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Guidelines for Welding Onto In-Service Pipelines

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About the Author...

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1. Introduction

In the pipeline industry it is not always economically desirable to shut down a pipeline system for making tie-in connections, repairs, or adding facilities such as pig launchers and receivers, pump stations, etc. There are also environmental incentives to perform this work without removing the pipeline from service, which can involve spillage or the venting of large quantities of gas to the atmosphere.

The use of the hot-tap method allows the installation of branch connections without shutting down a piping system. This method requires that hot-tap fittings be welded onto an in-service pipeline so that hot-tapping equipment can operate and STOPPLE® Line-Plugging Equipment can isolate and/or bypass line sections or other equipment. There are two primary concerns that are unique to welding onto an in-service pipeline:

A. There is danger of the welding arc causing the pipe wall to be penetrated allowing the contents to escape. This is often referred to as burnthrough and is a concern for welder safety during welding.

B. High hardness levels can result from the accelerated cooling rate associated with the ability of the flowing pipeline contents to remove heat from the pipe wall. This can make these welds more susceptible to hydrogen cracking and is a concern for pipeline integrity following welding.

Therefore, a thorough understanding of factors related to welding on in-service pipelines is required to ensure safe operating procedures and sound welded joints.

2. Avoidance of Burnthrough

A burnthrough will occur if the unmelted area beneath the weld pool no longer has the strength to contain the internal pressure of the pipe, and is governed by three primary factors: pipe wall thickness, weld penetration, and pipeline operating pressure. The relationship of these factors is shown schematically in Figure 1.

The risk of burnthrough will decrease as the pipe wall thickness increases and, in general, as the pipeline pressure decreases. Previous research has shown that the risk of burnthrough is minimal for pipelines with a wall thickness of 0.250 inch or greater (Ref. 1), provided that normal welding techniques are used.

The nominal pipeline wall thickness is not normally a parameter that can be changed for a given in-service welding operation, but should be checked using appropriate ultrasonic testing equipment. This will ensure that the actual wall thickness does not differ greatly from the nominal wall thickness as a result of corrosion, and that laminations are not present within the pipe wall that could lead to cracking or delamination upon welding.

Penetration of the welding arc into the pipe wall is a function of the welding parameters and, to a lesser degree, the welding process. Penetration increases as heat input* increases and as the hydrogen potential of the welding process increases. A low-hydrogen process, such as Gas Metal Arc Welding (GMAW), in conjunction with a low heat input level results in the least amount of penetration. Conversely, a high hydrogen potential process such as Shielded Metal Arc Welding (SMAW) using EXX10-type electrodes at a high heat input level results in much greater penetration.

$$*Heat\ Input = \frac{Voltage\ X\ Curmt}{Travel\ Speed}$$

When welding onto an in-service pipeline with a wall thickness of less than 0.250 inch, the penetration of the arc into the pipe wall should be minimized. This is achieved by using a low-hydrogen process and a low heat input procedure. This may conflict with other requirements, such as the need to use a high heat input procedure to avoid hydrogen cracking. For some applications, the heat input required to avoid cracking may be greater than the heat input allowed to avoid burnthrough, making welding prohibitive.

3. Types of Weld Discontinuities

For hot-tap welding, discontinuities can be classified into two separate categories: welder-induced discontinuities and hydrogen cracking. Welder-induced discontinuities include slag inclusions, porosity, undercut, lack of fusion, etc., and can be controlled by good practice with regard to welder technique and by following a qualified welding procedure.

Hydrogen cracking will only occur when the conditions are right and can generally not be controlled by the skill of the welder. Hydrogen cracking is also the most significant discontinuity with respect to pipeline integrity. The formation of Heat Affected Zone (HAZ) hydrogen cracking in welds made onto in-service pipelines requires three primary, independent conditions to be fulfilled. The requirements are as follows (Ref. 2):

High hydrogen level. All arc welding processes introduce hydrogen into the weld to some extent. Hydrogen can originate from moisture that exists in electrode coatings, in the atmosphere (humidity), or on the pipe surface (condensation). Hydrogen can also originate from hydrocarbons, grease, rust, or other organic contaminants on the pipe or on the welding wire.

Susceptible microstructure. In general, only hard HAZ microstructures are susceptible to hydrogen cracking. Such microstructures are promoted by steel that has a high carbon-equivalent value* and by rapid welding cooling rates. Weld cooling rates are determined by welding heat input and pipeline operating conditions. Operating conditions that influence weld cooling rates include ambient temperatures, pipeline flow rates, and pipe wall thickness.

$$\text{*IIW Carbon Equivalent (CE)} = C + \frac{MN}{6} + \frac{Cu + Ni}{15} + \frac{Cr + Mo = V}{5}$$

Tensile stresses acting on the weld. Tensile stresses can either be applied or residual. Applied stresses can result from movement of the pipeline due to soil settlement. Residual stresses arise from the restraint of the welded connection and strains imposed by the contraction of the weld on cooling.

The relationship of the conditions necessary for hydrogen cracking to occur is shown schematically in Figure 2.

4. Avoidance of Welding Discontinuities

4.1. Avoidance of Welder-Induced Discontinuities

When welding onto an in-service pipeline, welder-induced discontinuities, such as slag inclusions, porosity, lack of fusion, and undercut can be controlled by maintaining good practice with regard to procedural aspects and welding technique.

A welding procedure qualification is used to demonstrate that a procedure is capable of producing sound welds. Welder qualification is used to show that a particular welder is capable of executing the qualified procedure. Proper use of welding procedure and welder qualification, combined with close monitoring in the field to ensure that the welding procedure is being followed, should minimize the occurrence of welder-induced discontinuities.

4.2. Avoidance of Hydrogen Cracking

As noted earlier, hydrogen cracking requires that three primary simultaneous conditions be satisfied. Removal or prevention of any one of these conditions can be used to control hydrogen cracking. Removal or prevention of more than one of these conditions results in an additional margin of safety for hydrogen cracking control.

4.2.1. Hydrogen control

It is possible to severely limit the amount of hydrogen entering the weld by the use of suitably prepared low-hydrogen consumables and by rigorous cleanliness. It should be stressed that "low hydrogen" when applied to consumables (EXX18- or EXX16-type) does not mean "no hydrogen." Even low-hydrogen consumables can lead to hydrogen cracking under adverse conditions, as hydrogen can be introduced through moisture that can be absorbed by the electrode coating. Low-hydrogen electrodes should be stored at an appropriate temperature in portable field ovens or used from freshly opened, airtight containers.

