

REPORT

July 30, 2007

EWI Project Nos. 46996GTH, 47451CAP, and 46256CSP

DOT Award No. DTRS56-03-T-0009

PRCI Contract No. PR-185-04501

Advanced Welding Repair and Remediation Methods for In-Service Pipelines

Other Transaction Agreement No. DTRS56-03-T-0009

Technology Demonstration Report

September 2003 through June 2007

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Government Purpose Rights

Submitted to:

U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Research and Development
Washington, DC



MATERIALS JOINING TECHNOLOGY

Technology Demonstration Report

Project No. 46996GTH

Other Transaction Agreement No. DTRS56-03-T-0009

on

Advanced Welding Repair and Remediation Methods for In-Service Pipelines

to

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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. This report is a summary of the technology demonstration workshop at Edison Welding Institute in Columbus, Ohio. The objective of the workshop was to disseminate the project results to the pipeline industry.

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Acknowledgments

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Disclaimer

This research was funded in part under the Department of Transportation, Research and Special Programs Administration's Pipeline Safety Research and Development Program. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Research and Special Programs Administration, or the U.S. Government.

1.0 Introduction

This project was funded by the U.S. Department of Transportation Award No. DTRS56-03-T-0009 (EWI Project No. 46996GTH), Pipeline Research Council International (PRCI) Contract No. PR-185-04501 (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.

The objectives of the overall 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.

This report is a summary of the technology demonstration that was conducted on May 23, 2007 to disseminate project results to the pipeline industry.

2.0 Technology Demonstration Workshop

Per the PRCI cost-share agreement, 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. EWI and PRCI invited their member companies to attend; DOT/HMSA invited their regional inspectors to attend. Registration was held online via the EWI web site.

2.1 Workshop Participants

Twenty-two people attended the workshop from thirteen companies as shown in Table 1.

Table 1. 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

2.2 Workshop Agenda

The workshop began at 9:00 a.m. and ran until 4:00 p.m. Seven speakers from EWI presented the topics shown in the following agenda (Figure 1). Workshop presentations were followed by a technology demonstration. 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	<i>Bob Kratzenberg</i>
Project Overview	<i>Nancy Porter</i>
Welding Procedure Qualifications	<i>Matt Boring</i>
System Design & Development	<i>Connie Reichert</i>
System Demonstration	<i>Connie Reichert Matt Boring</i>
<ul style="list-style-type: none">• Weld a simulated corrosion patch• Weld a simulated pressure containing sleeve	
Identification of Future Improvements to the System	<i>Nancy Porter</i>
Lunch	
Technology Briefs of Other PRCI/DOT Co-Funded EWI Projects	
Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines	<i>Suhas Vaze</i>
Improved Inspection and Assessment Methods for Pipeline Girth Welds and Repair Welds	<i>Mark Lozev</i>
Strain-Based Design of Pipelines	<i>Bill Mohr</i>
Open Forum Discussion	<i>Bob Kratzenberg Nate Ames</i>
<ul style="list-style-type: none">• What are the future development needs of the pipeline industry?	
Adjourn	

Figure 1. Workshop Agenda

2.3 Workshop Presentations

The project overview presentation is located in Appendix A; the welding procedure development presentation is in Appendix B, and the evolution of the system design presentation is in Appendix C.

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.

2.4 Workshop Demonstrations

The system was demonstrated 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.

Figure 2 shows the longitudinal seam weld being setup on the simulated pressure-containing sleeve. Figure 3 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 2. Equipment Demonstration Setup for Longitudinal Seam Weld

