

Guide for Multipass Orbital Machine Pipe Groove Welding



American Welding Society



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Guide for Multipass Orbital Machine Pipe Groove Welding

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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

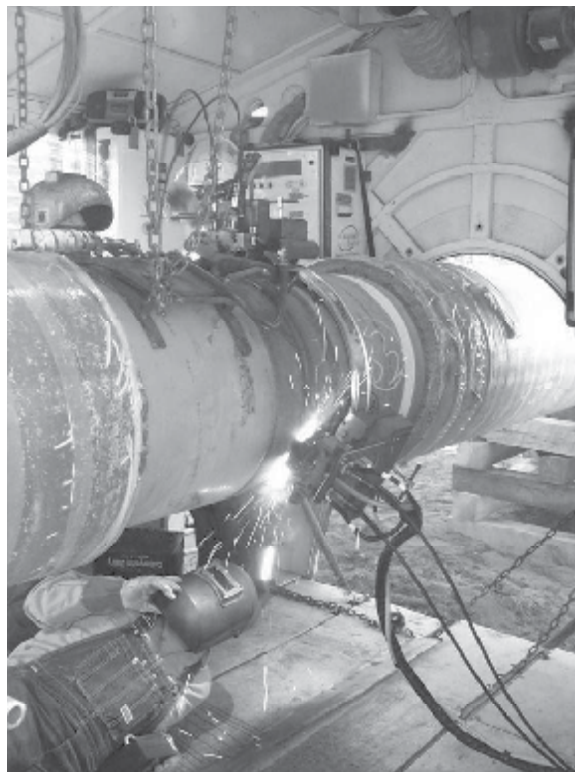
4.2.1 A typical orbital machine pipe groove welding clamshell track with multiple weld heads is shown in Figure 1. This type of system is typically used for offshore pipeline construction. Small clamshell track welders with single weld heads have been developed for plant pipe welding. Plant pipe welding 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

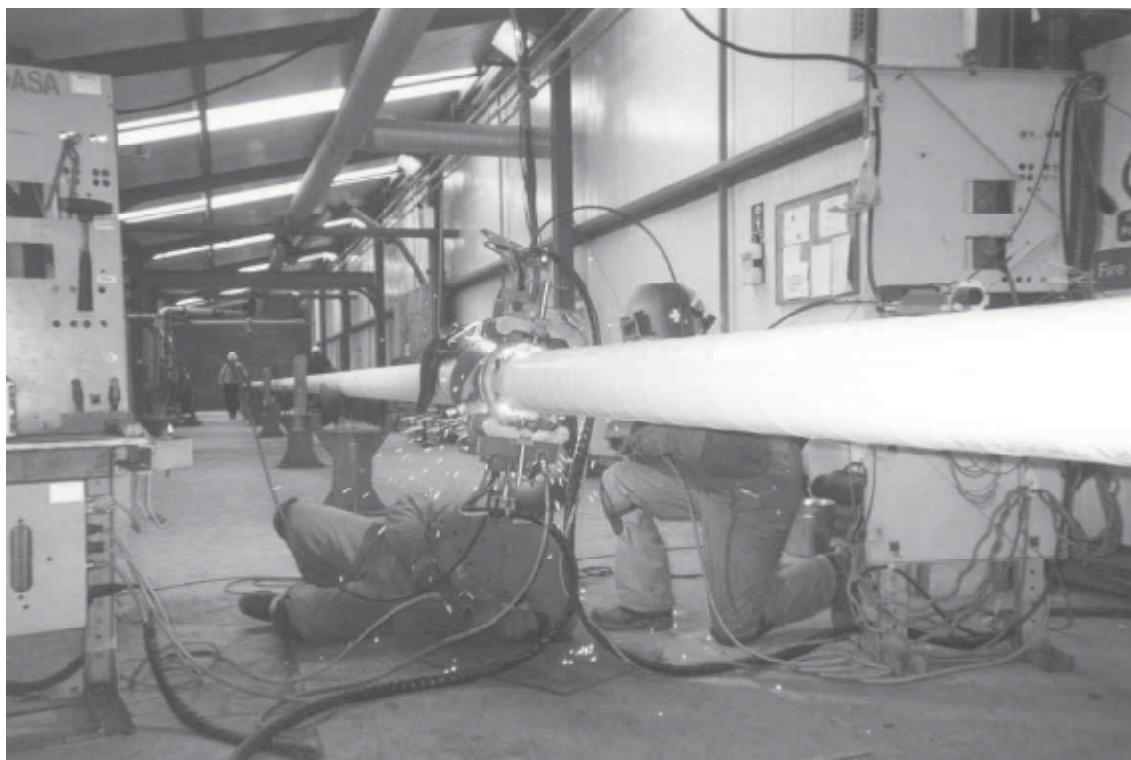
Figure 4—Typical Orbital Machine Pipe Groove Welding System Performing Offshore J-Lay Pipe Welding

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

Process	GTAW Family		Non-Flux Cored Welding Electrode Family		Cored Welding Electrode Family	
	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		Single Consum. Electrode		Twin Consum. Electrode	
	Ar or Ar/He mix	Ar-CO ₂ Mix	Ar-CO ₂ Mix	Ar-CO ₂ Mix	100% CO ₂	Ar-CO ₂ Mix
Shield Gas	Low	Moderate	Moderate	High	Low	Low
Deposition Rate	None	High	Moderate	Low	Moderate	Moderate
Spatter	None	Low	Low	Low	High	High
Slag	None	Low	Low	Low	High	High
Root without backing	Yes	No	No	No	No	No
Control of Heat	High	Low	Moderate	Moderate	Low	Low
Immunity from Drafts	Low	High	Moderate	Moderate	High	Moderate
Weld metal cleanliness	High	Moderate	Moderate	Moderate	Low	Moderate
Weld metal toughness	High	High	High	High	^a Low	^a Low
Cost of Shield Gas	High	Low	High	Low	High	High
Cost of Consumable	Low	Low	Low	Low	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.

4.3.3.3 Spray Transfer Mode. With increasing current and voltage, and with the use of argon-rich shielding gas (80% or greater) a transition occurs from globular transfer to spray transfer. Spray transfer is characterized by drops smaller than the electrode diameter that are formed and detached at the rate of hundreds per second. They are accelerated across the arc gap by arc forces that are sufficient to overcome the effect of gravity. This transfer mode results in deeper penetration and lower spatter level than either the short-circuiting or globular mode. However, the large weld pool size prevents its use for out-of-position pipe welding except for GMAW-P.

4.3.4 Flux-Cored Arc Welding Process

4.3.4.1 Electrodes. Flux-cored electrodes are available today for virtually any grade of carbon steel, low alloy steel, and stainless pipe material. Flux-cored electrodes are frequently made in two formulations: a standard formulation and an “all-position” formulation. The flux in the “all-position” wire causes the weld pool to freeze faster than the standard formulation. This is required when welding “out of position” relative to gravity. “All position” versions of flux-cored wire should be used for orbital pipe welding. The first flux-cored wires used an acidic rutile flux. This type of flux provides good penetration and high tolerance to weld surface contaminants. In the 1960s, basic calcium oxide low-hydrogen, gas shielded, all-position flux-core electrodes were developed that produce welds with high tensile strength and high low-temperature impact energy. However, basic flux-core electrodes provide less penetration and tolerance to weld surface contaminants

4.3.4.2 Shielding Gases. Particular attention should be paid to the flux-cored electrode manufacturer’s recommendation for shielding gas composition. Shielding gas affects the arc stability and the metallurgy of the deposited metal. Gasless type flux-cored wires, while excellent for many applications, require more cleaning between passes than the gas shielded flux-cored wires.

4.3.4.3 Travel Direction. With the pipe in the horizontal (5G) position, FCAW-G is normally done using a double up technique. Compared to GMAW, the travel speed for FCAW-G will be lower than for the GMAW process which is normally done using a double down technique. A double down technique is not normally used with the flux-core wires, due to the possibility of slag entrapment. While FCAW-G is capable of higher deposit rates than GMAW, the lower travel speed can be a limitation for certain applications such as pipeline welding where arc time per pass is more important than deposition rate. It is possible to develop procedures that allow metal-cored wires to be used with a double down technique. A true orbital technique, 360 degrees, can only be used with the pipe in the 2G or 1G position (sometimes used for double jointing pipe)

4.3.4.4 Advantages and Disadvantages of FCAW-G vs. GMAW. Some important differences to note with these two processes are as follows:

1. An advantage of the FCAW-G process over the GMAW process is that the FCAW-G is more forgiving, and thus less dependent on operator skill level than the GMAW process.
2. A disadvantage of the FCAW-G process compared to the GMAW process is that most flux-cored wires on the market today do not have a continuous 360 degree sheath, but have either a butt or overlap joint. This interruption in the metal sheath can permit moisture into the flux if the electrodes are improperly stored and exposed to moisture. Flux that has absorbed moisture can lead to several types of weld defects including porosity.
3. A disadvantage of the FCAW-G process is electrodes from different manufacturers with identical AWS specifications may have very different welding characteristics.
4. A disadvantage of the FCAW-G process is the requirement for removal of slag.

4.3.5 Carbon Dioxide-Shielded Non-Pulsed GMAW/FCAW Processes

4.3.5.1 Transfer Mode. The quality of carbon dioxide shielding gas for welding is specified by AWS Classification SG-C, AWS A5.32/A5.32M, *Specification for Welding Shielding Gases*. Carbon dioxide shielding gas results in the short-circuiting transfer mode of metal transfer. This is because the ionization potential for carbon dioxide is so low that the energy density needed in the arc to transition to globular or spray transfer cannot be achieved.

4.3.5.2 Strengths of the Carbon Dioxide-Shielded Non-Pulsed GMAW/FCAW Processes. The strengths of the carbon dioxide shielded short circuiting transfer GMAW and FCAW-G processes are as follows:

1. The process has been used very successfully for over 50 years in all parts of the world and in all kinds of environments.
2. Welds meet or exceed the requirements of welding codes such as API 1104.

3. Carbon dioxide shielding gas is more readily available around the world than inert gases.
4. Carbon dioxide shielding gas is less expensive than inert gases such as argon.
5. Welding power supplies used for carbon dioxide-shielded GMAW/FCAW-G welding are less expensive than GMAW-P/FCAW welding power supplies.
6. Recent developments in power supplies utilizing both microprocessor and inverter technology allow welds to be made at low voltages and short arc lengths without the spatter normally associated with short-circuit transfer mode. This technology allows carbon dioxide-shielded GMAW to be used for depositing the root pass from the outside without internal copper backup because of the small fast-freezing weld pool.

4.3.5.3 Limitations of the Carbon Dioxide-Shielded Non-Pulsed GMAW/FCAW Processes. The limitations of the carbon dioxide shielded short circuiting transfer GMAW and FCAW-G processes are as follows:

1. Carbon dioxide shielding produces more spatter than the argon—carbon dioxide mixed shielding gasses. The spatter requires more frequent cleaning/replacement of torch components and may require secondary work piece clean-up operations. Any spatter adhering to the pipe surface next to the joint will make it more difficult to ultrasonically inspect the weld joint and complicates secondary operations such as pipe coating.
2. The carbon dioxide-shielded GMAW/FCAW-G process cannot be used for internal welding because it produces undercut in the overhead position on the inside of the pipe, and the spatter produced quickly plugs up the gas nozzles of the torches.
3. Carbon dioxide-shielded welding requires careful control of torch (arc) placement in the weld seam, and thus places greater skill demands on the welder, if incomplete fusion defects are to be avoided.
4. Carbon dioxide shielding gases can produce harder deposits than argon-carbon dioxide shielding mixtures. This is not typically a problem, because the hardest area is normally in the heat-affected zone next to the last cap pass.

4.3.6 Argon-Carbon Dioxide-Helium Shielded Non-Pulsed GMAW/FCAW-G Processes

4.3.6.1 Shielding Gases and transfer Mode. The quality of argon-carbon dioxide gas mixtures and argon-carbon dioxide-helium gas mixtures for welding are specified by AWS Classification SG-AC-X and AWS Classification SG-ACHe-X in AWS A5.32/A5.32M *Specification for Welding Shielding Gases*. All-position pipe welding is possible with argon-carbon dioxide or argon-carbon dioxide-helium gas mixtures using short-circuiting transfer GMAW/FCAW-G process.

4.3.6.2 Strengths of the Argon-Carbon Dioxide Shielded GMAW/FCAW Processes. Strengths for this shielding are as follows:

1. Argon-carbon dioxide shielding gas mixes result in less spatter than 100% carbon dioxide.
2. Although joints should be clean and free of hydrocarbons (oil, grease) and iron oxide, the argon-carbon dioxide shielded GMAW/FCAW process is more tolerant of light contaminants on the joint (such as oil or oxide) than the GTAW-P process.
3. Argon-rich shielding gas mixtures produce weld metal with better toughness than carbon dioxide-rich shielding gas mixtures.

4.3.6.3 Limitations of the Argon-Carbon Dioxide Shielded GMAW/FCAW-G Processes. Some limitations characteristic of this shielding are as follows:

1. Argon-carbon dioxide gas mixtures are more expensive than pure carbon dioxide.
2. Care should be taken by the gas supplier to ensure that the gases are consistently mixed in the correct ratio.
3. It is often difficult to procure welding grade argon-carbon dioxide mixtures in many countries.
4. Argon and carbon dioxide can separate during storage in high pressure cylinders, resulting in excessive Argon when the cylinder is first opened, and resulting in excessive carbon dioxide when the cylinder is near empty.
5. Argon is lighter than carbon dioxide, so argon-carbon dioxide mixtures cannot tolerate drafts as well as pure carbon dioxide. Therefore, drafts are more of a problem when using Argon-carbon dioxide mixtures. Tents or metal shelters should be used for cross-country construction of pipelines.

4.3.7 Pulsed Gas Metal Arc Welding (GMAW-P) Process

4.3.7.1 Process Description. Pulsed-spray transfer alternates the current level between high amperage peaks and low amperage background current levels. The pulse peak currents are above the transition current, while the background current levels are lower than the transition current. The background current is sufficient to keep the plasma in the arc gap ionized, thus sustaining the arc, and provides some energy to melt the wire, but not enough to transfer metal. At the upper current level, above the transition level during which spray transfer occurs, the filler wire is melted and a small molten drop of metal is projected across the arc in a spray-transfer mode. The average current level is usually maintained below the transition current level. Typical pulse rates range from 20 to 400 pulses per second. Shielding gases for pulsed gas metal arc welding of carbon steels are normally 80% or 85% argon with a balance of carbon dioxide or carbon dioxide and helium.

4.3.7.2 Transfer Mode. The goal of the pulsed-spray process is to detach one droplet of wire with each energy pulse applied to the electrode. Applying precisely this amount of energy at precisely the correct time produces a stable arc, optimal weld pool formation conditions, and minimizes spatter. However, a number of variables—peak pulse current level, background current level, peak pulse time duration, and pulse frequency must be precisely controlled for this to happen. The interdependence and sensitivity of these parameters make it difficult for many users to properly adjust pulse welding power supplies.

4.3.7.3 Power Supplies and Wire Feeders. Power supply manufacturers have come to terms with this problem by developing power sources capable of “synergic” operation. Synergic programming is based on the concept that the pulse parameters are factory-preprogrammed for a given wire diameter, material, and shielding gas. The wire feeder interacts with the factory-preset program, which automatically adjusts one or more of the pulse variables to maintain a uniform energy output per unit of wire. The welder is free to simply increase or decrease the wire feed speed as pulse parameters are automatically adjusted to maintain a stable arc.

4.3.7.4 Strengths of the Pulsed GMAW Process. The advantages of the GMAW-P process over the non-pulsed GMAW/FCAW processes are as follows:

1. The use of inert shielding gas instead of an oxidizing shielding gas such as carbon dioxide improves the notch toughness and fracture resistance of the deposited weld metal.
2. The process can be used to weld difficult-to-weld alloys such as the duplex and super-duplex stainless steels and nickel alloy clad carbon steels.
3. The arc is more stable and produces less spatter.
4. GMAW-P arcs are less affected by rare earth-treated steels than non-pulsed GMAW/FCAW arcs.
5. Synergic power supplies allow the wire feed speed to be changed without the welder needing to readjust the other welding power supply parameters.

4.3.7.5 Limitations of the Pulsed GMAW Process. The limitations of the GMAW-P process over the non-pulsed GMAW/FCAW processes are as follows:

1. The process requires gas mixtures that are accurate to within a few volume percent. In many places in the world, it is difficult to procure accurately mixed shield gas with adequate purity and sufficiently low dew point. Gas mixtures that are common in one country may not be common in another, making it difficult to develop and qualify a welding procedure in one country and then use it in another.
2. The wire feed speed usually needs to be synchronized to the welding power supply output, requiring feeders that are specifically designed to be used with a particular power supply, or requiring control electronics that can synchronize the command sent to the welding power supply with the speed of the wire feeder.
3. Pulsed arc power supplies require greater user skill in optimizing the pulse parameters for a weld, unless they are of the synergic type.
4. Synergic pulsed arc welding power supplies are more expensive than constant potential welding power supplies used for the non-pulsed GMAW/FCAW processes.
5. The mixed shielding gases used with pulsed arc power supplies are more easily disturbed by drafts than heavier carbon dioxide shielding gas.

5. Pipe Beveling

5.1 Overview. Pipe ends can be prepared using thermal means, (including plasma, carbon arc, and oxy-acetylene torch). However, these processes do not lend themselves to the close tolerances required for multipass orbital machine pipe groove welding, and for this reason, these processes are not considered within the scope of this document. Joints for multipass orbital machine pipe groove welding are normally machined with “portable” pipe beveling machines (PBMs).

5.1.1 Weld Bevel Configurations. Permissible variations in weld bevel configurations are numerous. This document makes no attempt to address every conceivable bevel configuration. The bevel configurations illustrated in Figures 6 and 7 are commonly used in multipass orbital machine pipe groove welding. Some joint designs require a consumable insert backing ring and may require manual GTAW process. Typically, when manual GTAW is used for open butt welding, the root and hot passes must be completed before multipass orbital machine pipe groove welding can be used. Figure 8 shows AWS terminology for parts of a butt joint bevel.

The ASME recommended joint designs shown in Figure 6 are typically used for pipe welds in the process industry. The API recommended joint designs shown in Figure 7 are typically used for pipe welds in the transmission pipeline industry.

The API 30-degree standard bevel shown in Figure 7A is normally used for manual welding processes and sometimes used for machine orbital pipe welding. The disadvantage of this joint design is the large cross-sectional area and large volume of filler metal required per unit of weld length. The advantage of this joint design is that it is offered as an option by pipe mills, which eliminates the need for beveling each joint before welding.

The compound 37.5 and 10-degree bevel shown in Figure 6b is useful for heavy wall pipe. It allows the welding torch to reach the root, while reducing the amount of weld metal required compared to a standard 30-degree bevel.

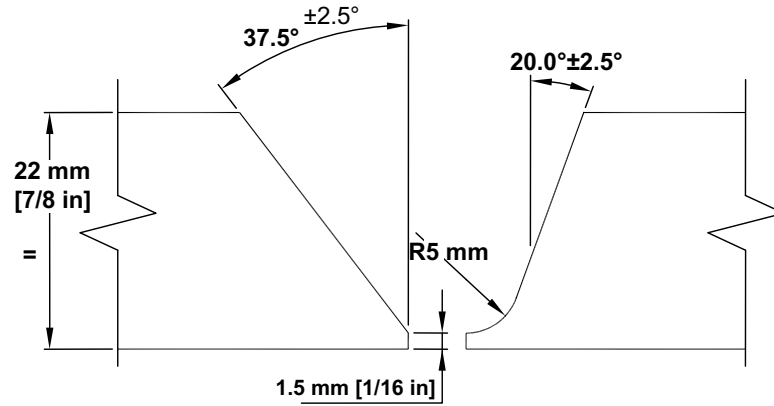
Narrow groove joint designs such as the compound bevel and J-prep bevel, shown in Figure 7b and 7c, are normally used for orbital machine pipe groove welding. Narrow groove bevels increase productivity by reducing the amount of weld metal that must be deposited per unit weld length.

5.1.1.1 Automatic Welding Bevel for External Root. The “J” bevel joint design shown in Figure 7c is typically used when the root pass is deposited from the outside of the pipe, either with or without a copper backup. The root face of the J-groove joint is totally penetrated by the external root pass. (Refer to Figure 8 for the AWS terminology for parts of a butt joint bevel.) The root face extension should be carefully controlled. If the extension is too great, the root face may be pushed into the pipe by the welding arc, leaving excessive internal reinforcement. Alternatively, the root face may be under-filled at the bottom of the pipe, leaving a concave root bead. If the extension is too small, the root pass may not penetrate the root face. In addition, the weld metal may be cold lapped against the bevel radius.

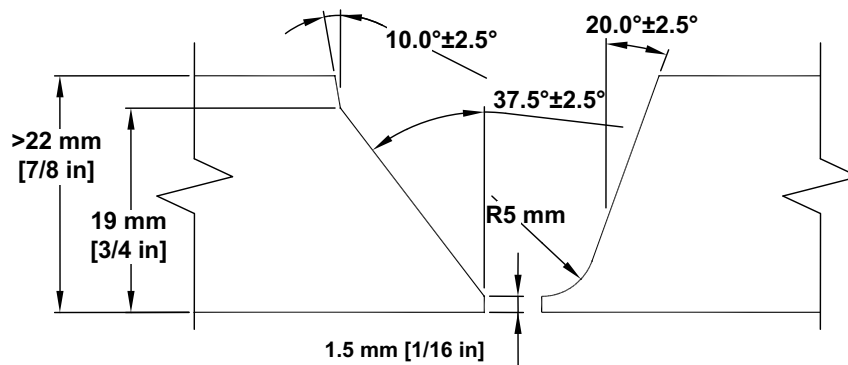
5.1.1.2 Automatic Welding Bevel for Internal Root. The compound bevel shown in Figure 7b is typical of bevels used for multipass orbital machine pipe groove welding when the root pass is deposited from the inside of the pipe. The land of this type of joint is not totally penetrated by the internal root pass. Instead, the hot pass, deposited from outside the pipe, cross-penetrates into the root pass. The root bevel is chosen to maximize penetration while providing an optimum weld bead shape and accommodate pipe weld joint mismatch. See Figure 8 for the AWS definition of weld joint mismatch. The land thickness is chosen to prevent root bead burn through, and at the same time ensure cross penetration by the hot pass. The root pass should be several millimeters thick. If the root weld pass is too thin, the result may be underfill or burn through. The angle from the land to the walls is chosen to ensure the hot pass nugget forms an acceptable profile. The sidewall angle is chosen to minimize the amount of filler metal deposited (for economic reasons) while providing adequate visibility and access to the bottom of the groove. The width of the joint is also chosen to minimize the amount of weld metal deposited while providing adequate visibility and access to the bottom of the groove. The width is also determined by the need to keep the weld pass dimensions within the range that will not lead to centerline cracking. Centerline cracking can be caused by too high or too low of a weld pass thickness to width ratio. Weld pass thickness also affects the ability of entrapped shield gas to escape the weld pool.

5.1.2 Mill Ends. Pipe can be purchased from the pipe mill with API 30-degree standard bevels, or square ends. For transmission pipeline automatic bevel configurations, such as the compound bevel shown in Figure 7b, it is better to have the pipe mill provide beveled ends for pipe with a wall thickness of 13 mm [0.5 in] or less, and square ends for pipe with walls thicker than 13 mm [0.5 in]. This minimizes the amount of material to be machined in the field as shown in Figure 9.