The moisture content of low-hydrogen electrode coatings can be reduced following exposure to the atmosphere by drying and storing them according to manufacturer's recommendations. This typically involves drying at temperatures between 250° C and 450° C (482° F and 842° F) and storing at temperatures above 100°C (212°F). Ovens should not be overloaded, and drying should last long enough to ensure that all the contents receive the minimum baking time as specified by the manufacturer.

Moisture removal from cellulosic-coated electrodes (EXX10-type) is undesirable because these electrode types require a reducing atmosphere (as provided by hydrogen) in the arc to produce the deep penetration for which they are characterized. In the past, many welds onto in-service pipelines have been made using cellulosic-coated electrodes. Previous work (Ref. 3) has shown that the risk of hydrogen cracking is significantly greater using these electrodes than for low-hydrogen electrodes. Therefore, cellulosic electrodes are not generally recommended for welding onto in-service transmission pipelines.

The input of hydrogen to the welds can also be reduced by the use of low-hydrogen processes, in particular gas-shielded processes such as GMAW or Gas Tungsten Arc Welding (GTAW). Under certain conditions, GMAW has the added benefit of higher deposition rates and, therefore, greater productivity. The GMAW process (short circuit transfer mode) has been known to be susceptible to producing lack-of-fusion discontinuities, however, particularly for welding onto in-service pipelines as the result of heat sink effects.

Cleanliness of weld preparation, welding wire, and welding apparatus is also important. Paint, rust, grease, and degreasing agents can all be hydrogen sources. Lubricants from the wire drawing operation are another potential source. Hydrogen levels can also be reduced by controlling the humidity level in the immediate vicinity of the welding operation by removing standing water, particularly if the pipe surface temperature is below the dew point.

An additional approach to hydrogen control is to allow hydrogen removal by diffusion, so the levels are reduced to acceptable values by the time the weld has cooled. This is achieved by increasing the weld thermal cycle, usually by applying a preheat, which reduces the weld cooling rate, allowing more time for they hydrogen to diffuse. This is made difficult, however, for in-service pipeline applications because the flowing contents can quickly remove heat from the pipe wall. The use of preheating is also beneficial in that moisture and contamination is burned off prior to welding. Using higher welding heat inputs is also beneficial since this also increases the weld thermal cycle time. However, using high heat inputs is often impractical for welding in all positions and can increase the risk of burnthrough in thinner wall pipe. The thermal cycle from a "hot pass" (i.e., a second pass applied within a few minutes of the first pass), which usually requires the use of more than one welder on larger-diameter pipe, also allows hydrogen removal by diffusion.

In severe cases where it is not possible to apply preheating or dry low-hydrogen electrodes satisfactorily, austenitic (i.e., stainless steel) weld metal can be used. This technique is particularly valuable when welding onto high-carbon-equivalent pipe material. Austenitic weld metal has a comparatively high solubility for hydrogen, coupled with a low diffusivity. The hydrogen therefore tends to remain in the austenitic weld metal, where it is rendered harmless. However, expert advice should be sought before taking this approach.

4.2.2. Microstructural control

The risk of hydrogen cracking in the HAZ increases with hardness. For a given weld cooling rate, HAZ hardness is a function of the carbon equivalent of the pipe and fitting materials, hardness increasing with carbon equivalent.

4.2.2.1. Carbon equivalent

Unfortunately, records that contain chemical composition information for older, existing pipelines are usually difficult or impossible to locate. In these cases, estimates of chemical composition are often made based on the maximum allowable limits of the specification to which the materials were produced. This usually results in an overestimation of the tendency for unacceptably high hardness levels to result, and is therefore restrictively over-conservative.

The chemical composition of an in-service pipeline can be determined by removal of samples for laboratory analysis, provided that care is taken in removing the samples and that they are properly analyzed. The chemical composition of fitting or sleeve materials can be controlled by proper use of purchase specification requirements, although low-carbon-equivalent material is not always available. The buttering technique can be used to deposit a layer of weld metal, which has an inherently low carbon equivalent, onto the weld preparation of higher carbon-equivalent fitting materials using preheating prior to installation. The buttering technique can also be used to deposit a layer of weld metal onto the pipe material under low restraint conditions. The welds attaching the branch or fitting are then deposited onto the low-carbon weld metal. This procedure, although cumbersome, results in a decreased risk of hydrogen cracking when welding onto high-carbon-equivalent pipe materials. This technique is illustrated in Figure 3.

4.2.2.2. Weld cooling rate

The HAZ hardness in line pipe steels will increase as the cooling rate through the transformation temperature range increases, due to the formation of lower-temperature transformation products such as martensite and lower bainite.

The cooling rate of welds made onto in-service pipelines is a function of the welding parameters and the pipeline operating conditions. Heat input can be increased by increasing the welding current or by decreasing the travel speed. Increasing the heat input results in a decrease in the weld cooling rate. Preheating is used in conventional welding applications to reduce weld cooling rates. Preheating using conventional techniques (e.g., flame methods) is difficult due to the ability of the in-service pipeline to remove heat from the pipe wall, particularly with thinner wall pipe. Induction heating coils with large power sources have been used to reduce the cooling rates of welds made onto in-service pipelines, however. The development of procedures for welding onto in-service pipelines has focused primarily on the use of high heat input levels.

Pipeline operating conditions that affect welding cooling rates include the pipeline contents, flow rate, pressure (gas only), pipe surface, ambient temperature, and pipe wall thickness. Unlike other welding applications, as pipe wall thickness decreases, the cooling rate of welds made onto in-service pipelines increases. Welds made onto thin-wall pipe are made in close proximity to the flowing pipeline contents, which removes heat from the pipe wall. This effect becomes less prominent as pipe wall thickness exceeds 0.500

inch and reverts back to a conventional relationship due to the thermal mass at greater wall thicknesses. Preheating of thicker wall pipe is often practical as the result of this less prominent effect. Also, the gap between the pipe and the fitting often allows effective use of preheating of the fitting material and can reduce bulk weld cooling rates.

An alternative method to reduce the weld cooling rate is the adjustment of pipeline operating conditions (e.g., by reducing the flow rate), but this may not always be practical.

