REPORT

July 30, 2007
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Advanced Welding Repair and Remediation Methods for In-Service Pipelines

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Washington, DC

EWI

MATERIALS JOINING TECHNOLOGY

Final Report

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July 30, 2007

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Abstract

This project developed a prototype multi-axis automatic welding system with adaptive control and tracking for use on in-service welding repairs on liquid and gas transmission pipelines. The system is capable of deploying either gas metal arc welding (GMAW) or flux cored arc welding (FCAW) to weld pressure-containing sleeves (Type B), to weld reinforcement sleeves (Type A), or to directly deposit a layer of weld over an area to replace metal loss due to corrosion. The welding system was field tested at TransCanada in North Bay, Ontario and was demonstrated during a workshop at Edison Welding Institute in Columbus, Ohio. In addition, preliminary in-service welding trials with GMAW and FCAW were performed on high strength pipeline steels (X80, X100 and X120) to determine the susceptibility of hydrogen cracking, under simulated in-service welding conditions.

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Disclaimer

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1.0 Final Technical Program

1.1 Executive Summary

The objectives of the project were to develop and build a prototype automated system for corrosion repair welding operations on in-service liquid and gas transmission pipelines that incorporates a real-time adaptive control system (to ensure reliable welding conditions) and to validate the system by performing a field trial.

The automatic corrosion repair system (ACRS) is capable of deploying either gas metal arc welding (GMAW) or flux cored arc welding (FCAW) to weld reinforcement sleeves (Type A), to weld pressure-containing sleeves (Type B), or to directly deposit weld metal over an area to replace metal loss due to corrosion.

When a full encirclement sleeve (reinforcing or pressure-containing) is installed on a pipeline, the two sleeve halves are held in place with a series of chain clamps. Tack welds are then made in between the clamps. When sufficient weld metal is deposited to hold the sleeves in place, the chain clamps are removed. In the voids where the chains were removed, welds are then added to complete the root pass of the joint. At this point, a manual welder currently adds a number of fill passes to build up the weld layer by layer until it reaches the required weld size. The ACRS is designed to make the fill passes after the root pass is completed.

The ACRS incorporates real-time adaptive control to ensure reliable and repeatable welding conditions. The real time control is based on a laser vision system that was developed by EWI originally for pipeline corrosion measurement and assessment.

The prototype ACRS required software development for a number of systems, which needed algorithms to perform task specific activities and software to allow them to interact with each other. Software was developed for the following systems/activities:

- Laser scanning of the pipe surface.
- Laser seam tracking during longitudinal welding.
- Motion control of welding tractors and hardware.
- Integration of the system with the operator interface.
- Remote (i.e., wireless) operator pendant control.

The ACRS will provide higher quality repair welds as compared to manual shielded metal arc welding (SMAW), which is current industry practice. It will also permit in-service repair welding

to be extended to future high strength and/or high pressure pipelines where manual SMAW repair welding is not suitable.

Weld qualification testing was conducted with GMAW and FCAW to determine if X80, X100 and X120 pipeline steel could be acceptably welded under simulated in-service pipeline conditions. The results from the destructive testing and metallographic analysis show no evidence of hydrogen cracking. The low diffusible hydrogen levels (below 4 ml/100g), and the low hardness values (below 350 Hv) both indicate that hydrogen cracking is extremely remote using these welding consumables, welding heat input levels, and cooling conditions.

However, the procedures did not produce acceptable welds, because of lack of fusion defects that were detected during nick-break testing and subsequent metallographic analysis. The lack of fusion defects were attributed to using too large of a weave pattern while depositing the root pass. This can be avoided by using a stringer bead for the root pass, which will allow the arc to penetrate into the corner to completely fuse the root. The two fill pass welding parameters produce sound welds and can be used as a basis for future weld procedure development and subsequent qualification testing with any of these consumables as evinced by the results of the destructive testing and metallographic analysis.

The prototype ACRS was tested under controlled field conditions at the TransCanada Construction Services facility in North Bay, Ontario Canada. TransCanada prepared a 30-in. (762-mm) diameter by 13-ft. (3.96-m) carrier pipe with a reinforcing sleeve (Type A) and a pressure-containing sleeve (Type B) attached to the pipe with completed longitudinal root passes. The ACRS successfully made three different types of welds: Type A sleeve longitudinal fillet welds at the 3 o'clock position, Type B longitudinal V-groove welds in the 3 o'clock position, and Type B circumferential fillet welds from 6 to 12 o'clock positions.

The prototype ACRS was then modified slightly with lessons learned from the field trial and demonstrated to twenty-two people from thirteen organizations who attended a workshop at Edison Welding Institute. The ACRS was demonstrated for two different types of welds: overlapping Type B longitudinal V-groove welds in the 3 o'clock position and a weld deposition repair of a simulated corrosion patch in approximately the 2 o'clock position.

Many welding equipment manufacturers sell systems for production pipeline welding, but none currently make systems for automated welding repair. The number one concern of the workshop participants was the lack of people (qualified or otherwise) to replace their retiring welders; the average age of which is upwards of 55 years old. The ACRS has the potential to enable a repair welder to multi-task (e.g., while the system is welding, the welder could be fitting or tacking the next sleeve). As the workforce continues to shrink, it will eventually reach a level where pipeline companies are forced to look for alternate ways to make the necessary repairs with fewer welders. The system developed for this project fits that niche.

In order to determine a rough order of magnitude cost savings achievable with the ACRS, welding costs were estimated for manual SMAW and automated FCAW for a 36-in. long reinforcement sleeve (Type A) welded with two 0.38-in. fillet welds. With automated FCAW it will take 30 minutes to mount the system on the pipeline and 36 minutes to make all the fill passes (1.1 hours total) at an estimated cost of $176.00 per sleeve. With manual SMAW, it will take 2.5 hours total to make all the fill passes at an estimated cost of $280.85 per sleeve. The ACRS with FCAW is approximately 2.3 times faster and 62% cheaper than manual SMAW repair.

Team members and workshop participants agreed that the potential of the ACRS is very promising; however, improvements are needed before it is fully deployable. The highest priority system improvement recommendations include adding through-the-arc seam tracking to increase the accuracy of depositing circumferential fillet welds. As currently configured, the circumferential welds must be manually steered on the fly, which is difficult because the system hardware is too close to the outside diameter of the pipe to allow a good view of the welding arc. Welding torch accessibility also needs to be improved by incorporating a quick disconnect feature and a more robust, straight barrel torch designed specifically for an automatic welding system.

The prototype system developed by this project should be further developed with commercialization partner Bug-O Systems. After the unit is field hardened, a series of field trials should be conducted on an in-service pipeline to weld a reinforcing sleeve, a pressure-containing sleeve, and to make a weld deposition repair.

1.2 Introduction

Natural gas consumption is predicted to double in the next twenty years. This will place increasing demands on maintaining the existing pipeline system and expanding the system with new loops and branches in order to handle the capacity. In addition, new federal regulations are requiring operators to place increasing emphasis on pipeline integrity. The demands for increased throughput and pipeline integrity both require the development of new and improved pipeline maintenance and repair technologies. In the mean time, there may also be the requirement to improve the pipeline infrastructure for the transportation of alternative fuels, e.g., hydrogen and ethane.

The repair and remediation of in-service pipelines is a safety critical process that must be closely controlled and performed using cost-effective techniques. For large diameter pipelines, the traditional use of manual, shielded metal arc welding (SMAW) is time-consuming and there is a great deal of risk associated with operator error/fatigue due to long welding times. Older pipelines tend to require precise weld placement to ensure correct tempering of previous weld beads; again resulting in longer weld times and an increased risk of operator error. For the new generation, higher strength pipelines, SMAW electrodes that are typically used tend to not provide adequate weld metal properties. All of these issues support a driving need to develop advanced welding repair and remediation methods for in-service pipelines.

1.2.0 Current Status of In-Service Welding on Pipelines

Pipeline repair (or modification) generally involves welding on the pipeline. This can be performed with the pipeline out-of-service or with the pipeline operating under normal or reduced operating conditions (i.e., in-service welding). The adoption of in-service welding offers tremendous cost benefits to operators and also provides significant environmental benefits. These benefits have resulted in the increased use of in-service welding for pipeline repair and hot tapping.

Full-encirclement sleeve repairs are the most commonly used in-service repair process for external or internal wall loss due to corrosion. There are two different types of full-encirclement sleeves: reinforcement (Type A) and pressure-containing (Type B).

Appendix A contains a TransCanada drawing of a reinforcement sleeve (Type A). It consists of two parts; a lower half and an upper half. The lower half has a bar fillet welded to the longitudinal seams on either side of the sleeve at the 9 and 3 o'clock positions. The top sleeve has no bars and is lowered onto the pipe so the bars on the bottom sleeve overlap the seam between the sleeve halves. The top sleeve is then fillet welded to the bars on the bottom sleeve. No circumferential welds are made on Type A sleeves. Cost share partner TransCanada primarily installs reinforcement sleeves to repair corrosion damage.

Appendix B contains a TransCanada drawing of a pressure-containing sleeve (Type B). It consists of two parts; the longitudinal seams of which are prepared with a 60° included angle single V-groove weld joint preparation. These sleeves are secured to the pipe and both longitudinal welds are completed first, then both circumferential fillet welds are made to assure the pressure-containing ability of this repair. Cost share partner TransCanada has only completed one Type A repair in the last two years. However, other pipeline companies like Enbridge, typically install more Type A sleeves.

In the last 20 years, in-service repair welding has been developed, evaluated, and validated for a broad range of pipeline repair applications and is now used routinely to repair operating pipelines. However, manual techniques like SMAW tend to not be suitable for welding pipeline grades X80 and above, and can be time consuming for large pipe diameters or long reinforcement sleeves.

For many years, semi-automatic welding (e.g. gas metal arc welding (GMAW) and flux cored arc welding (FCAW)) has been seen as an attractive alternative to SMAW for in-service repairs. Previous research has been performed to evaluate the applicability of GMAW or FCAW for in-service welding of pressure-containing repair sleeves and branch connections.[1,2] The results show that GMAW and FCAW can successfully be applied to in-service welding applications. The intent of the current project is to extend the current capabilities of in-service welding by developing an automated corrosion repair welding system for use on in-service pipelines. By developing an automated welding system for in-service repair welding applications, the full capabilities of applying a semi-automatic welding process could be achieved (e.g., improved welding parameter control and increased productivity).

The primary reason for pipeline repair is to mitigate corrosion-caused metal loss. Since corrosion is a time dependent process, as pipeline systems become older, more and more repairs are required. The application of pipeline repairs has also accelerated as a result of the increased use of in-line inspection, which effectively detects pipeline corrosion and other damage. Corrosion is normally repaired by installing a repair sleeve or by direct deposition of weld metal.

Changes in the structure of the U.S. pipeline industry have also resulted in increased in-service welding interest. The advent of “open access” and “common carrier” practices in the industry has resulted in the need for operators to provide branch connections for new suppliers and customers, many of which are made by hot tapping (see Figure 1).

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[1] Bruce, W.A., “Qualification and Selection of Procedures for Welding Onto In-Service Pipelines and Piping Systems,” Edison Welding Institute (EWI) Project No. J6176, Columbus, Ohio, January 1996.

[2] Bruce, W.A., Fiore, S.R., “Alternative Processes for Welding Onto In-Services Pipelines,” Pipeline Research Council International, Inc. (PRCI Contract No PR-185-0002, Edison Welding Institute (EWI) Project No. 43675CAP Columbus, Ohio, March 2002.

Figure 1. Hot Tapping a NPS 42 Pipeline

1.2.0.0 Historical Development

Hot tapping has been carried out for many years. Up to the mid-seventies, hot taps, with the branch welded to the carrier pipe, were made at full line pressure and full flow. SMAW was used with cellulosic electrodes for root passes and low-hydrogen electrodes for fill and cap passes. Then, due to increasing concerns around the possibility and consequences of burn-through and the lack of definitive research, the practice was to stop the flow of gas in the pipeline and reduce the pressure to less than 60% of maximum operating pressure of the carrier pipe. The only guidelines for welding on in-service pipelines available during this time period were designed to minimize the occurrence of burn-through by reducing the internal pressure of the operating pipeline to a level related to the pipe wall thickness. By the early nineties, as the technology to successfully develop, validate, qualify and complete welds on in-service pipelines became better defined, standard practice reverted to welding at full line pressure and full flow; under these circumstances low-hydrogen welding electrodes were used exclusively.

The use of repair sleeves for reinforcement and/or pressure containment is similar to that for hot tapping. Repair by direct weld deposition, where weld metal is directly deposited onto the pipe surface to replace metal loss from corrosion is still at an early stage of field use and is not sanctioned by all operators. Pipeline repair by direct deposition of weld metal, or weld deposition repair, is an attractive alternative to the installation of full-encirclement sleeves because it is direct, relatively inexpensive to apply, and requires no additional materials beyond welding consumables. This is especially true for wall loss in bend sections and fittings, where the installation of full-encirclement sleeves is difficult or impossible. A series of PRCI-sponsored projects at EWI,[3,4,5,6] beginning in 1991, were aimed at addressing the technical aspects of weld deposition repair, including the risk of burn-through during welding, the resulting integrity of the pipeline following repair, and the practical application of this repair technique in the field. The results of these projects are being used as a foundation for enhancements to industry codes and for regulatory acceptance of this alternative repair technique. Repair by weld deposition is also an enabling technology as local build up is sometimes required before a sleeve can be installed.

1.2.0.1 Importance of Welding Technology for In-Service Welding

Only recently, comprehensive collaborative R&D programs have been undertaken to understand and address the key issues related to welding on in-service pipelines. These programs have led to the development of tools and guidelines, which can assist the welding engineer in assessing the feasibility of a repair or hot tap at full line pressure and full flow, and in the development and qualification of the most appropriate welding approach and procedure.

Much of the literature on in-service welding, at least those publications before 1980, describes specific repairs or connections rather than attempting to understand or address the key issues that might have led to a generalized approach and the development of guidelines. Obviously, success stories are important to establishing confidence in a process or approach; however, an equally valuable source of information is an analysis of an unsuccessful application or component failure. One such failure occurred on a TransCanada pipeline in January 1992.[7] TransCanada's NPS 36 Western Alberta Mainline ruptured at a location 62 miles (100 km) north of Calgary. A fire at the adjoining James River Interchange Meter Station resulted from the rupture, rendering the exchange facility between the Alberta Eastern and Western systems inoperable (
Figure 2). The cost of this failure in terms of the required repair and lost revenue was estimated at $9M. The rupture initiated at a hot tap where a NPS 24 pipeline was tied into the NPS 36 mainline. The Western Alberta System had been in operation since 1962 and was constructed

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[3] Bruce, W. A., Mishler, H. D., and Kiefner, J. F. Repair of Pipelines by Direct Deposition of Weld Metal. A.G.A. Pipeline Research Committee, PRCI Project PR-185-9110. Edison Welding Institute. June l993.

[4] Bruce, W. A., Holdren, R. L., Mohr, W. C, and Kiefner, J. F. Repair of Pipelines by Direct Deposition of Weld Metal - Further Studies. PRCI, Project PR-185-9515. Edison Welding Institute and Kiefner and Associates. November 1996.

[5] Bruce, W. A, "Welding onto In-Service Thin-Wall Pipelines," Final Report to PRC International for PR-185-9908, EWI Project No. 41732CAP, Edison Welding Institute, Columbus, OH, July 2000.

[6] Bruce, W. A, "Burn-through Limits for In-Service Welding," Final Report to PRC International for GRI-8441, EWI Project No. 44732CAP, Edison Welding Institute, Columbus, OH, August 2003.

[7] Chiovelli, s., Dorling, D., Glover, A., Horsley, D., "NPS 36 Western Alberta Mainline Rupture at James River Interchange," EigthEight Symposium on Line Pipe Research, Pipeline Research Council Inc., Paper 26, 1993

of API 5L X52 pipe material; nominal dimensions were a 36-in. (914-mm) outside diameter (OD) with a 0.4-in. (10.3-mm) wall thickness. The line had a maximum allowable operating pressure of 845 psi (5,826 kPa), which gave it a hoop stress of 71.9% specified minimum yield strength (SMYS). The pressure at the time of failure was 782 psi (5,392 kPa). The hot tap was installed in 1980 using the standard procedure that required the flow to be curtailed and the pressure reduced.

Figure 2. James River Interchange

The subsequent metallurgical investigation concluded that the rupture originated at pre-existing hydrogen cracks located at the toe of the hot tap stub weld on the NPS 36 carrier pipe. Two areas were identified with dimensions of approximately 2.6-in. (66-mm) long by roughly 0.08-in. (2-mm) deep, which were separated by a distance of 1.25 in. (32 mm). Brittle fracture propagated in both directions consistent with the properties of the 1960s vintage pipe material. Viewed from the inside of the carrier pipe, the pre-existing defect was located at approximately the 1 to 3 o'clock position. The appearance of the cap pass of the stub weld indicated that one side, from 6 to 12 o'clock, was welded using an uphill weave technique as required by the qualified welding procedure. However, on the side containing the pre-existing defect, a stringer bead technique was used with a downhill progression from the 1 to 5 o'clock position at the weld toe onto the NPS 36 carrier pipe. Obviously, this area had not been welded in accordance with the applicable welding code or the qualified welding procedure. Chemical analysis of the stringer bead was consistent with a low-hydrogen E8018-C2 electrode. In order to weld downhill with a low-hydrogen electrode of this type, a very fast travel speed is required. Microhardness surveys taken in the heat-affected zone (HAZ) and weld metal adjacent to the origin of failure, revealed values in the range 518 - 546 Hv in the HAZ and 390 - 440 in the weld metal. The average hardness of the surrounding parent metal was 210 Hv. There was no doubt that the rupture originated at the hydrogen cracks that occurred during the installation of the stub and the primary event was the non-compliant procedure used to weld the NPS 24 stub to the NPS 36 carrier pipe; however, a fracture assessment and stress analysis showed that this alone was insufficient to cause failure. This example shows the importance of correct welding techniques as the other factors involved did not by themselves lead to failure.

1.2.0.2 Developments in In-Service Welding Technology

The two primary concerns when welding on in-service pipelines are burn-through and hydrogen cracking. Previous work has concluded that the risk of burn-through can be controlled by limiting inside surface temperature.[8] A useful tool in evaluating the risk of burn-through is thermal analysis computer models, which have been developed by Battelle and more recently by EWI.[9] The computer models use two-dimensional numerical solutions of heat transfer equations. The model predicts inside surface temperatures as a function of the welding parameters (e.g., current, voltage, and travel speed), geometric parameters (e.g., wall thickness, etc.), and the operating conditions (e.g., contents, pressure, flow rate, etc.).

Hydrogen cracking requires that following three primary independent conditions be satisfied simultaneously:

- Hydrogen in the weld.
- Susceptible weld microstructure.
- Tensile stresses acting on the weld.

To prevent hydrogen cracking, at least one of the above conditions must be eliminated or reduced below a threshold level. To avoid hydrogen cracking in in-service welds, many companies first minimize the hydrogen level by using low-hydrogen electrodes or a low-hydrogen welding processes like GMAW. As added assurance against hydrogen cracking, many companies have also developed procedures that minimize the formation of crack-susceptible microstructures by minimizing hardness levels, since low hydrogen levels cannot always be guaranteed.

[8] J. F. Kiefner and R. D. Fischer, "Repair and Hot Tap Welding on Pressurized Pipelines," Symposium during 11th Annual Energy Sources Technology Conference and Exhibition, New Orleans, LA, January 10-13, 1988 (New York, NY: American Society of Mechanical Engineers, PD-Vol. 14., 1987) pp. 1-10.

[9] Bruce, W.A., Li, V., Citterberg, R., “PRCI Thermal Analysis Model for Hot-Tap Welding – V4.2”, Pipeline Research Council International, Inc. Catalog No L51837, PRCI Contract PR-185-9632, Users Guide Revision 3, May 2002.

There are three commonly used options (or combinations thereof) for preventing hydrogen cracking in welds made onto in-service pipelines beyond the use of low-hydrogen electrodes:

- Specifying a minimum-required heat input level.
- Specifying a temper-bead deposition sequence.
- Specifying a minimum-required preheat temperature.

The use of a minimum-required heat input level welding procedure or a temper-bead deposition sequence welding procedure are the most common practices for reducing the cracking susceptibility. It tends to be difficult, if not impossible, to apply preheating to certain in-service welding application, because the pipeline contents remove the preheating in the same manner as the contents cool the weld. Preheating is therefore used for thicker walled pipelines where the contents of the pipeline do not have as much of an effect on weld cooling time.

To determine the minimum-required heat input necessary to avoid the formation of a crack susceptible microstructure, companies commonly use the thermal analysis computer models that have been developed by Battelle and EWI.[8,9] The computer models predict the weld cooling rate as a function of heat input for a given set of pipeline operating conditions. Limits on the weld cooling rates are then established based on the maximum tolerable HAZ hardness predicted using previously established empirical correlations and the anticipated carbon-equivalent of the pipe material. Using iterative computer model runs the selection of welding parameters that produce minimum-required heat input levels and thus the anticipated weld cooling rates can be determined. The computer model predictions can be verified by applying a short field usable test developed at EWI to assure that the cooling potential of the operating pipeline is similar to the cooling potential predicted by the computer models.[10]

The thermal analysis models are not applicable to temper bead deposition welding procedures. These welding procedures require experimental qualification to determine the heat inputs limits. The temper bead deposition welding procedure heat input levels tend to be much lower than the heat input levels used for other in-service welding procedures.

There are a number of related areas of concern for welding onto in-service pipelines that are addressed by a variety of industry practices. There are also a number of recent and on-going

[10] Bruce, W.A., Bubenik, T.A., Fischer, R.D., Kiefner, J.F., “Development of Simplified Weld Cooling Rate Models for In-Service Gas Pipelines,” Eight Symposium on Line Pipe Research, Pipeline Research Council Inc., Paper 31, 1993

research projects pertaining to these concerns, many of which are being undertaken at EWI or Cranfield University.[11] These projects include:

- Avoiding unstable decomposition of products, e.g., ethylene.
- Avoiding internal combustion of flammable mixtures.
- Determining the chemical composition of in-service pipelines.
- Qualification of procedures and welders.
- Inspection and nondestructive testing (NDT).
- Delay time prior to inspection for hydrogen cracking.
- Fitness-for-service based defect acceptance criteria.
- Proof testing.
- Verification of procedure suitability.
- Hot tap welding for sour service pipelines.
- Hot tap welding for lines charged with hydrogen.
- Hot tap welding for duplex stainless steel pipelines.

The work by EWI and others have resulted in the core of in-service welding technology becoming relatively mature, but there are significant areas requiring further research to improve the safety and cost-benefits of in-service welding. The most commonly used processes for in-service welding are SMAW using conventional low-hydrogen electrodes and, to a lesser extent, GMAW. The use of SMAW results in limited productivity. The use of GMAW is limited by the amount of heat input that can be applied and may be susceptible to producing lack-of-fusion discontinuities or defects. The use of variations of these commonly used practices, or the use of a totally different process, may have advantages for some in-service welding applications. For example, FCAW may offer the ability to make high productivity, low-hydrogen, high heat input welds. The use of alternative power sources, such as the Lincoln Electric surface tension transfer (STT) machine, may also be able to overcome the difficulties associated with GMAW. Either of these has the potential to result in high productivity pipeline repairs or modifications, and would allow the possibility of mechanization to be exploited. EWI has performed some preliminary research into applying these alternative welding processes for in-service welding; however, more research is required.[1,2]

[11] Bruce, W.A., "Hot Tap Welding: A Review of Industry Practice and Recent Research", First International Symposium on Process Industry Piping, National Society of Corrosion Engineers, Orlando, FL, USA, December 14-17 1993

One of the main benefits of mechanization, in addition to further increases in productivity, is that the heat input can be closely controlled. Applications where precise control of heat input is required include material/wall thickness/flow condition combinations where the maximum allowable heat input to prevent burn-through is not much higher than the minimum required heat input to prevent hydrogen cracking. Another example is where tempering in the HAZ of an initial layer of buttering by a subsequent layer is required (i.e., temper bead procedures). TransCanada and other pipeline companies use temper bead deposition procedures extensively.

A large proportion of the in-service welding research that has been conducted to date has focused on relatively low-strength, relatively thick-walled pipelines. While there are many exceptions, a typical transmission pipeline in the U.S. might be X52 or X60 material and have a wall thickness in the 0.375-in. (9.5-mm) range. In some parts of the world, Australia in particular, it has recently become common practice for pipelines to be designed and constructed from high-strength thin-walled materials. The results of research that has been conducted to date may not be applicable to the new high-strength thin-wall pipelines.

As noted above, the Battelle model allows burn-through risk to be controlled by limiting inside surface temperature. While this approach has been useful, it may be overly conservative for some applications and non-conservative for others. Additional work is required to investigate this for high-strength thin-wall pipelines and for these materials where the risk of burn-through is high and mechanized welding is extremely attractive.

Mechanized welding methods are widely applied for girth welding during construction of pipelines, but have not been used for in-service repair welding. Cranfield University and EWI have collaborated on the initial investigation of equipment for mechanized in-service welding and initial trials have been successful, although a more robust hardware platform is essential and improved automation and adaptive control would be beneficial. These areas were the key focus of the current project and are a natural progression from the previous developments in in-service welding and the trends towards thinner wall, higher pressure, higher strength pipelines for which in-service welding operations are more critical.

1.3 Results and Discussion

This project was funded by the U.S. Department of Transportation Award No. DTRS56-03-T-0009 (tracked via EWI Project No. 46996GTH), Pipeline Research Council International (PRCI) Contract No. PR-185-04501 (tracked via EWI Project No. 47451CAP), and EWI Project No. 46256CSP, which was funded via a subcontract with Cranfield University who was funded by PRCI. The project team was lead by Edison Welding Institute (EWI) in collaboration with

TransCanada, Cranfield University, Serimer DASA, and Bug-O Systems with oversight provided by DOT, PRCI, and PRCI member companies.

Based in Columbus, Ohio, EWI is North America's leading engineering and technology organization dedicated to welding and materials joining. EWI's staff provides materials joining assistance, contract research, consulting services, and training to over 3,300 member company locations representing world-class leaders in the energy pipeline, aerospace, automotive, defense, energy, government, heavy manufacturing, medical, and electronics industries. Based in Calgary, Alberta, TransCanada is a leader in the responsible development and reliable operation of North American energy infrastructure. With approximately 36,500 miles (59,000 km), their pipeline system taps into virtually all major gas supply basins in North America and delivers to markets across Canada and the United States. The Welding Engineering and Metal Science Centre at Cranfield University has worked with a number of major pipeline companies and welding contractors to investigate welding metallurgy of X100 pipe, to develop high productivity welding processes for pipeline construction, and to develop automated processes for in-service welding. Serimer DASA provides fully integrated services for automatic pipeline welding including, engineering, training, and equipment rental/leasing. Bug-O Systems is a manufacturer of an inexpensive, modular, building block family of portable machines designed to automate welding processes. Bug-O Systems feature a system of drives, carriages, rails and attachments that provide precise path and constant speed control in any plane or position. PRCI is a not-for-profit corporation comprised of energy pipeline companies who conduct a collaboratively-funded technology development program that enables energy pipeline companies around the world to provide safe, reliable, environmentally compatible, and cost-effective service to meet customer energy requirements.

The project was organized into seven tasks:

1. Review of Industry Needs, Requirements, and Current Practices.
2. Technical Specification of an Automated In-Service Welding System.
3. Design and Build of Automated In-Service Welding System.
4. Laboratory Development and Evaluation.
5. Weld Procedure Qualification.
6. Field Testing and Validation.
7. Final Report.

The objectives of the project:

- Develop and build an automated welding system for use on in-service pipelines.

- Implement a real-time adaptive control system to ensure reliable welding conditions.
- Evaluate system performance by performing laboratory trials.
- Validate the system by performing a field trial.

1.3.0 General Welding Terminology

A variety of standard[12] and nonstandard terms (a.k.a*.,* industry jargon) are used to describe different aspects of welding. Each industry sector, like the pipeline industry, has its own unique industry jargon specific to welding. To equip all readers with a common vocabulary, the welding terms and abbreviations used in this narrative are defined below in a way that relates to pipeline geometry where appropriate. A comprehensive summary of acronyms used in this report is located in section 5.0.

AWS. The American Welding Society (AWS) is the leading producer of codes, specifications, guides, recommended practices, and welding/joining books for the worldwide welding industry. Over 1,400 professionals currently serve on more than 200 AWS technical committees, dedicated to the development of consensus standards under the rules of the American National Standards Institute (ANSI). Accredited by ANSI to publish American National Standards on welding, AWS administrates the USA technical advisory groups to ISO/TC44 (Welding and Allied Processes) and most of the ISO/TC44 subcommittees, as well as, being the Authorized National Body (ANB) to the International Institute of Welding (IIW).

FCAW. The standard AWS letter designation for flux-cored arc welding is FCAW.

GMAW. The standard AWS letter designation for gas metal arc welding is GMAW. The most common industry jargon for GMAW is MIG.

SMAW. The standard AWS letter designation for shielded metal arc welding is SMAW. This process is most commonly called "stick welding". This manual welding process is the least productive of the processes discussed in this report. It has a deposition rate that is less than half that of GMAW and FCAW depending on the welding parameters selected.

Constant Voltage. GMAW, FCAW, and submerged arc welding (SAW) power sources are constant-voltage (CV) machines. A CV power supply, "has means for adjusting the load voltage and has a static volt ampere curve that produces a relatively constant load voltage. The load current, at a given load voltage, is responsive to the rate at which a consumable electrode is fed

[12] AWS A3.0, *Standard Welding Terms and Definitions* (Miami: American Welding Society, 2001).

into the arc."[13] A CV power supply combined with a consumable electrode delivered at constant wire feed speed, creates a self-regulating system that tends to maintain a constant arc length. This is a mature technology called automatic voltage control (AVC) and is the foundation of automatic welding systems including the one developed for this project.

Discontinuity. An interruption of the typical structure of a material, such as, a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is an acceptable flaw according to the given welding code. A discontinuity is not technically a defect; whether a discontinuity is a defect is dictated by the given welding code (see Defect).

Defect. A discontinuity that by itself makes a weld unable to meet minimum quality acceptance criteria designated by the applicable welding code or a series of discontinuities, the accumulated effect of which makes a weld unable to meet minimum quality acceptance criteria as defined by the applicable welding code. A defect is a flaw that results in a rejected weld according to the given welding code. For example, a welding code states that any crack exceeding 0.125-in. (3.2-mm) in length found in a 12-in. (305-mm) length of a weld is a defect and is thereby unacceptable. Cracks less than 0.125-in. (3.2-mm) in length found in a 12-in. (305-mm) length of weld are therefore considered discontinuities and are acceptable according to the code.

Burn-through. A nonstandard term used to describe excessive melt-through or a hole in the pipe caused by a root pass. Burn-through is a term commonly used by the pipeline industry.

Welding Position. Welding position is the 3D orientation of the weld joint during the deposition of weld metal. Figure 3 is the official AWS diagram that defines the ranges for welding positions for a T-joint fillet weld which is used to attach full-encirclement sleeves and hot tap connections. Figure 4 is an illustration of flat, horizontal, vertical, and overhead fillet welding positions and their corresponding AWS designations.

Downhill Welding. This is the AWS preferred term for welding vertically downward; the nonstandard term for this progression is vertical down. It describes welding on a pipe from 12 to 6 o'clock.

Uphill Welding. This is the AWS preferred term for welding vertically upward; the nonstandard term for this progression is vertical up. It describes welding on a pipeline from 6 to 12 o'clock.

Welding In Position. Depositing welds in the flat or horizontal position is welding "in position". Welding in position tends to have the greatest productivity, depositing (on average) twice as

[13] National Electrical Manufacturers Association, *EW 1, Electric Arc Welding Power Sources* (Washington: National Electrical Manufacturers Association, 1988), 3.

much welding wire as welding out-of-position per unit time for the same welding process. When welding in position, higher currents and voltages can be used; therefore, you can deposit the maximum amount of weld metal per unit time.

Welding Out-of-Position. Depositing welds in the vertical or overhead position is welding "out-of-position." Welding out-of-position is less productive, as 60% less weld metal is typically deposited per unit time as compared to welding in position for the same welding process. When welding out-of-position lower currents and voltages must be used to keep the molten weld pool in the joint; therefore you cannot deposit the maximum amount of weld metal per unit time.

Adaptive Welding. Adaptive welding makes use of some form of feedback sensor to measure and then adjust the process during welding. A typical feedback system is based on through-arc sensing and a laser-based vision sensor. For weld deposition repair applications, the sensor is able to scan the pipe area ahead of the welding torch and triangulation is used to assess the position of the pipe surface below the sensor. By comparing this with the predicted position of a pipe of the original wall thickness, the depth of metal loss can be determined. By controlling the welding parameters, the depth of the weld bead can be varied automatically to deposit the required weld metal thickness. Additionally, the laser sensor can determine the edge of the previously deposited weld bead, allowing for accurate overlap of weld beads. Laser sensing methods are being increasingly implemented to provide adaptive control of welding processes by detecting the weld bead position (and centerline), measuring contact-to-work distance, and calculating weld volume. Adaptive welding procedures can improve process robustness by increasing accuracy and modifying parameters in real-time to account for variations in weld preparation, etc.

TABULATION OF POSITIONS OF FILLET WELDS

POSITION	DIAGRAM REFERENCE	INCLINATION OF AXIS	ROTATION OF FACE
FLAT	A	0° TO 15°	150° TO 210°
HORIZONTAL	B	0° TO 15°	125° TO 150° 210° TO 235°
OVERHEAD	C	0° TO 80°	0° TO 125° 235° TO 360°
VERTICAL	D E	15° TO 80° 80° TO 90°	125° TO 235° 0° TO 360°

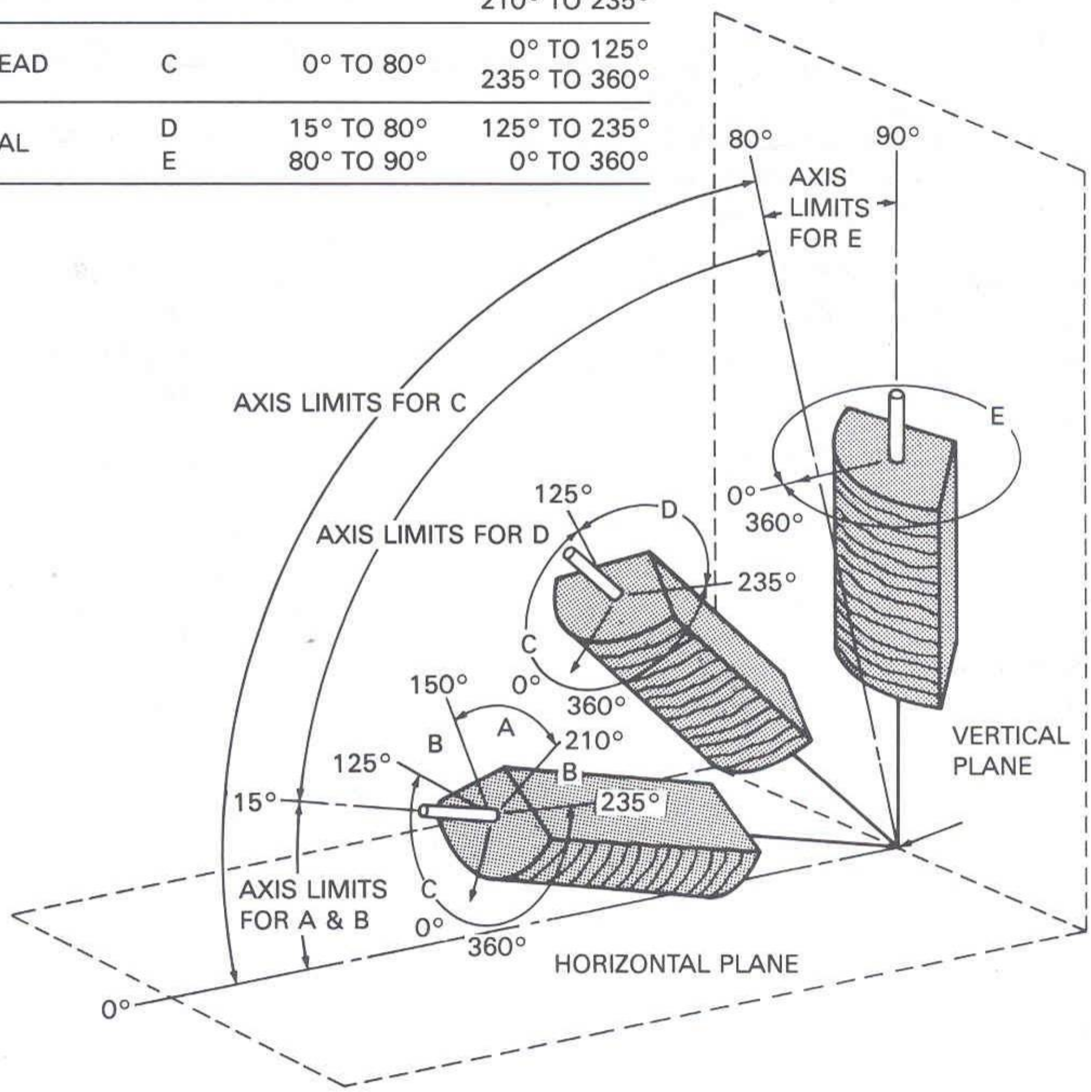
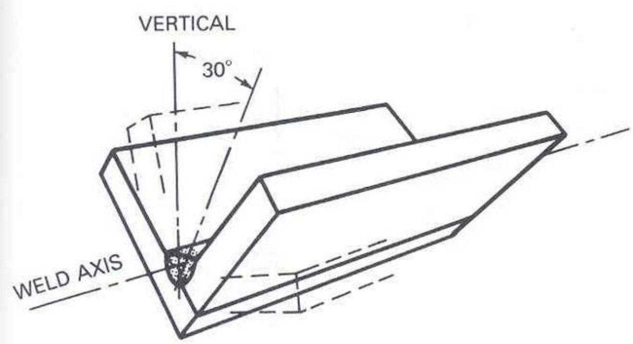
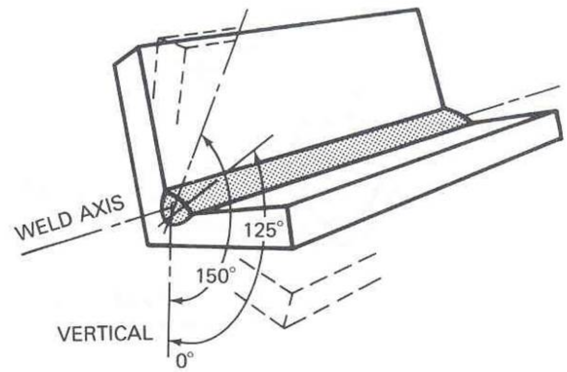


Figure 3. Diagram of Fillet Welding Position Ranges on Plate[14]

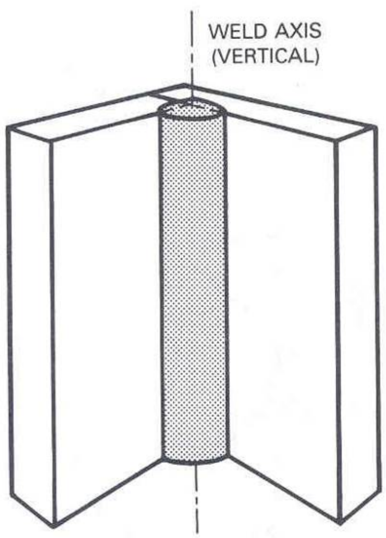
[14] American Welding Society (AWS), *Welding Handbook, 8th Edition, Volume 1, Welding Technology* (Miami: American Welding Society, 1987), 447.



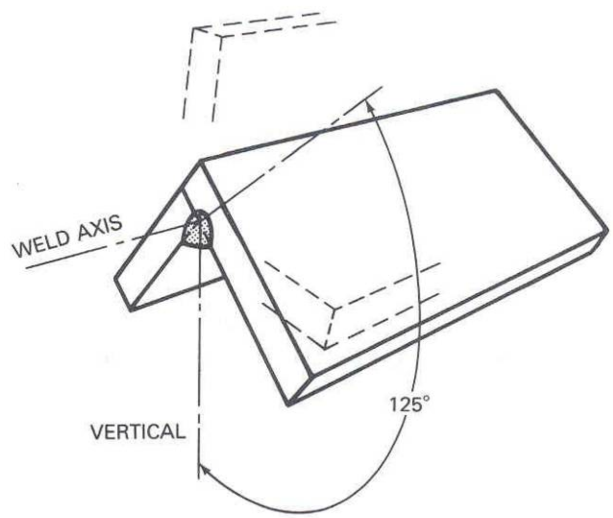
Flat Position (1F)



Horizontal Position (2F)



Vertical Position (3F)



Overhead Position (4F)

Figure 4. Fillet Welding Positions and their Designations[15]

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[15] American Welding Society (AWS), *Welding Handbook, 8th Edition, Volume 1, Welding Technology* (Miami: American Welding Society, 1987), 581.

Weave. A welding technique where the welder (or the automatic welding system) moves the arc in a repetitive pattern as weld metal is deposited in the joint. Weaving is standard practice in out-of-position welding in order to counter the effects of gravity and keep weld metal in the joint as it solidifies. A typical uphill weave pattern is illustrated in Figure 5.

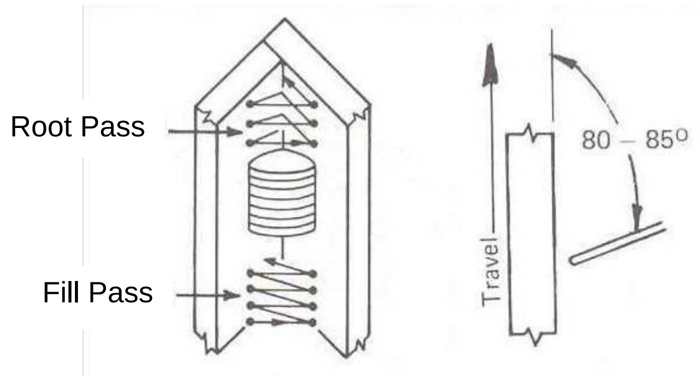

Figure 5. Typical Weave Pattern for Vertical-Up Welding[16]

Stringer Bead. A weld bead made with weaving.

Root Pass. The first weld placed in a weld joint; this pass produces the root bead.

Fill Pass. This is a nonstandard term for an intermediate weld pass that produces an intermediate weld bead. These passes are usually numbered in a weld procedure sequence drawing so the welder knows where to place subsequent weld beads over the root bead.

Buttering. A welding operation that deposits metal on one (or more surfaces) to provide a surface for subsequent weld beads. The first layer of a temper bead deposition welding procedure is commonly referred to as the buttering layer.

Heat-Affected Zone (HAZ). "The portion of base metal whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering or thermal cutting."[12]

[16] The James F. Lincoln Arc Welding Foundation, *Principles of Industrial Welding* (Cleveland: The James F. Lincoln Arc Welding Foundation, 1978), 12-28.

Work Angle. The work angle refers to the angle of the torch in relationship to the perpendicular faces of the tee joint shown in Figure 6. The ideal angle is typically 45°.

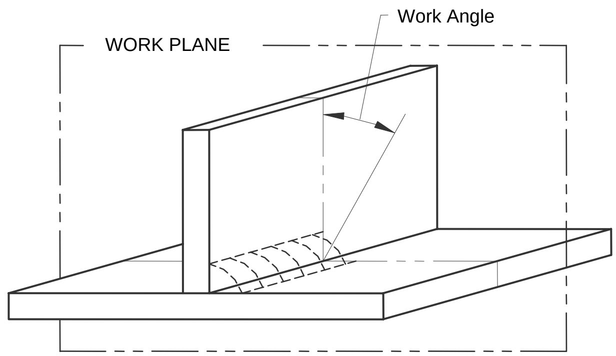

Figure 6. Work Angle

Travel Angle. The travel angle refers to the angle of the tip in relationship to the travel direction (Figure 7). The ideal is to have the tip perpendicular to the travel direction, which is 90°. In manual welding a push or drag angle can be used within the travel angle range of 70° to 110°.

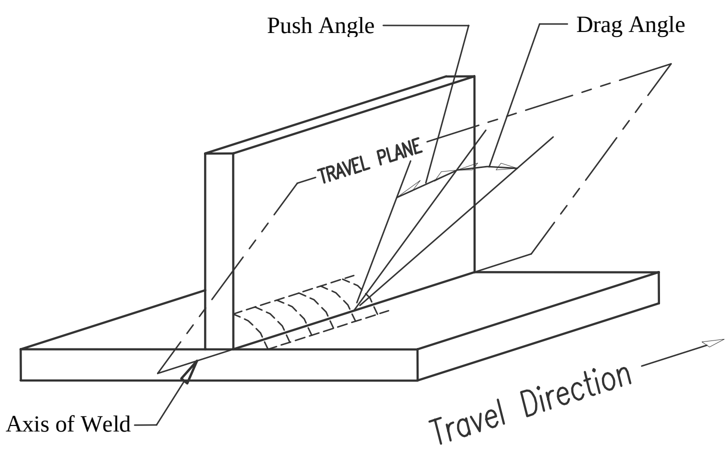

Figure 7. Travel Angle

Deposition Rate. The amount of weld metal deposited in the joint per unit time (typically measured in pounds per hour). Figure 8 contains a summary of deposition rates for several arc welding processes based on 100% duty cycle (without considering the effects of out-of-position welding or automation).

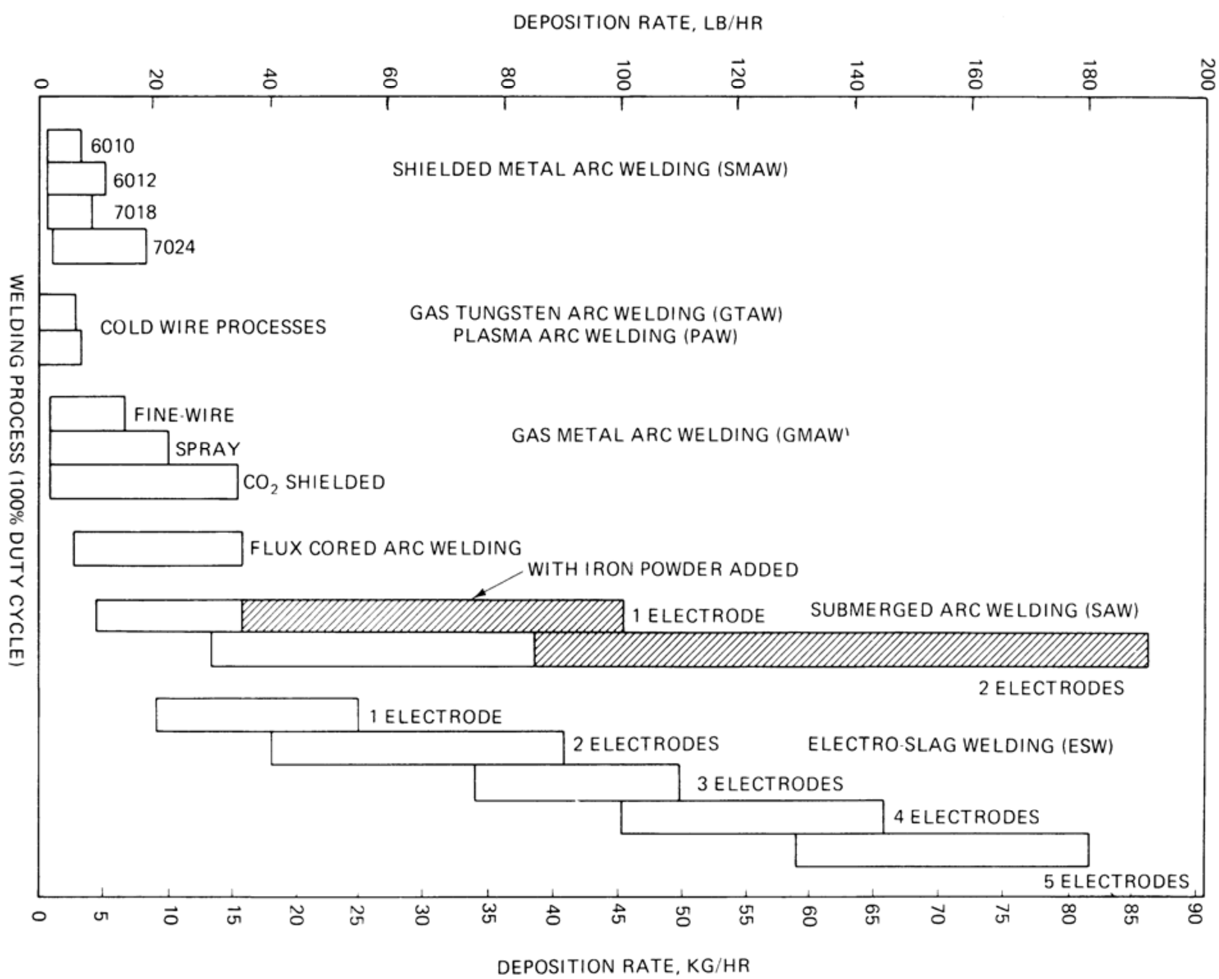

Figure 8. Deposition Rate by Welding Process[17]

Figure 9 contains typical deposition rates for various GMAW filler metal diameters with the appropriate welding positions and amperage ranges. Current levels appropriate for use in semi-automatic and automatic processes are also noted in this figure.

[17] Howard B. Cary, *Modern Welding Technology* (Englewood Cliffs: Prentice-Hall 1979), 194.

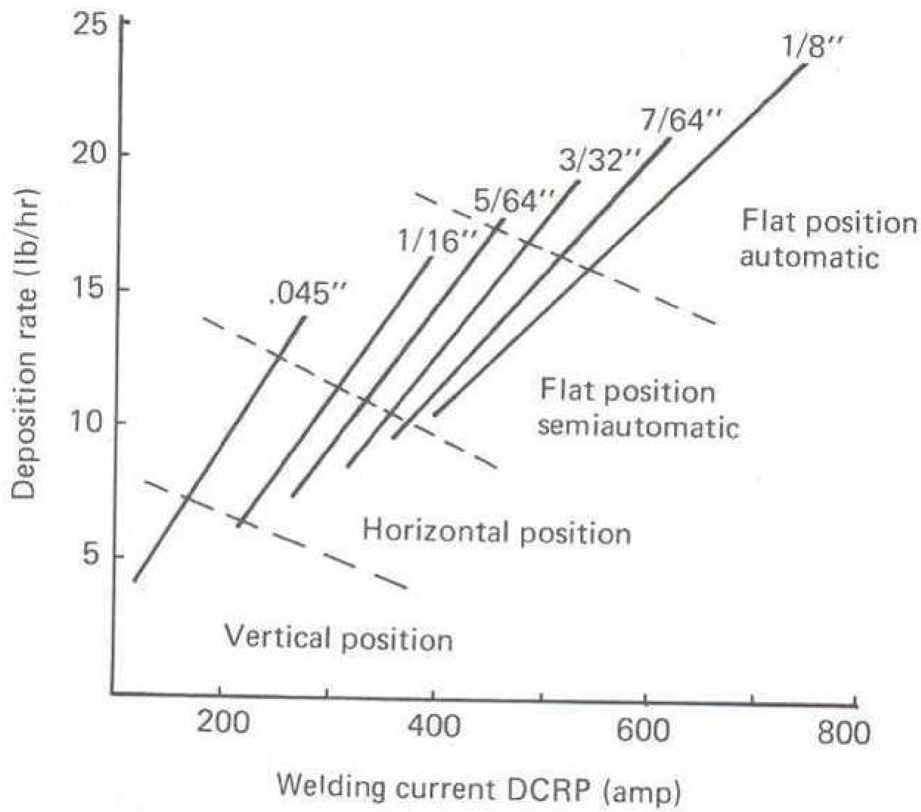

Figure 9. GMAW Deposition Rates for Various Positions and Electrode Diameters[18]

1.3.1 Industry Needs, Requirements, and Current Practices

During the accomplishment of Task 1, the project team reviewed current practices and industry requirements for in-service welding of pipelines. This report section summarizes that review.

There are often significant economic incentives to repair a damaged pipeline without removing the pipeline from service. These incentives include the ability to maintain operation during the repair and the ability to avoid the cost of evacuating and retaining the pipeline contents or, for natural gas, venting the contents of the pipeline. Since methane is a so-called “greenhouse gas”, there are also environmental incentives for avoiding the venting of large quantities of gas into the atmosphere.

The most frequent cause for repair of pipelines was identified as external, corrosion-caused loss of wall thickness. The most commonly used in-service repair method of such defects is welding

[18] The James F. Lincoln Arc Welding Foundation, *Principles of Industrial Welding* (Cleveland: The James F. Lincoln Arc Welding Foundation, 1978), 13-3.

a full-encirclement reinforcing steel sleeve over the area. Pipeline repair weld deposition repair is an attractive alternative to the installation of full-encirclement sleeves for repair of wall loss defects for in-service applications.[19] This is especially true for wall loss in bend sections and fittings, where the installation of full-encirclement sleeves is impossible. Weld deposition repair is a proven technology that can be applied directly to the area of wall loss or to the side opposite to the wall loss, e.g., external repair of internal wall loss (Figure 10). Weld deposition repair is attractive because it is direct, relatively quick, inexpensive to apply, does not create additional corrosion concerns, and requires no additional materials beyond welding consumables.

Several issues will be discussed in the following sections, which will need to be taken into consideration prior to in-service welding as they apply to weld deposition repair. The concerns for in-service welding a steel repair sleeve and making a weld deposition repair are similar, but there are some additional limits for weld deposition repair. The issues include in-service welding concerns, the integrity of the weld deposition repair, the economics of performing a weld deposition repair and the limitations of such a repair.

Figure 10. External Weld Deposition Repair of Internal Wall Loss in 90º Elbow

[19] Bruce, W. A., Swatzel, J. F., and Dorling, D. V., Repair of Pipeline Defects using Weld Deposition. 3rd International Pipeline Technology Conference. Brugge, Belgium. 2000.

1.3.1.0 In-Service Welding Concerns

As stated previously, there are two primary concerns with welding onto in service pipelines and piping systems. The first concern is for maintenance crew safety during repair welding, since there is a risk of the welding arc causing the pipe wall to be penetrated allowing the contents to escape. The second concern is for the integrity of the pipeline system after repair welding. Since welds made in-service typically cool at an accelerated rate as the result of the flowing contents' ability to remove heat from the pipe wall. These welds are therefore likely to have hard HAZ microstructures and tend to be susceptible to hydrogen cracking. These two primary concerns (as they relate to weld deposition repair) are briefly discussed in the next two report sections.

1.3.1.1 Burn-Through

A burn-through will occur when welding onto a pressurized pipe if the unmelted area beneath the weld pool has insufficient strength to contain the pressure within the pipe. Previous work concluded that a burn-through will not occur if the inside surface temperature beneath the welding arc is less than 1,800ºF (982ºC) when welding with low-hydrogen electrodes and that this temperature is unlikely to be reached if the wall thickness is 0.250-in. (6.4-mm) or greater, provided that normal welding practices are used.[8,20,21,22,23] The risk of burn-through will increase as the pipe wall thickness decreases and the weld penetration increases.

For weld deposition repair, the remaining ligament (i.e*.,* the effective wall thickness) tends to be thin. Previous work[5,6] has shown that welds can be made without burn-through on wall thickness as thin as 0.109 in. (2.8 mm) provided that current level is restricted and heat input limits are observed. Using a 0.062-in. (1.6-mm) diameter electrode is appropriate for this application, as they operate at current levels as low as 40 amps. 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 or, for a given heat input, as the welding current increases.

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[20] D. G. Howden, "Welding on Pressurized Pipeline," Loss Prevention, Vol. 9 (New York, NY: American Institute of Chemical Engineers), pp. 8-10.

[21] J. B. Wade, "Hot Tapping of Pipelines," Australian Welding Research Association Symposium, paper no. 14 (Melbourne, Australia, 1973).

[22] B. A. Cassie, "The Welding of Hot Tap Connections to High Pressure Gas Pipelines," J. W. Jones Memorial Lecture (Pipe Line Industries Guild, October 1974).

[23] J. F. Kiefner and R. D. Fischer, "Repair and Hot Tap Welding on Pressurized Pipelines," Symposium during 11th Annual Energy Sources Technology Conference and Exhibition, New Orleans, LA, January 10-13, 1988 (New York, NY: American Society of Mechanical Engineers, PD-Vol. 14., 1987) pp. 1-10.

1.3.1.2 Hydrogen Cracking

Fast cooling rates experienced when welding onto in-service pipelines are a result of the presence of the pressurized, flowing contents, which tend to quickly remove heat from the pipe wall. These fast weld cooling rates combined with the carbon equivalent (CE) of the pipeline (which tends to be higher for older pipelines) results in the development of hard, crack-susceptible weld microstructures. The development of a hard microstructure makes repair welds on in-service pipelines particularly susceptible to hydrogen cracking. As mentioned in the Introduction, for hydrogen cracking to occur, three primary independent conditions must be satisfied simultaneously:

- Hydrogen in the weld.
- A crack-susceptible weld microstructure.
- Tensile stress acting on the weld.

To prevent hydrogen cracking, at least one of these three conditions must be eliminated. Due to the nature of weld metal solidification, tensile stresses will always be present and must be assumed. As a result, the first step taken towards avoiding hydrogen cracking of in-service welds is to minimize the hydrogen level by using low-hydrogen electrodes or a low-hydrogen welding process. Since low hydrogen levels cannot always be guaranteed, procedures that minimize the formation of crack-susceptible microstructures are also used. The most commonly-used options for preventing hydrogen cracking of in-service welds are: the specification of a minimum-required heat input level and/or the use of a temper-bead deposition sequence or temper bead procedure. Weld deposition repair entails the use of a temper bead procedure because wall loss that necessitates a repair normally requires several weld layers to replace the wall loss.

1.3.1.3 Integrity of Weld Deposition Repair

The initial applications of weld deposition repair were repairing external corrosion on straight lengths of pipe. A typical weld deposition sequence is illustrated in Figure 11. As demonstrated in prior research,[3,4,24,25,26] repairs made by weld deposition are resistant to pressure cycles typical of a natural gas transmission pipeline and have the ability to restore the strength of the

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[24] Phelps, B., Cassie, B. A., and Evans, N. H. Welding Onto Live Natural Gas Pipelines. *British Welding Journal,* 8(8), p. 350. 1976.

[25] Kiefner, J. F., and Duffy, A. R. A Study of Two Methods for Repairing Defects in Line Pipe. A.G.A. Pipeline Research Committee, Catalog No. L22275. Battelle Columbus Laboratories. October 1974.

[26] Kiefner, J. F., Whitacre, G. R., and Eiber, R. J. Further Studies of Two Methods for Repairing Defects in Line Pipe. A.G.A. Pipeline Research Committee, NG-18 Report No. 112. Battelle Columbus Laboratories. March 1978.

pipe. The results also show, for a typical natural gas transmission pipeline, the presence of un-repaired general corrosion (as a result of a partial repair) would pass the RSTRENG® software[27] criteria (i.e., partial repair) and have no effect on either the resistance to pressure cycles or the ability to restore the strength of the pipeline. Partial repairs are not appropriate for high-cycle applications, such as some liquid petroleum pipelines.

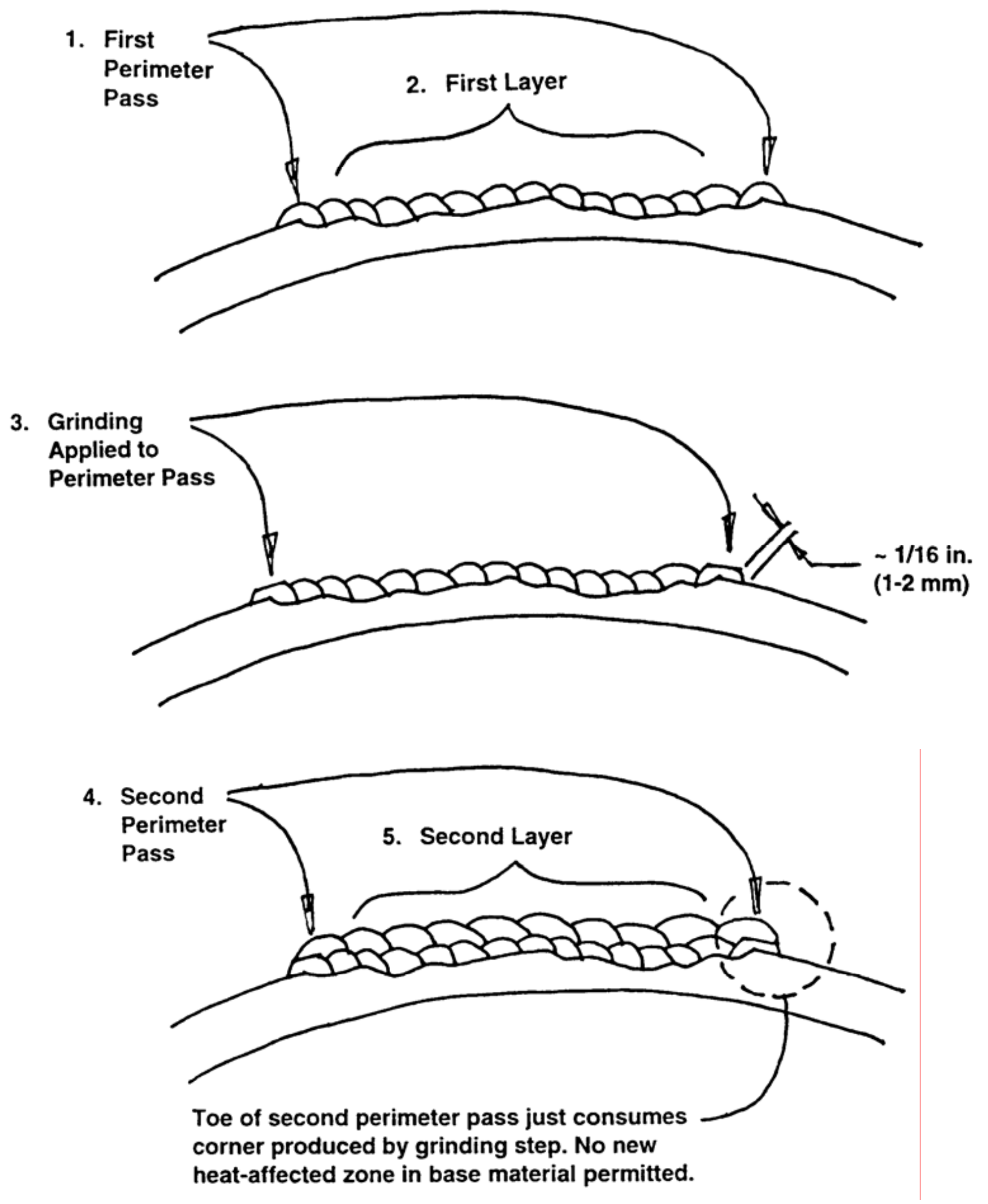

Figure 11. Illustration of Typical Weld Deposition Sequence

[27] Kiefner, J. F. and Vieth, P. H., "A Modified Criterion for Evaluating the Remaining Strength of Corroded Pipe" Final Report to A.G.A. Pipeline Corrosion Supervisory Committee, Project PR-3-805, Battelle, Columbus, OH, December 1989.

Weld deposition repair has also been applied to a pipe OD to repair internal wall loss.[28,29] This method is particularly useful for tees and elbows, which are particularly susceptible to internal wall loss and are difficult, or impossible, to repair using a full-encirclement sleeve or other repair method. The repair of internal wall loss involves applying the general weld deposition technique (e.g., a perimeter weld followed by consecutive parallel fill passes) to an area at least one wall thickness larger, in all directions, than the area of wall loss as mapped out using an ultrasonic thickness gauge. This is followed by a second perimeter pass and a second layer. This process is repeated until all areas are restored to at least the nominal thickness with one wall thickness overlap. Figure 12 is an illustration of a weld deposition sequence for external repair of internal wall loss.

