

Guide for Multipass Orbital Machine Pipe Groove Welding



American Welding Society



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Guide for Multipass Orbital Machine Pipe Groove Welding

1st Edition

Prepared by the
American Welding Society (AWS) D10 Committee on Piping and Tubing

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

The Standard *Guide for Multipass Orbital Machine Pipe Groove Welding*, [AWS D10.14M/D10.14:2010](#), provides an overview of the subject. The guide presents several aspects of multipass orbital machine pipe groove welding. Among the aspects presented are: arc welding processes, pipe beveling, pipe line up and welding equipment, nondestructive examination, consumable estimation, maximum repair length, and preparation for welding. Multipass orbital machine pipe groove welding of both plant pipe welding and transmission pipe welding are discussed.



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Foreword

This foreword is not part of [AWS D10.14M/D10.14:2010](#), *Guide for Multipass Orbital Machine Pipe Groove Welding*, but is included for informational purposes only.

This document was created as a result of the recognized need to bring together a description of the various technologies combined in orbital multipass machine pipe groove welding. This document should be of benefit to readers wishing to familiarize themselves with the mechanized orbital pipe welding option to manual or semiautomatic pipe groove welding.

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Guide for Multipass Orbital Machine Pipe Groove Welding

1. Scope

The scope of this document is multipass, orbital machine pipe groove welding of pipe by arc fusion processes with filler metal addition. The orbital machines described in this document are typically used to weld pipe in plants, such as power generation plants or chemical processing plants, and to weld transmission pipelines, both cross-country and offshore. Offshore pipeline construction includes “S-lay,” “J-lay,” and “Reel-lay.” Each of these will be described in further detail. This guide is organized into sections describing welding processes, pipe beveling, pipe line-up, weld heads, nondestructive examination, plant pipe welding, cross-country welding, “S-lay” welding, “J-lay” welding, and finally reel lay welding. The guide concludes with a brief description of methods used to estimate consumable usage, engineering critical assessments, methods to calculate maximum repair lengths, and safety.

This document excludes orbital tube welding, which is addressed by AWS D18.1, *Specification for Welding of Austenitic Stainless Steel Tube and Pipe Systems in Sanitary (Hygienic) Applications*.

This document presents an overview of multipass orbital machine pipe groove welding including the welding processes, pipe beveling equipment, pipe line-up equipment, welding equipment, and nondestructive examination equipment. This document includes the steps required to prepare for and use multipass, orbital machine pipe groove welding equipment.

The alternative to multipass orbital machine pipe groove welding is manual welding, which includes welding with a torch, gun, or electrode held and manipulated by hand. Orbital machine welding is a form of mechanized welding which offers an alternative to manual welding when the investment in mobilization and equipment costs can be offset by productivity gains. The goal of this guide is to familiarize the reader with the orbital machine alternative to manual welding.

This standard makes use of both the International System of Units and U.S. Customary Units. The latter are shown within brackets ([]) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

Safety and health issues and concerns are beyond the scope of this standard and therefore are not fully addressed herein. Safety and health information is available from other sources, including, but not limited to, ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, AWS *Safety and Health Fact Sheets* (see Annex B) and applicable federal and state regulations.

2. Normative References

The following standards contain provisions which, through reference in this text, constitute mandatory provisions of this AWS standard. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

AWS documents:¹

[AWS A2.4](#), *Standard Symbols for Welding, Brazing and Nondestructive Examination*

¹ AWS standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

AWS A3.0, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying.*

ANSI Documents²

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

3. Terms and Definitions

For the purposes of this document, the following definitions apply:

band. See guide ring.

bug. See weld head.

clamp operator. The fitter who uses the reach rod to engage the line-up clamp (raise the clamping shoes). For internal welders, the clamp operator also initiates the internal welding sequence.

compound bevel. Bevel in which two or more bevel angles are combined.

copper backup clamp. An internal line-up clamp that includes a set of copper shoes that are pressed against the inside of the pipe during welding to provide a temporary backing to the weld.

counterbore attachment. Counterbore attachments are used with the O.D. mount pipe beveling machines for counter-bore and transitions.

counterbore. End preparation on a pipe in which the I.D. of the pipe is enlarged for a short length and then tapered at a 4 to 1 rate to match a thinner wall pipe to a thicker wall pipe, Counterbores are needed at transition joints when copper backup shoes or internal welders are used.

