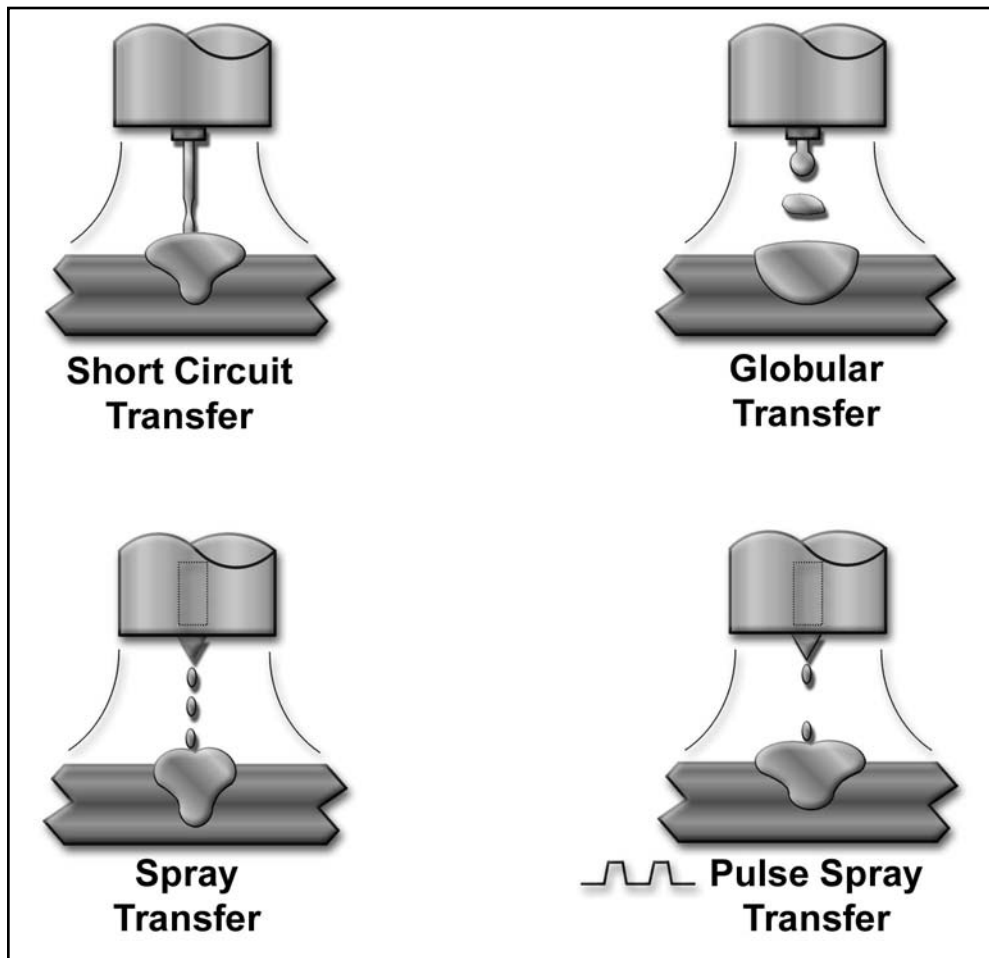
MODES OF GMAW TRANSFER

Definition

The term modes of transfer is used to describe the process by which the wire electrode is melted and deposited into the puddle. The most common way to classify metal transfer is according to the size, frequency, and characteristics of the metal drops being transferred. There are four modes of metal transfer:

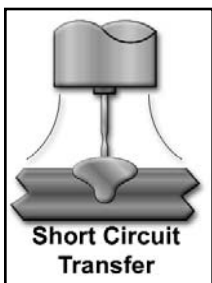
1. Short Circuit Transfer
2. Globular Transfer
3. Spray Transfer
4. Pulsed-Spray Transfer

The stability of the welding arc and the metallurgical changes in the electrode wire are dependent on the mode of transfer. Welding procedures are categorized according to the mode of transfer.



Modes of GMAW Transfer

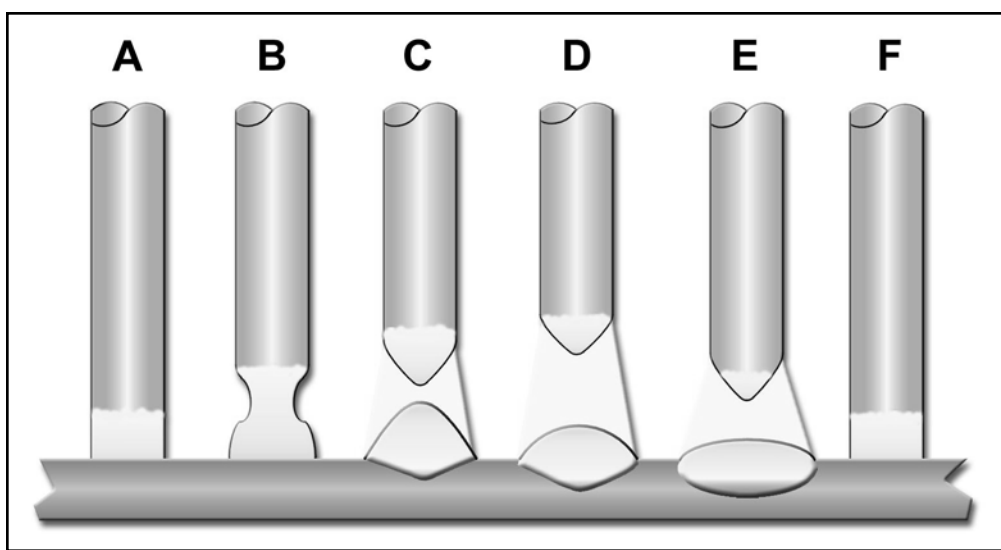
SHORT CIRCUIT TRANSFER (SCMT)



Short circuit transfer gets its name from the welding wire actually "short circuiting" (touching) the base metal many times per second. When the welding gun trigger is pressed, the electrode wire feeds continuously from the wire feeder, through the gun, and to the arc area, short-circuiting to the base metal, exploding and establishing an arc. While welding, this cycle can repeat itself between 20 and as much as 250 times per second.

An average welding condition would have between 90 and 150 short circuits per second. The number of short circuits per second will depend upon such things as the welding machine's volt/ampere slope and inductance settings, the diameter of wire being used and the wire feed speed (WFS) that is set on the wire feeder. The faster the wire feed speed, the more short circuits per second and also an increase in amperage.

The sequence of events in the SCMT is shown in Figure 1 at A the electrode has come out of the gun's contact tube and touched, or "short circuited" to the base metal. There is no arc, and current is flowing through the electrode wire and base metal. In B, the heat of the current flow is causing a magnetic field to envelope the electrode wire. The properties of the electrode wire have difficulty conducting all the current flowing through the electrode wire. The resistance increases in the electrode wire causing it to heat, melt, and "neck down." At C the electrode wire separates from the weld puddle, creating an arc. A small portion of electrode wire is deposited, which becomes part of the weld puddle or pool. At D the arc length, and load voltage are both at maximum. The heat of the arc is changing the shape of the weld puddle and the end of the electrode. It is "wetting out" the puddle (flattening it) and also increasing the diameter of the tip of the electrode wire. At E, the wire feed speed has overcome the heat of the arc, and the wire approaches the base metal again. Notice how the weld puddle has flattened out while the arc is "on." At F, the arc is again off as at A because the wire is touching the base metal again, and the short circuit cycle starts again. This short circuit cycle takes place 90 to over 200 times per second.



Mechanics Of Short Circuiting Transfer

With short circuit metal transfer, wire feed speeds, voltages, and deposition rates are usually lower than with other types of metal transfer. Short circuit metal transfer is a very versatile transfer, which allows welding in all positions on all metal thicknesses.

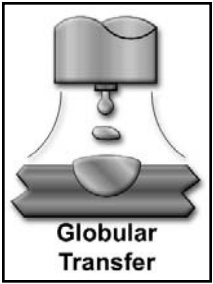
Limitations of short circuit transfer may include:

1. A relatively low deposition rate
2. Lack of fusion on thicker metals
3. More spatter

Each mode of metal transfer has a particular sound. Short circuit transfer is usually a crackling (bacon frying) sound.