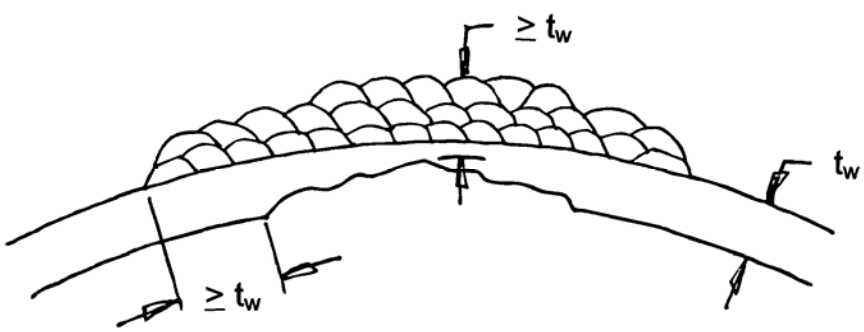

Figure 12. Weld Deposition Technique for External Repair of Internal Wall Loss

1.3.1.4 Economic Considerations

To date, there is not much data available on typical sizes of corrosion encountered in the field that weld deposition is used to repair. Weld deposition repair has been used in an experimental setting to verify the ability of the repair to restore pipe wall loss. Experimental repairs have been performed on external corrosion[8,30] from lines taken out-of-service, as well as on machined defects that simulate wall loss.[4,8,26,28,29,30,31,32,33] As stated previously, weld deposition repairs have been experimentally performed on internal wall loss of tees and elbow.[4,28,29,30] Table 1 gives a summary of the dimensions of wall loss that have been repaired experimentally using weld deposition repair. The maximum longitudinal length repaired was 13.88 in. (352.6 mm), the maximum circumferential length repaired was 3 in. (76.2 mm) and the maximum depth repaired was 75% of the nominal wall thickness.

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28 Bruce, W. A., and Wang, Y.-Y. Stress Analysis of External Weld Deposition Repair for Internal Wall Loss. EWI Project No. 07723CAP, PRC *I*nternational, Contract No. PR-185-9633. November 17, 1995.

29 Bruce, W. A., External Weld Deposition Repair for Internal Wall Loss in Tees and Elbows. EWI Project No. 45490CAP, PRC *I*nternational, Contract No. GRI-9506. August 26, 2004.

30 Morel, R.D., "Welded Repairs on API 5LX52 Pipe", 13th Annual Petroleum Mechanical Engineering Conference, ASME 1958.

31 Ferguson, T.A., "Progress Report on Welded Repairs to API 5LX52 Pipe", Paper Number 59-DET-34, Petroleum Mechanical Engineering Conference, ASME 1959.

32 Christian, J.R. and Cassie, B.A., "Analysis of a Live Welded Repair on an Artificial Defect", British Gas, Report No. ERS R113, October 1974.

Table 1. Dimensions of Wall Loss Experimentally Repaired with Weld Deposition Repair

Reference	Defect	Max. Length (in.)	Max. Depth (in.)	Max. Width (in.)	Profile Area (in^2)	Defect Location	Defect
4	1		0.375			External	Wall Loss Due to Mechanical Means
	2		0.375				
	3		0.344				
	4		0.344			Internal	
	5		0.187				
	6		0.187			External	
	7		0.156				
	8		0.156				
8	1	10.00	0.200		1.203	External	Wall Loss due to Corrosion
	2	10.50	0.180		1.230		
	3	6.00	0.190		0.959		
	4	5.50	0.260		0.733		
	5	8.00	0.230		1.215		
	6	4.50	0.200		0.365		
	7	3.50	0.170		0.451		
	8	2.50	0.120		0.157		
	9	2.25	0.230		0.285		
	10	4.75	0.120		0.400		
	11	2.75	0.130		0.281		
	12	7.25	0.140		0.554		
	13	7.00	0.100		0.368		
	14	7.25	0.80		0.350		
	15	7.00	0.200		0.267		
	16	2.00	0.200		0.267		
	A	13.88	0.180	1.18			Wall Loss Due to Mechanical Means
	B	5.25	0.230	1.25			
	C	3.00	0.290	2.00			
21	1	6.00	45% Wall	1.00		External	Wall Loss Due to Mechanical Means
	2		75% Wall				
	3		45% Wall				
	4		75% Wall				
	5		45% Wall				
	6		75% Wall				
	7		45% Wall				
	8		75% Wall				
23	Pipe	11.2	0.188	2.8		Internal	Wall Loss Due to Mechanical Means
	Elbow1		50% Wall				
	Tee1		50% Wall				
24	Elbow1	11	50% Wall	3		Internal	Wall Loss Due to Mechanical Means
	Elbow2						
	Elbow3						
	Elbow4						
	Tee1						
	Tee2						
25	1	9.00	0.135	0.375		Internal	Wall Loss due to Corrosion
	2					External	
	3	3.00		1.0		Internal	
	4					External	
	5	9.00	0.051	0.375			
	6						
	7	3.00	60% Wall	1.0		Both	
27	1	12	0.186	2		External	Wall Loss Due to Mechanical Means

It has been shown that weld deposition repair could be used to repair external or internal wall loss. Before weld deposition repair is implemented, a cost/benefit analysis should be performed. The analysis should determine the limit of total wall loss (both circumferentially and longitudinally) of all individual corroded areas in repair area that weld deposition repair would be used. The analysis should also consider alternative repair methods for tees and elbow sections. It is possible for external corrosion on a straight section of pipeline to be so extensive that encapsulating the pipeline with a full-encirclement sleeve would be preferred to performing several weld deposition repairs.

1.3.1.5 Limitations

To increase the safety of welding personnel, the minimum remaining thickness for which weld deposition repair should be attempted is 0.125 in. (3.2 mm). When the remaining thickness is thin, small diameter electrodes should be used in conjunction with a procedure that limits heat input to that which is appropriate for the remaining wall thickness. The use of weld deposition repair should be limited to corrosion caused metal loss and other non-dented defects that can be properly prepared for welding. The use of weld deposition repair for defects in or near electric resistance welding (ERW) seams and for crack-like defects should be prohibited. Partial repairs are not appropriate for high-cycle applications.

1.3.1.6 Regulatory Activities and Current Practices

The concept of repairing a pipeline by means of deposited weld metal is not new. Ample evidence exists that corrosion pits in old bare pipelines were often filled with weld metal via a practice called "puddle welding". In spite of early research that established the effectiveness of weld deposition repair,[3,4,25] the use of this technique has not become widespread. Weld deposition repair appears to have lost out in favor of the use of full-encirclement repair sleeves. British Gas appears to have begun reconsidering the use of weld deposition repair sometime prior to 1986.[33] Since then, both British Gas and Gasunie[34] have made use of weld deposition repair for isolated applications.

Until recently, weld deposition repair was prohibited in the U.S. for gas transmission pipelines that operate at or above 40% of SMYS. 49 CFR Part 192[35] had required that damage either be cut out as a cylinder, repaired using a welded full-encirclement split sleeve, or that the pressure be reduced to a safe level. A recently-adopted rulemaking by the U.S. Department of

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[33] Cassie, B. A., and Prosser, K. Weld Metal Deposition - A Repair Technique in Need of Exploitation. Welding and Performance of Pipelines, TWI. November 1986.

[34] Unknown. Repairs in Tricky Places - Looking Back on a Successful Experiment. Article from Gasuniek. September 1990.

[35] 49 CFR Part 192. U. S. Department of Transportation, "Pipeline Safety Regulations". October 1997.

Transportation, Office of Pipeline Safety (DOT OPS)[36] allows both gas and hazardous liquid pipeline operators to make repairs using other methods, provided that reliable engineering tests and analyses show that the method can permanently restore the serviceability of the pipe. This rulemaking is intended to allow not only weld deposition repair, but other repair methods as well (e.g., fiber-reinforced composite repairs).

Work is presently underway in the U.S. to update the requirements for weld deposition repair in ASME B31.8.[37] The proposed revisions allow small corroded areas to be repaired with weld deposition repair, provided that low-hydrogen electrodes are used. The actual size of the small corroded area is left up to interpretation. Repairs using deposited weld metal require a written maintenance procedure, an important factor of which is the selection of an appropriately qualified welding procedure and welder. In-service welding procedures and welders shall be qualified, with specific regard for avoiding both burn-through and hydrogen cracking. The maintenance procedure should be based on demonstrated methods that assure permanent restoration of the piping system's pressure integrity.

For in-service welding, the proposed revisions to ASME B31.8[37] indicate that procedures and welders for carrying out weld deposition repair should be qualified under Appendix B of API 1104 (19th Edition or later).[38] Appendix B is intended to provide a recommended practice for welding onto pipelines that contain crude petroleum, petroleum products, or fuel gases that may be pressurized and/or flowing. Procedures qualified under Appendix B for either branch or sleeve welds are suitable for weld deposition repair, provided the procedure is appropriate for the remaining wall thickness to which it is being applied.

ASME B31.8 allows repairs of other defects (i.e., other than corrosion, such as grooves and gouges) by grinding, provided that the defect is not dented. After grinding, if the ground area does not meet the remaining wall thickness requirement (i.e., enough wall thickness to meet either the ASME B31G or the RSTRENG® criterion), the proposed revisions allow the area to be repaired by filling it with deposited weld metal, provided that the area is small.

The API 1104 Appendix B subcommittee is currently revising Appendix B to address the procedure and welder qualification for weld deposition repair. The new API qualification procedures are similar to the requirements that are outlined in the Canadian standard Z662.[39]

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[36] Federal Register, Vol. 64, No. 239. Department of Transportation, Research and Special Programs Administration, Pipeline Safety: Gas and Hazardous Liquid Pipeline Repair, Rules and Regulations, 64 FR 69660, December 14, 1999.

[37] ASME B31.8. Gas Transmission Systems. American Society of Mechanical Engineers. 1995.

[38] API Standard 1104. Welding of Pipelines and Related Facilities. American Petroleum Institute. September 1999.

[39] Canadian Standards Association Z662-03. Oil and Gas Pipeline Systems, June 2003.

ASME has also formed a post construction committee to work on a post construction code for pipelines and piping systems. The next version of ASME PCC-2[40] will include an in-service welding article that will address weld deposition in a similar manner to that of the new version of API 1104 Appendix B.

1.3.1.7 Industry Experience

A large industry survey[41] was performed for the U.S. Department of Energy, National Energy Technology Laboratory (DOE NETL) to determine the repair methods that are most commonly used and the frequency of repairs. Four industry survey questions relative to weld deposition repair are summarized below and appear in bold type.

1. **Describe the corrective actions your company has taken due to degradation (corrosion, cracking, etc.) of transmission pipelines, especially repair or replacement actions.**

Figure 13 contains the responses received. One response summarized the companies perspective in the following fashion: cut-out and replace cylinder (seldom), full encirclement steel sleeves (most common), direct deposition of weld metal (seldom, but frequency may increase), grinding to remove gouges (common), and welding a plugged fitting like a Threadolet™ over the damage.

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[40] ASME PCC-2. Repair of Pressure Equipment and Piping. American Society of Mechanical Engineers, 2006.

[41] Harris, I.A., "Internal Repair of Gas Pipelines Survey of Operator Experience and Industry Needs Report." EWI Project No. 46211GTH, September 2003.

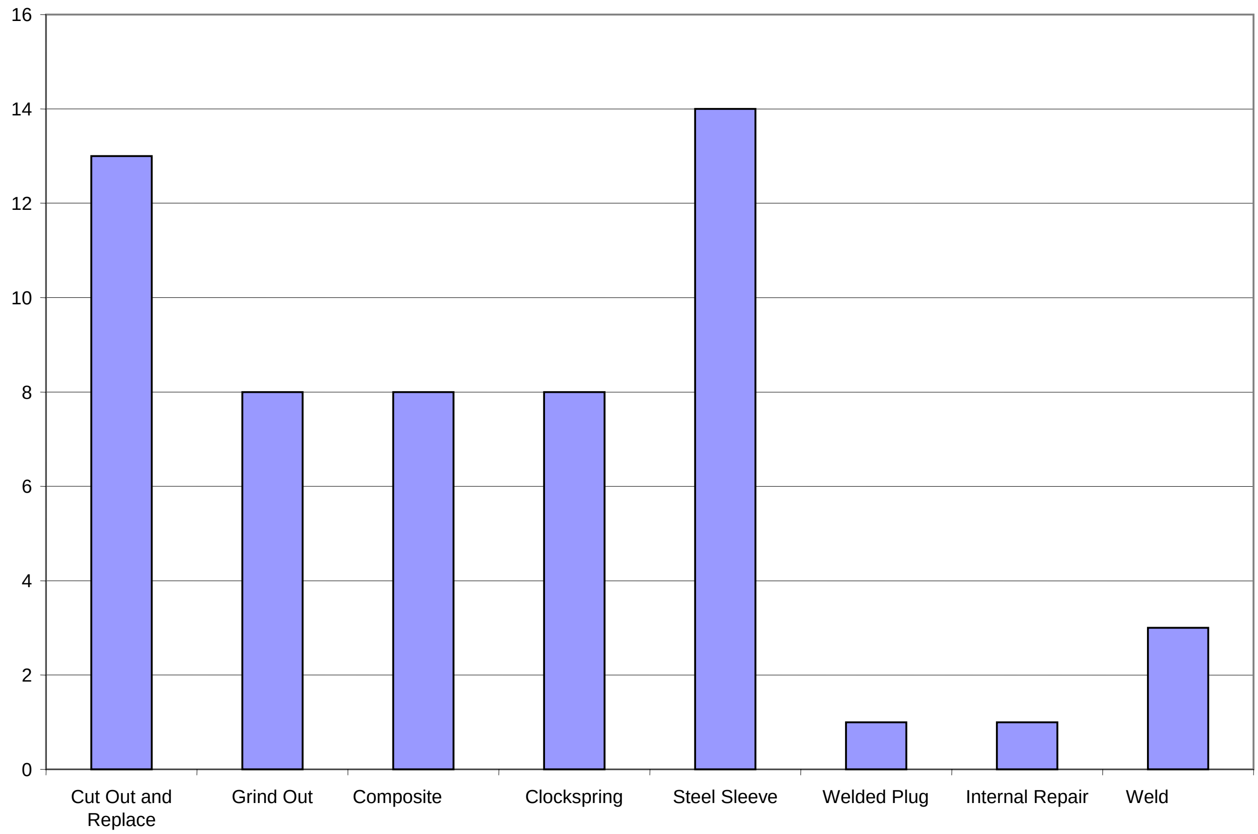

Figure 13. Currently Used Repair Methods

2. **Have you used methods other than external sleeve repairs or pipe replacement to repair different types of degradation?**

The responses to this question were split 50% "no" and 50% "yes." The "yes" responses typically gave examples, which are summarized as follows:

- Grinding is used to remove gouges (common), cracks, stress corrosion cracking, and sharp anomalies.
- Plugs are fitted and welded over the damage, e.g., a Threadolet™.
- Composite wraps are used.
- ClockSpring® is used.
- Direct deposition welding has been used to repair wall loss.
- “Encapsulating” a malfunctioning or defective area has been used.
- Taps have been used for small defects.
- Leak clamps have also been used.

Seven of the responses mentioned that grinding one type of defect or another and was the most common "other" type of repair. Three examples of different types of welding solutions were cited, of which only one involved direct deposition of weld metal on the OD of the pipe.

3. What criteria (including ease of pipe access) affect choice of the specific repair method to be used?

The compiled answers to this question are represented in Figure 14 and show twelve responses, of which cost and the availability of the repair method were those most frequently cited. The next important consideration is the position of the defect, and whether the line had to be out-of-service as the next most frequently mentioned criteria.

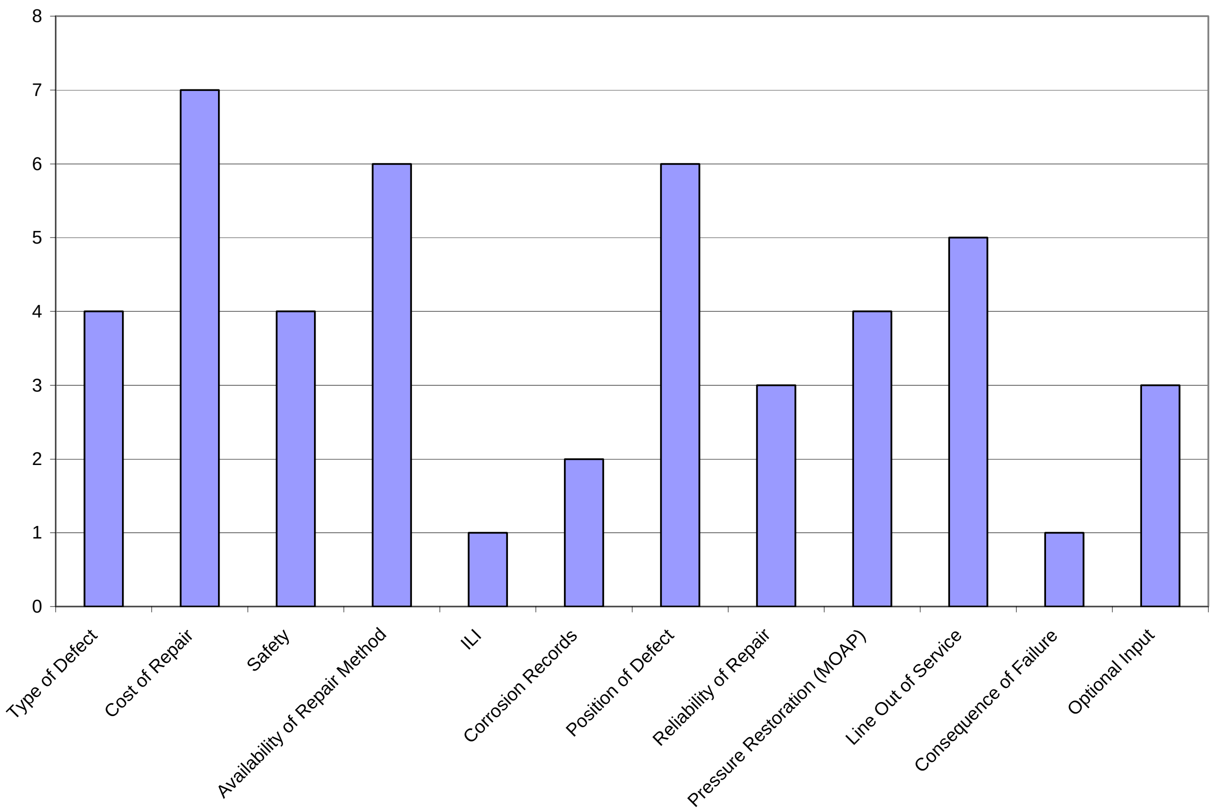

Figure 14. Criteria Affecting Choice of Repair Method

4. Comments pertaining to currently used repair methods.

Cut-out repair is considered the last resort due to flow disruption and overall cost. External faults are more readily repaired using sleeves than internal anomalies. Internal damage requiring repair in bends equate to a pipe replacement. The threshold for pipe replacement vs. repair decreases once the first replacement in a section is justified.

Live repair methods require a reduction in operating pressure. Normally the excavation trench requires tight sheeting and shoring, a certified welder, and qualified maintenance welding procedure with low hydrogen procedures (e.g., E7018 low hydrogen electrodes).

1.3.1.8 Survey Conclusions

Full-encirclement sleeve repairs are the most commonly used in-service repair process for corrosion. Weld deposition repair is also a viable repair for wall loss due to external and/or internal corrosion and this process is a more cost effective repair compared to full-encirclement sleeve repair. Any automatic welding system designed to mechanize repair welding operations should be capable of welding reinforcement sleeves (Type A), pressure-containing sleeves (Type B), and weld deposition repair.

1.3.2 Technical Specifications for the Automated In-Service Welding System

During the accomplishment of Task 2, the project team defined the functional requirements of an automated in-service welding system. This included dimensional requirements for pipe diameter, branch diameter, length of sleeve, etc., as well as operating requirements such as bead placement, and quality requirements such as process monitoring and adaptive control.

The following technical specifications were developed by EWI, TransCanada, PRCI, and Cranfield University. Primarily based on information from cost share partner TransCanada, the original system and the EWI improved system were both designed for use on a 36-in. pipeline. When the field trial logistics were finalized three months before the end of the program, the welding system had to be modified to accommodate a 30-in. diameter pipeline, which required a redesign of the EWI improved system. The following technical specifications are for the final EWI system design (i.e., the system that was field tested).

1. **Performance Requirements**

    a. Pipe Material and Sizes

        i. Material: Any material that can be welded by GMAW and/or FCAW, such as carbon steel currently found in existing pipelines and in new installations (e.g., Grade B through X120), stainless steels, duplex stainless steels and alloy steels (e.g., Cr-Mo).

        ii. Pipe diameter range: 20 in. (508 mm) to 44 in. (1,118 mm) inclusive. The diameter is limited only by the range of available working diameter tracks sizes made by commercialization partner Bug-O Systems. If smaller or larger diameter tracks are available, then the applicable diameter range would increase.

        iii. Pipe wall thicknesses: Any. The wall thickness will affect the diameter of the electrode used, which may require requalification of the welding procedure.

        iv. Sleeve thicknesses: Any.

    b. Welding Capabilities

        i. Welding processes: FCAW and GMAW including any alternative version of GMAW (e.g., STT).

        ii. Joint type on sleeve: fillet weld, longitudinal or circumferential; groove weld longitudinal

            1. For longitudinal seams located at 3 and 9 o'clock positions

                a. For a reinforcement sleeve (Type A): make a fillet weld in the horizontal position at 3 and 9 o'clock (see Appendix A for TransCanada standard drawing - marked as field weld).

                b. For a pressure-containing sleeve (Type B): make a 60° included angle V-groove weld in the horizontal position at 3 and 9 o'clock (see Appendix B for TransCanada standard drawing - marked as field weld).

                c. Potentially weld up to 4 longitudinal seams if using strap/bridge.

            2. For a pressure-containing sleeve (Appendix B): about the pipeline axis, make two circumferential fillet welds between the sleeve and the pipe completing the first circumferential fillet weld before starting the second. (Longitudinal seams are welded before the circumferential welds.)

iii. Weld deposition/corrosion patch build-up: multi-bead, multi-layer welding passes for building up corroded area on pipe

1. Welding can be made in the longitudinal or circumferential direction for building up patch (RSTRENG® calculation requirement). Circumferential is preferred whenever applicable.

2. Oscillation can be made in the longitudinal or circumferential direction.

3. Each corrosion area is treated as a separate fill sequence.

c. Evaluation Process for Corrosion Patch

i. Corrosion patch on pipe will have already been identified and pipe section excavated (if applicable).

ii. Scan square area of pipe, acquire and analyze the image from the laser.

iii. Determine welding method and sequence for filling corrosion patch either by software and/or by operator teach points.

iv. Corrosion patch will be encircled with a 2-pass bounding weld to assure that the weld toes are sufficiently tempered and to give the fill passes a location for starting and stopping, which will be less susceptible to cracking. The welding parameters can be changed between overlapping layers.

v. Weld area pass by pass.

vi. Grind/gouge if applicable between passes.

vii. Save data record and all inspection results for future reference.

2. Operational Requirements

a. Portability/Physical Parameters:

i. Physical parameters of the system include a weight of no more than ½ ton or the ability to be transported in, or operated from, a commercial pickup truck.

ii. Physical dimensions such that would easily fit within an excavated trench.

iii. Rugged for in-field application.

iv. Industrial cabinet for protecting control equipment.

b. Clamping System

i. System to be easily clamped on pipe using a device or component that will insure the system will remain stationary during inspection and welding.

ii. System must accommodate pipe out-of-roundness, inclined or declined pipe axes, and 2° out-of-plane pipe bends.

c. Main Components

i. System to accommodate two main components: **Welding System** and the **Laser Scanning System**. The final design will combine both systems into a single tool. The intent is to reduce the number of physical components required and to reduce operator error.

d. Alignment Requirements

i. The system shall provide proper alignment of the laser sensor and the welding torch on the pipe. The alignment must be such that the user can easily and correctly position and reposition the system as needed.

e. Welding System

i. A single welding power supply will be an off-the-shelf system from a known manufacturer.

ii. 480 volt power required for the power supply.

iii. Operator responsible for powering up the power supply and associated welding components. Welding start/stop will be independent from the mechanized system; both functions will be controllable via one GUI.

iv. System must be able to weld in all welding positions.

v. System must be able to oscillate in horizontal and vertical positions.

vi. Torch must have travel angle adjustment.

vii. Torch must have work angle adjustment.

f. Laser Scanning System

i. Sensor Requirements

1. The sensor type will be a laser sensor of CLASS 3B or lower.

2. Size of laser scan should be adequate to accommodate specified range of pipe diameters.

3. Sensor resolution will be sufficient to detect corrosion patches in specified pipe wall thickness.

4. Ease of calibration - the Laser Scanning System will include a sensor calibration routine that can be executed by the operator at will.

g. System Software Requirements

   i. Image recognition capabilities – the software must be able to detect edges of corrosion patches and previous weld passes (if applicable).

   ii. System must have and execute a homing routine upon startup. This will ensure a common zero point for a coordinate system when generating the topographical map.

   iii. Software must be able to “patch together” laser scans in order to make a larger topographical corrosion map.

   iv. Welding routine – the software must include an algorithm to either accept operator teach points and/or generate a welding sequence for multiple, independent corrosion patch areas.

h. System Hardware Requirements

   i. A personal computer (PC) will be used to run the C-based executable program.

   ii. A GUI on the computer screen will be used to accept operator input.

1.3.3 Design of the Automated In-Service Welding System

This report section describes the evolution of the automated welding system design and begins with the original system design concept, moves on to the improved EWI system design, and concludes with the system modifications necessary to accommodate the pipeline available during the TransCanada field trial.

The original objective of Task 3 was to design and build a mechanized welding system using either FCAW or GMAW. The system design was to be based on a concept design previously developed by Cranfield University using the band and carriage principle with additional axes carrying the welding torch. The system was to be developed from the concept stage to a fully functional production prototype. Cranfield University and EWI have previously collaborated on mechanized welding of in-service pipelines and the same processes and consumables were to be used. The system was to allow the welding of circumferential fillets and longitudinal seams on encirclement sleeves on all diameters of pipe, as well as weld deposition build up for repair and buttering operations. The system was to be portable and have a low height to minimize the requirements for excavation around buried pipelines. The final design was to incorporate the requirements identified in Tasks 1 and 2.

As shown in Figure 15, the Task 4 laboratory development and evaluation was conducted concurrently with Task 3 design and build. The system was put together subsystem by subsystem and as the laboratory evaluation of each subsystem was carried out, issues were discovered which required design changes and programming improvements.

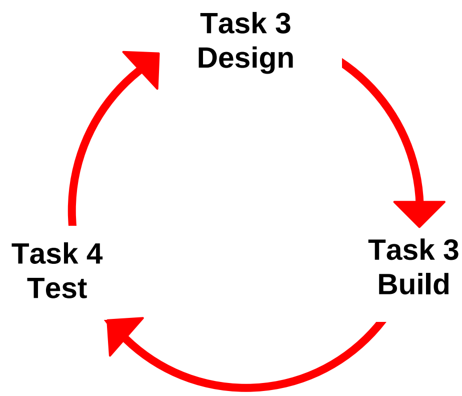

Figure 15. Concurrent Approach to Task 3 and Task 4 Execution

Task 3 and 4 activities ensured that the system can follow a precise preprogrammed path so that weld metal build up can be performed on the pipe surface using an appropriate deposition sequence and overlay of weld beads. This was achieved by interfacing the laser sensor and control software.

The success of the welding system is dependant on the capabilities of the control logic and the response of the welding equipment components and welding power supply to the control commands. The set of rules used to interpret the data from the sensor systems and to apply the adaptive welding algorithms is the heart of the system and is the primary intellectual property developed by this project. Software was developed to apply the rule set and implement the adaptive control.

1.3.3.0 Original System Design Concept

The original proposal called for Cranfield University to develop the system hardware design and for EWI to develop the control system and software, based on previous and concurrent collaborations between EWI and Cranfield (which were funded by PRCI). The system design concept was to be developed by Mr. Stephen Blackman while he was Director of the Welding Engineering Research Centre at Cranfield University (which is now known as the Welding Engineering and Metal Centre).

Shortly after the original design concept was developed (hereinafter referred to as the Blackman design), Mr. Blackman resigned from Cranfield to start his own company named SABREweld. Consequently, EWI's subcontract with Cranfield was terminated and the subcontracts to complete the design and build of the system were offered to SABREweld.

This report subsection contains the only narrative ever received that describes the Blackman design and concludes with a summary of the team decision to abandon this design concept.

The system was designed to operate and position the welding torch around a pipe of 36-in. (914-mm) nominal diameter.

- 33.64-in. (854.4-mm) diameter minimum.
- 37.64-in. (954.4-mm) diameter maximum.
- 39.4-in. (1,000-mm) linear welding length.
- Deviation from the projected parallel diameter can be accommodated with the proposed Z-axis motorised actuator with position control. It is proposed that the depth of penetration of the welding nozzle beyond the surface of the theoretical nominal tube diameter should be 0.59-in. (15-mm).
- The system is intended to accommodate pipe diameter deviation and ovality.

<u>Curved Pipe Operation</u>

- PIPE BENDS will require the available window to accommodate the curvature. On a 2° Pipe Bend the deviation at the crest position mid span of 3.3 ft. (1 m), is approximately 0.59-in. (15-mm) positive on the top and 0.59-in. (15-mm) negative at the base
- Figure 16 shows progression on a true curve. In reality however, the pipe curvature may be irregular.
- At this stage the system will have an allowance of +/- 0.39-in. (10-mm) of movement within the scope of adjustment to traverse the specified bend.

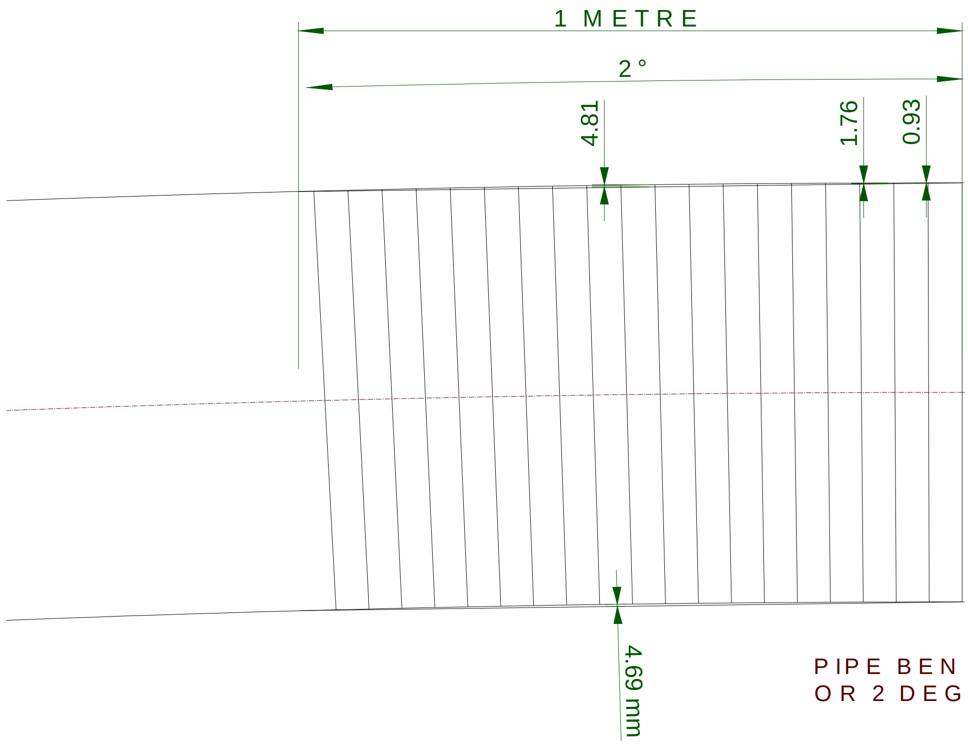

Figure 16. Pipe Curve Progression on a True 2° Curve

Z-Axis Range of Motion

- Figure 17 shows front and side views of the welding torch mounting device.

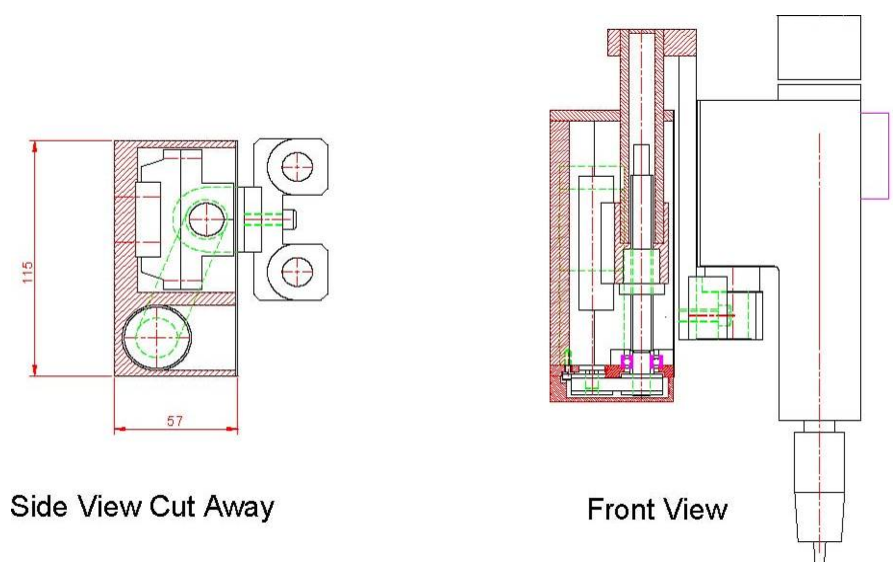

Figure 17. Welding Torch Mount

- The Z-Axis adjustment will be controlled via Automatic Voltage Control (AVC), which is based on the linear relationship between voltage and arc length and has been used for decades in automatic welding systems.

- Figure 18 shows the dimensional allowances that are built into the full 1.9-in. (50-mm) stroke of Z-axis movement: there is clearance for pipe bend, the fillet weld size at weld completion, and for arc penetration into the pipe wall for the root pass.

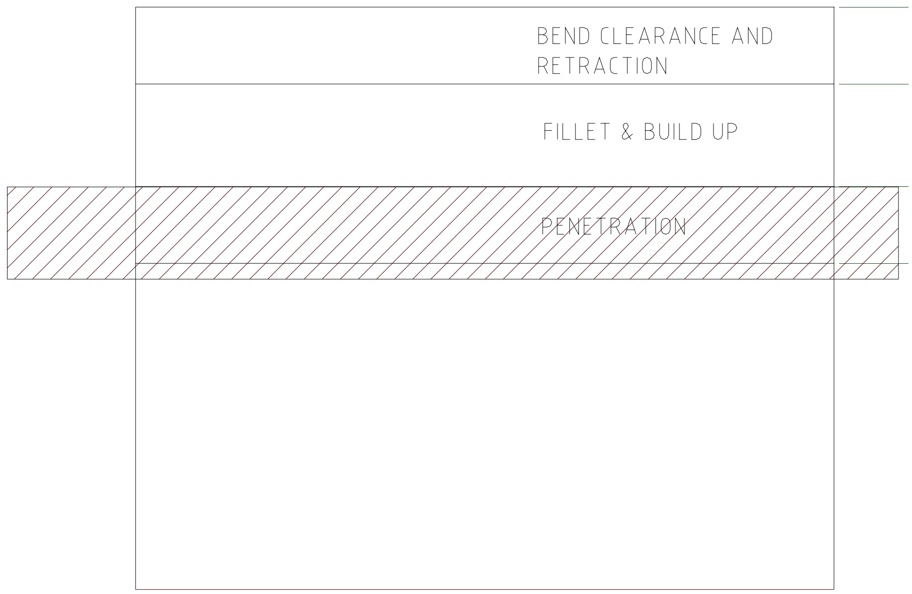

Figure 18. Combined Z-Axis Control

<u>Movement of Welding System</u>

- The weight of the assembled equipment is currently estimated at 772 lbs. (350 kg) and will require lifting equipment (Figure 19) to remove the system and place it over the excavated pipeline.
- It is envisaged that the welding system will be loaded into a trailer that is towed by an off road vehicle.
- The trailer will have receiver arms to house the main suspension frame with the Orbital Tracks in situ.

Figure 19. Lifting Equipment Used During Pipeline Construction

<u>Setting to Pipe Geometry</u>

The system can be set to a specified pipe geometry before installation.

Category Types

1. Parallel Pipe – Inclined / Declined
2. Vertical Pipe Bend - Pipe Support Leg on Parallel - Foot Support Stand over Bend
3. Vertical Pipe Bend - Pipe Support Leg on Bend - Foot Support Stand over Bend
4. Vertical Pipe Bend - Pipe Support Leg on Bend - Foot Support Stand over Parallel
5. Horizontal Pipe Bend - Pipe Support Leg on Parallel - Foot Support Stand over Bend
6. Horizontal Pipe Bend - Pipe Support Leg on Bend - Foot Support Stand over Bend
7. Horizontal Pipe Bend - Pipe Support Leg on Bend - Foot Support Stand over Parallel

To compensate for centerline shifts between the orbital cradle and the pipe centerline when changing from apex and crown locations, a manual adjustment of height of the two end support columns will be provided together with a digital reference wheel to assist setting.

System Set-Up

- Survey the pipe section for repair zones and decide strategic pipe crest areas for location of the Pipe Support Leg mounting. Use the Marking Beam provided to locate target.
- Check and make note of the Pipe Incline/Decline Angle along the target area.
- Check adequate earth clearance around pipe section (500 mm minimum).
- At Stand Position place ground sleeper support in a true level position.
    - Make ready the Orbital Welder (Figure 20).
        - Adjust the hand wheels to the nominal reference chart digital setting in accordance to the mounting category type 1 to 7 (as outlined above) and the relevant pipe incline/decline angles.
        - Remove both bottom clamp bars.
        - Ensure stand legs are hydraulically retracted.

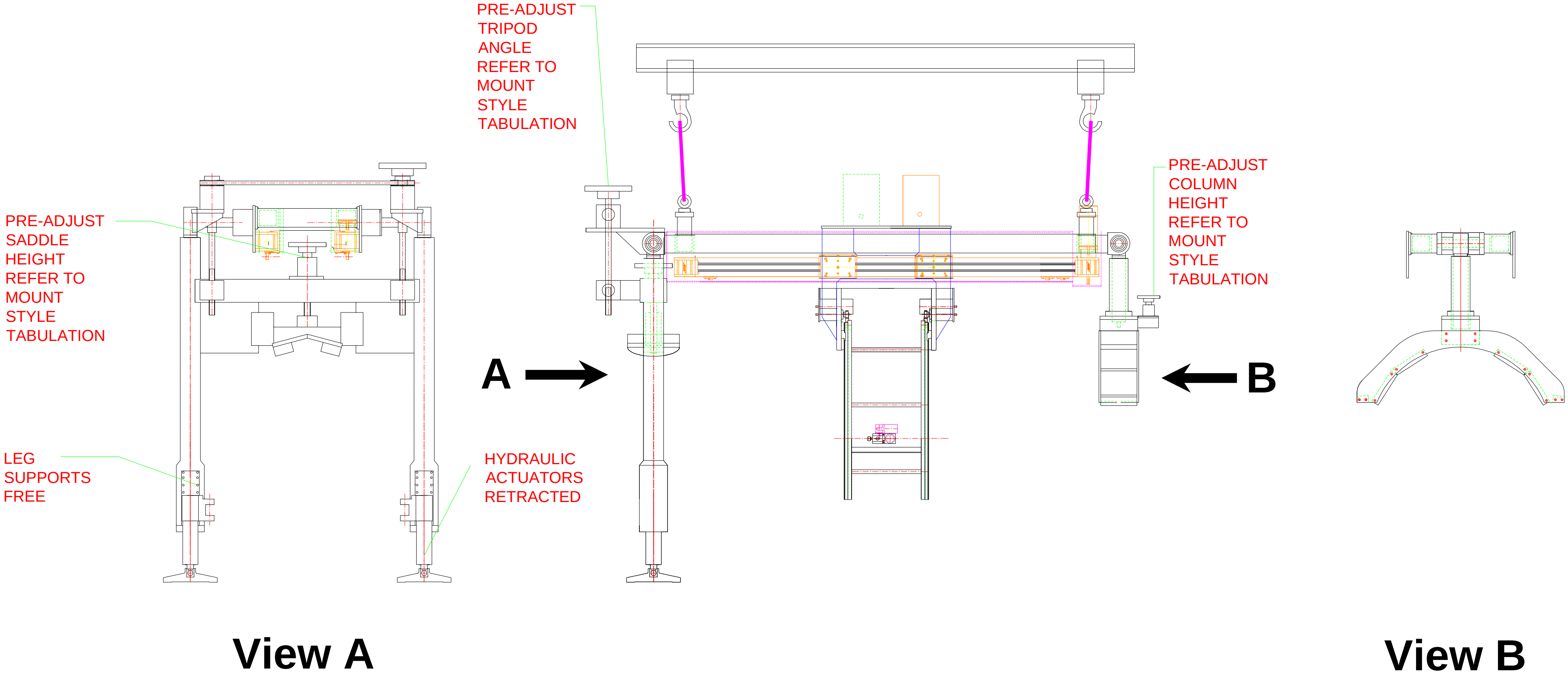

Figure 20. Make Ready the Orbital Welder

- Install Orbital Welder to Pipe (Figure 21)
    - Lift Unit with lifting device and lower into the pit positioning the support leg over the target. Lower until both leg and stand sections are in contact with the pipe crest. Keep lifting tackle taught before fitting and adjusting the bottom clamp bars, and finally jacking the legs on the stand to induce a slight reaction against the pipe. This reaction to be controlled by hydraulic pressure relief setting.

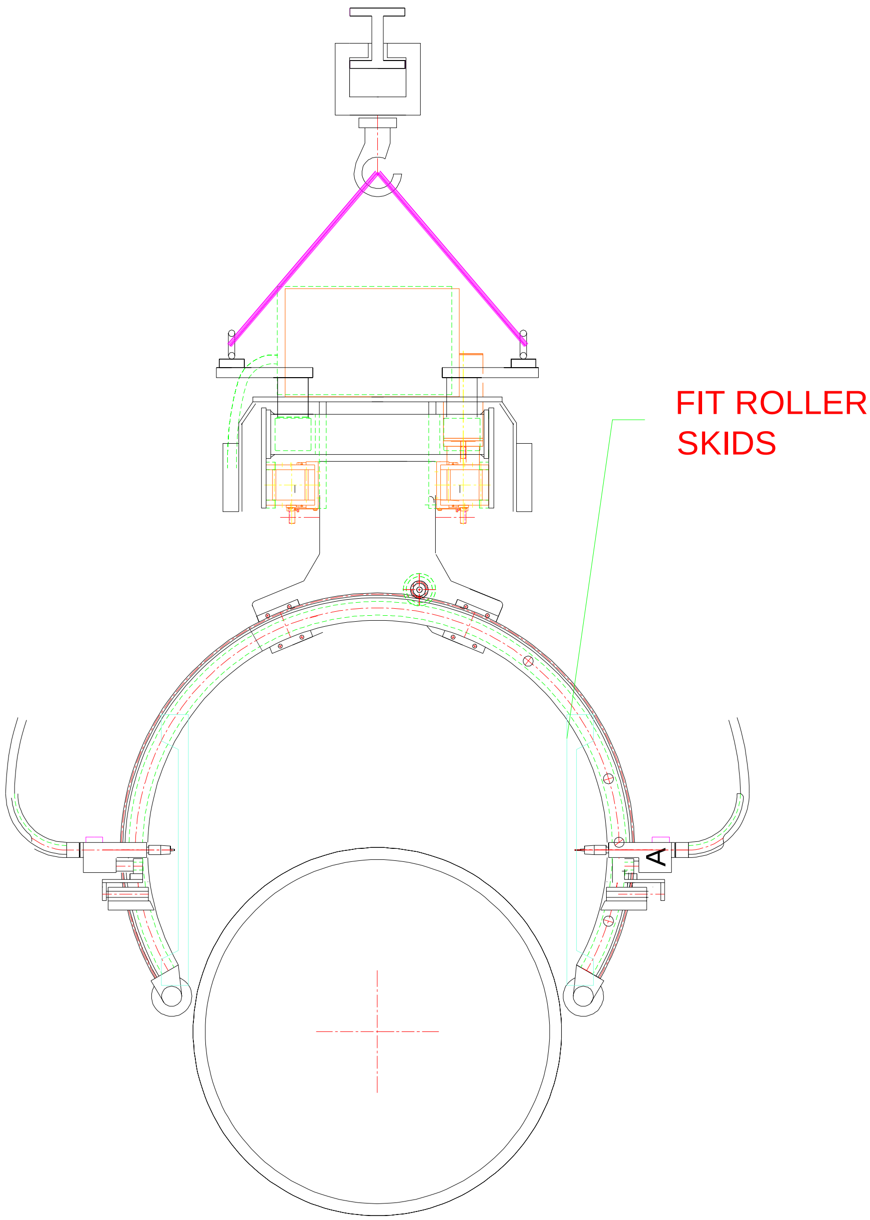

Figure 21. Install Orbital Welder to Pipe

- Secure the Orbital Welder to the Pipe (Figure 22).
    - Fit bottom brace then apply hydraulic pressure (Figure 22, View A).
    - Fit bottom brace then clamp (Figure 22, View B).

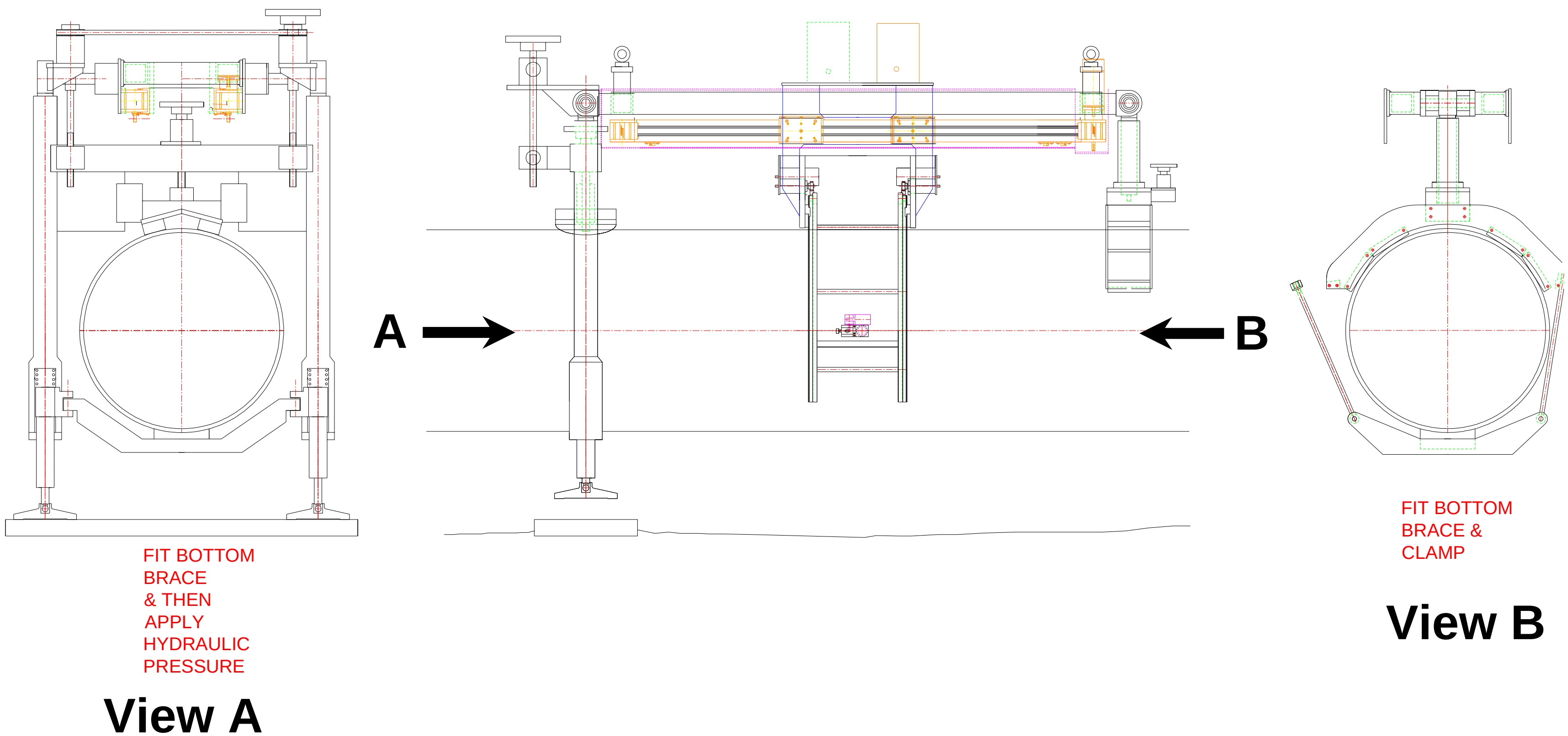

Figure 22. Securing the Orbital Welder to Pipe

Electrical Cable Management

- Arrangement of electrical cable feed harnesses (Figure 23) after system is installed on the pipeline.

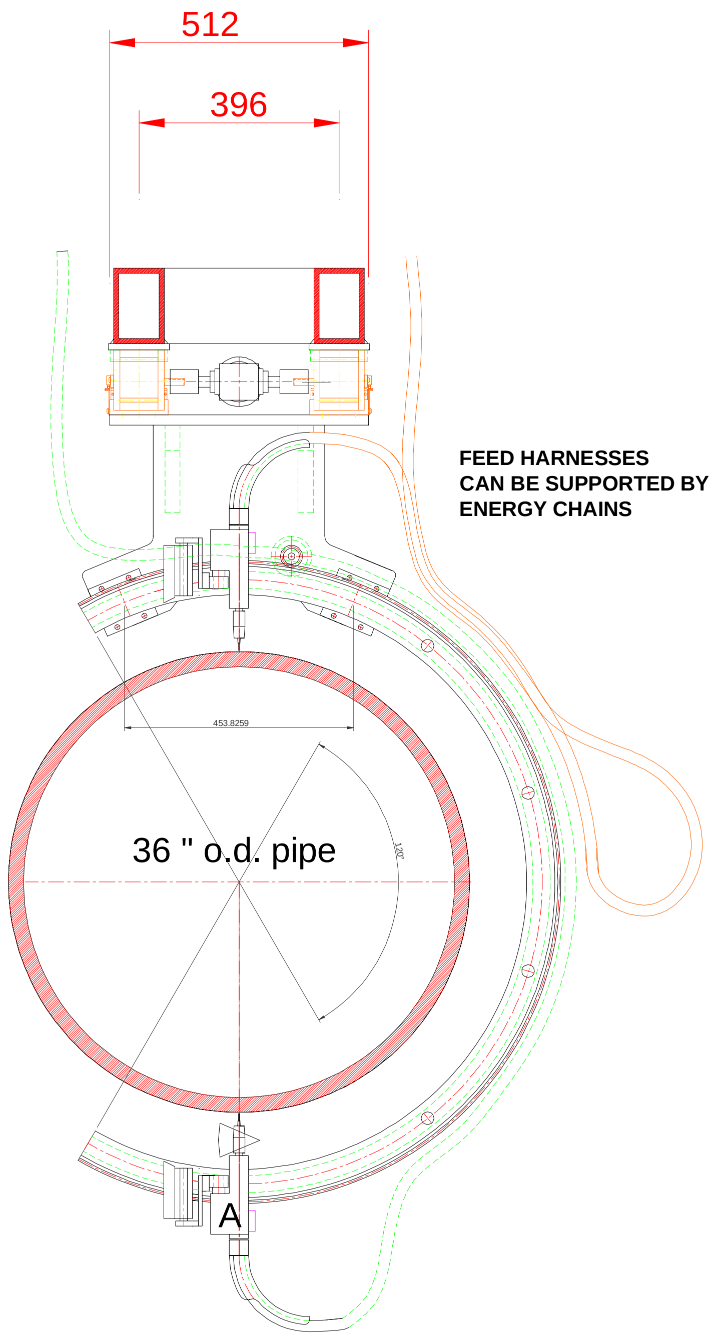

Figure 23. Arrangement of Electrical Harnesses

Circumferential Fillet Welding Configuration

- Figure 24 shows the system configuration for fillet welding, e.g., the circumferential welds at the end of a sleeve repair.

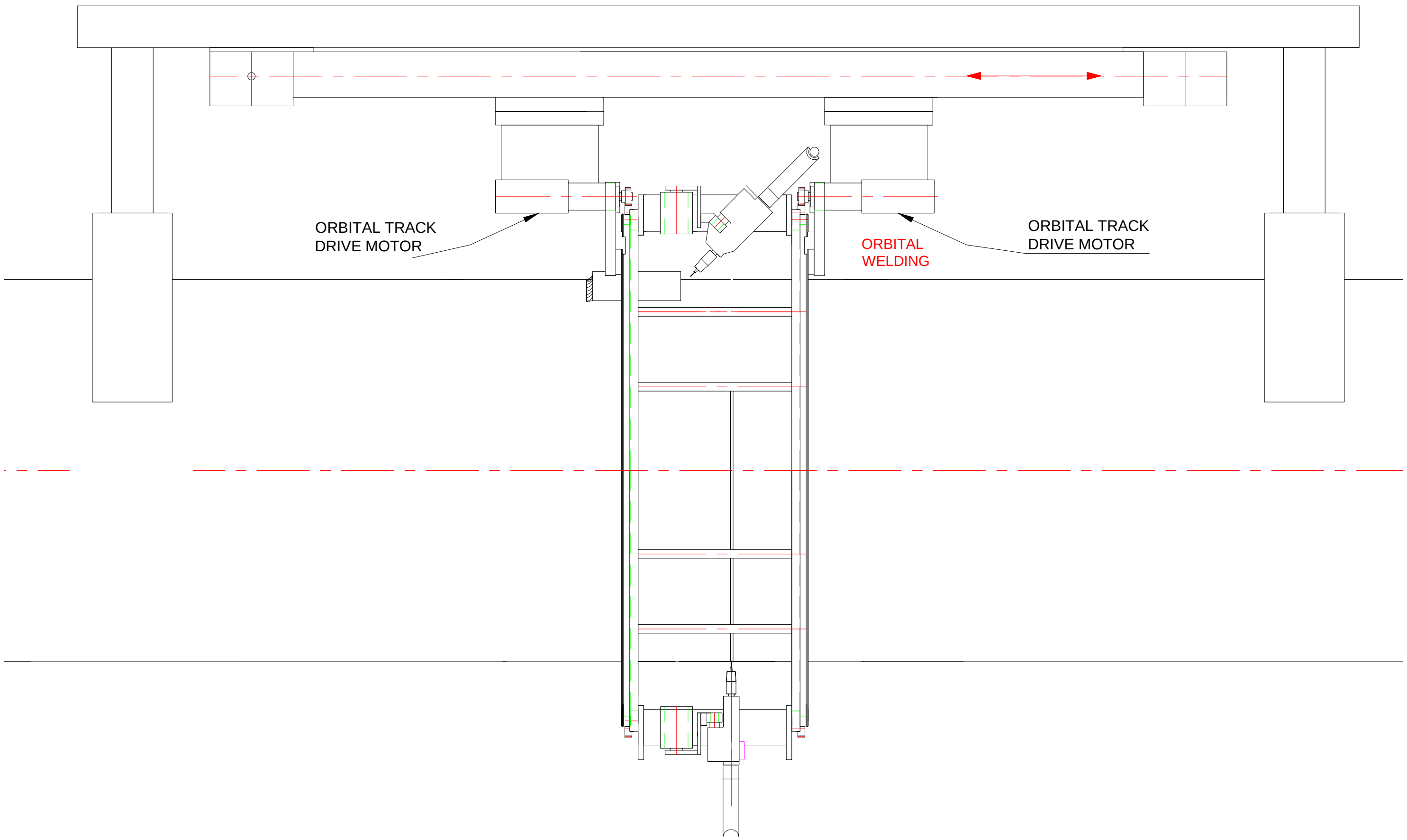

Figure 24. System Configuration for Fillet Welding

Longitudinal Welding Configuration

- Figure 25 shows the system configuration for girth welding a V-groove around the circumference of a pipe, for welding longitudinal seams, or for making a weld deposition repair on a patch of discreet corrosion.

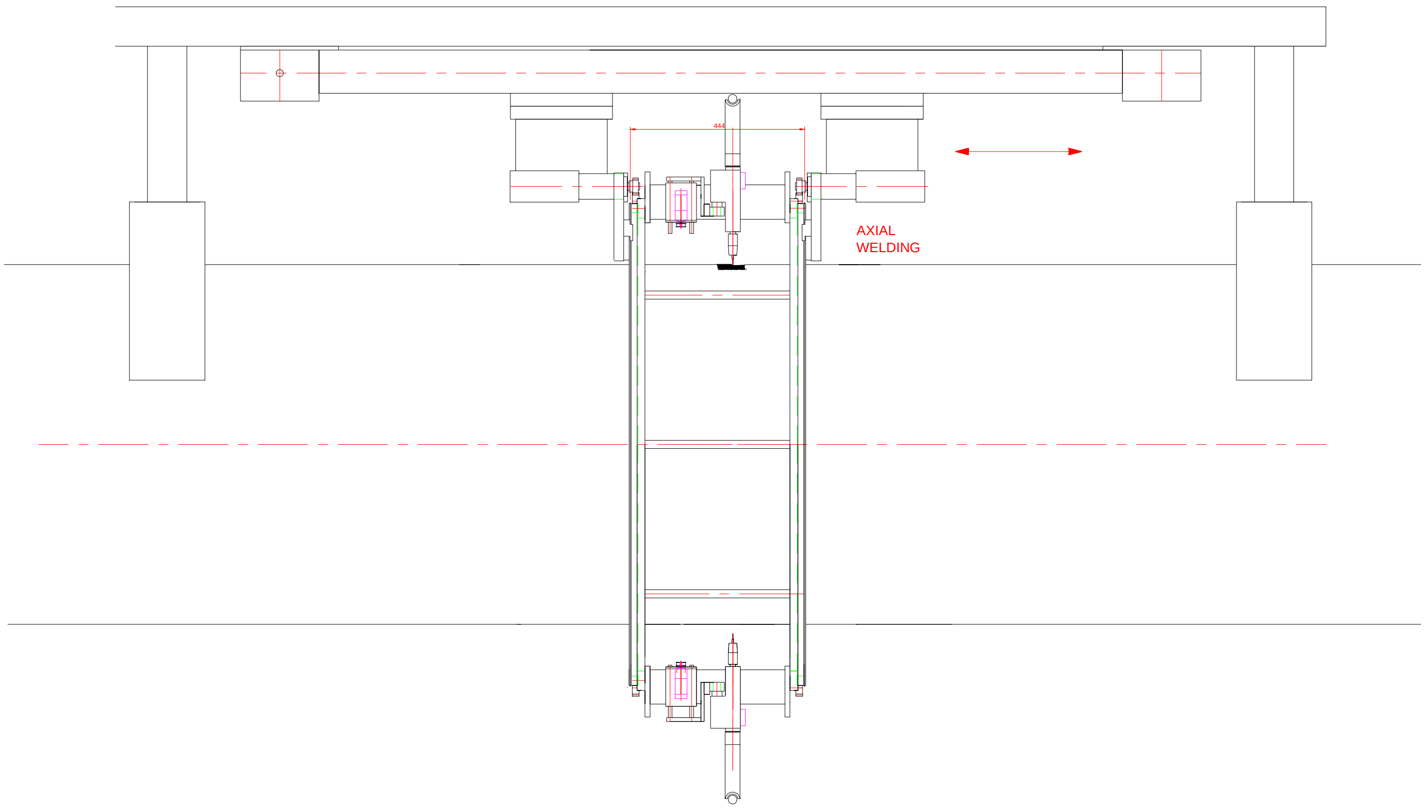

Figure 25. System Configuration for Longitudinal Welding

Examples Preset Mounting Type Operation

- Figure 26 shows a Type 2 declined pipe geometry installation.

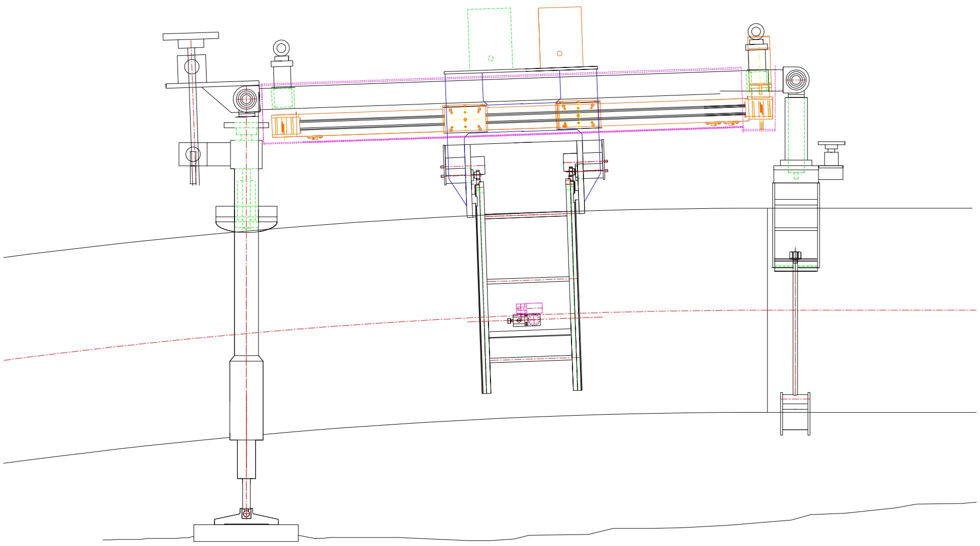

Figure 26. Type 2 Declined Pipe Geometry Installation

- Figure 27 shows a Type 2 inclined pipe geometry installation.

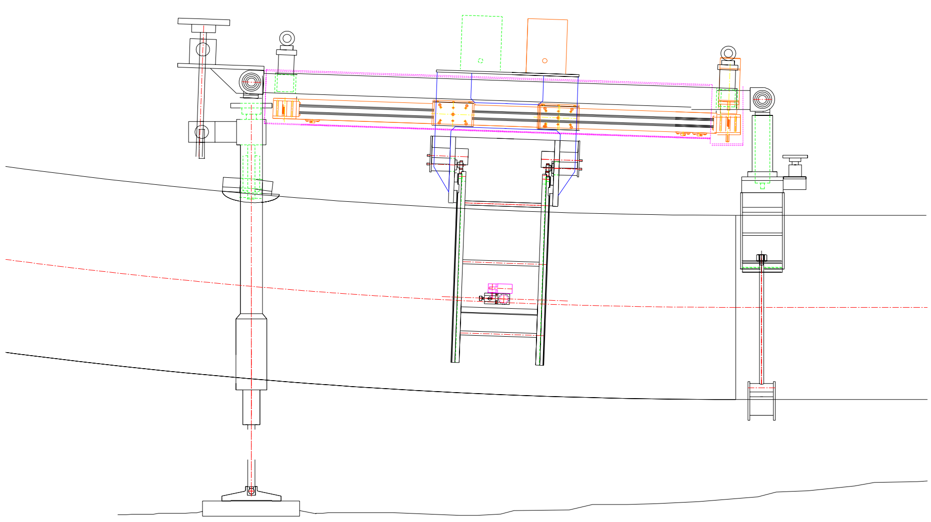

Figure 27. Type 2 Inclined Pipe Geometry Installation

- Figure 28 shows a Type 3 declined pipe geometry installation.

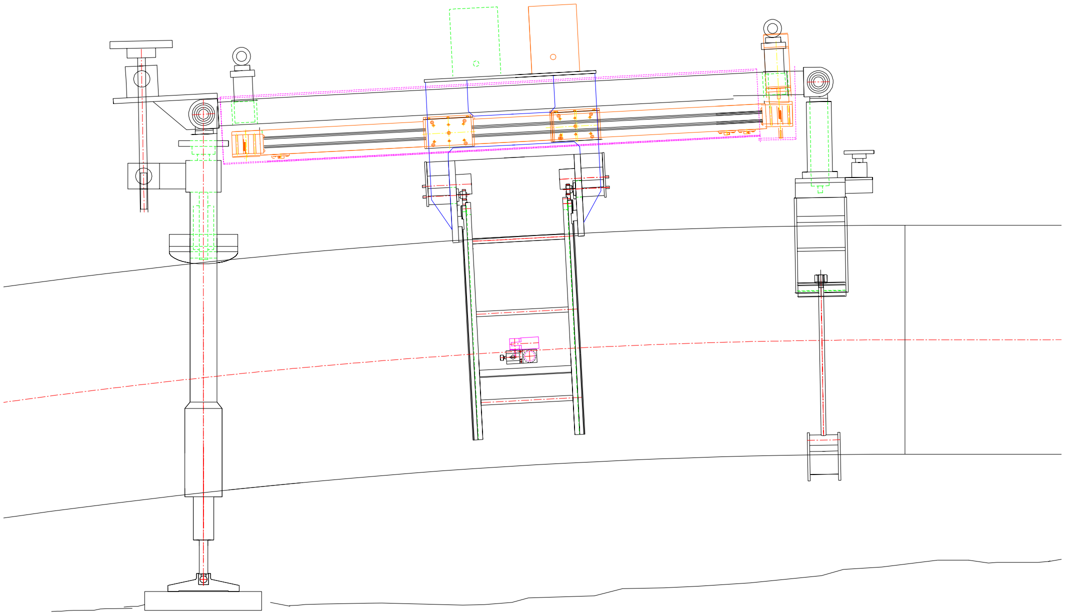

Figure 28. Type 3 Declined Pipe Geometry Installation

- Figure 29 shows an overhead view of a Type 6 horizontal bend geometry installation.