Two methods currently exist for predicting the cooling rates of welds made onto in-service pipelines. A thermal analysis model for mainframe computers was developed by Battelle (Ref. 4), Columbus, Ohio, in the late 1970s, which has since been modified to run on an IBM-compatible PC that allows the prediction of welding cooling rates over a wide range of conditions. A thorough knowledge of the pipeline operating conditions is required, as well as access to a relatively powerful PC. The second method was developed at Edison Welding Institute, Columbus (Ref. 3), and involves measuring the ability of the flow contents to remove heat from the pipe wall using a simple field-usable test. This simple test involves quickly heating a two-inch-diameter area on the pipeline with an oxyfuel torch to between 300°C (572 °F and 617 °F) and 325 °C (572 °F and 617°F) (Figure 4). The time required for the area to cool from 250°C to 100°C (482°F and 212°F) is then measured using a digital contact thermometer and a stopwatch (Figure 5). Six heat-sink-capacity measurement trials are made and the average calculated. This average value is referred to as the heat-sink capacity of the pipeline, and is used to predict the weld cooling rate using empirical data generated in the laboratory for a wide range of welding conditions.

With both of these methods, the predicted weld cooling rate is reported as a function of heat input for a given set of pipeline operating conditions. Limits on the weld cooling rates are established based on the maximum tolerable HAZ hardness predicted with empirical correlations and the anticipated carbon equivalent of the pipe material. These methods allow welding procedures to be selected based on anticipated weld cooling rates. Expert advice should be sought before using these methods.

Under certain severe conditions, even high heat input welds can cool faster than the limiting value required to avoid the formation of a crack-susceptible microstructure, however. This situation results in the formation of a HAZ that is not only hard, but is also large in size. Qualification of welding procedures under realistic conditions, which is discussed in Section 5, can be used to ensure that this situation does not arise.

4.2.2.3. Subsequent thermal treatment

Post Weld Heat Treatment (PWHT) is used in conventional welding applications to reduce hardness level by tempering. As with the application of preheating, PWHT is difficult due to the ability of the in-service pipeline to remove heat from the pipe wall, particularly with thinner wall pipe. Induction heating has been used for this purpose, however. The use of PWHT also allows for hydrogen removal by diffusion.

Weld bead deposition sequence (Figure 6) can influence the resulting HAZ hardness. The stringer bead technique, with the last pass deposited on a previous pass (i.e., the last pass is not allowed to impinge on the pipe material), has been shown to result in a lower HAZ hardness level than the stacked wave bead technique (Ref. 5). The use of a suitably developed multipass or temper bead procedure can be used to reheat the hard HAZ constituents of one pass by a subsequent pass. This can result in retransformation to form softer microstructures, or tempering of the hard structures without subsequent transformation. The use of buttering layers as part of a temper bead procedure is also beneficial in that weld cooling rates in the fitting side of the joint are reduced by increasing the local thickness of the run pipe. This temper bead technique is illustrated in Figure 7.

4.2.3. Control of stresses acting on the weld

The tensile stress required for hydrogen cracking can be applied externally or can develop as a residual stress. Examples of external loads that can occur during or soon after welding include loads imposed by pipeline movement or by the back-filling operation. Applied stresses should be minimized by restricting pipeline movement and preventing soil settlement.

Residual stresses develop as the result of the restraint imposed by the welded assembly and the thermal contraction of the weld as it cools. The restraint of a weld is often difficult to control, although a certain degree of control can be exercised by altering the design of the welded connection. For example, using unnecessarily thick fitting materials and/or over-matching strength electrodes results in a higher level of weld stress than a properly designed connection. Lower-strength electrodes allow strains to be accumulated in the less-crack-susceptible weld metal (as opposed to the HAZ). In production, the stress imposed on two identical joints may vary considerably; for instance, a circumferential weld made on the first end of a full-encirclement fitting will be lightly restrained, but the identical weld on the opposite end will be highly restrained. Opposite end tack welds are of particular concern, as a higher level of stress can occur as the result of their relatively small cross-sectional area. Stresses can also be reduced by minimizing the gap between the fitting and the pipe.

5. Welding Procedure Qualification/Verification

5.1. Welding Procedure Qualification

Procedure qualification guidelines for welding onto in-service pipelines are outlined in API 1107 "Recommended Pipe Line Maintenance Welding Practices." These guidelines require that "consideration" be given to the cooling effects of the flowing pipeline contents on the mechanical and metallurgical properties of the welds. API 1107 does not, however, specify how this consideration should be given. In the past, not much attention was given to the requirement for considering the cooling effects of the pipeline contents during welding procedure qualification, as this is often difficult and costly.

The purpose of qualifying a welding procedure is to demonstrate that the procedure is capable of producing sound welds under production conditions. It is clearly unacceptable to qualify procedures for welding onto in-service pipelines using a length of pipe that contains still air. Without simulating the ability of the in-service pipeline to remove heat from the pipe wall, unrealistically slow weld cooling rates result, in addition to different solidification characteristics of the weld pool. Several approaches exist for qualifying procedures under API 1107, where the thermal conditions experienced when welding onto an actual in-service pipeline are simulated.

Some companies have permanent flow loops at their facilities that can be modified to accept pipe spool sections on which procedure qualification welds are made, while flow from an adjacent pipeline is diverted through the section. Pipeline operating conditions such as flow rate and pressure can be set for either a particular application or for a worst-case condition. Except for inclement conditions that may predominate as the result of the actual welding occurring in a remote location on a buried pipeline, this method of procedure qualification most closely simulates actual conditions.

Temporary flow loops have also been used to qualify procedures for welding onto in-service pipelines. Either a representative liquid (crude oil, fuel oil, etc.) or water is circulated at atmospheric pressure using temporary pumps at representative flow rates while procedure qualification welds are made. The flow rate and fluid temperature can be set for either a particular application or for a worst-case condition. The use of water as a flow medium is thought to be more severe with respect to the resulting weld cooling rates than with hydrocarbon liquids, and reduces the complications associated with handling hazardous liquids.

Preliminary procedures have been developed on a small scale in the laboratory using specimens that simulate the configuration of the actual welded connection. In this method, cooling is provided on the back side of the specimen using a water spray so that welds made onto the specimens cool at the same rate as welds made onto an actual in-service pipeline. After the small-scale procedure is developed, it is then qualified as a full-scale mock-up, with the cooling again being applied to the inside diameter of the pipe.