GLOBULAR TRANSFER

A globular transfer for GMAW is often referred to as the state of transfer between short-circuiting and spray arc transfer. Large "globs" of weld metal transfer across the arc in a gravity transfer. The droplets are usually larger than the electrode wire. Although the electrode wire is pinched off at the arc, globular transfer does not achieve a true spray transfer. Globular is a more unstable transfer, with a less smooth weld bead appearance.



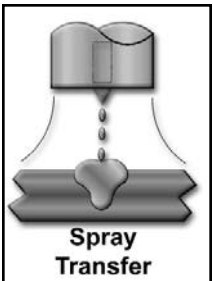
Globular transfer can, in many cases, yield more spatter. Since spatter is waste, it is not a desirable side effect of globular transfer. Globular transfer can also cause cold lapping or incomplete fusion due to the large metal droplets splashing metal out of the puddle.

Globular transfer is often a high voltage, high amperage, high wire feed speed transfer, and is the result of using CO₂ shielding gas (or 75% AR-25% CO₂) with parameters higher than the short-circuiting range. One popular use of globular transfer is a mild steel electrode wire and CO₂ shielding gas. This combination yields good penetration, and the CO₂ shielding gas is less expensive than many mixed gases. Some welders may refer to welding with 100% CO₂ or 75% Argon and 25% CO₂ gases as being spray transfer, but technically at about 22 volts and higher, it is always a globular transfer. Also, production applications often find success using 75% Argon and 25% CO₂ at amperages and voltages above short circuit transfer, but below spray arc transfer. An example is fillet welds on 1/4-inch mild steel, flat position using .035" wire at 350 IPM and 25 volts. The arc sounds and looks like a short circuit, but is actually a modified spray or could also be called globular transfer.

Limitations of globular transfer include:

1. The presence of spatter
2. A less desirable weld appearance than spray or pulsed spray transfers
3. Welding limited to flat position and horizontal fillet welds only
4. Welding limited to metal 1/8" or thicker

SPRAY TRANSFER



A spray transfer "sprays" a stream of tiny molten droplets across the arc, from the electrode wire to the base metal. These molten droplets are usually smaller than the diameter of the unmelted electrode wire. The arc is said to be "on" all of the time, once an arc is established. The spray transfer uses relatively high voltage (24 volts or higher depending upon the type of shielding gas), wire feed speed and amperage values, compared to short circuit transfer.

Because of the high voltage, wire feed speed and amperage, there is a resulting high current density. The high current density produces high metal deposition rates. The high degree of heat in the spray arc weld puddle makes for a larger weld puddle that is more fluid than the weld puddle for short circuit transfer. Because of this heat and the size of the weld puddle, spray transfer is somewhat limited in welding positions. The heat and size of the weld puddle also limits spray transfer to material 1/8" or thicker. Welding steel with spray transfer is usually done in the flat position, and the horizontal fillet weld position. Horizontal position spray arc welds are lap and T- joint fillet welds.

Because of the higher heat input, spray arc transfer is normally used on thicker metals. The high heat input could cause excessive melt-thru on thinner metals.

To achieve a true spray transfer, an argon-rich shielding gas must be used. Usually a gas mixture of over 80% argon is used, with the remainder being a gas that gives special metal transfer characteristics, such as oxygen or CO₂ or a combination of oxygen and CO₂.

Advantages of spray arc transfer include:

1. High deposition
2. Good fusion and penetration
3. Good bead appearance
4. Capability of using large diameter wires
5. Presence of very little (if any) spatter

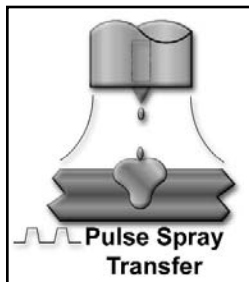
Limitations of spray arc transfer include:

1. Used only on material 1/8" and thicker (hand held)
2. Limited to flat and horizontal fillet weld position (except for some spray transfer on aluminum)

3. Good fit-up is always required as there is no open root capability
 When proper parameters are used, the spray arc transfer produces a characteristic humming or buzzing sound.

PULSED-SPRAY TRANSFER

In pulse spray transfer (GMAW-P) the welding power source's pulse control pulses the welding output with high peak currents (amperage) which are set at levels which will cause the transfer to go into a spray. The background current (amperage) is set at a level that will maintain the arc, but is too low for any metal transfer to occur.



Because there is no metal transfer during the background portion of the cycle, the weld puddle gets a chance to freeze slightly. This is unlike a spray transfer, where drops of molten metal are continuously transferred.

This faster-freezing weld puddle is what allows the pulsed-spray transfer to be used for thinner metals, and for better control on out-of-position work. GMAW-P often allows for larger wire sizes to be used on varied metal thicknesses. This is especially helpful for feeding aluminum wires through conventional (push vs push/pull) type gun assemblies.

Pulsed-spray transfer is often used to provide all-position welding on both light and heavy gauge metal thicknesses. A conventional spray arc type transfer could "roll out" of the weld puddle when welding out-of-position, or burn through could occur on thin metals. The pulse-spray transfer can help avoid this by producing the low average current.

Table 1 compares minimum current for spray transfer and pulsed-spray transfer. Notice how much lower the values are for pulsed-spray transfer.

Because heat input is lower, pulsed-arc spray transfer also allows for welding thinner materials with minimum distortion. For gauge material as well as out-of-position work, the advantages are due to the unique metal transfer.

Table 1. Minimum Currents - Spray Transfer vs. Pulsed - Spray Transfer

Wire Electrode Type	Wire Electrode Diameter		Shielding Gas	Minimum Spray Arc Current	Minimum Pulse Spray Average Current
	mm	in			
Mild Steel	0.89	.035	98% Argon – 2% Oxygen	165	48
Mild Steel	1.14	.045	98% Argon – 2% Oxygen	220	68
Stainless Steel	0.89	.035	99% Argon – 1% Oxygen	170	57
Stainless Steel	1.14	.045	99% Argon – 1% Oxygen	225	104
Aluminum	1.19	.047	100% Argon	135	44
Aluminum	1.59	.062	100% Argon	180	84
Silicon Bronze	0.89	.035	100% Argon	165	107
Silicon Bronze	1.14	.045	100% Argon	205	133

GMAW VARIABLES

WIRE FEED SPEED - AMPERAGE

Amperage is the term used when referring to the rate of current flow. (Amperage and current mean the same thing.) Amperage flows in a conductor, such as a welding cable, and provides the power needed for the welding arc. Amperage is measured as the amount of current flowing past a given point in one second. Amperage has the most effect on weld penetration.

Wire feed speed (WFS) refers to the rate at which the continuous electrode wire is fed out of the gun, through the contact tube, and into the weld puddle. This rate is usually measured in inches per minute and/or meters per minute.

For GMAW with CV welding machines, amperage (current) is controlled by wire feed speed. If wire feed speed is increased, amperage is increased. If WFS is decreased, amperage is decreased. This control for WFS can be adjusted whether or not welding is being done at the time.

In some cases, a welder may be welding according to a specific weld procedure. This procedure will call out a wire feed speed value that must be followed. When this is the case the welder must measure the WFS, or use a digital wire feed speed control.

Sometimes a welder may not have a procedure or guideline to follow. It is then up to the welder to "fine tune" or set up the parameters to make a good weld. Like setting voltage, the WFS setting can be set by a second person as welding is being done, or the welder can set it between trial welds on scrap metal. Digital readout WFS can often be preset by the welder. It is usually suggested that only one variable be changed at a time while fine tuning or setting up a welding situation.

Many variables can affect a fine tuning situation to get a good welding condition. These include metal thickness, type of welding joint, the position in which the welding is to be done, electrode wire size, type of gas being used, and the temperature of the metal being welded.

The thickness of the base metal to be welded is a good determining factor for the initial amperage selection. (Remember, current and amperage mean basically the same thing.) However, the final "fine tuning" of the WFS (amperage) will depend on several things, such as joint position, joint design, shielding gas, fit-up, material temperature, travel speed, and welder skill.

A good rule of thumb for a welder is to allow one ampere for every .001" (one one-thousandth of an inch) of metal thickness. Table 2 shows various metal thickness and amperages using this welder's rule of thumb. For comparison purposes, the nearest fraction of an inch is shown for the gauge thicknesses.