diameter nominal (DN). Denotes the metric nominal pipe size (NPS).

dovetail. Sliding track for mounting a tool holder on a pipe beveling machine faceplate.

external welder. See weld head.

guide ring. A split rigid track, a flexible band, or a chain-type guide clamped around a pipe on which an external machine weld head rides.

high-low mismatch. A nonstandard term for weld-joint mismatch.

hot pass. A nonstandard term used for the intermediate weld pass subsequent to the root pass.

intermediate weld pass. A single progression of welding along a joint subsequent to the root pass and prior to the cover pass(es).

internal line-up clamp. A mechanism that fits inside the pipe, has rollers so it can roll through the pipe, and has expanding radial pistons for rounding, centering, and clamping the pipe ends relative to one another.

internal welder. An internal line-up clamp that includes gas metal arc welding torch(es) that deposit the root bead from the inside of the pipe.

jam up joint. weld joint that has no gap between the pipe ends.

J-lay. An offshore pipe-laying technique in which the pipe is welded together in an orientation near vertical, and is laid by lowering the pipe to the seafloor, where it makes a single bend. Used when it is impossible to apply sufficient tension to the pipe to prevent buckling in S-lay mode, typically in deep water (over 150 m [450 ft]).

open root joint. An unwelded joint without backing or consumable insert.

orbital welding. Automatic or machine welding of tubes or pipe in-place with the electrode rotating (or orbiting) around the work in any position. Orbital pipe welding is typically done with the addition of filler. In some thin wall piping,

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autogenous welding may be permitted. For multipass orbital machine pipe groove welding when the pipe is horizontal (5G position), welding may be performed orbitally or using a double up or double down technique—180 degrees clockwise or counterclockwise followed by 180 degrees in the opposite direction.

pipe beveling machine (PBM). An apparatus designed to machine a bevel on the end of a pipe. See also pipe facing machine (PFM).

pipe facing machine. An apparatus designed to machine the edge of a pipe.

pig. A device intended to move through the pipe to clean it or inspect it.

pipe ramp. The corridor on a pipe-laying barge along which the pipe is welded and fed toward the stern of the barge or ship.

pool shift. A phenomenon which occurs when pipes of differing chemistries are joined. The pipe chemistry (particularly sulfur content) can have a profound effect on the surface tension of the weld pool and cause the welding arc and weld pool to favor one or the other side of the weld joint bevel.

PPM. Parts per million.

pup. A short piece of pipe.

purge dam. A temporary bulkhead placed inside the pipe on each side of the weld to allow the volume in between the bulkheads to be purged of oxygen.

QA. quality assurance.

radial arm. Pivoting arm for mounting a tool holder on a pipe beveling machine faceplate.

reel-lay. A method of pipe lay in which the pipe is welded onshore and reeled onto a large diameter drum (greater than 10 m) mounted on a ship. The pipe is subsequently laid offshore by unreeling the pipe from the drum.

surface meters [feet] per minute. A term used to express the rate at which material is passing by the tool point of a machine.

skid. A wooden beam typically 10 cm by 15 cm by 1.8 m long [4 in × 6 in × 6 ft long], made of oak or similar wood, used to construct stacks to temporarily support pipe during construction.

S-lay. An offshore pipe-laying technique in which the pipe is welded together in an orientation near horizontal, and is laid by paying the pipe out of the stern of the barge or ship and allowing it to bend to reach the seafloor.

spacer. The member of the pipe gang responsible for directing the tractor operator (on land), or hydraulic control operator (on a barge or ship) who manipulate the oncoming section of pipe so that the pipe joints line up and have a uniform root opening around the entire circumference.

stabber. The member of the pipe gang responsible for directing the tractor operator for guiding the approach of the oncoming section of pipe.

stalk. Multiple lengths of pipe joined together. J-lay ships utilize stalks ranging from two to five pipes in length. Reel lay ships are loaded with multiple stalks up to one hundred joints in length joined end to end as they are reeled onto the ship.

stalking. The operation of bringing a new piece of pipe up to the end of the pipes that have been previously welded together.

stinger. A structure which is attached to the rear of a pipe lay barge that serves as an extension to the pipe ramp. The stinger and tension on the pipe control the radius of curvature of the pipe overbend as it enters the water during S-lay.