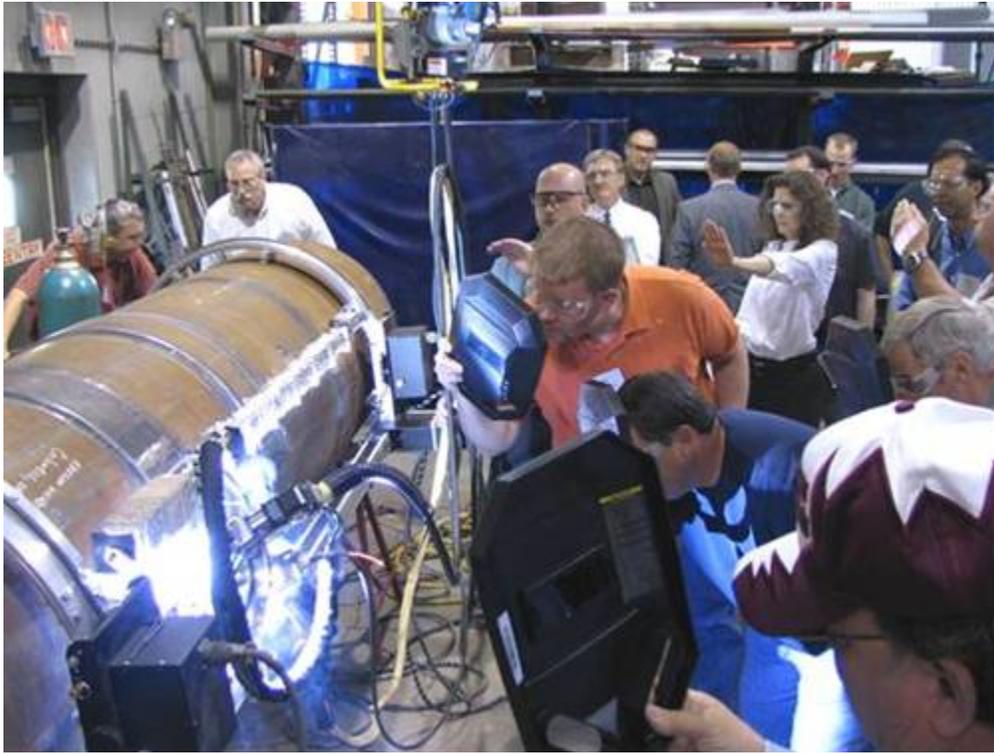


Figure 3. Demonstration Welding of Longitudinal Seam Weld

2.5 Workshop Survey

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 D. The results and analysis of the survey are located in Appendix E.

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 4.

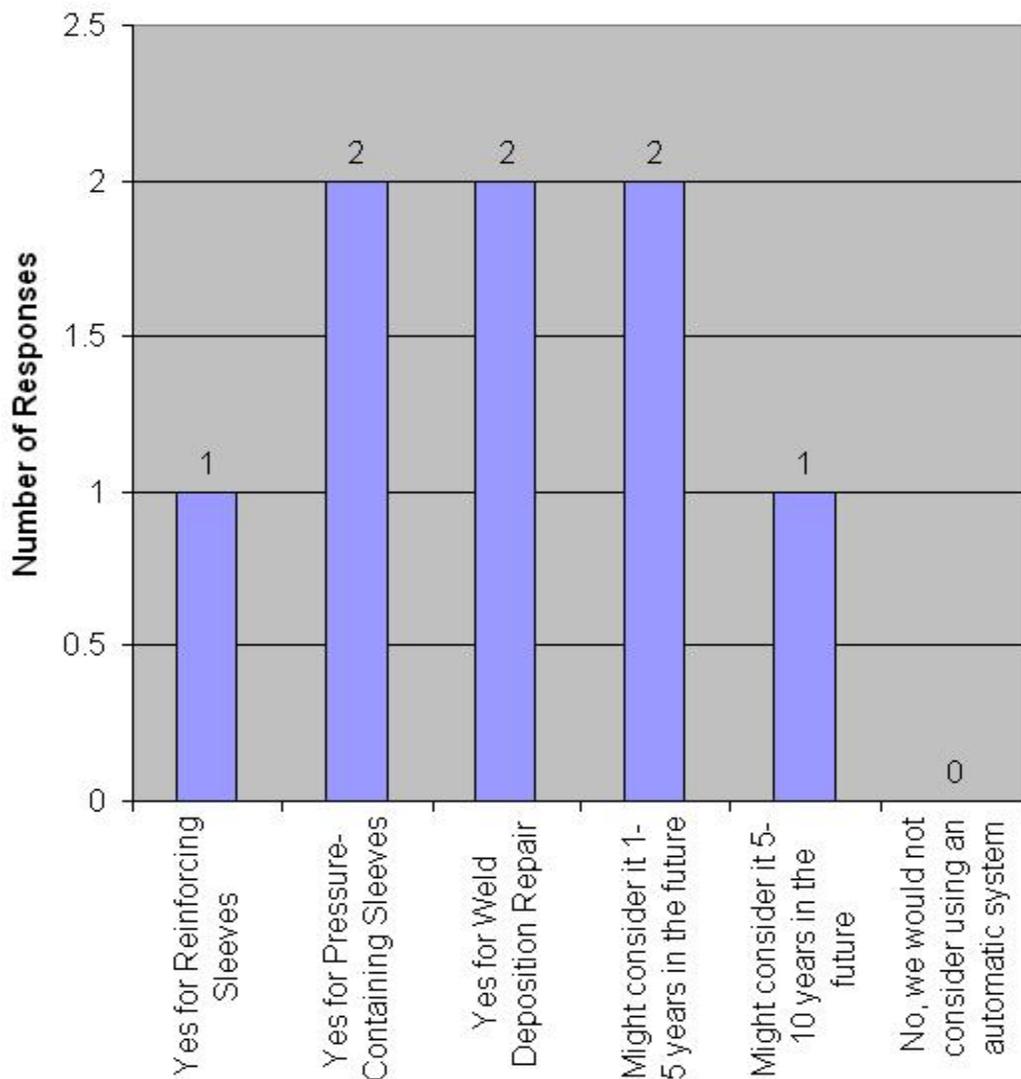


Figure 4. Potential Future Use of System

The participants also 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".

The vast majority of survey respondents rated the workshop as "interesting" or "very interesting".

3.0 Conclusions

The vast majority of respondents rated the workshop as "interesting" or "very interesting". The majority said length of the workshop was appropriate for the amount of material delivered. Attendee feedback was very informative and will be used to improve the next DOT/PHMSA technology demonstration workshop at EWI. End of project technology demonstration workshops are an excellent forum to solicit pipeline industry feedback for future pipeline research work.

4.0 Recommendations

All future DOT/PHMSA projects should feature an end of project technology demonstration to disseminate project results to industry and to solicit feedback regarding future focus areas for pipeline research and development.