Rule of Thumb Metal Thickness-Amperage Needed

Gauge Number	Nearest Fraction Of An Inch	Rule Of Thumb Amperage
18	3/64" = .047	47
16	1/16" = .062	62
14	5/64" = .078	78
12	1/10" = .100	100
10	1/8" = .125	125
8	5/32" = .156	156
6	3/16" = .187	187

As can be seen in Table 2, the start point or "ballpark" amperage selection depends upon material thickness. Less amperage is needed for welding thinner materials, and more amperage is needed for welding thicker materials. As will be explained later, less amperage is also needed for situations where there is a greater than normal gap between material being welded. Also, less amperage may be required when welding in a position other than in the flat, "downhand" position.

For example purposes, we will discuss setting wire feed speed (amperage) for four commonly used wire sizes for short circuit transfer on mild steel. They are: .023", .030", .035" and .045" wire diameter.

To determine which wire diameter would be best for a given metal thickness, a welder looks at the "ballpark" amperage for the particular material thickness being welded. Then the welder can consult a chart showing an amperage range for the particular wire size. Table 3 shows amperage ranges that can be used for the four sizes of wire most often used for short circuit transfer. (These wires could also be used for spray transfer with higher amperage and voltage values.)

**Table 3. Wire Size - Amperage Range - WFS Range Relationships
For Short Circuit Transfer On Steel**

Wire Size	Amperage Range	Wire Feed Speed Range
.023"	30 – 90	100 – 400
.030"	40 – 145	90 – 340
.035"	50 – 180	80 – 380
.045"	75 – 250	70 – 270

As can be seen in Table 3, the amperage ranges overlap somewhat. In some cases one wire size may be just as acceptable as the next. However, as a welder learns more about certain factors, it will become easier to choose a wire size. These factors include: deposition rates, spatter losses, material types and thicknesses, type of shielding gases, joint designs, etc.

For example, if 1/8" thick steel material is to be welded, the "ballpark" rule of thumb current setting is 125 amps (see Table 2). .035" diameter electrode wire would be a good choice because 125 amps is closer to the middle of the amperage range for .035" wire than it is for .030" wire. This can sometimes help avoid weld defects. If the amperage and voltage values are too close to the higher range of the wire size, the type of weld transfer may change. That is, a short circuit transfer could change to a globular or spray arc transfer. This could result in a bad weld. Therefore, even if amperage ranges overlap for two wires, the final weld amperage and voltage used should be closer to the middle range of one of the wire sizes.

Once a wire size has been selected for a given material thickness and amperage range, a welder has to set the proper wire feed speed (WFS) to obtain the desired amperage (current). The chart above shows wire sizes and their amperage ranges. It also shows wire feed speed ranges for the four common wire sizes for short circuit transfer welding of steel. By properly setting the wire feed speed control on a wire feeder, proper amperage will be obtained.

Another rule of thumb or "ballpark" approach to setting the WFS is shown below. Usually these inches-per-amps estimates work best in the middle amperage range for a particular wire size. That is, at either the low end or high end of an amperage range for a wire size, these estimates are not quite as accurate. Also, these inches-per-amp figures may vary from one model welding machine and wire feeder to another. This is due to each models volt/amp curve.

RULE OF THUMB:

1 ampere for every .001 thickness

1/8" material = .125 = 125 Amperes

Wire Burn Off:

.023 - 3.5" wire/amp - 125 amps = 437 IPM

.030 - 2" wire/amp - 125 amps = 250 IPM

.035 - 1.6" wire/amp - 125 amps = 200 IPM

.045 - 1" wire/amp - 125 amps = 125 IPM

Direct Current Electrode Negative (DCEN) settings will also vary considerably over the more commonly used Direct Current Electrode Positive (DCEP).

Actual inch per minute (IPM) settings that are found to be successful should be recorded. This way it can be referred to for future reference, or if the same job will be done again later.

An example of how to use this rule of thumb for determining wire feed speed (WFS) in inches per minute (IPM) is as follows: A wire diameter size .035 is chosen to weld on 1/8" steel material.

The "ballpark" amperage setting will be 125 amps.

Calculate:
$$\begin{array}{r} 125 \text{ amps} \\ \times 1.6 \text{ wire feed speed needed per amp} \\ \hline 200 \text{ IPM required wire feed speed setting} \end{array}$$

In many instances, wire feed speed is set by a rheostat control on a wire feeder. This control is usually marked as a percentage of the lowest and highest wire feed speed that the wire feeder is capable of. (That is, think of a feeder with a range of 70-750 IPM for example. 0% on the rheostat would be 70 IPM, and 100% on the rheostat would be 750 IPM.)

Wire can be fed out of the gun through the contact tube by an Inch (Jog) Switch or Button on the wire feeder (if the wire feeder used has this type of control).

Otherwise, the wire can be fed out of the gun by pressing the trigger switch on the gun, taking care not to let the wire touch the work piece. (This avoids the hazard of an unwanted arc, and "weld flash.") WFS is then determined by measuring a length of wire in a particular time period, and then converting to inches per minute. Manual measuring of WFS requires a tape measure at least six feet in length.

It also requires a timepiece that will measure time in seconds. However, any watch or clock that reads seconds will work. (If no clock is available, count "one thousand and one, one thousand and two", etc.)

By the time a welder gains some experience in welding, WFS can often be adjusted by the sound of the arc, and by the looks of the weld.

To determine the wire feed speed:

1. Turn "on" the welding machine and the wire feeder.
2. Set the wire feed speed control on the wire feeder to the midpoint setting, or 50%.
3. Cut the welding electrode wire flush with the end of the contact tube.
4. Press the welding trigger (or Inch or Jog Control on the wire feeder), and allow the electrode wire to feed for six seconds. Be very careful that the wire does not strike any objects.
5. Measure the length of the welding wire fed, from the contact tube to the end of the wire.
6. Multiply this length times 10. This will give you inches per minute (IPM).

VOLTAGE

To better understand the GMAW process, it will be helpful to understand the basics of voltage. Voltage (often symbolized by "E") is a force that overcomes a resistance (R) and allow current to flow. Remember, voltage does not flow, but it does cause electrons to become excited and thus move through a completed circuit. This movement of electrons is known as current flow and can be referred to as amperage (I).

CONSTANT CURRENT (CC)

Constant Current type welding machines set amperage. They are also referred to as variable voltage (VV) or Drooper type welding machines.

CONSTANT VOLTAGE (CV)

Constant Voltage type welding machines set voltage. They are also referred to as constant potential. They provide a relatively flat volt-ampere output characteristic.

There are three kinds of voltages that we are concerned about in welding. These are: Open Circuit Voltage (OCV), Load Voltage and Arc Voltage.

OPEN CIRCUIT VOLTAGE (OCV)

Open circuit voltage is determined when the welding machine is turned on but no welding is being done. Even though no welding is being done, as soon as the contactor is energized there is voltage present at the secondary output terminals of the welding machine. This is the voltage available before welding. The current flow at this point is zero because there is not a completed electrical circuit.

LOAD VOLTAGE

Load voltage is measured while there is welding being done. It is present at the secondary output terminals of the welding machine. It includes both the arc voltage and the "voltage drop" through the connections and weld cables. Load voltage is read on a welding machine that has meters. Amperage (current) is flowing in the welding circuit when load voltage is present.

ARC VOLTAGE

Arc voltage can only be measured near the welding arc. This is the voltage measured between the tip of the unmelted electrode wire and the surface of the weld puddle. A voltmeter can be connected between the gun head tube and the work piece. This is accurate enough in most cases.

Arc voltage is important for many reasons. First of all, it is one of the main factors for determining heat input into metal. Another reason is that it is a setting that may be recorded and used as a reference point to do identical jobs at different times. Usually a welder never sees his own arc voltage readings. Therefore, he must have something else to go by. Fortunately, there is a definite relationship between arc voltage and arc length - the welder can see arc length.

When setting voltage, many welders refer to the voltage reading on a welding machine voltmeter as the "arc voltage" when welding. This is not technically correct. There can be a voltage drop from the load voltage shown on the voltmeter, to the actual arc voltage at the arc. When conditions are right, the load voltage can be quite close to actual arc voltage. This is the case when weld cables and equipment are properly connected, and

weld cables are the correct size and relatively short.

