REPORT

April 28, 2006
EWI Project No. 47961GTH
DoT Transaction Agreement No. DTRS56-05-T-0001

Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines

Task 6 Report
Preferred Process/Technique Demonstration

Submitted to:

U.S. Department of Transportation
Research and Special Programs Administration
Washington, D.C.

EWI®

MATERIALS JOINING TECHNOLOGY

Task 6 Report

Project No. 47961GTH
U.S. Dot OTA No. DTRS56-05-T-0001

on

Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines
Task 6 – Preferred Process/Technique Demonstration

to

U.S. Department of Transportation
Research and Special Programs Administration
Washington, D.C.

April 28, 2006

Ian Harris and Suhas Vaze
EWI
1250 Arthur E. Adams Drive
Columbus, OH 43221

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Executive Summary

The objective of this task of the project, Task 6 – Preferred Process/Technique Demonstration was to describe and demonstrate both the welding procedures developed for root pass welding and the hardware and software developed during the project as a whole.

Invitations and reply slips (Appendix A) were sent out in March 2006 to potential participants for dates in the April 4-6 timeframe. April 6, 2006 was selected as the preferred date on a majority vote.

Five presentations were made as follows:

- Project Overview – Suhas Vaze, EWI
- Pipe Root Pass Welding, RTQM, and Economics – Ian Harris, EWI
- Fill Pass Procedure Development and Mechanical Testing – David Yapp, Cranfield University, U.K.
- Process Automation and Controls – Connie Reichert, EWI
- Future Projects (GSP and DOT) – Ian Harris, EWI

Copies of all presentations are included in Appendix B.

The agenda for the meeting is shown below.

<u>Agenda</u>

8:30-9:00	Coffee and pastries
9:00-9:15	Welcome and Introduction - Suhas Vaze, EWI
9:15-9:45	Task 1 – Root Pass, Task 5 RTQM, Task 7 Economics – Ian Harris, EWI
9:45-10:15	Tasks 1 and 2 – Laser and Laser Hybrid – David Yapp, Cranfield University
10:15-10:45	Tasks 3 and 4 – Process Control and Automation – Connie Reichert, EWI
10:45-11:00	Future Projects (GSP and DOT) – Ian Harris, EWI
11:00-11:30	General Discussion – All
11:30-12:00	Pipe Welding Demonstration in Highbay

12:00-13:00 Lunch
14:00-14:30 EWI Tour as needed
14:30- Adjourn

The work conducted within Task 1, “Root Pass Welding Techniques”, Task 3, “Improved Root Pass Techniques”, and Task 4, “Process Control Systems for Pipeline Girth Welding” was described and demonstrated. The results of this work can be summarized as follows:

1. Communication software was developed to control a mechanized welding bug through RS232 communication.

2. Automated torch travel angle control hardware was developed and integrated with the mechanized bug system.

3. Automated torch travel angle control software was developed and integrated with the mechanized bug system.

4. Spin Arc (GMAW-RE) torch hardware was integrated with the mechanized bug system.

5. A control system was developed for the Spin Arc torch and integrated with the automated torch travel angle control.

6. A building block for RTQM was developed and data gathered for future analysis with data acquisition from a cost-matched project.

7. An automatic control system was developed using the RTQM data acquisition system for measuring mean welding current and using this to maintain a user specified CTWD during welding.

8. The welding demonstration deployed the Spin Arc welding parameters developed in Task 1 of the project.

Acknowledgements

This report was prepared by Edison Welding Institute, as an account of work on EWI Project No. 47960GTH, under Contract to the U.S. Department of Transportation. Funding for this work was provided by the U.S. Department of Transportation.

1.0 Introduction

Advanced mechanization can be used to improve tolerance to fit-up conditions such as gap and mismatch, and ensure uniform bead shape around the entire circumference of the pipe. Since pipelines are welded in a fixed position, the welding process must be tolerant to the effects of gravity and deposit sound metal in all positions. The effects of torch weaving, rotating electrode, variable travel angle, and travel speed control were evaluated for improved root pass weldability. Typical mechanized welding bugs have travel speed, lateral oscillation, and torch height controls. These three degrees of motion are applicable to linear welding and work well for that purpose. For pipeline welding in all positions, torch angle must be taken into account in order to compensate for the effects of gravity on the molten pool. Task 3 of this project aimed at incorporating hardware onto an existing 3-axis bug and creating mechanized torch travel angle control as a fourth axis.

The quality of pipeline girth welds is largely affected by the ability of welders/operators to reliably track the weld seam and make necessary adjustments to travel speed, oscillation, and contact-tip-to-work distance (CTWD) without exceeding the qualified envelope of welding parameters. Typical mechanized gas metal arc welding (GMAW) systems used for pipeline welding require a high degree of operator intervention. This becomes much more difficult as travel speeds are increased and especially on single-sided root passes with high-strength weld metals. A matrix of pipe welding conditions were developed and used to assess process robustness and control techniques. Signals from welding sensors were analyzed for process control. Concepts for adaptive control of the welding processes that can be commercialized with existing pipeline contractors were developed. Task 4 of this project aimed to incorporate control of the electrode stick-out by using automated voltage control techniques. This control will regulate CTWD by data acquisition of the instantaneous voltage, sensing the desired set point of voltage for stick-out, and maintaining the CTWD during welding.

Work in Task 1 (development of innovative root pass welding procedures) determined that the best results were achieved using the rotating electrode GMAW process (GMAW-RE) embodied in the Spin Arc process from Panasonic. Work in Tasks 3 and 4 employed the Spin Arc torch used in Task 1 and achieved constant arc voltage through AVC, and control of torch travel angle as an additional axis on the STX welding tractor. Constant mean welding current control is achieved using. High-speed data-acquisition (DAQ) capability was added in Task 5 as a building block for RTQM. The use of constant welding current control and constant arc voltage control provides constant welding power and heat input control for a set travel speed. These are elements of RTQM also since they provide feedback control of welding power in real time.

2.0 Objective

The objective of this task of the project, Task 6 – Preferred Process/Technique Demonstration was to describe and demonstrate both the welding procedures developed for root pass welding and the hardware and software developed during the project as a whole.

3.0 Presentation of Project Results

Invitations and reply slips (Appendix A) were sent out in March 2006 to potential participants for dates in the April 4-6 timeframe. April 6, 2006 was selected as the preferred date on a majority vote.

Five presentations were made as follows:

- Project Overview – Suhas Vaze, EWI
- Pipe Root Pass Welding, RTQM, and Economics – Ian Harris, EWI
- Fill Pass Procedure Development and Mechanical Testing – David Yapp, Cranfield University, U.K.
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14:00-14:30 EWI Tour as needed
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A total of 10 presenters and attendees participated in the meeting; Appendix C.

4.0 Mechanized Pipeline Welding Demonstration

The system functionality is summarized below and described in more detail in the following sections of the report. The demonstration in the highbay was conducted to highlight the performance of the welding procedures developed for the root pass welding of 36-in.-diameter X80 pipe using Spin Arc (GMAW-RE), and also to demonstrate the software and hardware functionality developed during other Tasks in the project.

4.1 Summary of Current System Functionality – April 2006

4.1.1 Hardware

1. STX bug with torch tilt hardware (Figures 1 through 3) integrated with STX controller box.
2. Spin Arc torch mounted onto STX bug.
3. Spin Arc torch control system with motor amplifier.
4. PXI industrial computer system with data acquisition + sensors.

4.1.2 Software

1. One software program on PXI computer will run:
    a. STX bug control
    b. Spin Arc torch speed control
    c. AVC for power supply during welding
    d. Data acquisition for RTQM.

4.1.3 Functionality

A PXI industrial computer (Figure 4) running one main computer program, Intellipulse (Figure 5), controlled the software programs listed above, keeping the user interface clean and easy for the operator to use. This system runs all programs and provides pendant-like control of the STX bug (Figure 6), Spin Arc torch speed control (Figure 7), programmable weld travel sequences (Figures 8 and 9), AVC during welding (Figures 10 and 11), and data acquisition for RTQM (Figure 12).