Appendix A. Workshop Project Overview Presentation



**Automated Weld Deposition
for Repair of In-Service
Pipelines**
Equipment Demo Workshop

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

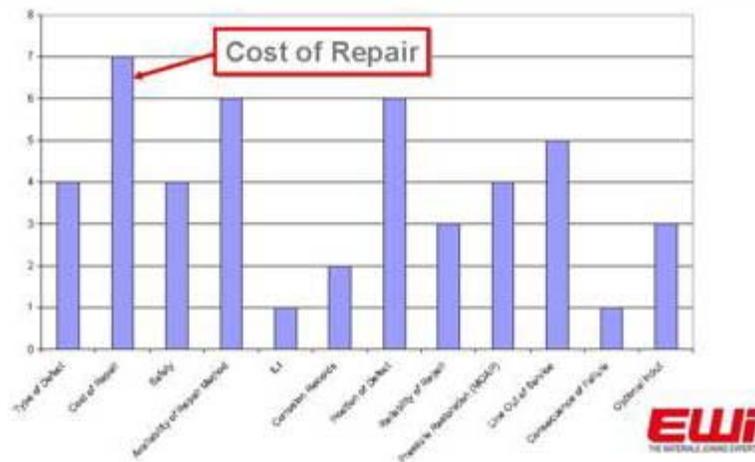


Industry Needs & Practices

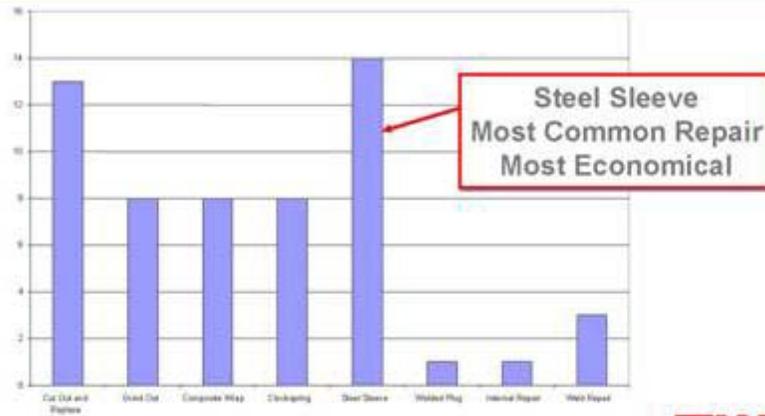
- Pipeline Repair (or Modification) Generally Involves Welding Out-of-Service or In-Service
- In-Service Welding Repair
 - Major Cost and Environmental Benefits
 - Mature Technology - Routinely Used
 - Usually Manual SMAW
- Large Diameters – SMAW Long Weld Times
- X80 and Above – SMAW Not Suitable
-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



What Affects Choice of Repair?



Corrosion #1 Reason for Repair



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Retaining Sleeve Repair



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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 B. Workshop Welding Procedure Presentation



Automated In-Service Welding Procedure Development

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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



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

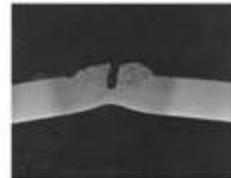
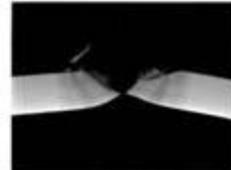


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THE INTEGRAL JOINT EXPERTS

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



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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
 - Heat Input =
$$\frac{(\text{amps} \times \text{volts} \times 60)}{(\text{Travel Speed [in./min]} \times 1,000)}$$
- Pipeline Operating Conditions
 - Contents, Wall thickness and Flow rate/pressure



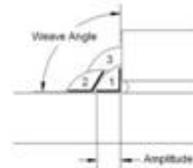
Experimental Approach

- 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% CO₂)
 - 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	E71T1-1MH4-12MH4	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