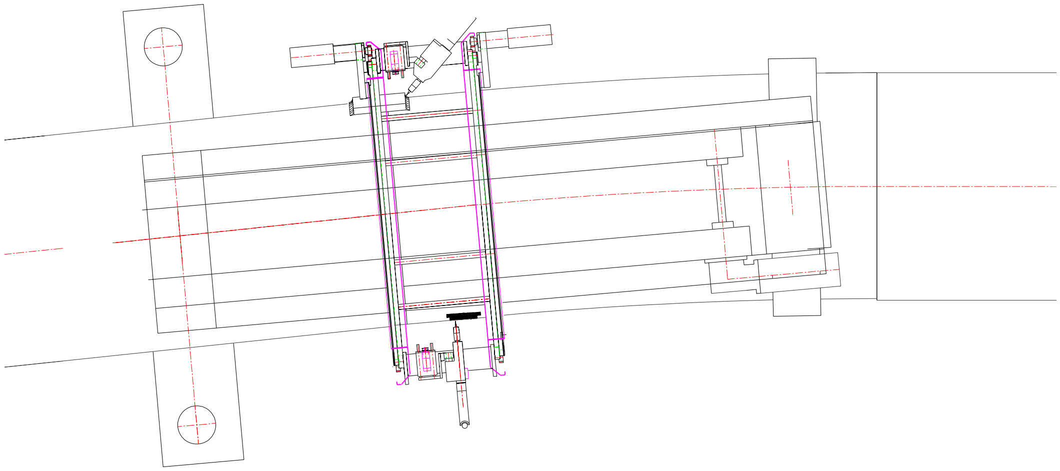

Figure 29. Overhead View of Type 6 Horizontal Bend Geometry Installation

Other Considerations

- Cost-share partner TransCanada provided pictures in Figure 30 and Figure 31, which show repair sleeves held in place with hydraulically operated chain clamps.

Figure 30. Type B Sleeve Repair Held with Chain Clamps during Preheat

Figure 31. Type A Sleeve Repair Held with Chain Clamps during Tack Weld

- Based on these pictures, an alternate clamping system was investigated for the orbital welder using chain clamps (see Figure 32).

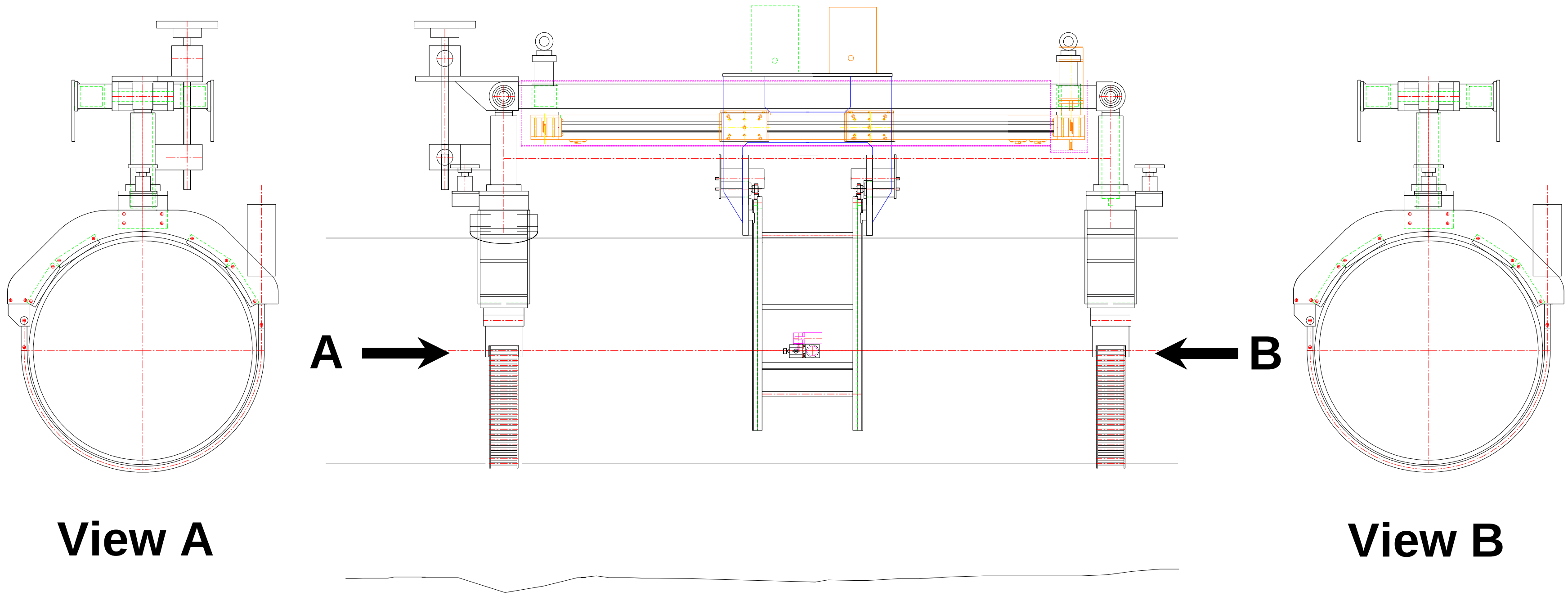

Figure 32. Alternate Clamping Concept with Chain Clamps

Decision to Abandon the Blackman System Design

At the PRCI Materials Technical Committee meeting on May 15, 2005, EWI's Connie Reichert presented a project status report that featured the Blackman design. At that time, PRCI and its member companies voiced numerous concerns about the Blackman system design. PRCI and its member companies were also unanimously against collaborations with Mr. Blackman given the number of PRCI funded and co-funded projects that were negatively impacted by Mr. Blackman's departure from Cranfield University. TransCanada's David Dorling (Ad Hock PRCI Materials Committee Chair) suggested that it was a good time to reconsider working with Mr. Blackman and to look at other designs. Bottom line: PRCI (project cost-share partner) and TransCanada (project cost-share partner) did not support the Blackman design.

The then acting director of the Welding Engineering Research Center at Cranfield University (Mr. David Yapp) was also present at the PRCI meeting. Mr. Yapp indicated that Cranfield University decided not to "contractually" complete the project and terminated the EWI subcontracts, as Cranfield also had no faith in Mr. Blackman's system concept. Bottom line: Cranfield University did not support the Blackman design either.

Mr. Yapp is in fact the author of the original PRCI proposal upon which this program (DTRS56-03-T-0009) is based. The original intent was to build on the Cranfield designed prototype bug and linear rail system built during a previous collaboration with EWI that was sponsored by PRCI (EWI Project No. 46256CSP). This design is a simple, cost-effective, portable design that can be operated by the welder in the field. It was obvious at the May 15, 2005 meeting that the PRCI conference participants all desire a more welder-friendly system than the Blackman design.

1.3.3.1 Alternative System Design Concept

This report subsection describes the evolution of the alternative system design developed by EWI.

With input from PRCI, TransCanada and Cranfield University, EWI developed an alternate system design concept that EWI could build in-house. The proposed alternative system design was presented to Mr. James Merritt of DOT on July 11, 2005 (see presentation in Appendix C). During a follow on teleconference on August 8, 2007 (see presentation in Appendix D), Mr. Merritt approved the proposed alternate system design. EWI subsequently terminated the relationship with Mr. Blackman/SABREweld and proceeded to design and build the system in-house.

The alternative system design was based on using off-the-shelf mechanized welding tractors (a.k.a., welding bugs) to achieve the performance requirements in the technical specification in section 1.3.2. The welding bugs would be controlled by one main motion controller unit. Additional software and hardware modifications would also be necessary to:

- Add torch work angle capability.
- Add torch travel angle for push/drag capability.
- Coordinate motion for corrosion patch and for weld fill.
- Increase length of cross-seam axis for filling corrosion patch.
- Integrate Laser Sensor onto bug system.

The first evolution of the alternative system design featured three hardware configurations. The system would be modular in that one box of common, mechanized welding bug parts could be configured to create three different hardware configurations for welding.

Figure 33 shows the system configuration for making longitudinal welds on reinforcing or pressure-containing sleeves. This design consisted of a standard bug system and a linear track. The linear track would attach to the pipe using magnetic clamps. The linear track could be placed anywhere on the pipe and make a longitudinal weld even if the weld was not parallel to the pipe axis. The system included a laser seam-tracker for pre-path planning and joint tracking during welding. The system would also include adaptive software from the multi-bead, multi-layer (MBML) project[42] for thicker sleeves and to accommodate excessive sleeve fit-up misalignment. The adaptive software would require a pre-scan of the joint area, which would then be fed into an algorithm that decides how to weld the longitudinal sleeve joint (i.e., the algorithm automatically determines the necessary number of weld layers and the number of weld passes required per layer). The adaptive software has the potential to allow an automated, one-touch operation for the welding operator.

[42] Ketron, D.L. Adaptive Mechanized Welding System. Edison Welding Institute, EWI Project No. 43113GDE, Columbus, Ohio, April 2004.

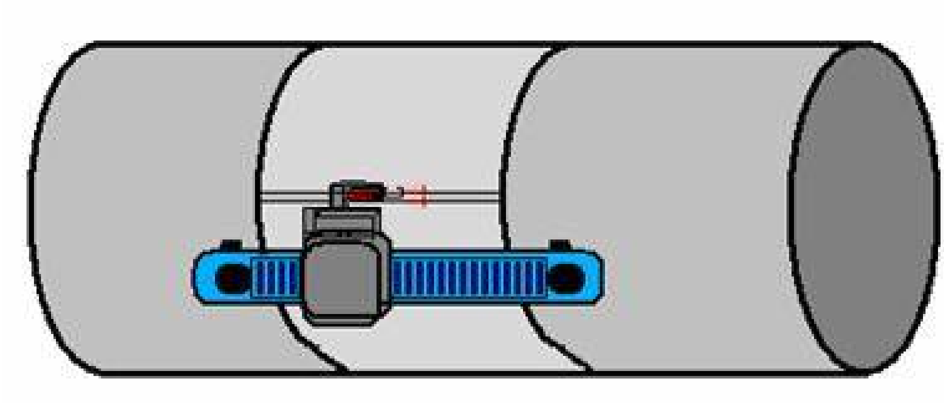

Figure 33. First Evolution of Hardware Concept for Longitudinal Welding

Figure 34 shows the concept of the first evolution hardware system for circumferential sleeve welding for pressure-containing sleeves, which could be accomplished with a standard orbital track and a modified welding bug. The welding bug could be modified to be more simplistic than the off-the-shelf version. The modifications would include reducing the number of standard axis from 4 to 1 with travel. A torch mounting bracket set at 45º could be mounted on a pendulum oscillator to accommodate torch weaving. A laser could not be used on the modified 1-axis welding bug design, so seam tracking will have to be accomplished by through-the-arc tracking or other means. The modular parts would include two of modified 1-axis welding bugs and two standard circular tracks. Two operators could potentially weld both circumferential welds at the same time.

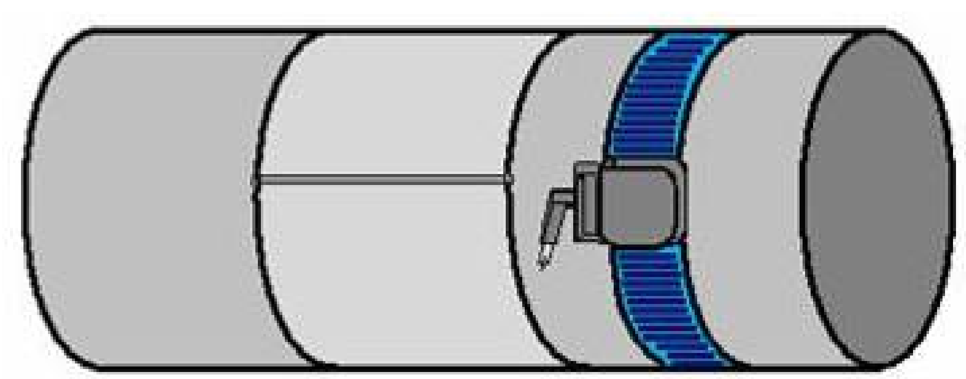

Figure 34. First Evolution Hardware Concept for Circumferential Welding

Figure 35 shows the first evolution of the alternative system hardware design for repairing a corrosion area using automated weld deposition. This hardware configuration includes two standard circular tracks, two modified 1-axis welding bug, one standard 4-axis welding bug and one linear track. The configuration for the automated weld deposition would be similar to longitudinal weld configuration except instead of using magnet clamps to secure the linear track to the pipe; the linear track would be secured to the two modified 1-axis welding bugs (Figure 35). The function of the modified 1-axis welding bugs is as a transport device to drive the linear track and standard 4-axis welding bug around the pipe circumference. The modified 1-axis welding bugs on the circumferential tracks would be tied together by the motion control system; one modified 1-axis welding bug would function as the Master and the second modified 1-axis welding bug would function as the Slave.

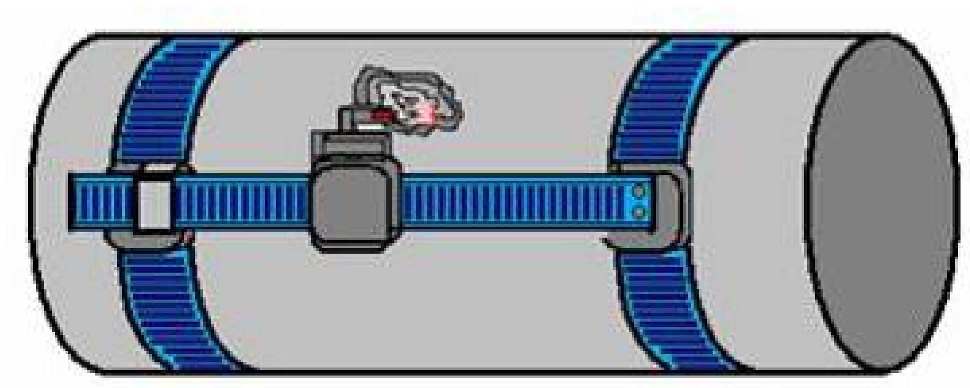

Figure 35. First Evolution Hardware Concept for Weld Deposition Repair

The operator would be required to teach the system the boundary of the corrosion patch. This could be accomplished by touch sensing (with the torch) or by other means. The boundary would then be used produce a two-pass elliptical outline of the corrosion patch. The two-pass elliptical outline is common in the manual weld deposition repair technique. The initial two pass outline allows a location for welding starts and stops, which are common hard spots for in-service welding, as well as providing tempering at the weld toe of the elliptical outline assuring a low HAZ hardness and less susceptibility to hydrogen cracking. Once the two-pass elliptical outline is completed, the corrosion would be automatically filled pass by pass. The laser sensor would be attached to this standard 4-axis welding bug, allowing for real-time seam tracking during welding.

During the development of the first evolution of the alternative system design concept, EWI identified additional technologies to leverage from another DOT project. The leveraging included borrowing welding equipment from Serimer DASA and hardware from Cranfield University. For DOT award number DTRS56-05-T-0001, "Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines" (EWI project no. 47961GTH, Task 4), EWI developed the GUI shown in Figure 22 and a communication protocol to run the motion control software of a Serimer DASA welding system.

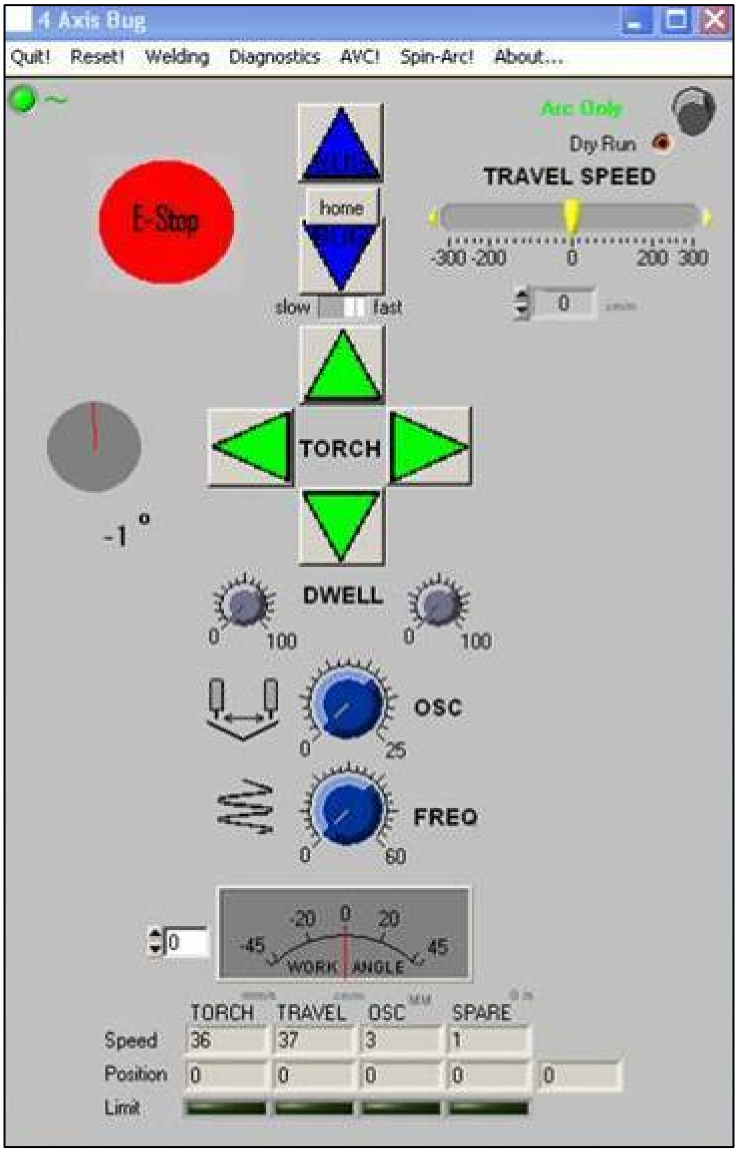

Figure 36. Control GUI for Serimer DASA Motion Control Software

For the alternative welding system design, EWI also planned to use the same Serimer DASA equipment from the DTRS56-05-T-0001 project (since this project had just ended and the equipment was already on loan to EWI). This system is shown in Figure 37.

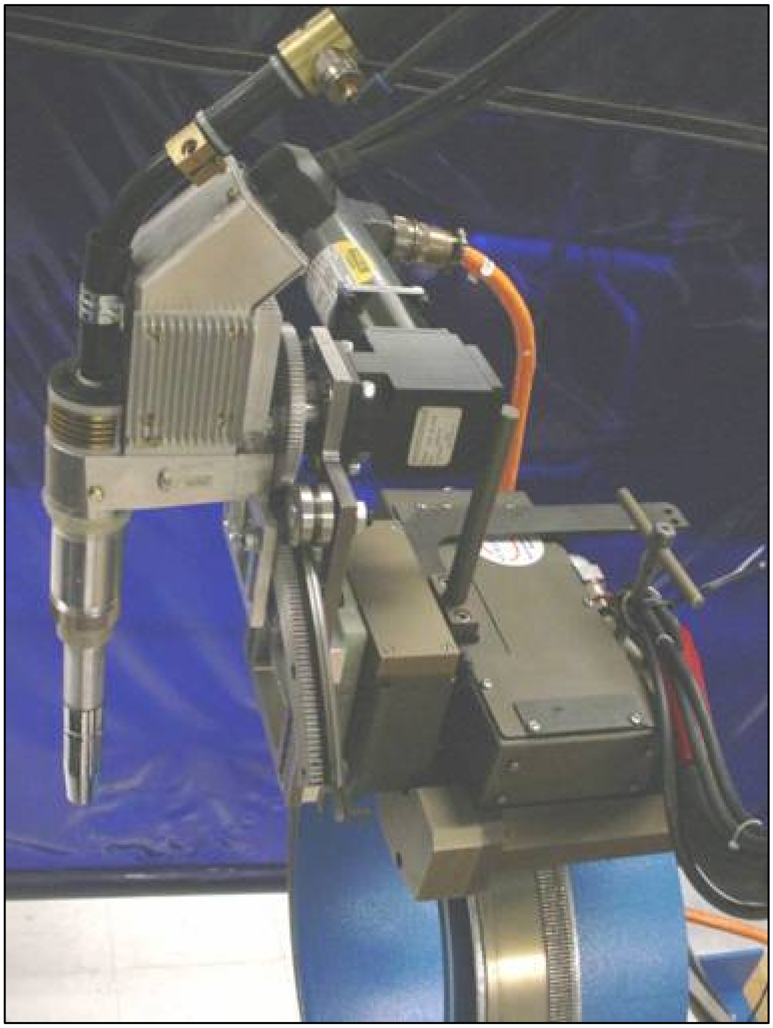

Figure 37. Serimer DASA Equipment Loaned to EWI

Serimer DASA agreed to loan the following equipment to EWI at no cost for the duration of the project:

- 2 STX mechanized bugs.
- 2 STX controllers.
- 2 rail sets for 36-in. diameter pipe.

The STX controller (Figure 38) was built by Serimer DASA specifically for EWI, it provides an RS-232 communication protocol for computer control of all axes, an auxiliary motor amplifier and additional digital I/O signals. This configuration allows EWI to control an welding bug with a laptop.

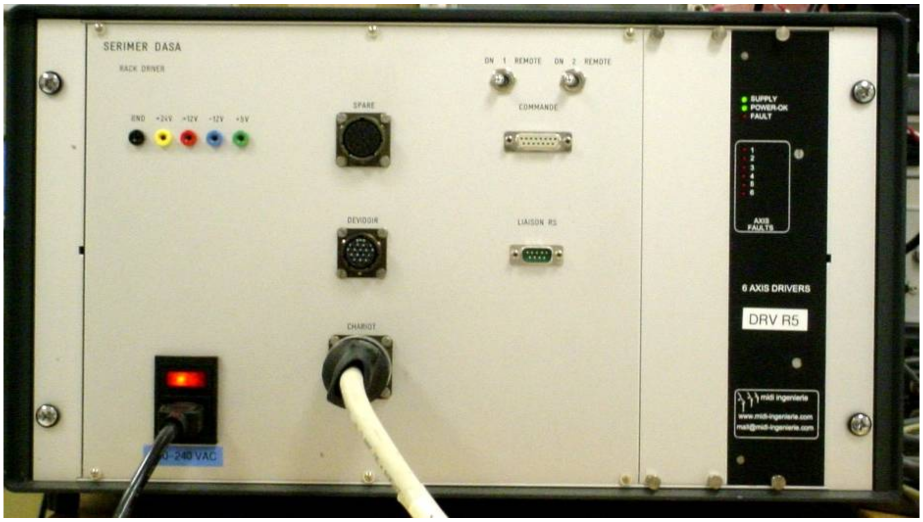

Figure 38. Serimer DASA Motion Controller Box

EWI also planned to use a Servo-Robot Mini i/90 laser stripe seam tracker with an EZTrac Smart Box controller (Figure 39) for weld joint seam tracking and adaptive welding. Cranfield University agreed to loan their laser sensor and controller to EWI at no cost for the duration of the project.

Figure 39. Mini-i/90 Laser and Controller on Loan from Cranfield University

The second evolution of the alternative system design concept with Serimer DASA welding bugs (Figure 40) departed from the modular concept into a more sophisticated system with greater functionality that is capable of making all of the targeted welds: longitudinal, circumferential, and corrosion patch fill.

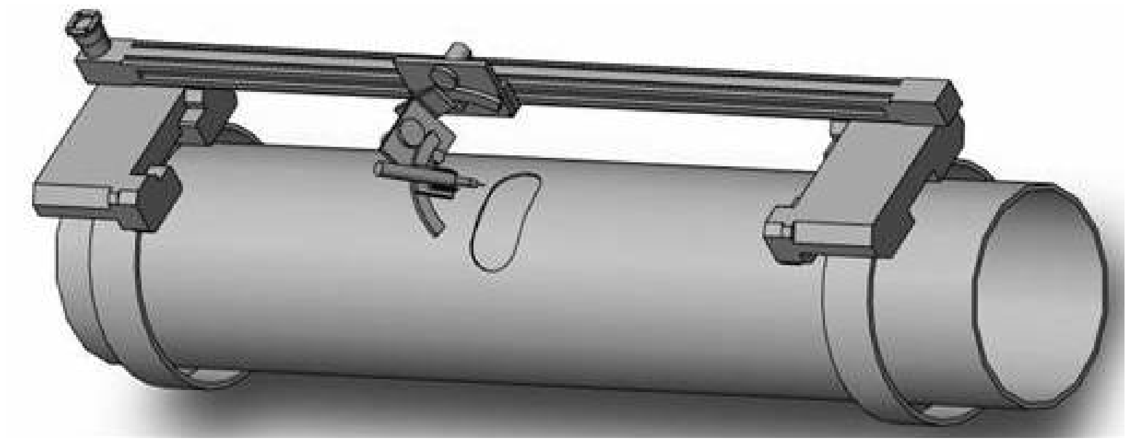

Figure 40. 2nd Evolution of Alternative System Design with Serimer DASA Welding Bugs

A series of tests were conducted to determine the amount of weight the Serimer DASA welding bugs could support and still operate effectively. The amount of weight was gradually increased until a Serimer DASA welding bug or linked Serimer DASA welding bugs failed to move or disengaged from the track. Tests were first conducted to characterize the individual performance of Serimer DASA welding bug #1 and bug #2 at a travel speed of 39.4 ipm (100 cm/min), the travel speed at which the bugs are programmed to return to "home" position (this is the maximum travel speed feasible for welding). The tests were conducted without any additional weight. There was a slight variation in speed as shown in Table 2.

Table 2. Independent Bug Travel Performance without Added Weight

	Travel Speed	Forward 360° (sec)	Backward 360° (sec)
Bug #1	100 cm/min	175.67	175.41
Bug #2	100 cm/min	176.32	175.89

Variation (sec)	0.65	0.48
Variation (%)	0.246370769	0.001822635

Tests were then conducted to characterize the performance of each Serimer DASA welding bug with varying amounts of added weight at a travel speed of 118.1 ipm (300 cm/min), which is the maximum travel speed that the Serimer DASA welding bugs. The added weight was attached to a mounting point at the center of the Serimer DASA welding bug. Results are listed in Table 3.

Table 3. Independent Bug Travel Performance with Added Weight on Top

Bug #1			Bug #2		
Weight Added (lbs)	**Forward 360° (sec)**	**Comments**	**Weight Added (lbs)**	**Forward 360° (sec)**	**Comments**
5	59.66	No problems observed	5	60.01	No problems observed
10	N/A (accelerated test)	N/A	10	59.96	No problems observed
15	59.53	No problems observed	15	59.63	No problems observed
20	59.59	No problems observed	20	59.99	No problems observed
25	60.09	No problems observed	25	60.19	No problems observed
30	N/A	• Difficulty traveling uphill. • Lost motor resistance downhill • Bug completely stopped working • Had to reset program.	30	61.2	Gear skipped once at 270°
N/A	N/A	N/A	36	62.12	• Started to Fall off @ 270° • Stopped adding weight at this point because of decreasing travel speed

Tests were then conducted on Serimer DASA welding bug #2 to characterize its travel performance at 118.1 ipm (300 cm/min) with weight added to a mounting point on the side of the bug. Results are listed in Table 4.

Table 4. Bug #2 Travel Performance with Added Weight on Side

Weight Added (lbs)	Forward 360° (sec)	Comparison with Center Mounted Weight (sec)	Variation (sec)	Variation (%)
15	62.75	59.63	3.12	3.37060444
30	65.73	61.2	4.53	4.702584865

Tests were also conducted with Serimer DASA welding bug #1 and bug #2 joined together with a 59.1-in. (1.5-m) plate (to simulate the "as welding" configuration) at 39.4 ipm (100 cm/min), travel speed with various amounts of weight added to the plate at the center point between the two bugs. The results are listed in Table 5.

Table 5. Joint Bug Travel Performance with Added Weight

Weight Added (lbs)	Observations	Modifications Made	Final Result
0	Initially, the two bugs were running at different speeds, with bug #1 traveling at a higher speed in the downhill direction, and bug #2 "catching up" to it in the uphill sections of the pipe.	Made adjustments to the spacing in the roller mechanism of both bugs, to make sure that the gears were meeting up with the track consistently, regardless of position.	While this fixed the initial problem, it was observed that when hitting the emergency stop button, bug #2 stops after bug #1. This delay throws off the alignment of the two bugs in relation to each other.
16	No problems observed	none	Weight acceptable
26	No problems observed	none	Weight acceptable
33.5	No problems observed	none	Weight acceptable
40	In the uphill direction, bug #1 began to skip gears and travel slower than bug #2.	The spacing of the roller mechanism was further adjusted (tightened) in order to ensure consistent contact between the	The problem was fixed, and the weight determined to be acceptable. However, it was observed that tightening the spacing to this degree was causing wear on the gears

Weight Added (lbs)	Observations	Modifications Made	Final Result
		gear and the track.	so a lubricant was applied to minimize wear.
44.5	At the 6 o'clock position on the pipe, bug #2 began to pull off of the track to the point where the gears were no longer contacting the track, and the bug stopped completely. In the uphill direction, bug #1 began to skip gears.	In order to avoid additional wear on the gears, it was determined that further adjustments of the spacing should not be made	Weight unacceptable

Testing determined that the Serimer DASA welding bugs could not support the amount of weight required by the second evolution of the alternative system design. This was due to both the mechanics of the Serimer DASA welding bugs and the changing center of gravity expected with the alternative system design. A modification to the torch holding mechanism was needed to both lower the center of gravity and redistribute the expected weight of the components to a level the bugs could easily manipulate.

The resulting torch positioner design is quite innovative and extremely low profile (see Figure 41 through Figure 43). The coordinated motion of circular slide and semi-circular slide simultaneously creates the torch travel and work angles. Kinematic equations were developed to coordinate motion depending on welding direction and orientation about the pipe axis. A dome of protective plastic lens could be placed over the torch control ring to provide ultraviolet protection from the welding arc. This modified design allows for the removal of the X and Z axes (i.e., oscillation and torch height controls) from both bugs, which decreased the weight of the alternative system design.

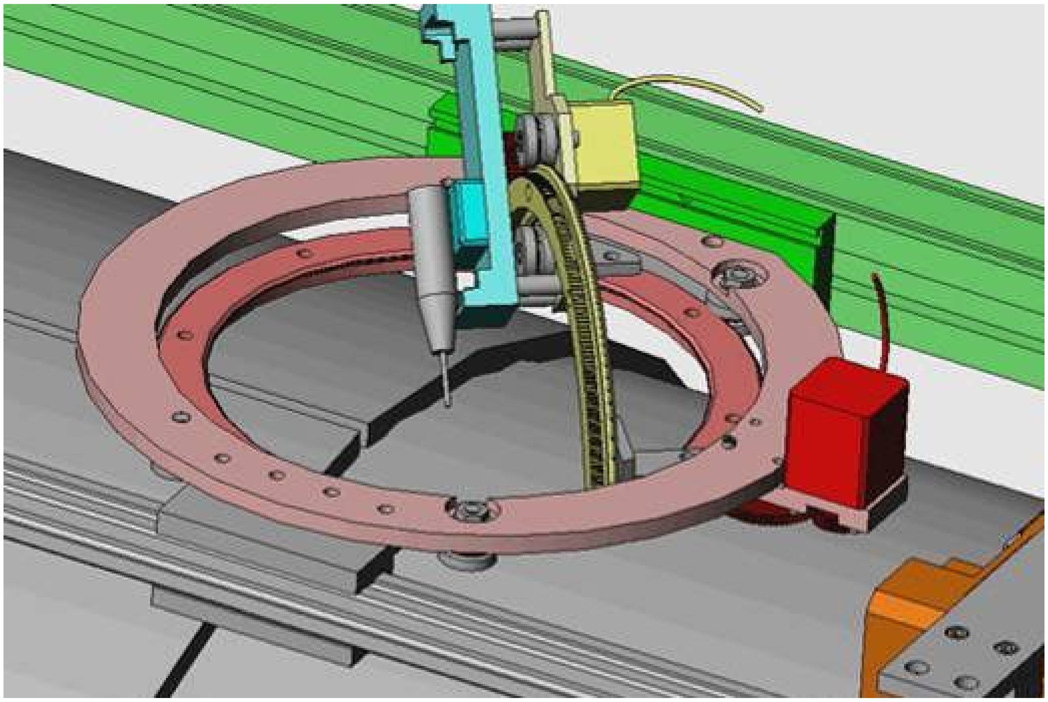

Figure 41. Torch Positioning Ring (View 1)

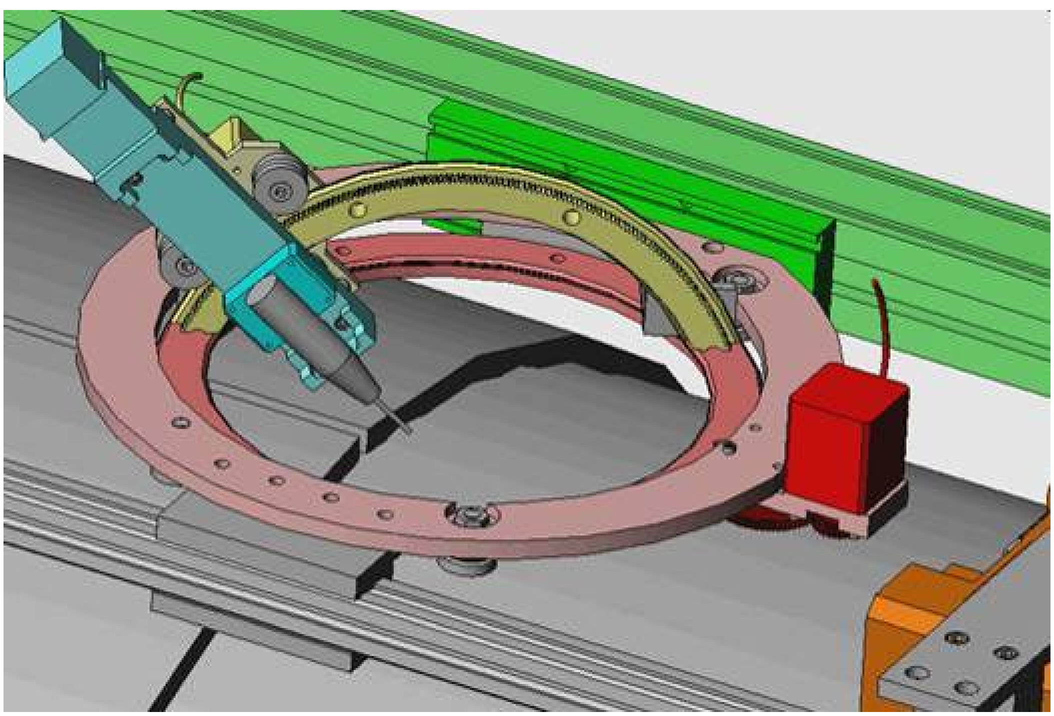

Figure 42. Torch Positioning Ring (View 2)

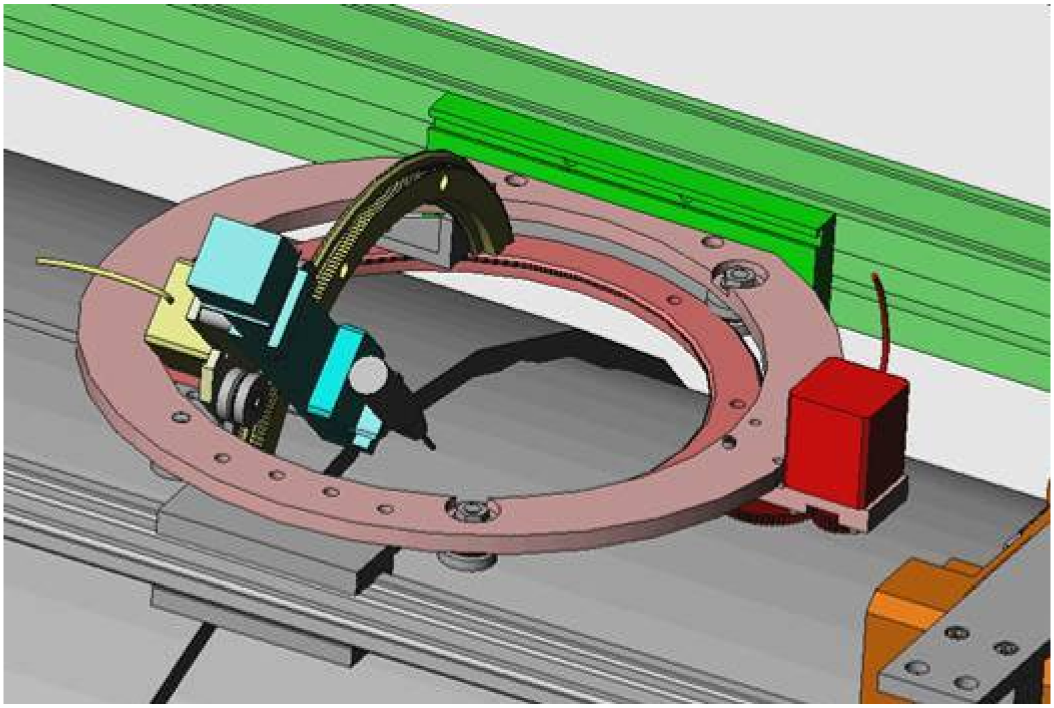

Figure 43. Torch Positioning Ring (View 3)

Total estimated weight of the torch positioning ring assembly was 34 lbs (15.4 kg). The removal of the X and Z axes from each Serimer DASA welding bug decreased total system weight from 56 lbs (25.4 kg) to 30 lbs (13.6 kg). Each bug now weighs 15 lbs (6.8 kg) instead of 27 lbs (12.2 kg). As seen in Table 5, two bugs working together can handle up to 40 lbs (18.4 kg) of payload without difficulty.

The final alternative system design with Serimer DASA welding bugs is shown in Figure 44 and Figure 45. The innovative torch positioning ring assembly allows the torch to be oriented in an infinite number of compound angles to weld in any conceivable position.

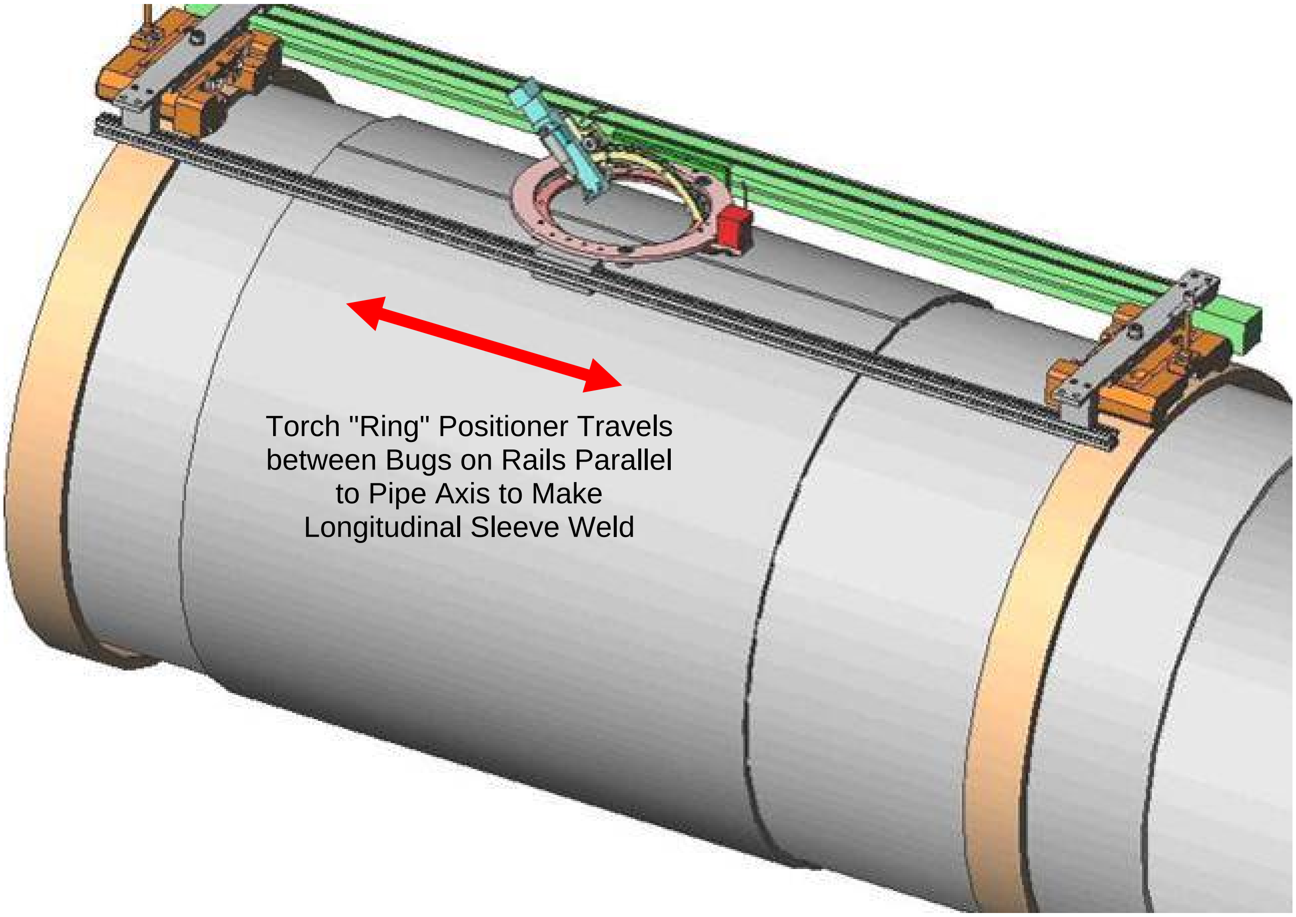

Figure 44. Side View of Alternative System Design with Lower Profile

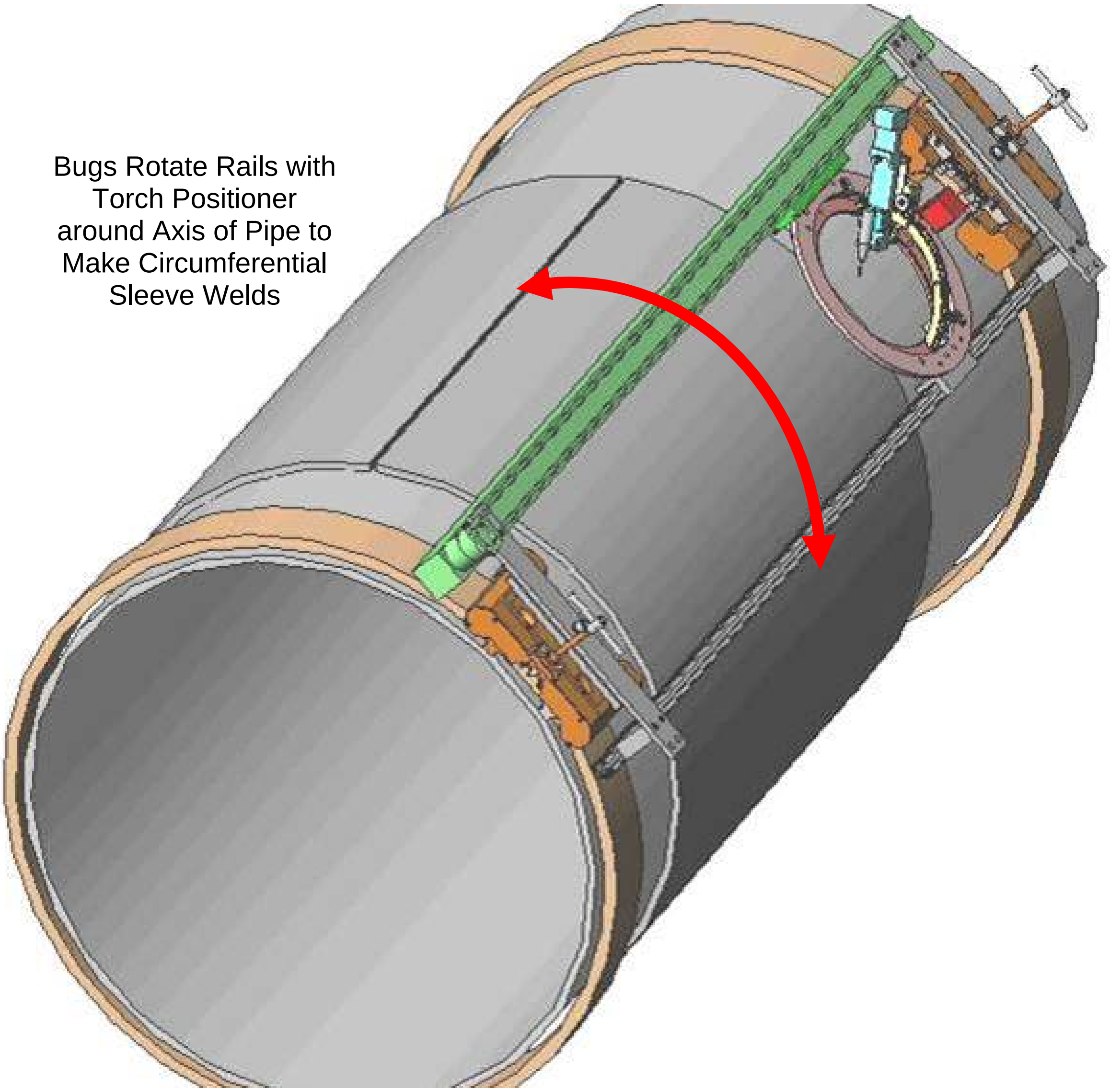

Figure 45. End View of Alternative System Design with Lower Profile

Figure 46 is a photo of the improved system with Serimer DASA welding bugs.

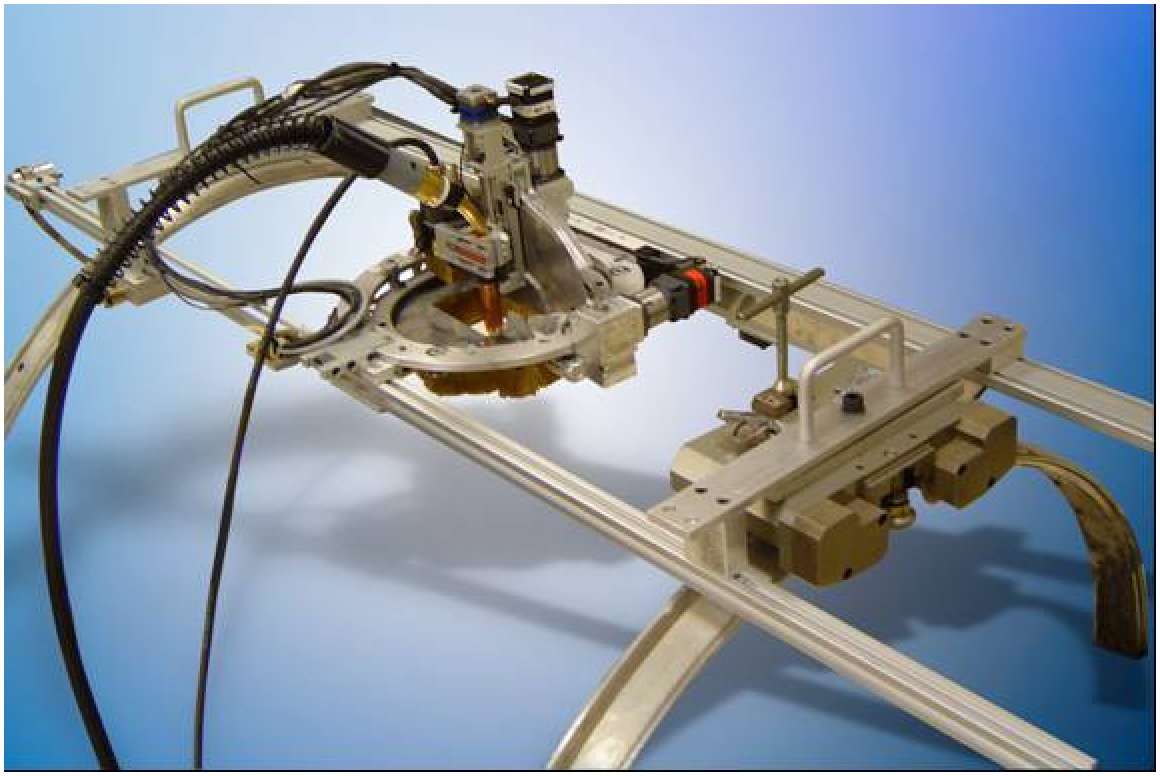

Figure 46. Alternative System Design with Serimer DASA Welding Bugs

<u>Laser Scanning System</u>

The laser scanning system is incorporated to provide seam tracking during sleeve welding (longitudinal and circumferential welds), to pre-scan the longitudinal V-groove of the pressure-containing sleeve to determine the amount of weld metal needed to fill the joint (i.e., adaptive fill) and to map a corroded area to determine the amount of weld metal needed to fill a corroded area. The pre-scan of the longitudinal V-groove and mapping of a corroded area are referred to as the inspection capabilities of the laser scanning system.

When a corrosion patch is scanned, the corrosion location and depth is mapped topographically. To account for the varying depths of the corrosion a multi-layer weld deposition approach is needed. The deepest portions of the pit must be filled in first to provide a level surface that can be built up uniformly (as shown in Figure 47, where layers #1 and #2 are filled in before layer #3). The adaptive fill algorithm determines the number of weld layers and beads needed to fill up the corrosion damage. The system then makes an elliptical outline of the corrosion area and fills up the corroded area with the requisite stringer beads.

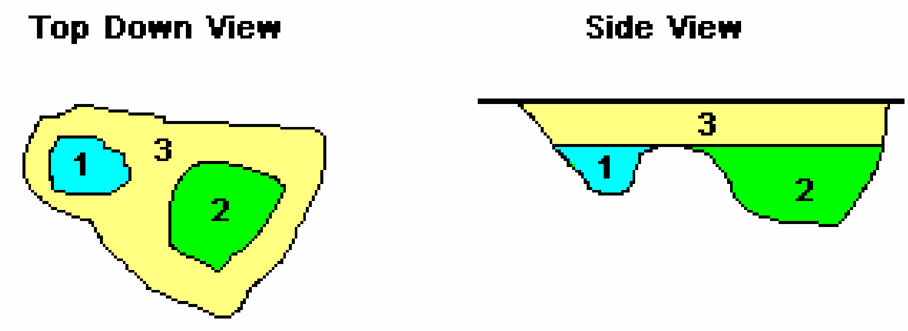

Figure 47. Weld Deposition Layers for Corrosion Pits

The laser sensor scans a 3-in. (76.2 mm) wide swathe, which is adequate to provide the necessary feedback for seam tracking all targeted longitudinal and circumferential weld joints and for providing the feedback needed for adaptive fill of the longitudinal V-groove of the pressure-containing sleeve. In order for the laser sensor to characterize corrosion patches that exceed 3-in. (76.2 mm) in size, EWI had to create motion control and image management algorithms to scan multiple areas and patch them together into one corrosion map that the adaptive fill program could use to determine the amount of weld metal needed to fill the corroded area.

Laser scanning system development began by collecting different types of scanned data from a calibration block, simulated corrosion and real corrosion from a pipeline removed from service. As the different types of data were collected and analyzed, the algorithms necessary for patching corrosion scans together and adaptive fill algorithms were written.

Figure 48 is a photo of the laser system scanning a calibration plate. Figure 49 is a screen capture of the GUI displaying data during a scan of the calibration plate. Figure 50 is a screen shot of the GUI displaying data after a scan of the calibration plate was complete.

Figure 48. ServoRobot Mini i/90 Laser Scanning Calibration Plate

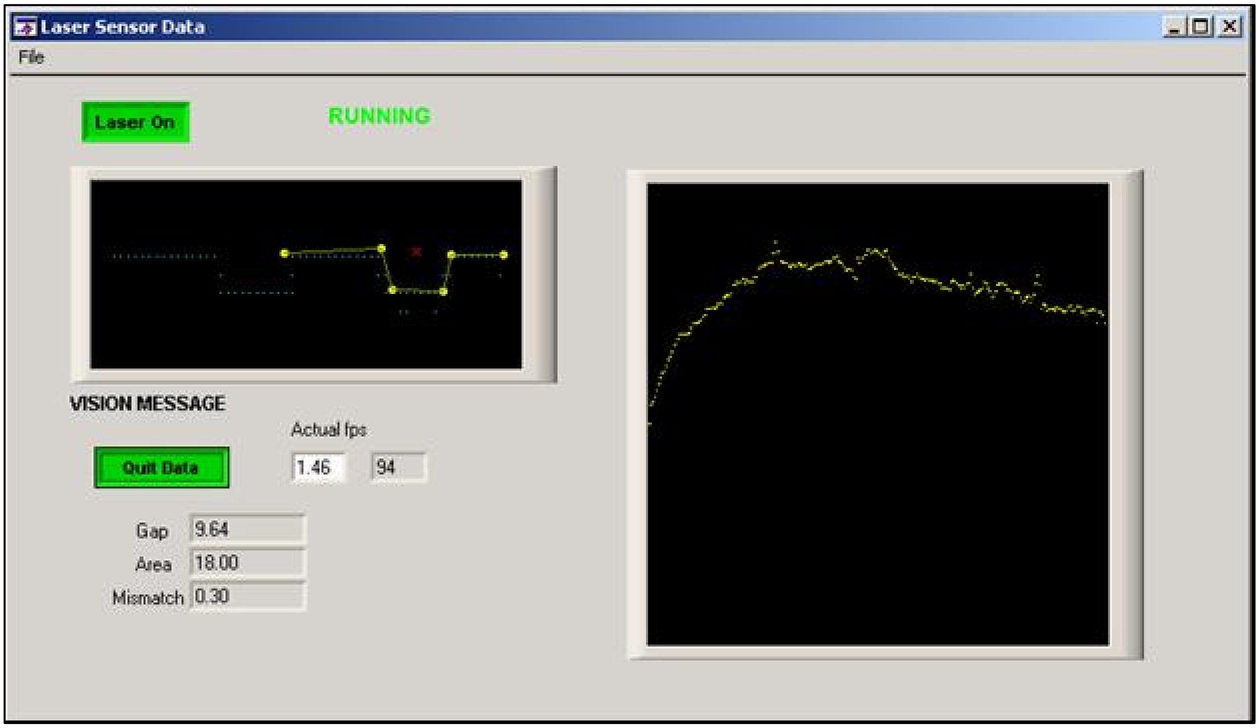

Figure 49. GUI Screen Shot of Laser Sensor Scanning Calibration Plate

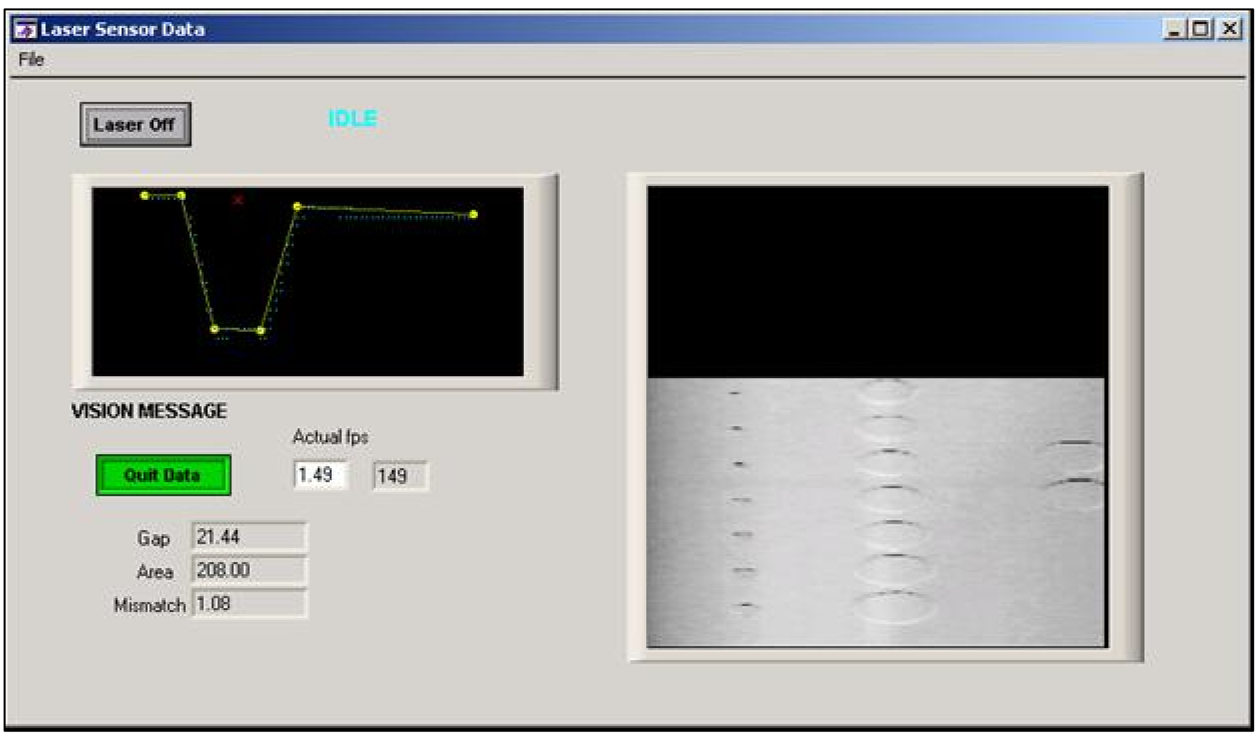

Figure 50. GUI Screen Capture of Data after Scanning Calibration Plate

After the data collection/analysis from the calibration plate was completed, the laser scanning system was calibrated on a pipe surface with simulated corrosion. During the laser scanning trials performed on the simulated corrosion the software was modified to included a color depth plot of the surface area scan. Figure 51 shows the laser scanning a simulated corrosion patch on a 36-in. (914-mm) diameter pipe section. Figure 52 shows the corrosion mapping software display of layer #1 of the simulated weld corrosion patch. Figure 53 shows the corrosion mapping software display of layer #2 of simulated weld corrosion patch. Figure 54 is a close-up of simulated corrosion layer #2.

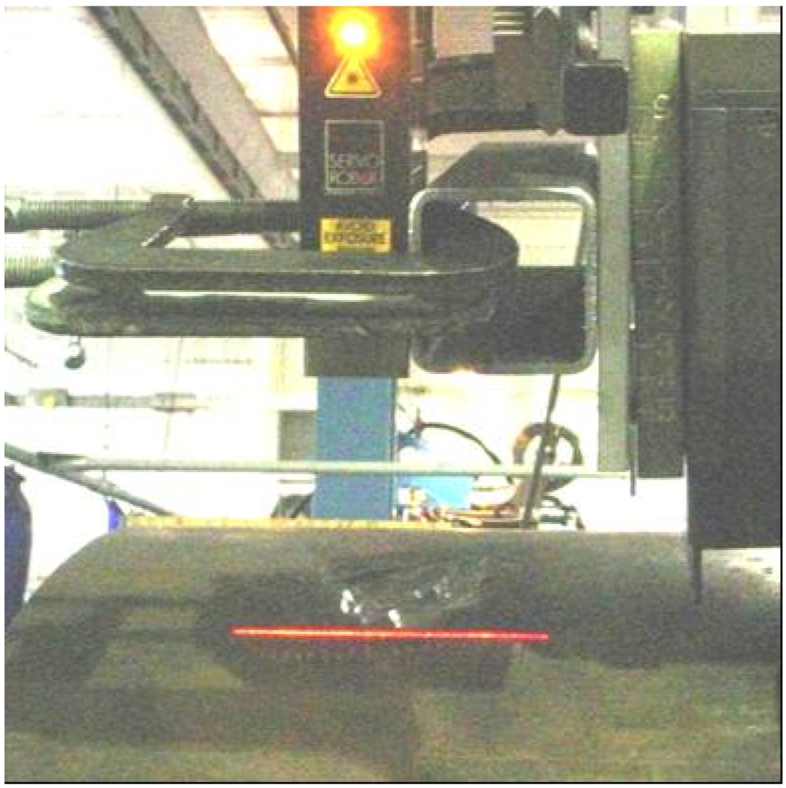

Figure 51. Laser Scanning of Simulated Corrosion Patch

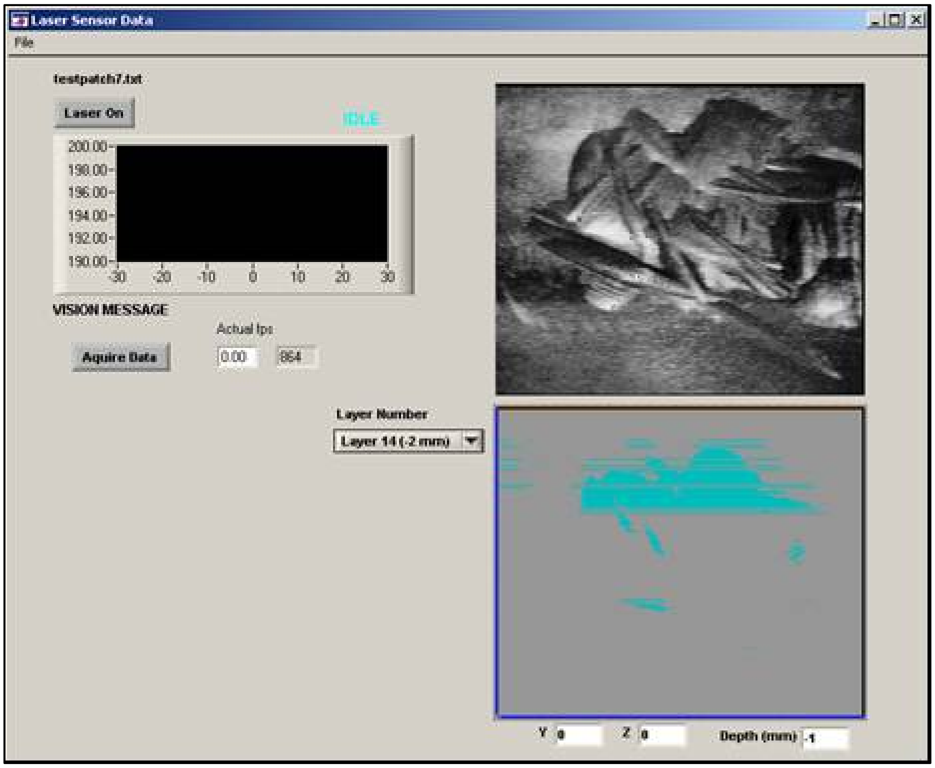

Figure 52. Corrosion Mapping Software Showing Layer #1 of Simulated Corrosion

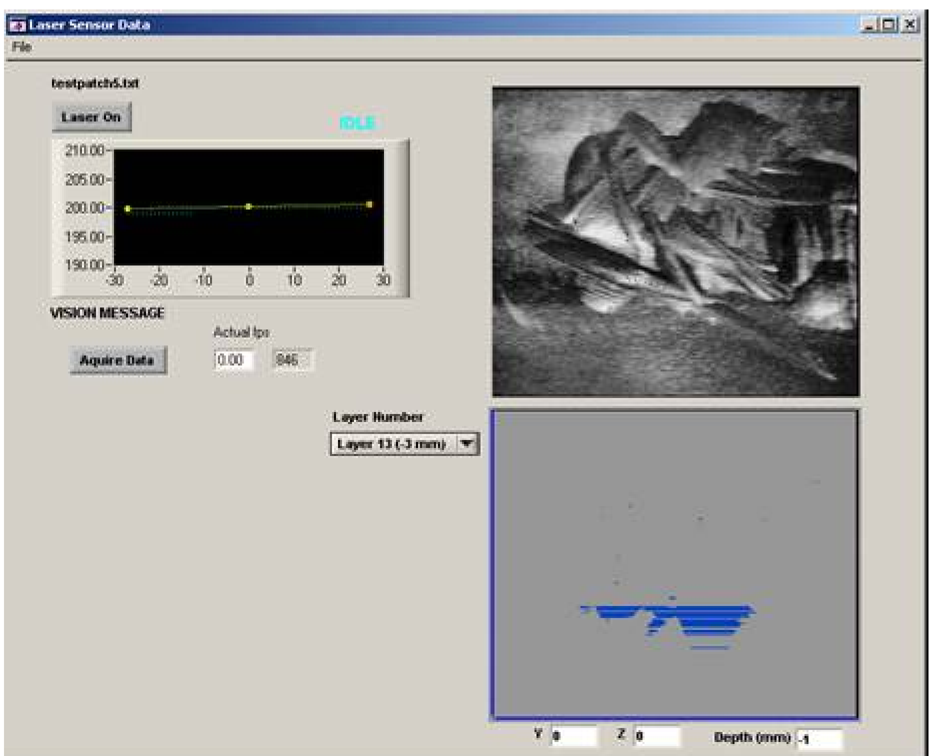

Figure 53. Corrosion Mapping Software Showing Layer #2 of Simulated Corrosion

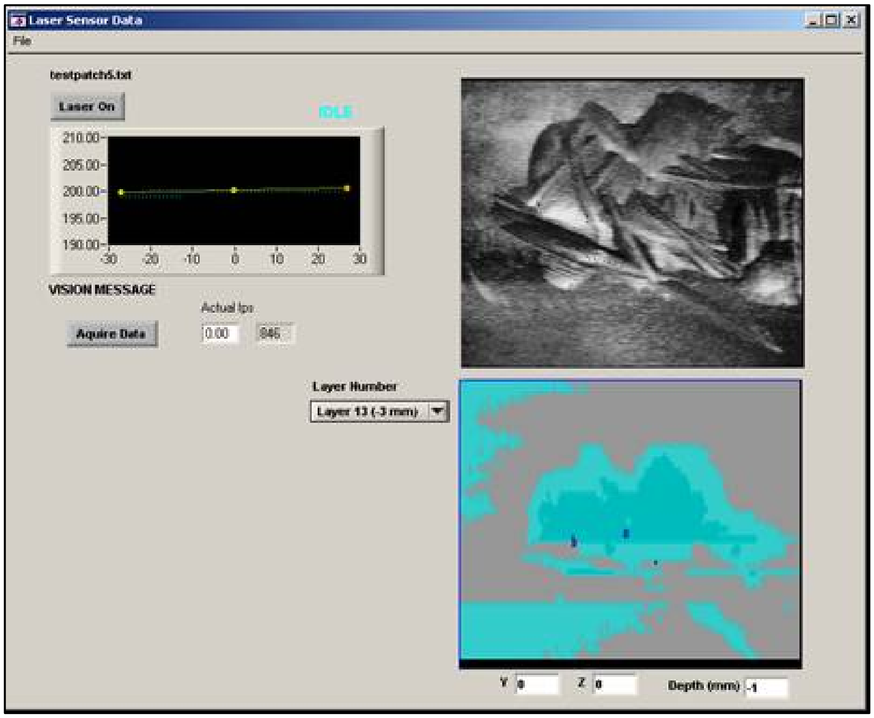

Figure 54. Close-Up of Simulated Corrosion Layer #2

The final laser scanning system trials were completed a section of X65, 36-in. (914 mm) diameter pipe with a wall thickness of 0.375 in. (9.5 mm). The pipe was previously donated to EWI by TransCanada and was a cut out section of pipe from a transmission pipeline with actual corrosion on the outside diameter surface. Prior to scanning the pipe surface was grit blasted (Figure 55). Figure 56 is a close-up of a typical corrosion patch.