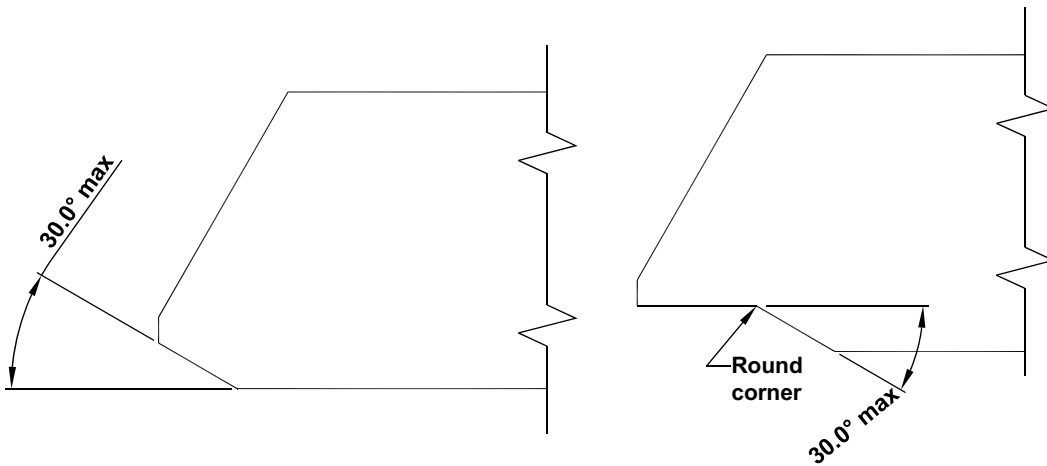
Pipe mills protect pipe bevels during shipment with metal or plastic caps. Despite this, some bevels are usually damaged during pipe transportation and handling. Bevels prepared at the pipe mill may also corrode during transportation,



(a) Wall Thickness 6 mm to 22 mm [1/4 in to 7/8 in]



(b) Wall Thickness Over 22 mm [7/8 in]



(c) Thicker Pipe Taper-Bored to Align

(d) Thicker Pipe Bored for Alignment

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Figure 6—ASME Joint Designs for Process Plant Pipe Groove Welding

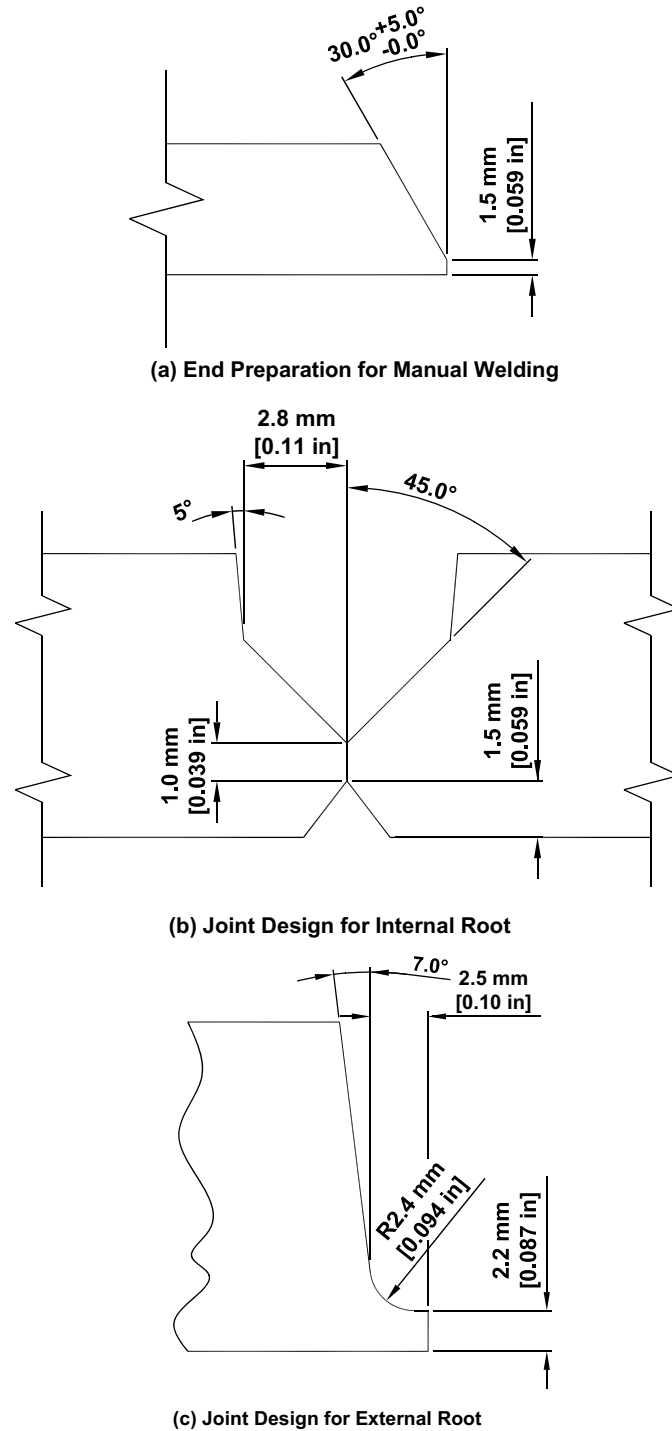
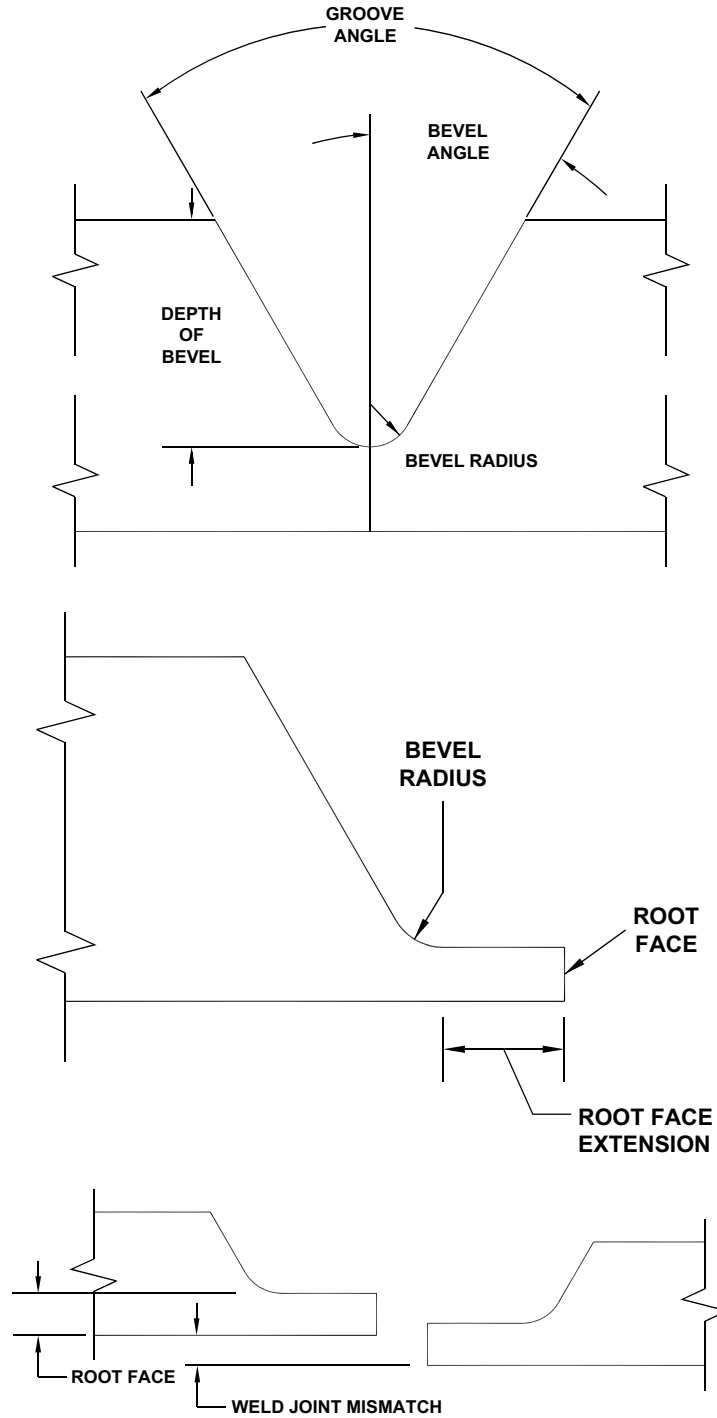


Figure 7—Joint Designs for Transmission Pipe Groove Welding

handling, and storage. By beveling the pipe ends in the field before welding, damaged bevels and oxidation are eliminated. For cross-country pipe using carbon steels, joints are beveled from a few minutes to one day in advance.

5.1.3 Chamfers and Counterbores. Chamfers similar to that shown in the top of Figure 10 are used in plant pipe welding situations at elbows where a counterbore similar to that shown in the bottom of Figure 10 would violate minimum wall thickness at the crest of the elbow. Chamfers are also used to match the inside diameters of some pipe for



Source: Adapted from American Welding Society A2 Committee on Definitions and Symbols, AWS A3.0M/A3.0:2010, *Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*, Miami: American Welding Society, Figure B.6 and Figure B.13.

Figure 8—AWS Terminology for Parts of a Butt Joint Bevel and Weld Joint Mismatch

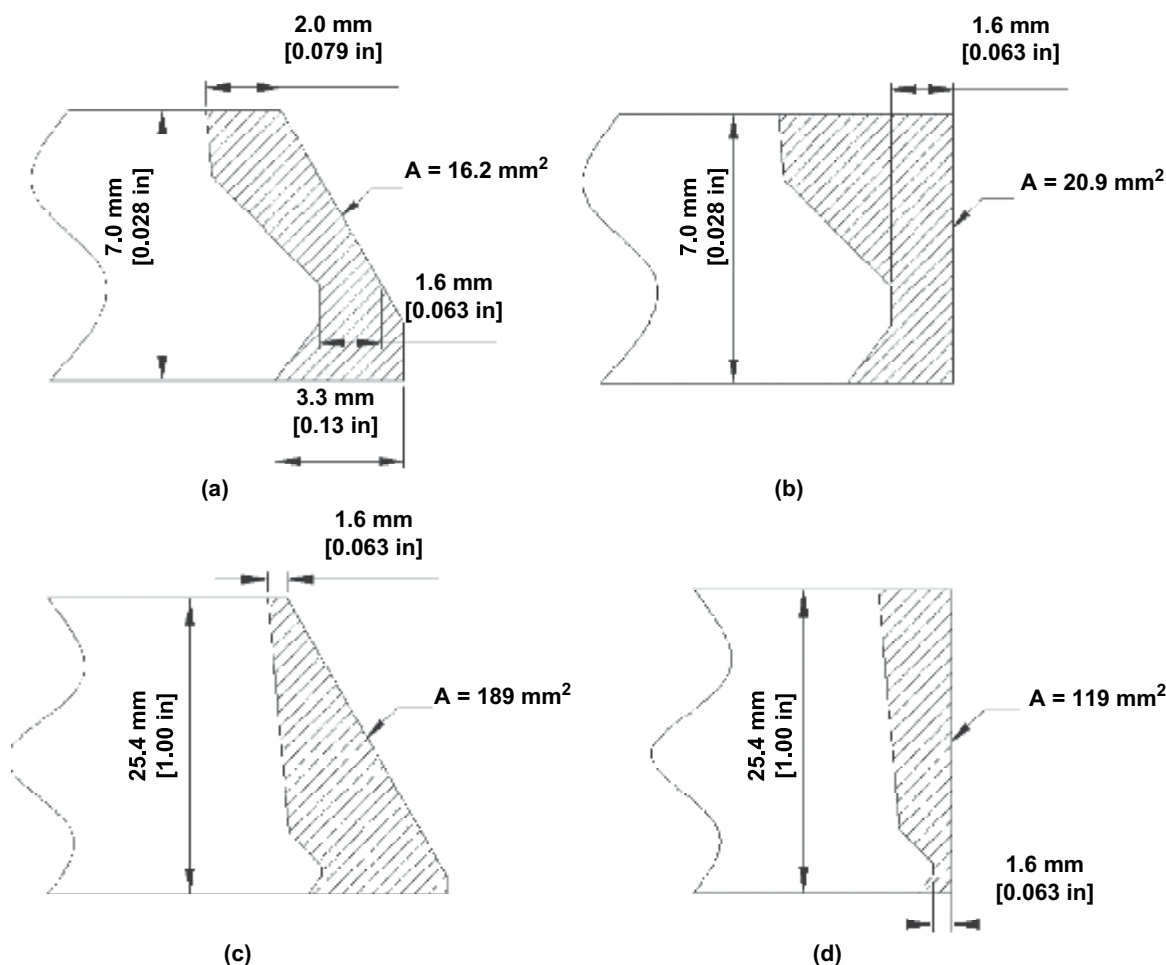


Figure 9—Material Removal Requirement for Compound Bevels

consumable insert root welding. Counterbores used with plant piping are similar in appearance to that shown in the bottom of Figure 10. For plant pipe welding, the non-tapered area typically extends for a distance of twice the pipe wall thickness. These counterbores are used principally to create a constant land for welding and to move the straight machining lines outside of the radiograph or ultrasonic test zone. Counterbores are also used for weld joints where the change in wall thickness must be moved outside of the HAZ zone to minimize notch effects. Other places where deep counterbores are used are for cladding operations ahead of dissimilar welds and pipe wall thickness matching.

For transmission pipeline welding, non-standard extended internal counterbores are needed. These counterbores typically reduce the wall thickness of the thicker pipe to match the wall thickness of the thinner pipe for a distance of 100 mm [4 in] from the open end. The extended counterbore then transitions to the full heavy wall pipe thickness at a 4 to 1 taper like the standard counterbore. Extended counterbores allow the weld joint to be examined by automated ultrasonic testing. The ultrasonic probes require the internal surface of the pipe to be parallel to the external surface for approximately this distance. The clamping shoes of internal line-up clamps and internal welders require this distance to be counterbored for the clamping shoes to line up the two pipes.

5.2 Inside Diameter (I.D.) Mounted Pipe Beveling Machines

5.2.1 Overview. There are three styles of I.D. mounted pipe beveling machines. Pneumatic motors drive the first style with power ranging from 1 to 3 kW [1.3 to 4 hp] (Figure 11 and 12). The second style is driven by electric motors with power ranging from 0.5 to 5.4 kW [0.7 to 7.2 hp] (Figure 13). The first two styles are mainly used for the process plant industry. The third style is driven by hydraulic motors with power ranging from 26 to 31 kW [35 to 42 hp] (Figure 14).

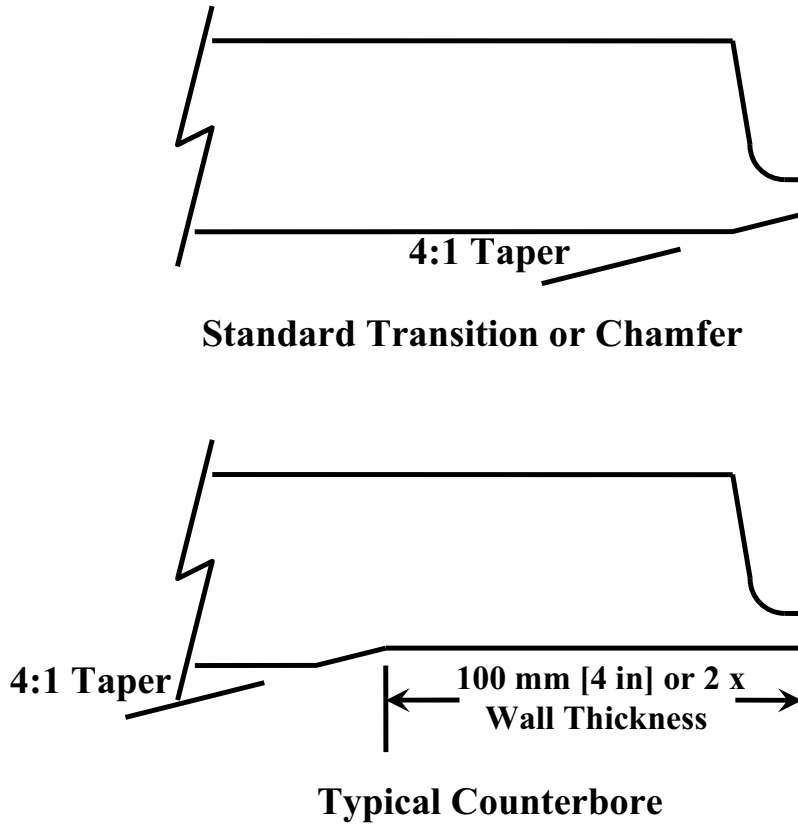


Figure 10—Standard Transitions and Counterbores

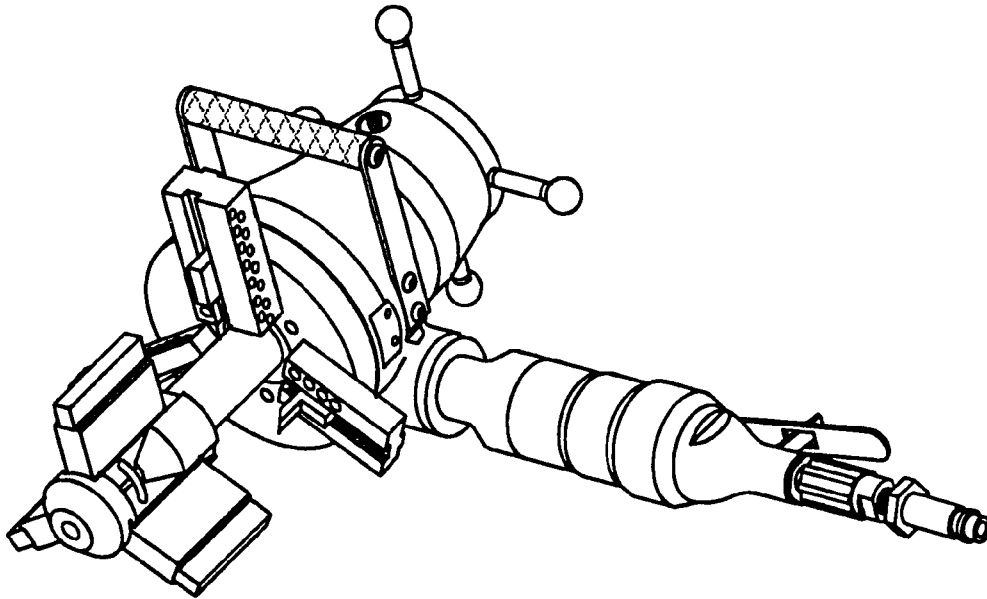


Figure courtesy of TRI TOOL INC

Figure 11—Pneumatic Motor Driven Internal Mount Pipe Beveling Machine for DN 50 to DN 150 [NPS 2 to NPS 6]

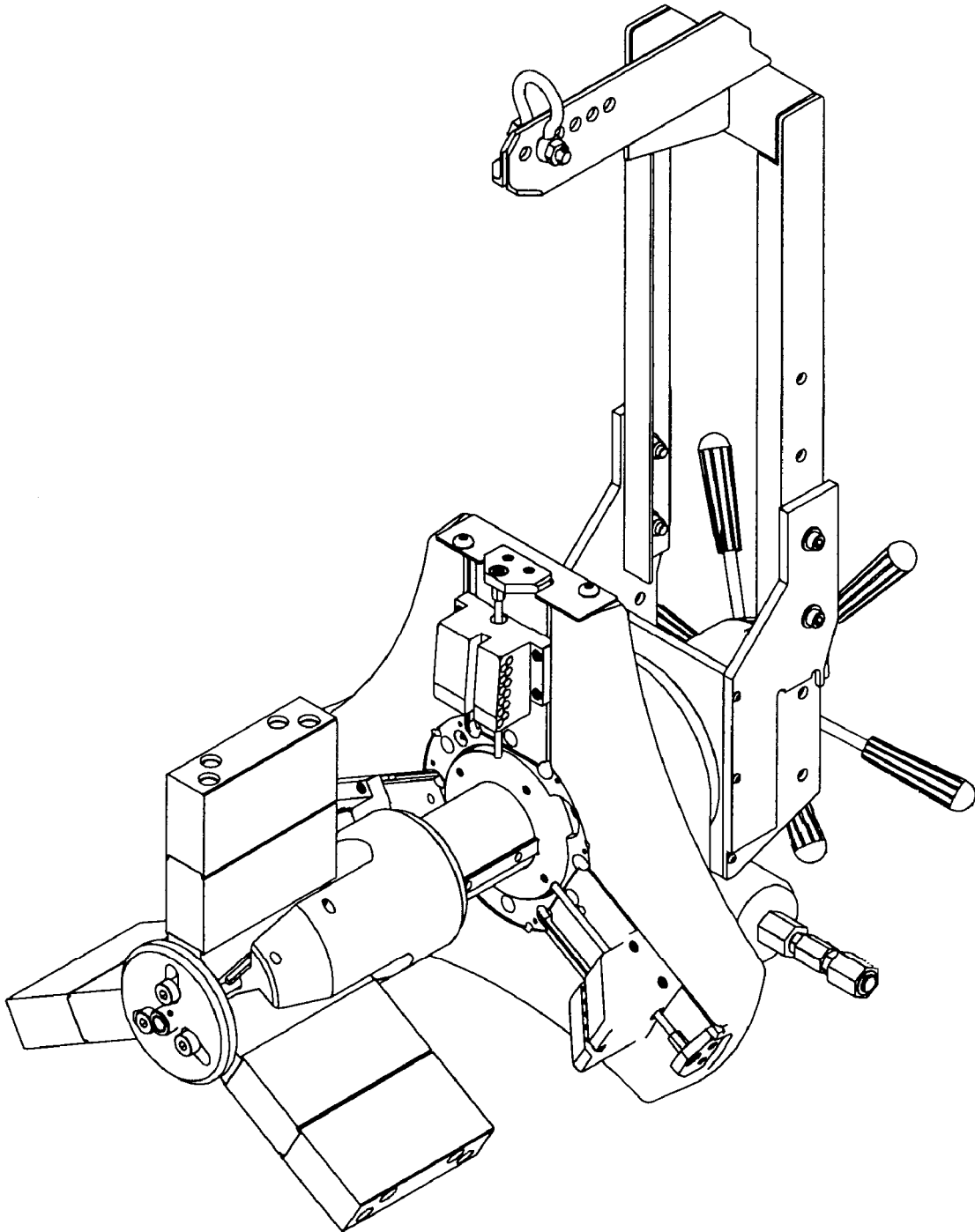
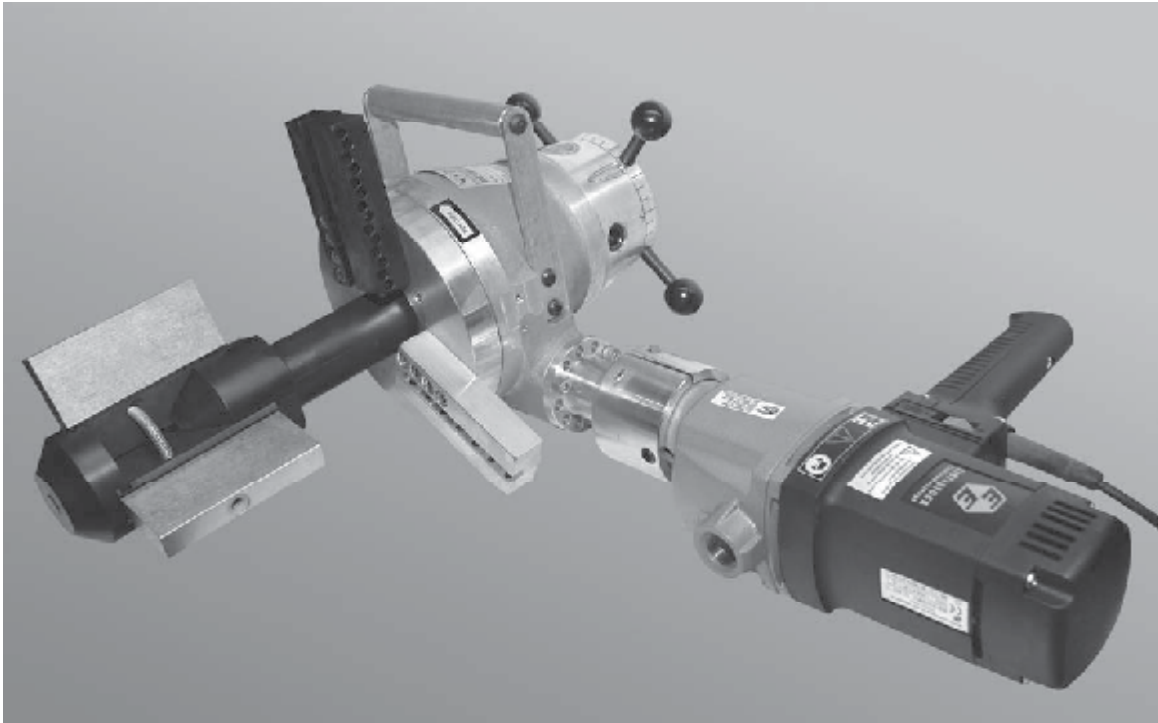


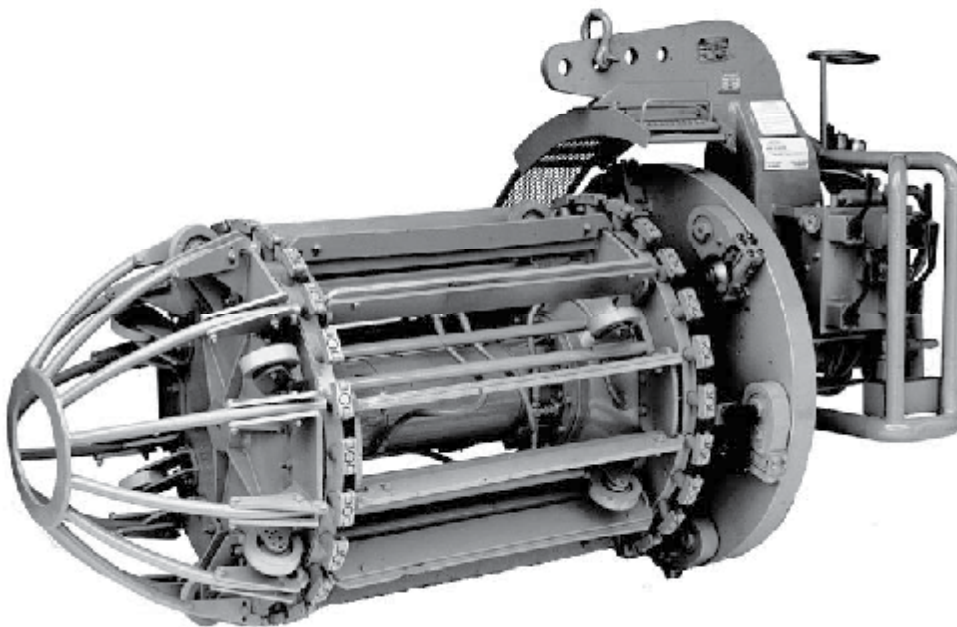
Figure courtesy of TRI TOOL INC

Figure 12—Pneumatic Motor Driven Internal Mount Pipe Beveling Machine for DN 200 to DN 600 [NPS 8 to NPS 24]



Photograph courtesy of TRI TOOL INC

Figure 13—Electric Motor Driven Internal Mount Pipe Beveling Machine



Photograph courtesy of CRC-Evans Automatic Welding

Figure 14—Hydraulic Motor Driven Internal Mount Pipe Beveling Machine

The hydraulic motors are in turn driven by hydraulic power units with 36 kW [48 hp] diesel engine or 44 kW [60 hp] electric motor primary movers. All three styles of machines can be used in most field environments, such as rain, snow, heat and cold.