tensioner. A device used on pipe lay barges for gripping the pipe and allowing it to move off the stern of the barge while maintaining tension on the pipe.

through-the-arc tracking. A technique to automatically keep the welding arc centered in the joint through electrical measurement of the arc characteristics as the arc is oscillated or moved back and forth across the joint.

tool holder. Steel block that can support and clamp tool inserts or tool bits for pipe bevel machining.

track. See guide ring.

transition. End preparation on a pipe in which the I.D. of the pipe is tapered to match a thinner wall pipe to a thicker wall pipe (see counterbore).

weld head. Mechanized external welder that mounts on a band or track wrapped or clamped around the pipe next to the circumferential weld joint.

weld joint mismatch. Misalignment of the joint members.

weld out. Completion of the weld by deposition of the remaining passes.

welding shack. A portable structure designed to be set on the pipe to provide protection from the elements to the welder and welding process in inclement weather.

4. General Description of Orbital Machine Pipe Groove Welding Equipment

4.1 Components. Orbital machine pipe groove welding equipment generally consists of the following components:

1. pipe beveling
2. pipe alignment
3. welding power and shield gas supply
4. weld head
5. welding head positioner
6. wire feed
7. controller
8. operator control

4.1.1 Pipe Beveling Machine. A method for beveling the pipe ends in preparation for welding is required. Pipe Beveling Machines (PBMs) range in capacity and price. The choice depends on bevel configuration, joint accessibility, and desired production rate. Flame cut and hand ground bevels, which are suitable for manual welding processes, are normally not suitable for orbital machine pipe groove welding. Transmission pipe beveling machines typically prepare a bevel on a pipe end in less than 3 minutes time.

4.1.2 Pipe Alignment. A mechanism is required for lining up the pipe. For plant pipe welding, manual external line-up clamps are typically used. Once the pipe ends are aligned, the pipe ends are tacked together using a manual welding process. The external line-up clamp is frequently removed after tacking. For transmission pipeline welding, the external line-up clamp must be left in place until 50% of the root pass has been completed per [API 1104](#), or until the first two passes have been completed per DNV OS-F101. Although some plant pipe root passes are deposited manually, most “jam up” (no root gap) joint root passes and root passes of joints utilizing consumable inserts are deposited by machine pipe groove welding. For transmission pipe welding, a self-propelled internal line-up clamp is typically used, which remains in place until the root pass and hot pass have been deposited.

4.1.3 Welding Power and Shield Gas Supply. A typical welding power supply used for multipass orbital machine pipe groove welding is remotely controlled and rated for 100% duty cycle at 225 Amperes minimum. Shield gas is typically supplied from high pressure 15 MPa [2200 psi] cylinders. Multiple cylinders are often manifolded together. Sometimes a means is provided to switch between two banks of cylinders so one bank can be replaced while welding continues using the second bank. The cylinder pressure must be reduced (to typically 350 kPa [50 psi]) by means of a pressure regulator. On pipe-laying ships, gas mixtures are often mixed on board, and liquefied gas in bulk containers is often used in those parts of the world where bulk containers are available.

4.1.4 Welding Head. The welding head holds the welding gun or torch, emulates the manual welder, and has the following functions:

1. moves the welding torch toward or away from the weld joint to regulate the contact tip to workpiece distance in the case of GMAW or to regulate the electrode to workpiece distance in the case of GTAW (for GTAW equipment, this function is commonly referred to as arc voltage control (AVC))

2. moves the welding torch toward the weld head (inboard) or away from the weld head (outboard) for the purpose of aligning the weld torch with the center of the weld joint and for the purpose of weaving the torch across the weld joint
3. changes the push or drag angle of the weld torch with respect to the pipe surface

4.1.5 Welding Head Positioner. Some mechanism is required for moving the welding head circumferentially around the pipe at a controlled travel speed. The welding head usually has rollers or gears, which clamp onto a circumferential track. There are several forms of circumferential track:

1. a band or guide ring which clamps around the pipe and provides mounting for the welding head. The welding head travels around the pipe on the band or guide ring, but typically must be “steered” by the welder or welding operator to make fine adjustments to cross-seam position and contact tip to workpiece distance for GMAW or electrode to workpiece distance for GTAW. In GTAW, the electrode to workpiece distance may be adjusted automatically if AVC is available;
2. a clamshell or open frame which clamps around the pipe and provides mounting for the welding head as above. Clamshells range in size from those designed for pipe several centimeters in diameter to those designed for pipe more than a meter in diameter.