The thermal conditions existing in the actual pipeline are measured and duplicated in the laboratory using the heat-sink-capacity measurement test, which was described in Section 4.2.2.2. In the laboratory, the water spray is varied until the 250°C to 100°C (482°F to 212°F) cooling time (i.e., the heat sink capacity) of the actual pipeline is achieved, after which the welds are deposited.

One additional method for qualification of procedures for welding onto in-service pipelines involves the use of a water-filled pipe section, where water flow at atmospheric pressure from the tap is provided only to prevent elevation of the water temperature. The effect of the absence of a representative flow rate on the resulting weld cooling rate is thought to be offset by the presence of the water, which very effectively removes heat from the pipe wall. Water temperature can be adjusted to match the anticipated pipe surface temperature in the field. This method of procedure qualification is certainly the most simple of those described above.

Regardless of the approach chosen for procedure qualification, the heat-sink-capacity measurement is useful in verifying that the thermal conditions that exist during procedure qualification are more severe than those during the actual welding operation.

5.2. Additional Consideration for Procedure Qualification

Similar to selecting the thermal conditions, pipe material for the procedure qualification exercise can be chosen for either a particular application or for a worst-case condition. Material choice should be made based on carbon equivalent and not simply on pipe grade, as specified in API 1107, as this can vary widely based on pipe manufacturer and vintage. A modern API 5LX-52 material that has been thermo-mechanically treated may have a low-carbon-equivalent value (and therefore a high resistance to hydrogen cracking), whereas most 1950s vintage X-52 materials have a high-carbon-equivalent value.

Consideration should also be given to more-stringent-than-normal recording of welding parameters and recording of variables not considered "essential" in API 1107 during procedure qualification. A good candidate for consideration is bead deposition sequence, since this can have an enormous effect on the hardness of the finished weld, especially if a temper bead sequence is used.

During the procedure qualification welding, conventional equipment, such as amp tongs, voltmeter, stopwatch, and pyrometer can be used for monitoring welding parameters, or purpose-built arc-monitoring equipment can be used. Similar equipment should then be used in the field to monitor the actual welding parameters to ensure that the limits established during the procedure qualification are being observed.

Regardless of the method chosen for qualifying procedures for welding onto in-service pipelines, careful consideration must be given to selecting procedure qualification test conditions that affect the occurrence of hydrogen cracking, beyond the essential variables listed in API 1107, and then to selecting the field conditions over which the qualified procedure is applicable. In all cases, the procedure qualification parameters should equal or exceed the most unfavorable parameters of the actual weld.

5.3. Verification of Procedure Suitability

The difficulty associated with simulating the thermal conditions experienced when welding onto an in-service pipeline during a procedure qualification exercise has been noted. A confirmation weld scheme can be used to verify that the welding procedure used to make hot-tap and STOPPLE fitting welds are representative of procedure qualification welds.

This scheme involves making a weld using the qualified procedure onto the portion of the pipeline that will be removed by the hot-tap cutter or after the STOPPLE operation. In the case of the hot tap, a mock-up of the welded connection (e.g., fitting material fillet welded to the pipe) that fits the geometric constraints of the hot-tap cutter must be used (Figure 8). After removal, mechanical testing and metallography (e.g., hardness testing) can be performed so a comparison can be made with the procedure qualification weld. Chemical analysis of the pipe material can also be made for comparison with that of the procedure qualification material and recorded for future reference.

6. Safety Considerations

Safety precautions must be taken in preparation for welding in a hazardous environment to prevent the possibility of an explosion or fire. Industry codes and company specifications should be referred to for specific requirements.

7. Installation Procedure

7.1. Fit-up

During the trial fit-up, the gap between the fitting and the pipeline (due to out-of-roundness of one or both components) should be minimized. Gaps in excess of 1/8 inch can be eliminated or minimized by the use of weld metal buttering layers. The root gap for the longitudinal seams, which should make use of mild steel back-up strips to prevent fusion into the pipeline, should be between 1/16 and 3/16 inch.

7.2. Longitudinal Seams

Since the longitudinal seams do not come into direct contact with the in-service pipeline, these welds are not subjected to the accelerated weld cooling rates caused by the ability of the in-service pipeline to remove heat from the pipe wall. These welds can therefore be preheated and welded in a conventional manner. Care should be taken at all times to prevent fusion of the longitudinal seam into the pipeline.

Following preheating, the longitudinal seams should be tack welded on both sides. These seams should be welded simultaneously so that the contraction strains will improve the fit-up between the fitting and pipeline. It is acceptable for one welder to deposit both seam welds in near equal increments if two welders are not available. The welds should be started from the center and subsequent starts should be staggered to prevent a concentration of weld discontinuities.

7.3. Circumferential Seams

Preheating is used in conventional welding applications to reduce weld cooling rates and to minimize hydrogen levels in completed welds by driving off moisture and contamination prior to welding and allowing hydrogen diffusion following welding. The use of preheating using conventional techniques (e.g., flame methods using a heating torch) for reducing the cooling rate of welds made onto in-service pipelines is difficult, particularly with thinner-wall pipe. Preheating is effective in reducing hydrogen levels by driving off moisture and contamination. Induction heating coils with large power sources have been used for this purpose, however,

It is strongly recommended that only low-hydrogen electrodes or a low-hydrogen welding process be used to deposit the circumferential welds. Low-hydrogen electrodes should be removed from a freshly opened package and immediately placed in a storage oven. The electrodes should be removed from the oven only in small quantities and protected from moisture contamination prior to use. Care should also be taken to ensure that GMAW and GTAW consumables are kept clean and dry. Shelter should be provided over the work area to prevent the direct impingement of precipitation.

The welding direction for the circumferential welds is most commonly vertical-up to allow high heat input levels (i.e., near the upper limit of the operating range) to be used, which reduces weld cooling rates and results in softer, less crack-susceptible HAZ microstructures. An additional benefit of this is that hydrogen diffusion following welding is promoted. Also, the stringer bead technique with the last bead deposited on a previous pass should be used as opposed to the stacked weave bead technique, as this results in higher toughness levels and lower hardness levels.

The circumferential welds should be initiated only after the longitudinal seams are complete. The circumferential welds should be deposited individually (i.e., the first weld should be completed before beginning the second weld) to minimize residual stress. Weld starts should be staggered, and if two welders are working simultaneously, the circumferential weld should be deposited in opposite quadrants. The second circumferential weld, including tack welds, should be initiated only after the first is completed.