Metal removal rate is directly related to horsepower. The constant of proportionality is higher for very machinable materials and lower for very hard materials. Knowing the desired final bevel shape, and the initial pipe end shape (square or mill end bevel), it is possible to calculate the amount of material that must be removed from the pipe end to machine the joint. If the horsepower and constant of proportionality for a pipe beveling machine are known, it is possible to calculate how many minutes of pipe beveling time will be required to machine a bevel. Horsepower is not the only consideration in determining which pipe beveling machine is the right choice for a particular application. Other factors such as portability are also important, and are discussed in the following sections.

5.2.1.1 Pneumatic Motor Driven I.D. Mounted Pipe Beveling Machines. Pneumatic motor driven I.D. mounted pipe beveling machines are typically used for end prepping open-ended pipe.

The machines provide quick set-up, high stock removal rates, and produce matching bevels. Once the tool bits have been set to obtain the desired bevel shape, the machine can be moved to the next pipe end without changing tool bits.

This style of pipe beveling machine utilizes pneumatic motors. The motors offer high kilowatt (horsepower) output per unit volume and weight. Output power ranges from 1.1 through 3.0 kW [1.5 to 4 hp]. Air requirements range from 160 through 220 L/min [5.7 through 7.8 ft³/min] at 620 kPa [90 psi].

Various types of mandrels are used to clamp this style machine in the I.D. of the pipe. The most commonly used mandrels for smaller machines (up to 760 mm [30 in] diameter) are 3 or 5 jaw self-centering and aligning mandrels that are actuated through a draw rod. The draw rod extends from the rear of the machine and is drawn by means of a threaded nut-wheel or by means of a pneumatic cylinder. The rotary plate of these machines is advanced into the pipe end along the mandrel shaft. Forward movement along the shaft into the end of the pipe is accomplished by manual or automatic feed. The cutting torque for the rotary plate is transmitted to the mandrel shaft by means of torque keys in the mandrel shaft. The rotary plates, referred to as cutting heads, generally carry 3 tool modules for beveling, facing, and counterboring the pipe end. In some cases, the rotary plates carry a single tool module with a single point tool bit. The single point machines incorporate an auto-feed mechanism that moves the tool bit radially as the rotating plate advances toward the pipe. The combination of motions can be set to produce any desired bevel angle.

These machines center to the I.D. of the pipe to provide end preps concentric to the bore as established by the mandrel. Ovality, wall variations, and flat spots in the pipe may shift the mounting center. If it is not practical to round the pipe, I.D. tracking tool holders can be used. The floating tool holder is guided by a tracking wheel or cam roller that is forced by spring pressure against the I.D. of the pipe to produce a constant land or extended counterbore. When there is a risk of violating minimum wall requirements, special mandrels can be used to optimize the machining center using measured data. Many optional accessories are available for the weld end prep tools to expand their capabilities, address out of round pipe, address thin wall pipe, or allow mounting in fittings. Commonly available accessories and their functions are as follows:

1. miter mandrels that provide the capability to mount the PBM in fittings and other short perch situations. The miter mandrels use multiple jack screws in the bore of the pipe to set the mandrel and thus the central axis of machining concentric to the I.D. of the pipe (or fitting)
2. elbow mandrels that provide self-centering clamping while requiring only 19 mm [0.75 in.] insertion length into elbows and tees

Single point modules with accompanying larger mounting systems allow form tool cutting machines to end prep larger bore pipe. The upper range for form tool machines is normally restricted by the stiffness of the mandrel and required gear reductions, which limit the cutting speeds to avoid burning the tool bits. Single point cutting is normally performed at higher surface speeds and at lighter loads using carbide inserts. This allows use of lighter mandrels relative to the pipe diameter. The wall capacity of single point machines is limited only to the minimum and maximum diameters the modules can be set to reach.

5.2.1.2 Advantages of Pneumatic Motor Driven I.D. Mounted Pipe Beveling Machines. Advantages of the pneumatic beveling machines are as follows:

1. Small pneumatic motor driven pipe beveling machines can be lifted manually (the larger pneumatic motor driven machines must be lifted into place by chain falls or some type of rigging).

2. It is usually easier to set up the tool bits or inserts for the beveling operations on the pneumatic motor driven machines than on the hydraulic motor driven machines.
3. The pneumatic motor driven machines are more maneuverable in restricted access spaces than hydraulic motor driven machines.
4. Pneumatic motor driven machines are safer for use in potentially explosive atmospheres than machines requiring a diesel motor or electric motor.

5.2.1.3 Disadvantages of Pneumatic Motor Driven I.D. Mounted Pipe Beveling Machines. The disadvantages of the Pneumatic driven machines are as follows:

1. Small pneumatic motor driven pipe beveling machines have lower metal removal rates than hydraulic motor driven pipe beveling machines, because there is less power delivered to the tool bits or tool inserts.
2. Because of the limited power delivered to the rotating plate, pneumatic motor driven beveling machines generally use high-speed tool steel bits. High-speed tool steel bits are less expensive than tool inserts, but cannot be operated at as high a surface cutting speed.

5.2.2 Electric Motor Drive I.D. Mounted Pipe Beveling Machines. Electric motor drive pipe beveling machines are comparable to pneumatic drive pipe beveling machines in terms of kilowatt (horsepower) per unit volume and weight. Output power ranges from 0.5 through 5.5 kW [0.7 through 7.3 hp]. Like pneumatic drive pipe beveling machines, the mandrels for electric motor drive PBMs are actuated through a draw rod. The draw rod extends from the rear of the machine, and is drawn by means of a nut-wheel or nut-lever. The same types of tools used for the pneumatic drive pipe beveling machines are used for the electric motor drive pipe beveling machines. Finally, metal removal rates are comparable to the metal removal rates of pneumatic drive pipe beveling machines because of similar horsepower.

5.2.2.1 Advantages of Electric Motor Drive I.D. Mounted Pipe Beveling Machines. Electric motor drive pipe beveling machines offer many of the features of the pneumatic drive pipe beveling machines, without the need for large volumes of compressed air.

5.2.2.2 Disadvantages of Electric Motor Drive I.D. Mounted Pipe Beveling Machines. Electric motor drive pipe beveling machines are somewhat larger and heavier than the equivalent pneumatic drive pipe beveling machines, and are therefore not as maneuverable in tight spaces. Electric drive PBMs that use open (non-explosion proof sealed) electric motors present a fire hazard compared to PBMs that use pneumatic motors.

5.2.3 Hydraulic Motor Driven I.D. Mounted Pipe Beveling Machines. Hydraulic motor driven PBMs use tool inserts in the tool holders. The tool insert holders are mounted on multiple spring-loaded pivoting arms or slide blocks. A guide roller is mounted on each pivoting arm or slide block. The guide roller is forced to ride against the inside diameter of the pipe by means of high force springs. This arrangement maintains a constant distance between the cutting tool radial position and the pipe inner surface. By maintaining a constant distance from the inside surface of the pipe, a constant root face dimension can be maintained. Pipe ovality is common. Without floating tool holders and guide rollers, that is, if the radial distance from the central axis of rotation to the tool holder was fixed, the root face thickness would vary around the circumference. Each tool insert cuts a single facet of the bevel. Once the inserts are set to create the correct bevel, the machine can be moved from joint to joint to produce matching bevels. Tools that are used to bevel a square face on the end of the pipe, such as those that machine the land, can be mounted in tool holders that do not float provided the width of the cutting face can accommodate the out of roundness of the pipe. Hydraulic motor driven I.D. mounted PBMs use hydraulically expanded clamping shoes to clamp the PBM to the inside of the pipe.

The faceplate of hydraulic motor driven PBMs is fed toward the pipe by variable speed hydraulic feeds. The feed rates range from 0.03 to 0.25 mm [0.001 to 0.010 in.] per revolution feed rate. The hydraulic power unit for this style of pipe beveling machine typically uses a diesel motor for cross-country pipelines or an electric motor for plant piping or lay vessel jobs. The power of the motors ranges from 5.6 to 37 kW [7.5 to 50 hp]. Machines are commercially available in various sizes to prep from 100 to 1500 mm [4 to 60 in.] diameter.

5.2.3.1 Advantages of Hydraulic Motor Driven I.D. Mounted Pipe Beveling Machines. The chief advantage of hydraulic motor driven pipe beveling machines is high metal removal rates due to the high horsepower delivered to the cutting tools.

5.2.3.2 Disadvantages of Hydraulic Motor Driven I.D. Mounted Pipe Beveling Machines. Many hydraulic motor driven pipe-beveling machines are heavy and large, requiring hoists or cranes to move them into place for

operation. Many are too big and bulky to be used for plant piping, because they cannot be maneuvered into restricted access locations. There are manufacturers who make PBMs with small hydraulic motors that can be used for plant piping. In potentially explosive atmospheres, the diesel driven hydraulic pumps may not be allowed, unless they have spark arrester mufflers. The electric driven hydraulic pumps may not be allowed in potentially explosive atmospheres unless equipped with explosion proof motors and explosion proof electrical controls.

5.3 Outside Diameter (O.D.) Mounted Machines for Inline Severing and Beveling

5.3.1 Overview. The O.D. mounted machines are used for severing and beveling inline pipes that may be part of existing plant piping, power piping, and/or pipeline pipe. Their main purpose is to cut out existing pipes, valves, tees, elbows, and flanges that may need to be replaced. These machines are generally bolted together in two halves around the pipe. They are clamped to the pipe by the means adjustable clamping pads for the smaller machines and four to eight jackscrews for the larger machines. The adjustable clamping pads are used to center the machine to the O.D. of the pipe. The machines have one or two tool module blocks mounted to the rotating ring of the machine (see Figures 15 and 16).

The tool bits are generally high-speed tool bits ground to the bevel configurations. These machines have the capability to simply sever the pipe, sever and machine a single bevel, or sever and machine a double bevel. The tool is fed radially inward by mechanical means of a star wheel attached to a fine-threaded shaft. As the tool module blocks rotate around the pipe, a tripper pin makes contact with the star wheel and rotates the star wheel a partial turn. The rotation of the star wheel advances the tool bit radially inward 0.08 to 0.10 mm [0.003 to 0.004 in] per revolution. The machines typically use pneumatic drive or hydraulic drive motors. On smaller O.D. mount machines electric drive motors may be used in some applications. The size ranges are from DN 25 to DN 1500 [NPS 1 to NPS 60] pipe. Two commonly used accessories are as follows:

1. Counterbore Modules which can be attached to the O.D. mount machines for counter-boring operations; and
2. O.D. Tracking Modules which can be mounted to track the O.D. of the pipe for severing and/or beveling operations. The O.D. tracking modules are typically used for thin wall pipe.

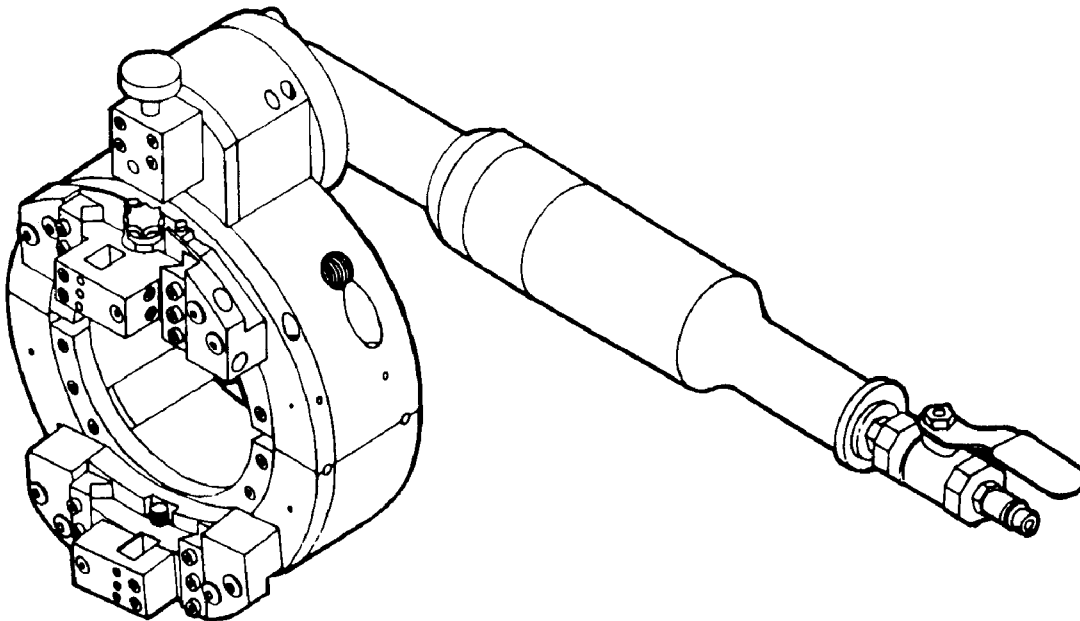


Figure courtesy of TRI TOOL INC

Figure 15—Pneumatic Motor Driven External Mount Pipe Beveling Machine for DN 50 to DN 150 [NPS 2 to NPS 6]



Photograph courtesy of TRI TOOL INC

Figure 16—Pneumatic Motor Driven External Mount Pipe Beveling Machines for DN 300 to DN 400 [NPS 12 to NPS 16] and DN 650 to DN 750 [NPS 26 to NPS 30]

5.3.2 O.D. Mounted Pipe Beveling Machines and Hazardous Environments. The O.D. Mount Machines are frequently used for simultaneously severing and beveling pipe when hazardous environmental conditions exist. That is, when the pipe being severed or beveled may contain the remnants of combustible liquids or gases that would be ignited by oxy-fuel flame cutting or beveling. These machines are considered cold cutting machines in the chemical, petrochemical, and refinery industries. They are also used for simultaneously severing and beveling pipe in the transmission pipeline industry when hazardous environments exist. The Safety Director of each job site must determine if the O.D. Mount Machines can be used in the specific environments.

5.3.2.1 Advantages of O.D. Mounted Pipe Beveling Machines: Advantages of the O.D. mounted machines are as follows:

1. The O.D. Mounted PBMs have the means to prep any bevel such as $37\frac{1}{2}$ -degree, 30-degree, compound bevels, counterbores, and transitions in addition to severing pipe. These machines make repeatable bevels both for manual and automatic orbital pipe welding processes;
2. The smaller O.D. Mounted PBMs can be lifted manually. The larger machines are normally lifted into place by chain falls or some type of rigging;
3. The O.D. Mounted PBMs are easy to set up for the severing and beveling operations; and
4. The O.D. Mounted PBMs can be used in most field environments, such as rain, snow, dust, hot climates, and cold climates.

5.3.2.2 Disadvantages of O.D. Mounted Pipe Beveling Machines: Disadvantages of the O.D. mounted machines are as follows:

1. The O.D. Mounted PBMs are centered to the O.D. of the pipe rather than the I.D. Variations in pipe wall thickness, such as that encountered in seamless pipe, can lead to variations in the bevel dimensions when using O.D. Mounted PBMs; and
2. Metal removal rates for O.D. Mounted PBMs are lower than for I.D. mounted hydraulic PBMs.

5.4 Tool Holders

5.4.1 I.D. Tracking Floating Tool Holders. There are two types of I.D. tracking floating tool holders: slide type and radial arm type.

5.4.1.1 Slide Type Floating I.D. Tracking Floating Tool Holders. There are two methods for mounting the tool holder such that it can slide on the surface of the faceplate in a radial direction:

1. *Dovetail slides.* Dovetail slides have been used to provide linear motion in machine tools for hundreds of years. When dovetail slides are used, a heavy slide base plate is bolted to the faceplate. A bar along one side of the slide can be pressed against the slide by means of setscrews that provide for removal of play in the dovetail. Dovetails are simple and work well, but they are heavy, require lubrication, and must be adjusted to remove the play as they wear;
2. *Linear ball bearings.* Linear ball bearings have only been available for the last 40 or 50 years. They are more complex than dovetails, but do not require lubrication or adjustment to compensate for wear because wear is very low. There is no way to accommodate wear in linear roller bearings. But as stated, this is not a problem because linear ball bearings wear very little.

5.4.1.2 Radial Arm Floating I.D. Radial arm tool holders eliminate the need for dovetails or linear ball bearings by mounting the tool holder in an arm that pivots. The tool can be either pushed along the edge of the pipe or pulled. Pulling the tool along the joint normally produces less tool chatter. Because the pivot bearing cannot provide adequate stiffness to the arm to resist the axial load, a cam roller is mounted in the arm that rolls on the faceplate. Radial arms require lubrication and adjustment of the cam roller, and therefore require more maintenance than a linear ball bearing type tool holder.

5.4.2. O.D. Tracking Floating Tool Holders. When counterboring pipes, a guide roller on the I.D. of the pipe cannot be used because the tool is constantly machining a new I.D. as the faceplate moves toward the pipe axially. Therefore, if stopped to clean chips or change tool bits, the guide roll cannot guide the tool because the I.D. is now larger, and the tool would cut an even larger I.D. The solution is to allow the tool holder to float, but guide it using a roller on the O.D. of the pipe.

5.5 Tools. Pipe facing tools can be made of either high-speed tool steels or tool inserts. In either case, the tool will not be cooled or aided with lubricants, for the following reasons:

1. The beveling frequently takes place in an area where lubricant cannot be caught and recycled.
2. It would not be possible to remove the lubricant before welding, which would lead to weld defects such as porosity.

Lack of tool bit lubrication and cooling reduces tool life compared to machine shop applications where cooling lubricant can be supplied.

5.5.1 M2 and M42 Tool Steels. M2 and M42 tool steels are molybdenum-type high-speed tool steels. They contain about 8% molybdenum with chromium, vanadium, tungsten, and cobalt as additional alloying elements. The M series high-speed tool steels have very high resistance to softening and very high resistance to wear. These tools are typically used with the types of pipe beveling machines that use pneumatic motors. The cutting speeds range from 45 to 75 surface meters per minute [150 to 250 ft/min] for stainless steel and 75 to 100 surface meters per minute [250 to 325 ft/min] for carbon steel. The tools are typically ground with a standard point of approximately 5 degrees. The pipe-beveling machine may index the tool holder on each revolution to create simple bevel geometries, or they can be ground with the shape of a compound bevel.

5.5.2 Tool Inserts. TNMG-coated carbide inserts are triangular, 0 degree clearance, “M” tolerance, chip breakers both sides tooling inserts that consist of a core of cemented carbides and physical or chemical vapor deposition coatings of, for

example, aluminum oxide, titanium carbide, titanium nitride, titanium aluminum nitride, titanium carbon nitride, or titanium boride. Typically, TNMG type coated carbide tool inserts are used with tool holders. The 0 degree clearance angle allows the inserts to be indexed as each point wears out. These tools are typically used with the types of pipe beveling machines that use hydraulic motors and cutting speeds in the range of 75 to 135 surface meters per minute [250 to 450 ft/min]. Multiple tool holders are used to create compound bevel shapes. The tool holders are forced toward the end of the pipe by controlled feed, and follow the contour of the pipe by means of rollers forced against the inside of the pipe by spring pressure.

6. Line-up Clamps.

For multipass orbital machine pipe groove welding, it is necessary to align the pipe ends prior to depositing the root pass. For plant piping, external line-up clamps can be used. See Figure 17 for a typical external pipe line-up clamp. In a process plant, the pipes are usually handled by hoists. Aligning the pipe ends by means of external line-up clamps and hoists



Photograph courtesy of Mathey Dearman, Inc.

Figure 17—External Pipe Line-up Clamp

requires more time than aligning pipe ends by means of an internal line-up clamp. See Figure 18 for an example of an internal pipe line-up clamp. Normally, plant piping involves short runs of pipe and 90-degree elbows. Internal line-up clamps of the type shown in Figure 18 cannot pass through elbows. Internal pipe line-up clamps are intended for transmission pipelines, which normally have joints bent to less than 30 times the pipe diameter as specified by ASME B31.4 or B31.8. The simplicity of the external line-up clamp and hoist method for lining up pipes is normally the only alternative for plant pipe welding. The time required to line up a pipe joint in a process plant may not be a critical path item. In some circumstances, many hours are allocated to a single weld in a process plant.

For transmission pipe welding, the time to line-up the pipes and deposit the root bead is a critical path event. The time required to line up the pipe and deposit the root pass and hot pass sets the production rate. Therefore, except for small diameter pipe, less than DN 250 [NPS 10], internal line-up clamps with copper backup shoes are typically used. Figure 19 illustrates typical copper backup shoes added to an internal line-up clamp. For orbital machine pipe groove welding of pipe larger than DN 400 [NPS 16], internal line-up clamps with internal GMA weld heads can also be used. Figure 20 illustrates an internal line-up clamp with GMA weld heads. Internal line-up clamps with copper backup shoes and internal line-up clamps with internal weld heads are discussed in the next two sections.