Figure 55. 36-in. (914-mm) Diameter Pipe Section after Grit Blast

Figure 56. Close-Up of Typical Corrosion Patch on 36-in. Pipe Section

Figure 57 is a photograph of the laser sensor scanning an actual corrosion patch on the 36-in. (914-mm) diameter pipe section. Figure 58 is a screen shot of the scanned corrosion patch taken from the final version of the GUI.

Figure 57. Laser Sensor Scanning Corrosion on Pipe

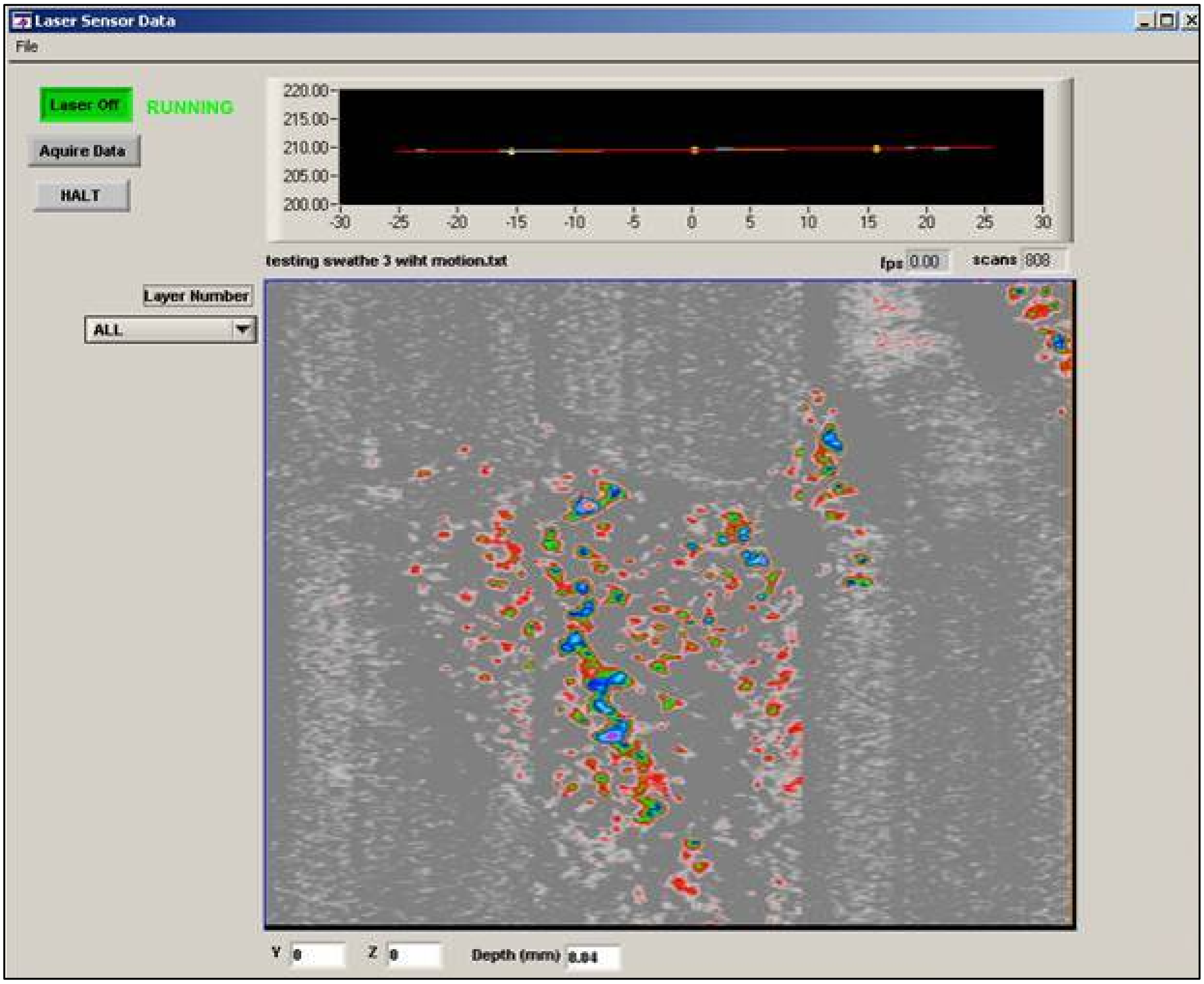

Figure 58. Screen Shot of Scanned Corrosion Patch

To perform the scanning for the longitudinal weld and corrosion patch mapping and seam tracking for the circumferential welds the laser sensor needs to be mounted in two different positions. For the longitudinal weld and corrosion patch mapping the laser needs to be mounted on the torch (Figure 59). For the circumferential weld application the laser needs to be mounted on a bracket (Figure 60). Two brackets were required and mounted on either side of the system to accommodate seam tracking of the circumferential weld joint on both sides of the pipe while travelling in the uphill weld direction (the laser need to be in front of the welding torch during seam tracking).

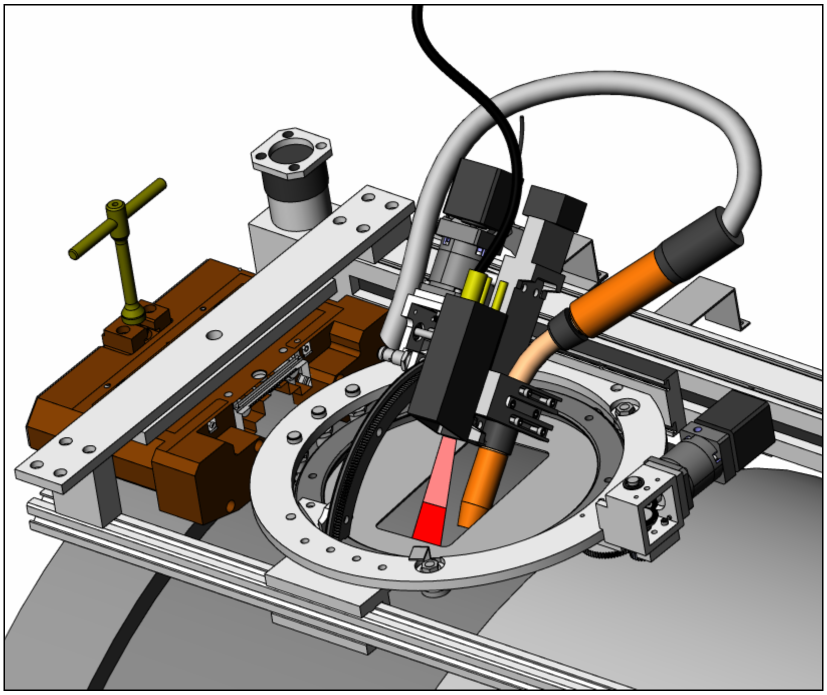

Figure 59. Illustration of Laser Sensor Mounted on Torch

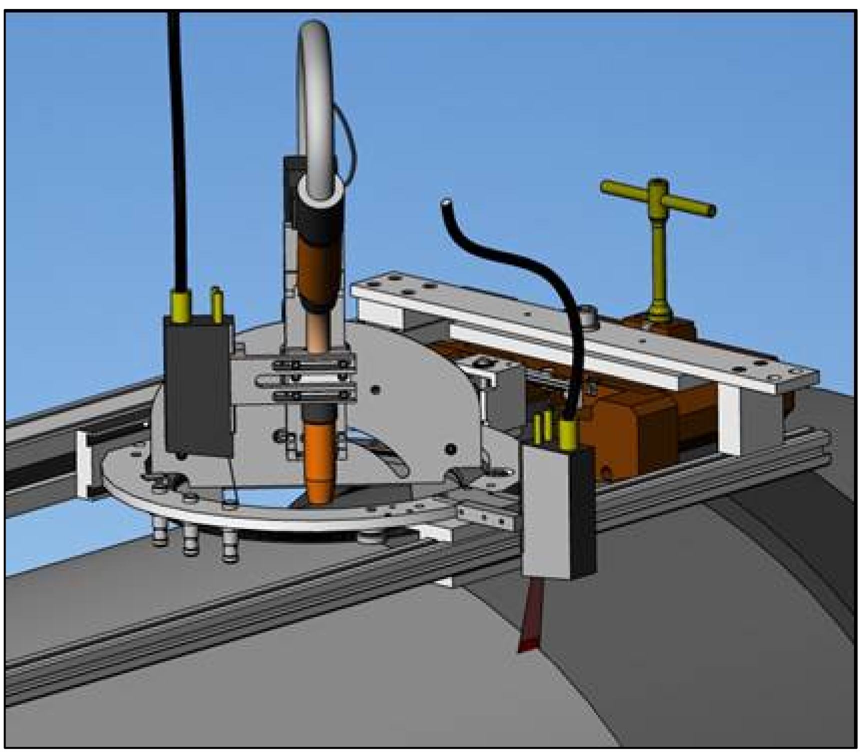

Figure 60. Illustration with Additional Laser Sensor Mounted on Bracket

Shielding During Welding

The torching positioning ring assembly required protection from arc welding debris (e.g., spatter). Several protection devices were built and evaluated. The brass brushes shown in Figure 61 were installed to contain welding spatter to the underside of the ring and to prohibit welding spatter to adhere to the gears. During subsequent welding trials, the brass brushes were trimmed down and then eventually removed, as they obstructed the operator's view of the welding arc.

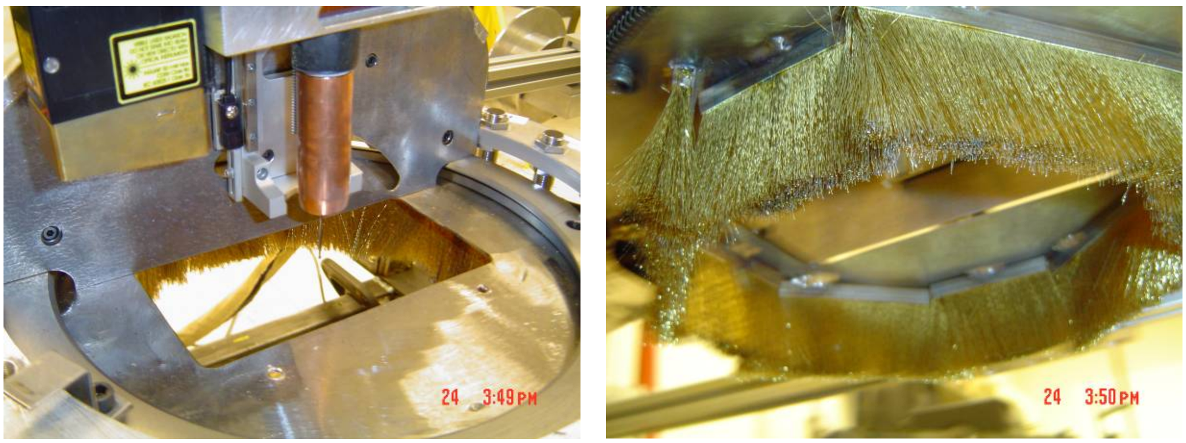

Figure 61. Top and Bottom Views of Anti-Spatter Brush System

As seen in the photo on the left of Figure 61, a shielding plate with a rectangular cut out was added to the bottom of the ring assembly. The shield plate was used to block weld spatter from coming off of the pipe and adhering to the AVC slide. The shielding plate slightly interfered with the operator’s view of the welding arc, but was considered acceptable.

A second, semi-circular shielding plate was mounted perpendicular to the first circular shielding plate (Figure 62). The purpose of the second shielding plate was to further block welding spatter from landing on the gears and AVC slide. This second shielding plate blocked the operator’s view of the welding arc to the point that it was removed from the system during the field trial.

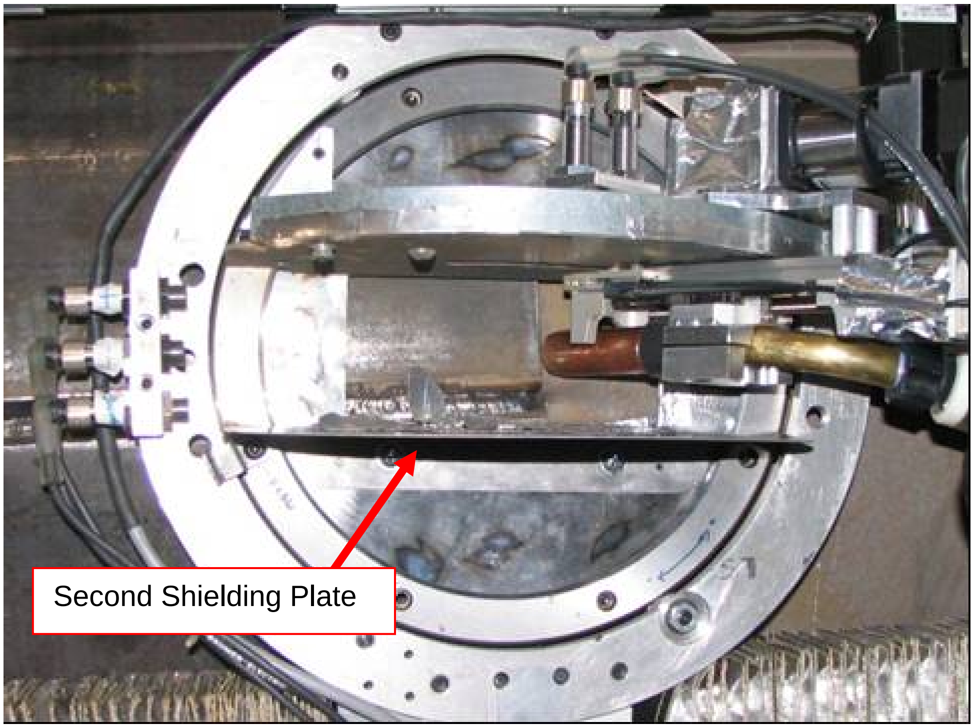

Figure 62. Second Shielding Plate

Developed Software

The automated welding system required software development for a number of systems. These systems needed algorithms to perform task specific activities and software to allow each system to interact. TO alleviate these two issues software was developed for the following systems/activities:

- Laser scan of pipe surface.
- Laser seam tracking during welding.
- Motion control of bug and hardware.
- Integrate with operator interface.
- Remote operator pendant.

The control hardware of the automated welding system is housed in a central control cabinet (Figure 63). The system is controlled by a Sony Toughbook laptop computer, which runs a Main Software Executable program. The Motion Controller is connected by Ethernet to the control cabinet laptop computer. The laser sensor is connected to the control cabinet laptop computer via an RS232 serial port. The Lincoln Electric welding power source is connected to the control cabinet via a digital I/O port. All hardware is using software to communicate to the control cabinet laptop computer.

Figure 63. Central Control Cabinet with Laptop Computer

All software developed in this project was written in ANSI C, National Instruments C-based environment or in Microsoft C++ computer language. When appropriate, software written for a specific hardware device was then converted into a DLL (dynamic link library), which aided in speed and simplicity of the software program. One C-based executable program was used to:

- Coordinate all communications with hardware devices using the DLLs.
- Run the User Interface and manage user requests.
- Monitor status of all hardware devices.

The C-based executable program is the software executable required to operate the automated welding system. The software developments discussed in subsequent sections were developed into DLLs and than attached to the main software program as libraries.

Laser Sensor DLL

The laser performs several functions as part of the hardware on the automated welding system. This functionality is performed by use of a DLL written specifically to communicate with the Servo-Robot EZTrac laser sensor. This DLL is included in the main software program and was written in National Instruments CVI. The Laser Sensor DLL provides the following functionality:

- Seam-tracking during welding of the circumferential sleeve weld.
- Seam-tracking the longitudinal sleeve weld by using a pre-scan method to determine joint geometry along the length of the weld.
- Surface topography mapping to determine location and depth of corrosion on the pipe.

Seam-Tracking Circumferential Sleeve Weld

During the laser seam-tracking during welding of the circumferential sleeve weld the laser travels along the joint at a fixed distance ahead of the torch. The laser measures the joint trajectory changes just prior to being welded. The changes are then sent to the motion system to allow for the adjustment of system, in real-time, to ensure the torch is welding in the correct position along the length of the joint. The laser makes measurements once per millimeter of travel independent of the travel speed. The laser data provides up to 6 points that the software can use to track the position of the joint. Figure 64 shows an example of laser seam tracking data with 6 tracking points. Prior to welding, the Laser Sensor DLL tells the Servo-Robot EZTrac laser the type of weld joint to expect (e.g., lap, fillet, V-groove, etc.), the size of the weld joint, and which of the 6 points to use as the tracking point.

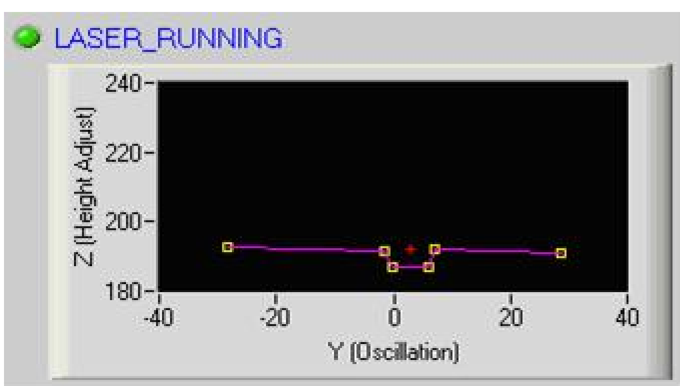

Figure 64. Laser Seam Tracking Data Example with 6 Tracking Points

Seam-Tracking Longitudinal Sleeve Weld

The Laser Sensor DLL is also used to perform seam-tracking on the longitudinal sleeve weld. During seam-tracking of the longitudinal sleeve weld, the laser sensor completes a pre-scan of the weld joint just prior to welding. The motion system moves the laser across the entire length of the weld joint and collects data. The software still uses the same 6 tracking points provided by the laser. After the laser has collected all the data, it calculates the area of the longitudinal weld joint and how the joint trajectory changes along the length. The trajectory changes (i.e., seam-tracking) and is then put into a data array and sent to the motion controller. The laser scans the joint first, and then the seam-tracking data is used while welding. This is not real-time seam tracking, but rather, pre-path programming. The two reasons for seam-tracking using this method are:

- The laser must pre-scan the joint to determine the weld joint area and thus number of layers and beads/layer to weld the joint.
- The laser is mounted on the torch, so if the torch angle changes (work or travel) during welding, the laser is moved out of proper scanning position.

The area of the weld joint determined by the pre-scan is used by the main software program to create a bead map. This bead map determines how many layers are required to weld up the V-groove, and how many bead are required per layer. The bead size is determined by the operator based on past welding experience or as required by the qualified welding procedure.

Surface Topography Mapping of Corrosion

The Laser Sensor DLL also provides all data used to generate the topography of the pipe surface. The laser must be moved over the corroded area while data is being collected. This movement is provided by the motion system. The Laser Sensor DLL provides all the data in X-Y coordinate format. A scan consists of one 3-in. (76.2 mm) wide swathe of about 500 individual X-Y measurements. Surface mapping is performed at a motion speed of 9.4 ipm (4 mm/sec) and a scanning rate of 4 scans per second. This ensures one laser data scan per millimeter of travel.

Laser data is patched together to generate areas that are wider than 3-in. (76.2 mm). The software continues to collect laser data until the motion system alerts the laser to begin patching areas together. Once finished scanning the user-defined area, the entire surface map is created and displayed on the GUI screen. The laser data is displayed in graphical format and can be viewed layer by layer. Figure 65 shows the graphical representation of the laser data.

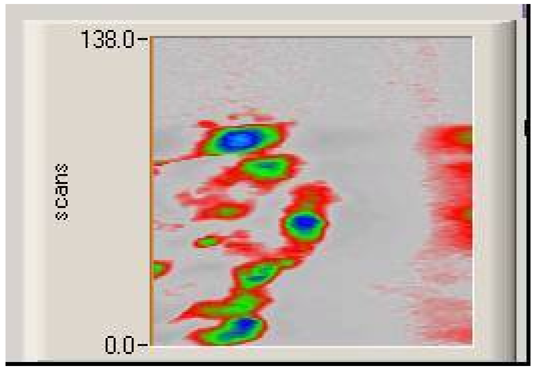

Figure 65. Graphical Representation of Mapped Corrosion Area

The surface topography data is used to determine how best to fill the corroded area. The bead size (determined by operator) is used to calculate how many layers are required to weld the corroded area. The main software program then determines where to deposit weld metal and how many beads are required for each layer. This information is sent to the GUI and is used to populate the welding parameters for each layer.

Motion Control DLL

The Motion Controller is the computer hardware used to coordinate all tasks of the motion system. A Parker 6K8 motion controller was used to control all axes of the automated welding system. The motion controller communicated with the main computer by Ethernet communication. A DLL was developed in National Instruments CVI and in Microsoft C++ computer language to communicate with the Parker 6K8. Each axis on the automated welding system can be controlled using the DLL. A Jogging GUI allows the user to independently move the any axis to any position at any point in time. This is useful for positioning the torch in the joint prior to welding. Coordinated motion is performed by use of individual motion programs written for the Parker controller. These motion programs run a sequence of movements to perform a specific task. The following motion programs were developed for this project:

1. SETUP.prj – performs setup and initialization of all axes connected to the Parker Motion Controller.
2. HOMALL.prj – provides homing routine to home all axes connected to the Parker Motion Controller. Homing routine executes upon startup and at will of operator.
3. DATA.prj – provides data array of variables from longitudinal pre-scan and holds data until motion controller is ready to use for position adjustments to maintain trajectory.
4. HOMEBUG.prj – performs homing of the bug axes only.

5. CIRC.prj – performs coordinated circumferential welding motion including torch work angle, travel angle, welding bug travel, oscillation and torch height control.
6. LONG.prj – performs coordinated longitudinal welding motion including torch work angle, travel angle, welding bug travel and torch height control.
7. LCAN.prj – performs the coordinated motion required to move the laser sensor across the joint for pre-scanning the longitudinal weld.
8. SCANWELD.prj – performs the coordinated motion required to move the laser sensor across the user-defined area to scan the corrosion and generate a surface map.
9. FILL.prj – performs coordinated motion required to weld the longitudinal stringer beads for fill of corrosion patches. Also controls welding bug movement for advancement of next bead in each layer.
10. ELLIPSE.prj – performs coordinated motion required to weld an elliptical outline around the selected area of corrosion on the pipeline.

The Motion Control DLL also provides status as to where each axis is located, (in millimeter increments) and is used in absolute position mode, which was also available on the Jogging GUI.

Operator Interface

The Main software executable program interacts with the operator by the GUI. The GUI provides the means for the operator to tell the automated welding system what task to perform. This software was created in National Instruments CVI computer language. The GUI provides the user with four options when using the automated welding system:

- Jog Mode
- Corrosion Mode
- Circumferential Sleeve Welding Mode
- Longitudinal Sleeve Welding Mode

When operating the system, the first screen an operator sees is the main GUI shown in Figure 66. This screen allows the user to select the desired welding operation or to jog the system.

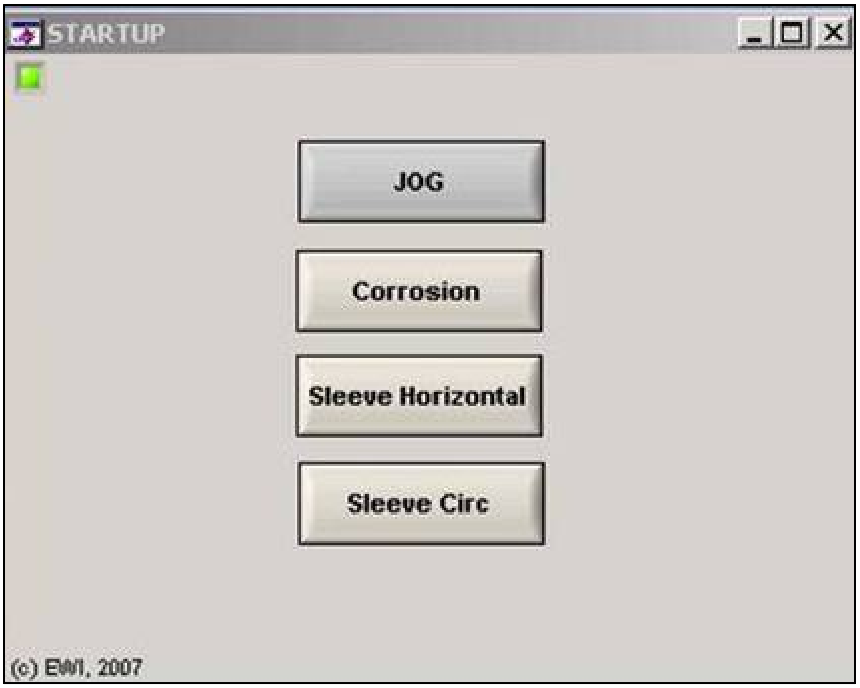

Figure 66. Main GUI Screen

Jog Mode

Jog Mode provides the user with free access to move any part of the automated welding system. This GUI allows the user to view the status of the motion control system, the laser sensor and the welding system. The user can make a weld wherever he wants and move the system however he wants in jogging mode. Figure 67 shows the Jog GUI and the functionality available to the operator.

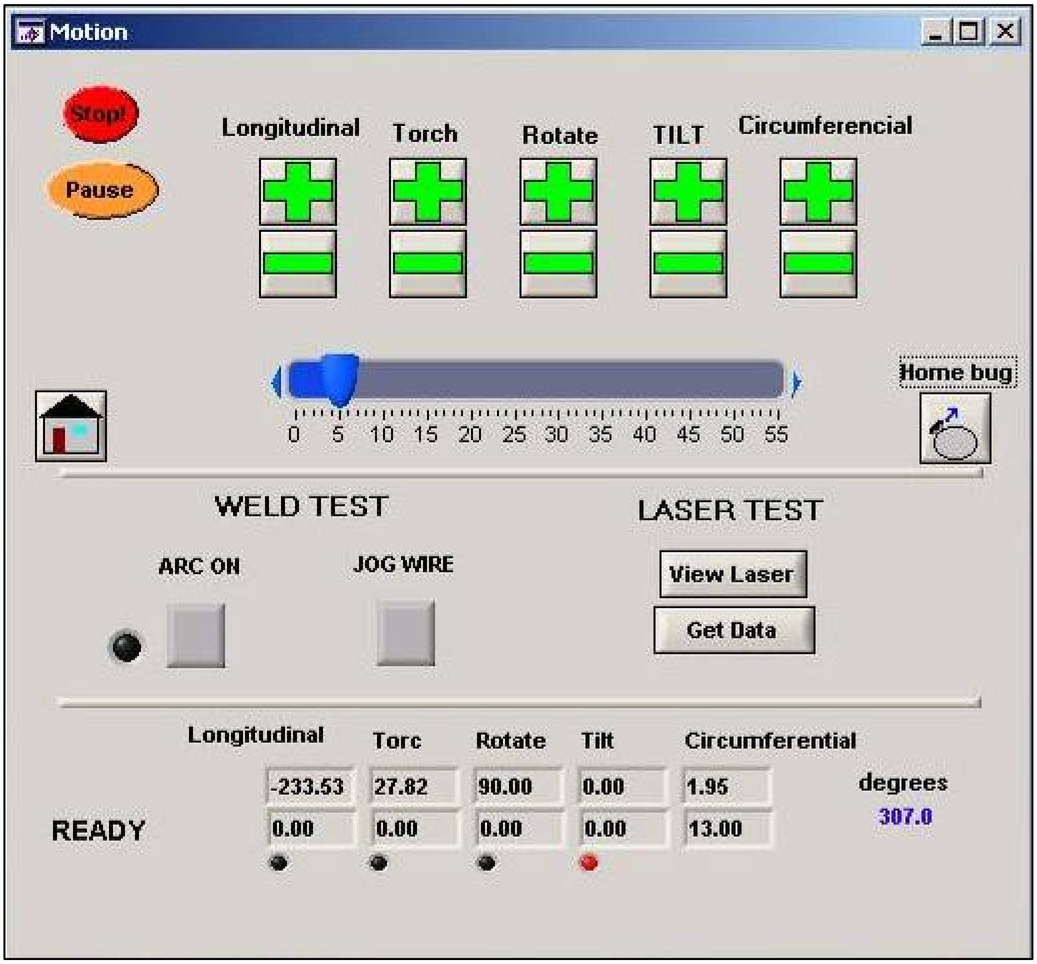

Figure 67. Jog Mode on GUI

<u>Corrosion Mode</u>

Corrosion Mode allows the user to define an area on the pipe that will require a laser scan to map a corroded area. After the area has been defined by prompting the operator to select an Upper Right and a Lower Left point of the corroded area, the system moves the laser and scans the area. A graphical representation of the surface scan is displayed on the graph as shown in Figure 68. Different corrosion layers can be viewed and welding parameters specific to each layer are now visible on the GUI. The user can use the recommended welding sequence or can input different parameters for weld layers, beads in each layer, bead size, travel speed, work and travel angles and weld length (i.e., distance). The user can perform a Dry Run of the welding sequence or Weld the sequence required to fill the joint.

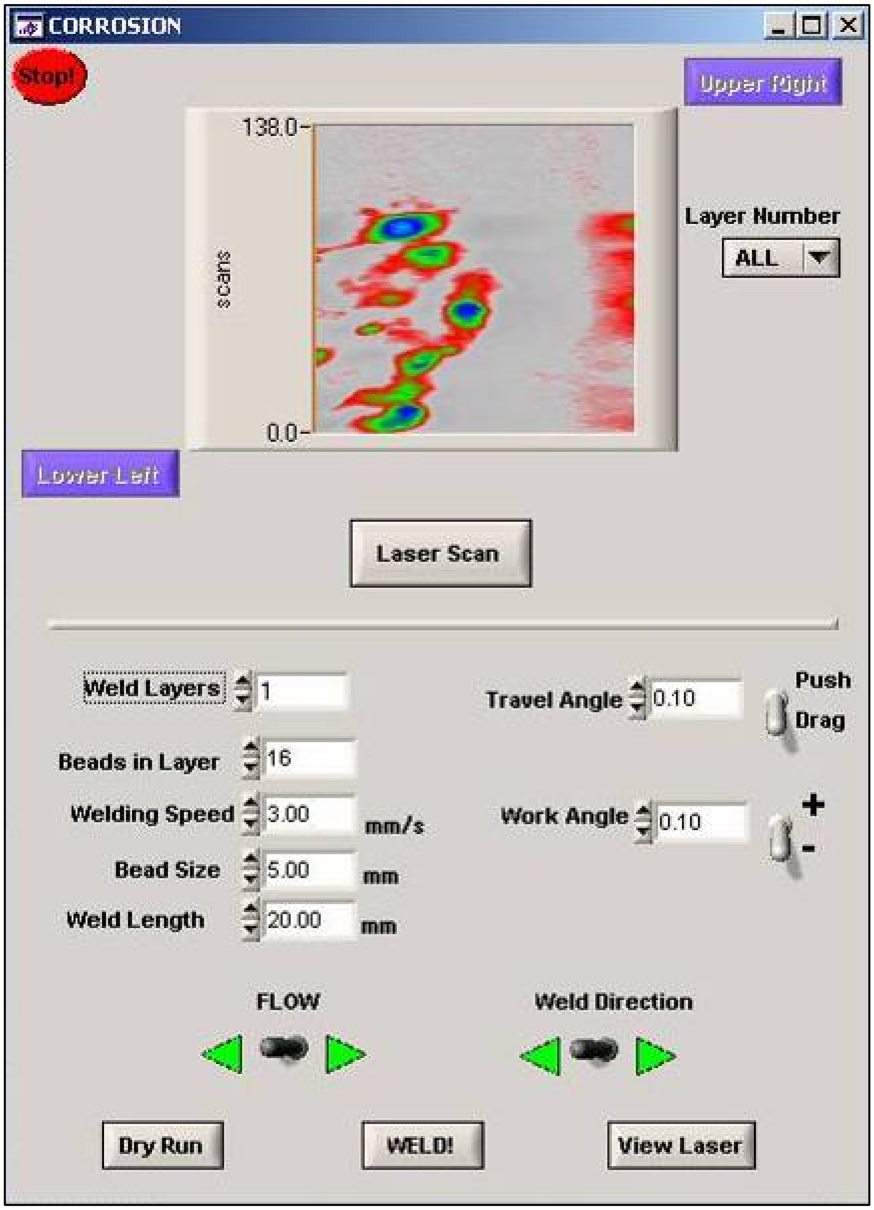

Figure 68. Corrosion Mode GUI Showing Results of Laser Mapping of Corrosion

Circumferential Sleeve Welding Mode

During circumferential welding operations, the user interacts with the system using the GUI shown in Figure 69. This screen has areas for the user to input sleeve thickness, weave speed, weave width, sleeve/pipe dwell, travel speed, and weld length. It also allows the operator to set the work and travel angles of the welding torch (both of which can be reversed with an on screen toggle switch). This interface allows the user to start and stop the weld. It also allows the user to reverse directions, move the center line position, flow direction (direction of gas flow in pipe is used for orienting the automated welding system with a frame of reference), view the laser, and turn on and off the seam tracking.

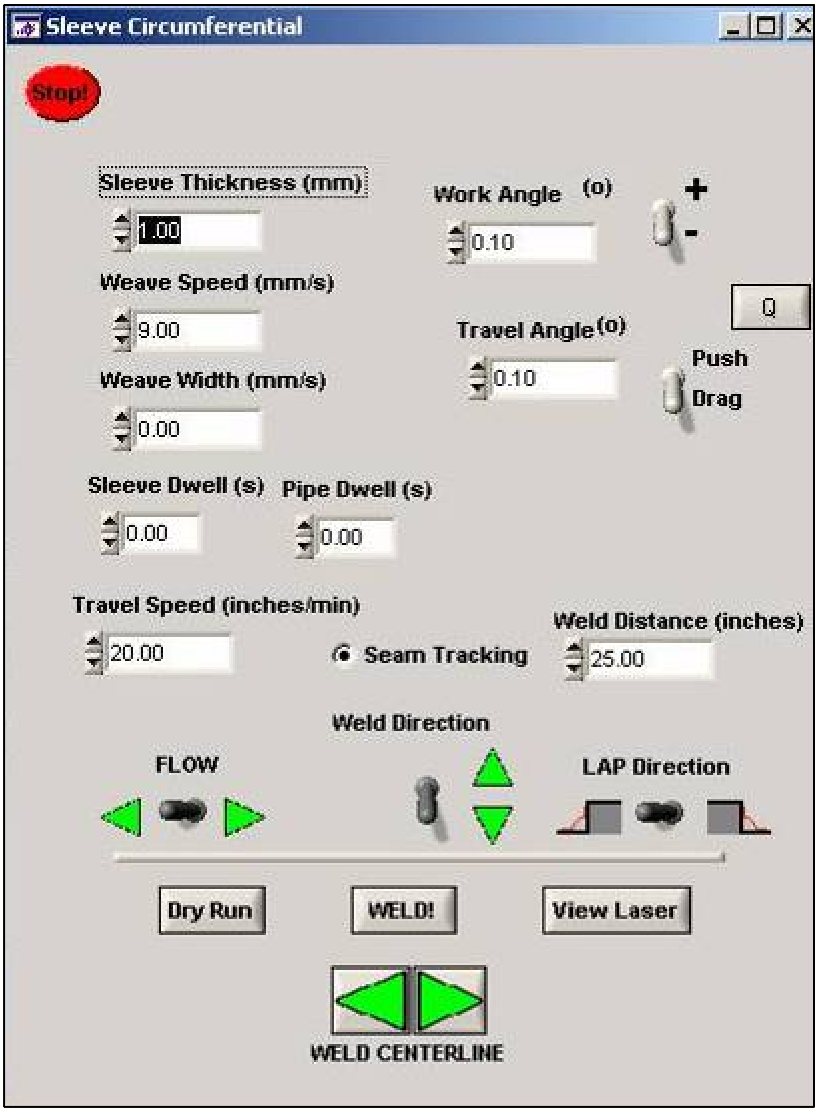

Figure 69. Circumferential Sleeve Mode of GUI

<u>Longitudinal Sleeve Welding Mode</u>

During longitudinal welding operations, the user interacts with the system with the GUI shown in Figure 70. This screen has areas for the user to input sleeve thickness, travel speed, desired number of beads/layers, bead size, work angle, travel angle, the length of the weld, and the number of layers. It also allows the user to pre-scan the joint, dry run the system, start/stop the weld, view the laser, jog the system for alignment, change the welding direction or flow direction.

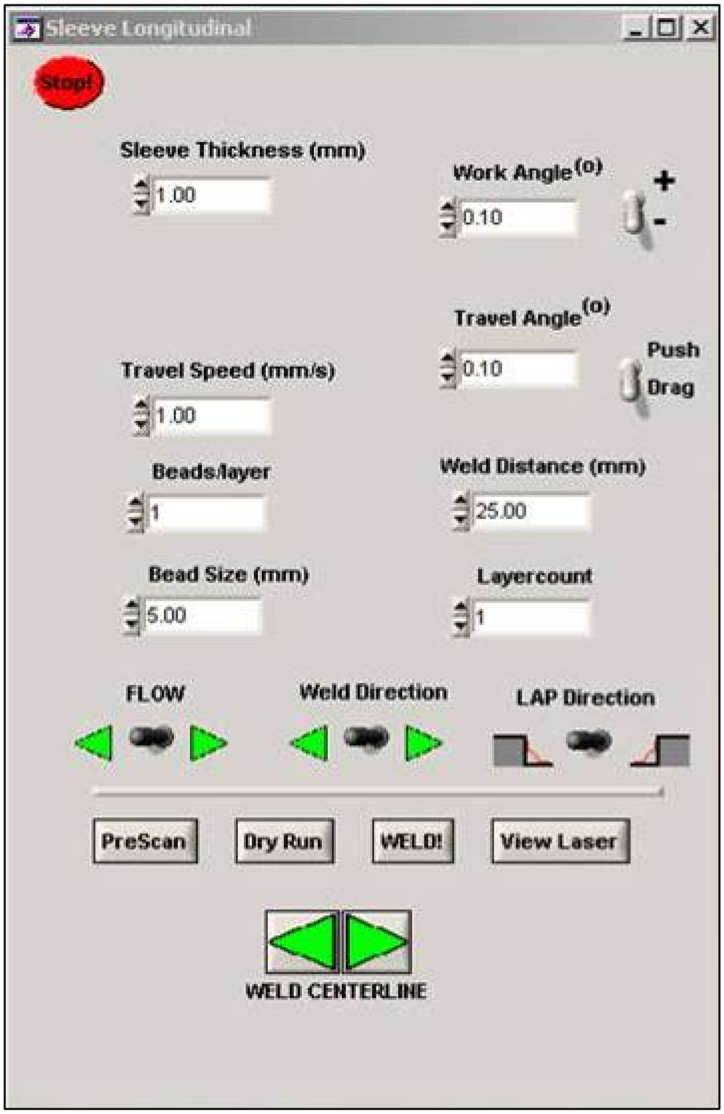

Figure 70. Longitudinal Sleeve Mode of GUI

<u>Remote Operator Pendant</u>

An operator pendant was incorporated for remote control of the automated welding system. The operator pendant displays the same information to the user as the GUI on the control cabinet laptop computer. The functionality was accomplished by using a Wireless Display that connected by WIFI to the control cabinet laptop computer. When connected, the pendant simply acted like the screen on the laptop computer, but gave the user mobility up to 100 yards (91.4 m) away from the laptop. Figure 71 shows the pendant in use. The system responds to the commands the user gives to the pendant as if the user were physically operating the laptop computer. All functionality was retained and the user is able to perform all functions of the automated welding system by using either the control cabinet laptop computer or the remote operator pendant.

Figure 71. Pendant in Use while Remotely Operating the System

System User Manual

A user manual for the alternative system design with the Serimer DASA welding bugs is located in Appendix E.

System Bill of Materials

Table 6 contains the bill of materials for the alternate system design with Serimer DASA welding bugs.

Table 6. Bill of Materials of Alternative System Design with Serimer DASA Welding Bugs

Description	Part Number	Quantity	Vendor
Software - PID Toolkit	779509-03	1	National Instruments
Pipe Stand:: rated @ 2500 lb	2683T26	2	McMaster-Carr
Pipe Stand V Wheels	2683T23	2	McMaster-Carr
Thrust bearing cage assembly	5909K31	5	McMaster-Carr
.032" thick for 1/2" shaft diameter thrust bearing	5909K44	10	McMaster-Carr
Software - Motion Toolkit	778804-03	1	National Instruments
Gear - 30 TEETH 0.8 MOD BRASS SPUR GEAR	A 1B 2MYK08030	2	ROCKFORD CONTROLS OHIO
Gear - 64 TEETH 0.8 MOD STAINLESS SPUR GEAR	S10T08M064S050	1	ROCKFORD CONTROLS OHIO
AVC SLIDE - MP5-3 with 4 carriages under the load plate	MP5-3	1	SMi4motion
360 degree ring slide	R25-255 R360P	1	Ohio Transmission and Pump
180 degree ring slide	R25-255R180P	1	Ohio Transmission and Pump
gear/bearing	RSJ25E	4	Ohio Transmission and Pump
gear/bearing	BHJ25C	3	Ohio Transmission and Pump
6K 8 axis motion controller from Parker	6K8	1	Motion USA
25 pin connector from 6K8 to breakout boards	vm25	4	Motion USA
60 watt power supply for 6K	PS-60W	1	Motion USA
base module for 6k	eym32-ii	1	Motion USA
Analog input module	sim8-an-in	1	Motion USA
Analog output module	SIM8-an-out	1	Motion USA
EAC series stepper motor drive	E-AC	2	Motion USA
NEMA 17 Stepper motor	HV173-01-30	2	Motion USA
10 ft command cable	71-0160137-10	2	Motion USA
gear reducer	pv17fe-010-parkert-hv17	2	Motion USA
Linear Unit Belt-driven Actuator	HLE060-RB-NL-E-1200	1	Motion USA
MS T-NUT	100-2353-01	10	Motion USA
LINEAR SLIDE	30-2828	1	Motion USA
ALUMINUM EXTRUSION 1800 MM LENGTH	12-028x 1800 MM	1	Motion USA

Description	Part Number	Quantity	Vendor
T-NUT	20-055	10	Motion USA
nylon socket head cap screw	95868A197	1	McMaster-Carr
high strength silicon rubber	5787t33	1	McMaster-Carr
6061 aluminum 2 x 2 x 2 inch	6546K271	1	McMaster-Carr
5 mm shoulder bolt	90278a371	3	McMaster-Carr
bevel gears 1:2 ratio	51346Z-48A30A060	2	SDP/SI
EAC series stepper motor drive	E-AC	1	Motion USA
Nema 23 motor	CS*HV233-02-FL-30	1	Motion USA
10 ft command cable	71-0160137-10	1	Motion USA
120 vac input stepper drive	pdo2035	1	Motion USA
25 pin cable 6K8 to EAC drive	71-016137-10	1	Motion USA
Proximity sensors	IFRW12P1501/S14L	2	Baumer
Prox sensor Cables	ESW33SH1000	2	Baumer
Spur Gear	A1B2MYK08064	1	SDP/SI
Shoulder bolt	90278A403	1	Mcmaster
Bearing	BHJ 25C	1	BishopWisecarver
limit/home switches for AVC slide	gxl-8F	3	smi4motion
Bernard MIG Torch	AQT-4-300-L-I-E-D	1	Valley National Gas
Metric SHCS	91290A348	1	McMaster-Carr
Laser cut sheet metal spatter guard	n/a	1	AllFab
Hoffman Cabinet	pgld1275DC	1	Graybar
Hoffman Cabinet caster kit	pc1m12	1	Graybar
Hoffman Cabinet back panel	pp116G	1	Graybar
Hoffman Cabinet heater	dah8001b	1	Graybar
30 MM PANEL CUTOUT PLASTIC PUSH-BUTTON SWITCH, ILLUMINATED PROJECTING, MAINTAINED, GREEN, 120V	7403k933	1	McMaster-Carr
DIN RAIL, 304 SS, DIN 3, 35MM WD, 7.5MM HT, 1 METER LG	8961K42	2	McMaster-Carr
DIN-RAIL AC/DC TO DC TRANSFORMER, 24 VDC OUTPUT, 50 WATTS, 2.1 AMPS	7009K76	2	McMaster-Carr
pnp limit switches	r-gxl-8fp-r	4	Smi4motion
pnp limit switches	IFRW12P1501/S14L	4	Motion USA
3pin cable 10 meter	ESW33SH1000	4	Motion USA
inclinometer	a2t-s	1	US Digital

Description	Part Number	Quantity	Vendor
incl adapter	ad2-b	1	US Digital
incl 30 ft cable	ca-1769-30ft	1	US Digital
IPS linear carriage block	30-2822	1	Motion USA
bellows	cqm#18286	1	Motion USA
bellows	cqm#18287	1	Motion USA
timing belt/pulley/flange	a6r25m040090	4	SDP/SI
Panasonic Toughbook Computer	toughbook	1	Panasonic
panasonic wireless display	cf-vdw07chm	1	Panasonic
wireless display dock	cf-veb081U	1	Panasonic
toughbook automobile adapter	pa1555-655	1	Panasonic
toughbook port replicator	cf-veb272a2w	1	Panasonic
90 degree cord grip 3/4 "	7466 k544	2	McMaster-Carr
straight cord grip 3/4"	7529 k544	6	McMaster-Carr
accessory kit for 3/4"	7466 k38	6	McMaster-Carr
polycarbonate enclosure	7360k752	2	McMaster-Carr
conn,db9m waterproof	wpsd9p	1	Black Box
3 pin cable male	69355K55	2	McMaster-Carr
3 pin socket female	69355K58	4	McMaster-Carr
6 pin cable male	69355k71	1	McMaster-Carr
9 pin cable male	69355K41	2	McMaster-Carr
9 pin socket female	69355K44	2	McMaster-Carr
12 pin socket female	69355k18	2	McMaster-Carr
12 pin cable male	69355k15	2	McMaster-Carr
touch safe terminal block	8839t24	1	McMaster-Carr
Din rail mount circuit breaker	7026k216	1	McMaster-Carr
Easy open polyester wrap-around sleeving	2649k45	2	McMaster-Carr
Spiral bundling wrap-around sleeving	7432k42	1	McMaster-Carr
BRASS PULL RING HAND-RETRACTABLE PLUNGER, LOCK NOSE, 1/2"-13, W/LOCK, 1.0-4.0# END FORCE	8482A732	2	McMaster-Carr
WATERTIGHT YELLOW STRAIGHT-BLADE DEVICE, NEMA 5-15 MALE RECEPTACLE, 125 VAC, 15 AMPS	7140K55	1	McMaster-Carr
16 MM PANEL CUTOUT PLASTIC SWITCH, EMERGENCY STOP,	65645K61	1	McMaster-Carr

Description	Part Number	Quantity	Vendor
TWIST RELEASE, SPST-NC, MAINTAINED			
Serimer DASA STX Saturnax bug system	STX5	2	Serimer DASA
Serimer DASA STX Controller Cabinet	STX5 Controller	2	Serimer DASA
Serimer DASA STX rigid bands for 36 inch diameter pipe	STX Band for 36"	2	Serimer DASA
db15hd mail breakout board	brk15hdm-r-din	2	Winford Engineering
db15hd extension cable m-f	ext15hd-6	4	Winford Engineering
Servo drives	viX250Ae-drive	4	Motion USA
32 V DC Motor / 134:1 Gearhead / 500ct Encoder Combo	35NT2R82426SP50	4	SDP/SI
1/4 inch bore flanged radial bearing	fs1kdd7	4	SDP/SI

1.3.3.2 Final EWI System Design

This report subsection describes system modifications necessary to accommodate the pipe size available during the TransCanada field trial.

During the coordination for the field trial, TransCanada was only able to obtain a 30-in. (762-mm) diameter pipe. EWI attempted to obtain a 30-in. (762-mm) track for the Serimer DASA based welding system. At that time, EWI discovered that the Serimer DASA welding bugs would only work on a 20-in. (508-mm) or a 36-in. (914-mm) diameter circular track.

EWI contacted Bug-O Systems to determine if a Bug-O track and bug system would work on a 30-in (762-mm) diameter pipe. Bug-O welding bugs were found to work on any pipe diameter from 20-in. (508-mm) to 44-in. (1,118-mm) inclusively. The circumferential Serimer DASA welding bugs and circumferential tracks were replaced by Bug-O welding bugs and circumferential rails. The estimated cost of equipment that should be removed from the system was $6,000. The cost of the new Bug-O equipment was approximately $13,000. Given the fact that this change occurred three months before the end of the project, the equipment budget was exhausted. EWI obtained permission from PRCI to sell the $6,000 of equipment to another EWI project and PRCI gave EWI an additional $7,000 to assist in purchasing the Bug-O equipment needed for the last minute redesign. A solid model of the final system design is shown in Figure 72 and photo of the final system is shown in Figure 73.

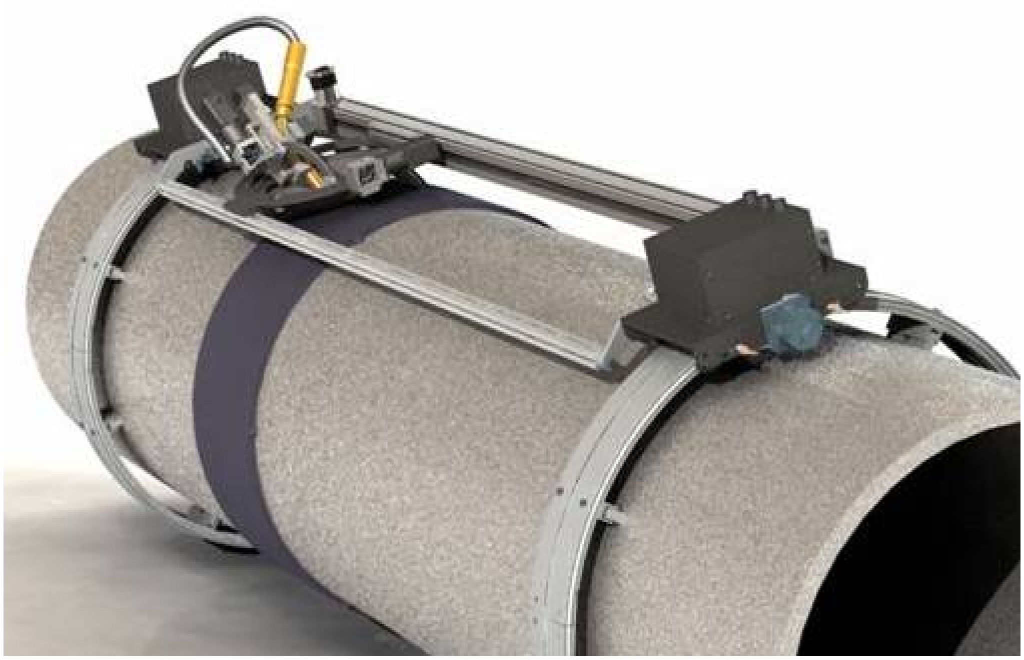

Figure 72. Solid Model of Final Design with Bug-O Components

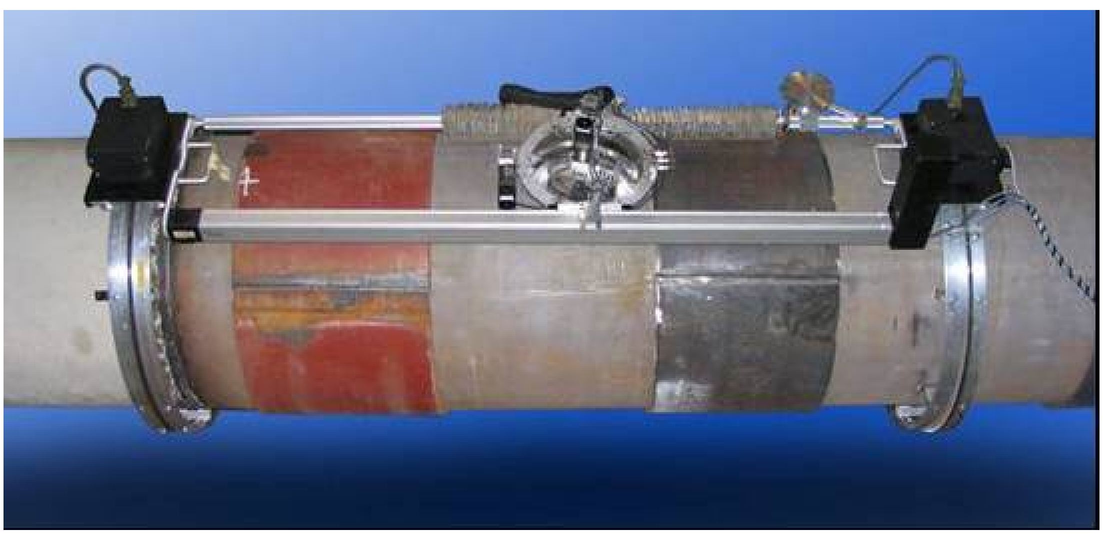

Figure 73. Photo of Final System with Bug-O Equipment

System User Manual

The operating commands of the system with Bug-O welding bugs is no different than the previous configuration with Serimer DASA welding bugs; therefore, the user manual in Appendix E is valid for the final system configuration as well.

System Bill of Materials

Table 7 contains the bill of materials for the alternative system design with Bug-O welding bugs.

Table 7. Bill of Materials of Final System with Bug-O Equipment

Description	Part Number	Quantity	Vendor
Magnets for track		2	Bug-O
Software - PID Toolkit	779509-03	1	National Instruments
Pipe Stand:: rated @ 2500 lb	2683T26	2	McMaster-Carr
Pipe Stand V Wheels	2683T23	2	McMaster-Carr
Thrust bearing cage assembly	5909K31	5	McMaster-Carr
.032" thick for 1/2" shaft diameter thrust bearing	5909K44	10	McMaster-Carr
Software - Motion Toolkit	778804-03	1	National Instruments
Gear - 30 TEETH 0.8 MOD BRASS SPUR GEAR	A 1B 2MYK08030	2	ROCKFORD CONTROLS OHIO
Gear - 64 TEETH 0.8 MOD STAINLESS SPUR GEAR	S10T08M064S050	1	ROCKFORD CONTROLS OHIO
AVC SLIDE - MP5-3 with 4 carriages under the load plate	MP5-3	1	SMi4motion.com
360 degree ring slide	R25-255 R360P	1	Ohio Transmission and Pump
180 degree ring slide	R25-255R180P	1	Ohio Transmission and Pump
gear/bearing	RSJ25E	4	Ohio Transmission and Pump
gear/bearing	BHJ25C	3	Ohio Transmission and Pump
6K 8 axis motion controller from Parker	6K8	1	Motion USA
25 pin connector from 6K8 to breakout boards	vm25	4	Motion USA
60 watt power supply for 6K	PS-60W	1	Motion USA
base module for 6k	eym32-ii	1	Motion USA
Analog input module	sim8-an-in	1	Motion USA
Analog output module	SIM8-an-out	1	Motion USA
EAC series stepper motor drive	E-AC	2	Motion USA
NEMA 17 Stepper motor	HV173-01-30	2	Motion USA
10 ft command cable	71-0160137-10	2	Motion USA
gear reducer	pv17fe-010-parkert-hv17	2	Motion USA
Linear Unit Belt-driven Actuator	HLE060-RB-NL-E-1200	1	Motion USA
MS T-NUT	100-2353-01	10	Motion USA
LINEAR SLIDE	30-2828	1	Motion USA
ALUMINUM EXTRUSION 1800 MM LENGTH	12-028x 1800 MM	1	Motion USA
T-NUT	20-055	10	Motion USA
nylon socket head cap screw	95868A197	1	McMaster-Carr
high strength silicon rubber	5787t33	1	McMaster-Carr
6061 aluminum 2 x 2 x 2 inch	6546K271	1	McMaster-Carr
5 mm shoulder bolt	90278a371	3	McMaster-Carr
bevel gears 1:2 ratio	51346Z-48A30A060	2	SDP/SI

Description	Part Number	Quantity	Vendor
EAC series stepper motor drive	E-AC	1	Motion USA
Nema 23 motor	CS*HV233-02-FL-30	1	Motion USA
10 ft command cable	71-0160137-10	1	Motion USA
120 vac input stepper drive	pdo2035	1	Motion USA
25 pin cable 6K8 to EAC drive	71-016137-10	1	Motion USA
Proximity sensors	IFRW12P1501/S14L	2	Baumer
Prox sensor Cables	ESW33SH1000	2	Baumer
Spur Gear	A1B2MYK08064	1	SDP/SI
Shoulder bolt	90278A403	1	McMaster-Carr
Bearing	BHJ 25C	1	BishopWisecarver
limit/home switches for AVC slide	gxl-8F	3	smi4motion
Bernard MIG Torch	AQT-4-300-L-I-E-D	1	Valley National Gas
Metric SHCS	91290A348	1	McMaster-Carr
Laser cut sheet metal spatter guard	n/a	1	AllFab
Hoffman Cabinet	pgld1275DC	1	Graybar
Hoffman Cabinet caster kit	pc1m12	1	Graybar
Hoffman Cabinet back panel	pp116G	1	Graybar
Hoffman Cabinet heater	dah8001b	1	Graybar
30 MM PANEL CUTOUT PLASTIC PUSH-BUTTON SWITCH, ILLUMINATED PROJECTING, MAINTAINED, GREEN, 120V	7403k933	1	McMaster-Carr
DIN RAIL, 304 SS, DIN 3, 35MM WD, 7.5MM HT, 1 METER LG	8961K42	2	McMaster-Carr
DIN-RAIL AC/DC TO DC TRANSFORMER, 24 VDC OUTPUT, 50 WATTS, 2.1 AMPS	7009K76	2	McMaster-Carr
pnp limit switches	r-gxl-8fp-r	4	Smi4motion
pnp limit switches	IFRW12P1501/S14L	4	Motion USA
3pin cable 10 meter	ESW33SH1000	4	Motion USA
inclinometer	a2t-s	1	US Digital
incl adapter	ad2-b	1	US Digital
incl 30 ft cable	ca-1769-30ft	1	US Digital
IPS linear carriage block	30-2822	1	Motion USA
bellows	cqm#18286	1	Motion USA
bellows	cqm#18287	1	Motion USA
timing belt/pulley/flange	a6r25m040090	4	SDP/SI
Panasonic Toughbook Computer	toughbook	1	Panasonic
Bug-O GANTRY XX CONTROL BOX 120 VAC	MUG-1680-XX	1	Weld Tooling Corp/Bug-O
Bug-O TUBE CARRIAGE	BUG-5910	2	Weld Tooling Corp/Bug-O
Bug-O DRIVE UNIT W/ ENCODER & BRAKE	POV-1030	2	Weld Tooling Corp/Bug-O
Bug-O CONTROL CABLES	SP-070313B	2	Weld Tooling Corp/Bug-O
Bug-O RING RAIL W/ HINGE & LATCH	BRR-3100-30	2	Weld Tooling Corp/Bug-O
Aluminum triangular spacers with threaded hex bolt for Bug-O rail	custom	16	custom part
panasonic wireless display	cf-vdw07chm	1	Panasonic
wireless display dock	cf-veb081U	1	Panasonic

Description	Part Number	Quantity	Vendor
toughbook automobile adapter	pa1555-655	1	Panasonic
toughbook port replicator	cf-veb272a2w	1	Panasonic
90 degree cord grip 3/4 "	7466 k544	2	McMaster-Carr
straight cord grip 3/4"	7529 k544	6	McMaster-Carr
accessory kit for 3/4"	7466 k38	6	McMaster-Carr
polycarbonate enclosure	7360k752	2	McMaster-Carr
conn,db9m waterproof	wpsd9p	1	Black Box
3 pin cable male	69355K55	2	McMaster-Carr
3 pin socket female	69355K58	4	McMaster-Carr
6 pin cable male	69355k71	1	McMaster-Carr
9 pin cable male	69355K41	2	McMaster-Carr
9 pin socket female	69355K44	2	McMaster-Carr
12 pin socket female	69355k18	2	McMaster-Carr
12 pin cable male	69355k15	2	McMaster-Carr
touch safe terminal block	8839t24	1	McMaster-Carr
Din rail mount circuit breaker	7026k216	1	McMaster-Carr
Easy open polyester wrap-around sleeving	2649k45	2	McMaster-Carr
Spiral bundling wrap-around sleeving	7432k42	1	McMaster-Carr
BRASS PULL RING HAND-RETRACTABLE PLUNGER, LOCK NOSE, 1/2"-13, W/LOCK, 1.0-4.0# END FORCE	8482A732	2	McMaster-Carr
WATERTIGHT YELLOW STRAIGHT-BLADE DEVICE, NEMA 5-15 MALE RECEPTACLE, 125 VAC, 15 AMPS	7140K55	1	McMaster-Carr
16 MM PANEL CUTOUT PLASTIC SWITCH, EMERGENCY STOP, TWIST RELEASE, SPST-NC, MAINTAINED	65645K61	1	McMaster-Carr

1.3.4 Weld Procedure Qualification

For Task 5, the original plan called for weld procedures to be developed on sample pipes of Grades X65, X80 and X100 with simulated in-service conditions and subsequent testing in accordance with API 1104 Appendix B (19th Edition). In an effort to provide greater value to the project sponsors and the pipeline industry as a whole the project team decided to include X120 material instead of using the lower strength X65 pipe since in-service welding on X65 grade material has been performed and is readily available in open literature. X120 is a newer material, which has no published in-service weldability data available.