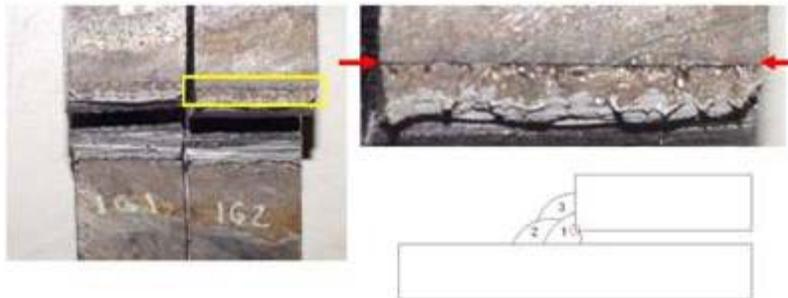
Destructive Testing

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



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THE METALLURGICAL EXPERTS

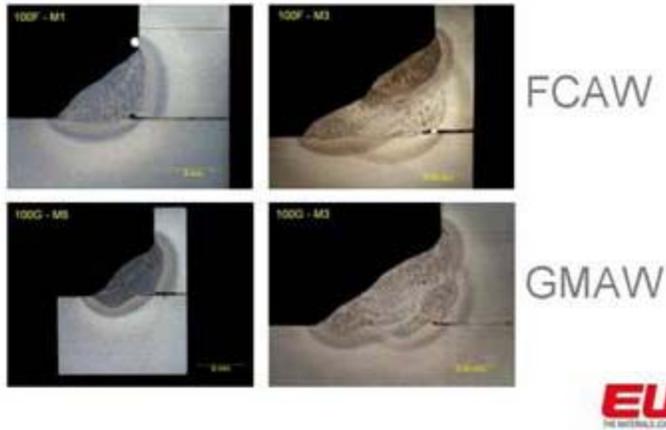
Destructive Testing Results



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

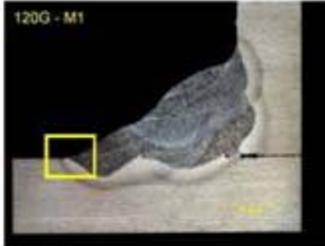
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THE METALLURGICAL EXPERTS

Destructive Testing Results



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

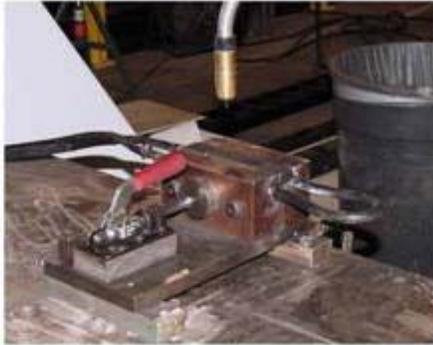


- The individual and average hardness values are below 350 Hv Hardness limit



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 C. Workshop System Design Presentation



Equipment Design and Development

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Presentation Outline

- Project Objectives
- Prototype Design
- Project Changes
- Hardware Development
- Software Development
- Field Trial
- Summary



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



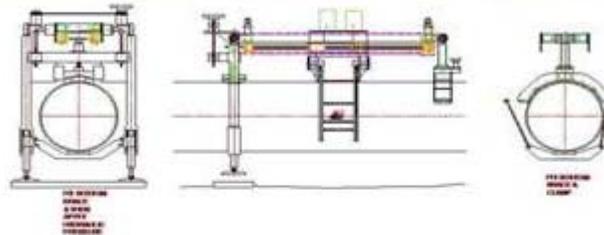
Equipment Specification Operational Requirements

- 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



SABKEweld

19

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EWI
THE ORIGINAL JOINT EXPERTS