6.1 Internal Line-up Clamps with Copper Backup Shoes. There are two common types of internal line-up clamps with copper backup shoes. They differ in the way the copper backup shoes are brought into contact with the inside pipe surface. The copper backup shoes must be retracted after the root and hot passes have been completed to allow the internal line-up clamp to travel through the pipe to the next joint. The shape of the copper backup shoes and the method for bringing them into contact with the inside of the pipe and method for retracting the copper backup shoes from contact with the inside of the pipe fall into two common groups:

1. Internal line-up clamps with overlapping copper backup shoes attached to the internal line-up clamp front clamping shoe pins.
2. Internal line-up clamps with rotating (as opposed to overlapping) copper backup shoes attached to the internal line-up clamp front clamping shoe pins.

6.1.1 Internal Line-up clamps with Overlapping Copper Backup Shoes. The easiest way to change an existing pipe line-up clamp into a copper backup clamp is to remove the outer ends of the front clamping shoe pins and replace them with cantilevered supports for copper plates rolled to match the internal radius of the pipe. The front clamping shoe pins and rear clamping shoe pins are extended or retracted by means of pneumatic cylinders and linkages. The rolled copper plates are typically about 6 mm [0.25 in] thick by 100 mm [4 in] long by 50 to 75 mm [2 to 3 in] wide.

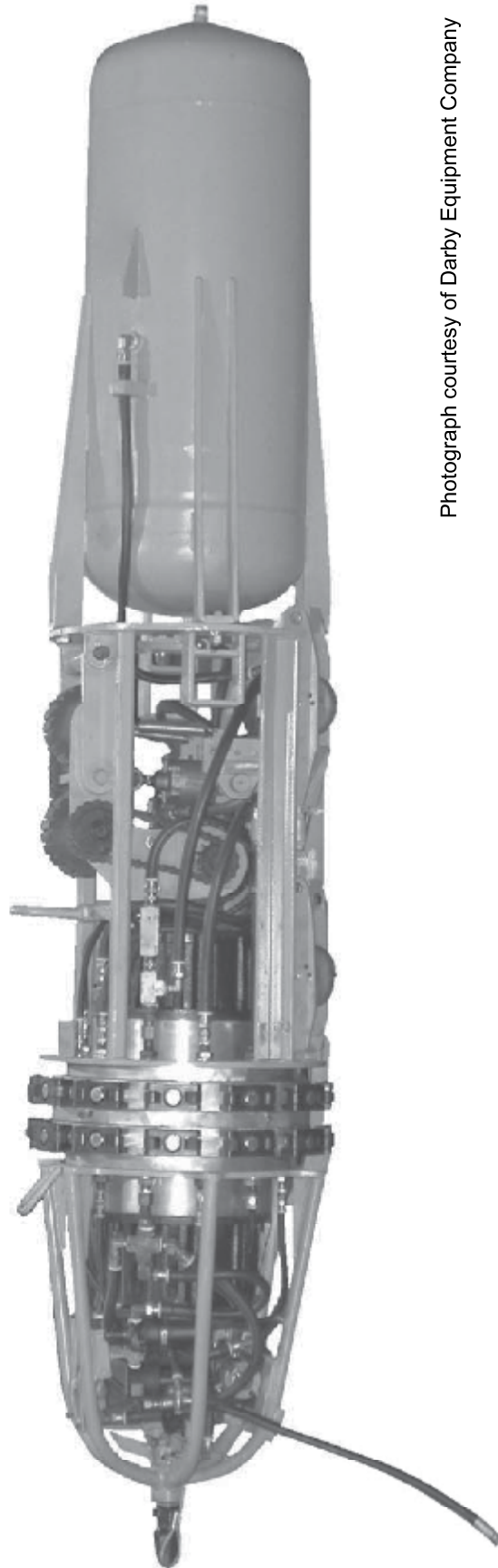
The ends of the copper plates are beveled at 45° angles. Alternate copper plates have the bevels facing up or facing down. The plates with the bevels facing up slide under the plates with bevels facing down.

Compression springs around the shoe pins and under the cantilever supports force the supports and copper plates outward toward the inner surface of the pipe when the shoe pins are extended. When the shoe pins are retracted the cantilever mounts and copper plates are retracted.

This type of copper backup clamp has historically been used in submerged arc double jointing stations. A limitation of this type of copper backup clamp is the inability of the copper plates to dissipate the heat from high production rate welds (one weld every three minutes). However, this type of clamp is very simple. The copper backup plates are easy to machine. Perhaps most important, if a copper plate becomes welded to the inside of the pipe, the clamp offers maximum force to tear the plate away from the inside of the pipe. By leaving the rear shoes extended, the clamp is centered in the pipe. When the front shoes start to retract, the links are at the position of maximum mechanical advantage, and can apply the greatest amount of downward force.

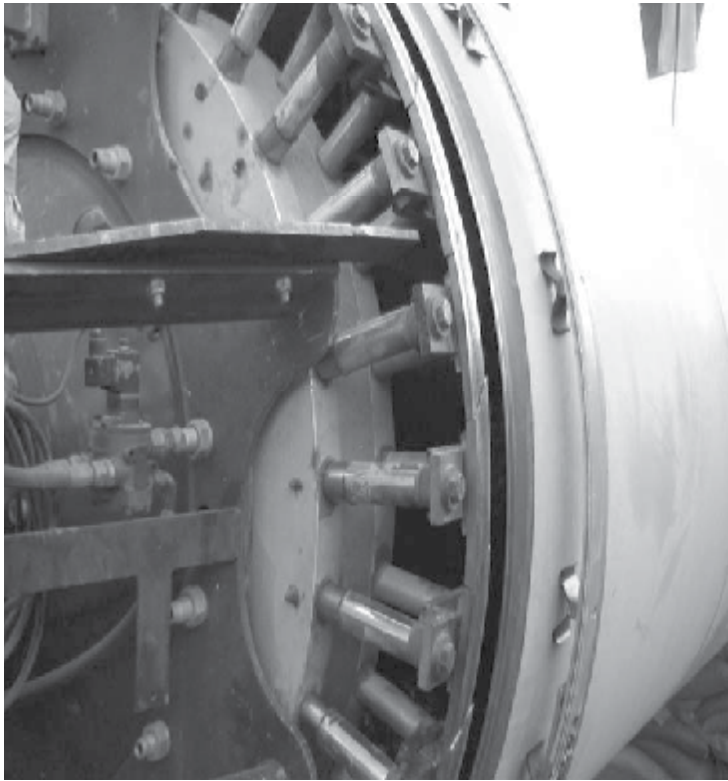
6.1.2 Internal Line-up Clamps with Rotating Copper Backup Shoes. Figure 19 shows a copper backup clamp with copper shoes that rotate. The shoes are mounted on cantilevers off the front shoe pins. Alternatively, the shoes can be mounted on a set of shoe pins radiating from a third expander section. The ends of the copper shoes, which are about 100 mm [4 in] long and 50 mm [2 in] wide, are beveled across the coppers at the ends so that each segment is shaped like a quadrilateral instead of a rectangle. As the copper backup shoes move up and down they rotate to keep the gaps closed between the shoes.

The advantage of this type of copper backup shoe is its ability to absorb more heat than can be absorbed by the thinner rolled copper plates used on the first type of copper backup clamp. The copper shoes are machined to match the nominal inside diameter of the pipe. With use, the coppers become pitted and must be re-machined to avoid becoming welded to



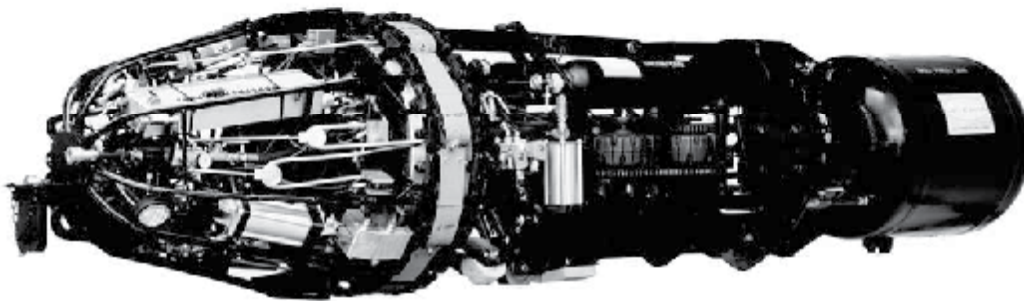
Photograph courtesy of Darby Equipment Company

Figure 18—Internal Pipe Line-up Clamp



Photograph courtesy of Serimax

Figure 19—Copper Backup Shoes on Internal Pipe Line-up Clamp



Photograph courtesy of CRC-Evans Automatic Welding

Figure 20—Internal Pipe Line-up Clamp with GMA Weld Heads

the root pass and to avoid unacceptable root profile. The shoes can only be re-machined a limited number of times before the external radius of the shoe has changed to the point where it no longer stays in contact with the inside of the pipe over its entire length.

Many materials have been tried for backup material. Ceramics typically fracture when pressed against the uneven root bead profile or spall because of the thermal shock caused by the molten weld metal coming in contact with the cool ceramic. Copper is able to withstand the forces caused by pressing the copper against the root of the weld. Copper can remove heat from molten weld metal that comes in contact faster than the molten metal can heat the copper to copper's melting point. Materials such as aluminum cannot remove the heat from the molten weld metal faster than the molten weld metal can heat aluminum to its melting point. Aluminum backup bars therefore experience local melting where the molten weld metal comes in contact. Other metallic materials will not only locally melt, but become welded to the molten weld metal that comes in contact with the shoe. Copper is unique in its ability to chill the molten weld metal of the root pass, forming the root contour. For this reason, copper is the backup material of choice. Common electrolytic tough pitch copper performs as well as any of the more expensive copper alloys. Some copper pickup by the weld metal may occur. In most transmission pipeline weld applications, the effect of copper pickup is not detrimental to the weld's fitness for service. The amount of copper contaminating the root weld metal is generally not sufficient to cause hot cracking during root bead solidification.

6.2 Internal Line-up Clamps with Internal Welding Torches

6.2.1 Overview. Figure 20 illustrates an alternative to internal line-up clamps with copper backup shoes. The internal line-up clamp in Figure 20 has been modified to include a rotating ring between the front and rear clamping shoes. GMAW torches are mounted on the rotating ring. The number of welding torches depends on the pipe diameter. Internal line-up clamps designed for pipe from DN 450 to DN 600 [NPS 18 to NPS 24] typically have two welding torches. Internal line-up clamps designed for pipe from DN 600 to DN 900 [NPS 24 to NPS 36] typically have 4 welding torches. From DN 900 to DN 1050 [NPS 36 to NPS 42], six welding torches can be used, and from DN 1050 [NPS 42] and larger, eight welding torches can be used.

6.2.2 Operation. Welding current is brought to the internal line-up clamp torches from welding power supplies located outside of the pipe. The welding power supplies are typically mounted on a support tractor that also has an air compressor, battery charger, auxiliary AC power source, and racks for cylinders of shield gas. Shielding gas is supplied from cylinders on the internal welder, which are recharged occasionally from the bottles on the tractor.

Welding is done down hill, with half of the heads welding while the other half of the heads are moving uphill toward their starting positions. After the first set of heads welds one side of the pipe downhill, the other half of the heads welds the second side of the pipe downhill. Each welding head ends its weld by tying into the weld start of the head traveling in front of it. The most difficult tie-in is at the top, where the second head to start at the top must tie into the previously deposited weld start as it starts welding.

The welding torches are aligned with the edge of the joint by means of blocks that are raised from the nose of the internal line-up clamp prior to bringing the two pieces of pipe together. The internal welder is brought to the end of the pipe and carefully inched forward until the welding torches are just past the end of the pipe. The internal welder is then driven backwards until the raised blocks touch the weld bevel. When all three aligner blocks touch the weld bevel, the rear clamping shoes are raised. This insures the welding heads will remain in alignment after the alignment blocks are retracted.

The weld cycle is initiated from a remote control box located at the end of the pipe by a welder. After the weld cycle is completed, the welding leads, compressed air recharging hose, and shield gas recharging hose are disconnected. The clamping shoes are dropped and the internal welder is driven forward. The remote control box on the end of the reach rod is threaded into the next section of pipe. It continues forward until the nose cone reaches the end of the welded sections of pipe, at which time forward travel automatically stops. The internal welder is then aligned as mentioned above, and the new section of pipe is then butted up against the previous section of pipe to form the next weld joint. Once the pipes are properly abutted, the welding sequence is started.

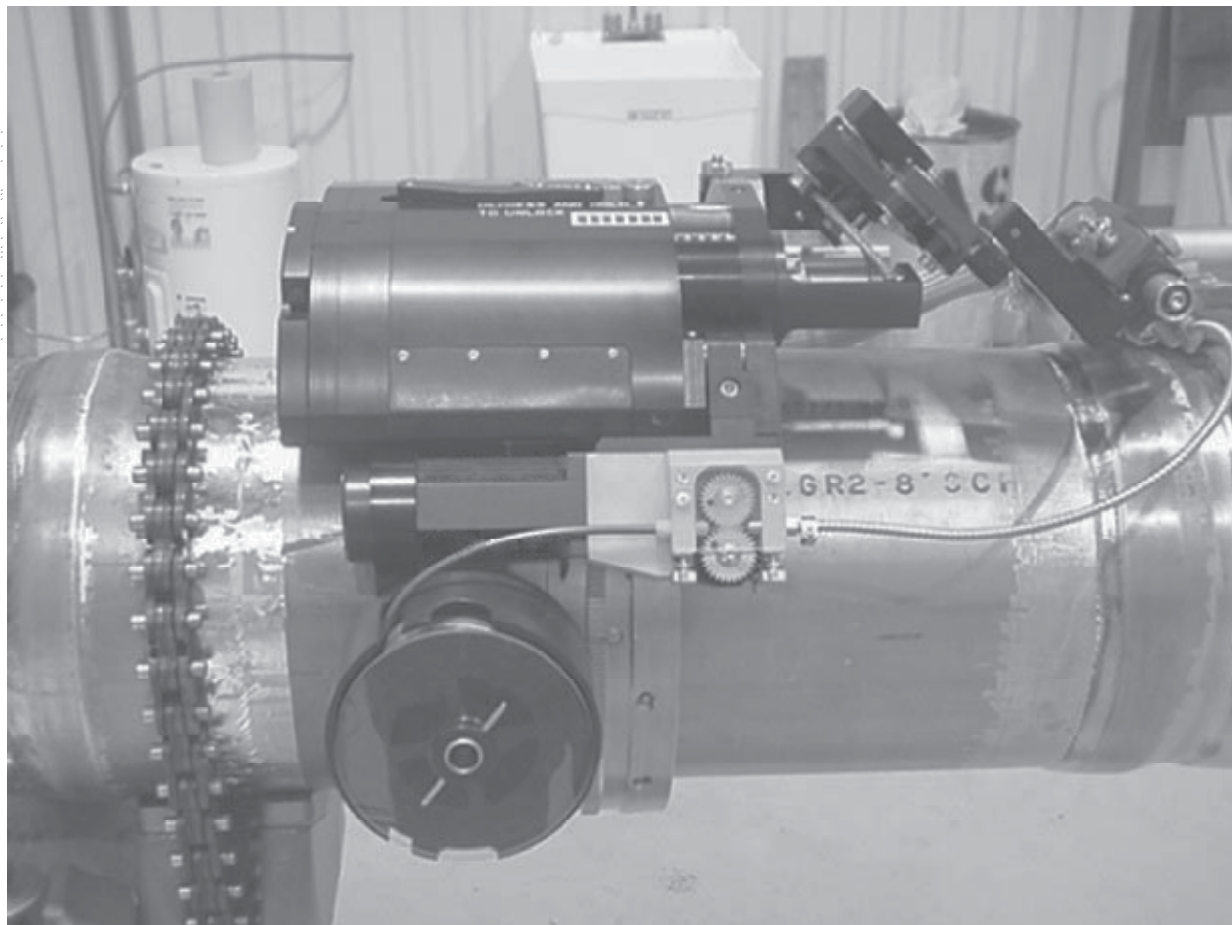
7. External Weld Heads

7.1 Overview. As mentioned in the introduction and shown in Figures 1 through 5, multipass orbital machine pipe groove welding systems take many different forms. Clamshell or open frame orbital machine pipe groove welding systems have

welding heads that are attached to a faceplate that encircles the pipe. The welding head includes the welding torch, some means for moving the torch and adjusting the torch position, and some means for feeding welding wire. Small clamshell welders are used for plant pipe welding in pipe up to DN 300 [NPS 12]. Large clamshell welders are used on pipe lay vessels for pipe up to DN 1200 [NPS 48]. Most systems which utilize a face plate for moving the weld heads have the welding wire mounted on or near the welding head, as opposed to in a separate cabinet remote from the weld head.

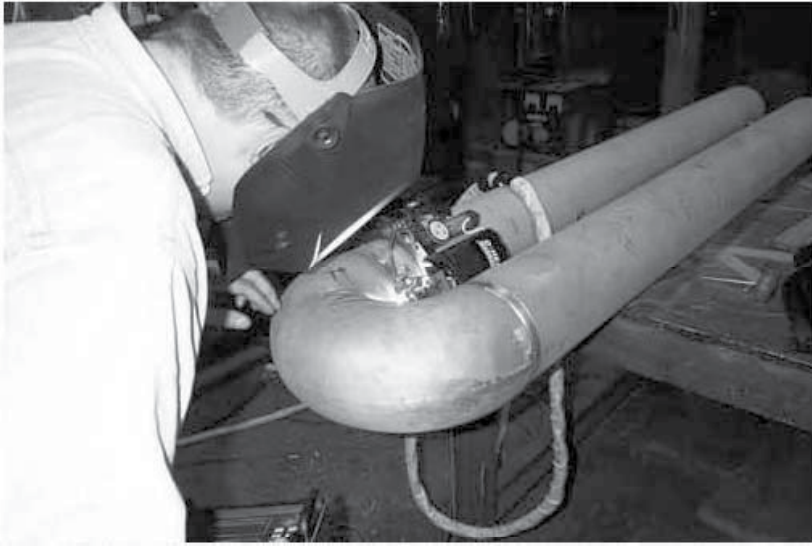
Orbital machine pipe groove welding systems that do not have the weld heads mounted to a faceplate have the weld head attached to a carriage mounted on a guide ring. The guide ring is wrapped around the pipe. The weld head includes a welding torch (sometimes two) and a means for moving the torch(es) and adjusting the torch position(s). The weld head also provides some means for feeding a welding wire. The welding wire and feeder may be mounted on the weld head, be freestanding, or mounted in a cabinet.

When the wire feeder is mounted on the welding head, small 2.7 kg or 5 kg [6 or 11 lb] spools of welding wire are used (see Figures 21 and 22). When a floor or wall mounted wire feeder can be mounted within 5 m [15 ft] of the weld head, larger 12 or 15 kg [25 or 30 lb] spools of welding wire are used (see Figure 23). Weld heads which use 12 or 15 kg [25 or 30 lb] spools in a wall mounted or floor mounted wire feeder cabinet result in lower welding wire cost. A torch cable/hose assembly connects the weld head to the wall or floor mounted wire feeder. The torch cable/hose assembly contains a guide tube for the welding wire, hose for shielding gas, and conductor for the welding current. Water-cooled torches include two additional hoses for the coolant circuit. Torch cable lengths are limited to 5 m [15 ft] between weld head and wire feeder.



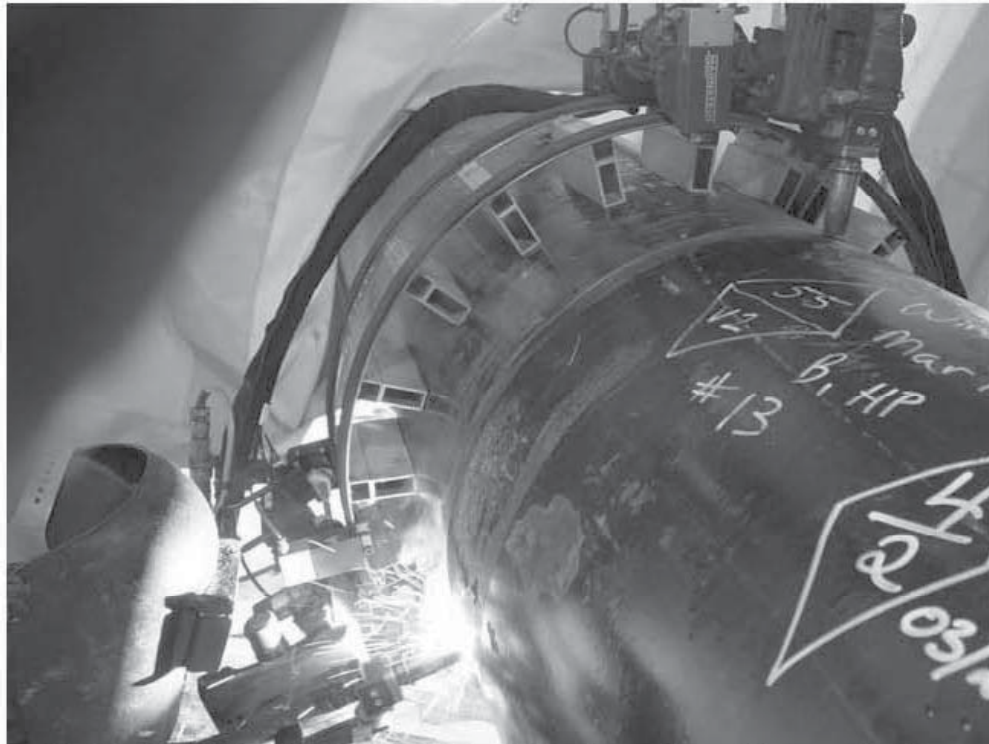
Photograph courtesy of Northrop Grumman Ship Systems Avondale Operations and Arc Machines, Inc.

Figure 21—Orbital GTA Weld Head with Torch Tilt Welding a Titanium Joint



Photograph courtesy of Magnatech

Figure 22—Single Torch Orbital GTAW-P Weld Head in Use on Stainless Piping



Photograph courtesy of Magnatech

Figure 23—Double-up FCAW Technique using 2 Heads on Cross-Country Pipeline (push-pull wire feeder allows use of larger 15 kg [30 lb] wire spool on floor-mounted “push feeder”).

There are advantages and disadvantages to having the welding wire spool mounted on the welding head. The first advantage is fewer electrode-feeding problems. The wire feed rollers are located a few centimeters from the wire spool, and feed the wire to a torch that is located only a few centimeters from the wire feeder. The second advantage is the freedom from the cable hose assembly and need to be within close proximity of the wire feed cabinet. The chief disadvantage of having the welding wire spool mounted on the weld head is the need to change the smaller wire spools more frequently than the larger spools that are used in separate cabinet mounted wire feeders. A second disadvantage is the added weld head weight due to the wire spool and wire feeder.

There are push-pull wire feed systems that incorporate a second wire drive motor adjacent to the torch. This allows the use of longer cable lengths between the weld head and wire feeder cabinet. Weld heads using push-pull systems are currently available with cable lengths of 7.5 m to 15 m [25 to 50 ft]. A disadvantage of this type of wire feeder is the length of time required to feed the electrode through cable after clearing a wire feed problem.

Most weld heads provide for weld torch oscillation and programmable “dwell” at the groove sidewalls. The torch oscillation may be a straight-line linear motion or a pendular motion. Either technique will produce satisfactory results. Some systems provide the capability to oscillate the torch either way, which allows the customer to select the best mode for a specific application. In plant piping, fillet or socket welds are often best done using pendular oscillation. Pendular motion is also beneficial when welding in deep grooves because it prevents the contact tip from touching the joint side walls. Pendular motion is also beneficial for depositing cap passes, since the increase in contact tip to work distance at the ends of oscillation helps prevent undercut.