The X80 material was provided by EWI from its existing inventory. The X100 material was provided by BP via the inventory at Cranfield University and the X120 material was provided by ExxonMobil.

1.3.4.0 In-Service Weld Procedure Experimental Approach

In-service weld qualification was conducted to determine if X80, X100 and X120 pipeline steel could be acceptably welded under simulated pipeline conditions. As mentioned previously, the main concerns when welding onto an in-service pipeline is burn-through and hydrogen cracking. For this application, burn-through was not a concern because the pipe wall thickness of the material being tested exceeded 0.25 in. (6.4 mm). Hydrogen cracking, on the other hand, was a concern because in-service welding has never been performed on high strength pipeline steel.

To evaluate the hydrogen cracking concerns simulated in-service welds were made. The setup for these experiments was developed by EWI and has been used extensively in other in-service welding programs. The simulated in-service pipeline setup was fabricated by welding sections of the X80, X100 and X120 pipe material into a pipe length, which is equipped with in and out water lines creating a simulated pipeline. Smaller pipe sections of each grade were then attached to the simulated pipeline to simulate a full encirclement sleeve (Figure 74). The simulated sleeves were 6-in. (152.4-mm) by 12-in. (304.8-mm), thus allowing a 12-in. (304.8-mm) long simulated in-service fillet weld to be deposited. A gap of 0.062-in. (1.6-mm), similar to that of a controlled thermal severity (CTS) test specimen, was used between the simulated sleeves and simulated pipeline. This geometry allows the welding stresses to be concentrated at the root of each weld. The simulated fillet welds were deposited using the GMAW and FCAW on all three grades of pipe for a total of six welds. All welds were made with the panels in the 45° degree position about the pipeline axis (i.e., between the 12 and 3 o'clock positions) with an uphill welding progression.

Water was circulated through the simulated pipeline (i.e., the test fixture) at an approximate flow rate of 5 gallons per minute (gpm) at ambient pressure and temperature during welding. The simulated thermal conditions that result from this experimental setup have been shown to result in weld cooling rates that are as fast as or faster than most typical in-service welding applications.

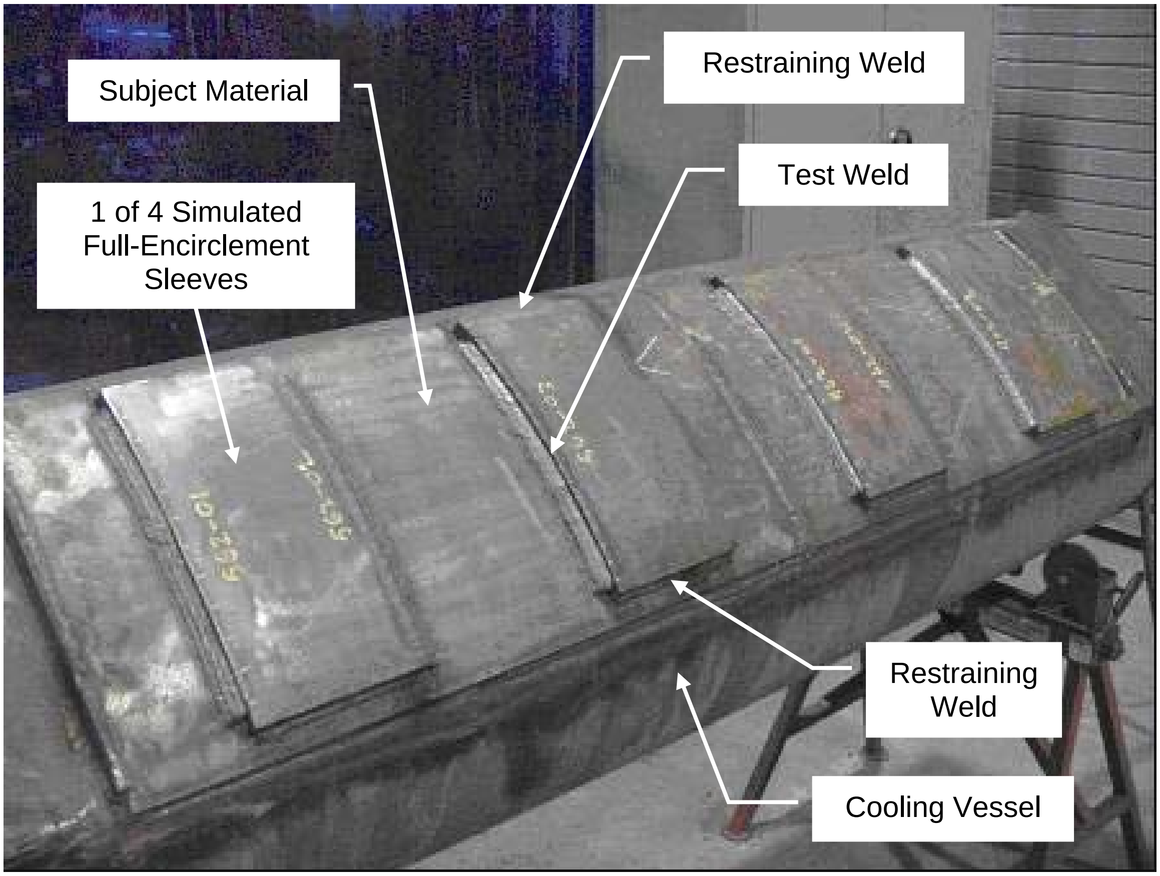

Figure 74. Test Fixture for In-Service Weld Procedure Development

Figure 75 shows a close up of the weld joint created by the simulated in-service pipeline and simulated sleeve prior to fillet welding.

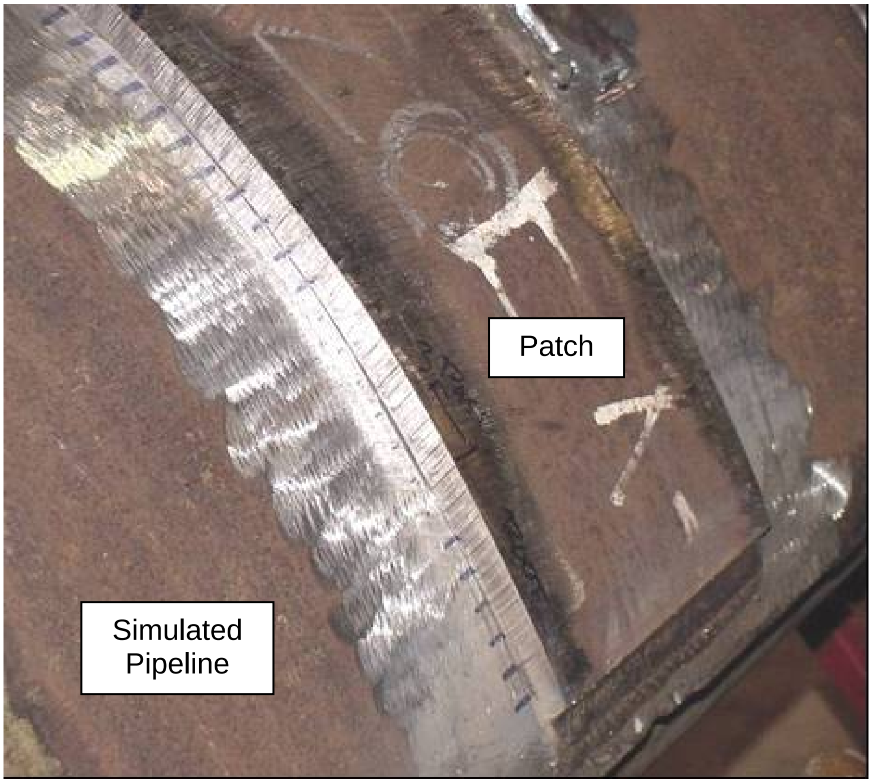

Figure 75. Typical Patch Tacked In Preparation for Fillet Welding

To produce in-service welding procedures which closely represented the welds which would be made by the automated welding system, it was decided to make the simulated in-service welds using a six axis FANUC welding robot. The robot allowed for better control over the welding and weaving parameters. Figure 76 shows the other simulated pipeline and the six axis FANUC welding robot that was used to deploy both GMAW and FCAW.

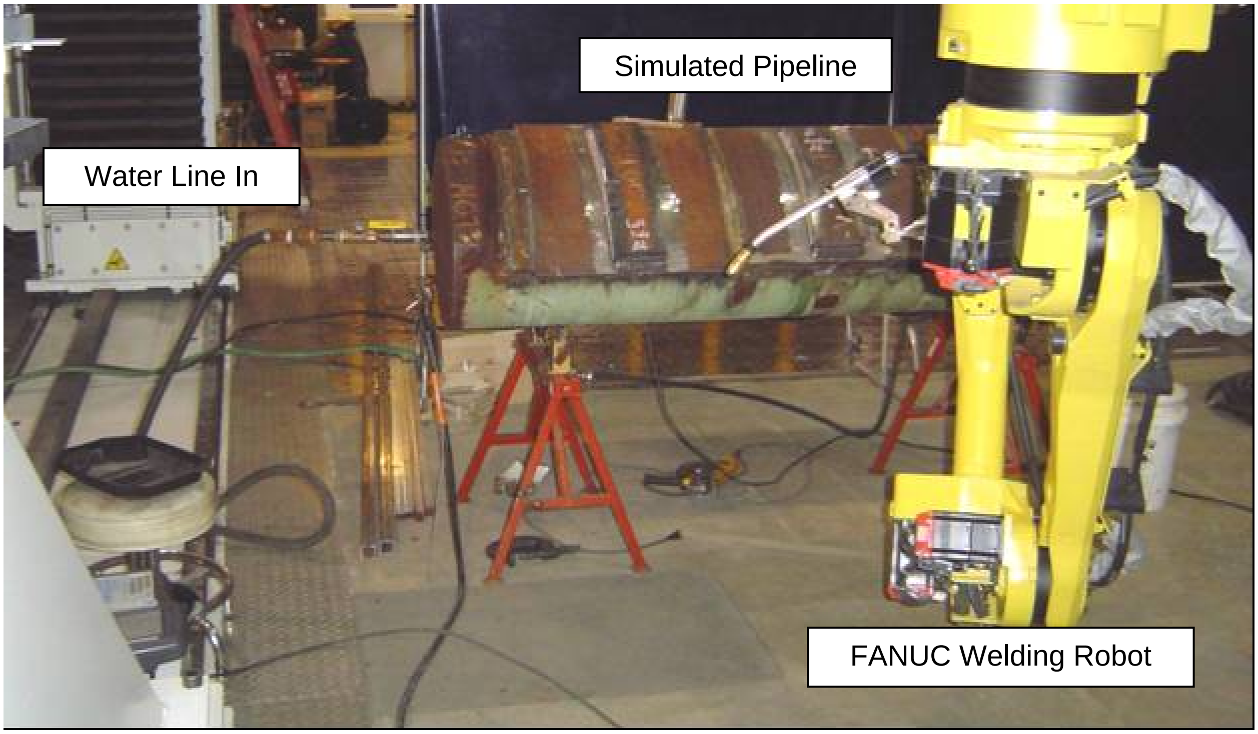

Figure 76. Simulated Pipeline and FANUC Welding Robot

Figure 77 shows the typical position of the welding torch prior to making the root pass on a simulated sleeve in the uphill welding progression from 3 to 12 o'clock.

Figure 77. Welding Torch Positioned Prior to Typical Root Pass

The two consumables that were used to deposit the simulated in-service fillet welds on the X80, X100 and X120 pipe sections were an ESAB Spoolarc 86 (AWS/ASME SFA5.17; ER70S-6 classification) GMAW consumable and an ESAB Dual Shield II 70T-12H4 (AWS A5.20; E71T-1MJH4/T-12MJH4 classification) gas shielded FCAW consumable. Both electrodes diameters were 0.045-in. (1.1 mm). The shielding gas for both welding processes was 75 Ar/25 CO_2.

The initial welding parameters (e.g., amps and volts) were provided by Cranfield University. The Cranfield welding parameters were screened by making some uphill welds on a lap joint to verify that the welding parameters could be transferred to the current welding application. The screening weld acceptability was based on visual inspection and cross-sections of the welds to assure complete penetration. As a result of the screening trials there were some modifications to the initial welding parameters prior to welding the simulated in-service weld trials. It is important to note that there was no attempt to optimize the welding or weaving parameters prior to depositing the simulated in-service welding trials. Once acceptable welding parameters were determined from the screening trials the parameters were transferred to the robot for the simulated in-service fillet weld trials.

1.3.4.1 Evaluation Methodology

The completed welds were allowed to sit for approximately one week, after which four metallographic sections and four mechanical test specimens were removed from each weld. The mechanical testing included both the nick-break test (fracture) and toe bend tests that are specified in API 1104 Appendix B (19th Edition). These tests were used because of their proven ability to expose root and toe cracks in sleeve fillet welds (see Figure 78 for fillet weld nomenclature). A shallow saw cut was made in the face of the weld of each mechanical test specimen, after which the top portion of the specimen was removed by fracturing the weld through the throat. This was accomplished by first driving a chisel into the 0.062-in. (1.6-mm) gap between the sleeve and pipe portions of the specimen and then bending the top portion away using a wrench. The fracture surfaces were visually examined for cracking and suspect areas will be further examined using a binocular light microscope.

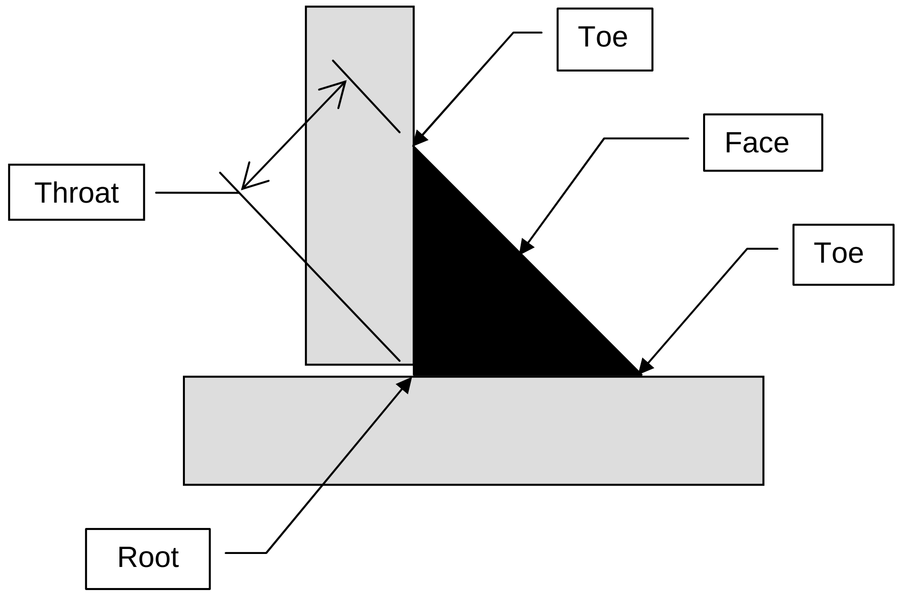

Figure 78. Fillet Weld Nomenclature

The bottom portion of each specimen was then used for the toe bend test. The toe bend specimens were prepared by removing the remaining weld metal from the specimen using a belt sander. Care was taken to not remove the weld toe. The weld toe was subsequently put into tension using a bend tester with a 1-in. (25.4 mm) radius. After bending, the weld toes were visually examined for cracking and suspect areas were further examined using a binocular light microscope.

Metallographic examination included an assessment of the general soundness of the welds (i.e., absence of cracks) and HAZ hardness testing. Four metallographic sections from each weld were mounted, ground, polished, and etched using standard metallographic procedures. The metallographic sections were initially examined for cracks at 100X magnification, and suspect areas were examined at magnifications of up to 400X. Hardness measurements were made in the HAZ of two sections from each weld using a Vickers hardness indenter with a 22-lb (10-kg) load. The indents were located in the coarse-grained HAZ and were spaced approximately 0.02 in. (0.6 mm) apart.

1.3.4.1.0   Diffusible Hydrogen Testing

GMAW filler metal ESAB Spoolarc 86 (AWS/ASME SFA5.17; ER70S-6 classification) and FCAW filler metal E71T1-1MJH4/-12MJH4 (AWS A5.20; E71T-1MJH4/T-12MJH4 classification) welding consumables are commonly referred to as low hydrogen consumables. To verify their applicability for this application, diffusible hydrogen testing, in accordance with AWS A4.3, was performed on the as-received welding consumables. Diffusible hydrogen testing was performed using the same FANUC welding robot and the same heat input levels that were used during the simulated in-service welding qualification. The diffusible hydrogen setup is shown in Figure 79. The measured diffusible hydrogen of the GMAW weld was 2.37 ml/100g. The measured diffusible hydrogen of the FCAW weld was 1.74 ml/100g. Both diffusible hydrogen results are below the 4 ml/100g, which is commonly used to characterize low hydrogen welding practice.

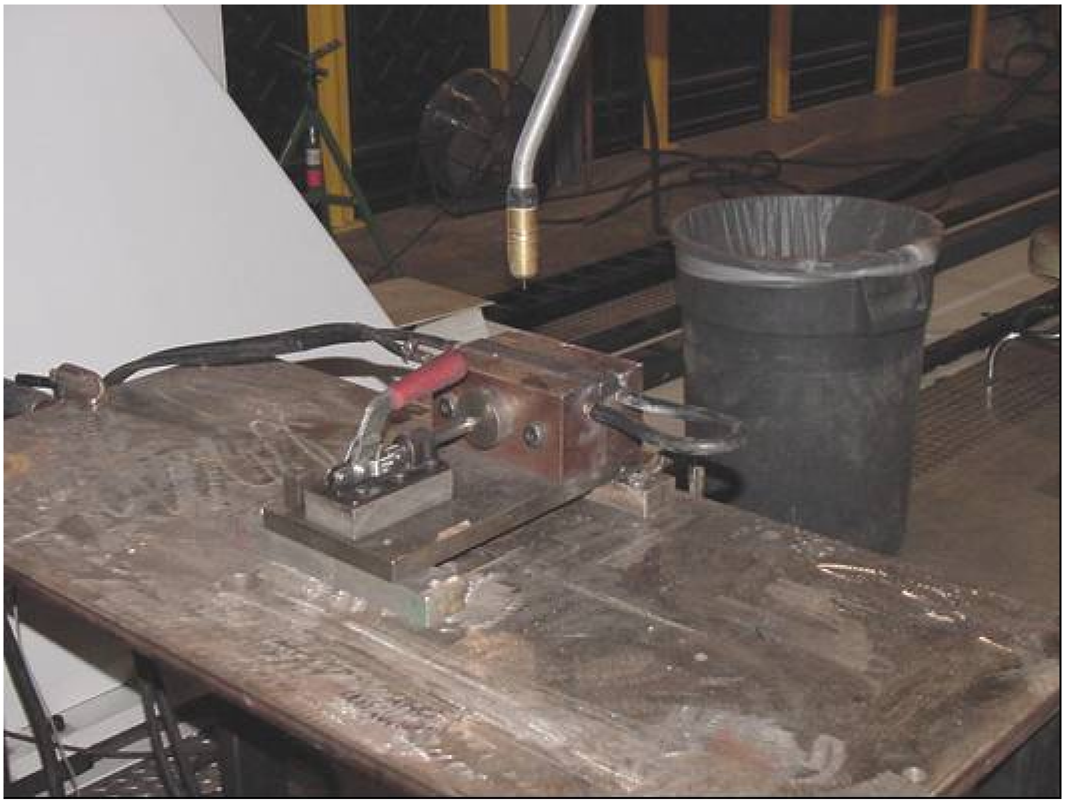

Figure 79. Diffusible Hydrogen Testing Apparatus

1.3.4.2 In-Service Welding Procedure Results

The initial welding procedure was provided to EWI by Cranfield is shown in Table 8. The modified welding parameters used by EWI are shown in Table 9. Other welding variables such as contact tip-to-work distance (CTWD) and shielding gas were kept constant between the two procedures. The weld sequence and weaving parameters are illustrated in Figure 80. This type of weave pattern is called an L-weave, because "L" describes the travel pattern of the welding arc (highlighted as the thick black lines in Figure 80). The weave angle is the angle between the two legs of the L-weave. The change in weave angle is highlighted by the L-weave locations for the root pass (Pass 1) and the first fill pass (Pass 2) shown in Figure 80. The frequency is the number of times the L-weave pattern is completed per second (the frequency does not include the dwell time at either end of the L). The amplitude is equal the leg length of the L-weave. The dwell time is the amount of time the welding arc stays at the left and right end points of the weave.

Table 8. Cranfield Welding Parameters

Pass	Travel Speed (ipm)	WFS (ipm)	Voltage (volts)	Current (amps)	Weave Parameters		
					Weave Width (mm)	Weave Length (mm)	Spacing (mm)
All	9.4	264	23.5	190-210	7.0	2.5	5 - 6

Table 9. FCAW and GMAW Procedures

	FCAW Procedure	GMAW Procedure
Welding Consumable	ESAB Dual Shield II 70T-12H4	ESAB Spoolarc 86
AWS Classification	E71T1-1MJH4/-12MJH4	ER70S-6
Welding Parameters		
Heat Input, kJ/in	25.0	29.5
Voltage, volts	20	18
Current, amps	165-170	120-125
Wire Feed Speed, ipm	250	120
Travel Speed, ipm	8.0	4.5
CTWD, in.	0.60	0.60
Weave Parameters		
Weave Type	L-Weave	L-Weave
Weave Angle	95º - 133º	95º - 133º
Frequency, hz	2.5	5
Amplitude, in.	0.17	0.17
Right Dwell, sec	0.35	0.7
Left Dwell, sec	0.35	0.7

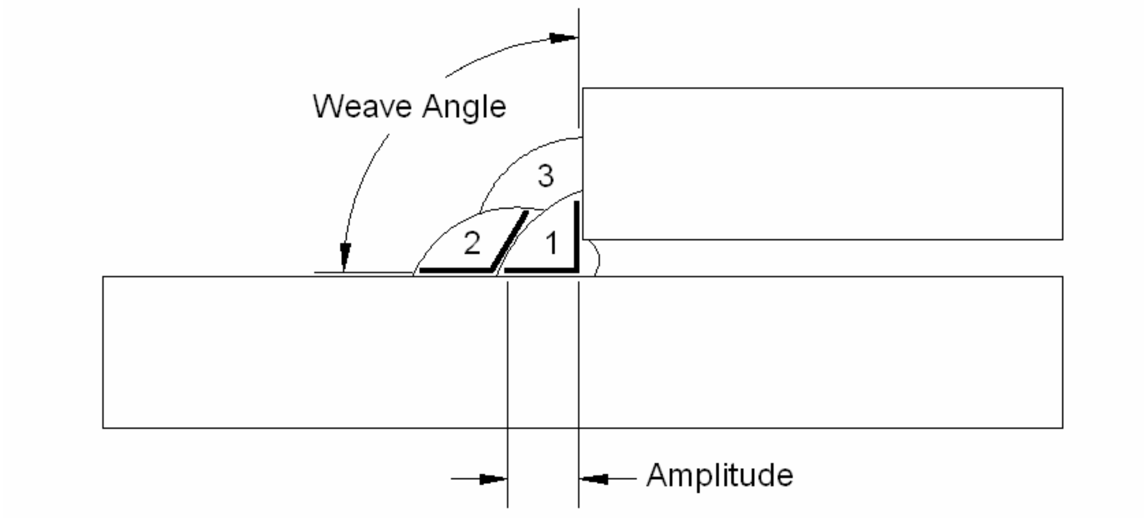

Figure 80. Weave Parameter Definitions and Bead Sequence

Each weld was completed in two portions, a single pass root bead and followed by 2 fill passes. The root bead was welded the entire length of the joint (typical profile show in Figure 81). The resultant three pass fillet weld was deposited ¼ of the length from the start for the remaining length of the weld (typical profile shown in Figure 82). The completed welds remained attached to the simulated pipeline until cooled to room temperature. The weld coupons were then removed from the simulated pipeline and allowed to sit for one week after welding to give sufficient time for hydrogen cracking to occur.

Figure 81. Typical Root Pass

Figure 82. Typical Three Pass Fillet Profile

In accordance to API 1104 Appendix B (19th Edition), the required destructive test samples included four nick-break samples, four toe bend samples and four metallographic samples per material per welding process. This resulted in a total of 48 test samples for both welding processes and all three material types. The destructive samples were taken from the three pass portion of the weld.

The facture surfaces of all 24 nick-break tests were free from porosity and slag inclusions; however, the welds did have several locations of lack of fusion at the root. The location of the lack of fusion defects are shown in the illustration in Figure 83. A typical fracture surface for a GMAW and a FCAW are shown in Figure 84. The yellow box in Figure 84 indicates a typical lack of fusion defect and is enlarged in Figure 85.

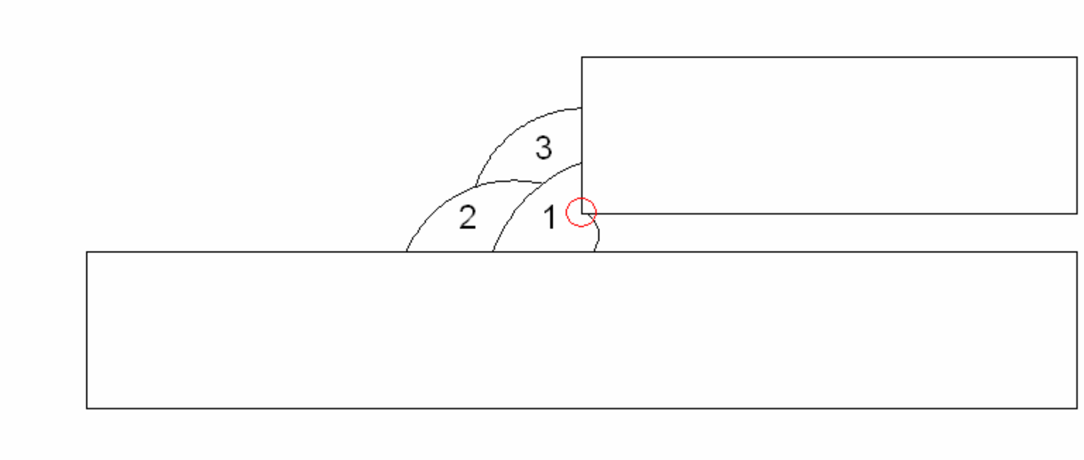

Figure 83. Location of Lack of Fusion Defects Discovered During Nick-Break Testing

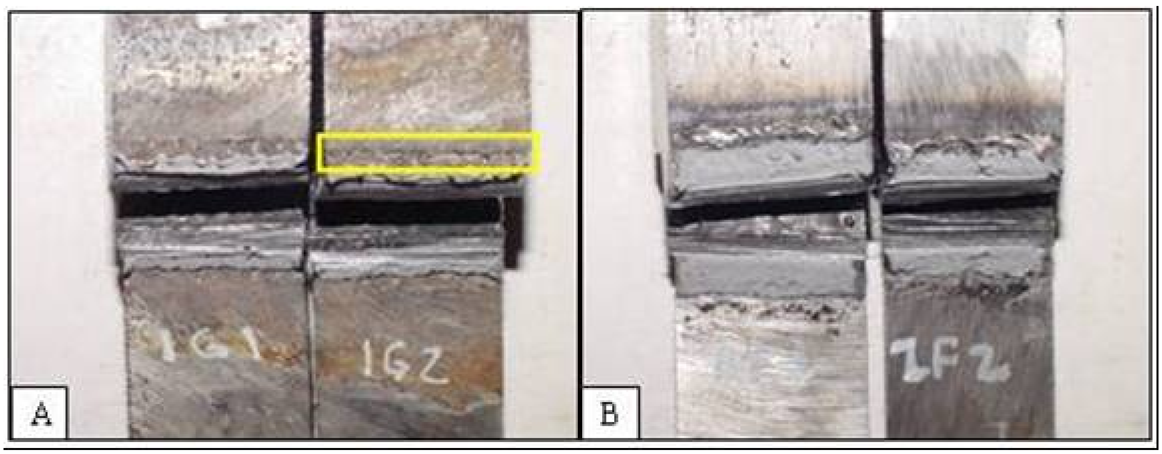

Figure 84. Typical Nick Break Results for a GMAW (A) and a FCAW (B)

Figure 85. Enlarged Lack of Fusion from Yellow Box in Figure 84

The toe bend samples were bent in a guided jig with a 1-in. (25.4 mm) bend radius. The 1-in. (25.4 mm) bend radius was used instead of the 1.75-in. (44.5 mm) radius specified in API 1104 Appendix B (19th Edition) because of the limited length of the toe bend samples. The 1-in.

(25.4 mm) bend radius is more severe than the 1.75-in. (44.5 mm) radius specified in API 1104 Appendix B (19th Edition), as such, if the welds bent with the more severe 1-in. (25.4 mm) radius are acceptable, the sample would be considered acceptable for a 1.75-in. (44.5 mm) radius. All 24 toe bends showed no signs of hydrogen cracking and passed the API 1104 Appendix B (19th Edition) criteria.

The four macro test samples were taken per material per welding process. This resulted in a total of 24 macro samples. Macro test samples were taken from both the single pass and the three pass portions of the welds. The macro test samples from the single pass portion of the weld were not used for qualification.

Typical cross sections of welds made on the X80, X100 and X120 pipeline steel using FCAW and GMAW are shown in Figure 86 through Figure 91. The macro on the left side of each figure is the single pass weld and the weld on the right side of each figure is the three pass fillet. All the macros are free from slag and cracking; however, there is evidence of lack of fusion in a majority of the macros. The lack of fusion defects were at the same location observed during the nick-break tests which are highlighted in Figure 83.

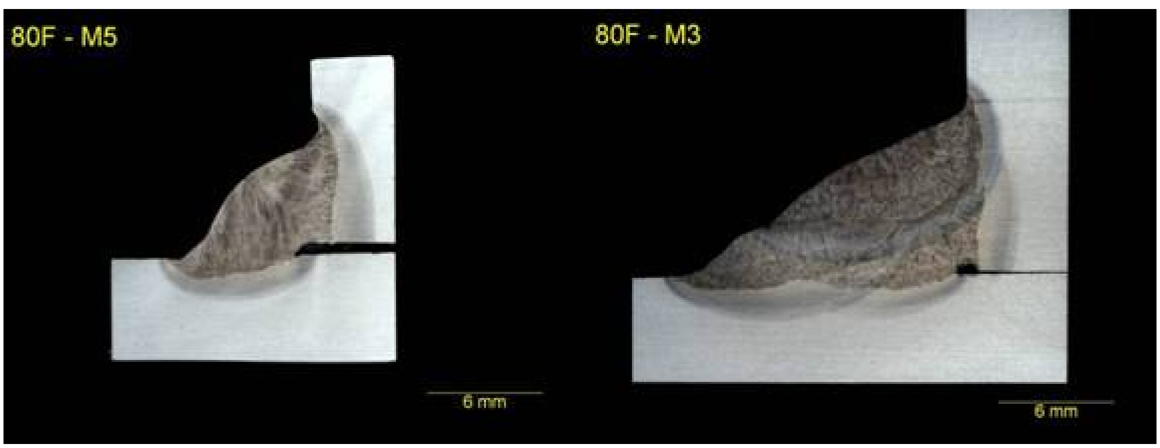

Figure 86. Macros of FCAW Welds on X80 Pipeline Material

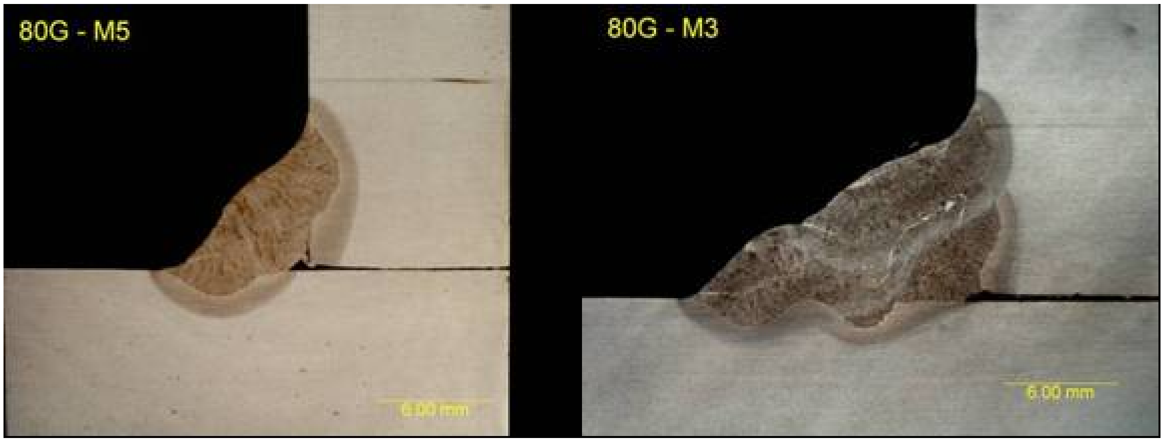

Figure 87. Macros of GMAW Welds on X80 Pipeline Material

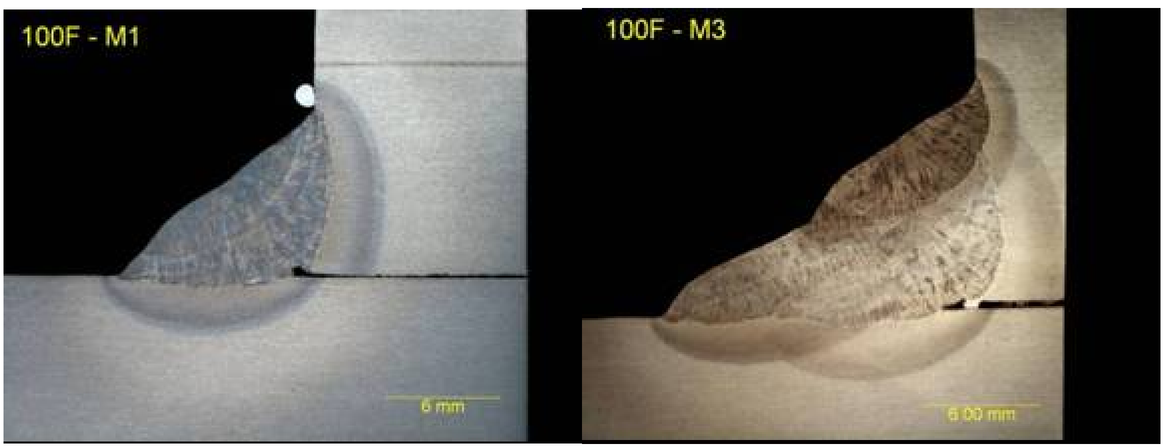

Figure 88. Macros of FCAW Welds on X100 Pipeline Material

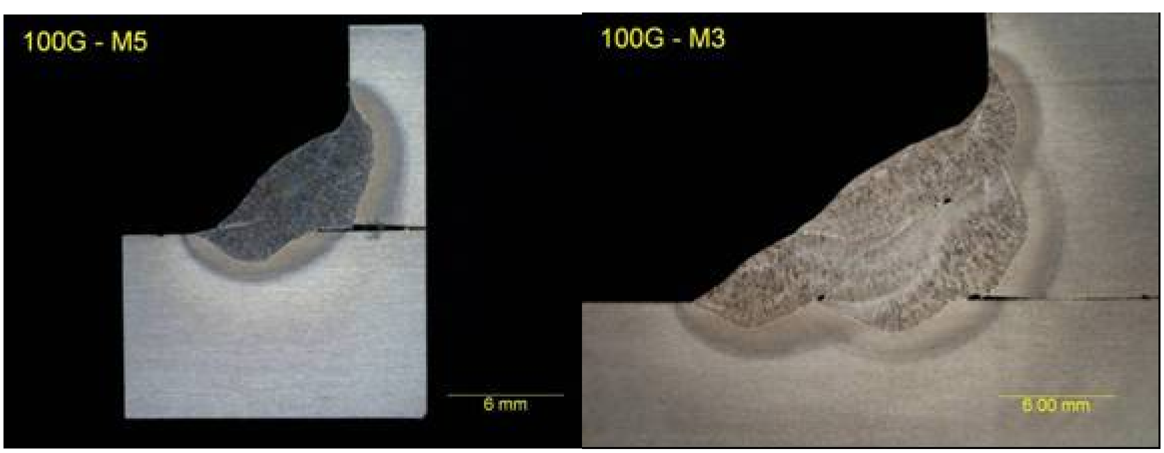

Figure 89. Macros of GMAW Welds on X100 Pipeline Material

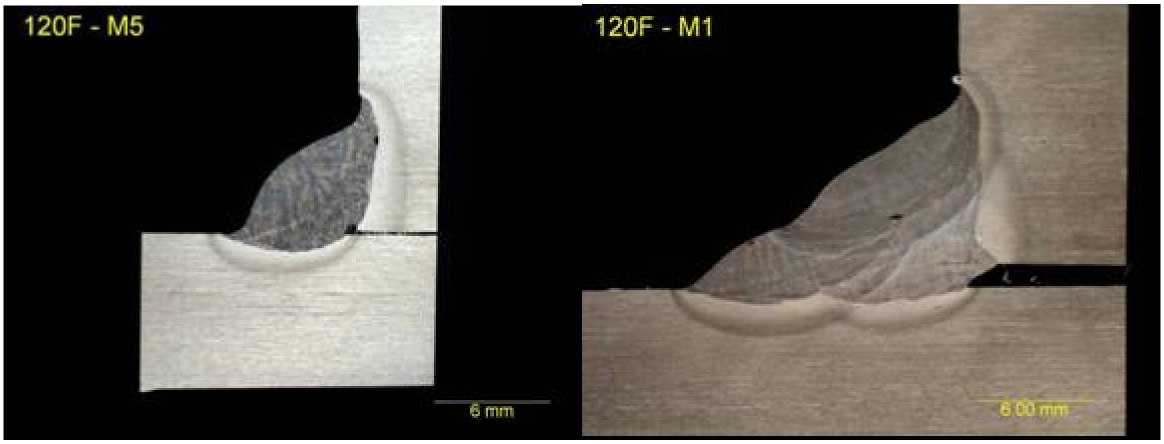

Figure 90. Macros of FCAW Welds on X120 Pipeline Material

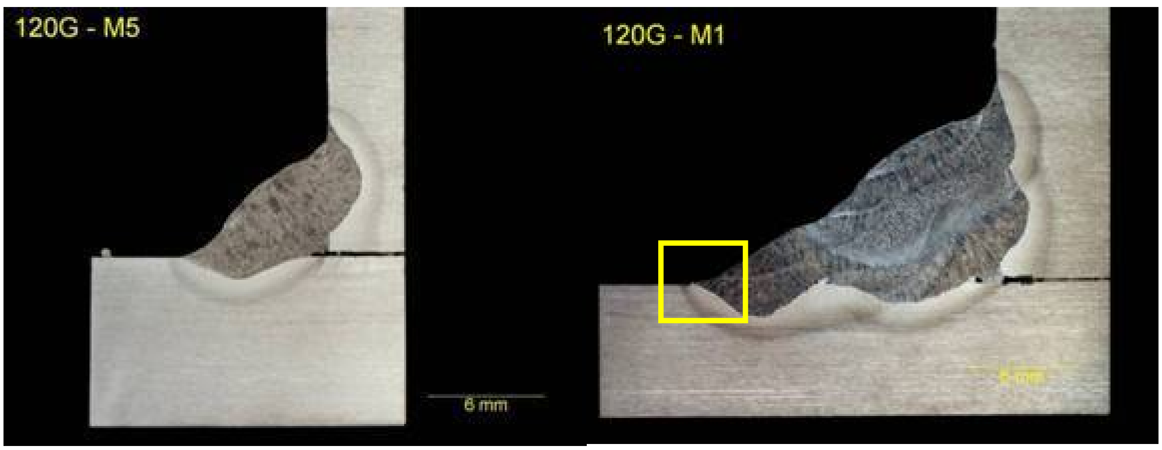

Figure 91. Macros of GMAW Welds on X120 Pipeline Material

In addition to the visual inspection of the macro sections, hardness measurements of the weld samples were taken. The hardness indents were located at the weld toe of the second pass, which is outlined by a yellow box in Figure 91. No hardness measurements were made on the single pass welds. The hardness indent values are listed in **Error! Reference source not found.**. None of the hardness values measured exceeds 350 Hv, which is commonly used as an industry limit for hydrogen cracking susceptibility. This data supports the mechanical testing results that indicate hydrogen cracking under simulated in-service welding conditions is not a major concern for these pipeline materials.

Table 10. Hardness Values for the In-Service Procedure Qualification Welds

Pipeline Material	Welding Process	Indent Number	Hv (10-kg)	Ave. Hv (10-kg)
X80	FCAW	1	292	286.2
		2	298	
		3	283	
		4	281	
		5	277	
	GMAW	1	267	283.8
		2	292	
		3	300	
		4	283	
		5	277	
X100	FCAW	1	271	287.2
		2	280	
		3	293	
		4	295	
		5	297	
	GMAW	1	297	307.4
		2	301	
		3	318	
		4	313	
		5	308	
X120	FCAW	1	310	310.6
		2	316	
		3	308	
		4	311	
		5	308	
	GMAW	1	310	311.2
		2	311	
		3	308	
		4	316	
		5	311	

1.3.4.3 Summary

Weld qualification testing was conducted to determine if X80, X100 and X120 pipeline steel could be acceptably welded under simulated pipeline conditions. The results from the destructive testing and metallographic analysis show no evidence of hydrogen cracking. The low diffusible hydrogen levels (below 4 ml/100g), and the low hardness values (below 350 Hv) both indicate that hydrogen cracking is extremely remote using these welding consumables, welding heat input levels, and cooling conditions.

However, the procedures did not produce acceptable welds, because of lack of fusion defects that were detected during nick-break testing and metallographic analysis. The lack of fusion defects were attributed to using too large of a weave pattern while depositing the root pass. It is believed that using a stringer bead for the root pass will allow the arc to penetrate into the corner to completely fuse the root. The two fill pass welding parameters produce sound welds and can be used as a basis for future weld procedure development and subsequent qualification testing with any of these consumables as evinced by the results of the destructive testing and metallographic analysis.

1.3.5 Field Testing and Validation

Under Task 7, a series of field trials were performed at a TransCanada facility in North Bay, Ontario to validate the performance of the automated welding system. The objective of the trial was to demonstrate the welding capability of the automated system and to identify the areas of improvement necessary for actual field deployment on in-service pipeline repairs.

In order to conduct welding trails on an in-service pipeline, EWI would have to develop and qualify a new set of welding parameters specifically for the pipeline material in the dig that TransCanada found for the project. EWI would have to obtain similar pipe material to perform welding procedure development trials and subsequent welding procedure qualification tests. It is nearly impossible to obtain these same materials, as most of the existing pipelines were laid decades ago and current pipeline materials of the similar grades have vastly different chemistries (carbon content in particular). A TransCanada welding engineer would then have to come to EWI to witness the welding procedure test and destructive testing would need to be conducted on subsequent samples cut from the welds to qualify the welding procedure. After the welding procedure was successfully qualified, one of TransCanada's welding contractors would need to be willing to use the welding equipment and subsequently be qualified on the equipment. Trying to find a dig and coordinate all of these factors proved to be a logistical nightmare and was not possible before the end of the project on June 1, 2007. As a result, the project team came up with an alternate field trial solution; to perform the system trials in a controlled "field conditions" experiment at a TransCanada facility.

1.3.5.0 Field Trial Preparation

In North Bay, Ontario, TransCanada has a construction services facility that is currently pressure testing sections of NPS 30 pipe for future installation. In the welding shop of this facility, TransCanada made a pipe section with both reinforcing and pressure-containing sleeves for the field trial evaluations. Using TransCanada welding procedures, the same welders that make field repairs fitted and tack welded a trimmed down reinforcement sleeve and a scaled down, pressure-containing sleeve onto a section of carrier pipe. The completed pipe section is shown in Figure 92 with welding bug tracks in place.

Figure 92. NPS 30 Pipe Section with Type A and B Sleeves for Field Trials

TransCanada obtained 13 ft. (3.9 m) of NPS 30 carrier pipe with an approximate wall thickness of 0.38 in. (9.5 mm) and placed it on pipe stands in their welding shop located at their North Bay facilities. TransCanada then cut a reinforcement sleeve roughly 18-in. (457-mm) wide. The sleeve was placed on the carrier pipe and held in place with chain clamps as shown in Figure 31. The sleeve was tack welded in place and then the root pass was made between the chain clamps. The clamps were then removed and the root pass was filled in where the chains had been. This is standard field procedure before fill passes are added. When finished, a 0.19-in. (5-mm) fillet weld root bead was completed on the bars on both sides of the pipe in exactly the same position as in a field repair (at 3 and 9 o'clock). The automated system is designed to take over at this point and add the fill passes after the root bead is made. The root welded reinforcement sleeve is shown in Figure 93. An enlarged view of the root weld and the joint preparation is shown in Figure 94. Several feet of carrier pipe was left on each side of the sleeve to allow for subsequent equipment set up.

Figure 93. Reinforcement Sleeve with Root Bead Ready for System Trials

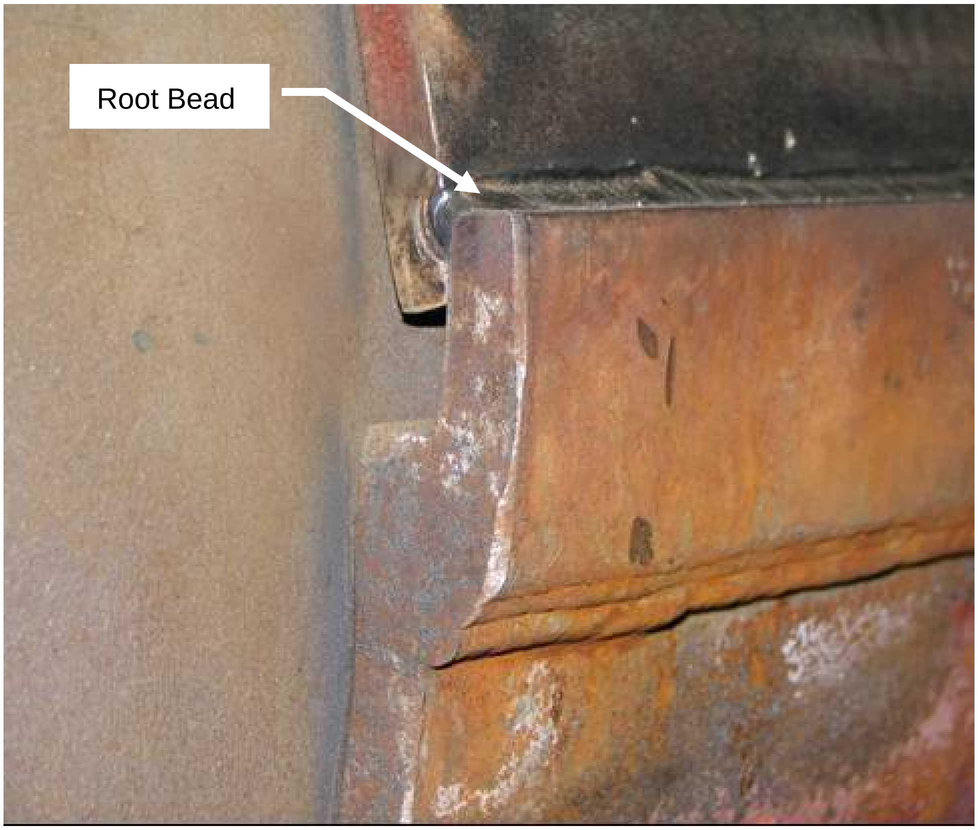

Figure 94. Enlarged View of Reinforcement Sleeve Root Bead

TransCanada contracted a local shop to roll an 18-in. (457-mm) wide plate into a split ring to simulate a pressure-containing sleeve. The longitudinal butt weld preparation between the sleeve halves was a V-groove with a 60° included angle as shown in the TransCanada drawing in Appendix B. The sleeve was placed on the carrier pipe and held in place with chain clamps as shown in Figure 95. The sleeve was tack welded in place and then the root pass was made between the chain clamps. The clamps were then removed and the root pass was filled in where the chains had been. This is standard field procedure before fill passes are added. When finished, a root bead was completed in the V-grooves on both sides of the pipe in exactly the same position as in a field repair (at 3 and 9 o'clock). The automated system is designed to take over at this point and add the fill passes after the root bead is made. The root welded reinforcement sleeve is shown in Figure 96. An enlarged view of the root weld and the joint preparation is shown in Figure 97. 12- to 14-in. of the carrier pipe was left between the sleeves to allow for subsequent equipment access to weld joints.

Figure 95. Type B Sleeve Held in Place with Chain Clamps during Tack Weld

Figure 96. Pressure-Containing Sleeve with Root Bead Ready for System Trials

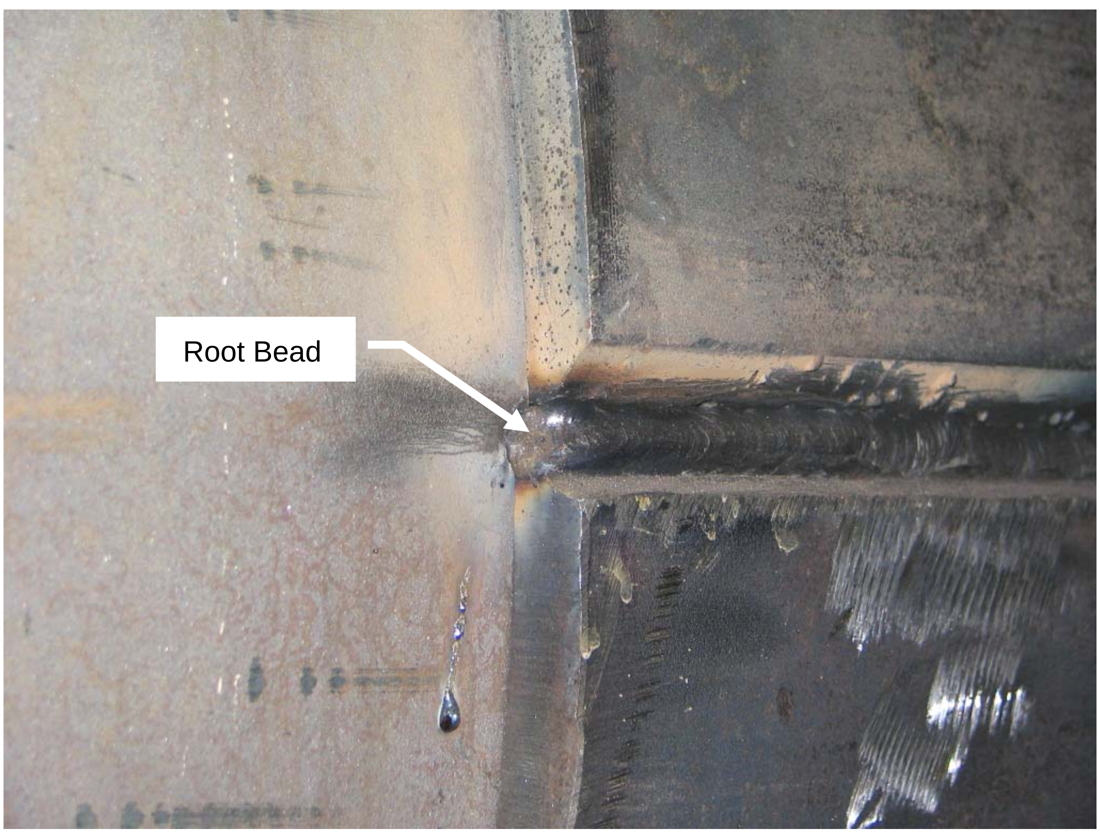

Figure 97. Enlarged View of Pressure-Containing Sleeve Root Bead

1.3.5.1 Field Condition Welding Trials

EWI packed and shipped the modified system to North Bay, Ontario (see Table 7 for the complete bill of materials of the shipped items). On April 10, 2007 the system was unpacked and assembled onto the pipe section as shown in Figure 98. Figure 99 shows the controller and the Lincoln welding power source. Figure 100 is the wireless operator pendant that is designed to go into the trench to control the system and the welding power supply remotely. Figure 101 shows the complete setup at a distance. The system was designed so the controller and welding power source could remain in the back of a pickup truck; power cords were made long enough to extend into the trench from the truck.

Figure 98. Automated System Mounted on Pipe Section at TransCanada

Figure 99. System Controller with PC Mounted on Top

Figure 100. Wireless Control Pendant

Figure 101. Complete System Configuration at TransCanada

On hand to assist with the field trial were the following TransCanada personnel: David Taylor (Welding Engineering Technologist), Ken Pigeau (Welding Coordinator), and Cy Doyle (Welding Engineering Consultant).

Almost immediately, an interference problem was found between a gear box on the bottom of the ring assembly and the top of both sleeves. The team removed the gear box cover to increase clearance height (Figure 102). Figure 103 shows the gears that were exposed after the gear box was removed. Figure 104 shows the interference experienced between the slide protector and the pressure-containing sleeve. This sleeve was ultimately moved out of the way during subsequent welding trials. Both of these interferences were corrected after the field trial by redesigning the brackets that attach the rail system to the welding bugs.

Figure 102. Reducing Interference Issues During Field Trial

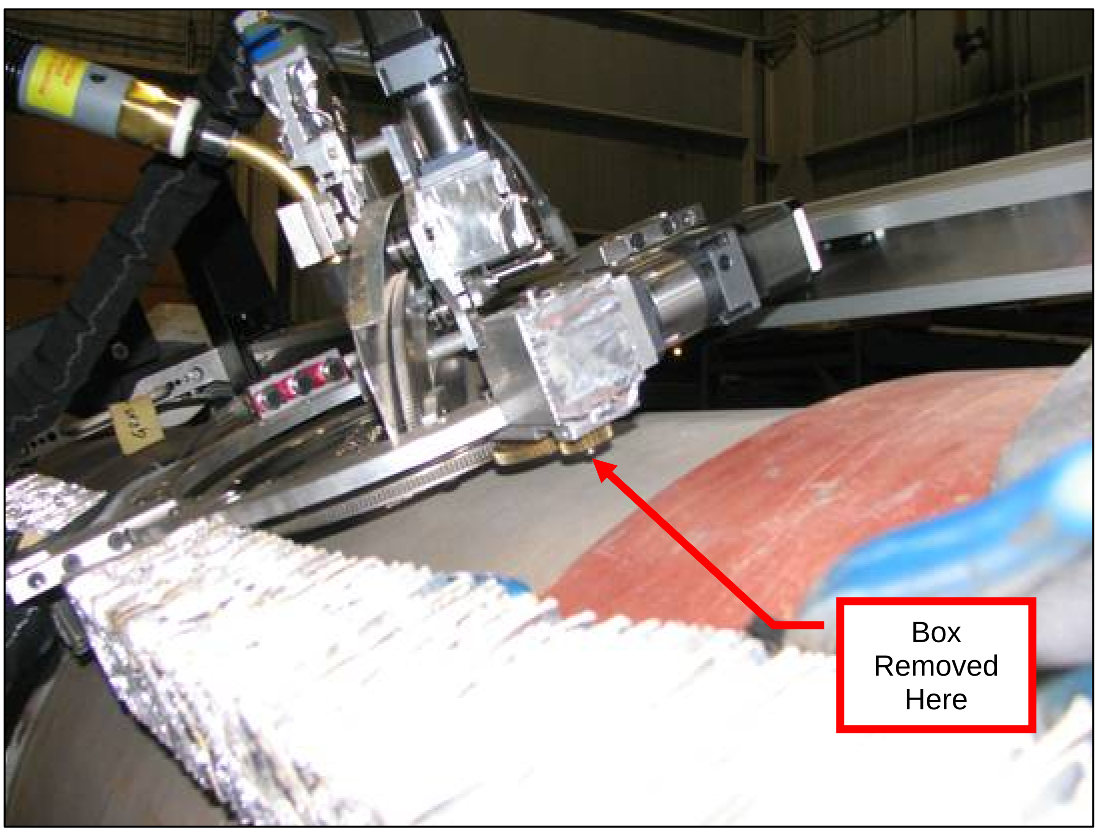

Figure 103. Gears Exposed After Gear Box Removed

Figure 104. Interference between Slide Protector and Pressure-Containing Sleeve

Once the gear box cover was removed, the team made a couple of practice welds on the carrier pipe (Figure 105) to try the welding parameters before welding on the sleeves. Figure 106 shows the two practice welds. The welds were made using the same ESAB Dual Shield II 70T-12H4 (AWS A5.20; E71T-1MJH4/T-12MJH4 classification) gas shielded FCAW consumable that was used in Task 5. Weaving was not used during the field welding trials, because the thickness of the pipe material did not lend itself to being welded with a weave technique.

Figure 105. First Test Welding Being Made on Carrier Pipe

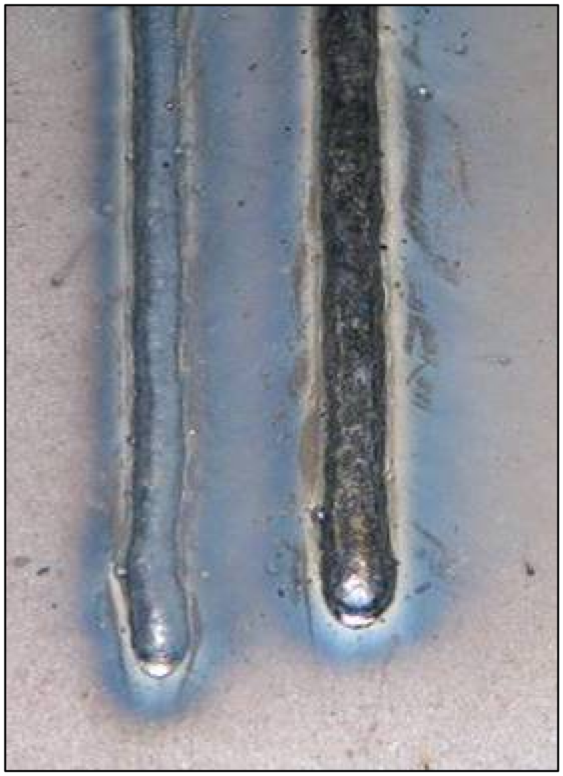

Figure 106. First Test Welds on Carrier Pipe

The laser sensor was not functioning properly and the remaining welds were made without seam tracking capability. Due to the age of the laser sensor that was on loan from Cranfield University, drivers for communication between the laser and the newer Toughbook computer do not exist. Before switching from a desktop computer in the lab to the Toughbook computer on the console, the laser sensor was working perfectly. Only after moving everything over did the issue arise. EWI worked with Servo-Robot to try to update drivers, but they were considered obsolete and thus, no longer supported by Servo-Robot. Because of this, EWI was forced to go to the field trial without the laser sensor. During the field trial, test welds were made by correcting torch position manually with the wireless control pendant.

Several circumferential fillet weld beads were made on the pressure-containing sleeve from the 6 to 12 o'clock positions around the pipeline axis. Figure 107 shows the system in position before making a fillet weld from the 9 to 12 o'clock positions. Figure 108 shows a circumferential fillet weld in process. The resultant fillet weld bead from the 9 to 12 o'clock positions is shown in Figure 109. A video of circumferential fillet welding is contained in the CD that accompanies this report and is named "circumferential weld".

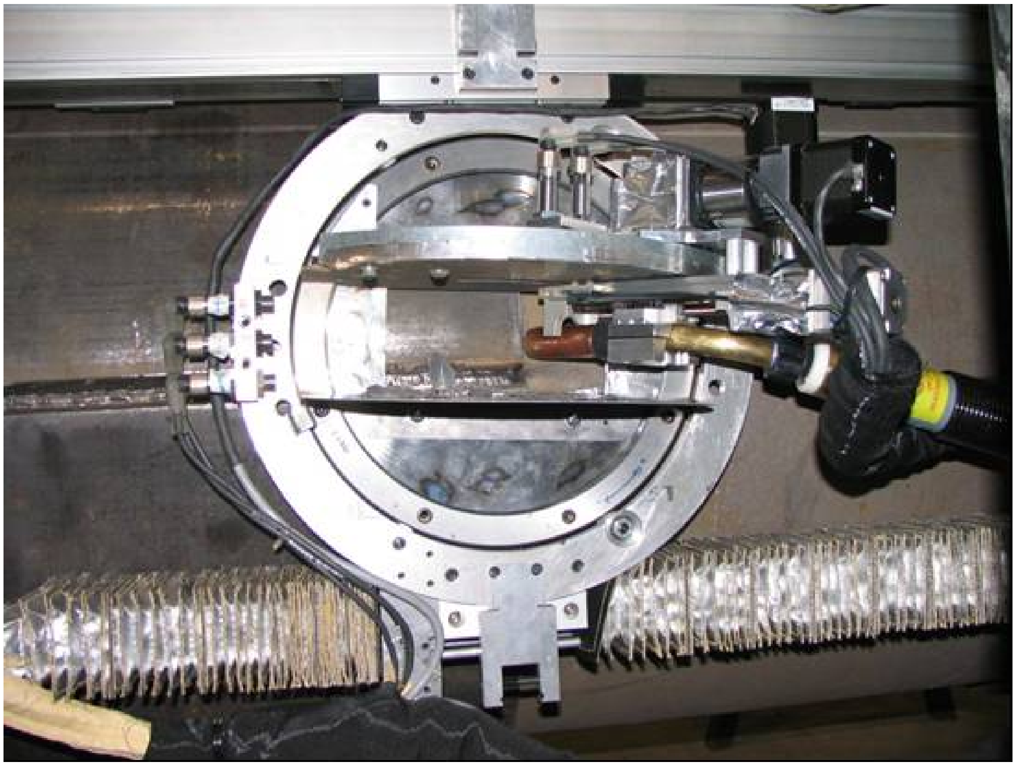

Figure 107. System in Position to Make Circumferential Weld from 9 to 12 o'clock

Figure 108. System Welding Circumferential Fillet

Figure 109. Resultant Circumferential Fillet Weld

Several longitudinal weld beads were made in the V-groove on the pressure-containing sleeve in the 3 o'clock position parallel to the pipeline axis. Figure 110 and Figure 111 show the system in position before a longitudinal V-groove weld. Figure 112 shows a longitudinal V-groove weld in process. The resultant V-groove weld bead is shown in Figure 113. A video of V-groove welding is contained in the CD that accompanies this report is and is named "v-groove weld".

Figure 110. System before V-Groove Weld on Pressure-Containing Sleeve (View 1)

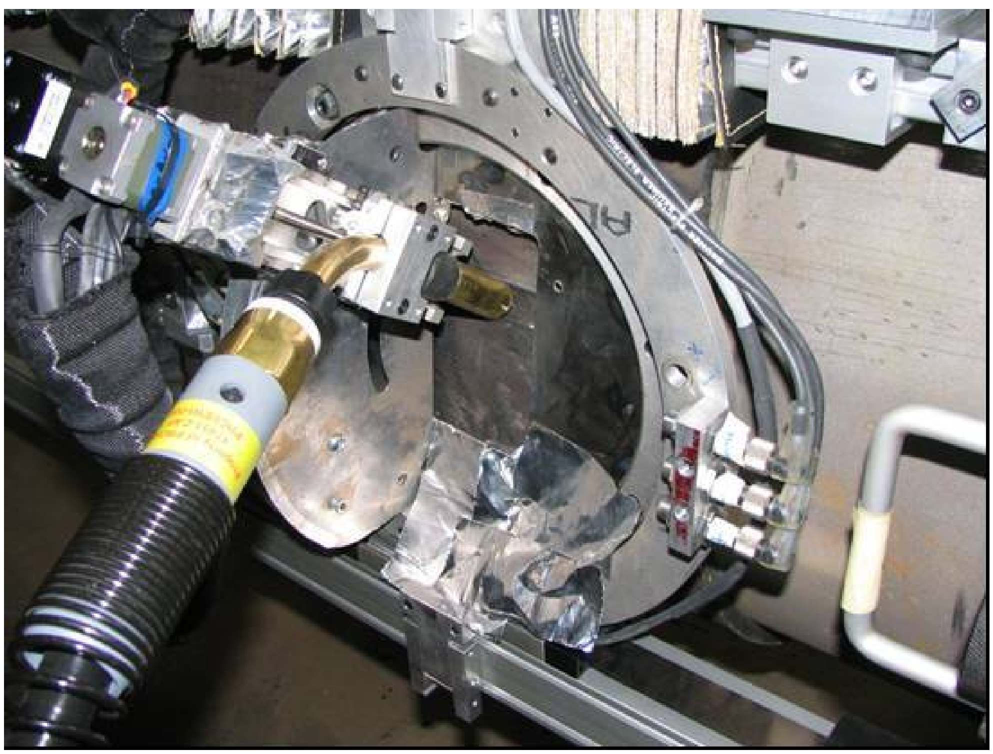

Figure 111. System before V-Groove Weld on Pressure-Containing Sleeve (View 2)

Figure 112. System Welding V-Groove on Pressure-Containing Sleeve

Figure 113. Resultant V-Groove Weld on Pressure-Containing Sleeve

Several longitudinal fillet beads were made on the reinforcement sleeve in the 3 o'clock position parallel to the pipeline axis. Due to interference problems, an additional bar (Figure 114) was tacked on top of the reinforcing sleeve so the system could make test fillet welds. Figure 110 shows the system in position before a longitudinal fillet weld. Figure 112 shows a longitudinal fillet weld in process. The resultant longitudinal fillet weld bead is shown in Figure 113. A video of longitudinal fillet welding is contained in the CD that accompanies this report is and is named "longitudinal fillet".