4.2 Hardware

The Saturnax (STX) Bug from Serimer-Dasa was developed for, and is normally used for, land-based pipeline welding during fabrication in the field. This rugged, 3-axis bug is used with straight or circular track for single and tandem gas metal arc welding (GMAW) applications.

4.2.1 STX Bug with Integrated Torch Travel Angle Control Hardware

The first modification or addition to the STX bug included motorized torch travel angle capability. The standard STX functionality upon delivery includes travel speed, transverse oscillation, and torch height. These three motions are automatic, motorized, and integrated to work with one another. In this task, EWI added hardware components onto the standard STX bug to complete torch travel angle control.

The tool center point (TCP) for welding was identified based on the length of the Spin Arc torch being used. This point was used for reference when designing the hardware for automatic torch travel angle control. The most effective design to create the motion needed for the torch was by using a rack and pinion system with a “radiused” rack in a specific arc (Figure 1). In order to create smooth motion rotating about the TCP, a specific radius and arc was calculated to maintain the TCP while traveling circumferentially around the pipe. A bracket was designed to attach the circular rack to the STX bug. The bracket is a solid piece of aluminum with four guide rollers and a primary pinion. The pinion was mounted with a motor attached to the back side of the aluminum plate (Figure 3). The torch was mounted onto the radiused rack. The bracket plate with roller guides and pinion was stationary. The radiused rack and torch moved between the roller guides to accomplish the torch travel angle motion. The hardware was assembled, mounted, and tested.

4.2.2 Spin-Arc Torch Mounted onto STX Bug with Torch Fixture

Based on the results of Task 1 of the project, a Panasonic Spin-Arc GMAW-RE torch (Figure 1) was chosen to be mounted onto the STX bug system. The Spin Arc torch contains a small motor assembly that moves the electrode wire in a circular pattern of 2-mm diameter. The torch is moved at a high speed and thus a high rotational frequency (0-100 Hz) and due to the constant spinning motion, creates even penetration, improved root-gap tolerance, and high-speed joint tracking at speeds up to 100 in./min. The Spin Arc torch is a good choice for use on the STX bug as it can also be used for tandem configuration. The Super Small Spin Arc torch weighs about 14 lb, so a special bracket had to be made to affix it to the STX bug and automated torch-tilt fixture. Figures 1 through 3 show the STX bug with the attached torch tilt hardware and torch.

4.2.3 Dry Run

Because the control system was now able to control the welding power supply contactor, it was necessary to provide the operator with the ability to go through the motions of a welding path, but without igniting the arc. The STX Control software was amended with the functionality to perform a “dry run” (Figure 6). The dry run task coordinates the bug travel motion, Spin Arc torch parameters and data acquisition, but does not engage the welding power supply. This allows the operator to practice the anticipated welding path and ensure proper torch angle changes prior to welding.

4.2.4 AVC Functionality

AVC uses the data acquisition voltage sensor which was attached to the welding circuit. The operator manually sets the torch height on the welding bug and begins welding. When the torch height is at the desired position, the operator then sets the AVC. This engages the AVC and maintains the voltage level to this set point by adjusting the torch height to maintain a constant CTWD. The AVC can be turned off at any time and the operator can manually jog the torch height at any time. The STX control software is responsible for making the automatic torch height adjustments during welding with the AVC.

4.2.5 AVC Hardware

The data acquisition system inside the industrial control cabinet has a 10:1 voltage sensor for measuring arc voltage in the welding circuit. This sensor was attached between the Spin Arc welding torch and the workpiece. The sensor continually gathers voltage data during welding. The STX bug’s torch height axis is automatically adjusted by the STX control software when the AVC is engaged.

4.2.6 PXI Industrial Computer System with Data Acquisition

Originally, the STX bug system was controlled by RS-232 ASCII commands through a serial port on a laptop computer. Because the STX bug was being used by a welder, the software program user interface was designed to look like a typical welding robot pendent. A data-acquisition card was used with the laptop computer to sense I/O signals also provided by the STX control box. The available signals included wire jog, through the arc seam tracking signals, inclinometer information, and general I/O. The general I/O was defined and used to connect to the welding power supply so that arc initiation and STX travel start began simultaneously.

As a result of the cost-matched EWI 48248GTO project, a PXI industrial computer system with data acquisition capabilities was available for use in this project (Figure 5). The PXI computer replaced the laptop used earlier. The PXI computer from National Instruments included data acquisition boards that were used to connect and control all signals from and to the Spin Arc torch. The 48248GTO project also resulted in a software program, Intellicontrol, which can be used for data acquisition during the welding process. The data acquisition included monitoring and saving data from the welding current, arc voltage, wire feed speed, and shielding gas flow rate (Figure12).

To develop adaptive welding techniques, data from the welding process must be gathered, studied, and tested. This data helps determine what relationships during the welding process cause which effects on the output or resultant weld. The first step to adaptive welding in this task began with the development of the data acquisition system.

4.3 Software

4.3.1 STX Control Software

The first program developed during this task was the STX control software. It was designed to mimic a pendant often found on conventional welding robots. This software serves the purpose of allowing the welder to move the bug to any position for welding. The welder can set the following items:

- Travel speed and direction
- Oscillation speed and amplitude
- Torch height, speed, and direction
- Torch travel angle, motion speed, and direction
- Jog in any axis
- Dwell times.

The software runs on the PXI computer connected to the STX control box by Serial Port (Figure 9). This RS-232 communication protocol allows the software program to send commands back and forth to the STX control box. Along with controlling motion of the bug, this software program also communicates with a data-acquisition card that is in the PXI computer. The data acquisition card reads the I/O that is available on the STX control box and the software program uses the information. The I/O information integrated by this software program includes:

- Through the arc seam tracking signals during oscillation
- Jog control of the wire feed speed motor (if attached to the STX box)
- Relay control for beginning STX motion when an arc has been established
- Inclinometers for STX orientation about the pipe.

The functionality of the STX bug and STX control software allow the welder to set-up welding motion prior to welding including setting a specific torch travel angle, synchronize STX motion with arc initiation, and change any STX motion parameter during welding (Figures 4 and 5).

4.3.2 AVC Software Development

A software program was developed that allows the operator to quickly turn on or off the AVC functionality during welding. The STX control software was amended with the AVC control which is selectable from the STX software screen (Figure 10). The AVC software screen displays the actual voltage level during welding and allows the user to manually adjust the trim, which corresponds to the CTWD. Once the operator is satisfied with the welding parameters, he can then click on the SET AVC button located on the AVC software screen. When the operator wishes to turn off the AVC functionality, he can click on the same button which now reads, QUIT AVC (Figure 11).

The welding demonstration in the high bay (Figures 13 and 14) deployed the Spin Arc welding parameters developed in Task 1 of the project.

5.0 Summary

The work conducted within Task 1, “Root Pass Welding Techniques”, Task 3, “Improved Root Pass Techniques”, and Task 4, “Process Control Systems for Pipeline Girth Welding” was described and demonstrated. The results of this work can be summarized as follows:

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8. The welding demonstration deployed the Spin Arc welding parameters developed in Task 1 of the project.