7.2 Types of External Weld Heads. There are basically three types of external weld heads:

1. *Single torch head without control pendant.* The first type is a single torch weld head without a control pendant. This type of weld head was common on the early transmission pipeline welding systems. The earliest transmission pipeline multipass orbital machine pipe groove welding system used a pipe line-up clamp with internal weld heads for the root bead and single torch external weld heads mounted on a guide ring for the hot, fill, and cap passes. Adjustment of the torch position was done by means of knobs on the weld head. The guide ring consisted of a strip or band of hardened steel approximately 125 mm [5 in] wide and 2.5 mm [0.1 in] thick. The band was wrapped around the pipe. Spacers attached to the underside of the band maintained a uniform band standoff from the pipe surface. Alignment tools were used to position the band a fixed distance from the end of the pipe before clamping. The placement of the band ensured the torch to work distance and torch cross-seam position remained constant within a few millimeters. Accuracy of a few millimeters is not adequate to prevent the occurrence of incomplete fusion and cross-penetration defects when using the GMAW-S process.

The welding head operator therefore has to observe the welding arc continuously and use the cross-seam adjustment knob and torch to work adjustment knob to maintain the torch centerline position relative to the welding groove. The welding head operator must maintain the correct torch position to within a few tenths of a millimeter with respect to the joint centerline. The welding operator is also provided with a travel speed override knob used for the last intermediate weld pass and cap passes. The travel speed override knob allows the welding operator to speed up or slow down the weld head travel speed within limits, (typically $\pm 20\%$), to control depth of fill and prevent the molten metal pool from flooding the arc. The controls for starting and stopping the weld travel and weld cycle on external weld heads without pendants are on the weld head itself;

2. *Single torch head with control pendant.* The second type of external weld head is the single torch type with a control pendant. Most mechanized orbital GTAW systems utilize a single torch with cold wire feeder(s) mounted on the weld head. Mechanized orbital GTAW systems normally provide controls for the operator to adjust the torch centerline and torch to work position. Additional controls are provided to start and stop the weld head travel and the weld cycle. The control pendants also include controls for setting the welding process parameters, such as filler wire feed speed and weld current high/low pulsation. There are also single torch GTAW systems that use the pendant for starting and stopping the travel and weld cycle, but use manually operated knobs on the weld head for adjusting torch position;
3. *Dual torch GMAW with control pendant.* The third type of external weld head is the dual torch GMAW type with a control pendant. The control pendant is used to guide the welding torches and start and stop the weld head travel and weld cycle. The hand-held control pendants also allow the welding head operator to jog the torch vertically and horizontally, and jog the carriage forward or backward. Torch to work tracking is often available to maintain torch height automatically, freeing the welding operator from this task. This leaves only the torch

cross-seam positions for the welding operator to control. Other systems provide cross-seam tracking as well as torch to work tracking, freeing the welding operator from the need to perform either of these tasks.

Dual torch GTAW-P welding systems are not common because GTAW-P multipass pipe groove welding systems are used where quality is tantamount and time to make the weld is normally not a critical path event.

There are two approaches to multiple torches. One manufacturer uses a single large rectangular gas nozzle with two contact tips inside. The gas nozzle is made of copper, with spring loaded side plates contoured to fit the O.D. of the pipe. The advantage of this approach is good resistance to air currents (drafts) which disturb the gas shielding. The disadvantage is restricted visibility of the arcs. Unique combinations of gas nozzles and contact tips are needed for the various passes.

The second approach is the use of separate torches, each with its own gas-shielding nozzle. This approach has the advantage of good arc visibility, but does not offer as much resistance to air currents as the single nozzle approach. Unique combinations of nozzles and contact tips are needed for the various passes with this approach also, long tips and short nozzles for the first passes, with short tips and long nozzles for the last passes.

There are basically four types of orbital machine pipe groove welding systems:

1. *External head without internal line-up clamp.* The first type consists of an external weld head with no internal line-up clamp. The weld head may be mounted on the faceplate of a clamshell for pipes under approximately DN 300 [NPS 12], or on guide rings. This type of system is used with tacked weld joints. This type of system is common in plant pipe welding, where internal line-up clamps cannot be used due to short pipe joints and fittings. External clamps are used to temporarily align the pipe ends while the joint is manually tack welded using the GTAW process. The external clamp is then removed and the orbital pipe groove welding equipment put in place;
2. *External heads with internal welder.* The second type uses an internal line-up clamp with internal weld heads for welding the root bead. External weld heads mounted on a guide ring are used to deposit the hot, fill, and cap passes. This type of system is used for transmission pipeline welding and not plant pipe welding;
3. *External heads with internal line-up clamp.* The third type uses an internal line-up clamp with or without copper weld backing shoes. External weld heads mounted on a guide ring are used to deposit the root bead, hot, fill, and cap passes. Like the second type of system, this type of system is used for transmission pipeline welding, not plant pipe welding; and
4. *Multiple heads with internal line-up clamp.* The fourth type uses an internal line-up clamp either with or without copper weld backing shoes and clamshell frame that straddles the pipe and has multiple welding heads attached to a rotating face plate. The weld heads are used to weld the root bead, hot, fill, and cap passes. Like the second and third type of system, this system is used for transmission pipeline welding on offshore vessels, not process pipe welding.

7.3 Joint Tracking. There are two methods of eliminating the need for the welding operator to constantly adjust the position of the torch relative to the weld joint. The first method is referred to as through-the-arc tracking. The second method is referred to as laser and video camera tracking.

Through-the-arc tracking uses changes in arc characteristics as the arc is moved towards or away from the work and/or oscillated from side to side across the joint. Through-the-arc tracking can control the torch to work position without weaving the torch across the weld joint. However, to use through-the-arc tracking for cross-seam tracking, the arc must be oscillated or weaved across the joint. Torch to work distance can be automatically maintained by measuring the arc voltage for GTAW-P welding heads, and by measuring arc current for GMA welding heads. GTAW-P is normally performed using constant current power supplies. Arc voltage varies with arc length. Therefore, by comparing the measured arc voltage against a reference, the difference can be used as an input to the motor drive that varies the torch to work distance. GMAW is normally performed using constant voltage power supplies. Arc current varies with wire feed speed and arc length. By holding wire feed speed constant, a measurement of arc current can be compared to a reference, and the difference can be used as input to the motor drive that controls the torch to work distance. Similarly, as the torch is oscillated from side to side, the voltage varies with GTAW-P, and the current varies with GMAW. The decrease in voltage or increase in current at each sidewall can be compared to one another and the difference used as an input to the motor control circuit that moves the center of oscillation. This cross-seam tracking method is affected by high low conditions, where the joint sidewall on one side is higher than on the other side. It is also affected by pipe chemistry variations, which can produce a difference in arc characteristics. If two pipes from two different mills are joined, through-the-arc cross-seam tracking may favor one mill's pipe over the other. Figure 24 shows the principle of through-the-arc tracking.

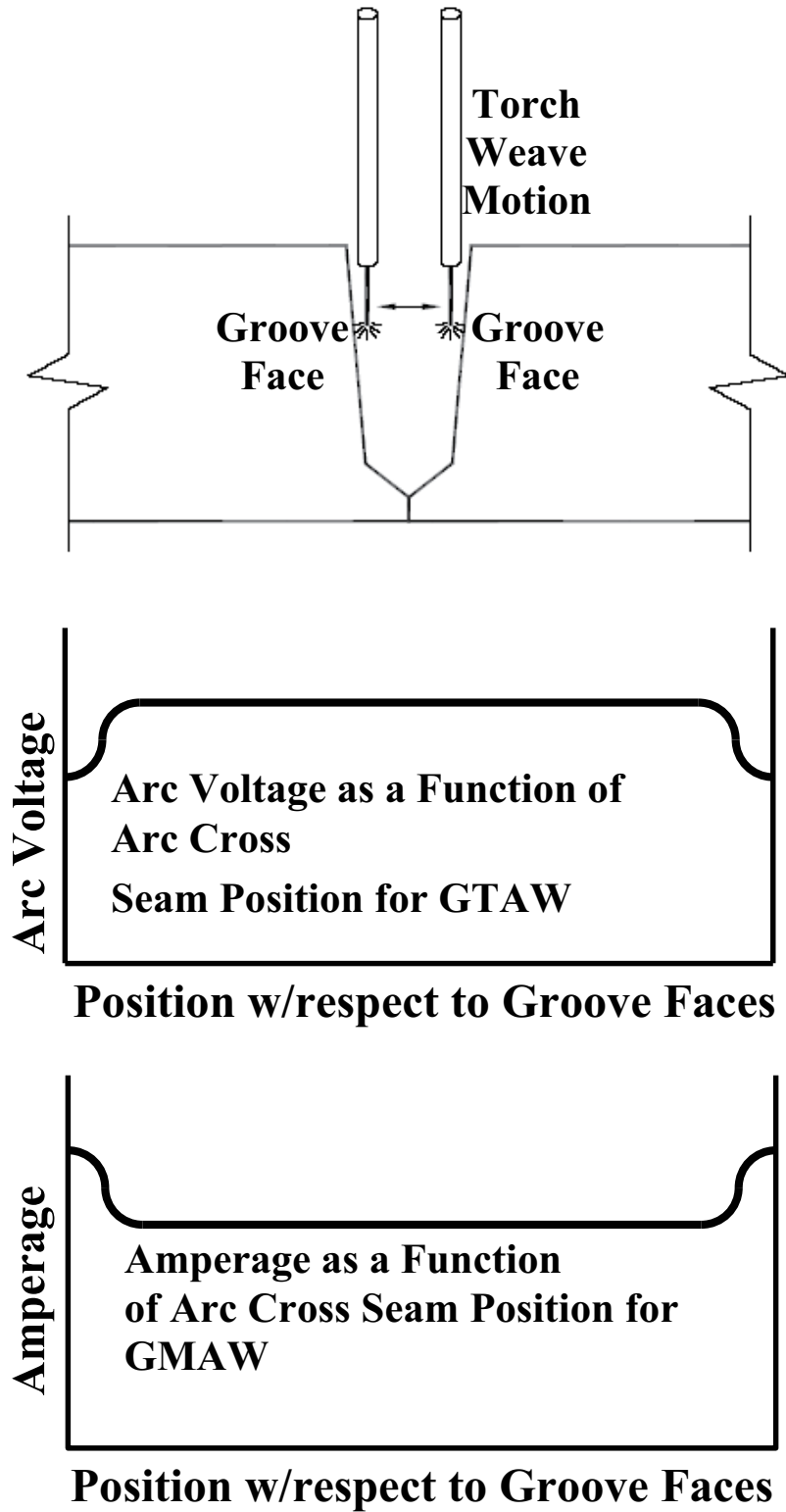


Figure 24—Principle of Through-the-Arc Joint Tracking

7.3.1 Laser and Video Camera. Laser and video camera tracking utilizes a line of laser light that is projected across the weld joint, usually slightly ahead of the welding arc. A video camera attached to the welding torch barrel receives an image of the joint and line of light. The line will exhibit breaks in its slope where the line crosses the upper edge of the weld joint and falls on the wall of the joint instead of the surface of the pipe. Software calculates where the slope break points occur in the video picture. The torch and camera are moved horizontally and vertically to keep the break points in the proper place on the video image. This movement in turn keeps the welding arc in the center of the groove.

A limitation of laser camera tracking is the dependency on the geometric relationship between the arc and the video image. If this relationship is disturbed, say for example by the bending of the contact tip, or by arc blow, laser video tracking will not position the arc correctly. Through-the-arc tracking, on the other hand, is not affected by bent contact tips or arc blow. But through-the-arc tracking cannot find the joint before striking the arc. The laser and video camera tracking method can. So each system has strengths and weaknesses. Laser tracking is better suited for high-speed welding where the travel speed is over 100 cm/min [3 ft/min]. High speed through-the-arc tracking requires high torch weave rates.

8. Nondestructive Examination

There are several methods of nondestructive examination used with multipass orbital machine pipe groove welding. Some methods reveal surface-connected weld discontinuities. Other methods are able to probe the subsurface volume of weld metal for weld defects.

8.1 Surface NDE. There are three commonly used NDE methods for finding surface connected weld discontinuities. Typical external surface connected discontinuities include incomplete fusion, porosity, weld toe undercut, crater cracks, and weld centerline cracking. On the inner surface of the pipe, incomplete penetration is an additional surface connected discontinuity.

8.1.1 Visual Inspection. The fundamental NDE method for surface connected discontinuities is visual inspection. Visual inspection can detect porosity, weld toe undercut, crater cracks, and centerline cracks. Discontinuities that are connected to the surface but tightly closed are difficult to detect by visual examination. For this reason, liquid penetrant or magnetic particle inspection is often used in addition to visual inspection.

8.1.2 Liquid Penetrant Inspection. Liquid penetrant testing is a second method for detecting surface connected weld discontinuities. Liquid penetrant testing requires time for the penetrant to be drawn into defects. For this reason, it is not normally used in transmission pipeline welding. It is sometimes used in plant pipe welding where more time is available for inspection. Liquid penetrant inspection does not reveal subsurface defects. Also, the developer must normally be removed by means of solvent-soaked rags, grinding, and wire brushing after inspection. For these reasons magnetic particle inspection using dry powder is normally preferred to liquid penetrant inspection.

8.1.3 Magnetic Particle Inspection. When a repair is made to correct an embedded weld defect that has been found by x-ray or ultrasonic inspection, it is necessary to remove weld metal to remove the defect before repair welding. Because the embedded defect may be difficult to see, magnetic particle inspection is often used to determine if the gouging and grinding have succeeded in removing the defect. Dry iron powder is normally used because it will not harm the repair weld if the pipe is a carbon steel alloy. This method can only be used on magnetically permeable materials. Magnetic particle inspection has an advantage over dye penetrant in that it is able to detect shallow subsurface weld discontinuities as well as surface connected discontinuities.

8.2 Volumetric Inspection. To find weld discontinuities that lie well below the surface, volumetric inspection methods must be used. The two most common methods are radiographic inspection and ultrasonic inspection. Radiographic inspection commonly used in orbital pipe welding can further be broken down into Gamma ray (radioisotope) inspection and x-ray inspection, depending upon the source of the radiation.

Ultrasonic inspection can further be broken down into manual and automatic ultrasonic inspection, depending upon whether the joint is being scanned manually or by means of an automated array of probes mounted on a band and carriage.

8.2.1 Radiographic Inspection

8.2.1.1 Gamma Ray Inspection. Gamma ray radiography employs a radioactive isotope in a “camera” that is self-propelled for landline or offshore jobs. When used offshore, a safety cable is usually connected between the self-propelled

camera and the internal welder, internal copper backup clamp, or line-up clamp. For process plant applications, the camera can be set inside the joint to be inspected using wooden blocks.

A remote control device is used to make the “camera” open its aperture to allow the gamma rays to escape and expose a film wrapped around the outside of the pipe. For land line jobs and lay vessel jobs, the “camera” is usually controlled by means of radioisotopes placed on the outside of the pipe that trigger operation of the camera shutter inside the pipe. The same technique is also used to position the camera aperture in the plane of the weld joint. For process plant applications, a hand-cranked cable similar to a speedometer cable usually controls the camera.

Gamma Ray radiographs reveal incomplete fusion, incomplete penetration, porosity, internal or external undercut, inadequate or excessive root bead height, inadequate or excessive cap pass height, hot cracks, and slag inclusions. Gamma ray radiography and x-ray radiography both have the disadvantage that personnel working in the area need to be protected from the radiation. Radiograph developing time and viewing time often approaches the length of time needed to make a transmission pipeline weld. Care should be taken so radiographic inspection does not become the time limiting the rate of production. One method to speed up radiographic inspection is by the use of fluorometallic intensifying screens packed with the radiographic film. The fluorometallic intensifying screens shortens the time needed for exposure.

8.2.1.2 X-Ray Inspection. X-ray radiography employs an x-ray tube instead of a radioisotope. The x-ray tube can be mounted in a self-propelled crawler for landline or offshore jobs. When used offshore, a safety cable is usually connected between the self-propelled crawler and the internal welder, copper backup clamp, or internal line-up clamp. For process plant applications, the x-ray tube can be set inside the joint to be inspected using radial legs to support the tube in the center of the joint. A remote control device is used to operate the x-ray tube to expose the film that is wrapped around the outside of the pipe. For land line jobs and lay vessel jobs, the x-ray crawler is usually controlled by means of radioisotopes placed on the outside of the pipe that trigger operation of the crawler electronics inside the pipe. The same technique is also used to position the crawler x-ray tube in the plane of the weld joint. For process plant applications, an electrical cable connected to the power source for the tube usually controls the x-ray tube.

Like gamma ray radiographs, x-ray radiographs reveal incomplete fusion, incomplete penetration, porosity, internal or external undercut, inadequate or excessive root bead height, inadequate or excessive cap pass height, hot cracks, and slag inclusions. As with gamma ray radiography, personnel working in the area need to be protected from the radiation. Because of the time necessary to wrap, expose, develop, dry, and view the film, radiographic inspection can become the operation whose length of time limits the rate of production. As with gamma ray inspection, fluorometallic intensifying screens packed with the radiographic film can be used to speed up x-ray inspection.

X-ray radiographs provide better resolution than gamma ray radiography because the x-ray source point is smaller than the gamma ray source point. For this reason, x-ray inspection is preferred for machine pipe groove welding. This is because the most common defect in multipass orbital machine pipe groove welding is incomplete fusion. Detection of incomplete fusion requires high resolution.

8.2.2 Ultrasonic Transducer Inspection. There are two methods of ultrasonically inspecting multipass orbital machine pipe groove welds: manual ultrasonic inspection and automatic ultrasonic inspection.

8.2.2.1 Manual Ultrasonic Inspection. Manual ultrasonic inspection is useful for determining the depth of a defect detected by radiography. It is not common to use manual ultrasonic inspection to examine an entire circumferential weld on pipe over DN 600 [NPS 24] because of the time required and lack of permanent record for viewing at a later date.

8.2.2.2 Automatic Ultrasonic Inspection. Mechanized ultrasonic inspection employs either ultrasonic probe arrays or single “phased array probes” to examine both sides of the weld joint (upstream side and downstream side) from the outside surface of the pipe. The array of probes is moved around the outer circumference of the pipe at travel speeds over 3 m [10 ft] per minute. Different types of probes and probe angles are used to obtain echoes off the root face, previous land, bevel face(s), and cap. The ultrasonic data is analyzed as the scan is made by means of high speed computers that display the data as it is measured and provide printed records at the end of each weld. Ultrasonic inspection reveals the same types of defects as revealed by gamma ray or x-ray radiography without the danger to humans from radiation. In addition, ultrasonic inspection provides quantitative measurements of defect depth and height, which cannot be provided by gamma ray or x-ray radiography. The ultrasonic data is available as the weld is scanned, which decreases the time delay before the joint can be moved. Permanent records are made of the scans, which allow the scans to be reviewed at a later date.

9. Multipass Orbital Machine Pipe Groove Welding of Plant Piping

9.1 Overview. Plant pipe welding contrasts sharply with transmission pipeline welding. Plant pipe diameters and wall thicknesses vary widely, so that welding procedures and operators have to be qualified over a broad range of materials, diameters, and wall thickness. Many considerations exist associated with facilities that integrate plant piping. Examples are the need for welding to be conducted from the exterior of the pipes and fittings, complexity of the systems, safety, health, environmental and security issues. Many factors need to be addressed to satisfy all of these concerns as prerequisites of multipass orbital machine pipe groove welding. This section addresses some of these concerns.

Multipass orbital machine pipe groove welding offers advantages over manual GTAW-P, SMAW, GMAW, and FCAW. Although its popularity has rapidly grown, machine pipe welding is still a relatively new process for many contractors. Caution should be exercised to assure the success of a project when it is employed. When properly executed, the contractor and customer should expect superior speed, consistency, and quality. Speed is increased through increased arc time, increased deposition rate, and reduced filler metal volume requirements. The reduced filler metal volume requirements are due to narrow gap bevel configurations not employed with manual welding. Consistency is achieved by reduction of dependence on human motor skills. Quality is improved through enhanced mechanical properties such as weld strength and toughness. Quality is also improved by the use of low hydrogen processes. Multipass orbital machine pipe groove welding provides excellent weld profiles and tools for weld parameter documentation. Finally, as welding operator skills for orbital machine pipe groove welding do not rely on hand-eye coordination, welder working lifetime can be increased by many years.

Primarily due to the limited capabilities of radiography and the technologies associated with ultrasonic testing to detect incomplete fusion or “cold roll” introduced during the use of the GMAW process while welding downhill, resistance to using GMAW welds in process and pressure piping developed and was generally merited. Technological innovations in inverter based power sources and advancements in ultrasonic testing, specifically with the entry angle of transducers, have overcome the inadequacies associated with GMAW, specifically when it is used in the GMAW-P mode. Because of these improvements, the use of GMAW-P with orbital welding is rapidly evolving.

9.2 General Considerations

9.2.1 Equipment Selection. Orbital pipe groove welding equipment used for plant piping has to be adaptable to changing conditions, otherwise additional equipment is necessitated. Piping, angular fittings, pumps, valves, flanges, and similar components are often nested. This limits clearance around the pipe and adjacent fittings. Therefore, the welding equipment has to meet limited axial and radial clearance dimensions.

There are two groups of multipass orbital machine pipe groove welding equipment for plant pipe welding. One group has the welding head mounted on a rotating faceplate (see Figure 25). The second group has the weld head attached to a guide ring fitted around the pipe (see Figures 26 and 27). When the equipment uses a guide ring, the weld head typically has wheels or gears for engaging the guide ring on which it rolls. The weld head is driven around the guide ring by various means including friction, a pinion/ring gear and other techniques. The weld head may or may not be cooled by recirculated fluid (see Figure 26 as an example of water cooled body) and typically includes one welding torch with automated torch to workpiece distance control. For GTAW-P equipment this function is referred to as arc voltage control or AVC (see Figures 26 and 27). Also included is an oscillating mechanism for torch “weave” and a means for adjusting the weld torch about the cross-seam position or center of oscillation. When the GTAW-P process is employed, a wire feed mechanism for pulsed or non-pulsed filler wire is provided through a filler wire nozzle external from the torch. When the GMAW, GMAW-P or FCAW processes are employed, a wire feed mechanism is integrated into the weld head for feeding the electrode through the torch.

Equipment with the welding head mounted externally or on a face plate uses a horseshoe shaped housing that integrates a clamping device, an annular “rotor” gear, a driving pinion “spur gear” meshing with the annular gear providing controlled face plate and weld head travel speed (see Figure 25). An interesting and cost saving feature of this type of equipment is its ability to adapt to a range of pipe/tube without the need for a size-specific guide ring. These “open frame” weld heads commonly include features such as:

1. An integral motor for oscillating and steering the weld torch. Alternatively, the weld head may be equipped with a manual cross-seam adjustment knob.
2. An integral AVC motor for automated torch to work piece control. Alternatively, the weld head may have a cam-follower for maintaining torch to work distance.

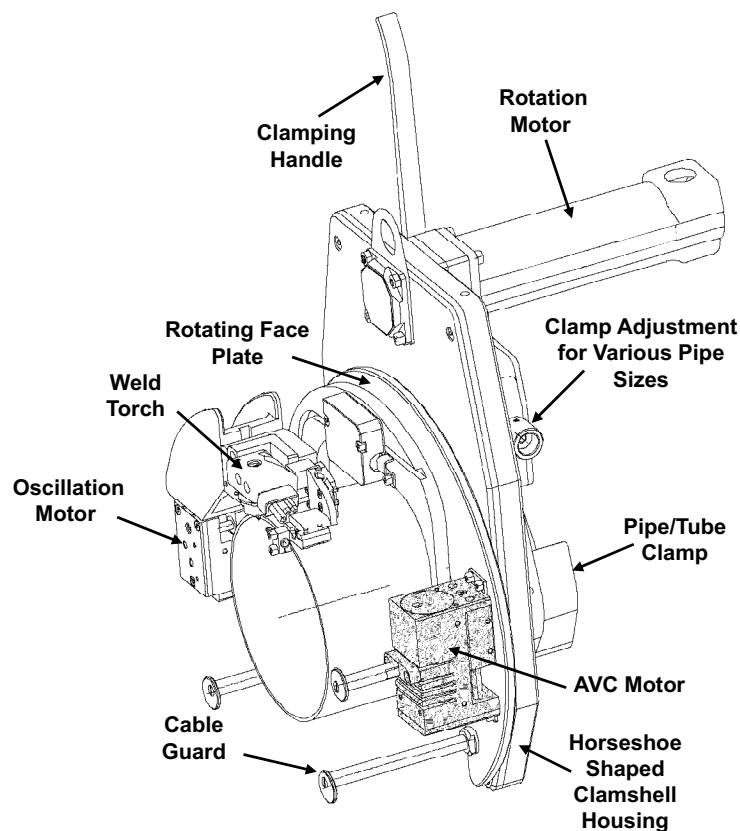


Figure courtesy Astro Arc Polysoude Inc.