4.1.6 Wire Feeder. Orbital machine pipe groove welding equipment may have one or two welding torches or filler metal guide tips. Welding electrode wound on spools is supplied to the torches or guide tips by wire feeders. The wire feeder(s) may be mounted on the welding head or mounted a few meters away from the welding head. When mounted on the welding head, the wire spool(s) are small (less than 5 kg [10 lb]). When not mounted on the weld head, the wire feeder(s) are typically mounted in a freestanding floor mounted enclosure or a wall mounted enclosure. In the later case, larger (12 kg [25 lb] or more) wire spools are used.

4.1.7 Controller. A weld controller that may be part of the welding head, integrated with the welding power supply, or in a separate enclosure that may be freestanding or wall mounted. Often, if the wire feeder is not mounted on the welding head, the wire feeder will be combined with the control cabinet.

4.1.8. Operator Control. Some type of hand-held control pendant for starting and stopping the welding process and making adjustments to the torch position and travel speed. Pendants may include additional controls for oscillation width, torch-to-workpiece distance, and filler wire feed speed. Alternatively, the controls may be part of the weld head.

4.2 Typical Systems

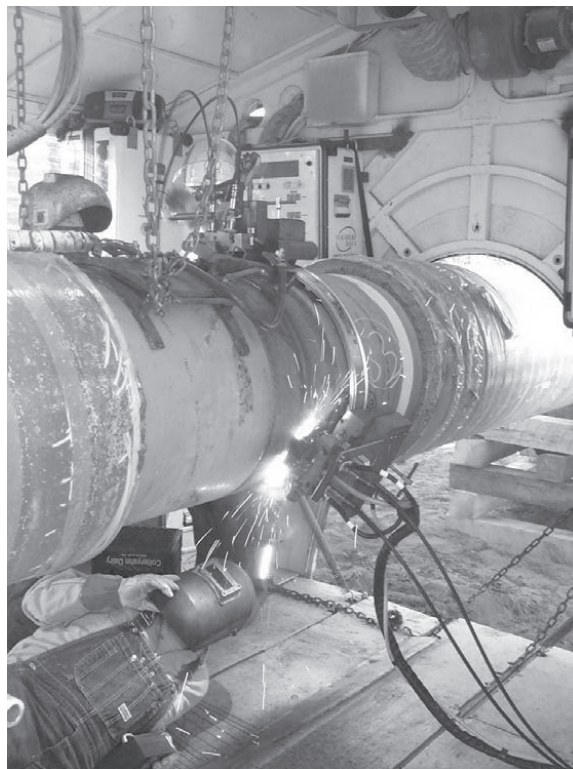
4.2.1 A typical orbital machine pipe groove welding clamshell track with multiple weld heads is shown in Figure 1. This type of system is typically used for offshore pipeline construction. Small clamshell track welders with single weld heads have been developed for plant pipe welding. Plant pipe welding is often done using the pulsed gas tungsten arc welding (GTAW-P), gas metal arc welding (GMAW), pulsed gas metal arc welding (GMAW-P), or flux core arc welding—gas shielded (FCAW-G) processes. Normally, a machine pipe groove welding system for plant pipe welding will use a single welding head to weld the joint. In contrast, transmission pipeline welding typically uses multiple welding heads, often with more than one welding torch per head.

4.2.2 Figure 2 is a typical machine pipe groove welding system used for transmission pipe welding. For transmission pipe welding, pipe beveling machines using multiple tool holders with tooling inserts and powered by hydraulic motors are used to machine a bevel typically in less than 3 minutes. The pipe sections are lined up by means of an internal pipe line-up clamp. There are two types of internal pipe line-up clamps. The first type has copper “shoes” which press against the inside circumference of the pipe at the weld joint allowing the root pass to be deposited from the outside using the GMAW process. The second type of internal line-up clamp has GMA welding heads that deposit the root pass from the inside of the pipe. The equipment illustrated in Figure 2 is operating in a welding shelter. Typically, several welding shelters are used. Five to seven shelters are common, although as few as three or as many as fifteen may be used. The shelters are transported from joint to joint by a side boom tractor or boom truck. The shelters are temporarily set down on the weld joint to protect the weld joint from rain, snow, and wind. The welding operators enter the weld shelters after the shelters have been set on the pipe. The welder attaches the weld head to the weld band. (The weld bands are typically left on the pipe until welding is complete.) Typically, two weld heads are attached to the band, one weld head on each side of the pipe. Both sides of the pipe are typically welded simultaneously using a double down technique (both weld heads traveling from top to bottom). After the heads have been used to deposit a particular pass, the weld heads are detached from the band and the shelter is lifted off the pipe and carried to the next weld. The shelter is then set on the next weld joint, and the weld heads are attached to the band on that joint and used to deposit the same type of pass. Separate shelters are dedicated to separate pass types.