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
THE ORIGINAL JOINT EXPERTS

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

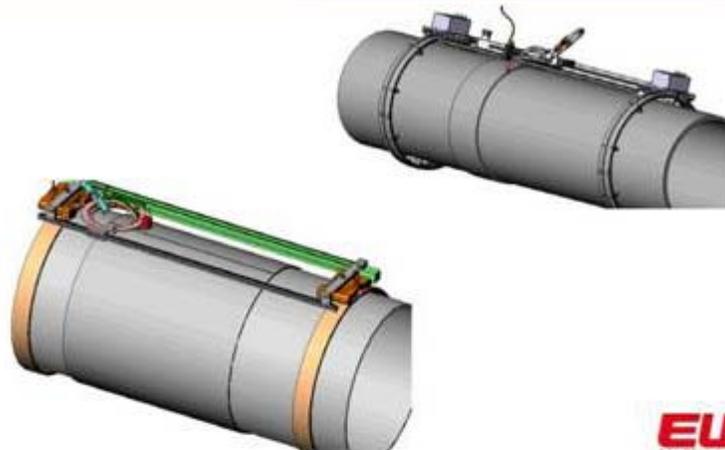


EWI Equipment Design Initial Thoughts

- 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

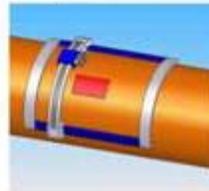


EWI Equipment Design



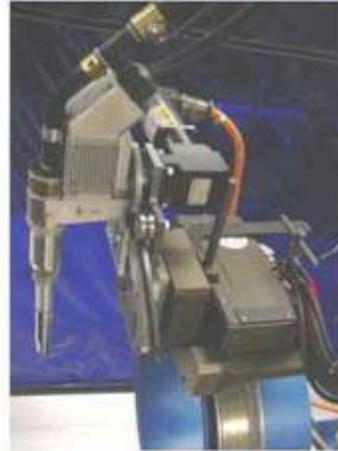
Cranfield University Assistance

- 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

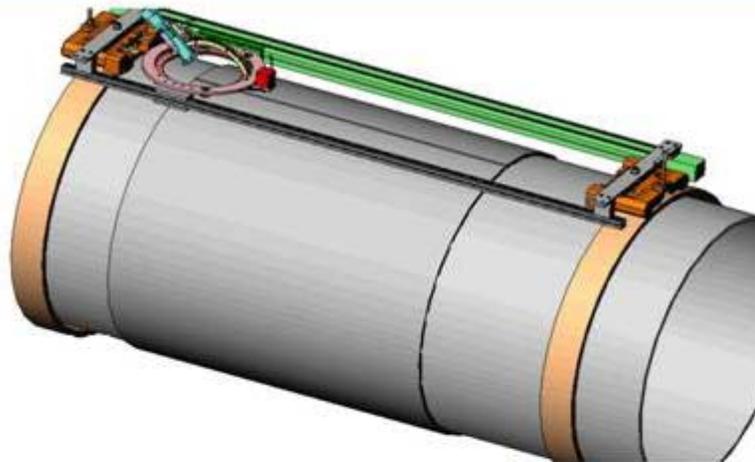
STX Controller

- 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

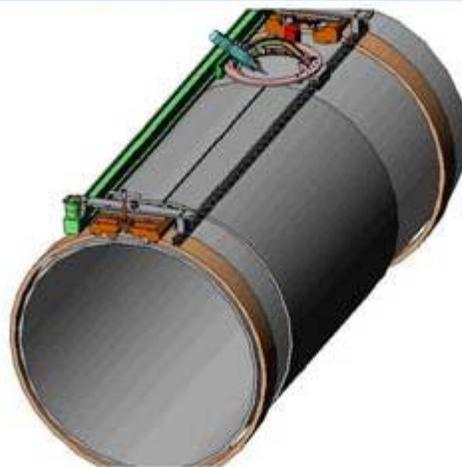


EWI
THE INDUSTRIAL CONTROL EXPERTS

**EWI Design with Serimer Bugs
Longitudinal Sleeve Weld**

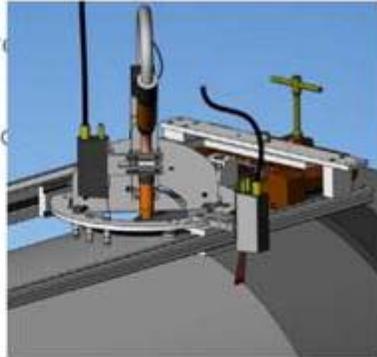


**EWI Design with Serimer Bugs
Circumferential Sleeve Weld**



Laser Sensor Functionality

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



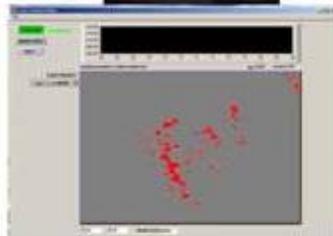
Laser Sensor Functionality Serimer Equipment with Laser



- 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



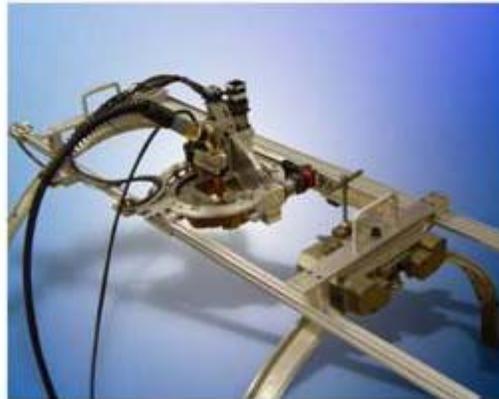
Laser Sensor Functionality Scanning Corrosion on Pipe



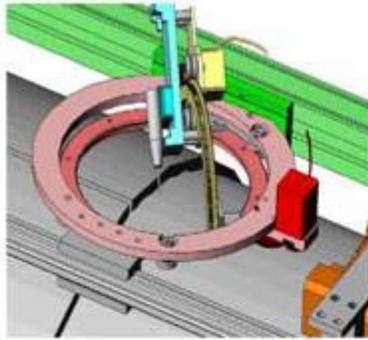
- Laser sensor scans 3-in. swathe
- Motion and laser coordinated to patch scanned areas together
- Corrosion location and depth is mapped
- Beads per layer is determined
- Stringer beads weld up corrosion patch area



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

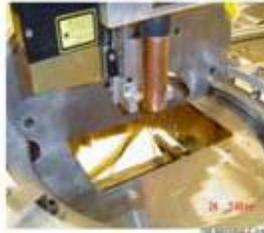


- Laser mounted at two different positions
- Position 1: On Torch
 - Corrosion Mapping
 - Longitudinal weld seam pre-scan
- Position 2: On Bracket
 - Seam-tracking during circumferential weld
 - Bracket on either side of system to accommodate each side of pipe



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



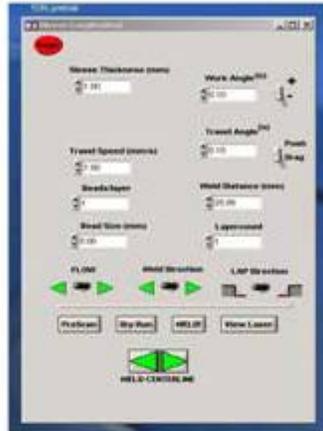
EWI
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System Software Development User Interface Design