8. Inspection/Nondestructive Testing

8.1. During Welding

The critical nature of welds made onto in-service pipelines justifies the application of additional quality assurance measures such as inspection and nondestructive testing (NDT). For example, particular attention should be given to monitoring welding procedure variables and welder techniques during the welding operation. Conventional equipment (e.g., amp tongs, volt meter, stopwatch, and pyrometer) or purpose-built arc-monitoring equipment aid in monitoring.

When welding onto in-service pipelines, it is important to perform between-pass visual inspections for discontinuities such as cracking, porosity, proper slag removal, etc. These welds are particularly difficult to inspect using NDT following welding due to their unfavorable geometries, and are more likely to contain these discontinuities as a result of their difficult nature.

8.2. After Welding

NDT of welds made onto in-service pipelines has been the subject of much concern in recent years. Historically, the amount of NDT given to these welds has been minimal. The configuration of these welded connections varies widely, and none are particularly suited to detailed examination. Surface techniques such as liquid-penetrant and magnetic-particle testing rely on discontinuities being slightly below or open to the surface, which is not necessarily the case with all discontinuities that can occur in these welds. Magnetic particle testing can be effective for the detection of toe cracking in the pipe side of fillet welds, provided that proper procedures are used and that the weld toe has been ground to a favorable profile.

Radiography is made difficult due to placement of the source, thickness changes, and the presence of liquid pipeline contents. The only alternative for a full volumetric examination is ultrasonic testing. However, this technique is also hampered by less-than-ideal weld geometries. The use of qualified personnel who are experienced in ultrasonic inspection of complex weld geometries should be employed. Inspection procedures, reference standards, and reporting criteria that have been developed for the specific weld geometries of interest should also be employed.

It is important to note that since hydrogen cracking can occur following a substantial time delay after welding, inspection should not occur immediately. Ideally, a period of 48 to 72 hours should elapse between weld cooling and inspection. This, however, will seldom find favor with production schedules.

9. Summary

Based on the preceding discussion, these items should, in general, be considered:

1. The risk of burnthrough is minimal for pipelines with a wall thickness of 0.250 inch or greater.
2. Properly use low-hydrogen electrodes or a low-hydrogen process to minimize hydrogen levels.
3. Use low-carbon-equivalent materials.
4. Reduce the cooling rate by using a higher heat input weld or by reducing flow.
5. Use preheating to eliminate moisture/contamination and to reduce the cooling rate.
6. Minimize external stresses acting on welds and residual stresses by using the proper welding sequence.
7. Use welding procedures qualified under conditions that simulate field conditions with regard to the occurrence of hydrogen cracking.
8. Perform inspection during and after welding and perform NDT after welding.

It should be noted that the use of low-carbon-equivalent materials pertains only to fitting materials since the line pipe material is fixed (except in the case of buttering). The use of high heat input levels will also aid hydrogen diffusion, although they may conflict with other requirements, such as minimizing the risk of burnthrough on pipe with less than 0.250-inch wall thickness.

As previously noted, preheating is made difficult by the ability of the flowing pipeline contents to remove heat from the pipe wall, particularly with thinner wall pipe. An alternative method to reduce the weld cooling rate is the adjustment of pipeline operating conditions (e.g., by reducing the flow rate), but this may not always be practical.

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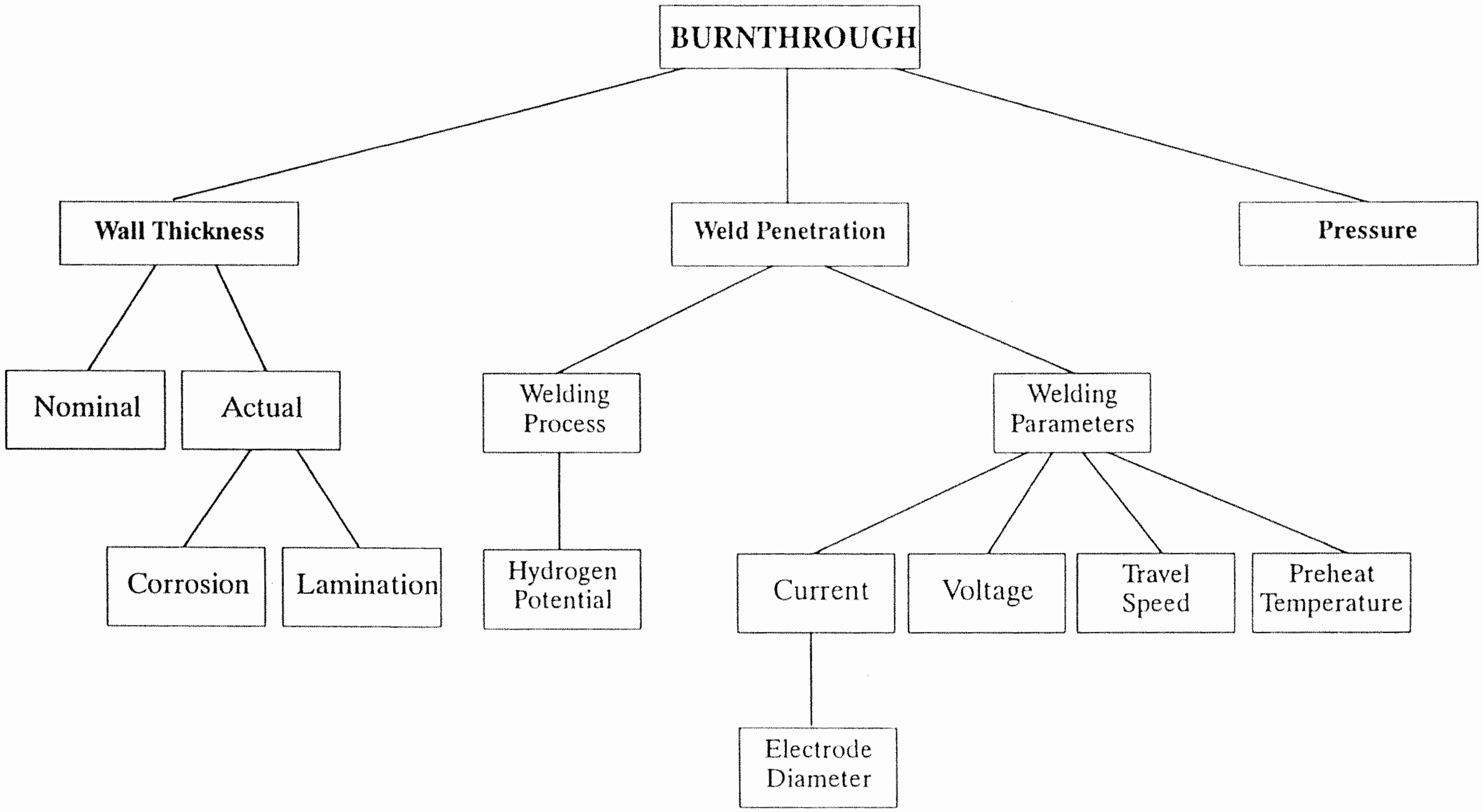