Figure 114. Additional Bar Tacked on Reinforcing Sleeve

Figure 115. System in Position to Make Longitudinal Fillet Weld on Retaining Sleeve

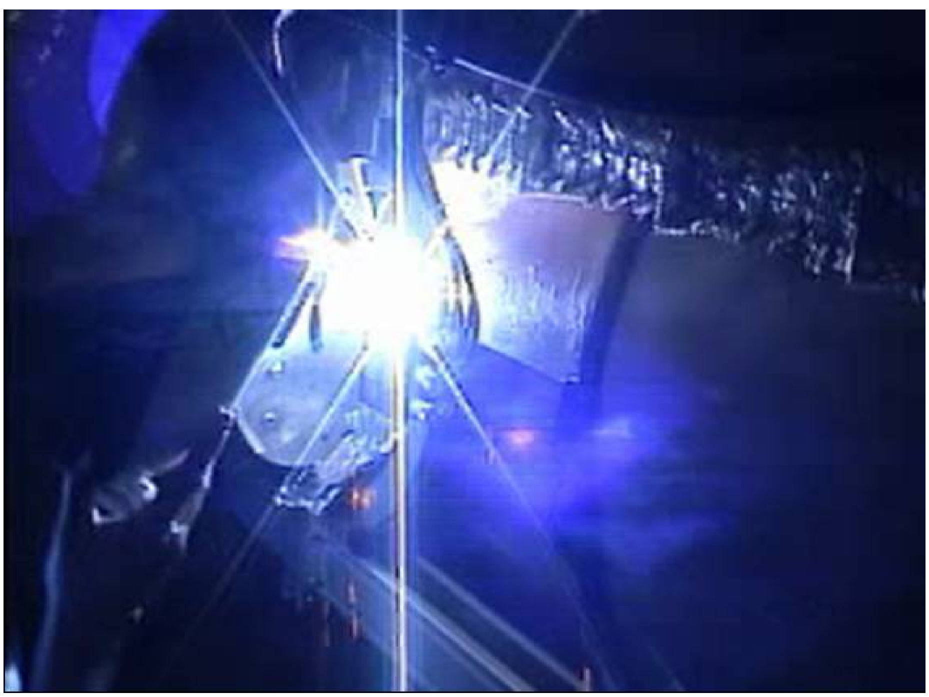

Figure 116. System Welding Longitudinal Fillet on Retaining Sleeve

Figure 117. Resultant Longitudinal Fillet Weld on Reinforcing Sleeve

The field trial was considered a success as the system was able to make all three types of field welds. (Validation testing of weld deposition to repair corrosion was demonstrated at the workshop and is described in the report section 1.3.7.) Two areas were identified for improvement: alleviate interference problems and fix the laser tracking system. These improvements were incorporated into the system before the demonstration workshop and are discussed in the next report section.

1.3.5.2 System Improvements Resulting from Field Trials

The TCP (tool center point) of the automated welding system was incorrect due to the change from the Serimer DASA to the Bug-O bug and band systems. In order to correct for the problem, new brackets were designed and mounted between the Bug-O system and the rest of the hardware system. This fixed the interference problem by raising the height of the entire assembly by 0.50 in. (13 mm). This allowed the system to function as intended and allowed for welding a sleeve with a thickness of 0.50 in. (13 mm) and below.

After the field trial, EWI was able to find a way to use the EZTrac laser sensor with the Toughbook computer. This was accomplished by rolling back the driver on the laser sensor to an even earlier version, communicating with the laser using an old computer and then rewriting part of the communication software to trick the laser into thinking it was talking to the old computer when it was actually communicating with the newer Toughbook. This was an unsupported solution, but did allow EWI to use the laser sensor with the Toughbook computer on the console as originally intended. Updating the Servo-Robot EZTrac laser sensor to a newer sensor will correct the issues experienced with communication and support.

1.3.6 Estimated Cost Savings for Manual vs. Automatic Welding

When a full encirclement sleeve (reinforcing or pressure-containing) is installed on a pipeline, the two sleeve halves are held in place with a series of chain clamps (Figure 31 or Figure 95). Tack welds are then made in between the clamps. When sufficient weld metal is deposited to hold the sleeves in place, the chain clamps are removed. In the voids where the chains were removed, welds are then added to complete the root pass of the joint. At this point, a manual welder currently adds a number of fill passes to build up the weld layer by layer until it reaches the required weld size. The automated system is designed to make the fill passes after the root pass is completed. Since both manual and automatic welding require the same sleeve fitting, tack welding, and root welding operations, these costs were not calculated.

After the chain clamps are removed, the automatic system must be mounted on the pipeline. It will take two welders approximately 30 minutes to perform the following steps:

- Fit tracks on pipe.
- Using spacers, adjust the tracks to accommodate for any pipe out-of-roundness, and secure.
- Add bug/rail assembly to secured rail system.
- Lock bugs to tracks by engaging the pinions.
- Add welding torch to positioning ring and secure.
- Position system for first weld.

As the system is hardened for field deployment, efforts will be made to select components that will minimize system mounting time.

The welding power source, shielding gas cylinder, wire feeder, and system control cabinet can stay in the back of a pickup truck. Power cables and hoses can be made in any length to extend into the ditch with the automated system. The wireless operator pendant is designed to both position the system and to initiate the arc as necessary from the ditch.

In order to determine a rough order of magnitude cost savings achievable with the automatic system, welding costs were estimated for manual SMAW and automated FCAW for a 36-in. (914 mm) long reinforcement sleeve (Type A) welded with two 0.38-in. (9.7-mm) fillet welds. Table 11 is the input screen of *Weld Cost CalcXL* a welding cost estimation program developed by Mark Mruczek of Mruczek Welding Engineering, which was used for these calculations.

Table 11. Parameters, Materials, and Labor Costs for Welding Cost Estimates

Type A Sleeve Installation Fill passes only Two 3/8-in. fillet welds 36-in. long sleeve	Project: 46996GTH Company: Edison Welding Institute Subject: Welding Cost & Time Estimate Welding processes Compared: FCAW and SMAW		Base Material: X65 Product Form: 36" Pipe Filler Material Low Hydrogen		
FCAW			SMAW		
Leg Size (in)	0.38	in	**Leg Size (in)**	0.38	in
AWS Filler Material Classification	E71T1-1MJH4/-12MJH4		**AWS Filler Material Classification**	E7018	
Process	FCAW		**Process**	SMAW	
Gas Used	75%Ar+25%CO_2		**Gas Used**	-	
Amps	170	A	**Amps**	123	A
Volts	20	V	**Volts**	23	V
Wire Feed (in/min)	250	in/min	**Wire Feed (in/min)**	-	in/min
Electrode Dia. (in)	0.045	in	**Electrode Dia. (in)**	0.125	in
Total Length of Weld (ft)	6	ft	**Total Length of Weld (ft)**	6	ft
Travel Speed (in/min)	8.0	in/min	**Travel Speed (in/min)**	6.0	in/min
Gas Flow Rate (ft^3/hr)	35	ft^3/hr	**Gas Flow Rate (ft^3/hr)**	-	ft^3/hr
Welder Efficiency	50%	Automatic	**Welder Efficiency**	30%	Manual
Cost Electrode ($/lb)	3.29	$/lb	**Cost Electrode ($/lb)**	2.25	$/lb
Labor/Overhead Rate	100.00*	$/hr	**Labor/Overhead Rate**	100.00*	$/hr
Cost of Gas	16.00	$/bottle	**Cost of Gas**	-	$/bottle
Gas Cylinder Size (ft^3)	330	ft^3	**Gas Cylinder Size (ft^3)**	0.00	ft^3
Power Cost	0.20	$/kwh	**Power Cost**	0.20	$/kwh
Cost of Flux ($/lb)	-	$/lb	**Cost of Flux ($/lb)**	-	$/lb

* Approximate fully burdened labor rate provided by TransCanada

The estimated welding costs for automatic FCAW are summarized in Table 12; the percent distribution of labor vs. material costs is shown in Figure 118. The estimated welding costs for manual SMAW are summarized in **Error! Reference source not found.**; the percent distribution of labor vs. material costs is shown in Figure 119.

Table 12. Welding Cost Outputs for Automatic FCAW

Amount of filler metal needed	2.08	lbs
Number of passes per joint ~	5	
Amount of shielding gas used	10.78	ft^3
Number of Gas Bottles Required	1	
Actual welding time	0.6	hr
System Mounting Labor Cost	$100.00	
Welding Labor Cost	$61.57	
Welding Electrode Cost	$6.90	
Gas Cost	$0.52	
Flux Cost	$-	
Power Cost	$0.25	
Initial Cost	$69.25	
Final Cost +10%	$176.75	
Total cost per ft of weld	11.63	$/ft
Filler cost per ft of weld	1.15	$/ft
Flux cost per ft of weld	-	$/ft
Gas cost per ft of weld	0.16	$/ft
Labor cost per ft of weld	10.26	$/ft

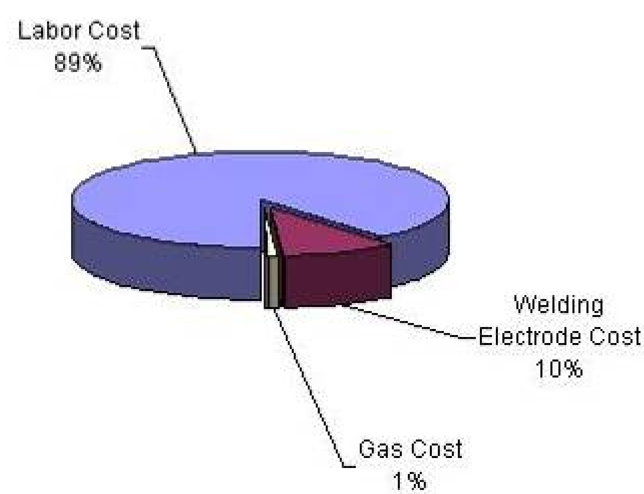

Figure 118. Percent Distribution of Labor vs. Materials for Automated FCAW

Table 13. Welding Cost Outputs for Manual SMAW

Amount of filler metal needed		2.77	lbs
Number of passes per joint ~		4	
Amount of shielding gas used		0.213	ft^3
Number of Gas Bottles Required		0.00	
Actual welding time		2.5	hr
System Mounting Labor Cost		$-	
Welding Labor Cost		$248.57	
Welding Electrode Cost		$6.25	
Gas Cost		$-	
Flux Cost		$-	
Power Cost		$0.45	
Initial Cost		$255.30	
Final Cost	**+10%**	$280.85	
Total cost per ft of weld		42.55	$/ft
Filler cost per ft of weld		1.04	$/ft
Flux cost per ft of weld		-	$/ft
Gas cost per ft of weld		-	$/ft
Labor cost per ft of weld		41.43	$/ft

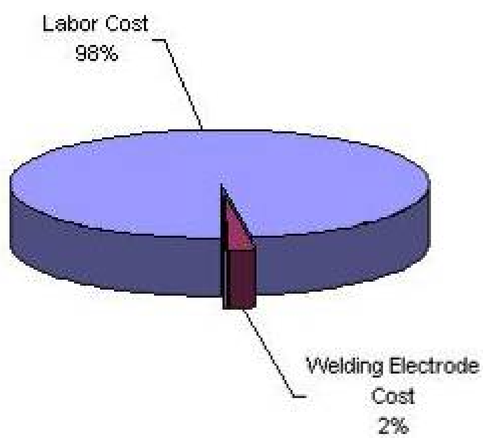

Figure 119. Percent Distribution of Labor vs. Materials for Manual SMAW

With the automated system, it will take 30 minutes to mount the system on the pipeline and 36 minutes to make all the fill passes (1.1 hours total) at an estimated cost of $176.00 per reinforcement sleeve (Type A). With manual welding, it will take 2.5 hours total to make all the fill passes at an estimated cost of $280.85 per sleeve. The automated system is approximately 2.3 times faster and 62% cheaper than manual welding. Once the system mounting time is reduced, this automatic welding system will be even more cost effective than manual welding.

1.3.7 Equipment Demonstration Workshop

Per the PRCI contract, an end of project workshop was held at EWI on May 23, 2007 to demonstrate the automated welding system to the pipeline industry including pipeline welding contractors specializing in pipeline repair and modifications. The one page flyer in Appendix F was created to advertise the event. EWI and PRCI invited their member companies to attend. Registration was held online via the EWI web site.

Figure 120 is the full workshop agenda, which began with a series of presentations: project overview (Appendix G), welding procedure development (Appendix H), and the evolution of the system design (Appendix I). This was followed by a demonstration of the system making a longitudinal weld on a simulated pressure-containing sleeve, a weld deposition repair of a simulated corrosion patch, and the circumferential fillet weld of a simulated pressure-containing sleeve. The participants then discussed ways the system could be improved for field deployment. In the afternoon, EWI presented the results of three other DOT/PRCI co-funded projects.

Welcome and Introductions	*Bob Kratzenberg*
Project Overview	*Nancy Porter*
Welding Procedure Qualifications	*Matt Boring*
System Design & Development	*Connie Reichert*
System Demonstration • Weld a simulated corrosion patch • Weld a simulated pressure containing sleeve	*Connie Reichert* *Matt Boring*
Identification of Future Improvements to the System	*Nancy Porter*
Lunch	
Technology Briefs of Other PRCI/DOT Co-Funded EWI Projects	
Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines	*Suhas Vaze*
Improved Inspection and Assessment Methods for Pipeline Girth Welds and Repair Welds	*Mark Lozev*
Strain-Based Design of Pipelines	*Bill Mohr*
Open Forum Discussion • What are the future development needs of the pipeline industry?	*Bob Kratzenberg* *Nate Ames*
Adjourn	

Figure 120. Workshop Agenda

Twenty-two people attended the workshop from thirteen companies. Table 14 is a list of the attendees and their respective organizations.

Table 14. Workshop Attendee List

Last Name	First Name	Organization
Arthur	Christopher	The Pipe Line Development Company
Byrd	Bill	TD Williamson, Inc.
Calvert	Jevin	Marathon Pipe Line
Cumpston	Keith	Columbia Gas (Nisource)
Dick	Andy	Bug-O Systems
Drake	Donald	ExxonMobil
Estep	Gary	Columbia Gas (Nisource)
Keane	Sean	Enbridge Pipelines Inc.
Kisasonak	Mark	Weld Tooling Corporation
Laudermilt	Danny	Columbia Gas (Nisource)
Lee	Ken	Lincoln Electric
Lorang	Ken	PRCI
Marsh	Steve	Columbia Gas (Nisource)
Merritt	Jim	DOT/PHMSA
Nelson	Frank	Bug-O Systems
Nemergut	John	Motion Technologies Co.
Pearce	James	Enterprise\Acadian Gas
Schlater	Bryan	Motion Technologies Co.
Smith	Mark	The Pipe Line Development Company
Thomas	Eric	PRCI
Tomsic	Douglas	Columbia Gas (Nisource)
Yazemboski	Michael	PHMSA Eastern Region

Figure 121 shows the longitudinal seam weld being setup on the simulated pressure-containing sleeve. Figure 122 shows this weld being made. No videos were shot during the demonstration, so the participants could have an unobstructed view of the system during welding.

Figure 121. Equipment Demonstration Setup for Longitudinal Seam Weld

Figure 122. Demonstration Welding of Longitudinal Seam Weld

Immediately following the workshop, EWI conducted a short online survey via surveymonkey.com to solicit feedback about the automated welding system, the workshop, and future technology transfer workshops. A print version of the online survey is located in Appendix J. The results of the survey are presented below.

The participants were first asked to rate the workshop from "not worth my time" to "can't wait until the next workshop". The answers to this question are graphically depicted in Figure 123. The vast majority of respondents rated the workshop as "interesting" or "very interesting".

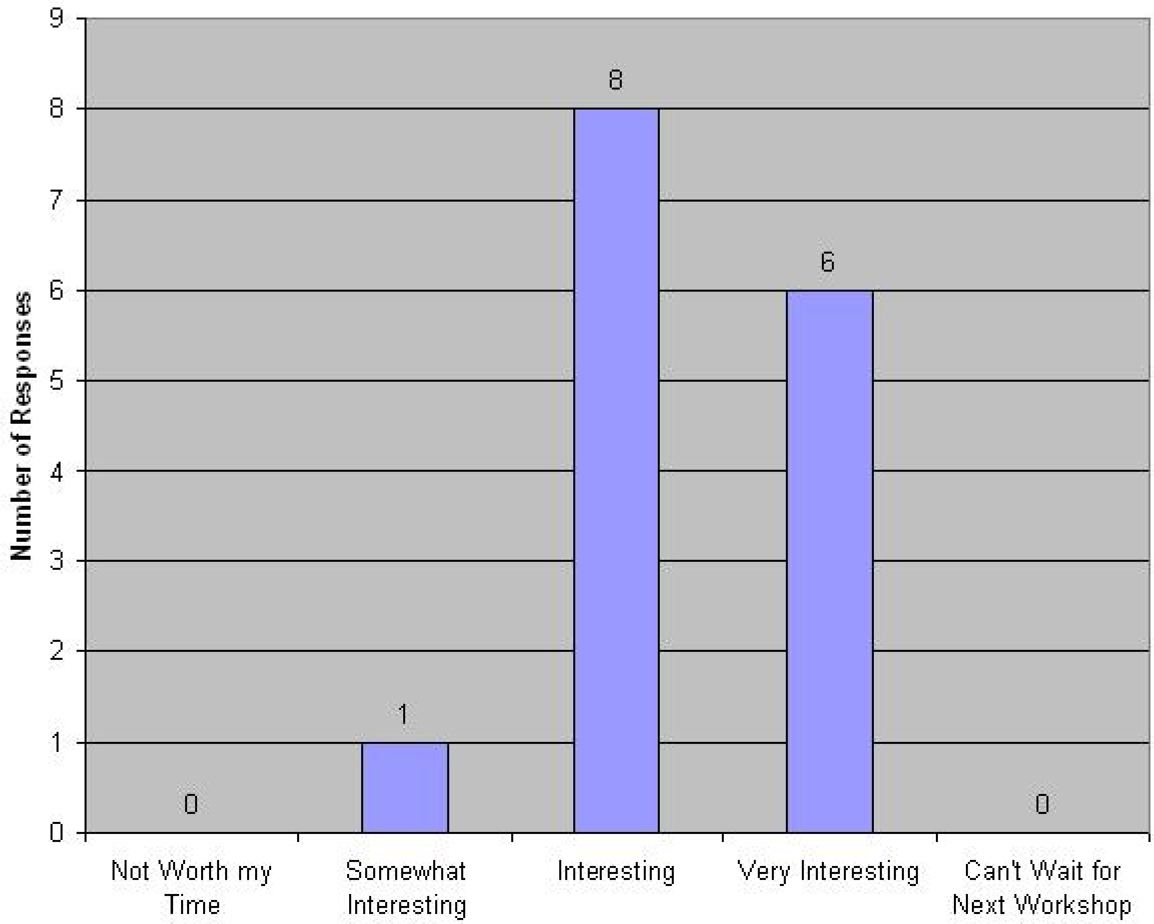

Figure 123. Overall Workshop Ratings

Workshop participants were asked how EWI could improve the workshop experience. Eight respondents provided the following feedback:

- The history overview of the project was a great piece of information, but might have been a little lengthy.

- My personal experience was just fine. There were a few times when there could have been a brief explanation of the graphing and how they represented the specific data.
- I thought the day went well. The setup - discussion, demonstration, lunch, more discussion and open forum seemed to work well.
- My own fault for not requesting it, but I would have liked to have a package of materials summarizing the background / current state of the prototype [before the workshop]. This may have provided others opportunity to bring additional questions / discussion ideas.
- Have a video demo of the unit. It would cut down on time and allow everyone an optimal view of the presentation. Video filters are available to allow the video taping of welding. Too much time was spent in the shop setting up the equipment for each of the welding procedures. At least with a video, you can make sure the equipment works instead of giving a poorly presented live demo.
- Include more discussion of other cutting-edge technologies relevant to the industry.
- I did not attend the whole workshop but speaking with people who attended made me feel that they were enjoying the experience.
- More hands on.

Participants were asked if paying $50 for future workshops (to cover food and CDs/handout materials) would prevent them from attending. The majority of respondents would not be deterred by a small workshop fee. Two respondents (15%) gave clarifying statements. One respondent indicated that his company would not charge a person for food (or handout materials) if they attended a business meeting at his company. Another respondent said it depends on what the workshop subject was; he probably would pay $50.

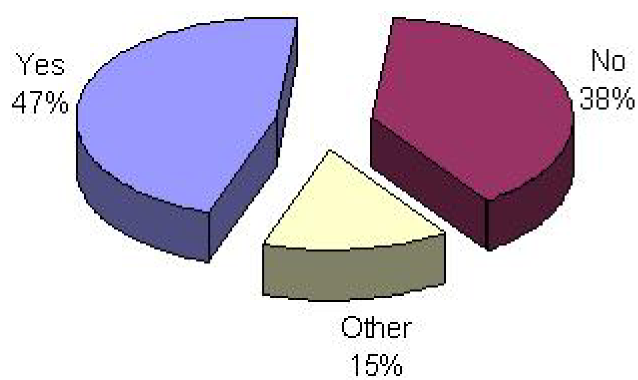

Figure 124. Would Paying for a Future Workshop Prevent You from Attending?

Workshop attendees were asked if they thought their company will ever use an automatic system for weld repair. The responses to this question are graphically depicted in Figure 125.

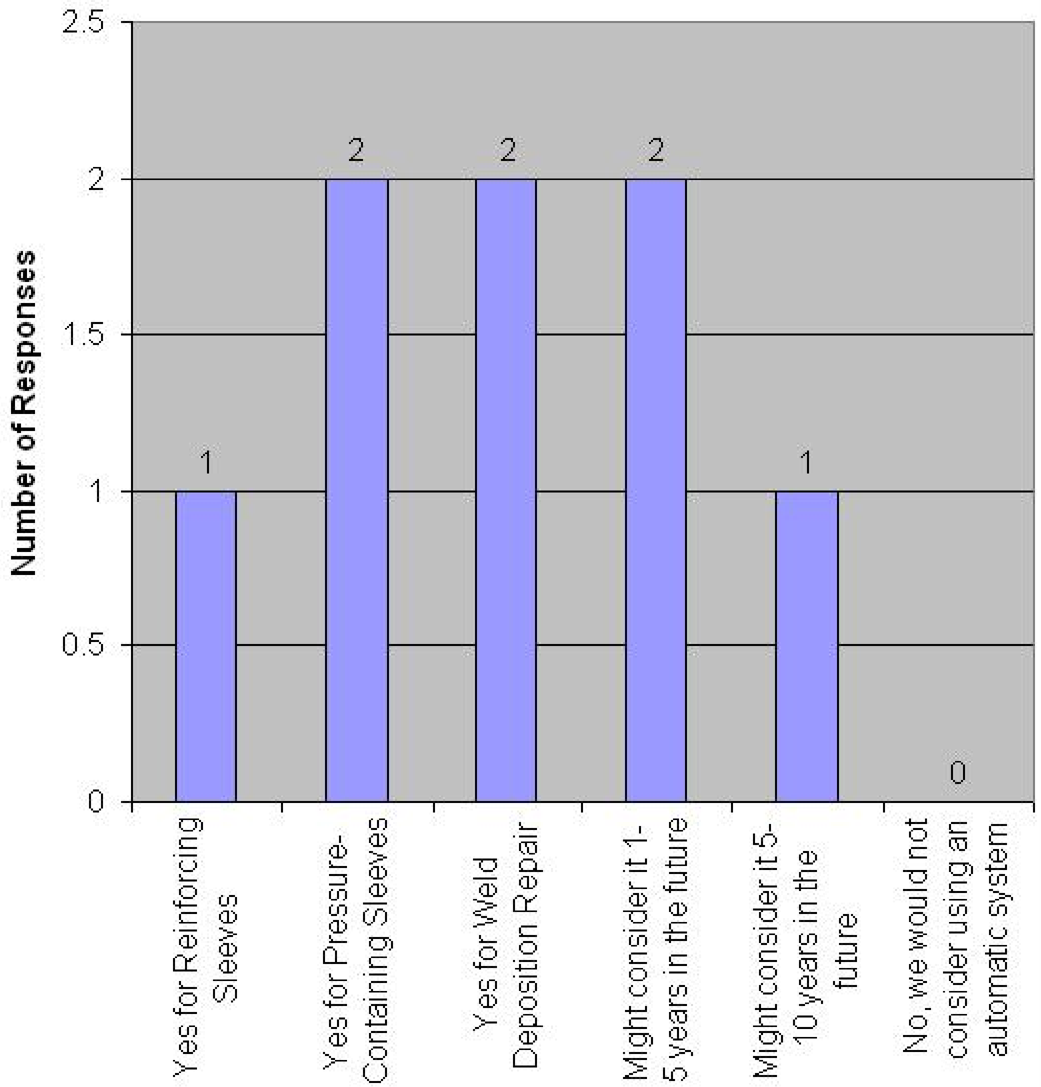

Figure 125. Potential Future Use of System

Four respondents provided the following additional feedback regarding potential uses of the system:

- It could be a possibility from a production standpoint.
- Our company is a manufacturer of the repair sleeves. There may be an application for the system in our manufacturing process.

- Probably not. The system we saw has some more development needed before it would make acceptable welds. Plus, it seems to be more ideal for large diameter pipelines (those greater than 36-in. diameter).
- I see automatic systems for repetitive processes (butt welds on new construction). A sleeve installation and corrosion repair is not a process that would be economical. Other factors such as welding inspection (visual, nondestructive) and weld repair are also things that limit the use of this type of welding.

During the workshop, participants were asked to identify ways that the current system could be improved. Following is a summary of their input:

- Protect the system from rain/humidity and the environment.
- Need to define the level of pipe cleanliness needed for the system to work.
- Integrate through the arc seam tracking with teach points along the way to define starts, stops and intermediate points along the weld joint path.
- [Need a button to] move the torch away from a circumferential weld to remove slag and [then push the button to] move it back to where you left off quickly.
- Consider snap on bands like CRC bands. (Will need to determine if the snap on bands will support the system weight without slipping.)
- Decrease system complexity by creating a system with longitudinal welding and scanning capability only (not circumferential). It would decrease system size, setup time and be used for longitudinal seams and weld deposition repair.
- Have the system produce a good quality weld every time.

Based on this feedback, a multiple choice question was designed for the respondents to indicate the system features of greatest interest to them. Figure 126 is a graphical representation of the survey responses to this question.

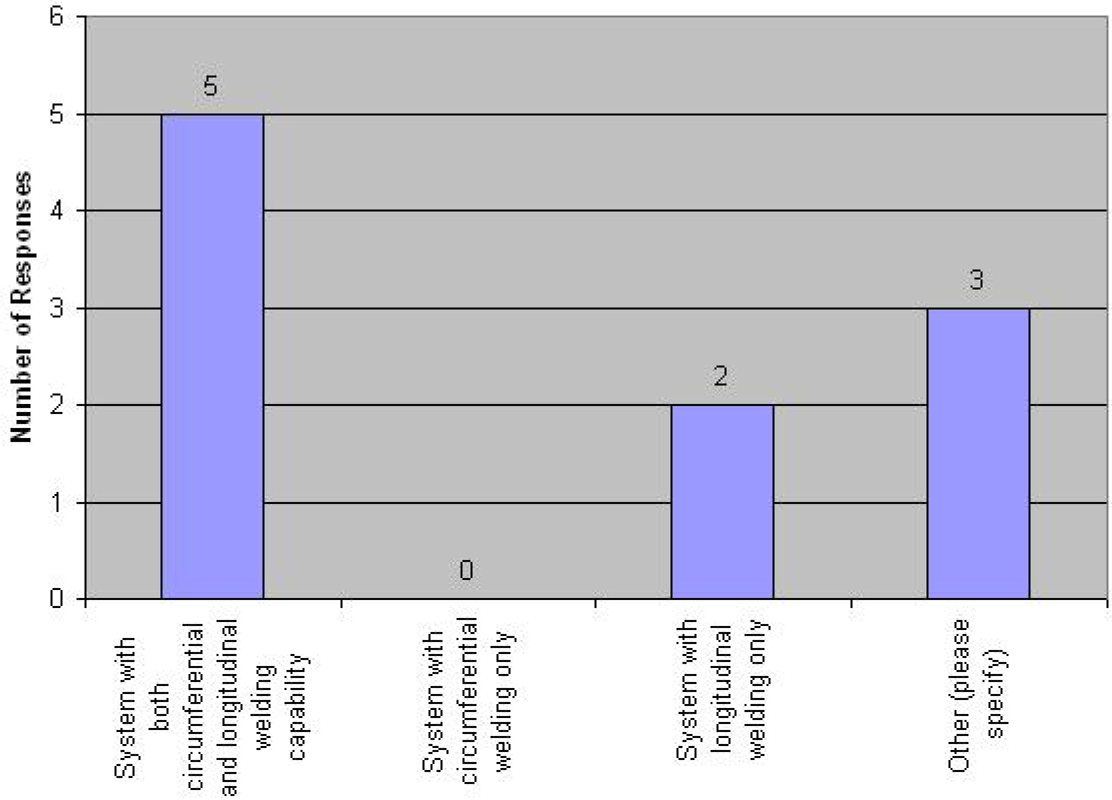

Figure 126. System Features of Interest to Workshop Participants

Three respondents provided the following additional feedback regarding features of interest:

- A system that could be set up to do one or the other or both if needed, as versatile as can be foreseen.
- I'm not sure if we would ever use the system, but I think both circumferential and longitudinal capabilities would make it more attractive.
- Seeing the basic features would be nice.

The participants were then asked to identify improvements to the current system to make it more field deployable, user friendly, etc. Eight respondents provided the following input:

- An "absolute" positioning button so you can reference all your welds off of a common point.
- Transmitters to decrease some of the hardwiring, rail system to reduce the geared tracking, which I could see becoming a nightmare to keep clean, smaller spools of wire that could be mounted directly to, or in close proximity to the torch.

- The current system seems to be at the mercy of the repair site environment and appears to be a little setup intensive.
- Feeder needs to be on the bug or in the ditch top for real world.
- For weld-deposit repairs: the system should be able to laser scan the corrosion, first deposit weld material in the deepest pits, and then go back over the entire defect to get the shallow corrosion and to double up the deposits on the deep pits.
- The end of the torch needs to be more accessible, and there needs to be an easier system for getting the end aligned with the sleeve.
- If the laser could scan the edge of the sleeve and automatically align it, that would be perfect.
- There needs to be a way so, once a completed weld pass is made, the system moves the torch to the side to allow wire brushing of the weld. Then, with a push of a button, have the torch return to its position, ready to make the next bead.
- Allow the welder more ability to visually observe welding process and quickly / easily make changes to tracking / weld parameters.
- I believe there are servo type automatic welding systems currently on the market with seam searching/seam tracking capabilities that can be adapted for pipeline welding.
- As a casual observer, it looked like the user interface required a lot of manual entry. It would be better if it were more "automatic".

Workshop attendees were asked if they would be interested in hosting an in-service field trial once the system is field hardened; three people provided the following input:

- I'm not sure our pipelines are large enough to support an in-service field trial. Plus, we'd have to get buy-in with the integrity department.
- Possibility in the installation of one of our company's pressure containing vessels.
- It would be up to engineering.

Participants were asked to identify the technology road blocks that the gas transmission pipeline industry is facing in the next two years that EWI could help with. Three respondents reiterated the feedback that all participants voiced during the workshop:

- Trained workforce.
- Qualified labor.
- More welding personnel.

As a final question, the workshop participants were asked to give EWI feedback on any topic of their choice. Three people identified the following technologies as being of interest to them:

- Underwater magnetic pulse welding.
- In-process pipe welding techniques.
- Cutting edge materials joining technology.

As a take away from the event, workshop participants were given a CD with all of the presentations and four videos of the system welding during the field trial at TransCanada.

1.3.8 Technology Readiness Level Assessment

A technology readiness level (TRL) assessment is used to identify a technology's performance risk and its integration risk. TRLs provide a common language and standard to assess the performance maturity/risk of a technology and the path for system maturation. Using the NASA developed TRL system[43] as a template, the TRL chart in Figure 127 was developed specifically for the automated welding system, which is currently a TRL 5.

[43] Author unknown, http://www.hq.nasa.gov/office/codeq/trl/trlchrt.pdf.

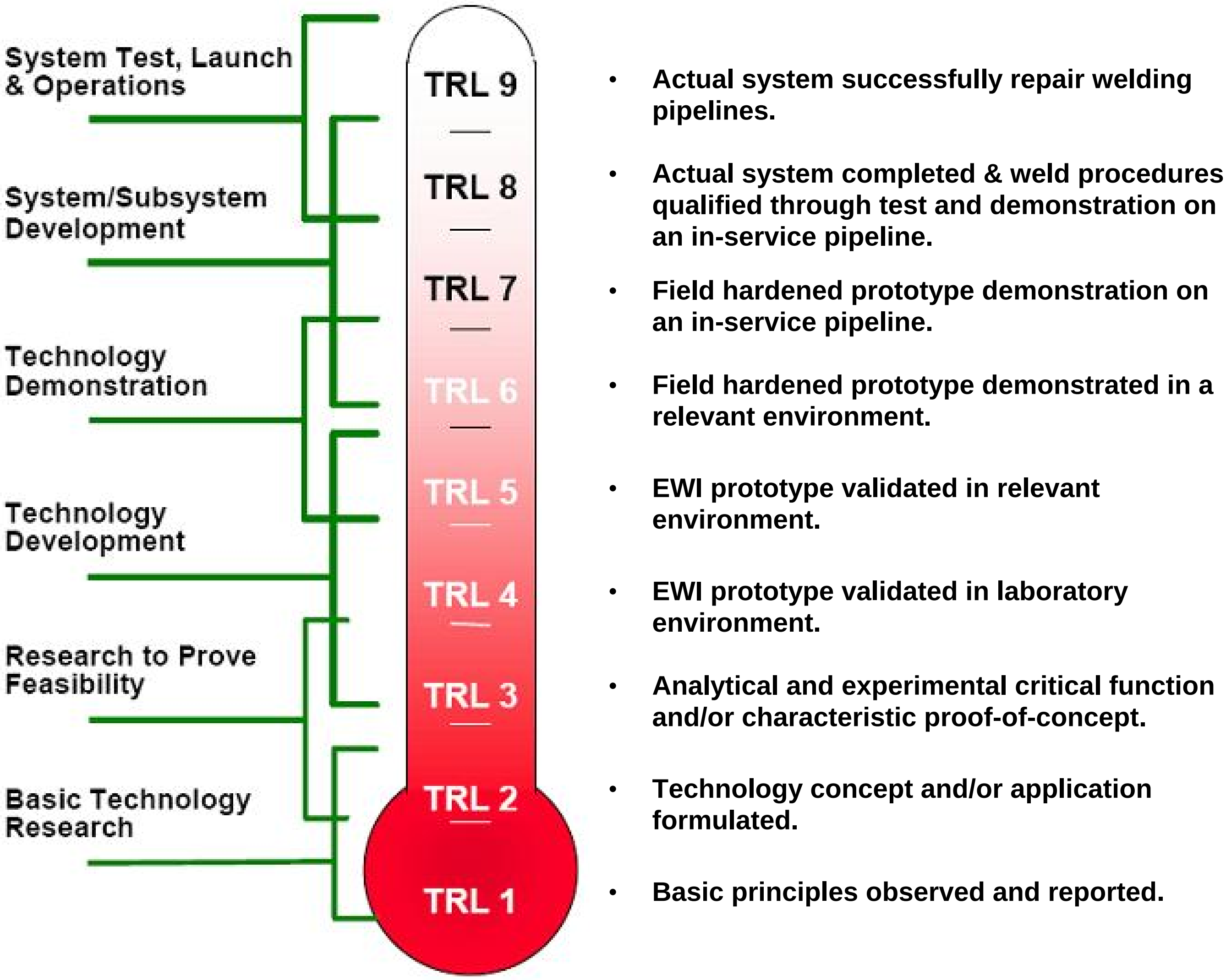

Figure 127. Technology Readiness Level of Automated Welding System

1.3.9 Commercialization Opportunity

Many welding equipment manufacturers sell systems for production pipeline welding, but none currently make systems for automated welding repair. The number one concern of the workshop participants was the lack of qualified personnel to replace their retiring welders. The automatic welding system has the potential to enable a repair welder to multi-task (e.g., while the system is welding, the welder could be fitting or tacking the next sleeve). As the workforce continues to shrink, it will eventually reach a level where pipeline companies are forced to look for alternate ways to make the necessary repairs with fewer welders. The system developed for this project fits that niche.

Before the automated welding system can be developed past TRL 5, the following must be determined:

- A commercialization partner (i.e., welding equipment manufacturer) must be identified.
- The market for the system must be understood.
- Funding source for developing field hardened system must be obtained.
- A customer (i.e., end user) must be identified who is willing to participate in future development activities.
- Customer's needs and expectations must be quantified.
- Customer's needs and requirements must be prioritized.
- Identify the necessary steps to accomplish the above.

In an effort to reach TRL 9 and turn the EWI developed system into a commercially available product, during a teleconference on May 30, 2007, EWI and Bug-O Systems put together a plan to assess the market and to identify a customer willing to participate in future development activities.

Action Items from the teleconference:

- A memorandum of understanding (MOU) is being written to establish the ground rules for the interaction.
- Bug-O is drafting a survey, the purpose of which is to identify the market potential and to identify potential customers who are willing to participate in future development activities.
- EWI will add to the survey and circulate it to EWI's liquid and gas transmission pipeline member companies.
- After the results of the survey are analyzed, EWI and Bug-O will decide if there is enough market interest to justify developing the system past TRL 5.

If EWI and Bug-O decide to move forward, EWI will ship the system to Bug-O so they can conduct a thorough evaluation of the system's performance/operation. A customer (or customers) will then be selected to assist with system development. Bug-O will estimate how much it will cost to work harden the system and how long it will take. The EWI/Bug-O team will then determine how to obtain the necessary funding and move forward once the funding is secured.

1.4 Conclusions

This project extended the current capabilities of in-service welding by developing a fully functional prototype automated welding system for use on in-service pipelines. A demonstration system suitable for welding pipelines was built and tested in controlled field conditions at TransCanada in North Bay, Ontario and demonstrated at EWI during a workshop in May 2007.

The automated welding system incorporates real-time adaptive control to ensure reliable and repeatable welding conditions. The real time control is based on a laser vision system that was developed by EWI originally for pipeline corrosion measurement and assessment. The laser based vision system was interfaced with an adaptive welding system that was designed with the knowledge developed during years of collaboration with Cranfield University. The combination of project partners provided a unique combination of skills and technical experience that enabled a reliable, cost effective, robust solution to be developed.

The system is capable of deploying either GMAW or FCAW to weld pressure-containing sleeves, to weld reinforcement sleeves, or to directly deposit weld metal over an area to replace metal loss from corrosion. Not only will this provide higher quality repair welds, but it will also permit in-service repair welding to be extended to future high strength and/or high pressure pipelines where manual SMAW repair welding is not suitable.

For installing a typical reinforcing sleeve on a 36-in. (914-mm) diameter pipeline, the automated system with FCAW is approximately 2.3 times faster and 62% cheaper than SMAW manual welding.

1.5 Recommendations

The automated system developed by this project should be field hardened and further developed with commercialization partner Bug-O Systems. Another series of field trials should then be conducted on an in-service pipeline to weld a reinforcing sleeve, a pressure-containing sleeve, and to make a weld deposition repair (if possible).

In addition to the laser tracking capabilities, adding a through arc seam tracking is recommended to aid in depositing the circumferential fillet welds. The largest hurdle deals with accurately locating the welding arc in the joint. Moving the arc on the fly becomes increasingly difficult since the visual accessibility to the welding area is hindered by the close proximity of the hardware to the OD of the pipeline.

The accessibility to the welding torch needs to be improved by incorporating a quick disconnection to the welding torch holder or by redesigning the torch mounts.

2.0 Final Financial Program

This section contains a final project financial report that summarizes the status of Government and Team contributions for the project and reconciles any prior discrepancies or variances in contributions.

2.1 Status of Government and Team Contributions

The project activities were performed with funding provided by the U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (DOT/PHMSA) via Other Transaction Agreement No. DTRS56-03-T-0009 and Pipeline Research Council International (PRCI) Contract No. PR-185-04501.

The project team was lead by Edison Welding Institute (EWI) working in collaboration with TransCanada, the Welding Engineering and Metal Science Centre of Cranfield University, PRCI member companies, Serimer DASA, and Bug-O Systems.

2.1.0 Planned Team Contributions

The cost of the project was shared between the Government and the Team. The minimum percentage of Team cost share for the program was to be the minimum value required by the source of the Government funding. The value of the Federal cost share was to be $409,673 and the value of the Team's cost share was to be $450,000 making the total project value $859,673. Making the Federal cost share of the project 47.65% and the Team cost share 52.35% (minimum). The following paragraphs describe the planned cost share contributions of the Team participants.

PRCI planned to provide $400,000 of cost share in the form of two PRCI-funded projects to be conducted in parallel with the DOT project, the results of which were available to the DOT program in support of Task 3. $180,000 was to be released for EWI and Cranfield University to develop computer control algorithms for adaptive control of mechanized welding of pipelines (tracked via EWI Project No. 46256CSP). $220,000 was to be released for EWI to purchase equipment for DTRS56-03-T-0009 (tracked via EWI Project No. 47451CAP).

TransCanada planned to provide $50K in cost share in the form of labor, materials, and a venue for the field repair welding trials (Task 6).

2.1.1 Actual Team Contributions

The DOT/PHMSA, provided $409,673 in support of all tasks of the project.

PRCI provided a total of $418,335 of cost share: $191,089 was provided via 46256CSP and $227,246 was provided via 47451CAP. When the system had to be redesigned to accommodate the 30-in. (762-mm) diameter pipe for the field trial, PRCI provided an additional $7,000 to assist with the purchase of new system components (via 47451CAP). Unfortunately, completing the system required $31,614 in additional labor and equipment costs (this will be counted as EWI cost-share against Task 3). Therefore the total cost share contribution for Task 3 is $449,949.

TransCanada provided $50,000 of cost share in labor and materials by hosting the field trial.

For welding procedure development:

- X80 material was provided by EWI from its existing inventory.
- X100 material was provided by BP via the inventory at Cranfield University.
- X120 material was provided by ExxonMobil.

No estimated dollar value was provided for these materials.

For DOT award DTRS56-05-T-0001, "Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines," EWI developed a graphical user interface (GUI) and a communication protocol to control the motion control software of the Serimer DASA welding system via EWI project no. 47961GTH, Task 4. EWI used this same GUI and communication protocol for the automated welding system developed for DTRS56-03-T-0009. Unfortunately, this can't be counted as cost share, but it is noteworthy as leveraged technology.

Due to the system redesign required for the field trial and the fact that the abandoned Blackman design cost the bottom line of the project $90K, EWI overspent the project by approximately $51,356 in labor costs (final numbers from the EWI automated accounting system). These costs were counted as cost-share and appear in the appropriate rows for Tasks 6, 7, and PM where the additional expenses were incurred.

The total cost of the effort was $960,979 and was shared between the Government and the Team. The value of the Federal cost share was $409,673; the value of the Team cost share was $551,306. The percentage of Federal cost share was 43%; the percentage of Team cost share was 57%.

2.2 Final Financial Accounting

The final per task financial accounting is summarized in Table 15.

Table 15. Final Financial Accounting

	Government Funding		Contractor Cost-Share	
Task	**Budget**	**Final**	**Budget**	**Final**
1	$28,008	$28,010	$0	0
2	$14,326	$14,326	$0	0
3	$85,216	$85,207	$400,000	$449,949
4	$49,856	$45,878	$0	0
5	$22,666	$32,041	$0	0
6	$36,140	$34,471	$50,000	$83,445
7	$14,440	$201	$0	$8,671
Sub-CU	$91,127	$91,127	$0	0
PM	$67,894	$78,412	$0	$9,241
Totals	$409,673	$409,673	$450,000	$551,306

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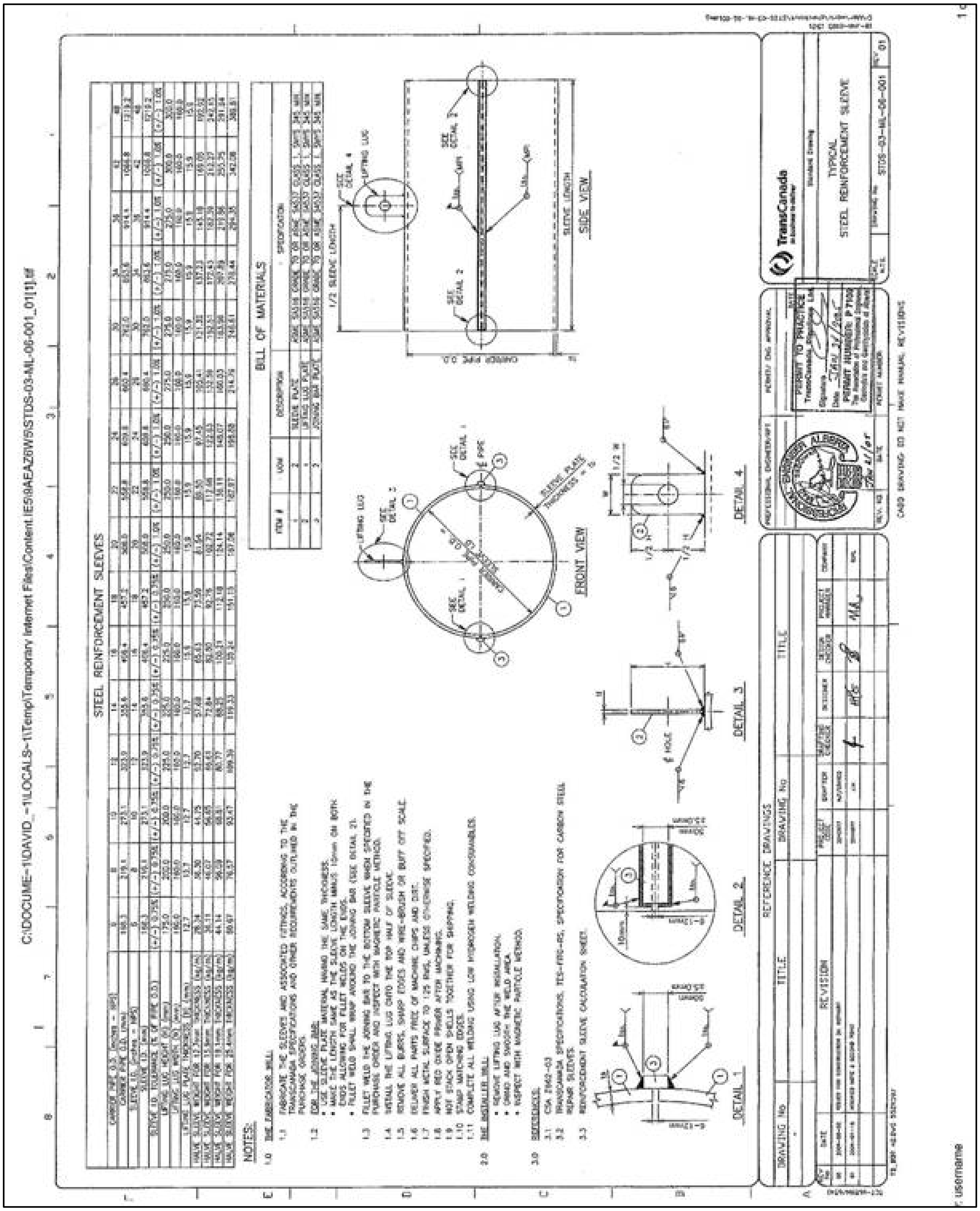
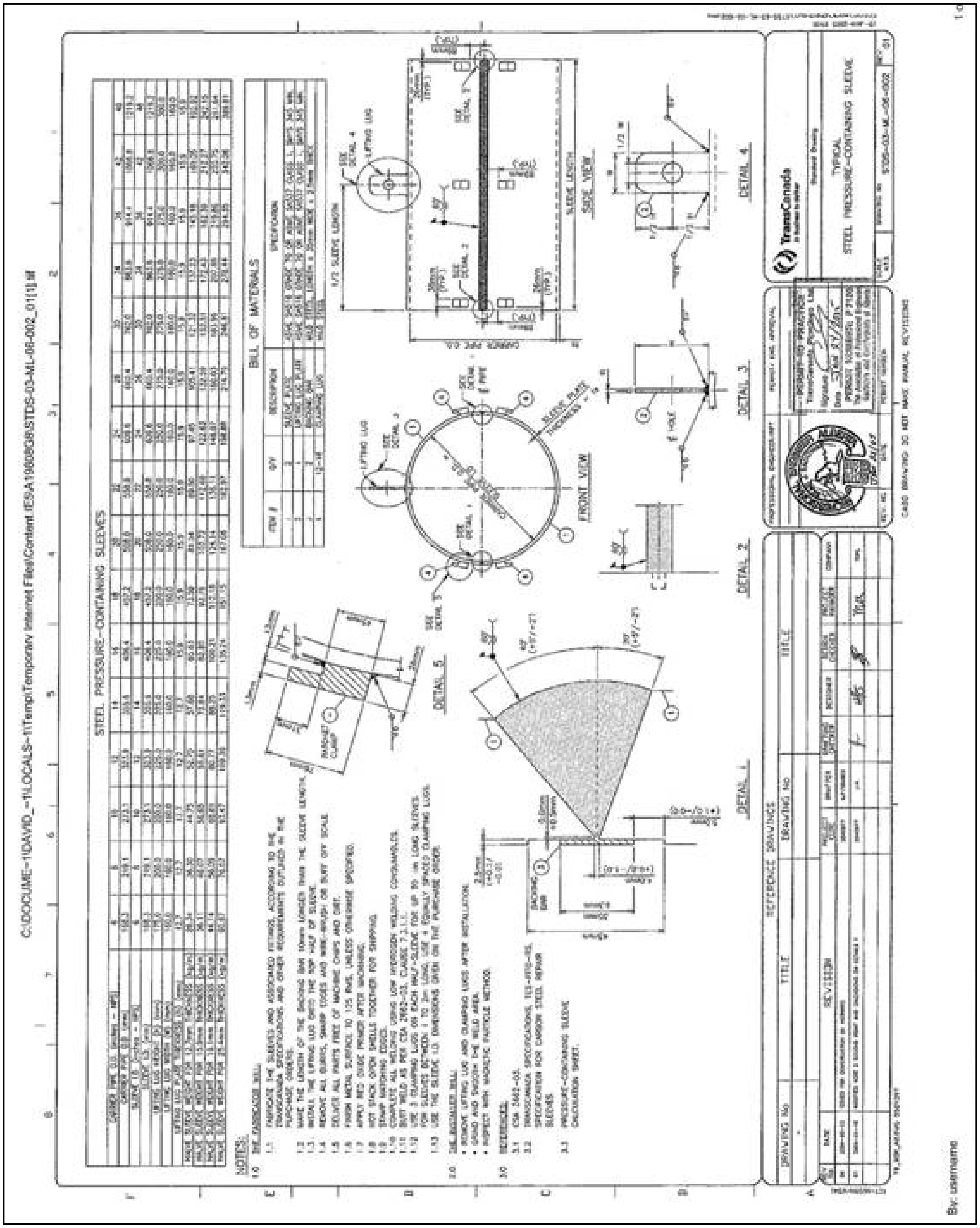
4.0 Appendices

Appendix A. TransCanada Reinforcing Sleeve (Type A)



Appendix B. TransCanada Pressure-Containing Sleeve (Type B)



Appendix C. July 11, 2005 DOT/PRCI Presentation

Advanced Welding Repair and Remediation Methods for In-Service Pipelines

EWI/DOT/PRCI/TCPL
July 11, 2005

THE MATERIALS JOINING EXPERTS

Overview

- Project Plan
- Project Funding
- Contractual Changes
- Review
- Technical Objectives
- Immediate and Long-Term Problems
- Solutions
- Supporting Actions
- Remaining Tasks
- Next Steps

THE MATERIALS JOINING EXPERTS

Nancy Porter

Project Plan

- Task 1 – Review of Industry Needs and Current Practices
- Task 2 – Write Technical Specification
- **Task 3 – Design and Build of System**
- Task 4 – Laboratory Development and Evaluation
- Task 5 – Weld Procedure Qualification
- Task 6 – Field Testing and Validation
- Task 7 – Final Report

THE MATERIALS JOINING EXPERTS

Connie Reichert and Nancy Porter

Project Funding

DOT Funds
46996GTH
Labor & Travel

$409,673

PRCI Funds
46256CSP
EWI + Cranfield Project
Cranfield Design

$185,589

PRCI Funds
47451CAP
Equipment & Travel to Cranfield

$220,000

TCPL Funds
Field Trials

$50,000

DOT = $410K PRCI = $406K TCPL = $50K => $860K Total

THE MATERIALS JOINING EXPERTS

Nancy Porter

Contractual Changes

- Sept-03: DOT Award Executed with EWI
- July-04: DOT & PRCI Subcontracts Executed with Cranfield
- Dec-04: Blackman left Cranfield and started SabreWeld
  - Provided concept drawings of system
- Jan-05: EWI Terminated Subcontracts with Cranfield
  - Tasks 1 and 2 Complete
  - Task 3 in Process – provided presentation with design concept*
- Jan-05: EWI Issued RFPs to SabreWeld for DOT & PRCI $$

* - Created for BP not EWI

EWI THE MATERIALS JOINING EXPERTS

Nancy Porter

Contractual Changes Continued,…

- Mar-05: SabreWeld Signed PRCI Subcontract
  - $100K wired to SabreWeld to Purchase Equipment
- Apr-05: SabreWeld stopped communicating
- May-05: SabreWeld not communicating status
  - Non-responsive to inquiries for status reports
  - DOT subcontract still not signed
  - Refused to provide list of equipment ordered
  - PRCI subcontract terminated; DOT RFP withdrawn

EWI THE MATERIALS JOINING EXPERTS

Nancy Porter

Contractual Changes Continued,…

- Jun-05: EWI Re-scoped Project
  - $100K PRCI funds recovered from SabreWeld
  - Scheduled telecon to review new design concept

THE MATERIALS JOINING EXPERTS

Nancy Porter

Project Background

- The repair and remediation of in-service pipelines is a safety critical process.
- For large diameter pipelines, the use of manual welding is time-consuming and there is a greater risk of operator error.
- Higher strength pipelines require precise weld bead placement to ensure correct tempering of previous weld runs.
- Conventional electrodes for in-service repair will not provide adequate weld metal properties on pipe grades above X80.
- **Need to develop advanced welding repair and remediation methods for in-service pipelines.**

THE MATERIALS JOINING EXPERTS

Connie Reichert

Technical Objectives

- To develop an automated welding system for use on in-service pipelines.
- To implement a real-time adaptive control system to ensure reliable welding conditions.
- To evaluate system performance by performing laboratory trials.
- To validate the system and gain regulatory approval by qualification of procedures complying with recognized industry standards and performing field trials.