Photograph courtesy of Serimax

Figure 1—Typical Orbital Machine Pipe Groove Welding Clamshell Head



Photograph courtesy of Serimax

**Figure 2—Typical Orbital Machine Pipe Groove Welding System
Performing Cross-Country Pipe Welding**

4.2.3 Figure 3 is a typical machine pipe groove welding system used for offshore “S-lay” pipe welding. Offshore “S-lay” pipe welding is similar to cross-country pipe welding in that the pipe is beveled by high-speed hydraulically powered pipe beveling machines, and a self-propelled internal line-up clamp is used. Instead of welding shelters, the offshore vessel will have welding equipment located along a pipeline construction “tunnel” that runs the length of the vessel. The “tunnel” is like a large hall-way with supports for the pipe providing clearance between the floor of the “tunnel” and the bottom of the pipe. A standard pipe length is 12.2 m [40 ft]. Therefore there are “stations” along the tunnel every 12.2 m [40 ft] corresponding to the location of the pipe joints. At the first weld station, the welding equipment is used to deposit the root pass and the hot pass. Depending upon pipe wall thickness, additional intermediate weld passes may be deposited in the first station. At the second weld station, the welding equipment is used to deposit additional intermediate weld passes. At the last weld station, the welding equipment is used to deposit any remaining intermediate weld pass(es) and the cap pass(es). Some vessels have as few as three welding stations spaced 12.2 m [40 ft] apart. Other vessels have more stations spaced 12.2 m [40 ft] apart, or even 24.4 m [80 ft] (two pipe lengths) apart. In the later type vessels, 12.2 m [40 ft] long joints of pipe are welded together into “double-joints” in a separate station before being transported to the “tunnel”. Submerged arc welding is normally used to weld the single joints into double joints. The reason for this is the pair of pipe joints can be welded in the 1G position. Submerged arc welding has the highest deposition rate of any of the welding processes when welding can be carried out in the 1G position.

4.2.4 Figure 4 is a typical machine pipe groove welding system used for offshore “J-lay” pipeline construction. For “J-lay” construction, the 12.2 m [40 ft] lengths of pipe are first welded together to form stalks from two to six joints in length. This welding may take place on shore or on the deck of the J-lay vessel. The stalks are then upended in a tower on the vessel. The bottom end of the new stalk is welded to the top end of the previous stalk in a single station. All the passes must be deposited in a single weld station. NDT and coating must occur in this station as well if the previous weld



Photograph courtesy of Serimax

**Figure 3—Typical Orbital Machine Pipe Groove Welding System
Performing Offshore S-Lay Pipe Welding**



Photograph courtesy of Serimax

Figure 4—Typical Orbital Machine Pipe Groove Welding System Performing Offshore J-Lay Pipe Welding

has been lowered to below the water surface. Typically, an internal line-up clamp is suspended from a cable inside the pipe to aid in aligning the pipe ends and provide copper backing.

4.2.5 Figure 5 is a typical machine pipe groove welding system used for offshore reel ship pipeline construction. Reeled pipe is typically welded together into long stalks in a yard onshore called a spool base. 12.2 m [40 ft] joints of pipe are welded together into stalks that range from 400 to 1600 m [1300 to 5200 ft] in length. The orbital machine pipe groove welding equipment is stationed inside a long building, similar to the welding tunnel on an “S-lay” vessel. Self-propelled internal line-up clamps are typically used to align and clamp the pipe. The number of weld stations can range from 3 to 14, depending on the length of the building and land available for stalk storage. Finished stalks are temporarily stored parallel to one another on a stalk rack outdoors. After the stalks have been welded, the reel ship docks at the spool base to reel the stalks. Reeling begins with the head of the first stalk. After reeling the first stalk onto the reel, reeling is halted until the head of the second stalk can be welded to the tail of the first stalk. This process continues until all the stalks have been welded to one another and reeled onto the ship.