FIGURE 1. Relationship of Factors Governing the Occurrence of Burnthrough in Welds Made Onto In-Service Pipelines.

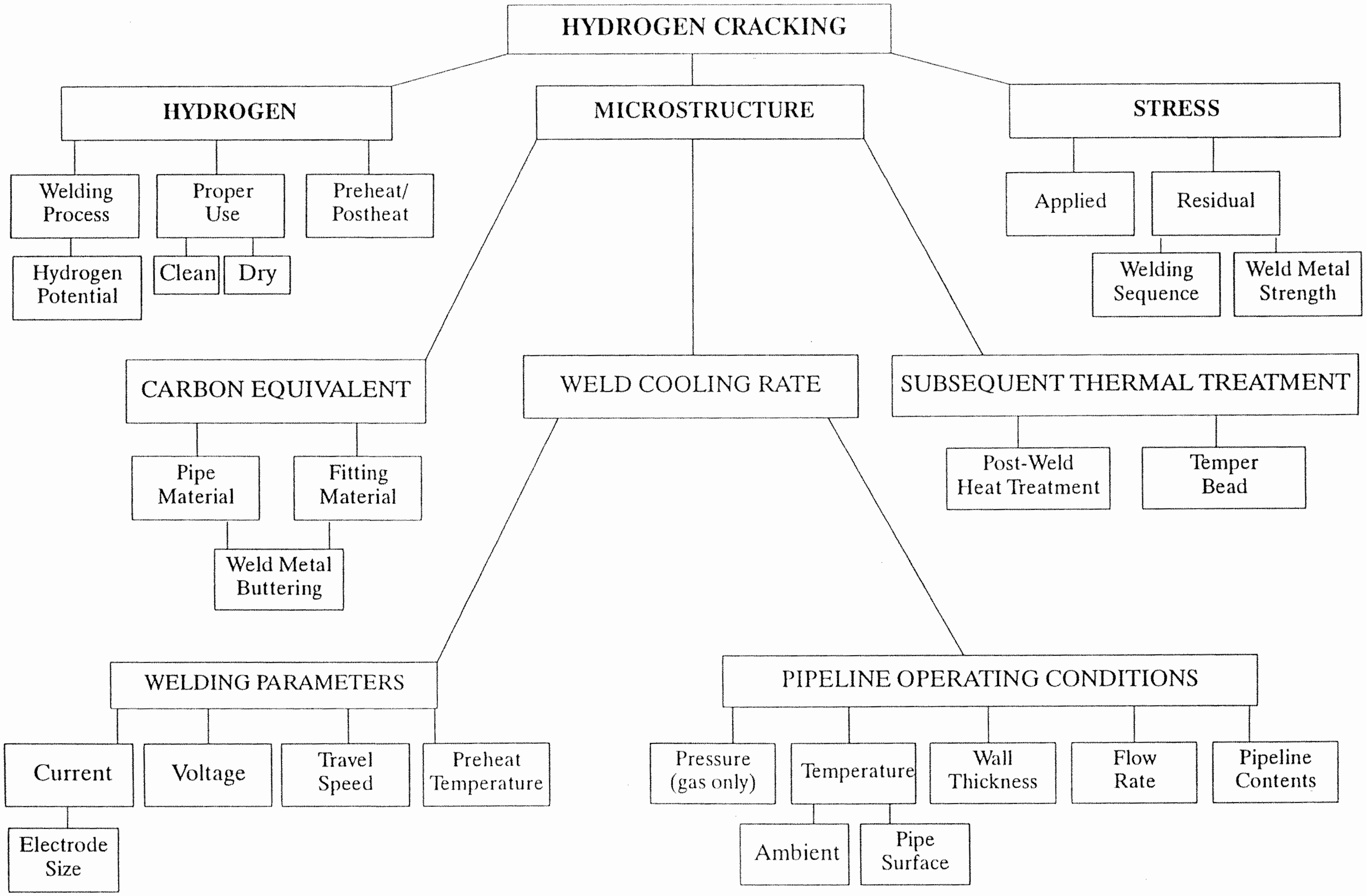


FIGURE 2. Relationship of Factors Required for the Occurrence of Hydrogen Cracking in Welds Made Onto In-Service Pipelines.