EWI THE MATERIALS JOINING EXPERTS

Connie Reichert

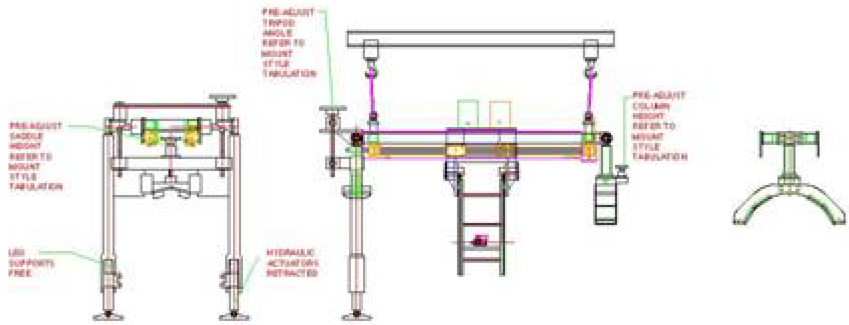
Hardware Design Progression

- New design was proposed to EWI & DOT Feb-05
  - Although more technically complicated, EWI supported the new design
  - EWI had all confidence that SabreWeld would deliver
- Lack of communication for several months which affected EWI's progression on the project
- EWI presented new design in May-05 to PRCI and members

EWI THE MATERIALS JOINING EXPERTS

Connie Reichert

SabreWeld Design



EWI THE MATERIALS JOINING EXPERTS

Connie Reichert

Immediate and Long Term Problems

- PRCI members do not support SabreWeld's design
  - Did not fit the original goals of the project
  - PRCI members support a system existing operators can use and that costs less than current alternatives
    - No special training requirements
    - No additional facilities needed
- SabreWeld's status on their Task was unknown for a period of several months
- Threat of EWI not receiving remaining $110,000 from PRCI

EWI THE MATERIALS JOINING EXPERTS

Connie Reichert

Solutions

- Pull hardware development in-house
  - Use original design based on Serimer DASA welding tractors
  - In-kind contribution based on previous project work completed with Cranfield using a Serimer DASA bug
  - EWI has current project with Serimer and have extensive knowledge of the hardware and control system

- Team up with mechanized tractor (bug) supplier
  - Meeting with Serimer DASA at EWI to discuss commercialization/support scheduled for July 18

EWI THE MATERIALS JOINING EXPERTS

Connie Reichert

Supporting Actions

- Cranfield is lending EWI the Servo-Robot laser system ($60,000)

- Using Cranfield's design from cost share project 46256CSP with suggested changes per original project plan

- PRCI Project Ad-Hock Chair-David Dorling supported the release of SabreWeld as contractor

EWI THE MATERIALS JOINING EXPERTS

Connie Reichert

New Design Concept

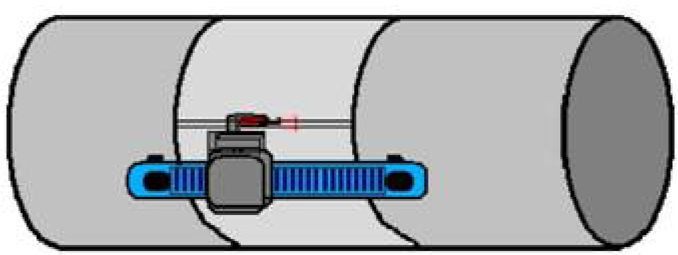
- 3 Hardware Configurations
  - Longitudinal repair sleeve weld
  - Circumferential repair sleeve weld
  - Weld deposition for repair of corroded area
- Once set of tools – different configurations
- Work with commercial bug manufacturer
- Add to existing and supported mechanized welding equipment

EWI THE MATERIALS JOINING EXPERTS

Connie Reichert

Sleeve Welding
- Longitudinal Weld

+ Magnetically attach track
+ Standard bug design
+ Pre-planning weld fill
+ Seam-tracking with laser
+ Adaptively filling joint

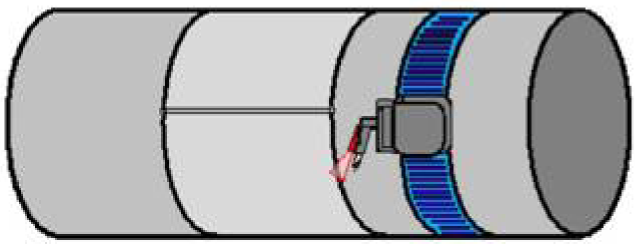


EWI THE MATERIALS JOINING EXPERTS

Connie Reichert

Sleeve Welding
- Circumferential Weld

- Standard orbital track
- Bug with 45 torch angle
- Seam-tracking with laser
- Adaptively filling joint
- Two operators can use two bugs to weld circumferential welds at the same time

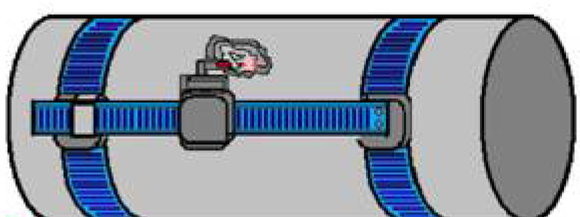


THE MATERIALS JOINING EXPERTS

Connie Reichert

Weld Deposition Repair
- Multi-bead, multi-layer longitudinal

- Two standard orbital tracks
- Two standard or "basic" bugs moving around orbital track
- One straight track design attached to substrate
- One standard bug system
- Operator selects boundary of deposition area
- Laser seam-tracking
- Adaptively filling joint

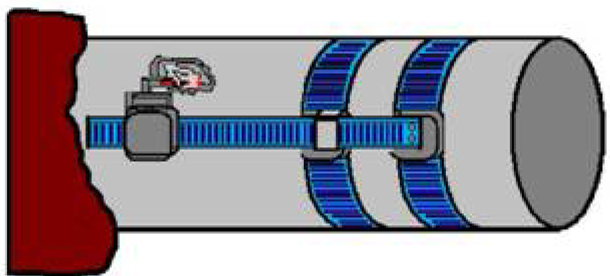


THE MATERIALS JOINING EXPERTS

Connie Reichert

Weld Deposition Repair in Limited Access Area
- Multi-bead, multi-layer longitudinal

+ Two standard orbital tracks
+ Two modified bug designs w/o 45 torch attached
+ One straight track design attached to substrate
+ One standard bug system
+ Operator selects boundary of deposition area
+ Laser seam-tracking
+ Adaptively filling joint



THE MATERIALS JOINING EXPERTS

Connie Reichert

Advantages to New Design Concept

- Partner understands welding environment and all perils of land-based pipeline fabrication
- System will be field ready, not a lab prototype
- System uses already existing equipment
- EWI can demonstrate longitudinal welding of sleeve very quickly (3 months)
- EWI can use basic system to start laboratory trials (within 3 months) concurrently with the rest of the hardware is under construction
- System will have a logical commercial supporter with chosen partner
- System can be maneuvered and operated by existing operators- no lifting equipment or tradesperson required
- System components are replaceable in the field and widely available

THE MATERIALS JOINING EXPERTS

Connie Reichert

Current Progress and Remaining Tasks

Task 1 – Review of Industry Needs and Current Practices

Task 2 – Write Technical Specification

Task 3 – Design and Build of System

Task 4 – Laboratory Development and Evaluation

Task 5 – Weld Procedure Qualification

Task 6 – Field Testing and Validation

Task 7 – Final Report

THE MATERIALS JOINING EXPERTS

Nancy Porter

Proposed Project Schedule

Task 3 – Need Vendor Input to Finalize
Task 6 – Need TCPL to Schedule

THE MATERIALS JOINING EXPERTS

Nancy Porter

Next Steps

- Obtain DOT and PRCI concurrence with new plan
  - Submit no-cost extension to DOT
  - Submit no-cost extension to PRCI
- Solidify new system architecture
- Decide tasks of commercial partner
  - Determine commercial partner funding

THE MATERIALS JOINING EXPERTS

Nancy Porter

Appendix D. August 8, 2005 DOT/PRCI Presentation

Advanced Welding Repair and Remediation Methods for In-Service Pipelines

DOT Follow Up Presentation
August 8, 2005

EWI
THE MATERIALS JOINING EXPERTS

Agenda

- Introductions
- Purpose of Today's Telecon
- Project Objectives
- Modified Task 3 Equipment Design
- Support from Partners
- Next Steps

EWI Nancy Porter THE MATERIALS JOINING EXPERTS

Purpose of Telecon

- Review Preliminary EWI System Design Drawings
- Present PRCI and TCPL Support Letter
- Present Cranfield University Support Letter
- Obtain DOT Approval of New Equipment Design
  - Obtain Permission to Continue Project
  - Obtain Permission for No-Cost Extension

DOT = $410K PRCI = $406K TCPL = $50K => **$860K Total**

EWI Nancy Porter THE MATERIALS JOINING EXPERTS

Project Objectives – No Changes

- Develop an automated welding system for use on in-service pipelines
- Incorporate real-time adaptive control system to ensure reliable welding conditions
- Evaluate system in laboratory
- Validate the system
  - Develop qualified welding procedures
  - Perform field trials

EWI Nancy Porter THE MATERIALS JOINING EXPERTS

Project Plan – No Changes

Task 1 – Review of Industry Needs and Current Practices

Task 2 – Write Technical Specification

Task 3 – Design and Build of System

Task 4 – Laboratory Development and Evaluation

Task 5 – Weld Procedure Qualification

Task 6 – Field Testing and Validation

Task 7 – Final Report

EWI Nancy Porter THE MATERIALS JOINING EXPERTS

Task 3: Design and Build System

- **EWI Moved Hardware Development Back In-House**
  - Use original design based on Serimer DASA welding tractors
  - In-kind contribution based on previous project work completed with Cranfield using a Serimer DASA bug
  - EWI has current project with Serimer and have extensive knowledge of the hardware and control system
- **Partner with Mechanized Tractor (a.k.a. Bug) Supplier**
  - EWI met with Serimer DASA to discuss commercialization/support

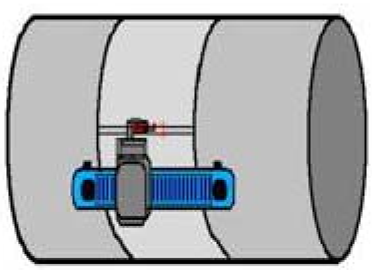
EWI Connie Reichert THE MATERIALS JOINING EXPERTS

Meeting with Serimer DASA

- Discussed EWI design concept
- Discussed equipment currently available or soon-to-be available from Serimer
- Discussed partnership and support of new equipment and interest in commercialization
- Serimer is interested in collaborating on the project and is determining staff availability
- Serimer can provide some equipment initially and additional equipment within a couple months

EWI Connie Reichert THE MATERIALS JOINING EXPERTS

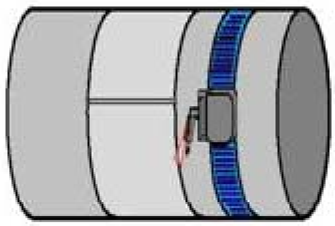
Serimer DASA Comments – Longitudinal Sleeve



- Magnetically-attached straight track has already been used and proven by Serimer
- This design concept is essentially ready to go
- Equipment required:
  - STX bug
  - STX controller box
  - Straight track
  - Magnets

EWI Connie Reichert THE MATERIALS JOINING EXPERTS

Serimer DASA Comments – Circumferential Sleeve

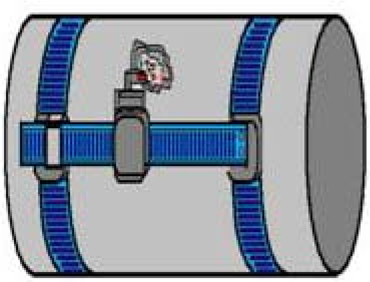


- Bug must have ability to tilt torch at 45° to make this weld
- Serimer suggest their new bug design with pendulum oscillator
- EWI suggests using standard bug and coordinated motion to create oscillation at 45° angle
- Equipment Required:
  - STX bug
  - STX controller box
  - Circumferential track
  - Torch tilt bracket
  - Coordinate STX motion

Connie Reichert

THE MATERIALS JOINING EXPERTS

Serimer DASA Comments – Corrosion Patch Fill



- Serimer did not agree with trying to coordinate two bugs for traveling
- Serimer suggested extending the reach on the cross-seam axis and using only one bug and track
- Serimer is already developing a more robust cross-seam axis for another application
- Equipment Required
  - STX bug
  - STX control box
  - STX circumferential track
  - Modified STX axis
  - Coordinate STX motion

Connie Reichert

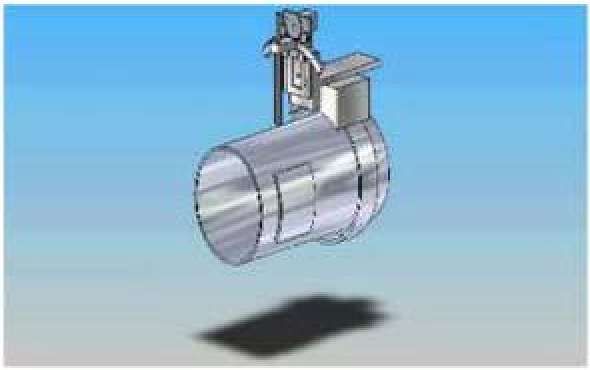
THE MATERIALS JOINING EXPERTS

New Design Concept

- **Three Welding Capabilities**
  - Longitudinal repair sleeve weld
  - Circumferential repair sleeve weld
  - Weld deposition for repair of corroded area
- **One set of tools – different configurations**
  - STX bug
  - STX control box
  - STX straight and circumferential track
- **EWI amends standard bug with software and hardware**
  - Coordinate motion for oscillation at 45° angle
  - Coordinate motion for encircling corrosion patch and for weld fill
  - Add on torch work bracket and hardware for torch work angle
  - Increase length of cross-seam axis for filling corrosion patch

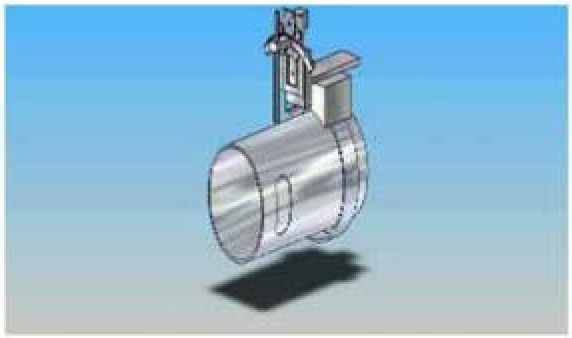
EWI Connie Reichert THE MATERIALS JOINING EXPERTS

Video of Preliminary Design Concept for Sleeve Repair



EWI Connie Reichert THE MATERIALS JOINING EXPERTS

Preliminary Design Concept for Corrosion Repair



Connie Reichert

THE MATERIALS JOINING EXPERTS

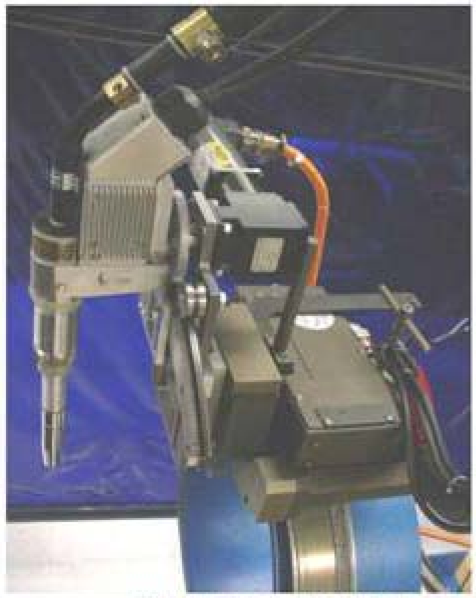
Advantages to New Design Concept

- Partner understands welding environment and all perils of land-based pipeline fabrication
- System will be field ready, not a lab prototype
- System uses already existing equipment
- EWI can demonstrate longitudinal welding of sleeve very quickly (3 months)
- EWI has extensive experience with the STX bug
- System will have a logical commercial supporter with chosen partner
- System can be maneuvered and operated by existing operators- no lifting equipment or tradesperson required
- System components are replaceable in the field and widely available

Connie Reichert

THE MATERIALS JOINING EXPERTS

EWI's STX Bug with added Hardware



Connie Reichert

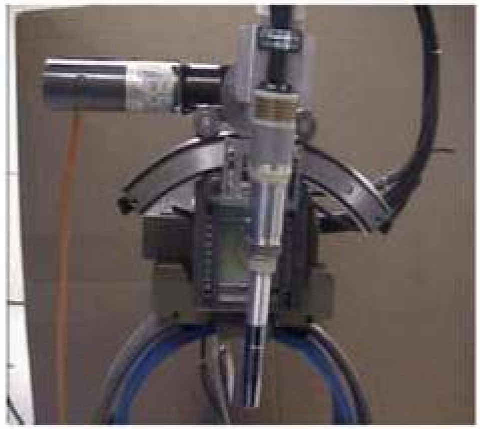
THE MATERIALS JOINING EXPERTS

Video of EWI System – Side View

Connie Reichert

THE MATERIALS JOINING EXPERTS

Video of EWI System – End View



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TransCanada/PRCI Support Obtained

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Assessment of Equipment Need

- There is a Need for this Equipment in Industry
  - Need capability to weld pipelines in-service
  - Gas flow not interrupted
  - Potential to reduce costs by 50%
    - Manual welding in-service saves ≅ $8K per sleeve
    - Automated GMAW will improve productivity over manual welding

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Opinion on Moving Design/Build to EWI

- This is the right decision
- Resignation of Stephen Blackman Director of the Welding Research Center of Cranfield University has negatively impacted several PRCI funded and co-funded projects of which this is one.
- Decision based on Input from PRCI Materials Technical Committee in May 2005.
- New design is far less complex and enhances tools that are routinely used
- Recruitment of in-service welding equipment supplier Serimer DASA adds further validation to modified approach

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PRCI Projects Successfully Competed by EWI

- Review of Procedures for Welding onto Pressurized Pipelines
- Criteria for Hot-Tap Welding, Further Studies
- Repair of Pipelines by Direct Deposition of Weld Metal
- Guidelines for Weld Deposition Repair on Pipelines
- Examination of External Weld Deposition Repair for Internal Wall Loss
- Effect of Procedure Variables for Welding Onto In-Service Pipelines
- Development of Simplified Weld Cooling Rate Models for In-Service Gas Pipelines
- Welding onto In-Service Thin Wall Pipelines

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PRCI Projects Successfully Competed by EWI

- Improved Root Pass Quality for In-Service Branch Connection Welding
- Evaluation of Preheat Requirements for In-Service Welding
- Burnthrough Limits for In-Service Welding
- Refinement of Cooling Rate Prediction Methods for In-Service Welds
- Effect of Factors Related to Hydrogen Cracking for In-Service Welds
- Enhance PRCI Thermal Analysis Model for Assessment of Attachments
- External Weld Deposition Repair for Internal Wall Loss in Tees and Elbows - Further Validation
- Realistic Hardness Limits for In-Service Welding

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PRCI Projects In Process at EWI

- Internal Repair of Pipelines
- Advanced Welding Repair and Remediation Methods for In-Service Pipelines
- Best Approach for Predicting Burnthrough for In-Service Welds
- Effect of Pressure on Burnthrough Risk
- Cooling Rate Simulation for Welding onto In-Service Pipelines

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TCPL/PRCI Conclusions

- Delay in completing project can't be avoided
- Work should continue at EWI
- EWI has successfully completed a long list of related PRCI projects
- EWI experience is invaluable and cannot be sourced elsewhere

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Cranfield University Support Letter


Cranfield

- Cranfield will load a Servo Robot Mini I Laser to EWI for the duration of the project
- Cranfield obtaining permission to provide EWI X100 pipe material

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Next Steps

- Obtain DOT Concurrence on New Design
  - Submit No-Cost 12-Month Extension to DOT
  - Submit Concurrent No-Cost Extension to PRCI
- Subcontract with Serimer DASA
- Obtain Equipment and Materials

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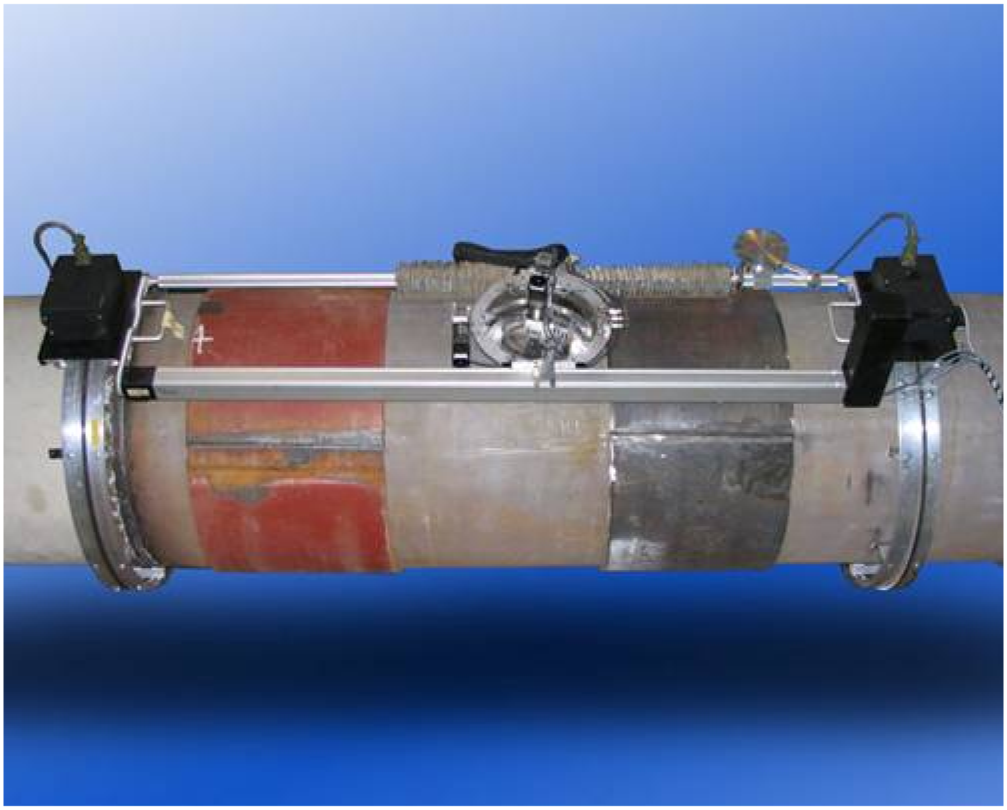
USER MANUAL

Automated Corrosion Repair System User Manual



Prepared by
EWI

MATERIALS JOINING TECHNOLOGY

Welcome

This manual was prepared for you by Edison Welding Institute (EWI).

EWI developed the ACRS (Automated Corrosion Repair System) for welded repair of corrosion on in-service, natural gas pipelines. The ACRS system was made to enable you to automatically weld circumferential and longitudinal joints on repair sleeves for pipelines. The ACRS system enables you to determine size and shape of corrosion area on the external surface of the pipeline. The ACRS system allows you to repair a patch of corrosion by adding layers of weld metal over the measured corroded patch area.

The ACRS is made of both hardware and software. The hardware unit is used to weld the fillets welds on repair sleeves, to scan an area of corrosion for measurement, and to weld up the corroded area. The software allows you to control the hardware system and make a repair of corrosion on the pipeline. The software will scan and area of the pipeline and tell you if there is corrosion in the area and how deep the corrosion area is.

This manual tells you how to use the ACRS so that you can inspect corrosion on a pipeline and repair the corrosion by welding a repair sleeve onto the pipe or by filling in the corroded area with weld metal.

Specifications

This manual was made specifically for the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (DOT/PHMSA) Award No. DTRS56-03-T-0009 (EWI Project No. 46996GTH) and Pipeline Research Council International (PRCI) Contract No. PR-185-04501 (EWI Project No. 47451CAP).

For use by DOT/PHMSA and PRCI.

Special Notes

Call 614-688-5000 for Technical Assistance.

Table of Contents

Introduction

This manual will guide you through using the ACRS to weld a repair sleeve onto a pipe, to inspect a corroded area, and to fill in the corroded area with weld metal.

Section 1. Identifying the ACRS System Parts

At the end of this section you will be able to:

1. Locate and identify ACRS System Parts
2. Get ready to connect the system parts

Section 2. Connecting ACRS System Parts

At the end of this section, you will be able to:

1. Locate all connectors on each part
2. Connect the ACRS Hardware
3. Power On the ACRS System

Section 3. Operating the ACRS System Software

At the end of this section, you will be able to:

1. Power on the ACRS system software
2. Locate the Main software screen
3. Locate the Jog software screen
4. Locate the Circumferential Sleeve Weld software screen
5. Locate the Longitudinal Sleeve Weld software screen
6. Locate the Corrosion software screen

Section 4. Weld a Circumferential Sleeve Joint onto the Pipe using the ACRS System

At the end of this section, you will be able to:

1. Place the ACRS system in position to make a circumferential weld on a repair sleeve
2. Make a circumferential weld on a repair sleeve

Section 5. Weld a Longitudinal Sleeve Joint onto the Pipe using the ACRS System

1. Place the ACRS system in position to make a longitudinal weld on a repair sleeve
2. Make a longitudinal weld on a repair sleeve

Section 6. Inspect a Corroded Area on the Pipe using the ACRS System

1. Place the ACRS system in position to scan an area of the pipe to determine corrosion area and depth
2. Review scan results and suggested welding parameters

Section 7. Repair a Corroded Area on the Pipe using the ACRS System

1. Place the ACRS system in position to make a corrosion repair patch
2. Make a repair of a corrosion patch

Section 8. Shut Down and Disconnect the ACRS System

At the end of this section, you will be able to:

1. Power Off the ACRS System
2. Unplug connections on each part
3. Remove the ACRS system from the pipe

Section 1. Identifying the ACRS System Parts

Instruction Pages

This section describes how to identify the ACRS System parts. Please use caution when unpacking the components as they are heavy and can cause injury if dropped or mishandled. Use help or assistance while unpacking parts that are too heavy to carry. The ACRS System is 4 main pieces of hardware.

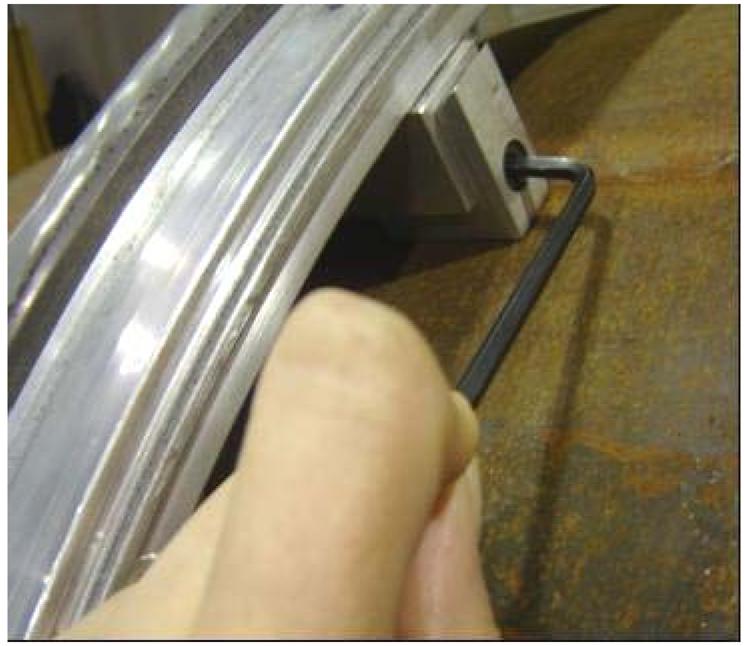
Bug-O 30 Inch Diameter Bent Rigid Rails
Two 30 inch diameter standard product rails from Bug-O.

Main Welding Unit
The ACRS Main Welding Unit includes two standard product mechanized welding tractors from Bug-O, a Servo-Robot laser sensor and a welding torch. . The ACRS Main Welding Unit is connected to the Control Cabinet but a set of cables.

Control Cabinet
The Control cabinet holds all the control hardware that makes the system work. The Control cabinet includes the control computer which runs all the software programs. All components are connected to the control Cabinet by with cables or connectors. The Control Cabinet has the main power plug to connect to a standard 120 Volt A/C grounded wall outlet. The main Power button and Emergency Stop button are located on the top of the Control Cabinet.

Control Pendant
A wireless control display is used for remote control of the ACRS system. This hand-held display unit responds to your commands.

Step-by-Step Instructions



- **Identify the Bug-O Rails**

- **Identify the Main Welding Unit**

- **Identify the Control Cabinet**

- **Identify the Control Pendant**

Section 2. Connecting the ACRS System Parts

Instruction Pages

This section describes how to connect the ACRS system components together. Hardware components connect to each other and to the main control cabinet with cables. At the end of this section, you will be able to connect the ACRS system together and power on the system.

Bug-O 30-in. Diameter Bent Rigid Rails

The rails require spacer to keep them a set distance of 1.25 inch away from the pipe surface. Each rail requires 16 sets of spacers. The spacers are two aluminum triangle-shaped pieces with a hex thumb screw holding them together. Make sure the rails are 92 inches apart when measuring from rack to rack on each rail.

Main Welding Unit

The ACRS Main Welding Unit weighs about 80 lbs. Please use two persons when lifting, carrying or attaching the unit to the rails.

Control Cabinet

Please use caution when moving the control cabinet. Make sure the wheels are locked when you have put the cabinet into position. Please note that the laptop computer on the control cabinet must be charged before using.

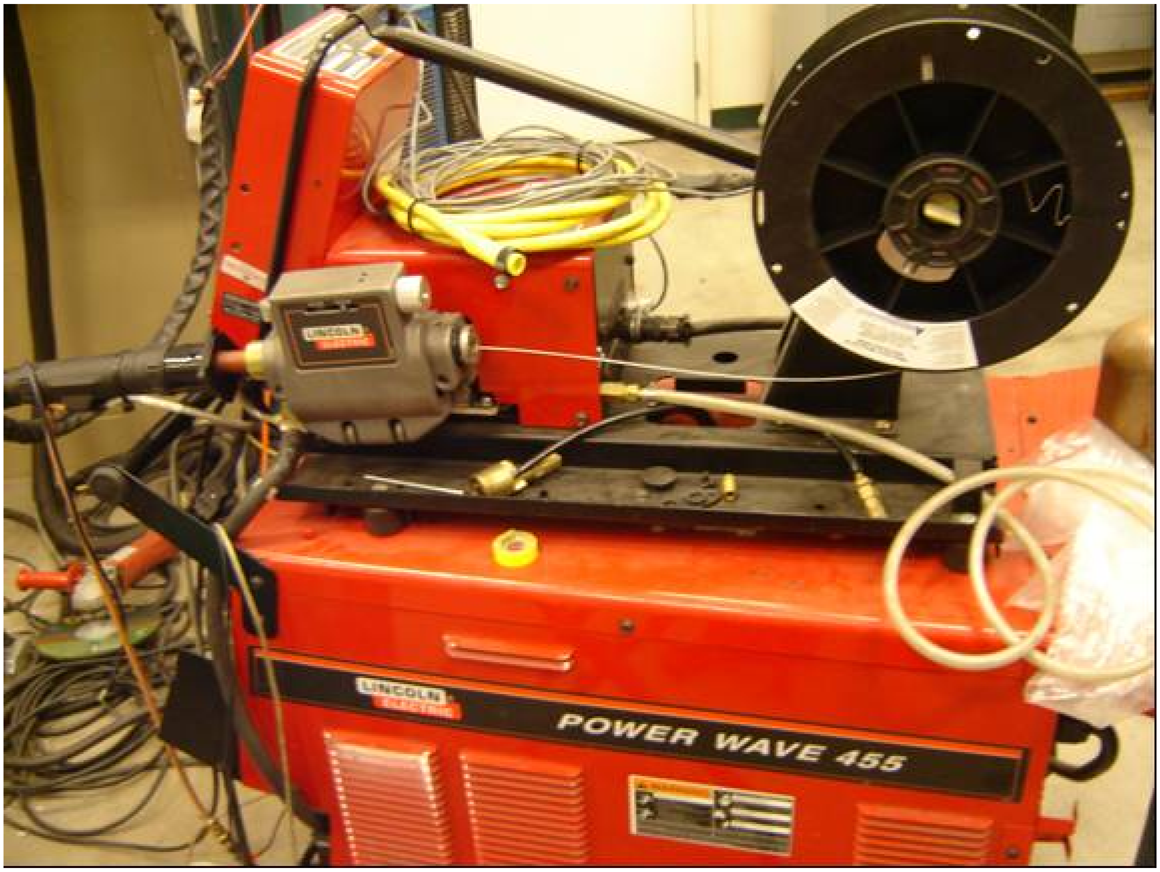
Control Pendant

The wireless display rests in a shelf on the front of the control cabinet. Please note that the wireless display must be charged before using.

Step-by-Step Instructions

- **Plug the Bug-O tractors into the Control Cabinet**

- **Plug the 5 yellow cables from the Main Hardware Unit into the Control Cabinet**



- **Plug the yellow cable from the Lincoln Power Supply into the Control Cabinet**

- **Push the green Power button on the top of the Control Cabinet**

- **Power on the laptop computer on the Control Cabinet**

Section 3. Operating the ACRS System Software

Instruction Pages

The ACRS system software allows you to make the ACRS system perform automatic repair of corrosion on pipelines. At the end of this section you will be able to weld a repair sleeve onto a pipe. You will be able to scan an area of corrosion and fill in the corrosion area with weld metal.

Main Software Screen

The main software screen allows you to select what you would like to do. You can select from the following items:

- Jog
- Corrosion
- Circumferential Sleeve
- Longitudinal Sleeve

Jog Software Screen

The Jog software screen allows you to move the ACRS system by jogging all motion in any direction you choose. You will be able to strike an arc or view the laser sensor data at any point.

Corrosion Software Screen

The Corrosion Software Screen allows you to scan an area of the pipe for laser-based inspection of corrosion. This screen allows you to fill in a corroded area of a pipeline by welding multi-bead, multi-layer welds.

Circumferential Software Screen

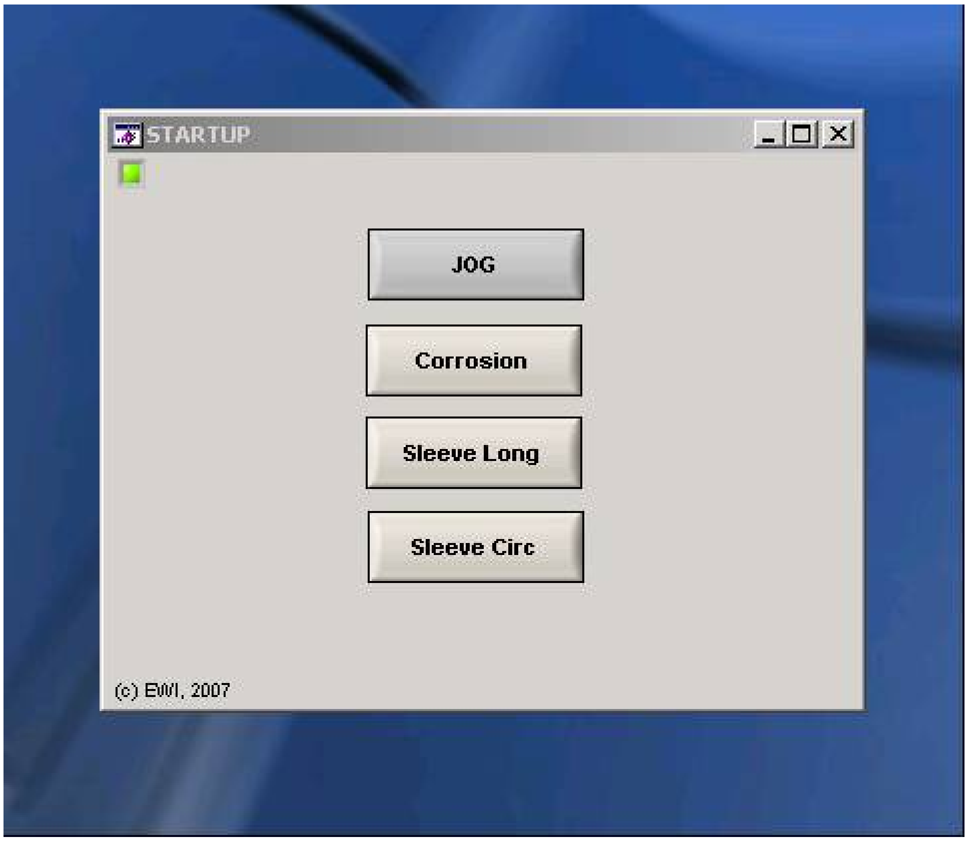
The Circumferential Sleeve software screen allows you to set up welding and motion parameters to make a circumferential fillet weld on a repair sleeve.

Longitudinal Software Screen

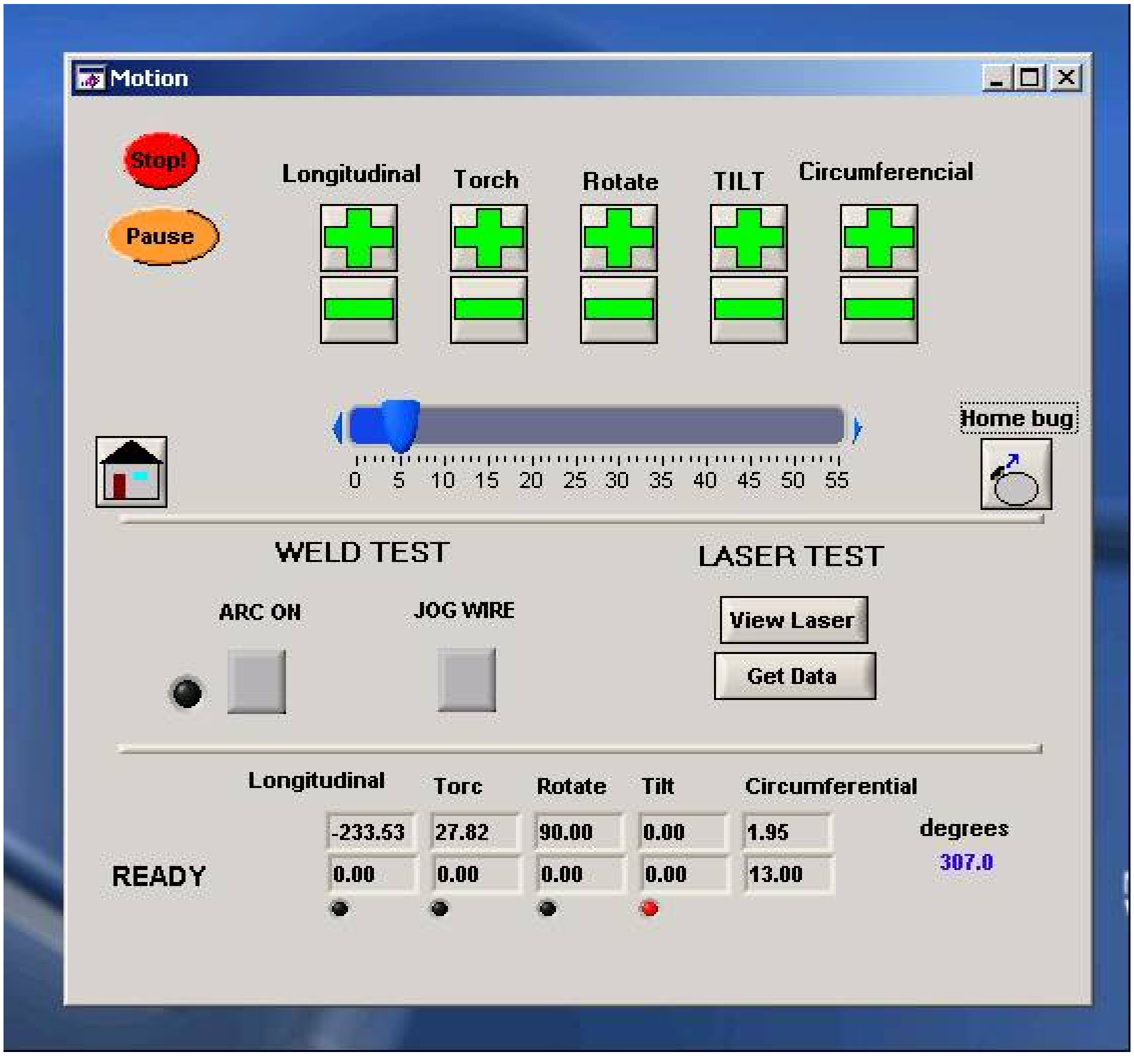
The Longitudinal Sleeve software screen allows you to set up welding and motion parameters to make a longitudinal fillet weld on a repair sleeve.

Step-by-Step Instructions

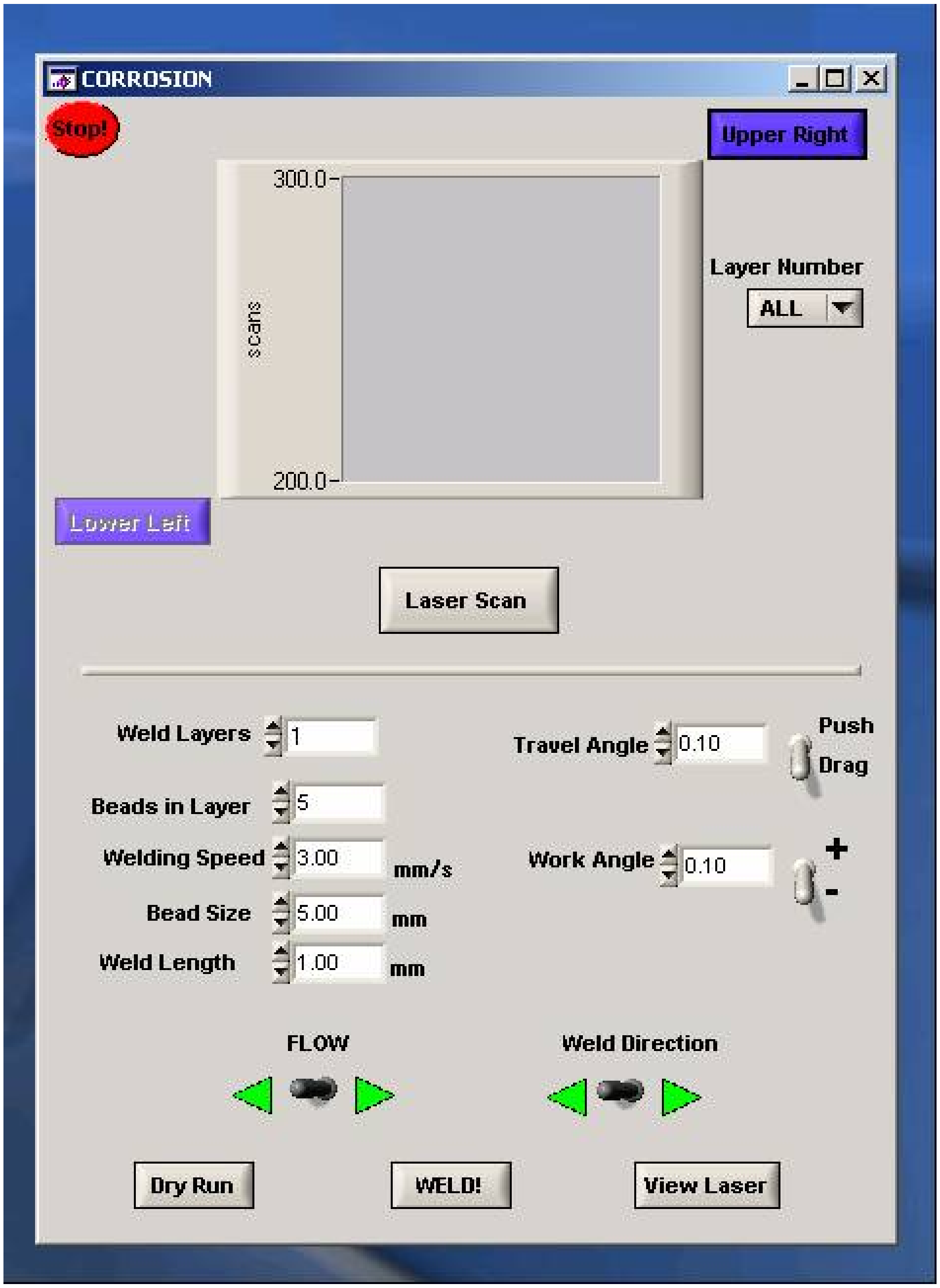
- **Power On the ACRS System Software**



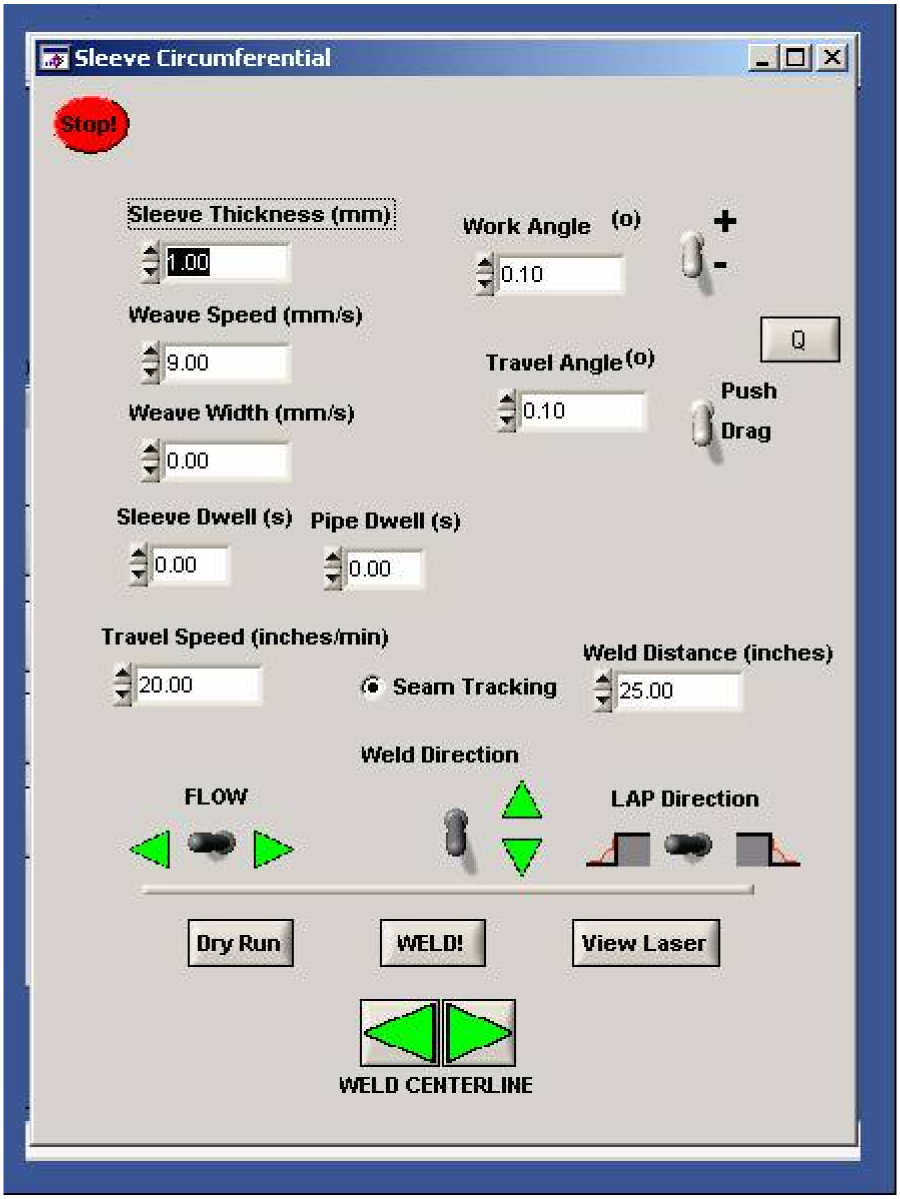
- **Locate the Main Software Screen**



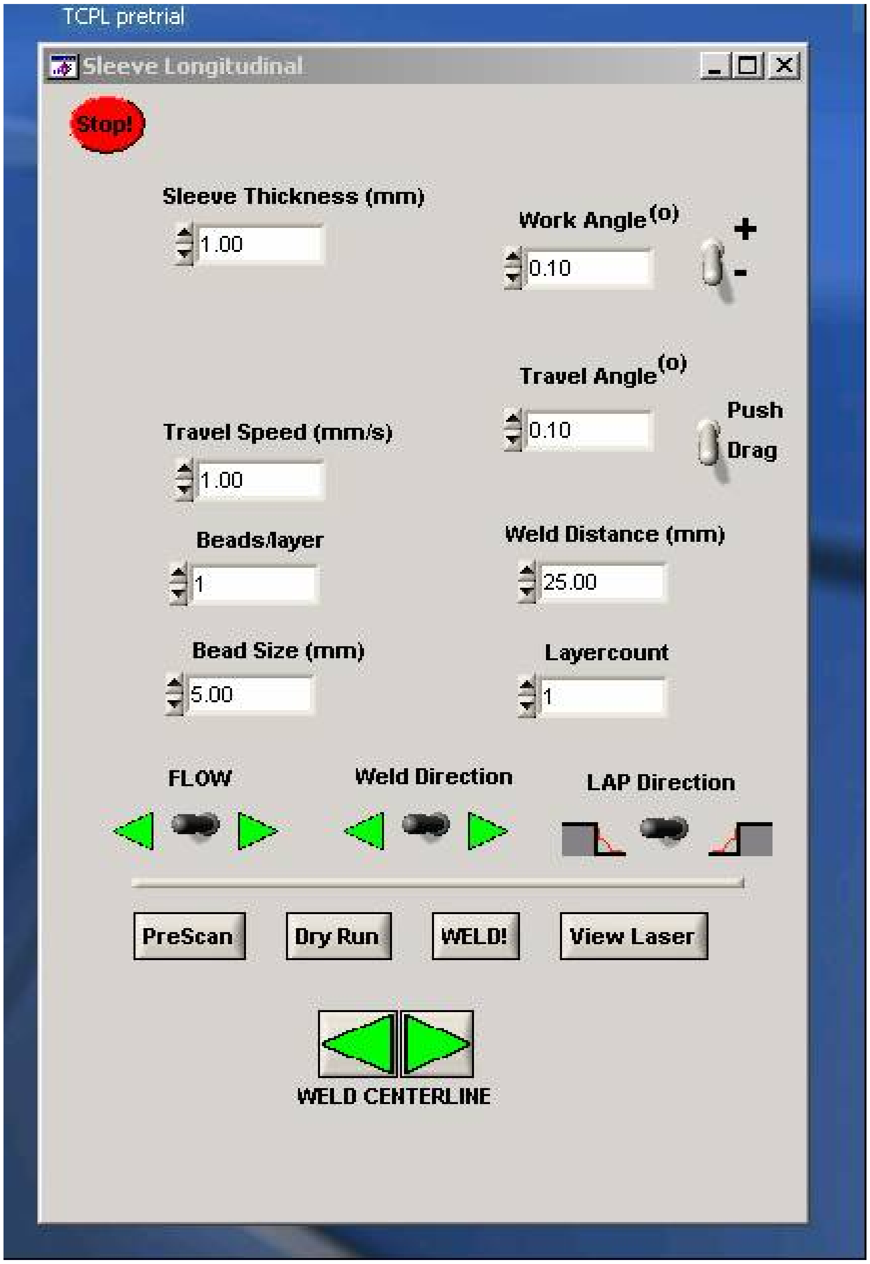
- **Select the Jog Software Screen**



- **Select the Corrosion Software Screen**



- **Select the Circumferential Sleeve Software Screen**



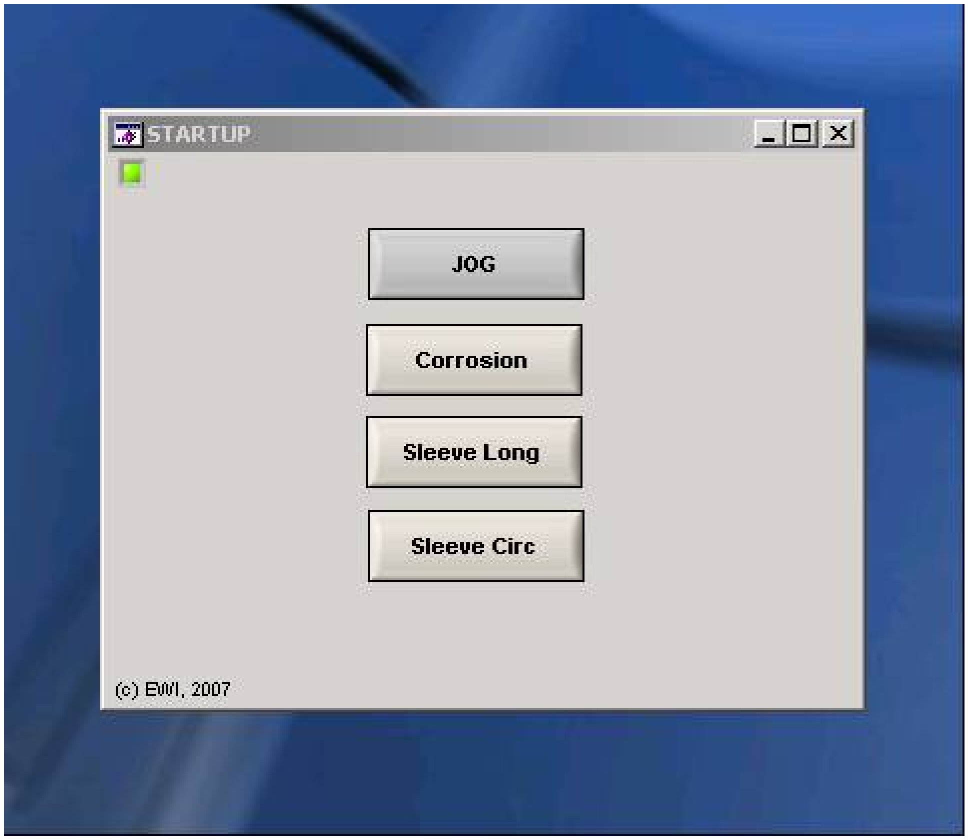
- **Select Display the Longitudinal Sleeve Software Screen**

Section 4. Weld a Circumferential Sleeve Joint onto the Pipe using the ACRS System

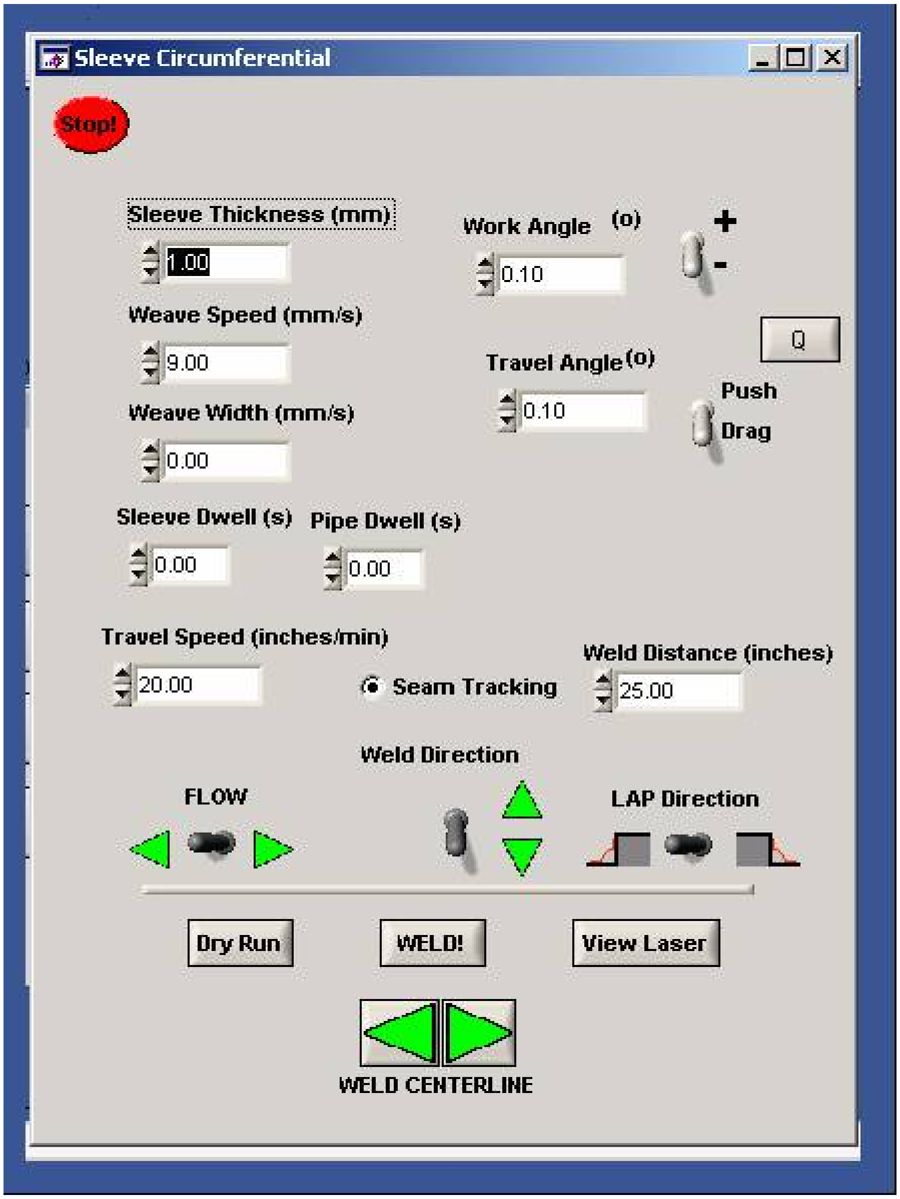
Instruction Pages

This section allows you to make a weld on a circumferential fillet joint on a repair sleeve. At the end of this section, you will be able to tell the ACRS to automatically make a circumferential weld on a repair sleeve.

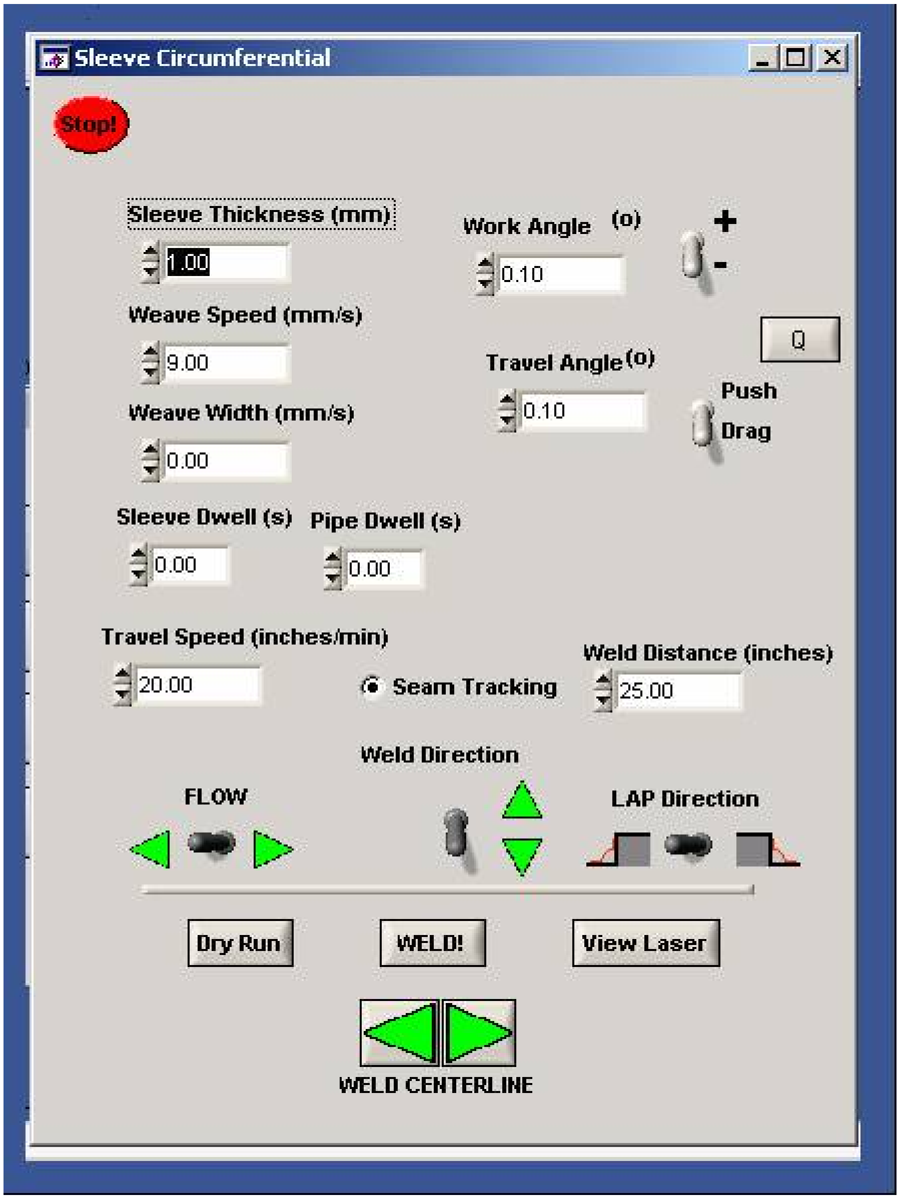
Step-by-Step Instructions



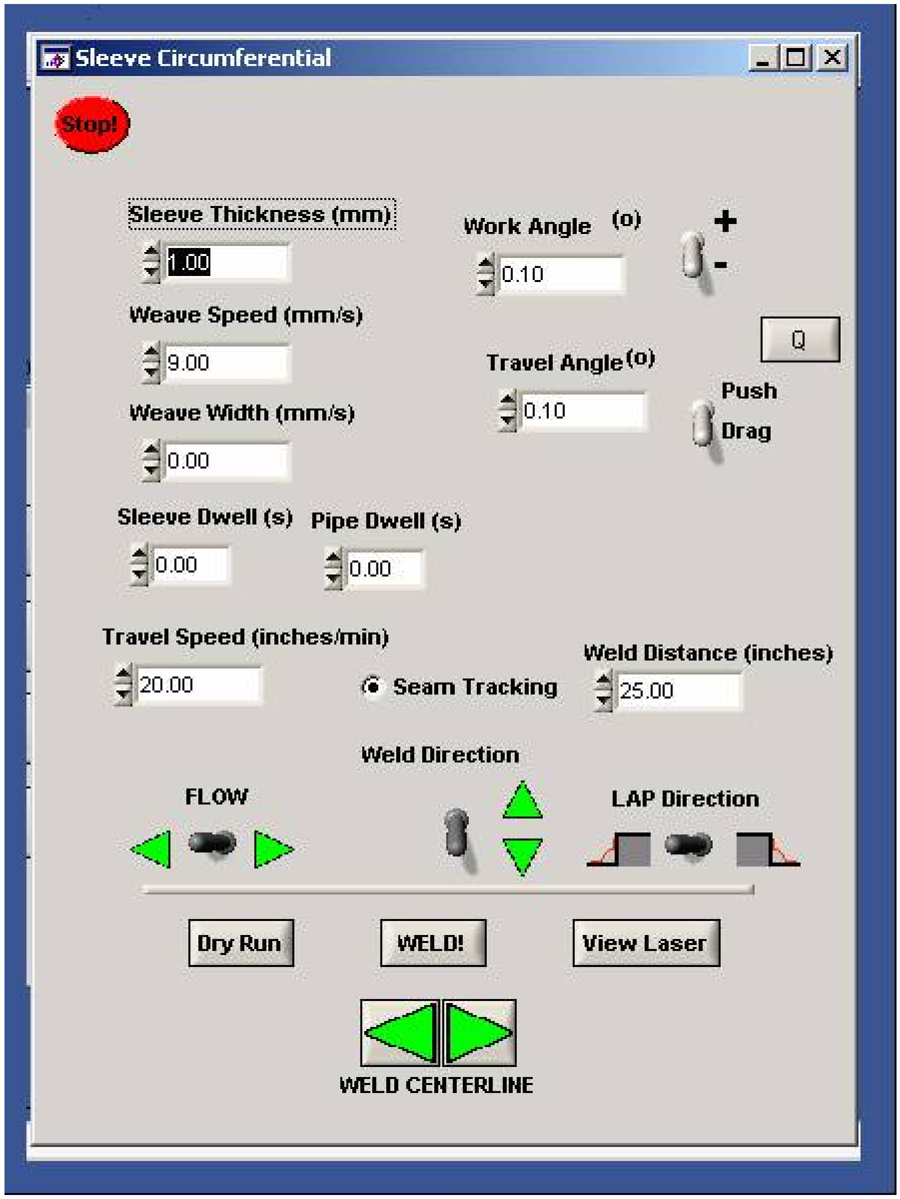
- **Select the Circumferential Sleeve Software Screen**



- **View the Welding parameters and make changes**

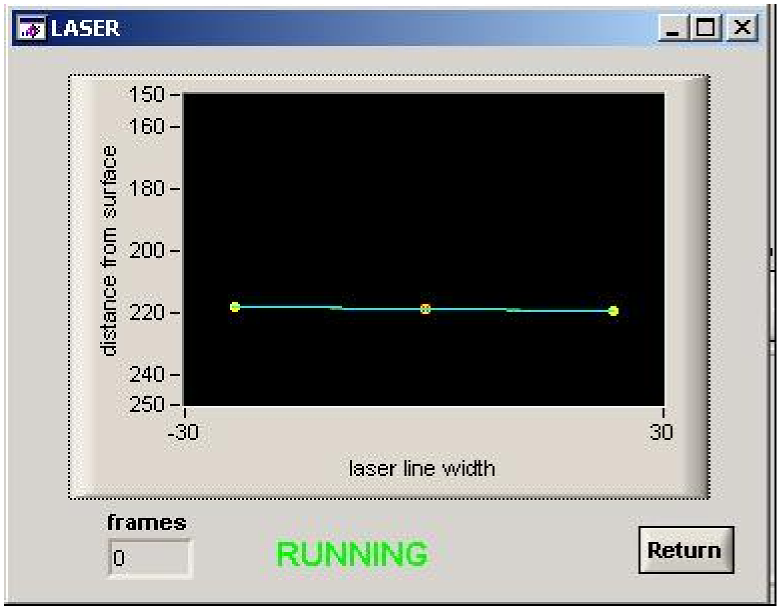


- **View the Motion parameters and make changes**



- **Select Dry Run button to run through the motion without welding**

- **Select Weld button to begin making the weld**



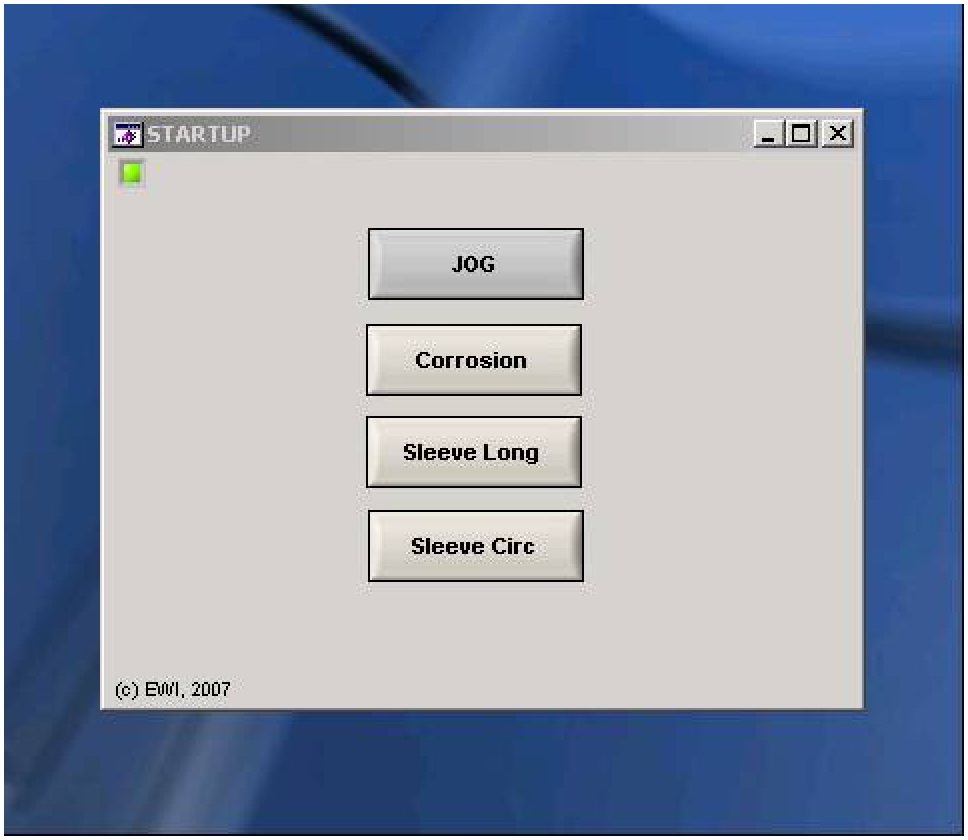
- **Select View Laser button at any time to view the laser seam-tracking window**

Section 5. Weld a Longitudinal Sleeve Joint onto the Pipe using the ACRS System

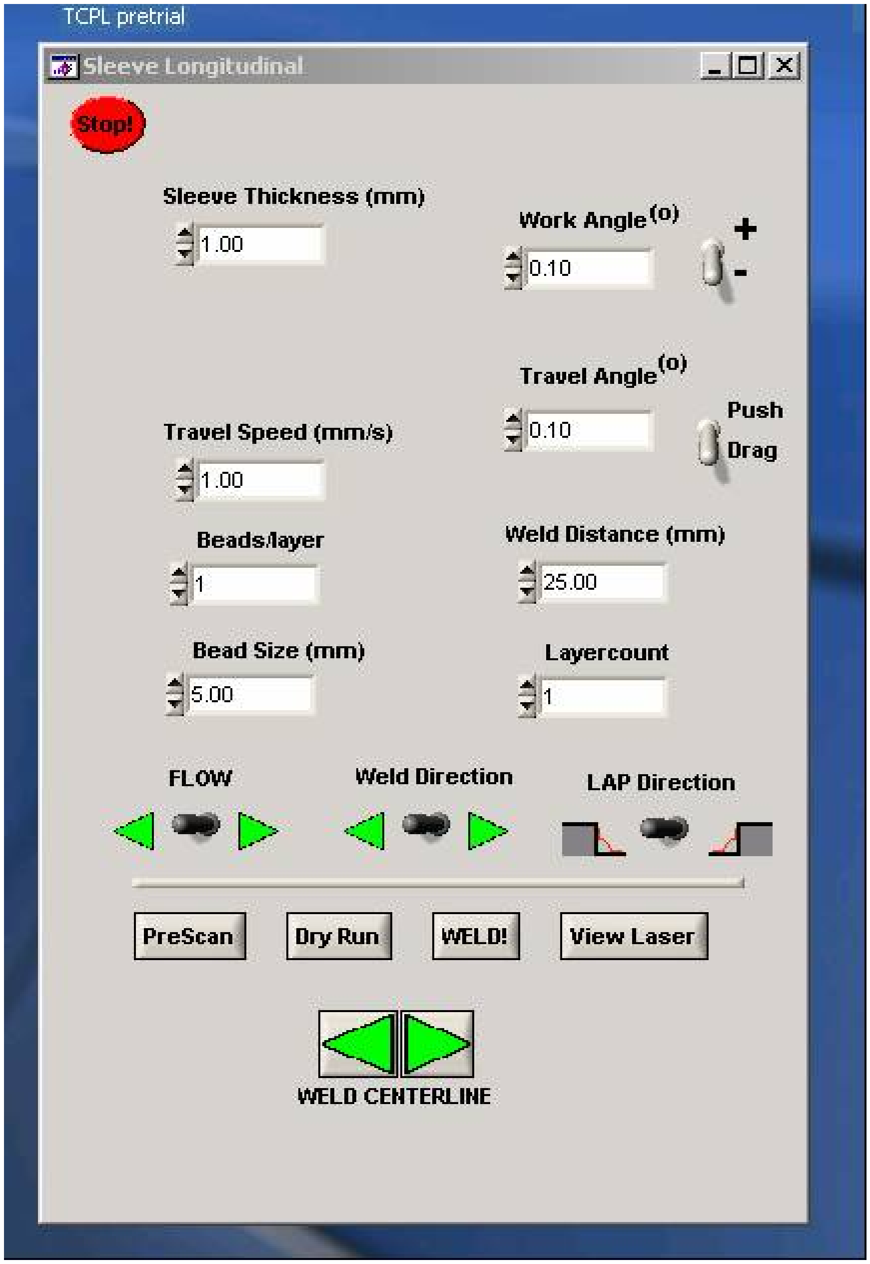
Instruction Pages

This section allows you to make a weld on a longitudinal fillet joint on a repair sleeve. At the end of this section, you will be able to tell the ACRS to automatically make a longitudinal weld on a repair sleeve.