For instance, a weld procedure may call for 19 arc volts. A typical GMAW setup will have 10-15 foot gun and work cables (leads). These cables can account for about a 1-volt voltage drop. If this is the case, a particular machine can be set to read 20 load volts when a welding procedure calls for 19 arc volts.

A welding procedure should specify arc volts. Because there are many different types of GMAW setups, the voltage drop value can change. Thus, specifying arc voltage will give more consistent welds.

Other than across the arc, there are many places in the welding circuit where a voltage drop may occur. If long cables or too small of diameter cables are used, a voltage drop of more than one or two volts can occur between load and arc voltage. These weld cables should be of proper size diameter to have enough amperage carrying capability. This will help to avoid excessive (more than four volts) voltage drop. Also, after welding for a time, if either the connections or the cables themselves become warm, high resistance is present. This can cause unwanted voltage drop, which can lead to bad welds or a need to constantly change the voltage setting on a CV machine.

Another voltage change that is often referred to as voltage drop is the difference between OCV and load volts. Knowing what voltage is needed for welding can make setting up a welding condition easier. By knowing how much the voltage will drop from OCV to load voltage, the welder can simply set the OCV. This is adequate for setting the arc. Running a practice weld while someone watches the machine's voltmeter will show load voltage.

Manufacturer's recommendations should be followed as to a particular machine's voltage setting. Since there are so many different types of GMAW CV welding machines, the voltage drop from OCV to load and arc voltage varies widely.

Also, some machines set OCV, while others permit presetting load voltage or arc voltage. It is important to know the machine's characteristics so that voltage can be set properly.

Figure 1 shows that changing the voltage will change the size of a weld (while keeping amperage [WFS]) the same.

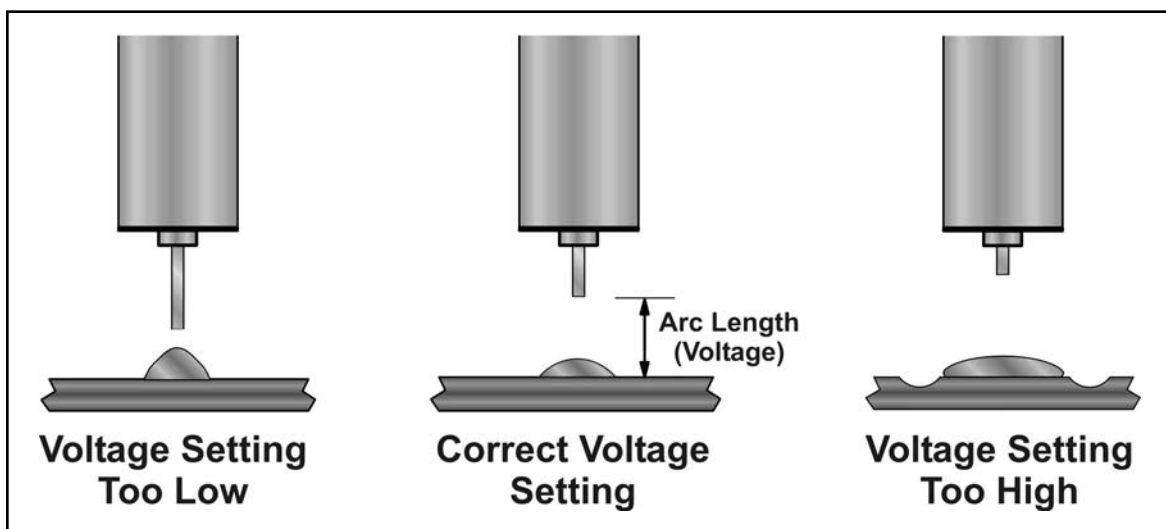


Figure 1. Voltage - Bead Changes

As you can see in Figure 1, for a given current, a short arc length (less voltage) yields a humpy, narrow bead. A longer arc length (more voltage), yields a wider, flatter bead. Too much arc length (too much voltage), yields a very flat bead and a possibility of undercut. It may also cause "burn back" or welding of the electrode wire to the contact tube. Obviously, arc voltage is the main tool used to control the height and width of the weld bead shape. We say that voltage "wets out" the weld bead.

ADJUSTING THE VOLTAGE

Most voltage (and WFS) controls are designed to be adjusted whether or not welding is being done at the time. However, if there is a load voltage range switch or a jack-plug type control, it should not be switched while welding is being done, or under load.

When adjusting the voltage (and WFS) for a welding job, it is common to "fine tune" the parameters on scrap metal first. Whether a weld procedure is used or not, the welder should be skilled enough to judge if the voltage and amperage (WFS) are proper. If they are not, a supervisor should be notified as to the possible problems.

SETTING VOLTAGE FROM A WELD PROCEDURE SPECIFICATION (WFS)

In many cases when welding must be done, specific guidelines are set up for that particular weld. These guidelines are tested beforehand and should be strictly followed. In some cases, the weld procedure may give a range of Arc Voltage, such as 19-21 volts. Therefore, an allowance must be made for voltage drop. For most GMAW setups with 10-15 foot gun and work leads, this voltage drop will be about 1 volt. To offset this, add 1 volt to the welding machine voltage reading.

If the given arc voltage range is 19, 20 or 21 volts, actual readings of the voltage meter should be 20, 21 or 22 volts respectively. (Another person can check these machine readings when trial settings must be done.)

Keep in mind that digital meters are usually more accurate and easier to read than conventional type meters. Also, on a digital voltmeter with all conditions correct, preset load voltage is normally very close to the desired arc voltage. This can be an important consideration when welding procedures are being used.

OTHER WAYS TO SET VOLTAGE

When the electrode wire diameter and amperage (WFS) have been selected, sometimes there is no chart to recommend a voltage. In many cases, with experience a welder will come to know a ballpark voltage value.

A method to determine the correct voltage is to start welding on a scrap piece of metal. While a partner watches the welding machine meters, the welder strikes an arc. The partner slowly decreases the voltage by turning the voltage adjustment dial until the wire starts "stubbing" into the base metal (work piece). When this occurs, stop and record this voltage.

Next, start welding again and have a partner slowly increase the voltage until the arc becomes unstable and sloppy. The voltage is too high, so the arc is too long. The puddle is quite large, and the metal starts to transfer across the arc in the form of large drops. Again, stop welding and record this voltage reading on the meter. (Or, if no meters, record the dial setting, switch range, jack plug tap, or whatever means is used for varying the voltage.)

Now, take the two voltages arrived at - high and low - and set the voltage to the middle of these values. Then check to see if this yields a good arc. Example: Low voltage is 16. High voltage is 24. Set the voltage for 20.

This method of finding the best voltage for the wire feed speed used gives the welder some leeway for welding gun movements. That is, if the welder's gun moves up or down slightly from the work piece, the arc should remain fairly stable. The welding machine will adjust for this slight movement. This is if the voltage is set in the midrange for the WFS being used.

Another method for arriving at a correct voltage and amperage (WFS) depends upon the sound of the arc. Another way is by sight, or the appearance of the weld bead.

Many welders learn to identify a type of crackling sound that is present with a good short circuiting condition. Spray arc transfer also has a very distinct sound. It is often described as a humming or buzzing sound. The

sound is a good indication that parameters are correctly set. If the arc "pops out" or occasionally stubs, there is a good possibility the parameters are not adjusted properly.

What the weld looks like after welding, is of course, a good indication of whether parameters have been set correctly. Sometimes, however, even a good-looking weld may have defects that are not obvious to the eye. A defect can be below the surface of the weld even though the surface of the weld looks good.

INDUCTANCE

The main function of an inductor (also referred to as a stabilizer) is to act as a shock absorber to the arc. It slows the response of the machine such that minimum spatter and optimum wetting action takes place. Depending upon its design and size, an inductor only very slightly changes the shape of the volt-amp curve. The shock absorber effect is especially important for the short circuit transfer, during the "arc on" time of the short circuit cycle. (This is the time when the electrode wire is not touching the base metal.)

As an example of this, suppose that without an inductor, the arc during one short circuit cycle is "on" 50% of the time and it is "off" 50% of the time. See Figure 2.