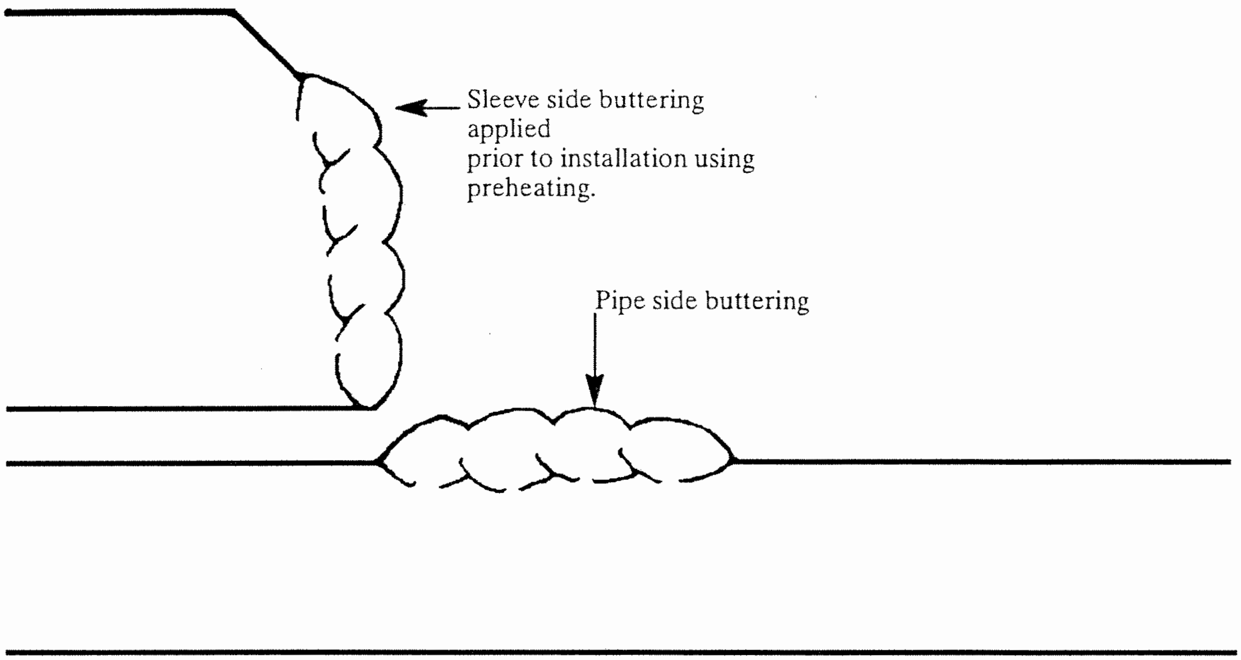


FIGURE 3. Weld Metal Buttering

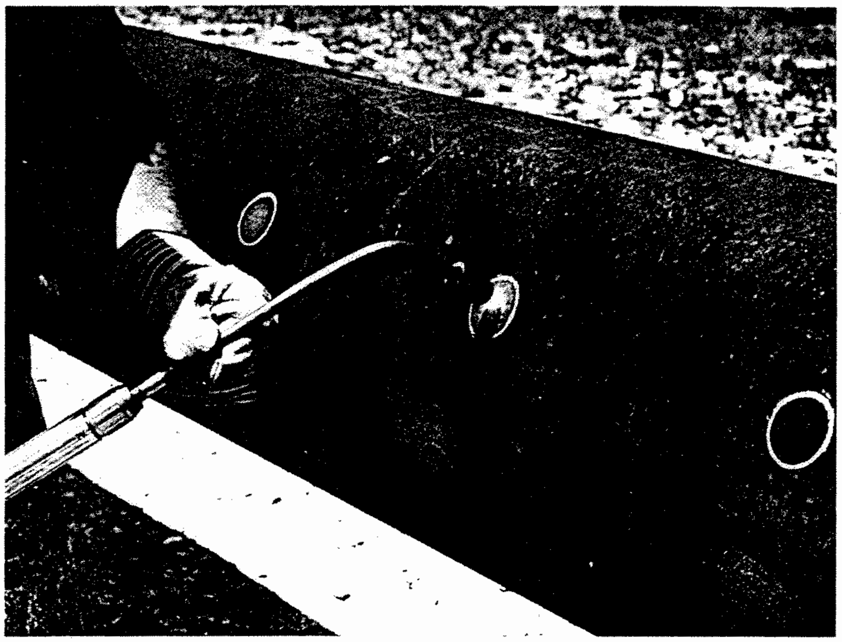


FIGURE 4. Heat Sink Capacity Measurement—Part 1

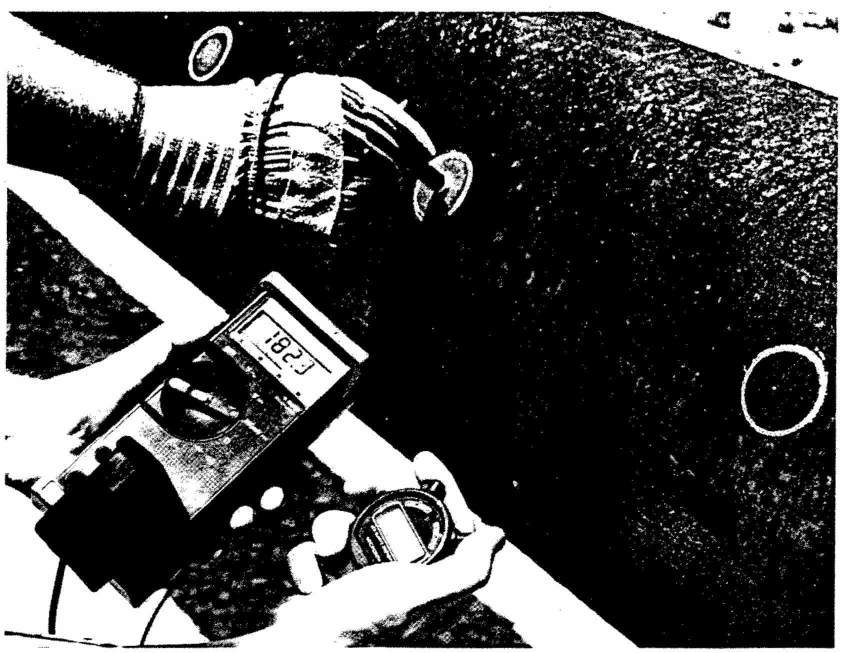
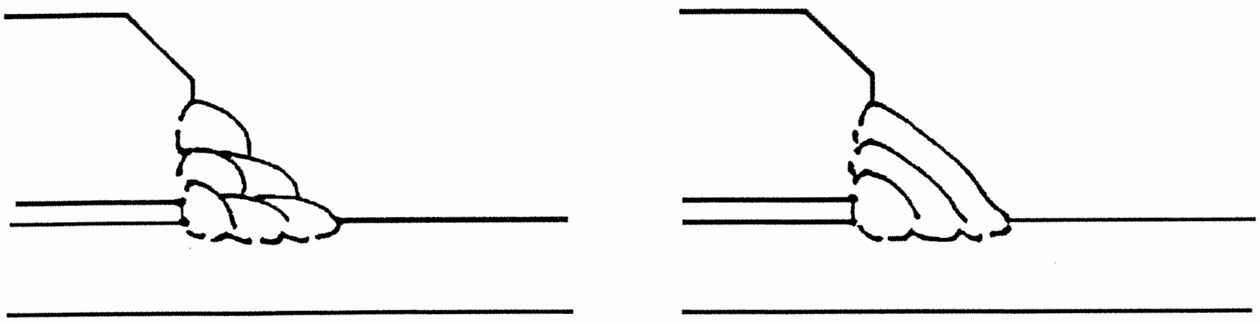