Figure 1. Torch Travel Angle Hardware Added to Standard STX Bug

Figure 2. Front View of Torch Travel Angle Hardware Added to Standard STX Bug

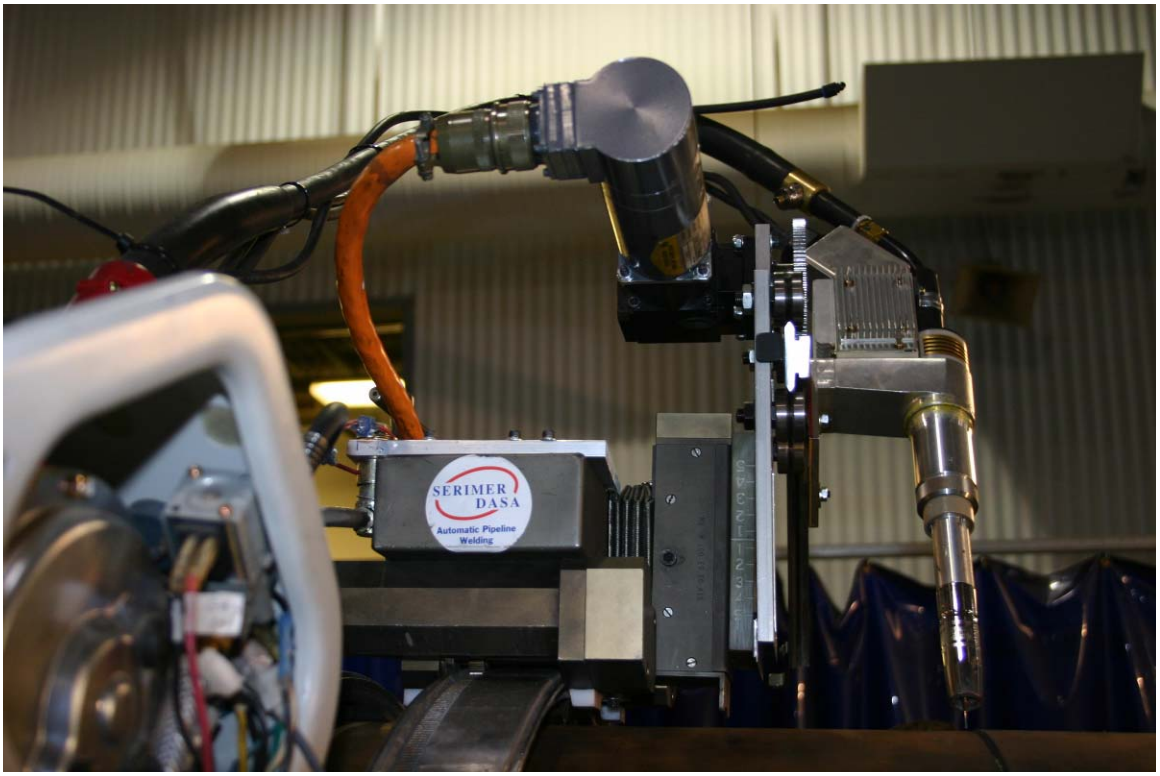

Figure 3. **Close-up Side View of Torch, Travel Angle Control, STX Tractor and Band, and Wire Feeder on a Separate Band**

Figure 4. Operator at the Industrial Control Cabinet Housing the integrated Hardware and Software for Process Control

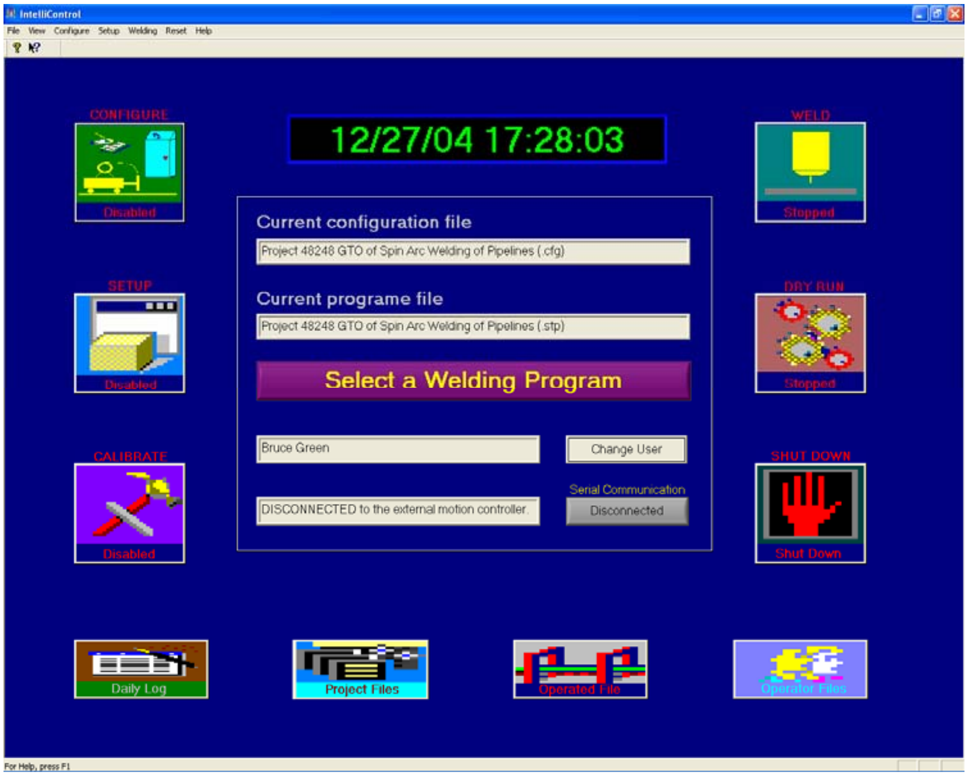

Figure 5. Intellicontrol Software Main Panel

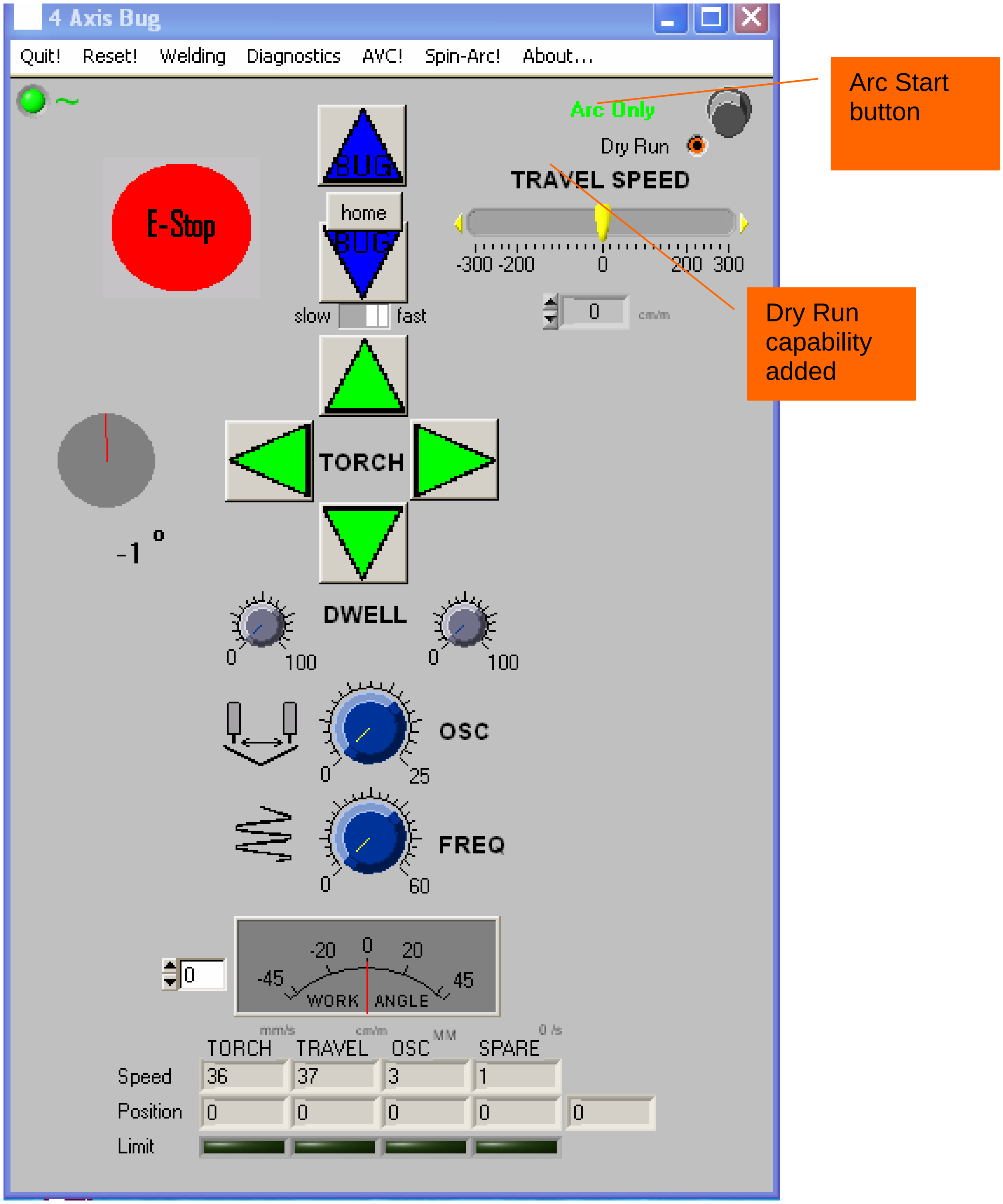

Figure 6. **Additions to the User Interface for Integrated STX Control Software Developed for Pendant-Like Control of the STX Bug Including Synchronizing Arc Start to Travel and Capability to Perform a Dry Run**