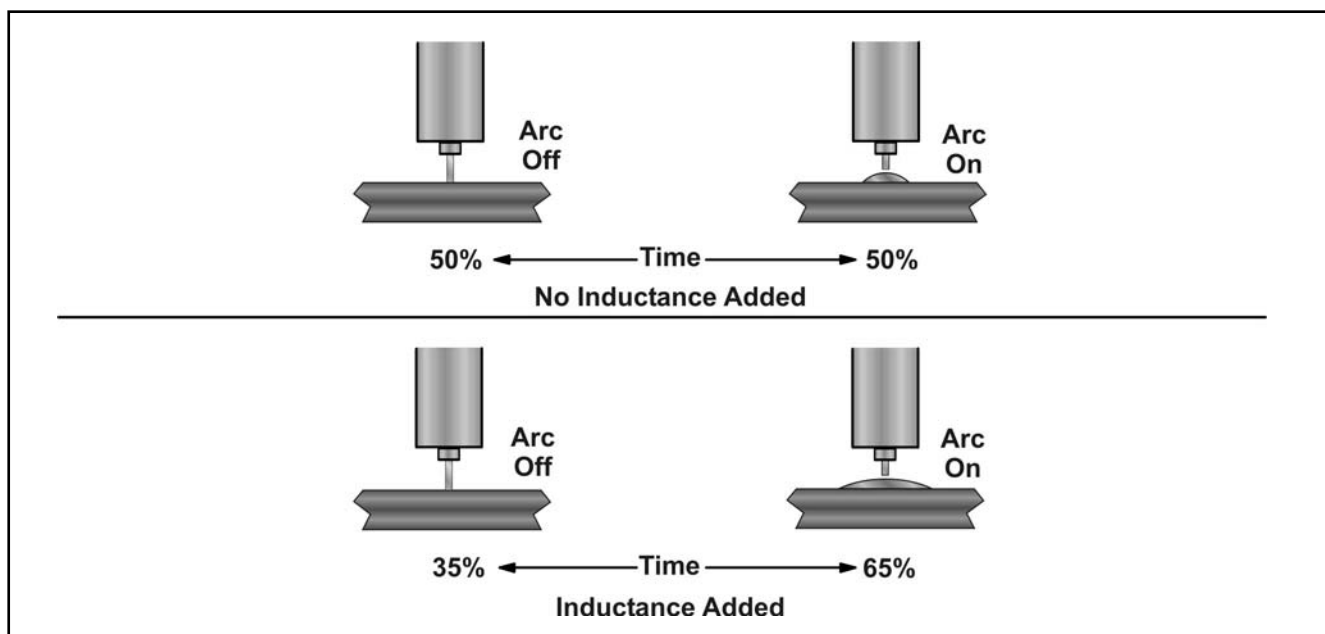


Figure 2. Inductor - Arc On Relationship

This means that when "on", the arc voltage and amperage is wetting out the deposited weld metal. When the arc is "off" (during the short circuit) the electrode is touching the base metal. When the electrode wire is pinched off, molten metal is deposited and the cycle repeats over and over again.

By adding an inductor (stabilizer) the relationship of the arc "on" and arc "off" times can be changed, as seen in the previous figure. More arc "on" time can be provided by adding inductance. Also inductance can provide fewer short circuits per second. With fewer short circuits, there is also more arc "on" time.

Keep in mind that the percentages for arc on and off time will vary depending upon how much inductance is added.

INDUCTANCE (STABILIZER) DISADVANTAGES

As inductance is added to the welding machine, the response time is slowed down. This means that attempting to start an arc becomes more difficult. With too much inductance, current supplied to pinch the wire free is very sluggish. This can result in wire stubbing into the work piece when trying to start an arc.

On the other hand, with minimum inductance, current supplied to pinch the wire free is very fast. It is perhaps so fast that a harsh, spattery arc will exist.

Thus optimum inductance should be obtained to provide good, clean starts with no stubbing and minimum spatter.

Too much inductance in the circuit can also cause burnback in the contact tube.

TYPES OF INDUCTANCE CONTROL

Inductors (stabilizers) may be built into a welding machine or added externally.

A way to add inductance to the welding circuit is to wrap a certain number of turns of the work cable around a chunk of steel or an steel pipe. Of course, the more turns of cable, the more inductance will be present. This can cause a problem if the welder doesn't want or need any added inductance. If the weld cables happen to be hung up or wound around a pipe or some type of steel hanger, unwanted inductance may occur. This is another reason why most manufacturers suggest cables be held to a minimum length for a particular job.

Many CV welding machines have either a fixed amount of inductance or some type of variable inductance.

INDUCTANCE (STABILIZER) EFFECT - SHORT CIRCUIT TRANSFER

We have so far discussed some of the variables for the short circuit transfer. These included response time, short-circuiting current level, and slope.

By varying a type of inductance control on an appropriate welding machine, a short circuit transfer can be "fine tuned." It is important to remember that one control alone cannot make a good weld. Only when all controls involved are fine-tuned will a good weld condition exist.

Therefore, such controls as voltage, WFS, and Slope, (where they apply) must also be set appropriately. Depending upon these settings and the metal being welded, changing the inductance value will have various effects. In some cases the changes will be quite evident, and in other cases the changes may be very slight or hardly noticeable.

Some of the possible effects of changing inductance for the short circuit transfer include: Changes in spatter, freeze lines (appearance), wetting action, penetration, and arc starts.

Most welders will agree that for short circuit transfer, the inductance affects spatter and freeze lines, and to a lesser degree, penetration. In some cases, too much inductance can cause a stubbing, or hard-to-start situation at the beginning of a weld.

Adding inductance can help reduce spatter. Slightly deeper penetration can be gained with minimum inductance. A somewhat wider penetration pattern is noticed with added inductance.

Reducing the spatter and smoothing the freeze lines can be helpful when weld bead appearance is very important. Spatter and rough freeze lines would not look good on such items as ornamental furniture and kitchen chairs.

Another consideration when short circuiting out-of-position is to keep the weld puddle small and less fluid because of gravity. Using less inductance can help achieve this. Less arc on time can avoid the spreading out of the weld bead and can make for a faster freezing weld puddle. This is often called a "stiff arc." The welder is accepting some added spatter and rough freeze lines in order to gain better puddle control in all positions.

INDUCTANCE (STABILIZER) EFFECT - SPRAY TRANSFER

A machine's response time is not as critical with spray transfer as it is with short circuit transfer. One of the

main requirements for spray transfer is enough short circuit current to provide the pinch force to separate the wire.

However, if the response time is too fast, at the start of a spray arc weld for example, there may be a problem establishing a smooth arc. The high amperage spray arc condition and flat volt-amp curve could cause a "blasting" start. With minimum inductance, the current rises to a high value in a very short time. With this fast current rise, a harsh, spattery arc starting condition exists.

Adding some inductance can delay this "current rise" at the start of the weld for just an instant. This can help the wire to be pinched off more smoothly at the beginning of the weld. The added inductance provides for what is called a softer start.

Too much added inductance can cause a "stumbling" or hunting start. If the current rise isn't fast enough, the electrode can stub at the weld start. A poor weld start can cause lack of fusion in that area of the weld.

With pulse spray transfer, too much inductance will reduce pulse peaks, especially when using narrow pulse widths. Also, when using very low background currents, added inductance can help sustain the arc during background.

TRAVEL SPEED

Another factor that can influence welding results is travel speed. This is the rate at which a welder or automatic control moves the welding gun (and arc) along a weld joint. It is measured in inches per minute (IPM) or mm/sec. Many welders, once they have become familiar with the GMAW process, determine the correct travel speed by judging the puddle size and keeping the arc on the leading edge of the puddle. The faster travel speed associated with GMAW compared to SMAW may take a beginning welder some time to adjust to.

Travel speed is just as important as any of the other welding parameters. In reference to travel speed (and economy), faster welding speeds can be obtained using the push technique in some situations. For a fillet weld, as an example, a push technique tends to produce a flatter, wider weld. Thus a faster travel speed can be used with a push technique to get the same leg size as a slower travel speed with a drag angle.

Manual travel speeds are, of course, limited to a welder's ability to control the weld puddle. Most travel speeds for various joints are well below 40 inches per minute. It is generally agreed that at a travel speed of 40 inches per minute (IPM) and above, the welder's eye has a difficult time focusing on the arc area.