4.3 Welding Processes Used for Multipass Orbital Machine Pipe Groove Welding. Table 1 is a summary of the welding processes used for multipass orbital machine pipe groove welding along with the strengths and weaknesses of each process. Several generalizations are made in Table 1. The following section describes each process and its strengths and weaknesses in relation to machine pipe groove welding in more detail.

4.3.1 Pulsed Gas Tungsten Arc Welding (GTAW-P) Process. Multipass orbital machine pipe groove welding can be performed using either the pulsed or non-pulsed GTAW process. However, use of non-pulsed GTAW is uncommon in machine pipe groove welding and therefore will not be discussed.



Photograph courtesy of Serimax

Figure 5—Typical Orbital Machine Pipe Groove Welding System Performing Offshore Reel Lay Pipe Welding

In the GTAW-P process, the welding arc is established between a non-consumable tungsten electrode and the part being welded. Filler wire is fed into the molten weld pool as the weld progresses. The welding power supply typically pulses the current from a low background level to a higher pulse peak level at a rate of a fraction of a pulse per second to several pulses per second. Some pulsing power supplies can alternate between electrode negative for penetration and electrode positive for cathodic etching cleaning effect of the part being welded, which is particularly useful for welding aluminum. In GTAW-P, the arc and molten pool are shielded from the air with inert gases such as welding grade argon, helium or mixtures of the two. Hydrogen is sometimes added to the shield gas for stainless steel to insure the arc atmosphere is reducing and not oxidizing. One or two percent nitrogen may be added when welding duplex or austenitic stainless steels.

Low frequency current pulsation is usually synchronized with the wire feed rate. It may also be synchronized with torch oscillation and torch travel, which provides three benefits:

1. Pulsing to high current levels when the torch is at the sidewalls helps to ensure sidewall fusion.
2. Dropping to a low value of current between pulses while the torch travels across the joint helps to prevent melt through or underfill of the root pass and reduces the overall heat input.
3. Reducing torch rotation speed, or momentarily stopping forward rotation on the high current pulse can improve root penetration capability.

Some manufacturers combine high pulsing frequencies for stiffening the arc column with low pulsing frequency for synchronization with wire feed or torch oscillation.

4.3.1.1 Strengths of the Pulsed Gas Tungsten Arc Welding Process. The strengths of the GTAW-P process are as follows:

1. It has the capability to create a uniform root bead profile from the outside of the pipe. In some cases, GTAW-P is used to deposit just the root or just the root and hot pass with the balance of the joint welded with the GMAW-P or FCAW-G processes. This is particularly true for duplex and super-duplex stainless steel pipe;

Table 1
Arc Welding Process Summary for Steel Pipe

	GTAW Family	Non-Flux Cored Welding Electrode Family						Cored Welding Electrode Family		
Process	GTAW-P	GMAW-S		GMAW-P		GMAW-P		FCAW-G		
Welding Arc	Pulsed	DC Short Circuit		Pulsed		Proprietary Pulsed		DC Short Circuit		Pulsed
Arc Welding Electrodes	Non Consumable Tungsten Electrode	Consumable Wire Electrode		Single Consum. Electrode	Twin Consum. Electrode	Consumable Wire Electrode		Flux Cored Consumable Electrode		
Shield Gas	Ar or Ar/He mix	100% CO2	Ar-CO2 Mix	Ar-CO2 Mix	Ar-CO2 Mix	100% CO2	Ar-CO2 Mix	100% CO2	Ar-CO2 Mix	Ar-CO2 Mix
Deposition Rate	Low	Moderate	Moderate	Moderate	High	Low	Low	Moderate	Moderate	Moderate
Spatter	None	High	Moderate	Low	Low	Moderate	Low	High	Moderate	Low
Slag	None	Low	Low	Low	Low	Low	Low	High	High	High
Root without backing	Yes	No	No	No	No	Yes	Yes	No	No	No
Control of Heat	High	Low	Low	Moderate	Moderate	Moderate	Moderate	Low	Low	Moderate
Immunity from Drafts	Low	High	Moderate	Moderate	Moderate	High	Moderate	High	Moderate	Moderate
Weld metal cleanliness	High	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Low	Low	Low
Weld metal toughness	High	High	High	High	High	High	High	^a	^a	^a
Cost of Shield Gas	High	Low	High	High	High	Low	High	Low	High	High
Cost of Consumable	Low	Low	Low	Low	Low	Low	Low	Moderate	Moderate	Moderate