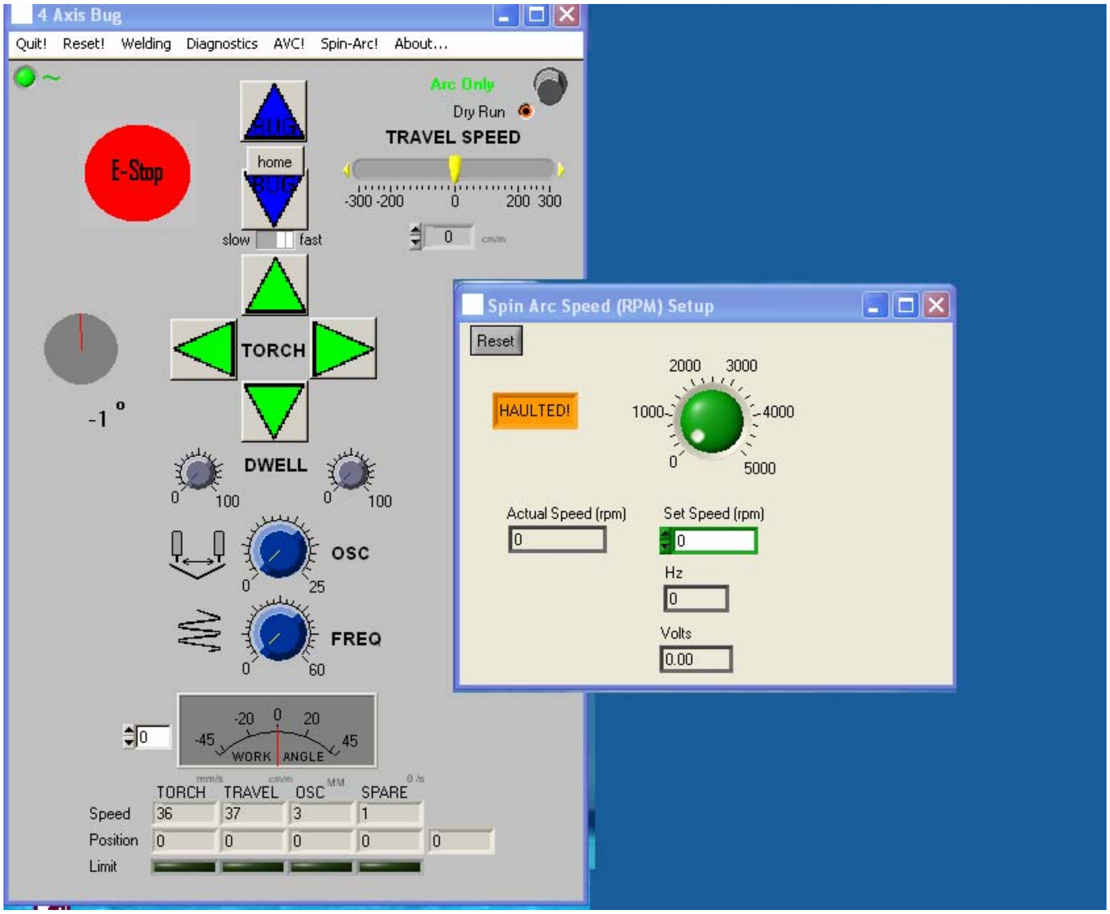

Figure 7. **Spin Arc Control Software for adjusting Spin Arc Frequency during Welding**

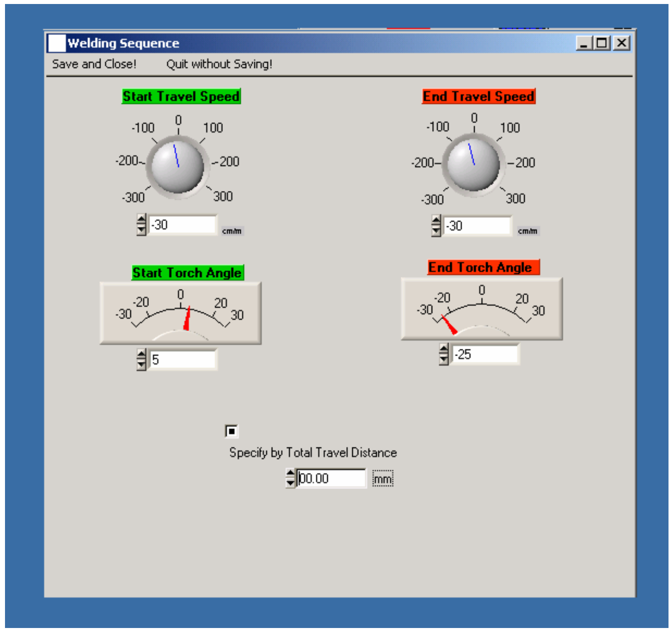

Figure 8. **Software User Interface for Programming a Welding Sequence by Specifying a Total Distance**

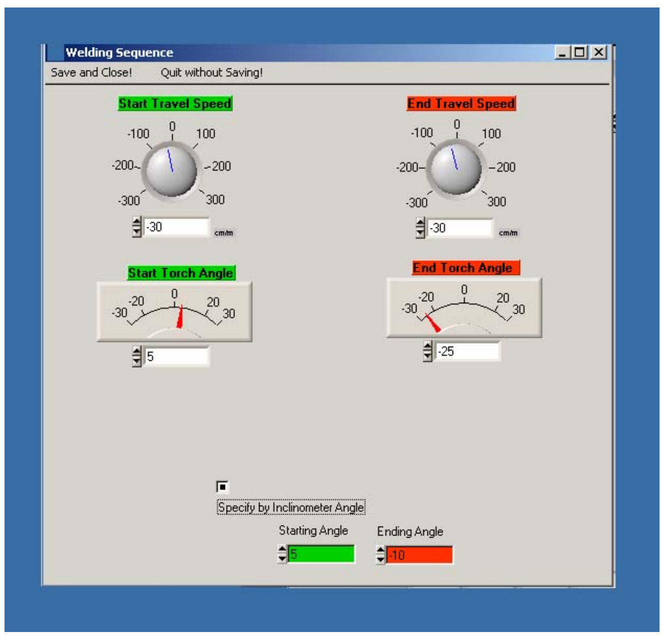

Figure 9. **Software User Interface for Programming a Welding Sequence by Specifying a Beginning and Ending STX Angle of Orientation about the Pipe**