TRAVEL SPEED VARIATIONS

Thickness of the material to be welded must be considered in a discussion of travel speed. If, for instance, a thicker metal were to be welded, travel speed would have to be decreased. More will be written later about the sizes of various weld joints. It can be pointed out now that if a larger fillet weld would be needed for thicker material, a slower travel speed would be used along with a higher voltage and amperage (WFS) to fill the fillet weld with a minimum of passes.

However, if the base metal thickness and joint design remain the same, and the amperage is increased, travel speed must also increase. This is because with the wire being fed faster, more metal is deposited. Therefore, for the proper size fillet weld, travel speed would also be increased. If these changes in travel speed are relatively great, the gas flow rate may have to be changed. That is, higher gas flow is needed for faster travel speed, and lower gas flow for slower travel speeds.

TRAVEL SPEED PROBLEMS

Just as gun angles can affect penetration and bead shape, so can travel speed. With all other parameters correct, too slow of a travel speed may produce a large weld with limited penetration. This is because the welding arc is dwelling on top of the weld puddle instead of concentrating the arc on the leading edge of the puddle.

Thus the arc force is no longer penetrating the base metal, but rather its energy is being used up by the molten puddle. Since the heat sink (cooling effect) of the base metal pulls the heat out of the puddle very rapidly, poor penetration and fusion will occur. The net result is a wider bead with more deposited weld metal per inch, but with poor weld quality.

If the travel speed is too fast, there would not be as much heat input per inch of weld. This is simply because the arc does not stay in one place as long as it would if proper travel speed was used. Too fast of travel speed will, therefore, tend to reduce the melting of the base metal. This means melting occurs near the surface of the base metal, yielding less penetration. Smaller bead width may also occur due to the lack of wetting out of the puddle at high travel speed. In most cases, proper travel speed is when the arc is on the leading edge of the puddle.

Therefore, unless travel speed is just right, either an increase or decrease in speed may yield shallower penetration.

On thinner metals, too slow of a travel speed can cause burn through due to excessive heat.

Faster travel speeds can in some cases cause the weld bead to solidify quite fast. This can cause gases to be trapped in the weld. This will result in porosity, because the molten puddle needs a slow enough cooling rate to allow gases to escape from the weld metal before it solidifies.

If travel speed is too fast, undercutting at the toes of a weld may also occur. Because the arc voltage and amperage have left a depression in the base metal, travel speed is too fast to allow molten filler metal to flow into the depression.

When using a spray arc transfer there is high heat input into the work piece. Too fast of a travel speed can be the cause of undercut, poor penetration, porosity, or other defects. Too slow of a travel speed can cause a large molten weld puddle with the arc centered on already deposited weld metal. This could result in excessive melt-thru due to too much heat.

When a spray transfer mode is used with smaller diameter wires (.035" diameter for example) on thinner materials, a slightly faster travel speed is sometimes necessary. This is to avoid excessive melt-thru or a weld puddle too large to control. This could happen when welding in the horizontal position for example when metal could "roll out" of the weld joint.

As a welder gains experience, travel speed begins to come naturally. Experience gives a welder a good idea of how to control a weld puddle and what to look for in a weld deposit. Electrode extension and gun angle technique can also affect the weld in association with travel speed.

In many cases, a welding joint travel speed is given in inches per minute (IPM) in the Weld Procedure Specification.

This will often show a range of travel speed to correspond to a given joint design and metal thickness.

ELECTRODE EXTENSION (STICKOUT)

A diagram of a typical GMAW weld puddle area is shown in Figure 3. Electrode extension may also be referred to as electrical stickout. It is the length of unmelted electrode extending from the tip of the contact tube. Sometimes stickout is mistakenly said to include arc length, but the technical reference when including arc length is: Contact tube-to-work distance.

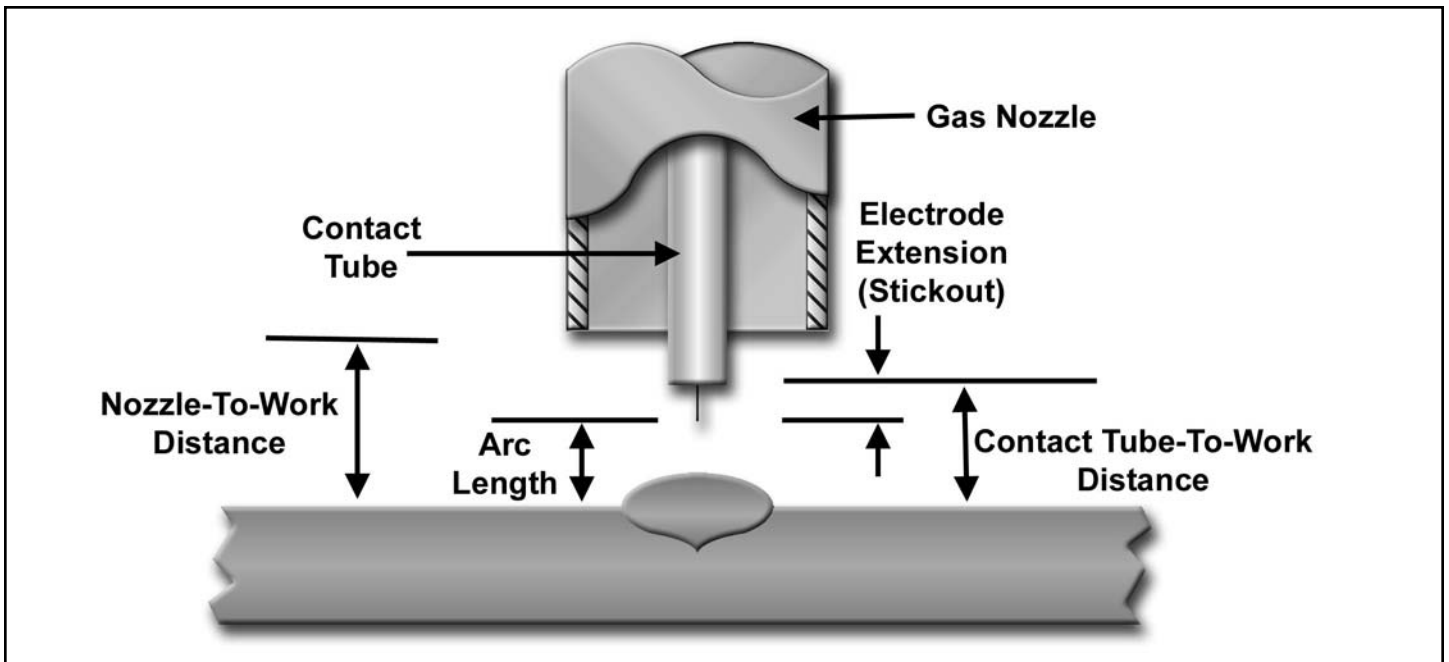


Figure 3. GMAW Gun And Weld Area

As mentioned earlier, with constant speed wire feeding, a slight change in electrode extension (stickout) will change both voltage and amperage. The change in amperage is greater with only a slight change in voltage. This can happen when the weld puddle (weld area) encounters a tack weld or similar bead shape or bevel edge.

Or, it can occur when the welder moves the gun up or down, changing the electrode extension. This can be used to great advantages in welding. For example, when starting a weld, a short stickout will help ensure a good hot start. A longer stickout will help bridge a gap when encountering poor fit-up. A longer stickout will also help reduce penetration when welding on very thin material. For critical welds, a constant stickout should be maintained. This will help avoid such things as incomplete fusion (cold lap), due to loss of current.

As electrode extension increases, a higher resistance value is placed upon the length of electrode wire beyond the contact tube. Since the longer the unmelted wire the higher the resistance value, more preheating of the wire is evident. It follows that longer electrode extensions will require less welding current to melt the electrode at a constant wire feed speed.