Figure 25—Typical Orbital Machine Pipe Groove Welding Head on Rotating Face Plate used for Plant Pipe Welding

3. An integral wire feed motor with electrode guide tube and nozzle. Alternatively, an external wire feeder may be used.

A number of weld heads on carriage and guide band welding systems are available for welding large diameter and heavy-wall carbon-steel and corrosion resistant alloy (CRA) pipe for the process plant industry. These systems often use the gas-tungsten-arc-welding (GTAW) process for the root pass and the GMAW-P process for the hot, fill, and cap passes (see Figures 26 and 27).

In some applications two electrode feeders are included for bi-directional welding. This decreases weld time by eliminating the need to prewrap the weld head cabling around the pipe. In other applications preheated wire (Hot Wire) is used while employing the GTAW-P process for high deposition rates specifically in narrow groove bevel applications. By welding in an uphill progression only on a pipe in the 5G position, a higher deposition rate can be achieved. The solidifying bead below the molten weld pool provides support, and allows a larger weld pool to be controlled. When welding downhill, weld pool size should be carefully controlled at the expense of deposition rate to prevent it from flooding, or rolling out in front of the torch. On large diameter pipe, two welds heads may be clamped to the same guide ring to increase weld deposition rate and decrease total weld time. Articulating torches are employed for fusing beveled edges of limited angularity, e.g., 5 to 10 degrees on thick walled applications.

Occasionally, video cameras mounted on and/or near the weld areas are required when video remote control of the equipment is necessary.

Numerous configurations of brackets have been devised for use in conjunction with over- or undersized tracks. These configurations allow welding of components that would otherwise not be possible. An example is when an oversized guide ring is mounted on a small diameter pipe with brackets that reach to the opposite side of a reducer joined to an

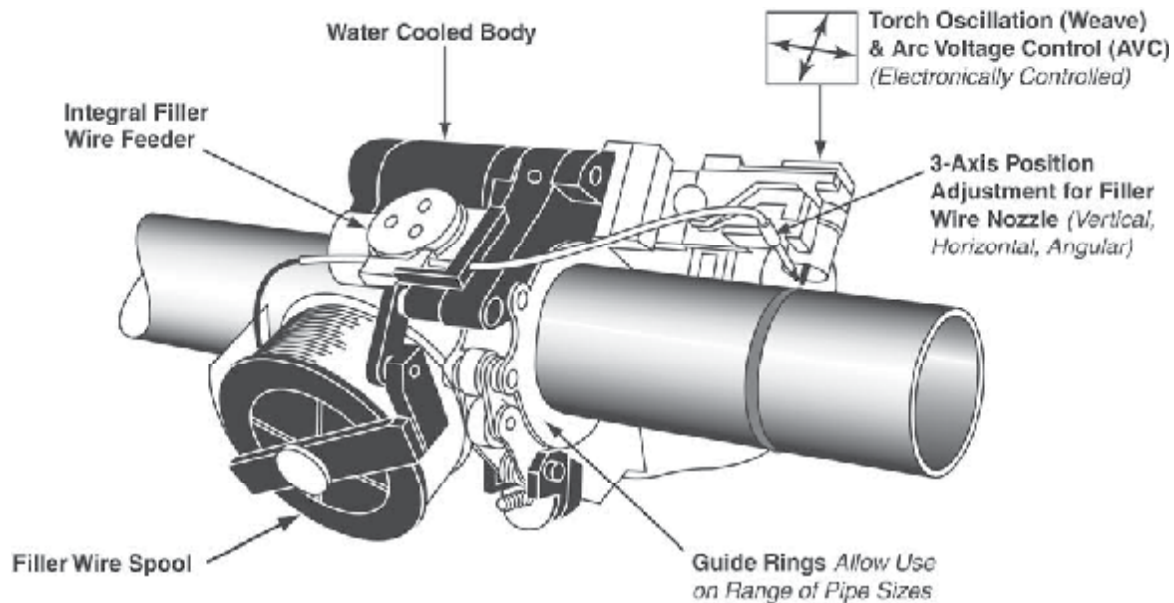


Figure courtesy Magnatech

Figure 26—Typical Orbital Machine Pipe Groove Welding Head and Guide Band used for Plant Pipe Welding

elbow. Another example is a significantly oversized track attached to an elbow to accommodate the radius of the elbow. Another example is extensions attached between the carriage and the torch that reach to the weld joint far from the guide ring. Occasionally, mandrels are inserted in the end of a pipe and the guide ring is attached to the mandrel. Inverted guide rings are available for mounting the carriage on the I.D. of the ring for welding inside of pipes and/or (wall) penetrations.

The welding system controller is designed to employ previously developed weld programs, including setting the electrode to work distance, allowing inert gas flow for prepurge, and a period of current upslope. Depending on the application, oscillation upslope may take place simultaneously with current upslope. Current upslope usually includes pulsation between a greater “primary current” level when the weld pool achieves a maximum size, a lesser “background current” level when the weld pool partially chills and solidifies. When properly employed, this technique inhibits gravitational-induced flow of liquid weld pool metal, reducing sagging and/or protruding of the weld metal into the inside of the pipe. Pulsing also reduces the potential for tungsten contamination and the chances of an extinguished arc.

Subsequent to upslope in the GTAW-P mode, automatic electrode to work piece distance control (AVC) is enabled if available, travel commences and pulsed current continues through the end of the weld. Depending on the material type, wall thickness, and pipe diameter, the weld program may include provisions to gradually reduce the current through a series of steps or levels during the weld sequence to overcome development of excess heat in the base material.

Upon reaching the end of the weld, the welding current and optionally the oscillation is down sloped. Downslope typically includes current pulsation. After downslope ends, motion ceases and postpurge continues for a programmed period. Gas flow then ceases and travel is reversed as needed for cable/hose unwrapping and/or prewrapping. The next program is then executed to deposit the next pass.

9.2.2 Operator Training. Operator training varies depending on the nature of the application and the technical aspects of the equipment that is being used. In small fabrication facilities equipment vendors usually provide training upon delivery of a system(s). Typically this is a relatively simple process lasting from one to five days. On large projects, due to the technical nature of the associated equipment, highly skilled operators are selected that have undergone extensive training which is primarily conducted at manufacturer facilities, qualified union training centers, and during similar previous employment.

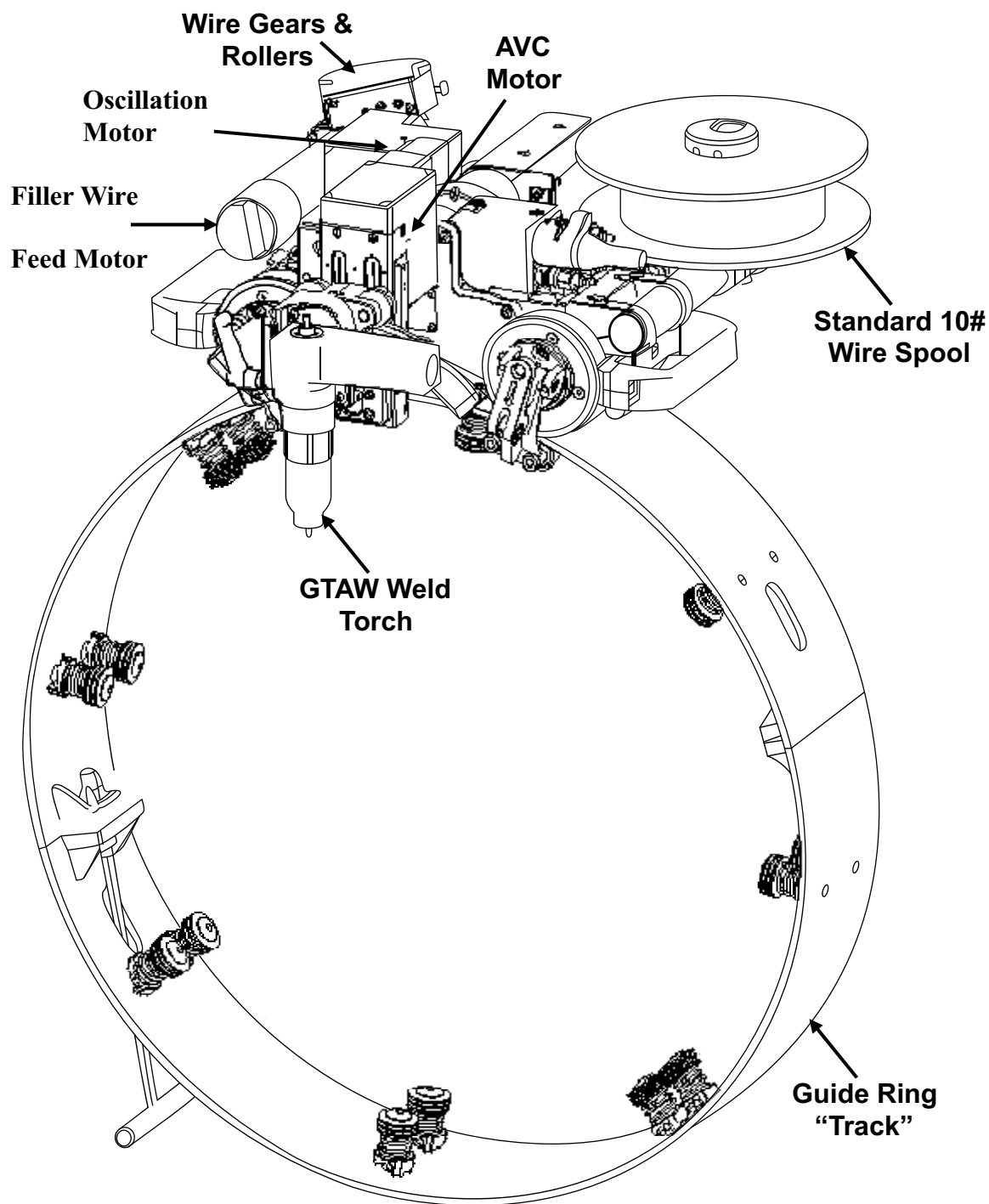


Figure courtesy Astro Arc Polysoude Inc.

Figure 27—Typical Orbital Machine Pipe Groove Welding Head and Guide Band used for Plant Pipe Welding

9.2.3 Weld Procedure Qualification. While ASME B31.3 governs fabrication of process piping and ASME B31.1 governs fabrication of power piping, ASME BPV Code section IX addresses welder, welding operator, and welding procedure qualifications. The approach taken by ASME is to group pipe by material properties rather than by pipe O.D. and wall thickness. This differs from API 1104, which takes the approach of lumping all material greater than API 5L Grade X42 and less than API 5L Grade X65 into a single group. API 1104 groups welding procedures by pipe O.D. and wall thickness. To qualify a procedure to ASME boiler and pressure vessel code, a weld must be carried out on a piece of pipe that falls into an ASME P number and group number. Mechanical testing of the weld normally consists of two tensile tests and four bend tests. Once the procedure has been qualified on a piece of pipe from a given P number and group number, that procedure can be used to weld any pipe from the same P number and group number. There are diameter and wall thickness restrictions based upon the dimensions of the pipe or plate used to carry out the weld procedure qualification. Additional procedure qualification testing requirements must be met when minimum impact properties are specified. A company may use a procedure it has qualified multiple times provided the pipe to be welded falls within the P number and group number of the material used to qualify the procedure.

9.2.4 Performance Qualifications. On large projects welders are required to undergo a manual welder performance qualification test and at least one but usually two or more semi-automatic hands-on multipass orbital machine pipe groove welding welder qualification tests. When warranted by project requirements, welders may also be required to pass one or more video remote controlled multipass orbital machine pipe groove welding welder qualification tests. Necessarily, this type of test is conducted with some type of visual obstruction between the welding mechanism and the operator.

9.2.5 Quality Control Groups. Quality Control (QC) personnel or groups are typically employed for inspection and verification of pipe welding. Quality Assurance (QA) personnel may be given the responsibility to audit the documentation and oversee the activity of other QC personnel. When nuclear work is involved, Authorized Nuclear Inspector(s) (ANI) may be employed to oversee the integrity of the work being done. Quality control groups oversee and verify fabrication activity at all levels. Working crews become intimately aware of the need for quality and safety due to these inspections.

9.2.6 Documentation. In the embryonic stage of a project, engineers begin to develop packages that delineate the work that is expected to be done. Complications associated with the inability to access portions of the facility due to adverse environments that may exist while the facility is operational cause this development to be researched utilizing existing documentation and dimensional drawings.

Contract documents are developed for mockup/training to familiarize the personnel with the flow of work during this phase. Additionally, a separate group of documents is issued for the project execution phase. In addition to the associated isometric/dimensional drawings, the bevel configurations are delineated. These work packages, sometimes termed “travelers,” may include entry areas for sign-off (initials and date) by supervisors, QC, QA, and ANI personnel. Other items that are recorded include component part and serial numbers, heat and lot numbers of pipe and fittings, weld material requisitions, measuring and testing equipment (M & TE) calibration data. Typically some form of a document control station is established for updating, control, and issuance of the packages.

9.2.7 Pipe Material Chemical Composition. Pipe material chemical composition is an often overlooked critical factor in the ability to weld pipe using multipass orbital machine pipe groove welding. Pipe chemistry differences between two pipes being joined may cause pool shift. The pipe chemical composition may have a profound effect on the surface tension of the weld pool. One of the elements that affect surface tension is Sulfur. Material codes provide a wide range of sulfur content, for example, 0.001 through .030%. The sulfur content variation between adjoining bevels should be limited to 0.010% to avoid the phenomenon of “pool shift.” Furthermore, less than 0.008% sulfur causes excess surface tension, requiring higher amperage for fusion, which ultimately causes a wide, shallow weld pool. Conversely, greater than 0.020% sulfur causes weak surface tension, a narrow deep weld pool and requires less amperage. While this situation may be good for penetration, it is problematic for fusion of adjacent surfaces, for example, root pass fusion and/or sidewall tie-in. Sulfur content in the range of 0.010 to 0.017% is considered to be an acceptable range.

9.2.8 Segregating and Marking Components. Material traceability of components and supplies including pipe, valves, flanges, and welding filler metal is of particular importance in ASME Code work. Some sections of the ASME Code require more traceability than others. The traceability can be provided by several methods. The most common is by heat numbers. Lot numbers are a secondary means and are usually only used with some types of filler metals. In addition to being able to correctly identify the heat number and the identity of every item to be welded, it is also necessary to separate carbon and low alloy steels from contacting stainless steels and nickel alloys. When particles of carbon or low alloy steel become embedded onto a stainless steel or a nickel alloy surface, it can cause rust spots or in many

environments, corrosion to develop. Tooling, abrasive wheels, or other abrasive products that have been used on carbon or low alloys steels should not be used on stainless steels, nickel alloys, or titanium. Tooling that is to be used on nonferrous material only is typically marked with red paint. Depending on the application (e.g., when austenitic stainless steels are involved) the paint that is selected will be confirmed to be of low fluorine, chlorine, and sulfur content since these elements are known to affect certain types of stainless steel. Occasionally, the remaining tooling will be painted a different (other than red) color signifying that it is acceptable for ferrous material. Quality control personnel should regularly inspect tooling for safety aspects and to assure that the proper items are selected. Some of the items that may fall into this category are as follows:

1. *Rigging.* Chain-falls, come-a-longs, port-a-powers, slings, chokers, spreaders, shackles, pipe supports (jack-stands), and roller-stands;
2. *Cutting/Prepping.* Compression pads associated with mandrels that come in contact with the I.D. or clamshells that come in contact with the O.D. of a pipe;
3. *Purging.* Inflatable bladders and plugs, mechanical purge dams, and flexible purge enclosures; and
4. *Welding.* Guide ring compression pads.

9.2.9 Mockup and Enhanced Training. Prior to shutdown for plant piping repair or replacement, the sequence of events described in this section are repeated numerous times during the mockup/training phase. If the plant's outage is properly planned and orchestrated, the ordered sequence of events are routine by the time the outage commences.

Projects requiring plant shutdowns are usually labor intensive and are limited in duration. Thus, mockup/training is paramount to the completion of a project in a safe, timely manner. Mockup/training usually starts several months prior to the expected plant shutdown. During this phase of the project's development numerous crews may be established for rigging, cutting and beveling, purging, line-up, tacking, depositing the first few layers of weld metal, weld completion, radiography, repairs, preservice inspection (PSI), and/or in-service inspection (ISI) preparation. During mockup training, each of the crews performs their tasks in substantially the same manner as will be conducted during plant shutdown. Collectively these crews coalesce and bring about what is needed for multipass orbital machine pipe groove welding of plant piping.

9.3 Preweld Preparations

9.3.1 Joint Preparation. Utilizing the contract work packages, arrangements of pipe and fittings are cut, faced, counterbored, and beveled by the prepping crews. For multipass orbital machine pipe groove welding, the use of flame, plasma arc, and to some extent, saw cutting is limited to rough-cuts. In the interest of consistency and repeatability, pipe ends are beveled with pipe severing and beveling described in the previous sections of this guide. An accurately beveled pipe end that is within the specified tolerances is paramount to the success of multipass orbital machine pipe groove welding. High quality pipe beveling and counterboring equipment and adequately trained pipe beveling machine operators are necessary to assure properly beveled pipe.

The following are typical measurements supplied in contract drawings:

1. Within the confines of a consistent plane in the end of the bevel, a knife-edge should be supplied when a land thickness is not specified on an angled bevel (e.g., 75 degrees included angle or 45/5 degrees compound bevel).
2. The land thickness for carbon steel "J" beveled pipe is 1.14 ± 0.13 mm [0.045 ± 0.005 in].
3. The land thickness for stainless steel "J" beveled pipe is 1.52 ± 0.13 mm [0.060 ± 0.005 in].
4. The transitional radius and land extension (i.e., distance from the end of the radius to the end of the bevel) for carbon or stainless steel "J" beveled pipe is 2.4 mm [$3/32$ in].

9.3.2 Purging. Back purging of stainless steels, titanium, copper-nickel and other similar alloys is normally required. Occasionally carbon steel is also back purged to enhance internal bead profiling for nondestructive examination (NDE). Purging crews may use mechanical purge dams such as rubber sandwiched between metal pancakes attached to stainless steel airline cable and gas conducting tube or clear Plexiglas or polycarbonate. Alternatively, inflatable purge bladders or plugs, water soluble purge film or paper and water soluble purge tape are frequently used. When water soluble film or paper is employed, an adhesive with acceptable fluorine, chlorine and sulfur content (such as white school glue) is used to attach multiple layers of film/paper together for strength and to enhance the dam's gas inhibiting efficiency.

When purging is mandated, commercial welding grade argon, nitrogen, and helium or mixtures of these gases are used. Consideration should be given to the inlet and outlet (venting) locations. Because argon is heavier than air, the argon

should enter near the bottom and exit near the top of the confinement. Conversely, because helium is lighter than air, it should enter near the top and exit near the bottom. These inlet and venting locations are important to fully purge the air from the area between the purge dams. If these rules are not observed, the purge gas may mix with, or entrap air and cause unacceptable oxygen levels. Consideration should also be given to the size of the vent opening. Too small an opening may cause pressurization of the area between the purge dams, which may expel molten weld metal during welding. Conversely, too large of a vent opening may inhibit expulsion of the air and inhibit achievement of acceptable oxygen levels. Consideration should also be given to covering or encapsulating the flared groove (weld bevel or joint) with tape when an open root joint has been established to further confine the purge gas from exiting at this opening. The tape is removed progressively as the root pass is completed.

9.3.3 Rigging Adjustments. After the purge dams are properly installed, the line-up (rigging) crew brings the components that are to be welded in close proximity of each other to assure axial alignment.

9.3.4 Joint Configuration/Fit-up Preparations. With the closely fit opposing ends of the sequentially arranged pipe segments and fittings properly aligned, tacking crews begin the final steps of alignment. This may include positioning consumable inserts between the components, which are typically used for “J” bevels, 45/5 or 45/10-degree compound bevels. An additional application may include positioning the components in contact with each other (jam-up joints) typically when “J” bevels are employed. Another application may include a slight gap, for example, 2.4 to 4.0 mm [3/32 to 5/32 in] for open root joint welding, which is commonly employed for a 75-degree included angle joints.

If a consumable insert is used, a space referred to as a “window” is generally incorporated between the two ends of the insert for viewing the internal fusion of the insert to the beveled edges. Consumable inserts are metallic rings of various shapes that are placed between two beveled pipe ends and melted during welding to bridge the gap between the bevels and serve as preplaced filler material. Depending on the diameter of the pipe, this window should be approximately 19 to 38 mm [3/4 to 1-1/2 in] in length. The ends of the insert are typically cut on an approximate 45-degree angle to accommodate a smooth transition “tie in” between each end of the insert and the filler that is supplied to fill the window. The obtuse (wide) angle of the ends of the insert should be positioned toward the surface of the pipe where the orbital equipment is mounted. If the consumable insert material is to be used to fill the window, a piece of insert is prepared the same length as the window with its ends tapered to the same degree as the ends of the window. The width of this piece of insert is reduced to accommodate expected shrinkage during welding.

9.3.5 Weld Joint Fit-Up. During plant shutdown, the challenge associated with juxtaposed pipe and fitting axial and planar line-up is significant. Rigging crews are inclined to induce considerable stresses in an effort to minimize the gap between adjacent components and axial misalignment. This stress is undesirable because of its effect on various components such as pumps, expansion bellows and flanged components. The stresses caused by misalignment and the stress associated with the tendency for orbital welding to stop each pass near the top of a pipe tends only to become apparent near the end of a plant piping outage. Efforts to minimize stresses should be exercised.

9.3.6 Purge Testing. When completion of the purge is expected, oxygen analyzers or purge monitors are usually used to test the oxygen content in parts per million (PPM). Depending on the application and material being welded, acceptable oxygen levels can range from 5000 to 10 000 PPM (0.5 to 1%). However, with stainless steels to be used in services where heat tint discoloration needs to be very minimum, the oxygen level must be kept much lower.

9.3.7 Tacking. After purging (if required) has been completed and determined to be acceptable, and the components are properly aligned, they are tack welded to maintain alignment and proper spacing.

When tacking a consumable insert, the gap between the insert and the beveled edges is critical. If the bevels are properly prepared, this usually is not an issue when welding nonclosure joints. However, when system closure joints are being welded, gaps are common. Not only do these gaps present purging concerns when purging is being employed, but they may cause undercut, concavity, and other discontinuities. This gap is typically specified to be no greater than 0.8 mm [0.03 in] around the entire joint or a maximum of 2.4 mm [0.09 in] in one location. The length of this maximum gap may be specified as not to exceed one-third of the diameter of the pipe. If the length of this maximum gap is not specified in contract documents, the discretion of quality assurance personnel may be applied, which could be to the advantage or disadvantage of the contractor. It should be noted that a gap in excess of 1.3 mm [0.05 in] may require additional filler metal to be introduced manually while multipass orbital machine pipe groove welding is taking place. While tacking the insert to the beveled edges, small circular or slightly elongated autogenous tack welds are generally made. Spacing between these tack welds is usually on 25 to 38 mm [1 to 1-1/2 in] centers. The inserts are tacked on both sides (upstream and downstream) and are generally not placed across from each other. Rather, they are placed in a staggered fashion due to

changes in heat convection and arc wandering that may be caused by the tack weld. This staggering is usually offset by approximately 6 mm [1/4 in]. If a consumable insert is used that does not include a window, the ends of the insert are tacked/fused together to facilitate heat transfer, a smooth transition, and to circumvent melt back of the ends of the insert, which may cause an opening or void.