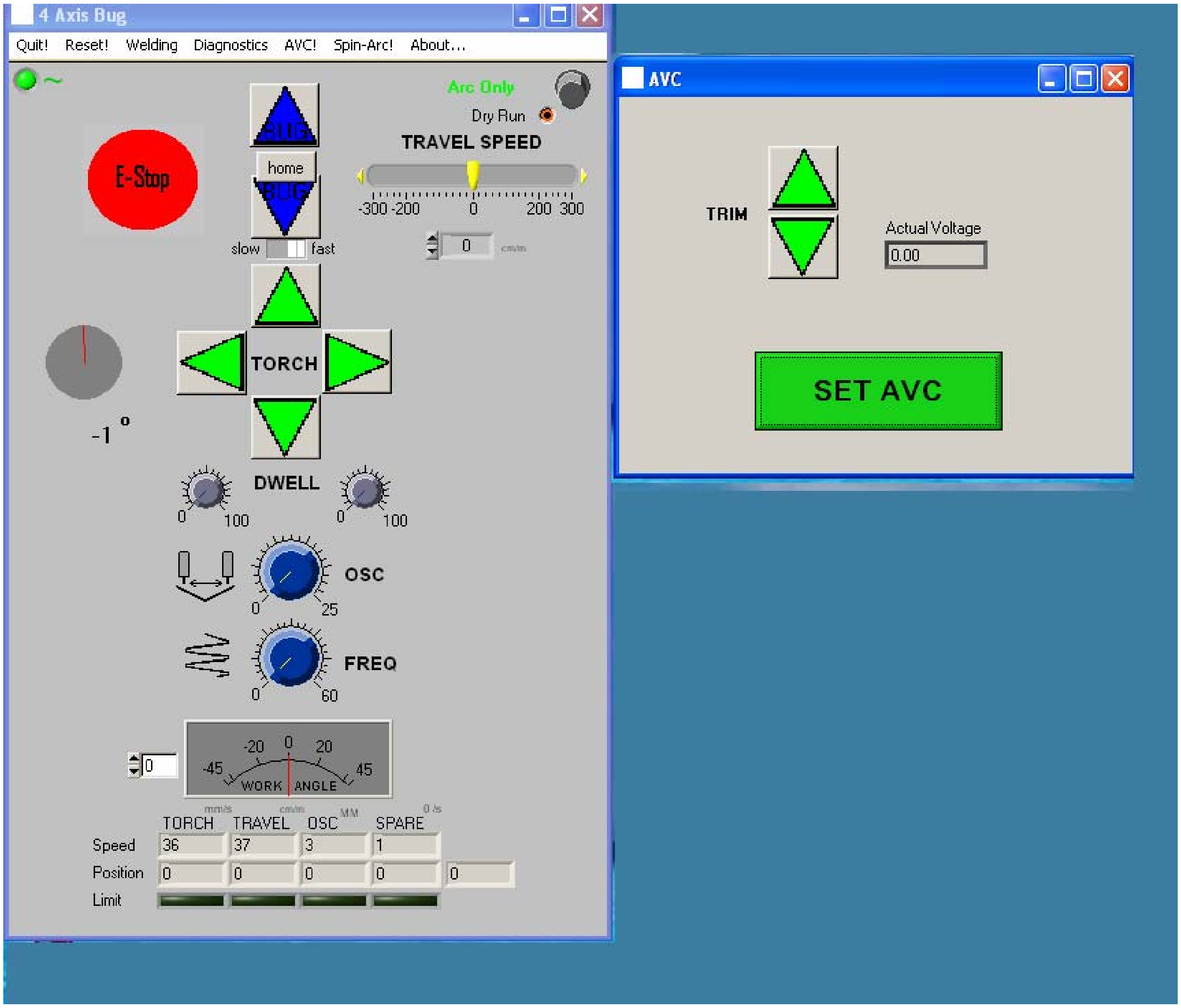

Figure10. STX Control Software with AVC Control Panel before Arc Initiation

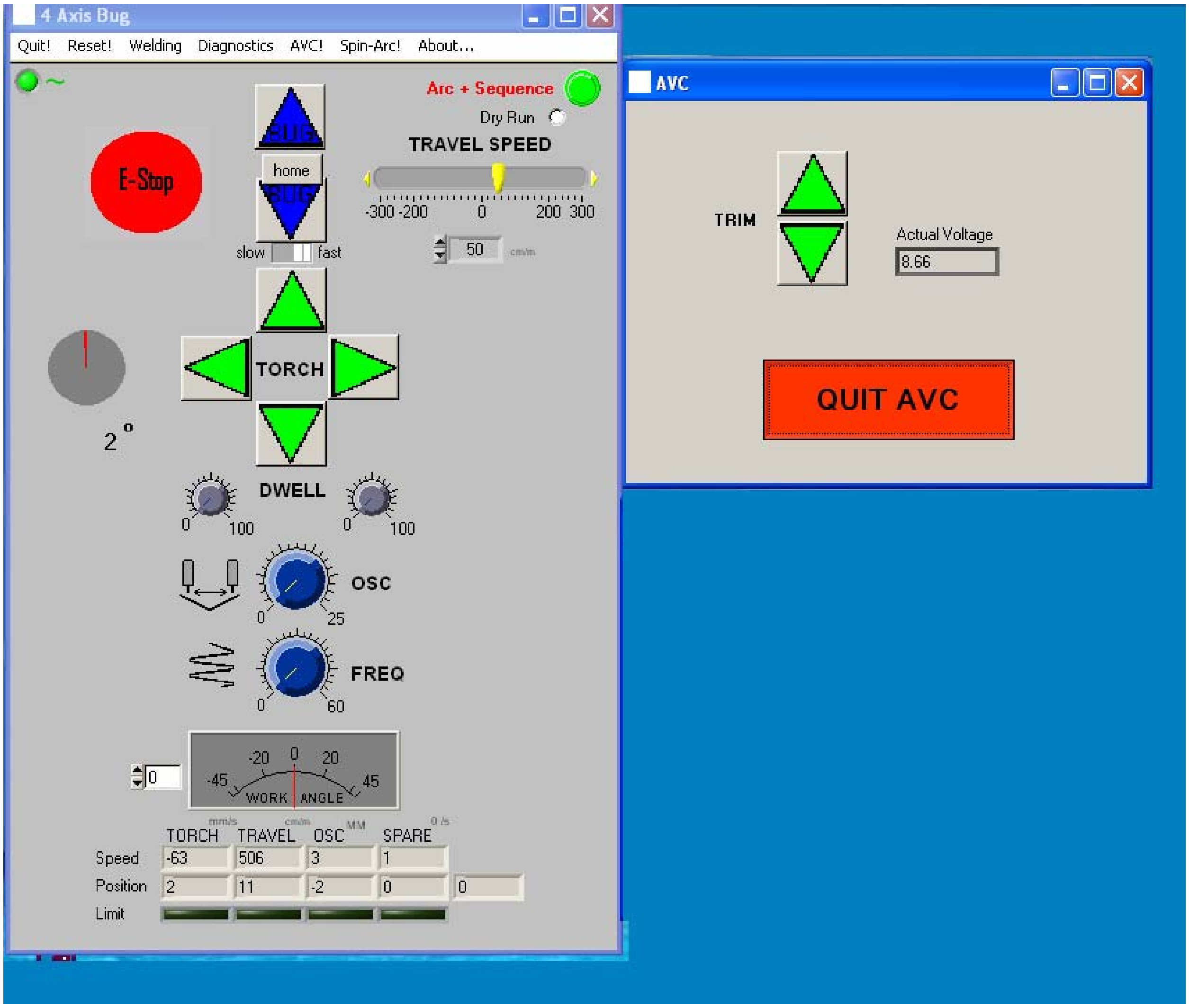

Figure 11. STX Control Software During Welding with AVC Engaged

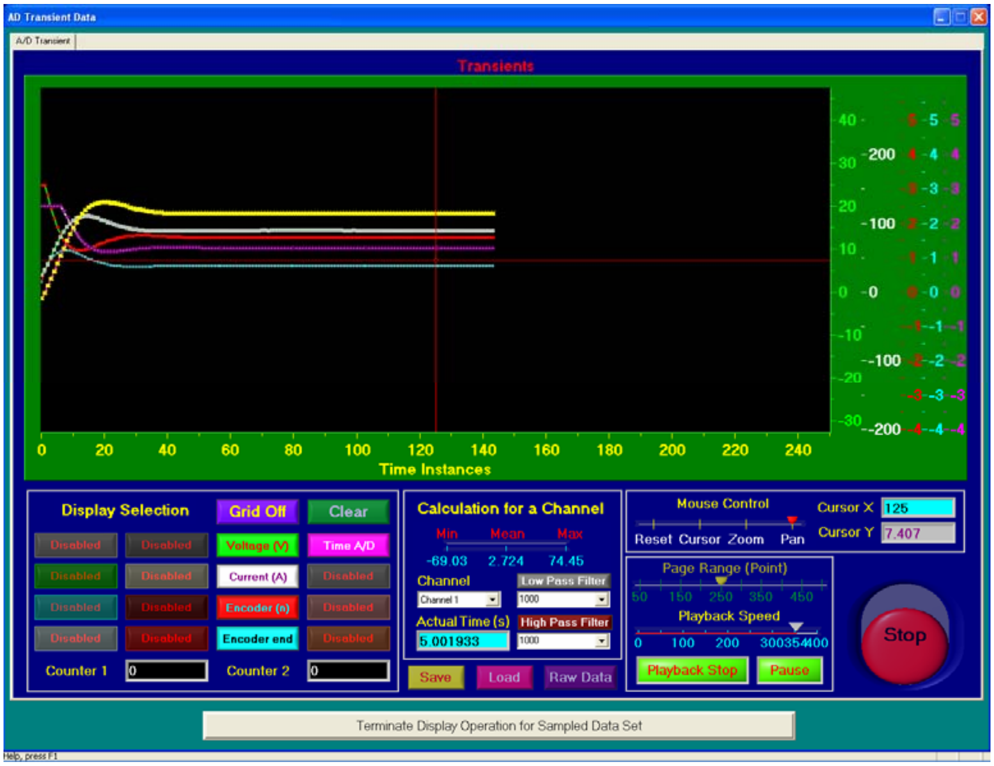

Figure 12. **Intellicontrol Software Interface Module During Data Acquisition of Welding Parameters and Spin Arc Control**

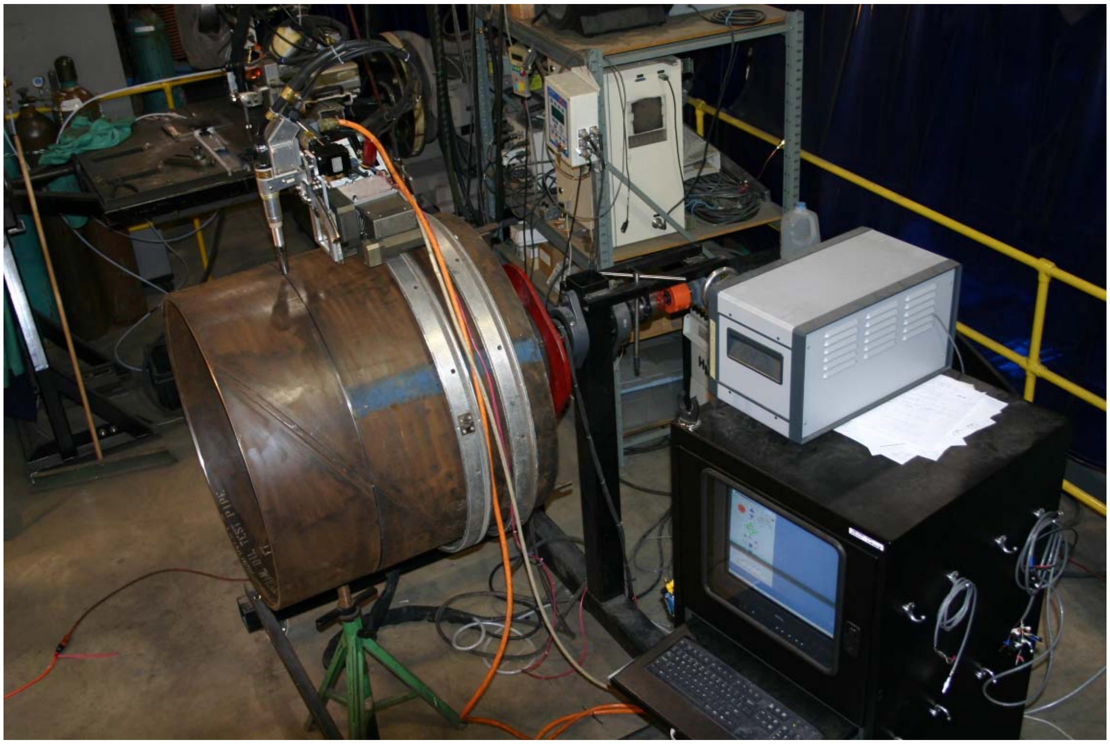

Figure 13. **GMAW-RE Torch Setup at 12:00 o'clock Position on 36-in.-Diameter X80 Pipe, Also Showing Industrial Controller**

Figure 14. Demo Dry Run Showing Twin Tractor Relative Position when Welding is in the Vertical-Down Position

Appendix A

Invitations to Task 6 Presentations and Demonstration

REPLY SLIP

Please complete and return

To:
Beth Jackson
EWI, Columbus, Ohio, USA
Fax: 614-688-5001
Tel: 614-688-5143
Email: elizabeth_jackson@ewi.org

From:
Name: ______________________________
Company: ______________________________
Fax ______________________________
Tel: ______________________________
Email: ______________________________

Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines EWI Project No. 47961GTH

EWI is concluding the US Dept. of Transportation (DoT) project 47961GTH "Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines". This $400K project included root pass development, property testing, automation, and process control elements.

As stakeholders in this project you are invited to participate in a meeting and demonstration for the DoT project to be held in April 2006 at EWI. The intent is to brief you on the project results through three presentations and to demonstrate the technology for mechanized external root pass welding of 36-in diameter X80 pipe using GMAW-RE.

Please indicate your availability in the April 4, 5 and 6 timeframe to attend this meeting and demonstration. EWI will advise you of the date selected based on majority vote.