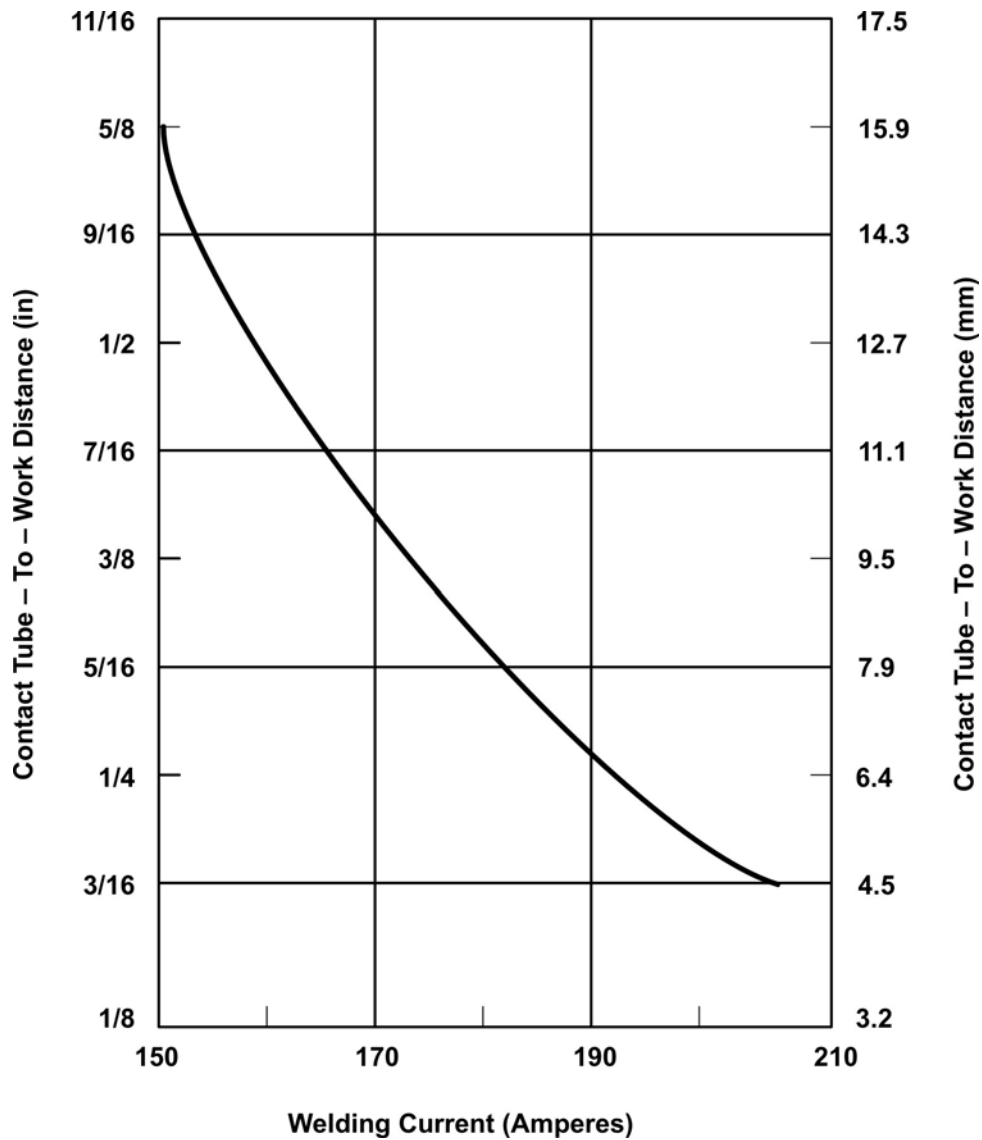


Figure 4. The Effect Of Electrode Extension On The Welding Current With A Constant Arc Length

The GMAW process is said to be self-regulating for arc length. However, problems will occur if electrode extension is varied, due to extremely long or short distances extending from the gun's contact tube to the work. Long electrode extension may cause the welder to increase the WFS on the wire feeder. This excess wire being fed into the puddle in relation to the voltage and amperage available will result in very shallow penetration and possible incomplete fusion at the toes of the weld. Welds with correct and incorrect electrode extensions are shown in Figure 5.

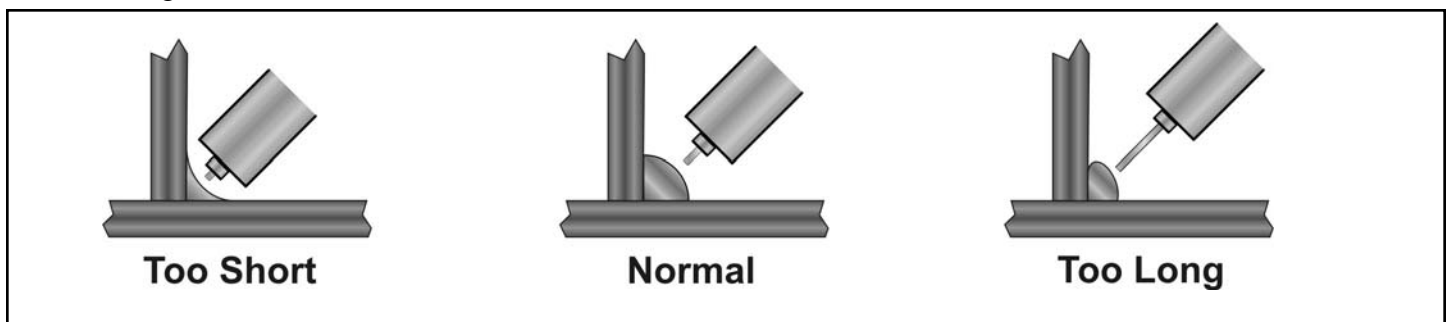


Figure 5. Electrode Extensions (Stickout)

It is difficult to set specific guidelines for correct electrode extension due to the many variables in a welding situation. Variables include: joint design, fit-up, metal thickness, wire type and diameter, along with amperage (WFS) and voltage settings being used. General guidelines however, would be as follows:

Short Circuiting Transfer - 1/4" to 1/2" electrode extension

Other types of transfer (GMAW) - 1/2" to 1" electrode extension

CONTACT TUBE-GAS NOZZLE RELATIONSHIP

On a standard type-welding gun, it is important how far the contact tube sticks out of the gas nozzle.

This contact tube-gas nozzle relationship is important for proper electrode extension (stickout), gas shielding, and heat buildup in the contact tube and gun.

For short circuit transfer, electrode extensions (stickouts) are shorter than for spray transfer. Therefore, it helps to have the contact tube nearly flush with the end of the gas nozzle for short-circuiting transfer. In some cases, the contact tube may even extend slightly beyond the end of the gas nozzle. This can be accomplished by using either a shorter gas nozzle or a longer contact tube. Gun manufacturers will vary on the method used. The contact tube should not be recessed up inside the nozzle for short circuit transfer. This can cause a long electrode extension (stickout), causing a high, ropey, spattery weld.

For spray or globular transfer, more heat and longer electrode extensions are used. This can provide higher deposition because of higher parameters and the wire having a longer "preheat" time before it enters the arc. Thus it takes less amperage from the welding machine to melt to wire. This allows faster wire feed speed at a given amperage. The higher wire feed speed deposits more metal in a given amount of time.

A contact tube too close to the weld puddle could easily overheat, expand and seize the wire. Overheating, expanding, and seizing the electrode wire can cause burnback or poor wire feeding characteristics. To help eliminate this it helps to have the contact tube recessed about an 1/8". This is to allow for more electrode extension, and the contact tube is further from the weld puddle. It also allows the gas nozzle to be closer to the work, thus providing better shielding. This is done with either a longer gas nozzle or a shorter contact tube.

GUN ANGLES AND GUN TECHNIQUES

Gun angles can help shape the weld bead and help determine the degree of penetration into the work piece. When describing the fundamentals of a good weld, three relationships with regard to electrode wire position are important:

1. Travel angle
2. Direction of travel (gun technique)
3. Work angle

Many different terms are used when describing the angles associated with electrode position. For example, some welders may refer to the forehand technique rather than the push technique. But it is more important to remember what a term stands for than to decide which term is more correct. The direction of travel is often determined by the position of the welder in relation to the joint to be welded.

DIRECTION OF TRAVEL - TYPE OF TECHNIQUE

Gun position, or technique, usually refers to the way in which the gun (and electrode wire) is situated in relationship to the work piece. When welding from either left to right or right to left, the direction of travel is said to be progressing with either a push technique, a drag technique, or a perpendicular technique, all shown in Figure 6.