If a jam-up joint is being used, elongated autogenous tacks are generally deposited. Depending on the application, filler metal may be added, but filler metal additions should be limited. The length and frequency of these tack welds depends on the size of and stresses associated with the components.

In either of these cases (consumable insert or a jam-up joint), autogenous tacks or significantly limited filler metal addition is usually desirable. While depositing the initial (root) weld pass it is preferable for the tack welds to be entirely consumed (remelted). If a build up of metal is deposited during tack welding, consumption of these tack welds is difficult and may not occur. In some circumstance the Weld Procedure Specification (WPS) prohibits autogenous welding. In other circumstances the material being welded may be prone to hot or solidification cracking. In either of these situations addition of filler metal should be added sparingly. If an open root joint configuration is used, the addition of filler metal is required but should be in limited quantity for the reasons explained above.

9.3.8 Preheat. Caution should be exercised during preheating due to the expansion of the pipe. If a guide ring is installed around the pipe, its coefficient of expansion may be significantly different than that of the pipe material being preheated. Guide rings may rupture in an explosive fashion during preheating due to this difference.

9.3.9 Welding. Due to the effects of oxidation, welding is often mandated within 4 to 8 hours of completing the tacking process. Root pass welding on a consumable insert that includes a window should start approximately 13 mm [1/2 in] from the edge of the window in an effort to leave the tapered ends unconsumed. When it is possible and when the internal fusion is considered to be visually acceptable during welding, the prepared insert is placed/pressed into the window and closure of the window occurs nonstop, providing a smooth transition. Occasionally the prepared piece will not fit due to shrinkage. Or repairs may be required, causing a temporary stoppage in welding of the root pass. The window may be filled manually with conventional filler wire, or a prepared piece of insert is altered to fit the opening in the window and closure is conducted either manually or with the orbital equipment. In either case, consideration is required during closure of the window to reduce gas flow if purging is taking place.

If a consumable insert is used that does not include a window, welding should start approximately 13 mm [1/2 in] from and progress away from the ends of the insert. The heat from the arc does not transfer evenly at the ends of the insert, which may cause them to melt, creating an opening or void.

The root pass, hot (second) pass and a sufficient number of intermediate weld passes are typically deposited to achieve 6 mm [1/4 in.] thickness prior to stopping for radiography when desirable or mandated. Radiography may be deemed desirable if complications arose during the root or hot pass or from visual observation of the internal bead profile. Frequently a borescope or telescope is used or a weld crewmember will gain access to the interior of the pipe in the proximity of the weld to observe the root and hot pass while it is being deposited. Furthermore, a videoscope may be used to document the internal integrity of the deposited weld.

9.3.10 Repairs. During the mockup phase, specially trained crews that focus on “wide opening root” repairs repeatedly grind wide root openings on or near the bottom of pipe and practice repair welding these openings utilizing the manual GTAW process. When some form of NDE in a completed weld locates unacceptable indications, these crew’s services are utilized to make repairs in the initial weld. Depending on the thickness of the material and the application, radiographs may be taken of the repaired area prior to weld completion.

9.3.11 Weld Completion. When the repair and NDE requirements for the initial weld passes have been met, weld completion commences. On large joints, accurate bead placement is paramount to a high quality weld. Depending on the material type, heat input (kilojoules per mm or inch) may be of particular importance. This attribute (heat input) is consistently controllable, easily calculated, and readily documented with orbital welding. While it is possible, less accurate results are usually achieved with manual welding. As a separate issue from heat input, temperature-sensitive marking sticks or pyrometers are commonly used to monitor and control interpass temperatures.

Consideration should be given to selection of the welding process used for weld completion as it relates to the deposition rate. It should be expected that when the GTAW-P process is employed a deposition rate of approximately 0.7 kg/h [1.5 lb/h] will typically be achieved. However, depending on the expertise of the welder and on larger diameter pipes, up to 1.2 kg/h [2.5 lb/h] has been achieved. In comparison, for the SMAW, GMAW and FCAW processes, deposition rates of 1.4, 1.8, and 3.6 kg/h [3, 4 and 8 lb/h], respectively, may be expected.

9.3.12 Nondestructive Examination Preparation. Multipass orbital machine pipe groove welding of plant piping tends to be associated with thick material. Thick material is generally subjected to extensive preservice inspection (PSI) and/or in-service inspection (ISI). Subsequent to weld completion, material cooling and removal of the welding mechanism and guide ring, ISI/PSI weld preparation (cap grinding) is typically conducted to facilitate accurate inspection.

9.3.13 Postweld Heat Treatment (PWHT). Postweld heat treatment is frequently required when thick carbon steel and/or materials containing high chromium content are being welded. Before beginning postweld heat treatment, preparations should be made for NDE (cap grinding) and the welding head guide ring should be removed. Failure to remove the guide ring poses a safety hazard (the ring may rupture with explosive force) and typically destroys the ring.

9.4 Production Rates for Plant Piping. In the past, multipass orbital machine pipe groove welding on plant piping was slower than manual welding processes. Orbital pipe welding equipment was primarily used because of its ability to produce consistent, predictable results, particularly in harsh environments. As technologies have advanced, components associated with multipass orbital pipe welding equipment have gotten smaller, computers and integrated circuitry have been adopted, and the systems have become faster and more rugged. The ability of orbital welding equipment to weld components that humans cannot access due to size and access constraints is also recognized.

Multipass orbital machine pipe groove welding systems are being used in countless fabrication facilities where time and cost are the primary motivating factors. Today, in many cases multipass orbital machine pipe groove welding can be done faster, at less expense, and with greater consistency, quality and predictability than manual welding. As labor markets have tightened, finding welders who are skilled in the art of manual welding can be challenging. With the advanced system designs that are available, the level of operator skill that is required has been significantly reduced. Frequently, for in plant piping, multipass orbital machine pipe groove welding is becoming the method of choice.

10. Multipass Orbital Machine Pipe Groove Welding of Cross-Country Pipelines

10.1 Overview. The methods, procedures, and equipment for girth welding of cross-country pipelines are considerably different than those used for power and petrochemical plant piping. Cross-country pipeline construction is unique in that the construction environment and location are constantly changing as pipe is added to the line. It may be flat, level ground one day and steep, rugged terrain the next day.

Cross-country pipelines can be hundreds of kilometers long. Normally, the outside diameter of cross-country pipelines remains the same for the length of the pipeline, although the wall thickness may be increased for road crossings and near compressor stations. Machine pipe groove welding equipment used for welding cross-country pipelines therefore does not have to accommodate a range of diameters, only a small range of wall thicknesses. The same bevel configuration and welding procedure is used repeatedly hundreds or thousands of times over the length of the pipeline. This repetitive nature gives the pipeline welding crew the opportunity to become very skilled in the welding operation, which increases productivity and reduces weld defects.

Cross-country pipeline construction can be spread out over a long distance. The construction pace is ultimately limited by the ability to fit up new pipe lengths to the existing pipeline and deposit the root and hot passes. Once these two passes have been deposited, the front end crew can move forward 12 or 24 m [40 to 80 ft] to add another pipe length. The fill and cap welding can be done with the same equipment as the hot-pass, or can be done with separate equipment spaced along the line. The layout of a typical cross-country pipeline spread (operation) is shown in Figure 28. Cross-country pipeline construction involves many operations such as right-of-way clearing, trenching, back filling, etc., but only those steps dealing directly with the welding operation are considered here. The number of steps involved in the girth welding operation varies with the welding system used.

When multipass orbital machine pipe groove welding systems use the GMAW process, a double down welding technique is used. High productivity in terms of joints-per-shift is of paramount importance. Therefore, multiple weld stations with two or more welding heads per station are used. The welding heads are used simultaneously. Each station is usually dedicated to one pass—for example, a root pass station followed by hot pass stations, two intermediate weld pass stations, and the final cap pass station. In cross country pipeline construction, when each station has completed the pass or passes assigned to that station, all of the stations are lifted off the pipe and moved forward to be set down on the next joint and deposit the assigned pass or passes on the that joint. Because the stations must wait for the stations ahead to finish, the weld cycle time is dependent on the speed of the lead station. While multiple stations can be used to deposit intermediate



Photograph courtesy of CRC-Evans Automatic Welding

Figure 28—Typical Orbital Machine Pipe Groove Welding Cross-Country Pipe Welding Spread

weld passes and cap passes, only the lead station can deposit the root bead and hot pass. The rate at which the root bead and hot pass can be deposited becomes the limiting factor in terms of maximum joints per shift. Downhill welding with the GMAW process allows higher rotational travel speeds to be used compared to uphill welding with GMAW or FCAW. The higher travel speed reduces the time to deposit the root bead and hot pass, permitting higher production rates than can be achieved with uphill welding.

The intermediate weld pass(es) and cap pass(es) can be deposited as single beads which span the joint from wall to wall, or multiple narrower side by side deposits. In multipass orbital machine pipe groove welding, narrow groove bevel configurations are normally used. In narrow groove joints, single beads that span the joint from wall to wall are normally used.

There are two main types of multipass orbital machine pipe groove welding systems used for cross country welding. The first type of system uses external welding heads on carriages and guide rings with an internal welder. As described previously, an internal welder is a line-up clamp with welding heads for depositing the root pass from the inside of the pipe. The second type of system uses external welding heads on carriages and guide rings with an internal line-up clamp with copper backup shoes.

There are advantages and disadvantages to each type of system. For example, the internal welder can deposit root passes with consistently low internal root reinforcement height while accommodating the greatest weld joint mismatch. However, internal welders are costly and are limited to DN 450 [NPS 18] minimum pipe O.D. The systems utilizing internal line-up clamps with copper shoes are limited to about DN 150 [NPS 6] minimum pipe O.D.

10.1.1 Internal Root Pass—External Hot, Fill, and Cap System. The earliest multipass orbital machine pipe groove welding system for cross country pipe welding was the internal root pass, external hot, fill and cap pass system. This system is normally used on pipe diameters ranging from DN 600 to DN 1500 [NPS 24 to NPS 60]. Internal welders with two weld heads have been designed to fit into pipe as small as DN 450 [NPS 18]. However, internal welders with only two weld heads weld with only one weld head at a time. The welding speed is therefore limited to the speed of a single head. Such a system is actually slower than a system using an internal line-up clamp with copper backup shoes and two external weld heads.

In production, after the internal line-up clamp has completed a weld and the hot pass has been deposited, the radial clamping shoes are retracted and the internal welder is put into travel mode. The internal welder then propels itself along the inside of the pipe until it reaches the open end of the pipe. Sensors stop the travel of the internal welder as its leading end protrudes from the open end of the pipe. The internal welder is then aligned with the end of the joint before the next section of pipe is brought into contact with the already welded section of pipe. The internal welder is then clamped into position, and welding of the root pass is initiated.

A typical bevel configuration used with internal line-up clamps with internal welding heads is shown in Figure 7b. The internal welder welds the internal V-groove. This forms the root pass and partially penetrates the land. For carbon steel pipe, the root pass is normally deposited using a 75% Argon / 25% CO₂ (SG-AC-25) shielding gas at a travel speed of about 750 mm/min [30 in/min]. SG-AC-25 shielding gas helps prevent undercut at the top of the pipe, which would occur if 100% CO₂ were used. The internal welder may contain four, six, or eight welding heads depending on the pipe diameter. Each welding head contains a small spool of welding filler wire. The welding heads rotate in unison at a fixed speed. On weld start, the weld heads rotate in a clockwise direction with the welding heads on one side welding downhill and completing one-half of the root pass. Subsequently the weld heads rotate in unison in the counterclockwise direction with the remaining heads completing the other half of the root pass. Welding is done in the downhill direction because welding uphill on the inside of the pipe causes highly crowned beads and undercut.

After completion of the root pass, the hot pass is deposited using external weld heads on carriages and guide rings. The hot pass melts the remaining unfused portion of the land and fuses into the root bead providing cross penetration. The hot pass is followed by intermediate weld pass(es) and cap pass(es) done with additional external welding heads on carriages and guide rings.

10.1.2 Internal Clamp with Copper Shoes and External Welding Heads. There are several external welding systems that use an internal line-up clamp with copper backup shoes. External weld heads on carriages are used to deposit the root pass from the pipe O.D. against the copper backup shoes.

Most of these systems use welding heads with two welding torches spaced 50 to 75mm [2 to 3 in] apart. The welding operator controls cross-seam position of the welding torches by means of a hand held pendant. Torch to work position is maintained automatically.

Most systems of this type deposit the root pass and hot pass simultaneously at a travel speed of 20 to 25 mm/sec [47 to 59 in/min]. Intermediate weld passes and cap passes are deposited at nearly the same speed. The external weld heads are used in pairs, one welding in the clockwise direction and the other in the counterclockwise direction. The welding travel speeds and wire-feed speeds are preset, but the welding operators are allowed to make changes to the travel speed and oscillation width within predetermined limits. Although available, through-the-arc tracking is not commonly used. The welding operator must constantly adjust the cross-seam position of the weld torch as the external welding head travels around the pipe.

With modifications, external weld heads have been used on pipe as small as DN 150 [NPS 6]. Typically, the welding wires used are 0.9 to 1.0 mm [0.035 to 0.039 in] diameter. 100% CO₂ shielding gas with a short-circuiting metal transfer can be used. However, use of 100% CO₂ shielding gas produces spatter which adheres to the pipe surface. The spatter may create problems for automated ultrasonic testing (AUT) of the weld or for coating of the weld. The alternative to 100% CO₂ shielding gas is 50% Argon – 50% CO₂ and short circuiting transfer. This produces an acceptable amount of spatter. For less spatter, the pulsed gas metal arc welding (GMAW-P) can be used. The shielding gas for GMAW-P is typically 75% argon – 25% CO₂ in the USA and 80% argon – 20% CO₂ in Europe. Trimix gases are also available with a few percent Oxygen in addition to the Argon and CO₂. The external weld head with copper backup clamp system has also been used with the flux-core-arc-welding (FCAW) process.

10.1.3 Skidding. To be welded, cross-country pipe has to be raised and supported above the ground by some means to allow the multipass orbital machine pipe groove welding equipment to move completely around the pipe. Prior to being welded, the pipe is trucked to the pipeline right-of-way and laid on the ground. Typically, 50 to 75 cm [20 to 30 in] is needed between the ground and bottom of the pipe. Where wooden skids are available, stacks of skids are used to support the pipe. Skids are typically 10 × 15 cm by 2 m [4 in × 6 in × 8 ft] timbers of high-strength wood, such as oak. In desert regions, piles of sandbags can be used to support the pipe. Sandbags settle, so when sandbags are used, the pipe should be skidded higher than the desired final height. Supports should be located far enough from the weld joint to allow the external welding equipment to pass by the support. If welding shelters with doors for the pipe are used, the supports should be located far enough away from the joint for the doors to open and close with the shelter in place.

10.1.4 Welding Shelters. Welding shelters are small portable tents or sheet metal buildings used to protect the welding operation from wind, blowing sand, and light rain (see Figure 29). Wind can disturb the coverage of the welding shielding gas and cause porosity in the weld. The shelters are usually suspended from a side-boom tractor that also carries the welding-power supplies and bottles of shield gas (see Figure 28). Tent shelters are constructed from canvas over a lightweight frame. Sheet metal shelters are constructed from sheet metal welded to a tubular-steel frame (as in figures 28

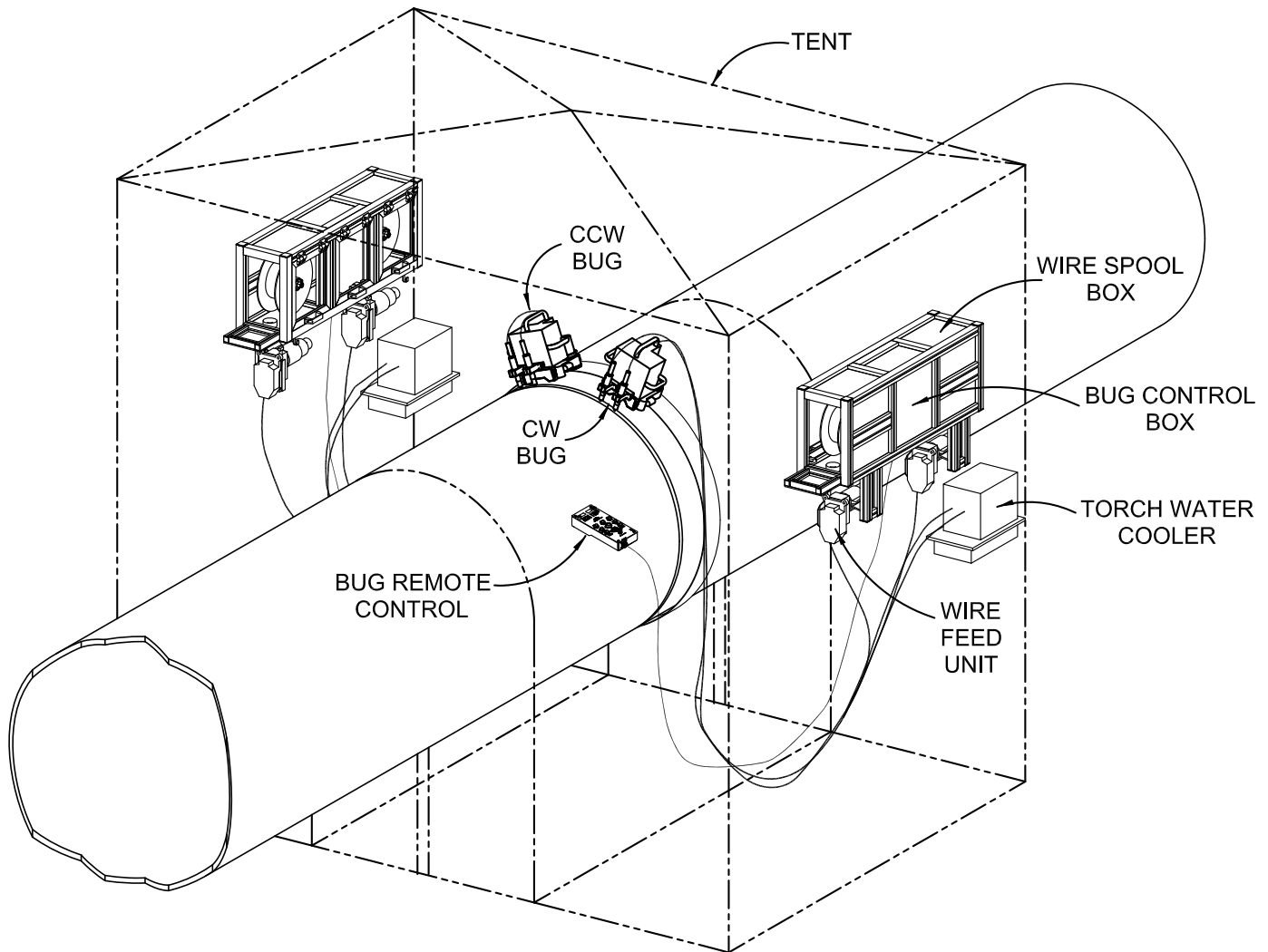


Figure courtesy of CRC-Evans Automatic Welding

Figure 29—Typical Cross-Country Welding Shelter

and 29). Adequate ventilation and lighting must be provided inside the shelter. See AWS Z49.1 for guidance on proper ventilation in confined spaces. Power must be provided for grinders. In sheet metal shelters, power must also be provided for lighting and ventilation fans. Cold weather shelters may also include space heaters to improve the welder's ability to operate the orbital welding equipment. Sheet-metal shelters usually have hinged floors. The hinged floors must be folded back when it is time to lift the shelter off the pipe. Rubber bumpers and saddles are provided where the shelter comes in contact with the pipe to protect the pipe surface and coating from being damaged by the shelter when the shelter is lowered onto the pipe. Shelters must be sized so they can be transported on highways, and be light enough to be handled by the available support tractor booms.

10.1.5 Weld Joint Mismatch. Weld joint mismatch refers to the effect on the inner and outer surfaces of the pipe at the weld joint caused by diameter differences between the two pipe ends or by ovality of the two pipe ends (see Figure 8). API 1104 recommends the offset between the two pipe inside surfaces not exceed 3 mm unless the variation is caused by the pipe mill, in which case the variation is to be distributed uniformly around the circumference of the pipe. BS 4515-1 section 11.4 states any offset greater than 1.5 mm [0.06 in], provided it is caused by dimensional variations within specified tolerances, shall be equally distributed around the circumference of the pipe.

10.1.6 Internal Line-up Clamp Unclamping Restrictions. API 1104 section 5.3.2.11 states that if an internal clamp is used, the minimum percentage of root bead welding that must be completed must be specified. API 1104 section 7.3 states that if an internal pipe line-up clamp is used and conditions make it difficult to prevent movement of the pipe or if the weld will be unduly stressed, the root bead shall be completed before the clamp tension is released. Similarly, BS 4515-1 section 11.5.1 states internal line-up clamps shall not be removed before the completion of the root run or at a stage later as qualified, the pipe remaining adequately supported. DNV-OS-F101 section G 207 states line-up clamps shall not be removed before the first two passes are completed. Until the clamp is released and moved to the new open end of the pipeline, a new length of pipe cannot be added. This restriction on when the internal line-up clamp can be released and moved makes the speed of welding the root pass critical. Rack welding systems with multiple arcs depositing separate portions of the root pass simultaneously and internal line-up clamps with multiple internal welding heads depositing separate portions of the root pass simultaneously have an advantage over systems that use two external welding heads to deposit the root pass.

10.1.7 Hot Pass Delay. The hot pass is so named because it tempers the root pass. The root pass is cooled quickly by the mass of base metal on each side of the joint. Because the root bead cools quickly, it has the potential for forming martensite in some materials. As percentage of martensite in the weld metal increases, the hardness and strength of the weld metal increases. At the same time, ductility and toughness of the weld metal decreases. A hard root bead microstructure increases the chances for delayed hydrogen cracking and stress corrosion cracking. The hot pass reduces root pass hardness by tempering the microstructure. API 1104 section 12.4.2.10 requires the maximum time between the completion of the root pass and the start of the hot pass to be specified. Therefore, during weld procedure qualifications, welds must be made with a delay between the root pass and hot pass to qualify the delay time. If possible, 30 minutes should be qualified to allow ample time to repair or replace external weld heads that malfunction and prevent the hot pass from being deposited immediately after the root pass.

10.1.8 Intermediate weld passes. Intermediate weld pass layers typically range from 3 to 6 mm [0.12 to 0.24 in] in thickness. If intermediate weld pass thickness is increased, centerline hot cracking may result. Also, if intermediate weld pass thickness is increased, the surface tension forces that hold the weld metal in the groove in the overhead position may be overcome, resulting in the molten weld metal falling out of the groove.

10.1.9 Cap Passes. The Cap pass can be deposited as one wide cap pass, or as two narrower side by side cap passes. Single torch weld heads use one wide cap pass, while dual torch weld heads use the two parallel weld passes. In both cases, the welding torch(es) is (are) oscillated.

10.2 Production Rates for Cross-Country Pipeline Welding. Production rates for cross-country pipeline welding are most affected by the rate the root pass and hot pass are deposited. The internal welder cannot be released until the root pass has been completed. The internal line-up clamp with copper backup shoes cannot be released until the root and hot passes have been completed. Therefore, the next length of pipe (single or double joint) cannot be added to the end of the existing line until the root pass (in the case of the internal welder) or root and hot pass (in the case of the copper backup clamp) have been deposited. Total weld to weld cycle time includes the time to advance the internal welder or internal line-up clamp to the new end of the pipe, line up the internal welder or copper backup clamp, clean the welding torches of the internal welder or brush the copper shoes of the copper backup clamp, align the new pipe with the old and clamp the new pipe, and make the weld. For cross-country pipelines, this total time can be as low as 3 minutes, allowing 20 welds to be made per hour.