APRIL 2006				
Mon	***Tue***	***Wed***	***Thu***	***Fri***
	4	**5**	**6**	

Comments: ______________________________

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REPLY SLIP

Please complete and return

To:
Beth Jackson
EWI, Columbus, Ohio, USA
Fax: 614-688-5001
Tel: 614-688-5143
Email: elizabeth_jackson@ewi.org

From:
Name: ____________________
Company: ____________________
Fax ____________________
Tel: ____________________
Email: ____________________

Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines EWI Project No. 47961GTH

EWI is near to completion of the US Dept. of Transportation (DoT) project 47961GTH "Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines". This $400K project was cost shared with project 46380CPQ to share information on parallel efforts. The know-how developed in both projects has been exchanged for mutual benefit. The work scope for the DOT project included root pass development, property testing, automation, and process control elements, which are complementary to the GSP work scope.

As sponsors or the Novel Arc Welding Processes GSP, you are invited to participate in a meeting and a demonstration for the DoT project to be held in April 2006 at EWI. The intent is to brief you on the DoT project results through three presentations and to demonstrate the technology for mechanized external root pass welding of 36-in diameter X80 pipe using GMAW-RE.

Please indicate your availability in the April 4, 5 and 6 timeframe to attend this meeting and demonstration. EWI will advise you of the date selected based on majority vote.

APRIL 2006				
Mon	***Tue***	***Wed***	***Thu***	***Fri***
	4	**5**	**6**	

Comments: ____________________

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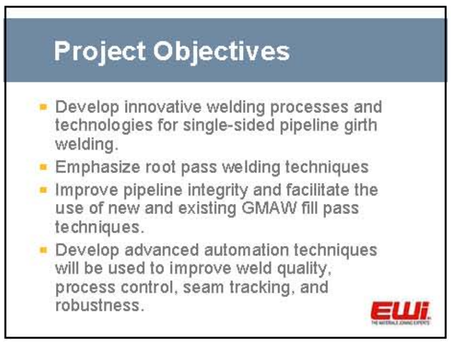
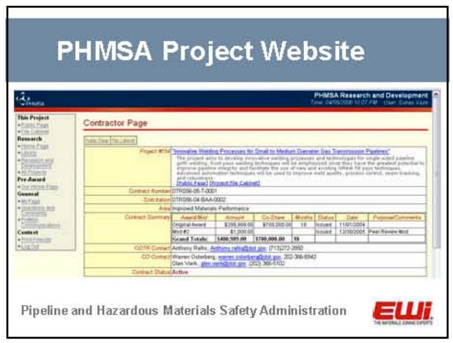
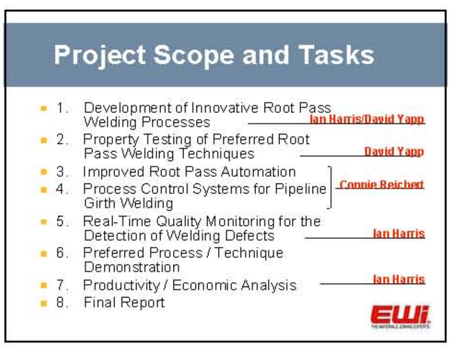
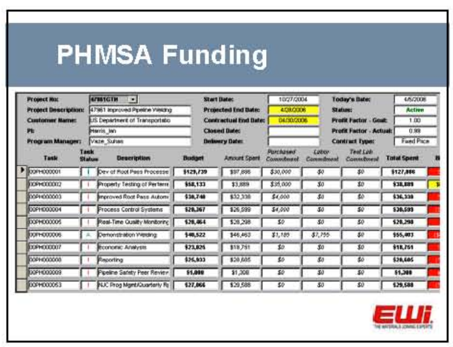
Appendix B