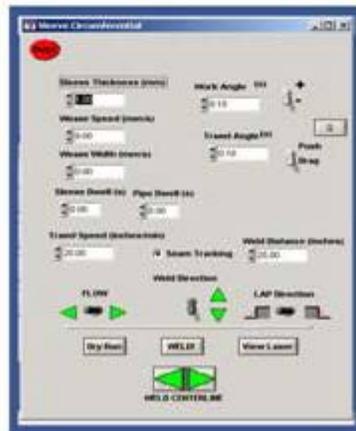


EWI
THE MANUFACTURING EXPERTS

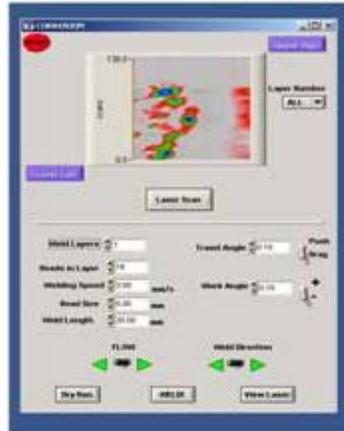
System Software Development Longitudinal Seam Welding



System Software Development Circumferential Seam Welding



System Software Development Corrosion Map and Welding

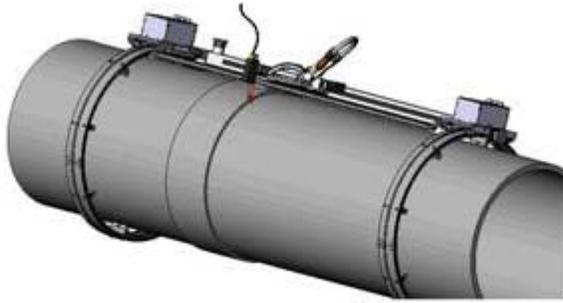


System Field Trial

- 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



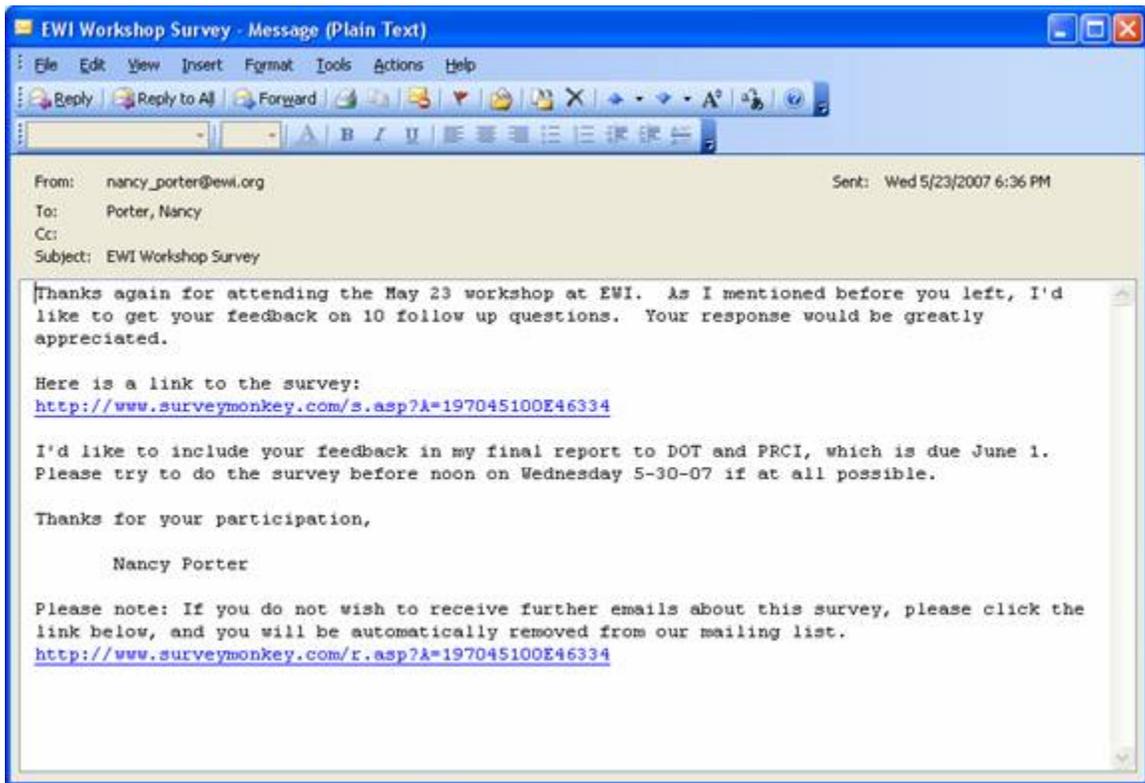
Summary

- 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 D. 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.



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

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?

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

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

- 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	<input type="text"/>
Company	<input type="text"/>
Phone	<input type="text"/>
Email	<input type="text"/>

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

Appendix E. Survey Results and Analysis

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 5. The vast majority of respondents rated the workshop as "interesting" or "very interesting".