10.3 Welding Training. Welder training is normally carried out in the pipeline contractor's yard or at the kickoff site. When the training is done in a yard, a building or shed is often used. When a building or shed is not available, the welding shelters are commonly used. Training is normally done using 230 mm [9 in] long pups of project pipe material. (The pups must be long enough to permit the guide ring to be clamped around the pup at the required distance from the weld groove.) Owing companies frequently require the welder to qualify on the heaviest wall pipe to be welded from each diameter range. When using an internal welder, four or five pups can be joined together using the internal welder. The short string of pups is then tacked onto the end of a longer piece of pipe supported on legs or stands to provide clearance between the bottom of the pipe and the floor. At least 500 mm [20 in] of clearance should be provided. If an internal line-up clamp with copper backup shoes is used, one pup will have to be tacked to the clamp nest, and the line-up clamp used to clamp a second pup to the first. Guide rings can then be placed on one of the pups and practice welds deposited with external weld heads.

If the weld head is capable of doing each of the various types of passes, then one weld head can be used to deposit the entire weld. In such a case, a single weld station or weld shelter can be used. If the weld heads are not capable of doing each type of pass, then either multiple weld heads will have to be available at one practice station, or multiple practice stations will have to be provided. If shelters are used for the training, each shelter can be equipped with a weld head for one type of weld pass. In that case, instead of pup pieces, a string of pipes should be provided. The shelter support side boom tractors then move the weld shelters and welding heads from joint to joint along the pipe string, stopping at each weld joint to allow the welding operators to use the weld heads to deposit the appropriate weld pass. The welder operators learning how to deposit each pass stay with a single joint and use the welding heads in the shelters that are moved from joint to joint along the string of joints.

10.4 Weld Defects

10.4.1 Root Bead Concavity. Root bead concavity refers to concavity in the first weld pass that joins the pipes together and creates the weld surface exposed to the inside of the pipe. The profile of the root bead on the internal pipe surface (I.D.) should be flat or slightly convex to reinforce the joint. Concavity of the root bead is considered a defect according to API 1104 section 9.3.6 if the density of a radiograph of the joint reveals the area with concavity to be thinner than the thinnest adjacent parent material, and any of the following conditions apply:

1. The length of concavity exceeds the lesser of the pipe wall thickness or 6 mm [1/4 in].
2. The length of concavity exceeds 12 mm [1/2 in] in any continuous 300-mm [12 in] length.
3. If the weld length is less than 300 mm [12 in], the length of concavity exceeds 12-mm [1/2] total length.

10.4.2 Root Bead Convexity or Reinforcement. Excessive reinforcement is also undesirable, since it will impede the flow of pipeline product and pipeline pigs. API 1104 section 13.8.3 states the inside diameter weld reinforcement shall not be raised above the parent metal more than 2 mm [0.078 in]. Both the internal line-up clamp with internal weld heads and internal line-up clamp with copper backup shoes provide the desired internal root bead profile.

10.4.2 Incomplete Fusion. Of the several types of welding defects that can occur when using multipass orbital machine pipe groove welding systems, the most common type is incomplete fusion, which can be caused by a welding torch which is not properly centered in the weld groove, or by torch oscillation that is either too narrow or too wide, or by welding parameters which cause the molten weld pool to "flood the arc" when welding downhill. Flooding the arc refers to the event in which the molten pool becomes too large to be supported by the force of the arc plasma, and therefore flows under the arc. When the molten pool flows under the arc, the pool prevents the arc from melting the base material.

10.4.3 Melt-Through. Another type of defect is melt-through. Melt-through can occur when welding against a copper backup shoe that is not in contact with the inner surface of the pipe. Melt-through can also occur when welding parameters do not match the weld bevel configuration in a weld that does not use a copper backup.

11. Multipass Orbital Machine Pipe Groove Welding of Offshore S-Lay Pipelines

11.1 Overview. Offshore construction on a lay-vessel differs from cross-country pipeline welding principally in that the welding equipment remains at the same location and the pipe passes through the equipment. Lengths of pipe (12 or 24 m

[40 or 80 ft]) are added to the front of the line. As each length of pipe is welded to the end of the pipeline, the lay-vessel moves forward and the pipeline is fed off the back of the vessel into the water. The pipeline forms the shape of the letter “S” as it is stretched from the back of the lay vessel to the touch down point on the seabed. Lay-vessels typically have 6 to 10 workstations 12 m [40 ft] apart. The welding, inspection, repair, and field joint coating have to be accomplished in this limited number of workstations. If double-jointed pipes (24-m long [80 ft]) are used, the number of working stations are reduced by a factor of two. Typically, only the first 3 to 5 workstations are used for welding. The remaining workstations are used for nondestructive examination, repairs, attachment of anodes, field joint coating, and occasionally attachment of buoys. Therefore, multiple weld passes have to be deposited in each welding workstation. Heavy wall pipe requires additional external weld passes, and therefore additional welding stations or weld passes at each station.

After each workstation has completed its operation, the lay-vessel is moved forward and a new length of pipe is added to the line. The workstation requiring the most time determines the production rate. Usually, the inspection and/or weld repair workstation requires the most time. A typical welding workstation for an S-lay vessel is shown in Figure 3. The marine environment requires that the equipment be protected from saltwater corrosion.

Most offshore pipelines require more pipe than can be held on deck or in the holds of pipe lay vessels. Therefore, as the pipe lay vessel lays pipe, additional lengths must be brought to the vessel. After the pipe lengths are on board, individual pipe lengths are brought to a beveling station. At the beveling station, the ends are beveled prior to sending the pipe to the ready rack or waiting queue of pipes awaiting joining to front end of the pipeline.

11.1.1 Bead Stall. The root bead is deposited in the root bead stall, the first welding workstation on the vessel. The speed with which the root bead can be deposited sets the pipe-laying rate. The following sequence of events occurs in the bead stall:

11.1.2 Move Up. After the vessel has moved forward, the pipe end will have moved toward the stern of the vessel. The internal welder or copper backup clamp will still be clamped in the pipe at the recently completed root bead location.

11.1.3 Stalking. A new piece of pipe will be moved into position from the ready rack or waiting queue. A rod attached to the internal welder or copper backup clamp will be positioned in the end of the oncoming piece of pipe. The internal welder or clamp will be put into travel mode to cause it to travel toward the bow of the boat. Alternatively, a tow cable may be passed through the piece of oncoming pipe and attached to the reach rod to tow the internal welder towards the bow end of the completed pipe string. The drive mechanism on the line-up clamp may have an over-running clutch to allow the tow cable to pull the line-up clamp faster than the line-up clamp motor can propel it.

11.1.4 Aligning. When the reach rod emerges from the bow end of the new pipe, controls on it are used to raise the rear clamping shoes to clamp the internal welder or copper backup clamp into the end of the complete pipe string. The internal weld heads of an internal welder are then serviced (electrode fed out and snipped, shield gas nozzles cleaned) or the copper backup shoes of a copper backup clamp are brushed.

11.1.5 Spacing. The new piece of pipe is then butted up against the pipe string, and controls on the end of the reach rod (which is now sticking out of the end of the new pipe) are used to activate the front clamping shoes.

11.1.6 Welding. After the new pipe has been clamped to the existing pipeline, welding can commence. The welders in the second, third, and additional stations (depending upon the length of the vessel) will have commenced welding on new joints in their station as soon as the pipe has been advanced and stopped moving. Depending upon the wall thickness, the welders in the bead stall may have to weld additional passes after completing the root and hot pass. When all the welders in all the stations have completed their weld passes, the pipe is once again advanced and the process repeated.

11.1.7 Torch Angle and Travel Speed. Typically, intermediate weld passes are deposited with a fixed leading torch angle, and cap passes with a fixed trailing angle. Head angle may be automated and varied as a function of position around the pipe. Typical travel speed for the hot pass is 1.5 m/min [60 in/min]. Typical travel speed for intermediate weld passes range from 0.62 to 1.5 m/min [24 to 60 in/min]. Typical travel speed for cap passes ranges from 0.30 to 1.5 m/min [12 to 60 in/min]. Welding parameters may be fixed for the entire pass, or may be varied as a function of position. Many welding control systems offer print out of the weld parameters whenever requested by welding inspectors.

11.2 Tensioners. The pipe is played out of the stern of the vessel as the vessel moves forward. Tension is maintained on the pipe by means of tensioners, which are similar to the treads of an earthmoving tractor. Normally the tensioner’s tracks are pressed against the top and bottom of the pipe. The tensioner shoe faces may be coated with polyurethane to protect the pipe coating. When heavy wall pipe is used to achieve negative buoyancy and stability, lower yield strength steel can be used than for light wall pipe. Alternatively, if concrete coating is used to achieve negative buoyancy and stability,

lighter wall pipe with higher yield strength is normally used. Coating is removed a distance of 250 to 350 mm [10 to 14 in] from the end of the pipe to provide space for the external welder guide rings to be clamped around the pipe and provide clearance for the external welder carriage. Normally, the outside diameter of the guide rings is less than the outside diameter of the concrete coating, so the guide rings can be left on the pipe as the pipe moves across the support rollers and through the tensioners. The external weld heads, however, must be removed from the guide rings before the weld joint moves from the welding station.

11.3 Clamshell Multihead Welding Systems. Clamshell multihead external welding systems (figure 1) are designed for use on lay-vessels. Their size and weight make them impractical for cross-country pipeline welding. Clamshell multihead welding systems typically use an internal line-up clamp with copper backup shoes.

Clamshell multihead welding systems typically have four to eight (depending on pipe diameter) GMAW heads. The sequence of operation depends on the number of welding heads. With four heads, welding begins with the weld heads at the 12:00 and 3:00 o'clock positions welding downhill on one side of the pipe. The other weld heads begin welding at the 10:30 and 7:30 o'clock positions welding downhill to the 9:00 and 6:00 positions, respectively. These heads return to complete the 12:00 to 10:30 and 9:00 to 7:30 segments, respectively while the first heads complete 12:00 to 3:00 and 3:00 to 6:00.

The operator on each side of the pipe has a pendant to track the joint, and control oscillation width. The pendants are tied to a main control cabinet, which contains the controls for the four (or more) welding heads. Each head can be programmed with multiple procedures. The welding heads are used with the GMAW, GMAW-P, or FCAW processes. Shielding gas is typically an Argon CO₂ mixture.

11.4 Production Rates for S-lay. Production rates for S-lay range from 3 to 7 minutes per weld. Production rates of 20 welds per hour or 480 welds per day are possible. Typical lay rates are in the range of 200 to 300 welds per day due to repairs and the need to carry out preventative maintenance on the equipment at some point each day. Preventative maintenance usually requires 1 hour out of every 24 hour day. Repair rates are typically 3% or less.

12. Multipass Orbital Machine Pipe Groove Welding of Offshore J-Lay Pipelines.

J-Lay welding is employed where water depth makes it impossible to provide sufficient tension to the pipe string to prevent it from buckling.

12.1 Pipe Joints. Normally for J-lay welding two to five 12 m [40 ft] lengths of pipe are joined while in the horizontal position before being upended to the vertical position and added to the pipe string. The pipes are raised to the vertical welding position by means of support frames that grasp the pipe while it is in the horizontal position and raise the pipe to the vertical position. The pipe is then transferred to the pipe lay tower. Grippers in the pipe lay tower are used to position the pipe and lower it until the lower end comes in contact with the previous section of pipe. The tower is usually mounted to the side of the vessel. Towers normally have the capability to tilt up to 15° fore and aft for laying pipe in shallow water near the shore. After the new section is welded to the previous section, a hoist mechanism in the welding tower is used for hoisting the internal line-up clamp out of the pipe. Typically internal line-up clamps with copper backup shoes are used for J-Lay welding. This is due to the fact that the pipes are typically less than DN 600 [NPS 24]. Also, when welding pipe in the J-Lay position, multiple external weld heads can be used simultaneously, making it possible to deposit the root pass quickly. The internal line-up clamp is then inserted into the new string of pipe and lowered to the point of the weld joint. The lower clamping shoes are activated before the upper string of pipe is lowered for the final line-up. After the pipes meet, the upper clamp shoes are activated and welding can commence.

12.2 Welding Deck. In a J-lay vessel, all welding, inspection, repairing, and coating may have to be performed in a single workstation (see Figure 4). Some J-lay vessels have two stations, but the length of pipe strings must be limited to typically two joints. It is therefore essential to complete the weld as quickly as possible. Multiple external welders are therefore used. The limitation becomes one of heat buildup in the weld. The welding equipment should be designed to permit switching from one pass to the next without breaking the arc. The service leads are usually wound around the pipe prior to striking the arcs, which are struck simultaneously. As the welders go around the pipe, the cables unwind and wind up the other direction. Alternatively, a turntable can be provided that rotates around the pipe as the weld progresses so the cables to the external weld heads do not have to wrap around the pipe.

12.3 Inspection. Because of the need to quickly inspect the joint and the difficulty in shielding personnel from radiation, mechanized ultrasonic inspection is normally used on J-lay vessels rather than radiographic inspection.

12.4 Production Rates for J-lay. A production rate for J-lay vessels is typically one new stalk every 15 to 30 minutes. This varies with pipe diameter and pipe wall thickness. The length of time per stalk includes not only alignment time and welding time but also inspection time and coating time. All these operations must be carried out before the stalk can be lowered.

13. Multipass Orbital Machine Pipe Groove Welding of Offshore Reel Lay Pipelines.

In this method, pipe is welded onshore and wound on a reel. The length of pipe that can be held by the reel depends on the diameter of the pipe plus any coating on the pipe. Reel lay ships typically are used to quickly lay small diameter gathering lines between wells and underwater gathering points. A typical reel base has an area capable of storing multiple strings of pipe approximately 1 km [3200 ft] in length. Welding is carried out in a building on the spool base. The building is typically long enough to have multiple workstations (see Figure 5). In the first work station, new lengths of pipe are aligned with the string being fabricated. The root pass is deposited, and the pipe string is moved one joint length. In the second work stations, the hot pass is deposited. Pipe movement continues after each operation is completed, bringing the pipe joint into successive welding stations where the intermediate weld passes and cap pass are deposited. The weld joint then moves to an NDE and repair station, and finally to a coating station. The joint then moves out into the spool base yard. This process continues until a string 1 km [3200 ft] in length has been fabricated. The string is then rolled to the side to allow another string to be welded and eventually stored parallel with all the previous pipe strings. After all the pipe strings have been welded, the reel ship comes to the spool base and docks in a position that allows the pipe strings to be reeled onto the reel. To begin reeling, a cable is used to pull the first long string from the storage rack onto the reel. The pipe end is then secured to the reel and the reel is rotated. When the end of the first string reaches the lead end of the remaining strings, reeling stops and one of the remaining strings is welded to the tail end of the first string. This weld occurs in a shelter in the reel base yard. The complete weld plus NDE and coating must all be carried out in this shelter. After the weld is complete, reeling begins again until the tail end of the second string reaches the head end of the remaining strings. This process is repeated until all of the strings of pipe have been welded end to end and reeled onto the reel. The reel ship then sails to the site where the pipe is to be laid. The pipe is unreeled onto the ocean floor. Pipe lay from a reel ship can be tens of kilometers [tens of miles] per day.

14. Calculation of Filler Metal Requirement

Calculation of the amount of filler metal that will be required for multipass orbital machine pipe groove welding jobs is straight forward. The dimensions of the joint are used to calculate the area. The area times the circumference yields the volume of weld metal needed per joint. This multiplied by the number of joints yields the total volume, which can be converted to kilograms using the density of steel. A wastage factor of approximately 20% should be added to account for wire left on reels and weld metal deposit efficiency. Additional weld metal is needed for training and qualification of welders. Each welder needs to weld at least one half of a joint for practice and one half of a joint for his test. So enough additional filler metal needs to be purchased to provide at least one complete joint for each welder to be tested. Additional practice welds aid in passing welders and insuring low repair rates at the start of production.

15. Calculation of Shield Gas Requirement

Shield gas requirements can be estimated two ways. One way is to calculate the time required for each weld pass based on the circumference and weld travel speed. The total weld time can then be calculated and multiplied by the shield gas flow rate in liters per minute [cubic feet per minute]. Shield gas required for welder qualification must be included. Some gas will be wasted when cylinders are changed out. If bulk storage systems are used, the product will evaporate at about 1% of volume per day even if no welding is occurring. If welding is occurring, the evaporation losses will be less than 1%. A waste factor of 20 to 30% should be used for shield gas. Alternatively, knowing the deposition rate in kg/hour [lb/hour] and the number of kilograms [pounds] of filler metal required, the approximate welding time can be calculated and used to calculate total flow by multiplying flow rate by time. This results in a factor of proportionality between

kilograms [pounds] of welding wire and cubic liters [cubic feet] of shielding gas. A typical constant of proportionality is 1 cubic meter [35 cubic ft] of shield gas per 1 kg [2 lb] of weld metal. For example, using the above constant of proportionality, if a job is estimated to require 8000 kg [17 600 lb] of welding wire, it will require 8000 cubic meters [283 000 cubic ft] of shield gas.

16. Engineering Critical Assessments

Engineering critical assessments are used to quantify the largest flaw size that can be tolerated based on (1) the maximum strains a pipe will see during the pipe-laying process, (2) the fatigue stress amplitude and cycles the pipeline will experience in service, and (3) environmental factors such as the H_2S in the product inside the pipe and the coating and anodic protection on the outside of the pipe. For reel type pipe laying, the maximum stresses and strains occur during the reeling and de-reeling process. These strains are often as high as 2%. For S-lay, the maximum stresses and strains occur as the pipe makes the overbend into the water or sag bend as the pipe touches down on the bottom. These stresses are normally kept below 96% of yield as recommended by API RP 1111. These lower maximum stresses produce strains less than 0.5%. In these cases, the maximum allowable flaw size can be calculated using Appendix A of API 1104. For the case of strains above 0.5%, or for cases where fatigue life and environmental effects must be considered, Appendix A cannot be used, and a more rigorous fracture mechanics analysis must be performed. The ECA provides to the pipeline inspection technicians graphs or tables of maximum allowable flaw height versus flaw length as a function of flaw depth. The allowable flaw heights versus flaw lengths will be presented in the form of graphs or tables. Normally, there are different acceptance criteria for surface flaws and buried flaws. For S-Lay, there may also be different acceptance criteria for deep water and shallow water because of the difference in installation stress. For reel lay, there may also be different acceptance criteria depending upon the location of the flaw from the neutral axis of the pipe. Appendix A of API 1104 cannot be used if the cyclical stress severity spectrum exceeds a maximum value. To compute the severity spectrum, an analysis must be made of the cyclical stresses the pipeline will experience due to hydrostatic testing, installation stresses, and, where applicable, thermal, seismic, and subsidence stresses.

17. Maximum Weld Repair Lengths

Maximum weld repair length is the maximum length of circumference that can be safely excavated by arc gouging or grinding when the weld joint is under stress. When multipass orbital machine pipe groove welding is used on pipe lay vessels using the “S-lay” method, the repair station is sometimes behind the tensioner station. In this situation, the completed weld joint experiences tensile stress and may also experience bending moment. If NDE has revealed defects that must be repaired, the amount of weld metal that can safely be removed is often limited. Failure to observe this limit can result in the pipe parting at the joint while removing weld metal. The result can be catastrophic. Maximum weld repair length limits are calculated based on the pipe dimensions, coating type and thickness, depth of water and configuration of the rollers supporting the pipe. The aforementioned items determine the maximum axial stress and bending moment experienced by the pipe. The amount of weld metal remaining must be sufficient that the maximum stress in the remaining joint will not lead to yielding anywhere around the circumference. When the excavation is near the top of a pipe that is in tension and experiencing an overbend, the maximum stress will be at the ends of the excavation.

18. Safety

Safety information is available from ANSI Z49.1, *Safety in Welding, Cutting and Allied Processes*, published by the American Welding Society, AWS Safety and Health Fact Sheets, and Material Safety Data Sheets (MSDS) available through material suppliers.

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Annex A (Informative)

Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS D10.14M/10.14:2010 , *Guide for Multipass Orbital Machine Pipe Groove Welding*, but is included for informational purposes only.

A1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

A2. Procedure

All inquiries shall be directed to:

Managing Director
Technical Services Division
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

A2.1 Scope. Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

A2.2 Purpose of the Inquiry. The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

A2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for the revision.

A2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

A3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the

standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation is an official interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

A4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

A5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

A6. AWS Technical Committees

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

Annex B (Informative)

AWS Safety and Health Fact Sheets

This annex 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.

- 1 *Fumes and Gases*, October 2005
- 2 *Radiation*, October 2003
- 3 *Noise*, October 2003
- 4 *Chromium and Nickel in Welding Fume*, October 2003
- 5 *Electrical Hazards*, August 2006
- 6 *Fire and Explosion Prevention*, August 2006
- 7 *Burn Protection*, September 2009
- 8 *Mechanical Hazards*, September 2009
- 9 *Tripping and Falling*, September 2009
- 10 *Falling Objects*, September 2009
- 11 *Confined Spaces*, September 2009
- 12 *Contact Lens Wear*, September 2009
- 13 *Ergonomics in the Welding Environment*, May 2008
- 14 *Graphic Symbols for Precautionary Labels*, September 1995
- 15 *Style Guidelines for Safety and Health Documents*, September 1995
- 16 *Pacemakers and Welding*, March 1997
- 17 *Electric and Magnetic Fields (EMF)*, January 1996
- 18 *Lockout/Tagout*, March 1997
- 19 *Laser Welding and Cutting Safety*, March 1998
- 20 *Thermal Spraying Safety*, February 1997
- 21 *Resistance Spot Welding*, February 1999
- 22 *Cadmium Exposure from Welding & Allied Processes*, January 2002
- 23 *California Proposition 65*, September 2009
- 24 *Fluxes for Arc Welding and Brazing: Safe Handling and Use*, January 2002
- 25 *Metal Fume Fever*, January 2002
- 26 *Arc Viewing Distance*, July 2004
- 27 *Thoriated Tungsten Electrodes*, October 2003
- 28 *Oxyfuel Safety: Check Valves and Flashback Arrestors*, April 2005
- 29 *Grounding of Portable and Vehicle Mounted Welding Generators*, July 2004
- 30 *Cylinders: Safe Storage, Handling, and Use*, March 2005
- 31 *Eye and Face Protection for Welding and Cutting Operations*, December 2006
- 33 *Personal Protective Equipment (PPE) for Welding & Cutting*, May 2008
- 34 *Coated Steels: Welding and Cutting Safety Concerns*, September 2009
- 36 *Ventilation for Welding & Cutting*, September 2009
- 37 *Selecting Gloves for Welding & Cutting*, May 2008

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List of AWS Documents on Piping and Tube Welding

Designation	Title
D10.4-86R	<i>Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Piping and Tubing</i>
D10.6/D10.6M:2000	<i>Recommended Practices for Gas Tungsten Arc Welding of Titanium Piping and Tubing</i>
D10.7M/D10.7:2000	<i>Guide for the Gas Shielded Arc Welding of Aluminum and Aluminum Alloy Pipe</i>
D10.8-96	<i>Recommended Practices for Welding of Chromium-Molybdenum Steel Piping and Tubing</i>
D10.10/D10.10M:1999	<i>Recommended Practices for Local Heating of Welds in Piping and Tubing</i>
D10.11M/D10.11:2007	<i>Recommended Practices for Root Pass Welding of Pipe Without Backing</i>
D10.12M/D10.12:2000	<i>Guide for Welding Mild Steel Pipe</i>
D10.13/D10.13M:2001	<i>Recommended Practices for the Brazing of Copper Tubing and Fittings for Medical Gas Systems</i>
D10.18M/D10.18:2008	<i>Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing</i>

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