Presentations Made During Task 6 Demonstration









Project No:	47961GTH	Start Date:	10/27/2004	Today's Date:	4/5/2006
Project Description:	47961 Improved Pipeline Welding	Projected End Date:	4/28/2006	Status:	Active
Customer Name:	US Department of Transportatio	Contractual End Date:	04/30/2006	Profit Factor - Goal:	1.00
PI:	Harris_Ian	Closed Date:		Profit Factor - Actual:	0.99
Program Manager:	Vaze_Suhas	Delivery Date:		Contract Type:	Fixed Price

Task	Task Status	Description	Budget	Amount Spent	Purchased Commitment	Labor Commitment	Test Lab Commitment	Total Spent
00PH000001	I	Dev of Root Pass Processe	$129,739	$97,898	$30,000	$0	$0	$127,898
00PH000002	I	Property Testing of Perferre	$58,133	$3,889	$35,000	$0	$0	$38,889
00PH000003	I	Improved Root Pass Autom	$38,740	$32,338	$4,000	$0	$0	$36,338
00PH000004	I	Process Control Systems	$28,367	$26,599	$4,000	$0	$0	$30,599
00PH000005	I	Real-Time Quality Monitoring	$28,464	$28,298	$0	$0	$0	$28,298
00PH000006	A	Demonstration Welding	$48,522	$46,463	$1,185	$7,755	$0	$55,403
00PH000007	I	Economic Analysis	$23,825	$18,751	$0	$0	$0	$18,751
00PH000008	I	Reporting	$25,933	$28,605	$0	$0	$0	$28,605
00PH000009	I	Pipeline Safety Peer Review	$1,000	$1,308	$0	$0	$0	$1,308
00PH000053	I	NJC Prog Mgmt/Quarterly Rp	$27,066	$29,588	$0	$0	$0	$29,588

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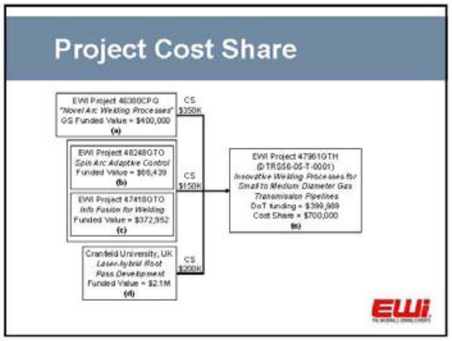
Project Cost Share
EWI Project 46300CPQ
"Novel Arc Welding Processes"
GS Funded Value = $400,000
(a)
CS
$350K
EWI Project 48248GTO
Spin Arc Adaptive Control
Funded Value = $86,439
(b)
EWI Project 47418GTO
Info Fusion for Welding
Funded Value = $372,952
(c)
CS
$150K
Cranfield University, UK
Laser-hybrid Root
Pass Development
Funded Value = $2.1M
(d)
CS
$200K
EWI Project 47961GTH
(DTRS56-05-T-0001)
Innovative Welding Processes for
Small to Medium Diameter Gas
Transmission Pipelines
DoT funding = $399,989
Cost Share = $700,000
(e)

2

THE MATERIALS JOINING EXPERTS

THE MATERIALS JOINING EXPERTS

Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines

Ian D. Harris, Principal Engineer
Arc Welding, Lasers, and Automation

614.688.5131
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Project Scope and Tasks

1. Development of Innovative Root Pass Welding Processes
2. Property Testing of Preferred Root Pass Welding Techniques
3. Improved Root Pass Automation
4. Process Control Systems for Pipeline Girth Welding
5. Real-Time Quality Monitoring for the Detection of Welding Defects
6. Preferred Process / Technique Demonstration
7. Productivity / Economic Analysis
8. Final Report

Objective

- Develop and demonstrate innovative arc root and fill pass welding processes that improve travel speed, quality, and robustness.
  - Single-sided
  - Without backing
  - Without gap
  - With real-time quality monitoring

Industry Benefit / Applications

- **Single-side processing**
  - **Large diameter tie-ins**
  - **Medium diameter pipelines**
- **Better property control**
- **Deployment of high strength steels**
- **Cross Country Gas Transmission**
  - Medium to Large Diameter (12-56 in.)
  - Thickness (6-25 mm)
  - High Strength (X80-X100)

Task 1 - Innovative Root Pass Welding – EWI Scope

- VP-GMAW
- RE-GMAW
  - Pipe sections for weld development
  - Macrosections
  - Best process recommended for further Tasks

1

Initial RE-GMAW Set-up

- Narrow contact tip for narrow groove
- Variable downhill TS procedure
- Spin Arc robotic seam tracking system



Robotic RE-GMAW, C-Steel


VP-GMAW Pipe Welds, C-Steel

Flat - TS = 1.3 m/min on a **closed root – 1 mm root face** (0- to 20-degree position) 2.9-mm throat

90Ar-10CO$_2$, WFS 440-in./min 226 A, 40% DCEN, 24.6 V

V-Down - TS = 1.35 m/min on a **closed root – 1 mm root face** (50- to 90-degree position) 2.9-mm throat

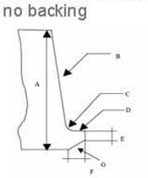
90Ar-10CO$_2$, WFS 410-in./min 220 A, 30% DCEN, 25.5 V

EWI Task 1 - Innovative Root Pass Welding

- Pipe X80 36-in. diameter
- Robotic welding for RE-GMAW (using Panasonic Spin-Arc)
- Welding procedures established for 12 o'clock through 3/9 o'clock positions
- VP-GMAW Kobelco 350 – Work conducted on 1-mm root face – process eliminated from study based on 1.6 mm ±0.2 mm minimum root face requirement - decision of March 2005

Joint Preparation

- Serimer Dasa design w/Cu backing
- Root face reduced to 1.6 mm (closed root, no backing



A = 19.1mm (0.75")
B = 3°30 ±1°
C = 2.4 ± 0.2mm / 0.094" ± 0.007"
D = 0 ± 0.2 / 0" ± 0.007"
E = 2.1 ± 0.2mm / 0.08" ± 0.007"
F = 5 ± 2.5mm / 0.2" ± 0.1"
G = 4°

Innovative Root Pass Welding

- 168 welds made for RE-GMAW procedure development
- "Plate" (cut from X80 pipe) butt welds and pipe girth welds segments
- Welding procedures developed in
  - 12 o'clock
  - 3/9 o'clock
  - 6 o'clock (system weight exceeded ability of tractor to stay on pipe band/ring)

2

36-in. Diameter X80 Pipe Set Up for Robotic RE-GMAW

Tractor/Bug RE-GMAW Set-up

X80 Welding Procedures ER70S-6

Weld SA-115
Flat Position
TS = 0.7 m/min,

Throat 4.5 mm

"Weld" SA-109
Vertical Down

TS = 1.45 m/min

X80 Welding Procedures ER80S-D2

Vertical down – Weld SA-129

Travel speed 0.8 m/min

Throat thickness 4.2 mm

WFS 448 in/min, 209 A, 22.0 V, WFS/TS = 14.2

X80 Welding Procedures ER90S-G

Weld SA-155 Flat Position
No Cracking
Throat = 5.6 mm

TS = **0.7** m/min.