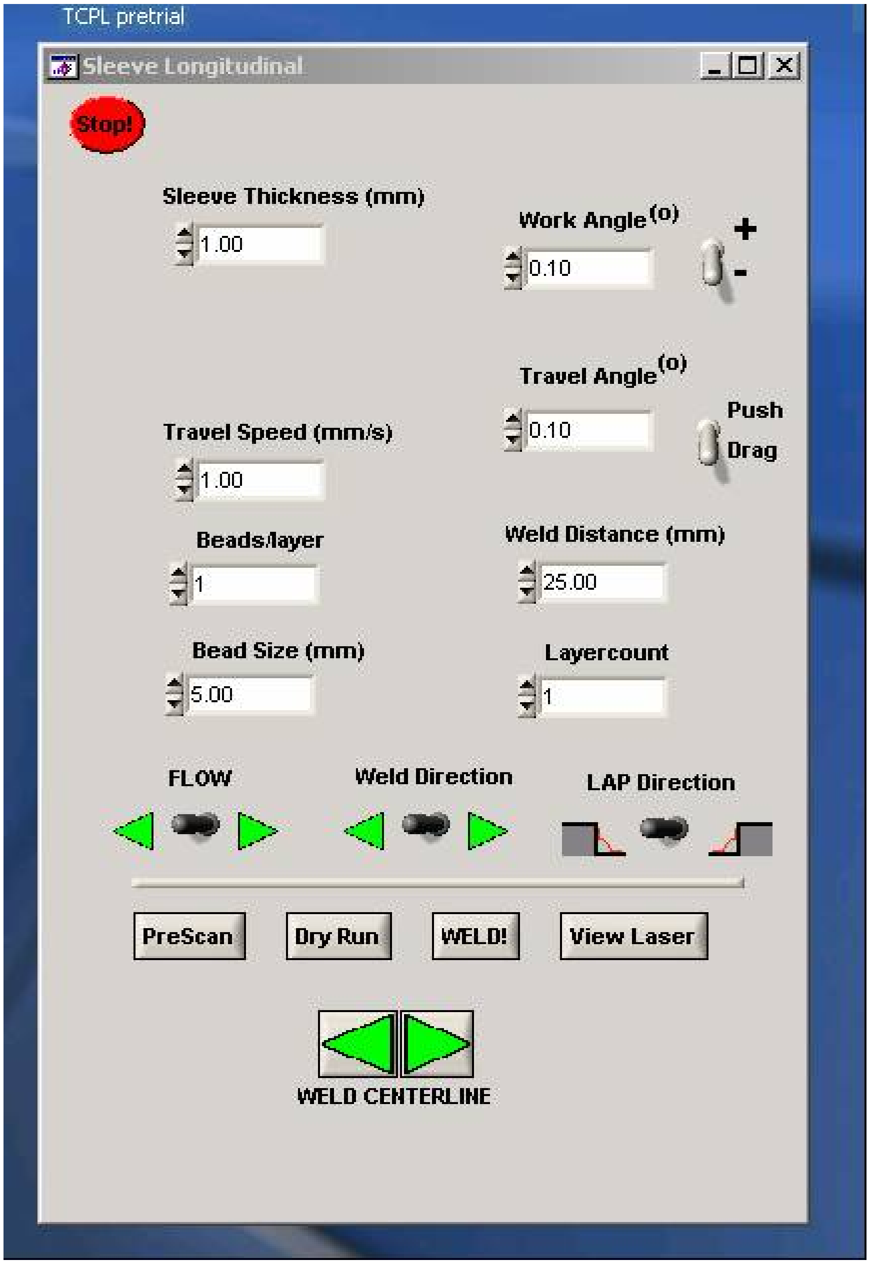
Step-by-Step Instructions



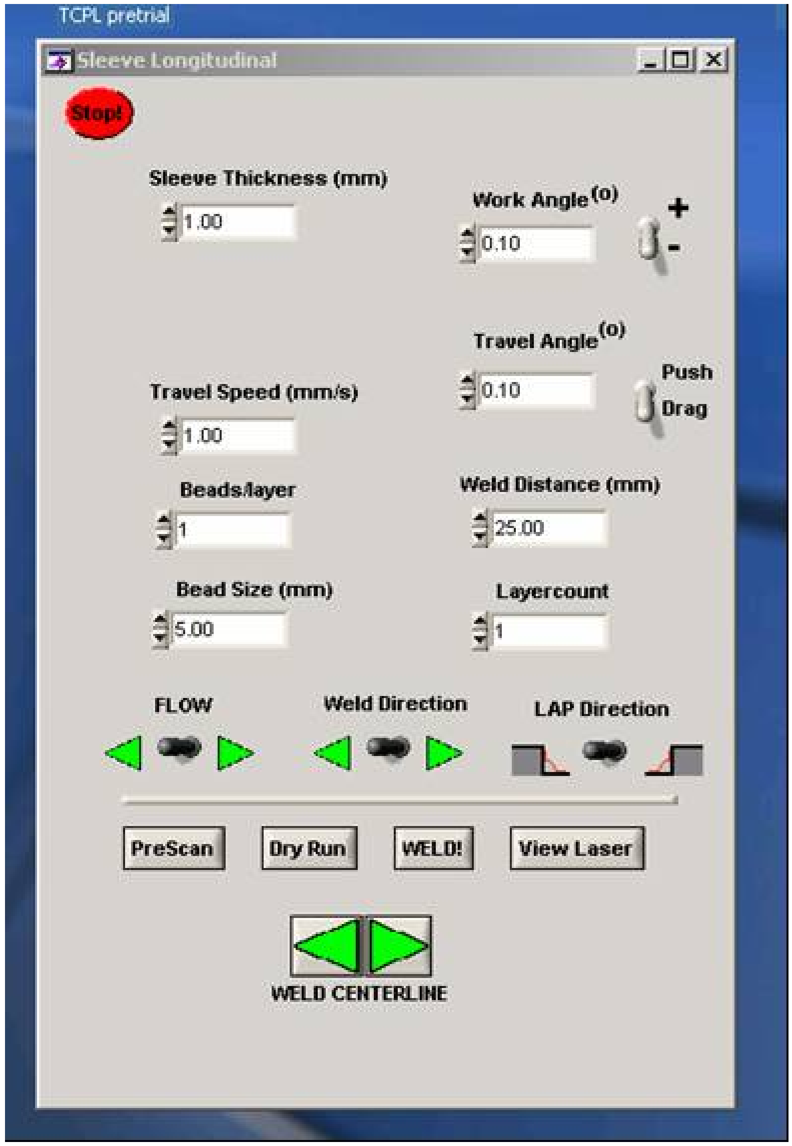
- **Select the Longitudinal Sleeve Software Screen**



- **View the Welding parameters and make changes**



- **View the Motion parameters and make changes**



- **Select the PreScan button to use the laser to scan the joint trajectory before welding**

- **Select Dry Run button to run through the motion without welding**

- **Select Weld button to begin making the weld**

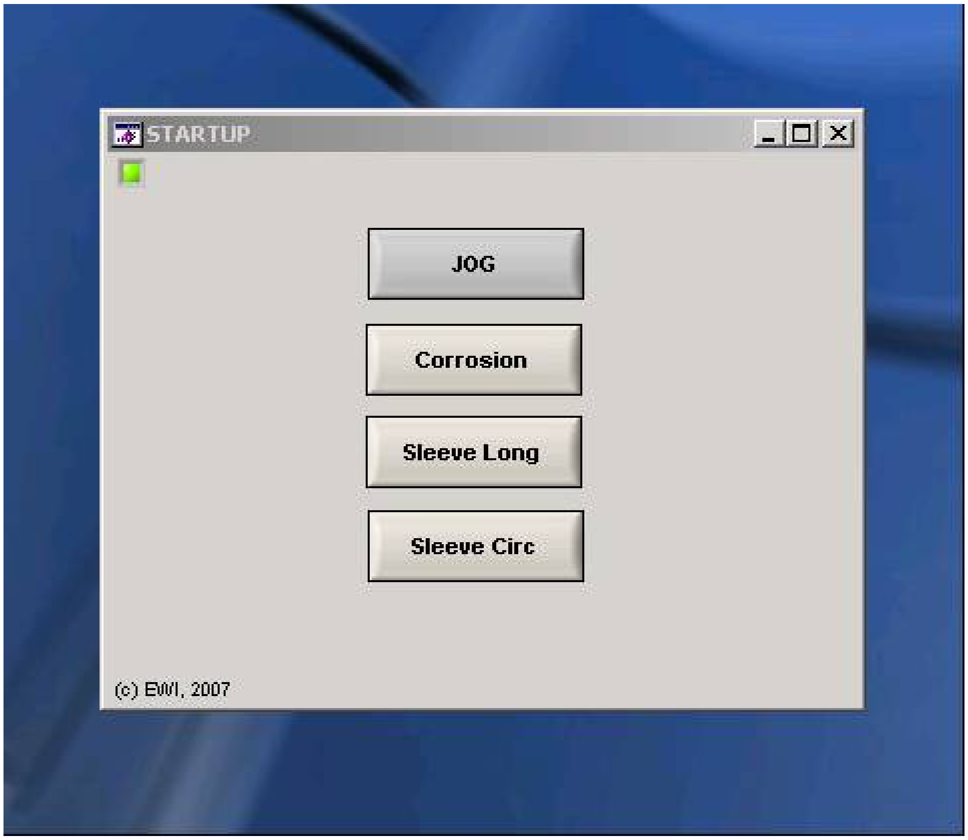
- **Select View Laser button at any time to view the laser seam-tracking window**

Section 6. Inspect a Corroded Area on the Pipe using the ACRS System

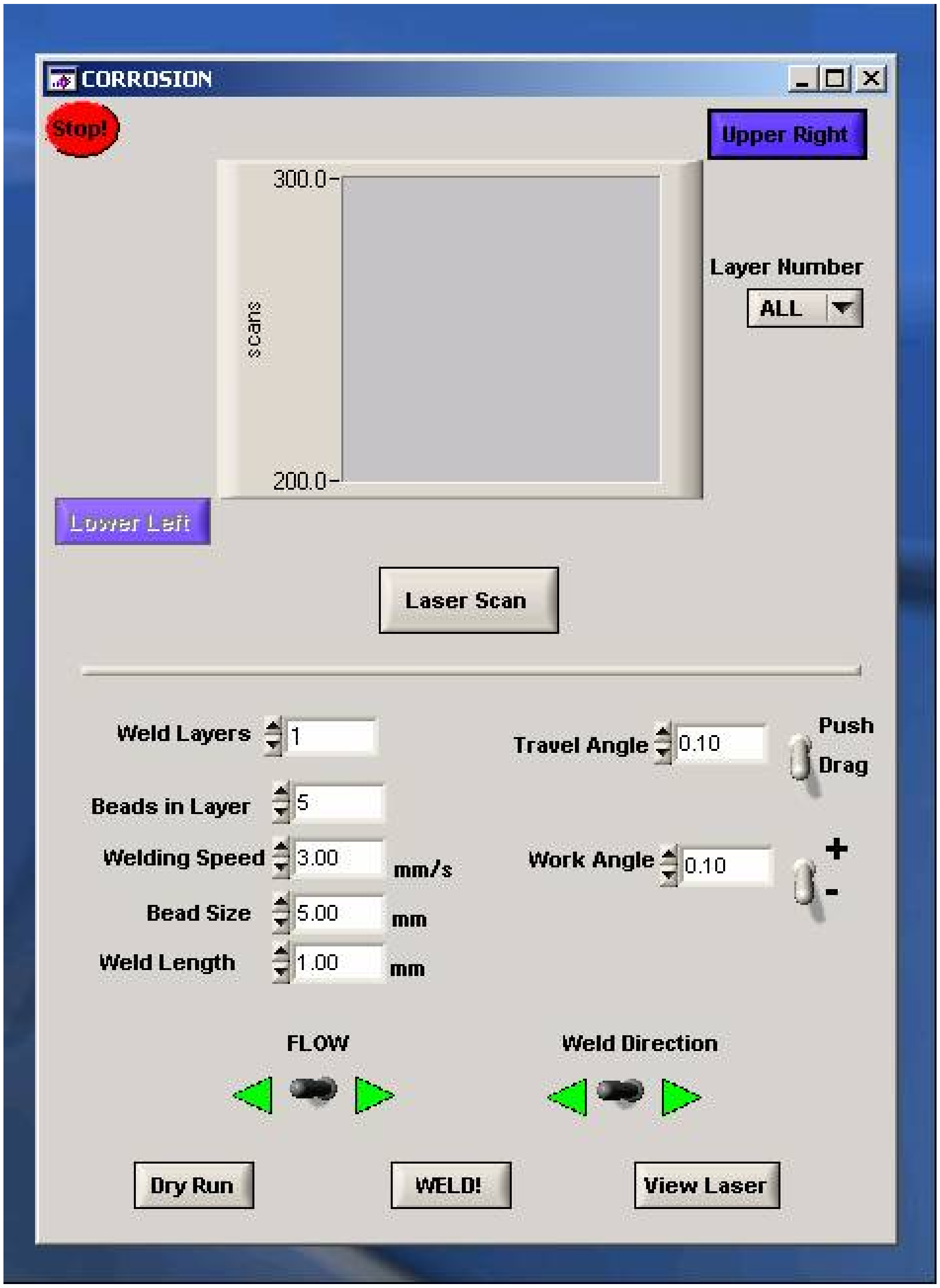
Instruction Pages

This section allows you to select a square area on the pipe scan for corrosion. The laser sensor will scan the area of the pipe you selected and tell you where the corrosion is and how deep the corrosion is. The system will then tell you how to weld up the corrosion patch by telling you the welding and motion parameters. At the end of this section, you will be able to tell the ACRS to scan an area of the pipe and check for corrosion.

Step-by-Step Instructions

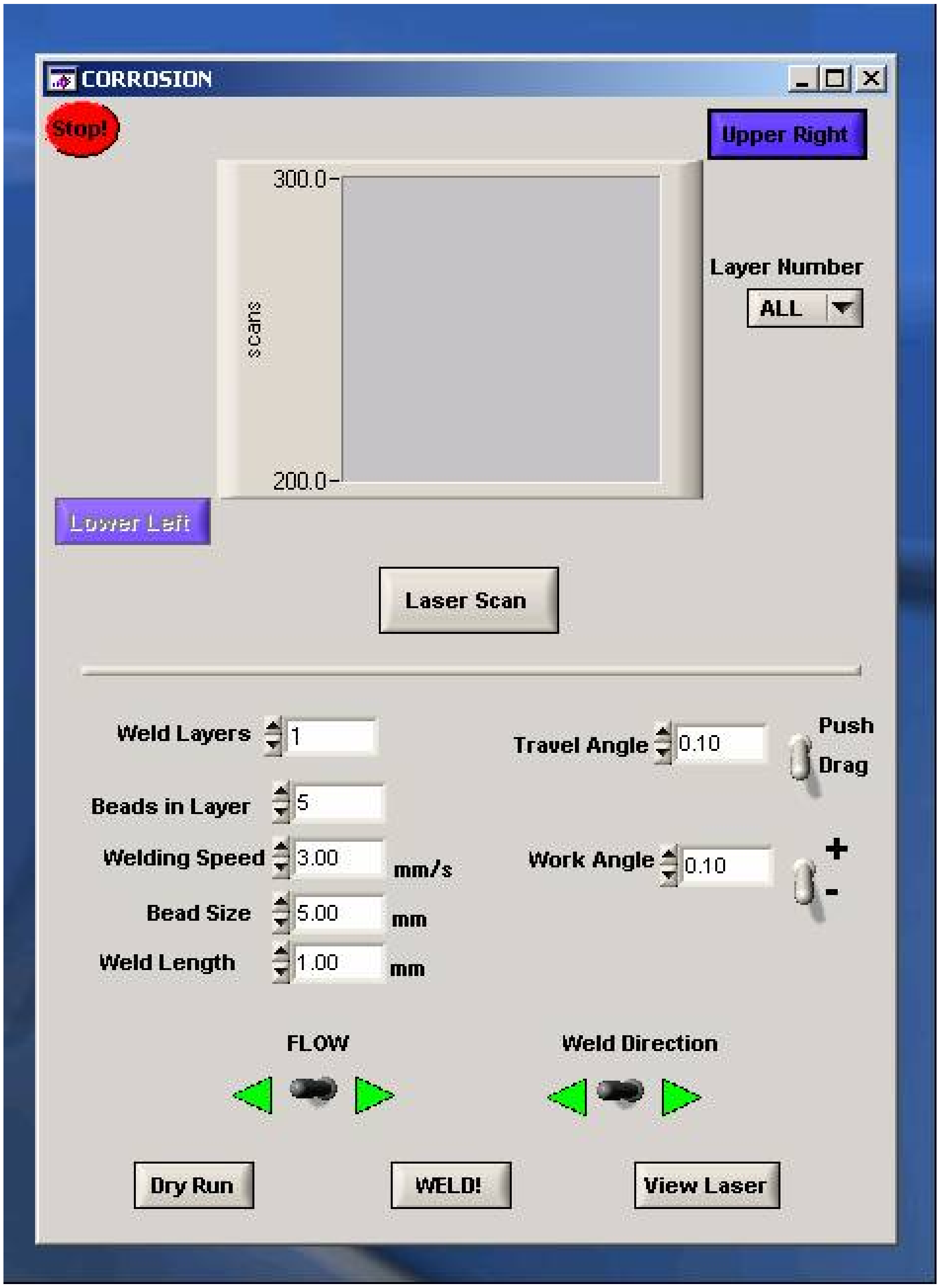


- **Select the Corrosion Software Screen**



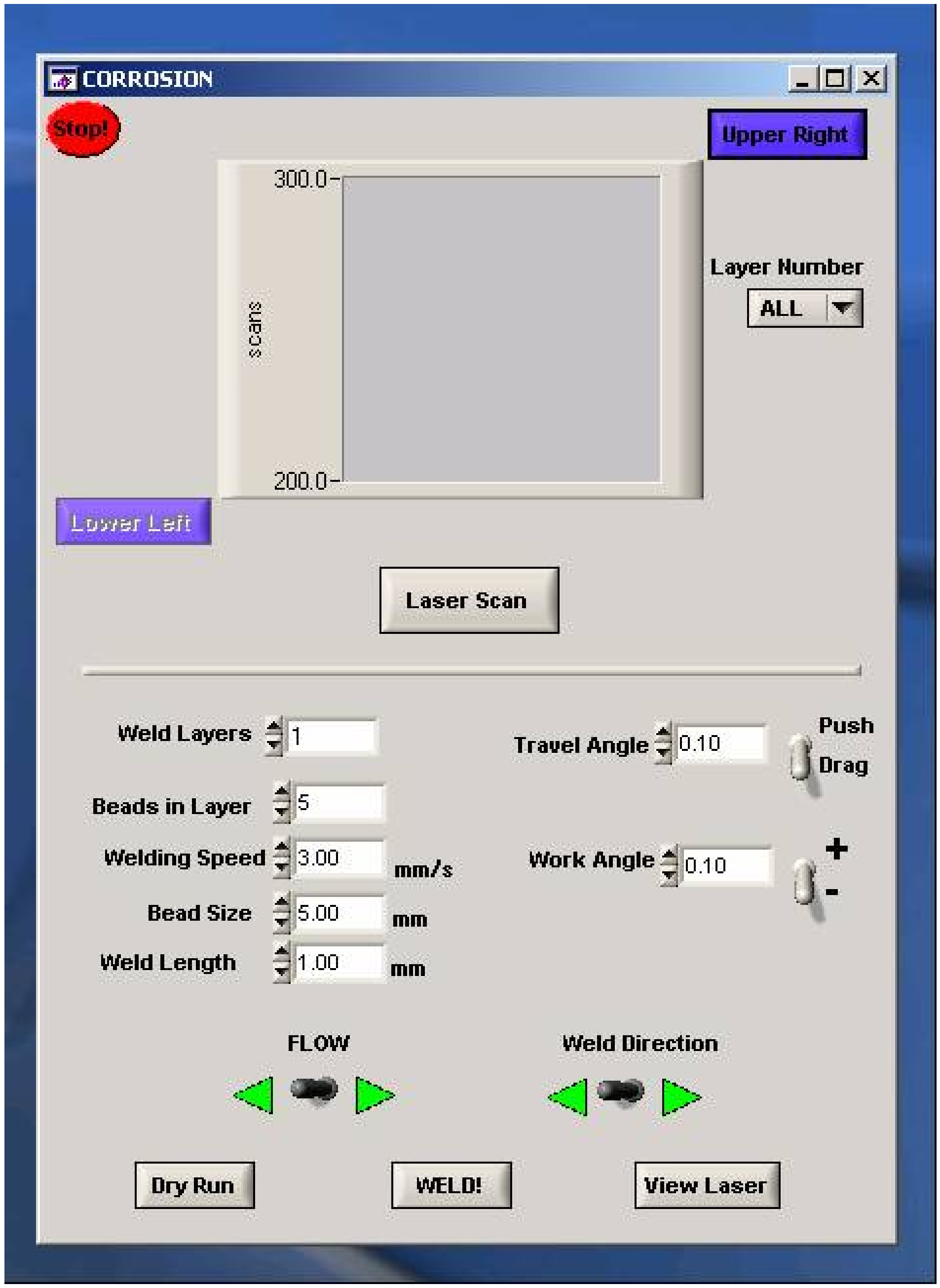
- **Move the ACRS system using the Jog Software Screen to the upper right of the area you want to inspect for corrosion**

- **Select the Upper Right button on the Corrosion Software Screen**

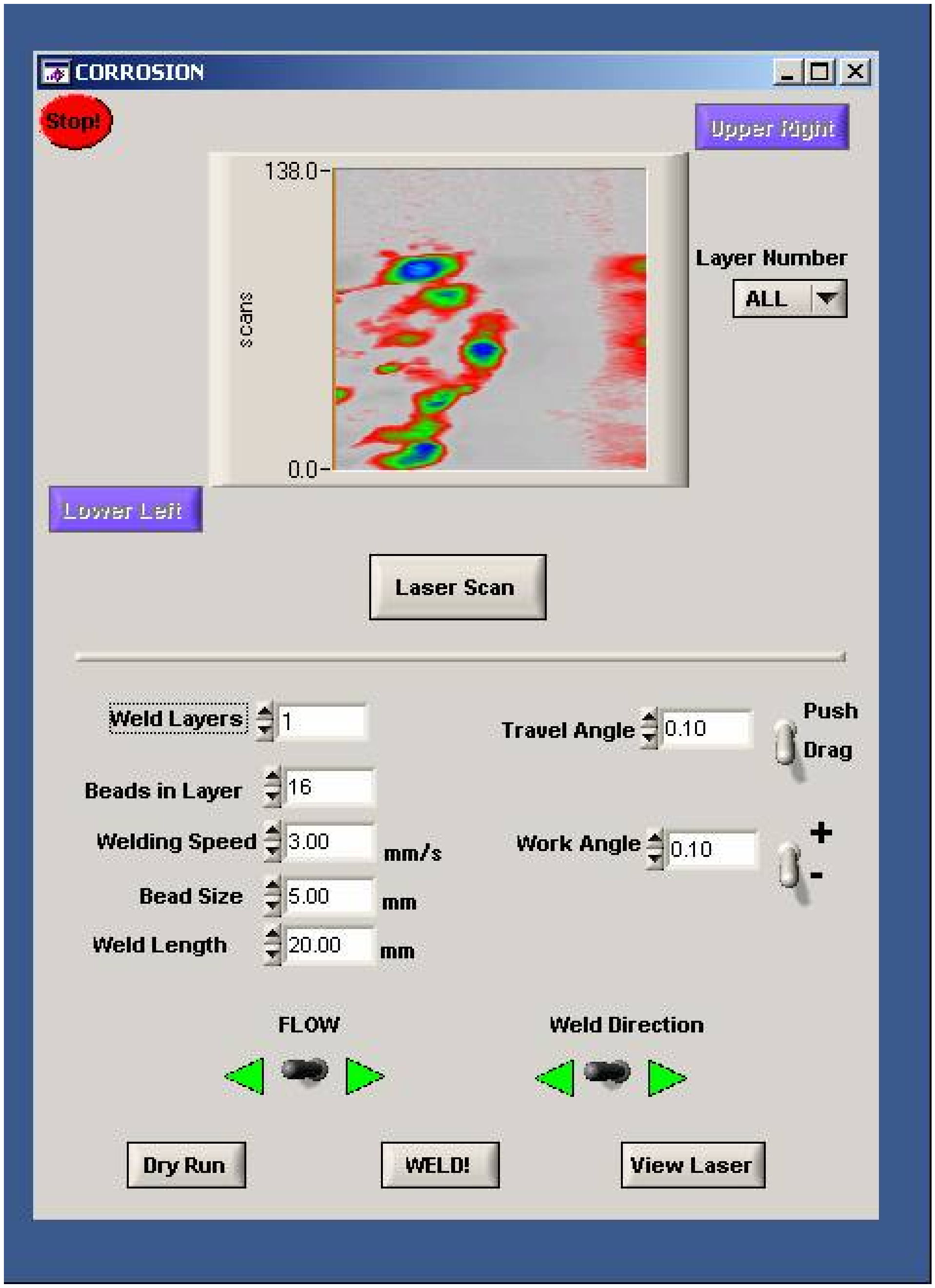


- **Move the ACRS system using the Jog Software screen to the lower left of the area you want to inspect for corrosion**

- **Select the Lower Left Button on the Corrosion Software Screen**



- **Select the Laser Scan button on the Corrosion Software Screen to begin the laser scan**



- **View the Results of the laser scan on the graph on the Corrosion Software Screen**

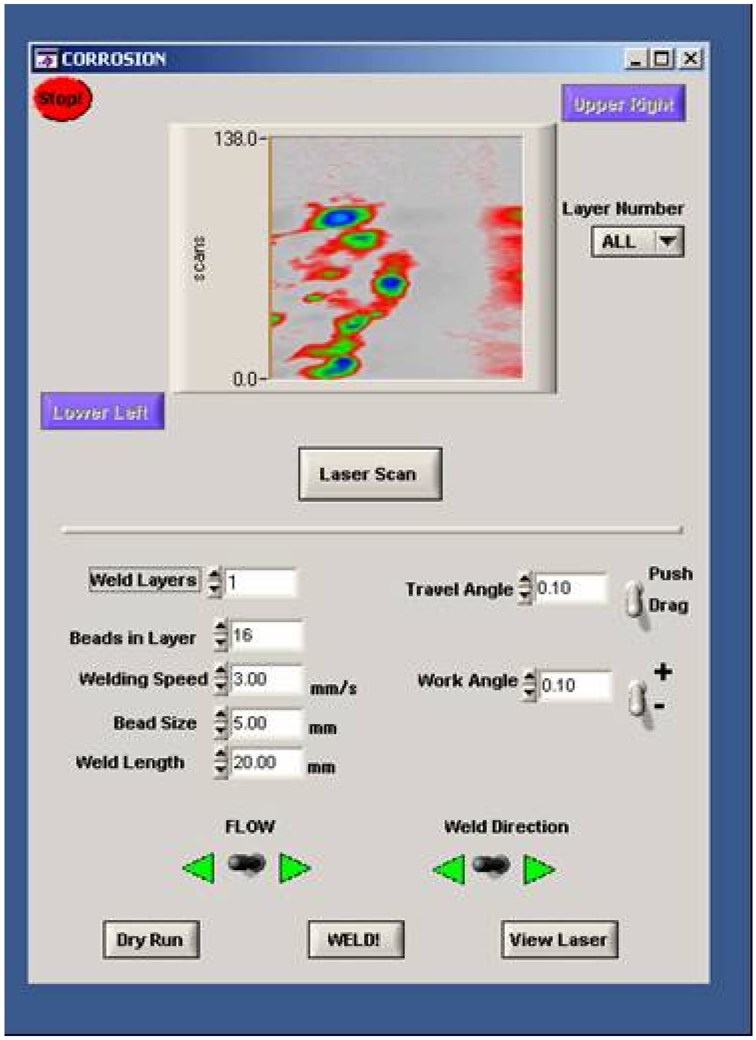
- **View the different layers of the corrosion by selecting the Layer button to the right of the graph on the Corrosion Software Screen**

Section 7. Repair a Corroded Area on the Pipe Using the ACRS System

Instruction Pages

At the end of this section, you will be able to tell the ACRS system to weld up a corrosion patch on the pipe. The system will use the laser scan created in the last section to determine how to weld up the corroded area. The system will suggest welding parameters for each layer to weld up the corroded area. Please note that the area for each layer will not be the same. Deeper areas are welded first and will likely not be the entire patch.

Step-by-Step Instructions



- View the Welding Parameters for Layers 1 thru 5 of the Corrosion patch on the Corrosion Software Screen and make changes
- View the Motion Parameters for Layers 1 thru 5 of the Corrosion patch on the Corrosion Software Screen and make changes
- Select Dry Run button to run through the motion without welding
- Select Weld to begin welding up the corroded area of the pipe

Section 8. Shutdown and Disconnect the ACRS System

Instruction Pages

At the end of this section, you will be able to power down and disconnect all parts of the ACRS System. Make sure the system is turned off before disconnecting any cables from the control Cabinet.

Step-by-Step Instructions

- **Power Off the laptop computer on the top of the Control Cabinet**

- **Power Off the Control Cabinet by pushing the green button on the top of the cabinet**

Appendix F. Workshop Flyer

Automated Weld Deposition for Repair of In-Service Pipelines

Free Equipment Demonstration Workshop May 23 at EWI

Discover how the current capabilities of in-service welding are being extended through the development of an automated welding system for use on in-service pipelines. The system features a real-time adaptive control tracking system to ensure reliable welding conditions. The result is a mechanized system with a multi-axis welding carriage designed for use with low hydrogen gas metal arc welding and flux cored arc welding.

The purpose of this workshop is to demonstrate the welding system to pipeline welding contractors and the pipeline industry. View the complete workshop agenda.

Project Participants
The Automated Weld Deposition for Repair of In-Service Pipelines Project and this free Equipment Demonstration Workshop is co-funded by the Pipeline Research Council International and the U.S. Department of Transportation's Research and Special Programs Administration. This project is a collaborative effort made possible by TransCanada, Bug-O Systems International, and the Welding Engineering Research Centre of Cranfield University; and led by EWI (Edison Welding Institute).

Workshop Date & Time
The workshop begins at 9 am and ends at 3 pm on Wednesday, May 23, 2007.

RSVP by May 18
There is no fee to attend this event. Attendance is limited to the first 30 people who RSVP.

(In compliance with security requirements, you will be asked to indicate your citizenship when registering for the event.)

Register Online Today!
www.ewi.org/contact/rsvp.asp

For questions about the project and workshop, please contact Brad Hudson at brad_hudson@ewi.org or call 614-688-5146.

For more information, please contact:

Brad Hudson,
at (614) 688-5146
(brad_hudson@ewi.org)

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Columbus, Ohio 43221-3585
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www.ewi.org

05/07

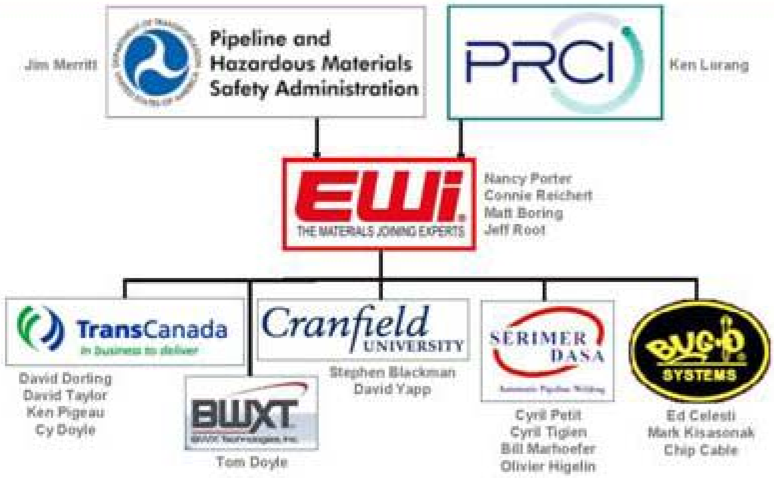
Appendix G. Workshop Project Overview Presentation

Project Overview

Objectives

- Develop and Build an Automated Welding System for Use on In-Service Pipelines
- Implement a Real-Time Adaptive Control to Ensure Reliable Welding Conditions
- Evaluate System Performance with Lab Trials
- Validate System with a Field Trial

Project Team 2003 - 2007



Technical Approach

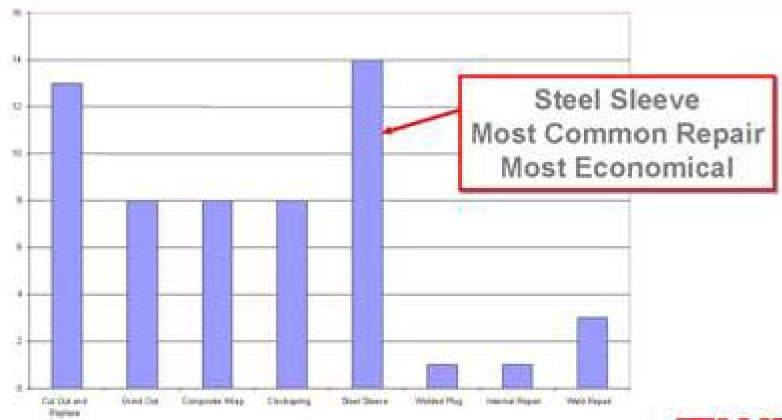
- Review Industry Needs, Requirements and Current Practices
- Weld Procedure Qualification
- Develop System Specification
- Design and Build System
- Laboratory Development and Evaluation
- Equipment Demonstration Workshop

Industry Needs & Practices

- Pipeline Repair (or Modification) Generally Involves Welding Out-of-Service or In-Service
- In-Service Welding Repair
  - Major Cost and Environmental Benefits
  - Mature Technology - Routinely Used
  - Usually Manual SMAW
- Large Diameters – SMAW Long Weld Times
- X80 and Above – SMAW Not Suitable
- Aging/Decreasing Workforce

What Affects Choice of Repair?

Corrosion #1 Reason for Repair



Retaining Sleeve Repair

Pressure-Containing Sleeve Repair

- Longitudinal V-Groove Welds
- Circumferential Fillets Welds

Weld Deposition Repair

- Attractive Alternative to Sleeve Repair
- Even Cheaper; Consumables Only no Sleeves
- Applied Externally to Repair External or Internal Wall Loss
- Great for Repair in Bend Sections and Fittings, Where Sleeve Installation is Impossible
- Not Widely Adopted Used by Industry Yet

Weld Deposition Repair

In-Service Welding Repair

- Mechanized Repair Welding Attractive Alternate
- In 2003, Not Sufficiently Developed for Field Implementation
- This Project Extended Current Capabilities by Developing an Automated Welding System
  - Suitable for Materials Grade B and Above
  - Retaining Sleeves
  - Pressure-Containing Sleeves
  - Weld Deposition Build Up or Buttering Operations

Appendix H. Workshop Welding Procedure Presentation

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Automated In-Service Welding Procedure Development

Matt Boring
Applications Engineer

614.688.5257
mboring@ewi.org

Pipeline Repair/In-Service Welding

- Continues to be an area in which there is much interest
- Repair of corrosion damage
  - As pipelines become older, more repairs are required
- Installations of hot tap branch connections
  - More branch connections required as the result of "open access" and "common carrier" practices

EWI
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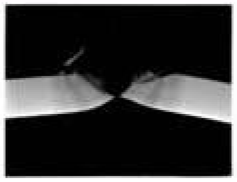
Incentives/Primary Concerns

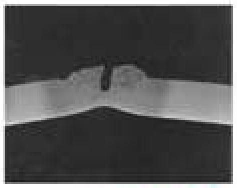
- Incentives
  - Economic incentives
    - Maintain delivery
    - Avoid loss of contents
  - Environmental incentives
    - Avoid venting methane
- Primary concerns
  - Repair crew safety
    - Avoiding "burn-through" or "blow-out"
  - Resulting pipeline integrity
    - Avoiding hydrogen cracking

Burn-Through

- Burn-through will occur if the unmelted area beneath the weld pool has insufficient strength to contain the internal pressure of the pipe
- Many companies prohibit in-service welding below specified wall thicknesses limits
  - Typically, 0.156 to 0.188 in. (4.0 to 4.8 mm)

=>Heat input from weld versus heat removal by contents





Hydrogen Cracking Requirements

- Hydrogen in the Weld
- Crack-Susceptible Microstructure
- Stress Acting on the Weld

- All Three Must Occur Simultaneously

Hydrogen in the Weld

- Hydrogen cracking susceptibility increases with increasing amount hydrogen in the weld
- Low hydrogen processes
  - SMAW w/EXX18-type electrodes
  - Gas shielded processes (GMAW, GTAW)
- High hydrogen processes
  - SMAW w/EXX10- and EXX13-type electrodes
- Preheating allows hydrogen diffusion, reduces hydrogen cracking susceptibility

Crack-Susceptible Microstructure

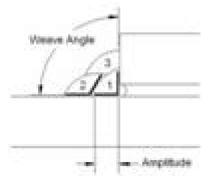
- Hydrogen cracking susceptibility increases with increasing carbon content/carbon equivalent
  - Conventional alloy steel (IIW formula) - %C > 0.10
  - Modern microalloyed steel (Pcm formula) - %C ≤ 0.10
- Welding Heat Input
  - $\text{Heat Input} = \dfrac{(\text{amps} \times \text{volts} \times 60)}{(\text{Travel Speed [in./min]} \times 1{,}000)}$
- Pipeline Operating Conditions
  - Contents, Wall thickness and Flow rate/pressure

Experimental Approach

- Weld Parameter Development – Lab Trial
  - Cranfield University
- Simulated In-Service Weld Trials
  - Circumferential fillet weld on a repair sleeve
  - Gantry robot system
  - GMAW and FCAW (75% Ar + 25% CO_2)
  - X80 (19-mm), X100 (23-mm) and X120 (17-mm)
- Diffusible Hydrogen Testing
  - GMAW and FCAW

Weld Parameter Development

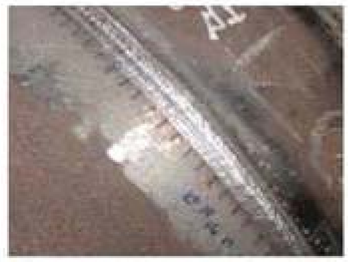
	FCAW Procedure	GMAW Procedure
Welding Consumable	ESAB Dual Shield II 70T-12H4	ESAB Spoolarc 86
AWS Classification	E71T1-1MJH4/-12MJH4	ER70S-6
	Welding Parameters	
Heat Input, kJ/in	25.0	29.5
Voltage, volts	20	18
Current, amps	160-175	115-130
Wire Feed Speed, ipm	250	120
Travel Speed, ipm	8.0	4.5
CTWD, in.	0.60	0.60
	Weave Parameters	
Weave Type	L-Weave	L-Weave
Weave Angle	95° - 133°	95° - 133°
Frequency, hz	2.5	5
Amplitude, in.	0.17	0.17
Right Dwell, sec	0.35	0.7
Left Dwell, sec	0.35	0.7



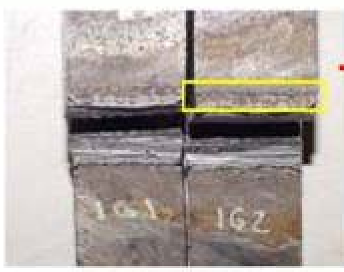
Simulate In-Service Weld Trials

Destructive Testing

- Single Pass and Multiply Pass Welds
- API 1104 Testing Requirements
  - Nick-Break Tests
  - Toe Bend Tests
  - Metallographic Analysis
    - Hardness Testing

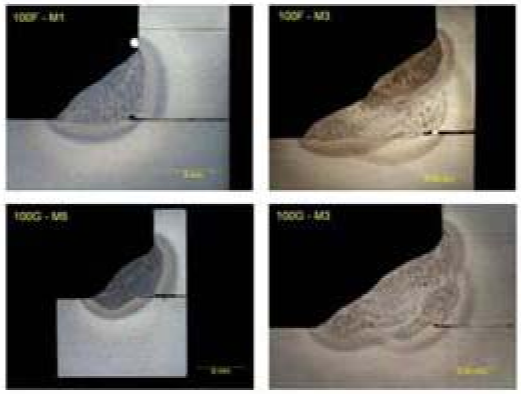


Destructive Testing Results



- Toe Bend Tests
  - No face bends showed signs of cracking

Destructive Testing Results

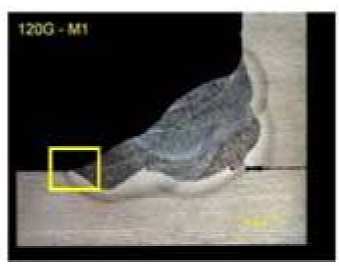


FCAW

GMAW

Destructive Testing Results

Pipe Material	Process	Avg. Hv (10-kg)
X80	GMAW	286.2
	FCAW	283.8
X100	GMAW	287.2
	FCAW	307.4
X120	GMAW	310.6
	FCAW	311.2



- The individual and average hardness values are below 350 Hv Hardness limit

Diffusible Hydrogen Results

- Verification of Low Hydrogen Welding Process
- GMAW
  - 2.37 ml/100g
  - St. Dev. 0.18 ml/100g
- FCAW
  - 1.74 ml/100g
  - St. Dev. 0.13 ml/100g

Summary

- Simulated in-service qualification was performed on X80, X100 and X120 pipeline material
- The welds did not pass due to the lack of fusion defects
  - Lack of fusion was a result of the weave parameters in the root
- The toe bends and metallographic analysis showed no evidence of the hydrogen cracking.
  - Low diffusible hydrogen levels (below 4 ml/100g)
  - Hardness values below 350 Hv
- Even though the welding procedure was not qualified, the results would indicate that the susceptibility for hydrogen cracking is extremely remote using these welding consumables, welding heat input levels and cooling conditions.

Appendix I. Workshop System Design Presentation

Project Objectives

- Develop an automated welding system for use on in-service pipelines
- Incorporate real-time adaptive control system to ensure reliable welding conditions
- Evaluate system in laboratory
- Validate the system
  - Develop qualified welding procedures
  - Perform field trials

Project Plan

Task 1 – Review Industry Needs/Current Practices

Task 2 – Write Technical Specification

Task 3 – Design and Build of System

Task 4 – Laboratory Development and Evaluation

Task 5 – Weld Procedure Qualification

Task 6 – Field Testing and Validation

Responsibilities for System Design

- Cranfield University to develop System Hardware design
- EWI to develop Control System and Software
- Cost Match project includes previous collaboration between EWI and Cranfield University

Cost Match Project Contributions

- Serimer DASA STX bug integration and control
- Servo-Robot Laser sensor hardware and software
- Lincoln PowerWave 455 Ethernet control interface

Equipment Specification

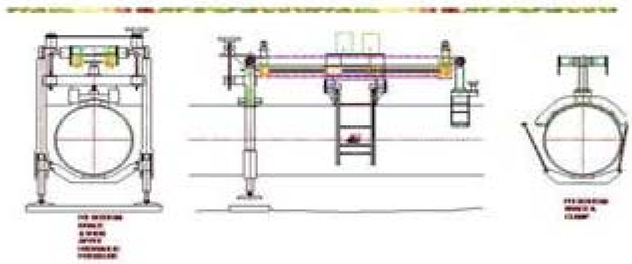
- Performance Requirements
  - FCAW, GMAW
- Operational Requirements
  - Longitudinal, circumferential and patch welds
- Welding System
  - Single power supply with GMAW and FCAW
- Inspection System
  - Scan area of pipe and determine depth of corrosion
- Operator Requirements
  - Ability to set-up and take-down portable system

Equipment Specification
Operational Requirements

- Sleeve Joint Type: Fillet weld, Longitudinal or Circumferential
  - Weld both longitudinal seams first and simultaneously
  - Potentially weld up to 4 longitudinal seams if using strap/bridge
  - Weld each circumferential sleeve independently and only after the long seams have been welded
- Corrosion Patch Build-up: Multi-bead welding passes for building up corroded area on pipe
  - Welding will be in the longitudinal direction for building up patch (RSTRENG calculation requirement)
  - Each corrosion area is treated as a separate fill sequence

Original Equipment Design

SECURE TO PIPE



SABREweld

19

Copyright 2000

EWI Developments during Cranfield University Equipment Design Stage

- Began development of motion control system using in-house motion controller from Galil
- Used software from cost match project
- Continued discussions with Cranfield on equipment design
- Finished equipment specification

EWI

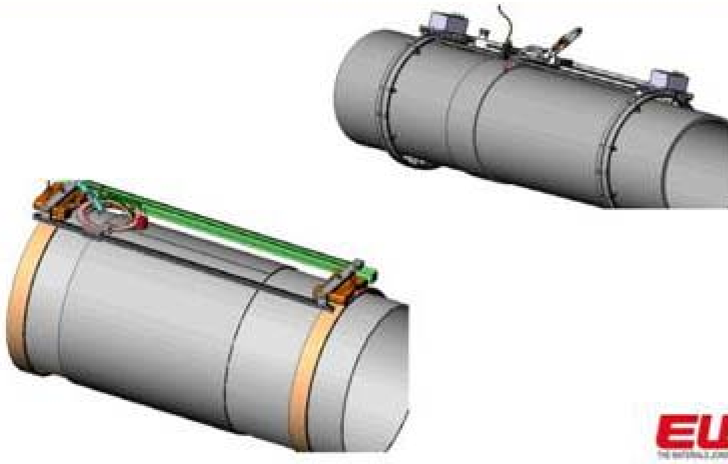
Equipment Design Change

- Original design from Cranfield University-SabreWeld
- PRCI did not approve of design in May/05
- SabreWeld was released in May/05; and DOT & PRCI approved end-date extension
- EWI pulls equipment design in-house to Design Engineers
- Serimer-DASA agrees to partner with EWI and loan equipment
- Concurrent DOT projects shared in-house equipment while awaiting delivery of new

EWI Equipment Design
Initial Thoughts

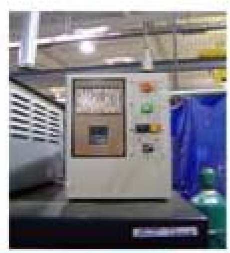
- Augment an Off-the-Shelf Mechanized Bug
  - Use standard and available bugs and add additional axes
  - Integrate bugs onto main motion controller
- Amend standard bug with software and hardware
  - Add torch work angle capability
  - Add torch travel angle for push/drag capability
  - Coordinate motion for corrosion patch and for weld fill
  - Increase length of cross-seam axis for filling corrosion patch
  - Integrate Laser Sensor onto STX bug system

EWI Equipment Design



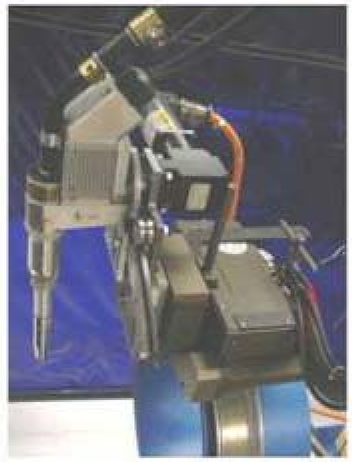
Cranfield University Assistance

- Cranfield lends EWI
  - Servo-Robot Mini-I laser
  - EZTrac Controller box
- Cranfield also assists with design ideas during hardware design



Serimer DASA Assistance

- Serimer DASA to loan EWI
  - 2 STX Mechanized bugs
  - 2 STX Controllers
  - 2 Rail Sets for 36" diameter pipe
- Some Serimer equipment already at EWI
- Second set to be delivered April/06
- EWI continues work while awaiting delivery of remaining equipment
  - Laser Mapping
  - Control System

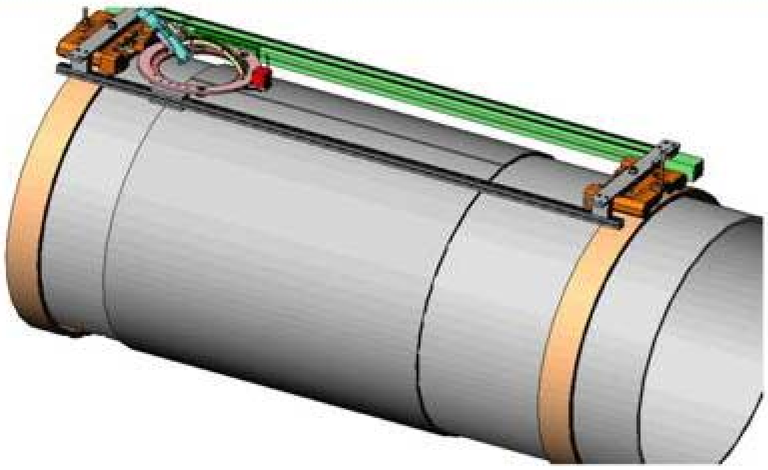


STX Controller Box

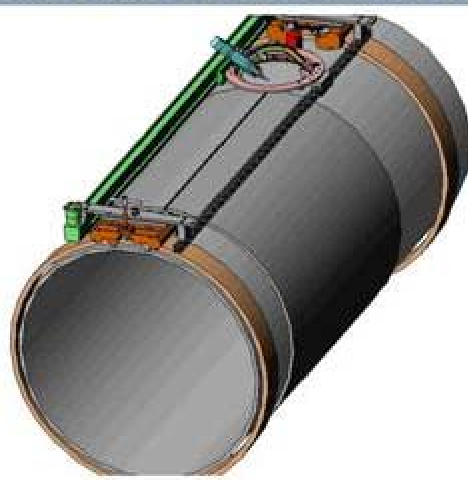
STX Controller

- Built by Serimer DASA specifically for EWI
- Provides RS-232 communication protocol for computer control of all axis
- Contains an auxiliary motor amplifier
- Additional digital I/O signals
- EWI controlled the STX bug by laptop

EWI Design with Serimer Bugs
Longitudinal Sleeve Weld

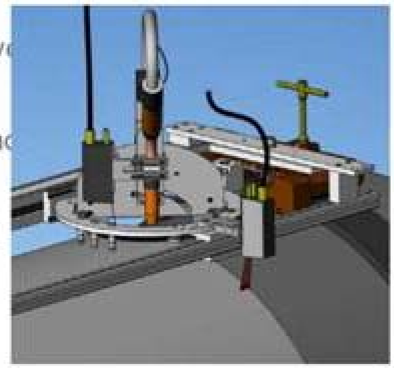


EWI Design with Serimer Bugs
Circumferential Sleeve Weld



Laser Sensor Functionality

- Seam track during sleev welding
- Pre-scan sleeve joint an determine fill
- Map corroded area and determine corrosion fill pattern



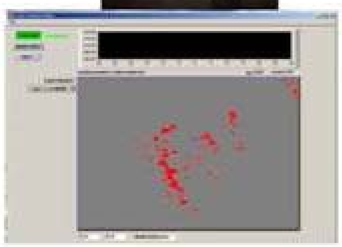
EWI

Laser Sensor Functionality
Serimer Equipment with Laser

- Serimer DASA remaining equipment arrives and bugs are synchronized
- Continue laser software development
- EWI acquires corroded pipe of 36" diameter from the field
- EWI finished laser mapping and patching scans together to cover larger area

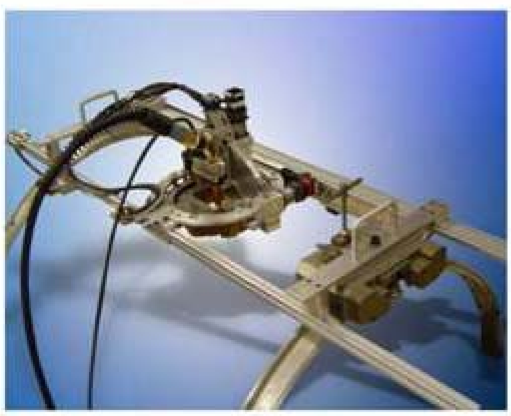
EWI

Laser Sensor Functionality
Scanning Corrosion on Pipe

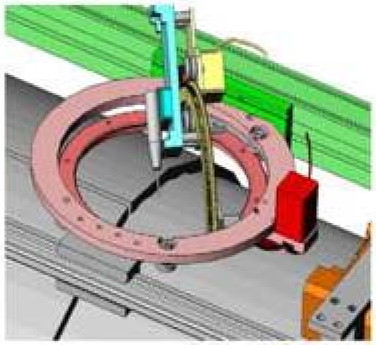


- Laser sensor scans 3-in. swathe
- Motion and laser coordinated to patch scanned areas together
- Corrosion location and depth is mapped
- Beads per layer is determined
- Stringer beads weld up corrosion patch area

System Hardware Development



System Hardware Development
Circular Slide Assembly



- Coordinated motion of circular slide and semi-circular slide create travel angle and work angle
- Kinematics equations developed to coordinate motion depending on welding direction and orientation about the pipe

System Hardware Development
Laser Sensor Integration

- Laser mounted at two different positions
- Position 1: On Torch
  - Corrosion Mapping
  - Longitudinal weld seam pre-scan
- Position 2: On Bracket
  - Seam-tracking during circumferential weld
  - Bracket on either side of system to accommodate each side of pipe

System Hardware Development
Shielding from Arc Welding

- Brushes added to protect equipment from arc welding debris
- Shielding plate added to bottom of circular assembly
- Shielding plate added to side of circular assembly

System Software Development

- Laser Scan of Pipe Surface
- Laser Seam Tracking during Welding
- Motion Control of Bug and Hardware
- Integrate with Operator Interface
- Remote Pendant

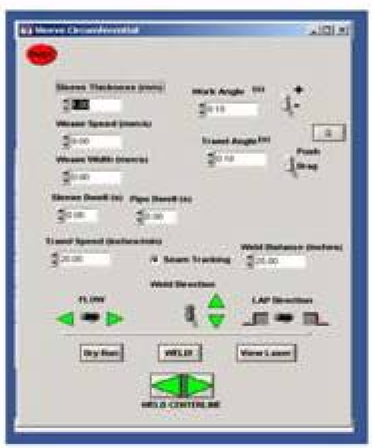
System Software Development
Control Panel

- Sony Toughbook laptop computer
- Ethernet to Motion Controller
- Serial (RS232) to Laser Sensor
- Digital I/O to Lincoln Power Supply
- All connections to motorized hardware

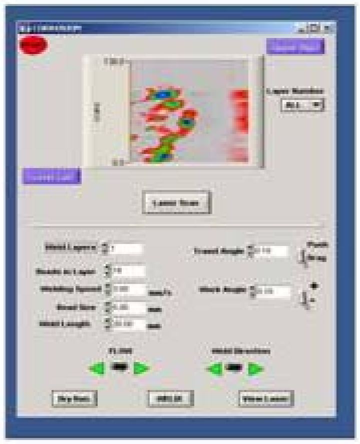
System Software Development
User Interface Design

System Software Development
Longitudinal Seam Welding

System Software Development
Circumferential Seam Welding



System Software Development
Corrosion Map and Welding



System Field Trial

- Field Trial coordinated with TransCanada Pipeline at their facility in North Bay, Ontario
- Only available pipe was 30" diameter
- EWI had to modify design to accommodate 30" pipe diameter
- Best solution was to use Bug-O bugs and purchase new rail for new pipe size
- Only the circumferential travel carriages changed

System Field Trial
System Modification with Bug-O

System Field Trial
TCPL North Bay, Canada

- Bug-O Carriages
  - Pipe diameter change
  - Rail availability
- Pressure-Containing Sleeve Weld
  - Weld longitudinal seam
  - Weld circumferential ends
- Reinforcement Sleeve
  - Weld longitudinal seam
  - No circumferential

System Field Trial
Welding Results

- Welded from 6 o'clock to 3 o'clock position
- Doubled the speed of the manual welder
- Multi-layer linear weld over root pass
- System performed and demonstrated capability

System Field Trial
Welding of Longitudinal Weld

System Field Trial
Results

- Next Steps
  - Seam tracking improvements
  - Weld parameter improvements
- Future Work
  - Improve system robustness
    - More protection from welding debris
    - Easy torch on/off
    - Easier view of the arc
  - Commercialization and support

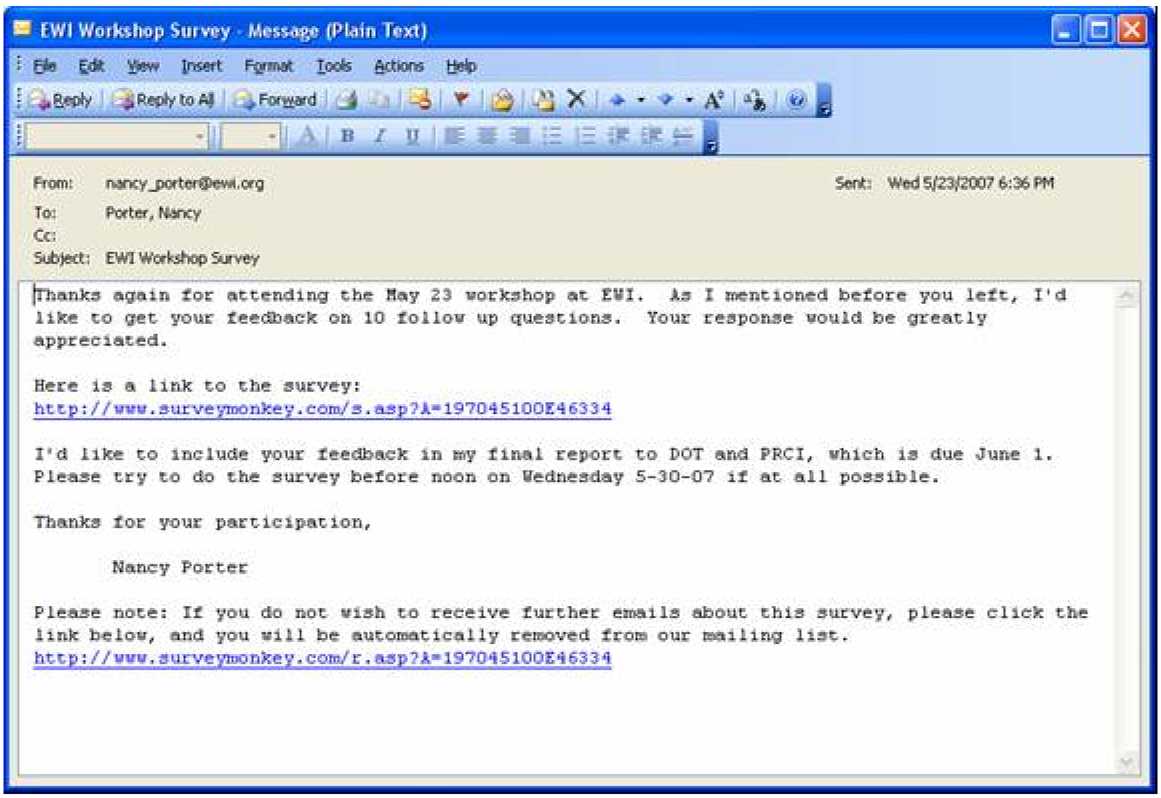
Final Hardware System with
Bug-O Carriages and Rail

Summary

- Automated pipeline corrosion repair prototype system developed
- Successfully completed field trial
- Demonstrated welding of repair sleeves
  - Reinforcement
  - Pressure containing
- First step in automating a manual process
- Demonstration

Appendix J. Workshop Online Feedback Survey

The survey was created and administered online via SurveyMonkey.com. SurveyMonkey.com allows you to create professional online surveys with your web browser. There is no software to purchase; the online survey editor is intuitive and easy to use. For each question you compose, you select from over a dozen types of questions including single choice, multiple choice, rating scales, drop-down menus, etc. The Email addresses of the workshop participants were uploaded to surveymonkey.com, which generated the automated Email invitation shown below.



EWI Workshop Survey - Message (Plain Text)

File Edit View Insert Format Tools Actions Help

Reply | Reply to All | Forward

From: nancy_porter@ewi.org Sent: Wed 5/23/2007 6:36 PM
To: Porter, Nancy
Cc:
Subject: EWI Workshop Survey

Thanks again for attending the May 23 workshop at EWI. As I mentioned before you left, I'd like to get your feedback on 10 follow up questions. Your response would be greatly appreciated.

Here is a link to the survey:
http://www.surveymonkey.com/s.asp?A=197045100E46334

I'd like to include your feedback in my final report to DOT and PRCI, which is due June 1. Please try to do the survey before noon on Wednesday 5-30-07 if at all possible.

Thanks for your participation,

Nancy Porter

Please note: If you do not wish to receive further emails about this survey, please click the link below, and you will be automatically removed from our mailing list.
http://www.surveymonkey.com/r.asp?A=197045100E46334

The following four pages are a print out of the online survey.

DOT/PRCI Funded Prototype Automated Weld Repair System for In-Service Pipelines

1. May 23, 2007 EWI Workshop Survey

Thank you for attending the equipment demonstration workshop at EWI on May 23, 2007. As promised, I put together a short survey to get your feedback for 10 questions. Your responses will help us make future workshops better and help us understand your most pressing technology needs. Your responses are totally anonymous, so please give us the brutal facts - don't hold back. Feel free to forward the survey invitation Email to anyone else in your organization that you think could give us good input for the open ended questions that are not related to the workshop.

Thanks again for attending the workshop and for providing us your post workshop feedback.

Nancy Porter
Project Manager
EWI, Government Programs Office

2. Workshop Related Questions

1. How would you rate the workshop overall?

- ○ Not worth my time for attending
- ○ Somewhat interesting
- ○ Interesting
- ○ Very interesting
- ○ Can't wait until the next one

2. If you had to pay $50 for the next workshop to cover the cost of food and presentation handouts (CD or hardcopies), would this prevent you from attending?

- ○ Yes
- ○ No
- ○ Other (please specify)

3. How can we improve the next workshop experience at EWI?

Page 1

DOT/PRCI Funded Prototype Automated Weld Repair System for In-Service Pipelines

3. Automatic Welding System Questions

4. Do you think your company will ever use an automatic system for weld repair? Check all that apply.

- ☐ Yes for Reinforcing Sleeves
- ☐ Yes for Pressure-Containing Sleeves
- ☐ Yes for Weld Deposition Repair
- ☐ Might consider it 1-5 years in the future
- ☐ Might consider it 5-10 years in the future
- ☐ No, we would not consider using an automatic system
- ☐ Other (please specify)

5. Would the system be more attractive to you if it were available with different features? Check all options that are of interest.

- ☐ System with both circumferential and longitudinal welding capability
- ☐ System with circumferential welding only
- ☐ System with longitudinal welding only
- ☐ Other (please specify)

6. What improvements would you make to the current system to make it more field deployable, user friendly, etc.?

7. Once a more field hardened system is available, would your company be interested in hosting an in-service field trial?

- ○ Yes

Page 2

- No
- Maybe (please explain)

4. Other Questions

8. What technology road blocks are the gas transmission pipeline industry facing in the next two years that EWI could help with?

9. Please give us additional comments about any subject of interest to you.

10. Do you want someone from EWI to follow up with you on your responses?

- Yes
- No

11. Please provide your contact information below.

Name

Company

Phone

Email

DOT/PRCI Funded Prototype Automated Weld Repair System for In-Service Pipelines

5. Thank You!

Mark your calendars: on February 6, 2008, EWI will host another workshop for DOT project Define, Optimize & Validate Detection & Sizing Capabilities of Phased-Array Ultrasonic Technique to Inspect Joints in Polyethylene Pipes by Dr. Mark Lozev.

Again, thank you for attending the workshop and for your survey feedback!

Sincerely,

Nancy Porter
Project Manager
614-688-5194
nporter@ewi.org

5.0 List of Abbreviations

Abbreviation	Meaning or Definition
AWS	America Welding Society
CTS	Controlled Thermal Severity
CTWD	Contact Tip-to-Work Distance
FCAW	Flux Cored Arc Welding
GMAW	Gas Metal Arc Welding
HAZ	Heat-Affected Zone
MBML	Multi-Bead, Multi-Layer
SMAW	Shielded Metal Arc Welding
STT	Surface Tension Transfer

6.0 Distribution List

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