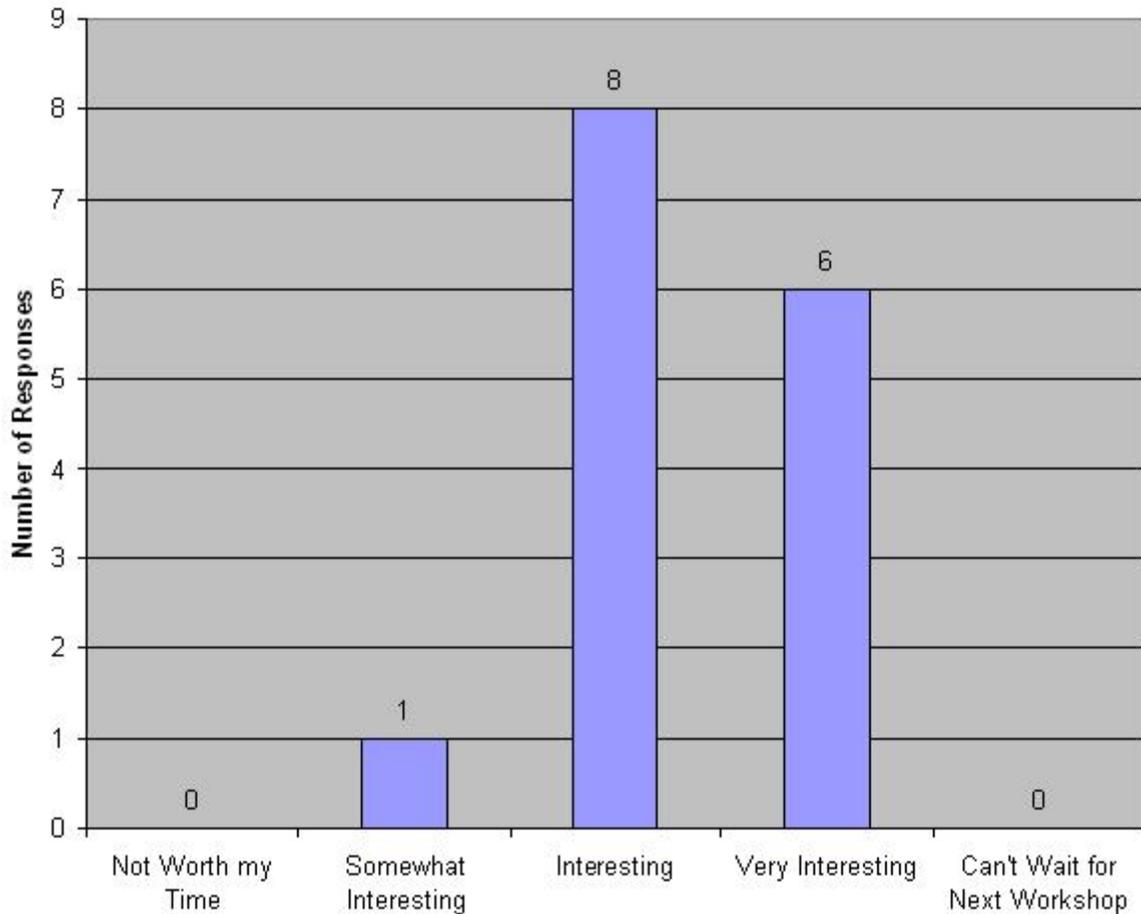


Figure 5. Overall Workshop Ratings

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.

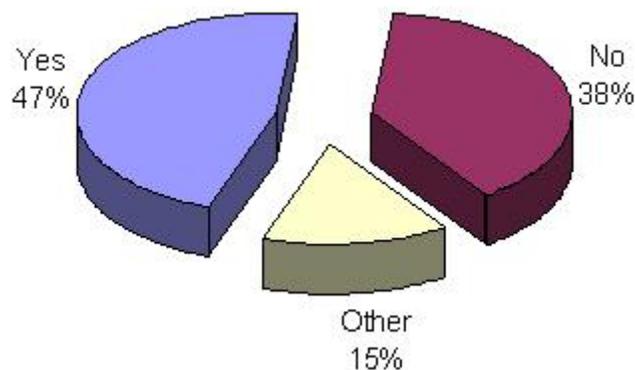


Figure 6. Would Paying for a Future Workshop Prevent You from Attending?

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 7.