^a The flux in a FCAW can be high in titanium dioxide and silicon dioxide, making the flux acidic. Acidic electrodes create welds with good appearance but low toughness. Alternatively, the flux can be high in manganese dioxide and calcium oxide, making the flux basic. Basic electrodes provide better toughness at the cost of weld appearance.

2. It has the capability to deposit weld metal with fewer oxide inclusions than the GMAW, GMAW-P, FCAW-G, and FCAW processes.
3. Heat input can be controlled independent of filler metal addition rate. Many of the welding systems that use the GTAW-P process have sophisticated welding controls, capable of pulsing the current to high levels at the side walls, and changing the weld parameters as the external welder moves around the pipe.
4. Most pulsed gas tungsten arc welding control systems allow multiple welding schedules to be entered for individual passes, various wall thickness and pipe diameters.

4.3.1.2 Limitations of the Pulsed Gas Tungsten Arc Welding Process. The limitations of the GTAW-P process are as follows:

1. GTAW-P has a lower deposition rate than the GMAW, GMAW-P, FCAW-G, and FCAW processes. Deposition rates are typically in the order of 0.25 to 1.4 kg [0.5 to 3 lb] per hour. The higher deposition rates are associated with hot wire welding. Hot wire welding is a variation of the GTAW-P process in which a filler metal wire is resistance heated by current flowing through the wire as it is fed into the weld pool.
2. Welding should be carried out in a draft free area.
3. Weld joints should be free of contaminants, such as cutting oils and oxides.
4. Accurate machined joint preparation is critical to successful GTAW-P welding.

4.3.2 Gas Metal Arc (GMAW), Pulsed Gas Metal Arc (GMAW-P), and Flux-Cored (FCAW-G) Arc Welding Processes. Multipass orbital machine pipe groove welding can be performed using either the gas-shielded or non-gas-shielded FCAW process. However, use of non-gas-shielded FCAW is uncommon in machine pipe groove welding and therefore its discussion is limited within this document.

It is convenient to consider GMAW, GMAW-P, and FCAW-G as a closely related family of processes. All of the members of this family, when used for pipe welding, have the following characteristics in common:

1. A continuous small diameter (1 to 1.2 mm [0.039 to 0.047 in]) consumable electrode is used, with the arc forming between the end of the electrode and the work piece.
2. The consumable electrode is mechanically fed into the weld pool.
3. External shielding gas is used to prevent the electrode and weld pool from oxidizing and to influence the metallurgical characteristics of the deposited weld metal.
4. A gas nozzle is used to direct the flow of shielding gas around the arc and weld pool.
5. Replaceable contact tips guide the filler wire into the weld pool and transfer the welding current to the wire.

4.3.3 Nonpulsed Gas Metal Arc Welding Processes. The characteristics of the non-pulsed GMAW process are best described in terms of the basic means by which metal is transferred from the electrode to the work, namely:

1. short-circuiting transfer
2. globular transfer
3. spray transfer

The mode of transfer is determined by the following factors:

1. welding amperage level
2. electrode diameter
3. shielding gas
4. electrode type/composition
5. electrode stick-out (extension from the contact tip)
6. power source design

4.3.3.1 Short-circuiting Transfer Mode. The short-circuiting transfer mode of GMAW (GMAW-S, commonly known as short arc) is associated with low average currents and voltage levels and high spatter levels. Spatter refers to the metal particles expelled during fusion welding that do not form a part of the weld.

4.3.3.2 Globular Transfer Mode. As the voltage and amperage of the process increase, the electrode starts to melt before contacting the work piece surface, and metal is transferred across the arc. At a transition point, globular transfer occurs, which is characterized by a droplet with a diameter greater than that of the electrode. The large droplet size is affected by gravity, limiting this operating mode to welding in the flat or near flat position.