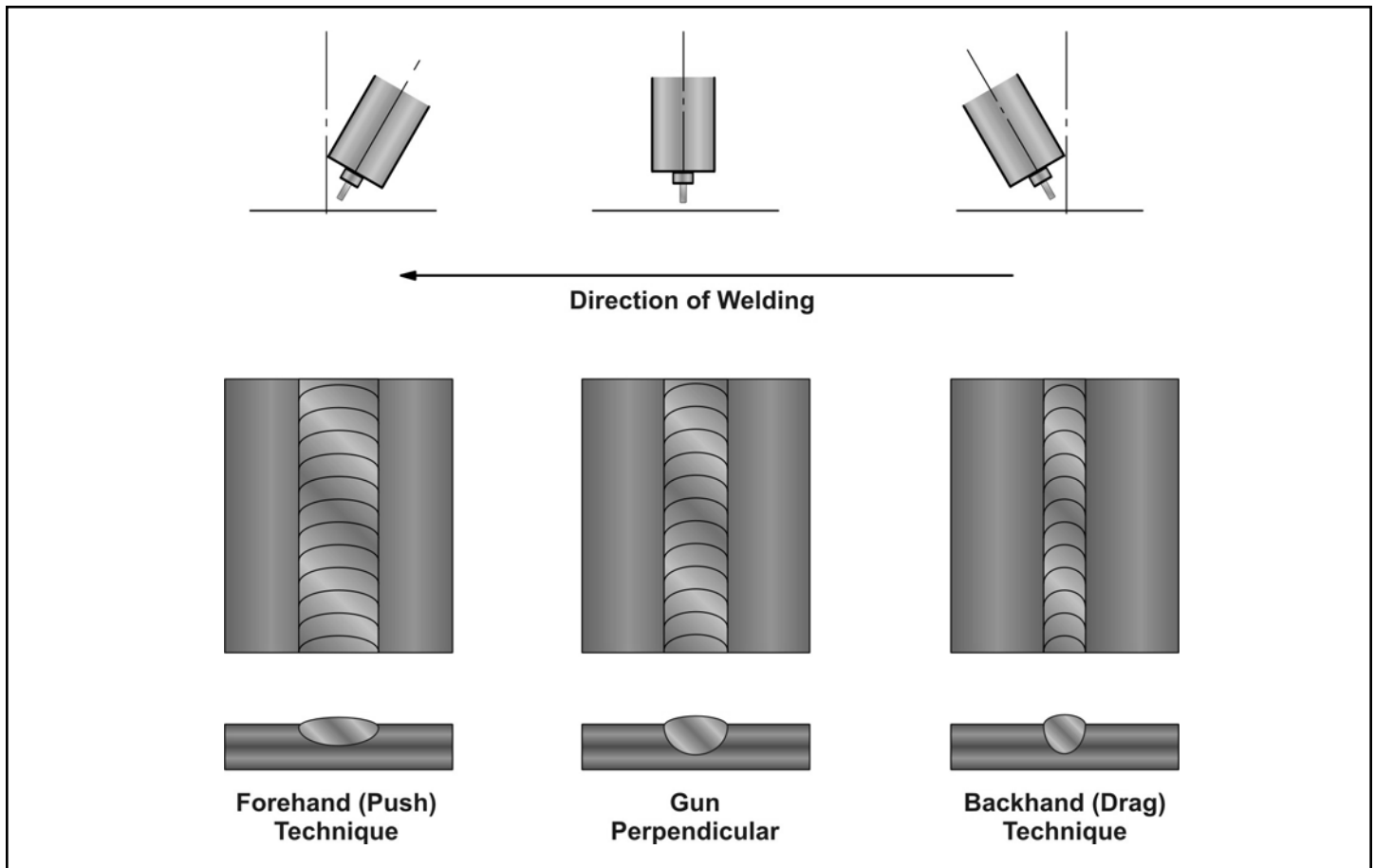


Figure 6. Gun Techniques

A perpendicular technique means that the wire is being fed straight into the weld rather than at an angle, as shown in Figure 6.

A drag technique is sometimes referred to as a backhand, pull, or trailing technique. Figure 6 shows the welding gun pointed back at the weld as the gun is "dragged" away from the deposited weld metal. A drag angle can in many cases produce better penetration than a push angle, when all other variables are the same. Once the arc is started and a puddle is formed, the arc will be directed at a preheated base metal, which improves penetration. This gun technique also tends to produce a narrower bead with more buildup. Again, all other variables must be the same.

A third type of technique is the push technique shown in Figure 6. It is often referred to as a forehand or leading technique.

The push technique is shown with the gun pointed away from the weld as the gun is "pushed" away from the weld. There are some distinct advantages of a push technique. One advantage is when relatively thin materials are to be welded, or when doing a process such as hardfacing. Low penetration would be required, and a push technique along with a faster travel speed can help achieve this in certain applications. The concentrated heat and arc force are now directed away from the weld puddle (and its thermal heat). This generally results in less penetration and a flatter, wider bead. There is less chance of undercut at the toes of a weld.

Gun angles are important, because if a welder normally uses a drag technique, certain situations may occur when a push technique would work better. This would be the case if a certain welding procedure specification called for a fillet weld with a flat face, or surface. In this case, if proper fusion is obtained to satisfy the specification, a push technique could be used to obtain a flatter weld face. If grinding would have to be done to flatten the weld, it can be seen that a push technique could save time and money by eliminating the grinding.

Some welders feel that with a push technique the hand holding the gun is closest to the weld and thus closer to the heat from the weld. However, a push technique can offer a better view of the weld joint and the direction of the wire into the joint. But the actual puddle outline and size is somewhat hidden from the welder's view as a result of this gun position.

TRAVEL ANGLE

Travel angles can also be seen in Figure 6. It can be seen that the perpendicular angle is zero degrees from the vertical. Travel angle can then be defined as the angle relative to this perpendicular value of zero. Both drag and push angles in Figure 6 are shown at 10 degrees from the perpendicular. Normal welding conditions in all positions call for a travel angle of from 5 to 15 degrees for good weld puddle control. However, travel angles beyond 20 to 25 degrees can lead to more spatter, less penetrations and general arc instability. This is due to poor metal transfer, poor direction of the weld metal, and poor shielding gas coverage.

WORK ANGLE

Undercut is one of the problems with fillet welds as can be seen in Figure 7, where a fillet weld was made with improper work angles. Always keep in mind the fact that you have to point the wire where you want the bead to be placed. Problems with undercut can often be corrected by dropping the gun work angle down (Figure 7), thus forcing molten metal to fuse to the vertical member. Of course, the base metal must have enough mass to absorb the heat input. The welding parameters must not exceed the heat sink qualities of the base metal being welded.

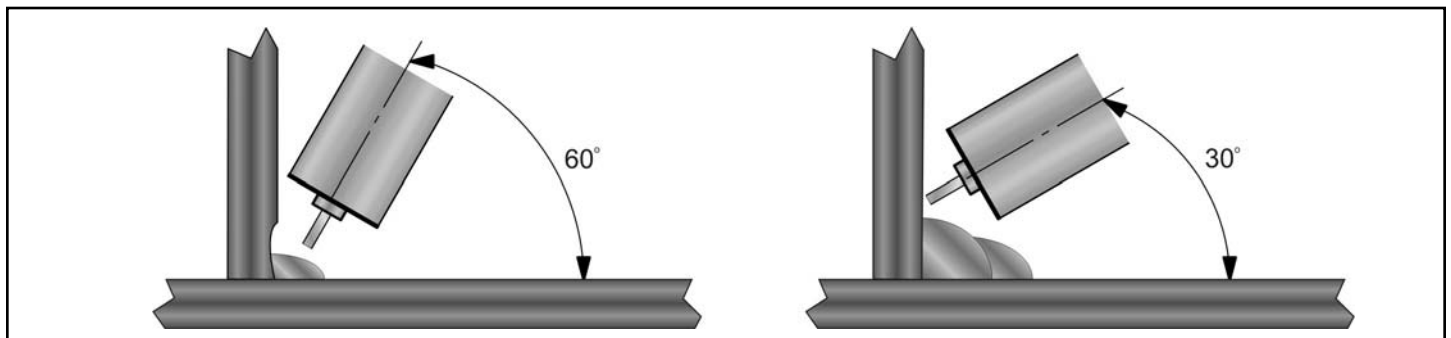


Figure 7. Undercut With Improper Work Angles; Proper Work Angles

Incomplete fusion (cold lap) can also be a problem with fillet welds. Cold lap can be a function of improper gun position or work angle.