FIGURE 5. Heat Sink Capacity Measurement—Part 2



Stringer Bead Sequence

Stacked Weave Beed Sequence

FIGURE 6. Weld Deposition Sequence

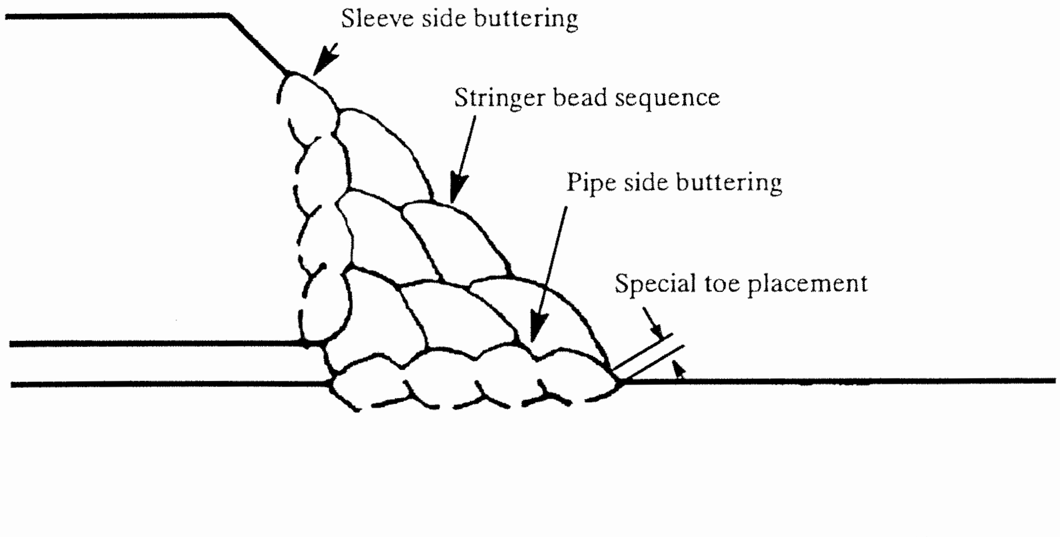


FIGURE 7. Temper Bead Sequence

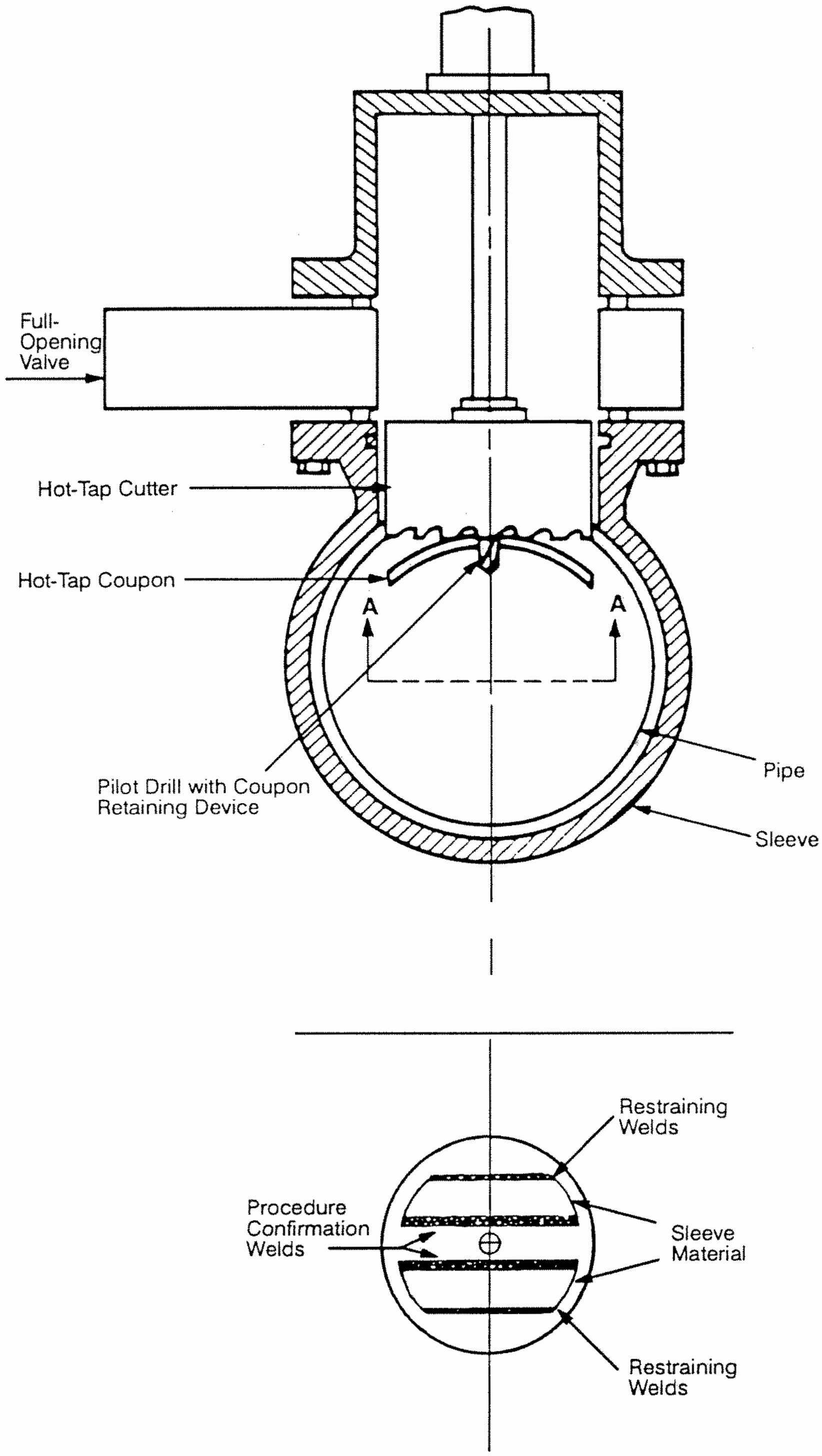


Figure 8. Confirmation Weld Scheme

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