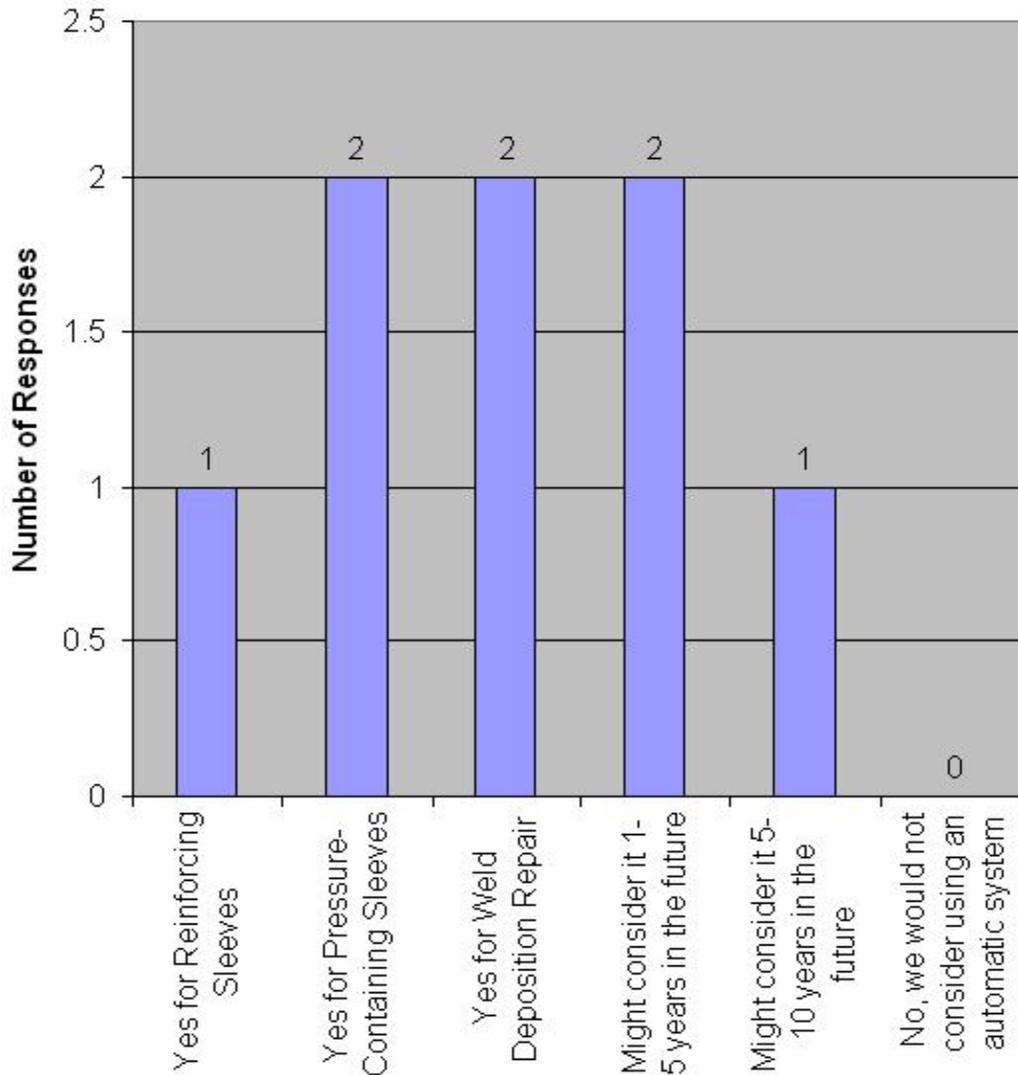


Figure 7. Potential Future Use of System

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 8 is a graphical representation of the survey responses to this question.

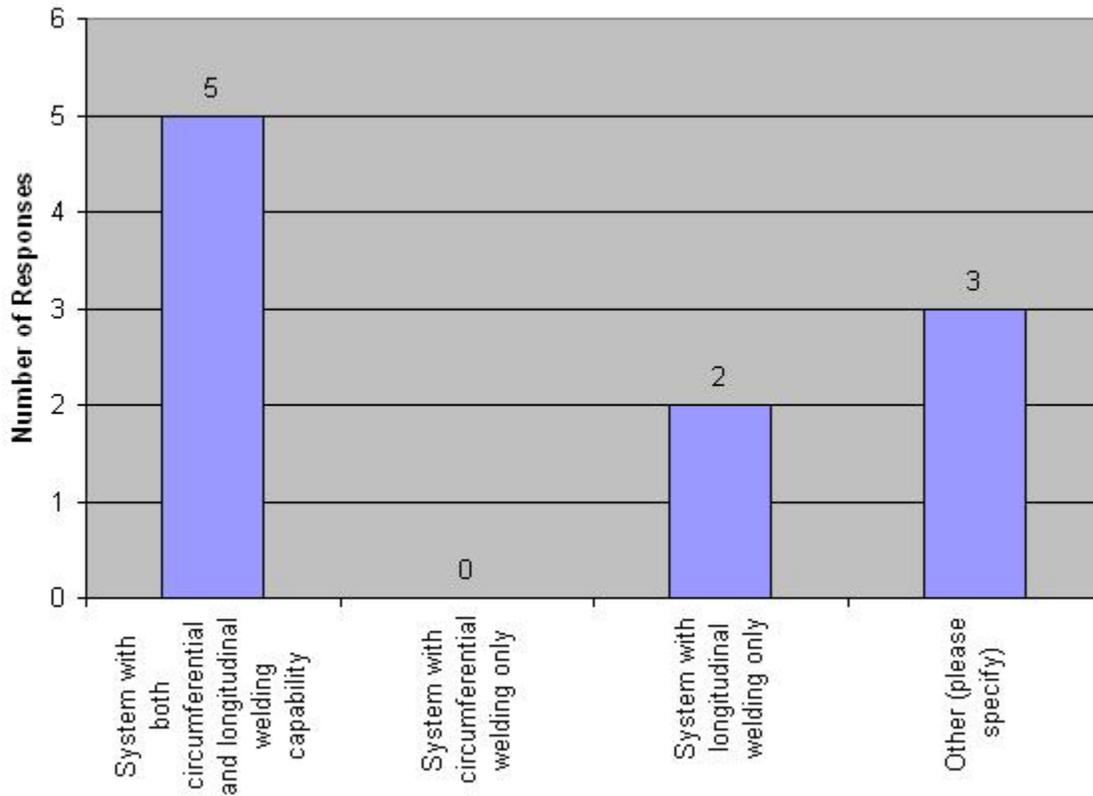


Figure 8. System Features of Interest to Workshop Participants

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.