Weld SA-137 Vertical Down Position
No cracking

Throat = 4.1 mm
TS = **1.2** m/min.

X80 Welding Procedures ER90S-G

- Weld SA-164
- Vertical Down Position
- **No** cracking
- Throat = 5.0 mm
- TS = 0.7 m/min.

3

Present Mechanized Set-Up

Task 5 – RT Quality Monitoring

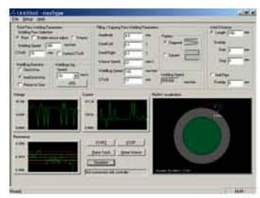
- Intellicontrol Software Interface Module during Data Acquisition of Welding Parameters and Spin Arc Control

RTQM

- DAQ for Dip Transfer Root Pass in Pipe (CRC-WS)

RTQM

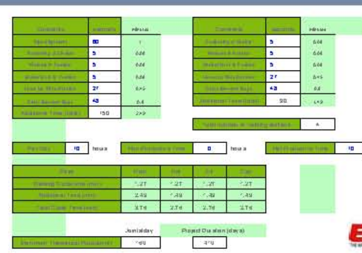
- Graphical User Interface for Resistance Based CTWD Control and RTQM System for Pipe Girth Welding (CRC-WS)
- EWI has developed a welding current based CTWD control for compensation for pipe ovality



Task 7 – Productivity and Economic Analysis

- Welding speed of 0.7 to 1.2 m/min for a single torch RE-GMAW equates to 1.4-2.4 m/min for a double down welding approach
- This compares favorably to 1.5 m/min for a 6-mm root face with an 8-kW laser
- A travel speed of 4.0 m/min is possible with 1-mm root face, 5-kW laser and 7.5-kW arc in hybrid laser/GMAW with one torch for orbital welding
- The system cost for a 8-kW fiber laser is about $1M, for a 4-kW fiber laser about $500K, whereas the cost for a two-torch GMAW-RE system is less than $100K

PRCI Productivity and Economic Estimation Tool For Mechanized GMAW Welding of Pipelines



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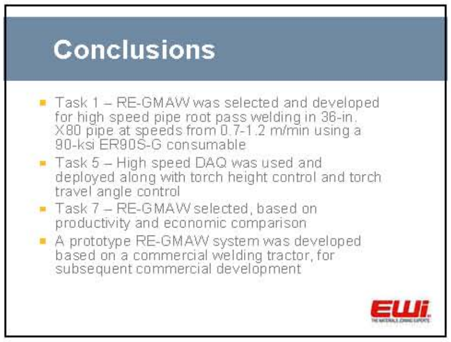
Conclusions
Task 1 – RE-GMAW was selected and developed for high speed pipe root pass welding in 36-in. X80 pipe at speeds from 0.7-1.2 m/min using a 90-ksi ER90S-G consumable
Task 5 – High speed DAQ was used and deployed along with torch height control and torch travel angle control
Task 7 – RE-GMAW selected, based on productivity and economic comparison
A prototype RE-GMAW system was developed based on a commercial welding tractor, for subsequent commercial development


Questions?


THE MATERIALS JOINING EXPERTS

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THE MATERIALS JOINING EXPERTS

Task 3-Improved Root Pass Techniques and Task 4-Process Control Systems for Pipeline Girth Welding

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Task 3: Background

- Advanced mechanization can accommodate gap and mismatch around the entire pipe circumference.
- Since pipelines are welded in a fixed position, the welding process must be tolerant to the effects of gravity and deposit metal in all positions.
- Typical mechanized welding bugs have travel speed, lateral oscillation, and torch height controls, which work well for linear applications.
- For pipeline welding in all positions, torch angle must be taken into account in order to compensate for the effects of gravity on the molten pool.

Task 3: Objective

- Incorporating hardware onto an existing 3-axis bug and creating mechanized torch travel angle control as a fourth axis.

Benefit

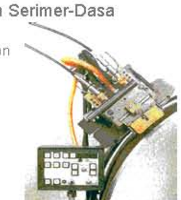
- Mechanized torch travel will improve weld pool control for-out-of position welding

Task 3: Approach

- Develop automated torch travel angle control hardware and integrate it with the mechanized bug system.
- Develop communication software to control a mechanized welding bug through RS232 communication.
- Develop a usable interface for an operator to control the bug from a laptop computer.
- Develop automated torch tilt software and integrate it with the mechanized bug system.

Off-the-Shelf Mechanized Bug

- Saturnax (STX) from Serimer-Dasa
  - Travel Speed
  - Transverse Oscillation
  - Torch Height
  - Torch Travel Angle



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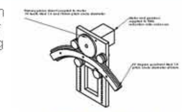
STX Controller Box with RS232

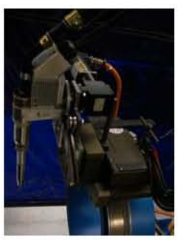
- STX Controller
  - Built by Serimer specifically for EWI
  - Provides RS-232 communication protocol for computer control of all axis
  - Contains an auxiliary motor amplifier
  - Additional digital I/O signals
  - EWI controlled the STX by serial port on laptop

Task 3: Hardware Development Torch Travel Angle

- Rack and Pinion System
  - Allows smooth change of travel angle while welding
  - Able to transition the weight of the Spin-Arc torch
- Radius Arc for Motion
  - Calculated radius and arc based on Super-Small Spin-Arc torch size
  - Maintains proper tool center point (TCP) while moving torch around pipe

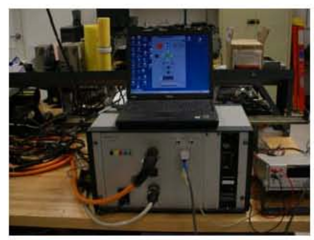


Spin-Arc Torch Mounted onto STX Bug with Torch Fixture



- Panasonic Spin-Arc GMAW-RE torch
  - "Super Small" model
  - 14 lbs additional weight
  - Servo motor inside the torch provides spin speed
- Panasonic Minas™ Amplifier
  - 220 VAC 3 phase
  - Contained encoder signals for spin-arc

Laptop Computer System for STX Motion Control of 4 Axes



Task 3: Hardware Incorporate Data Acquisition

- Cost match project included development of a data acquisition system for RTQM including Spin-Arc torch signal analysis
- An industrial computer system was assembled including welding sensors
- A software program was developed for RTQM of data from the welding sensors
- Spin Arc encoder signals were able to be collected and analyzed with the system

Industrial Computer System with Data Acquisition

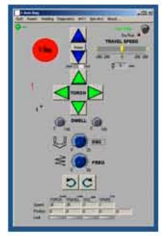
- PXI-based computer
- Data acquisition
  - Current
  - Voltage
  - WFS
  - Travel Speed
  - Gas Flow
  - Spin-Arc Encoders
- Intellicontrol Software
  - Real time data acquisition
  - Data analysis
  - Understand Spin-Arc signals

2

Task 3: Software
STX Control Software Tasks

- Communicate with the STX bug
- Coordinate motion of travel axis with bug position and welding sequence
- Allow operator to program a welding travel sequence and torch travel angle trajectory
- Control the Panasonic welding power supply
- Control the Spin-Arc torch spin speed
- Provide constant torch height control (AVC) while welding
- Coordinate arc initiation, spin-arc speed, travel sequence and AVC control

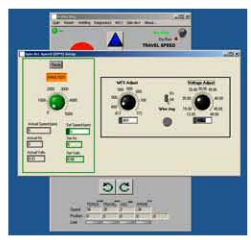
Task 3: Software
STX Control Software Interface



- Pendant – based GUI
- User can:
  - Preprogram weld path trajectory
  - Use AVC for constant torch height control
  - Adjust Spin-Arc speed
  - Change Power Supply parameters of WFS and Voltage

Task 3: Software
Pre-program Welding Path

Task 3: Software
Spin-Arc and Power Supply



Task 3: Conclusions

- For pipeline welding in all positions, torch angle must be taken into account in order to compensate for the effects of gravity on the molten pool.

- Development of improved root pass automation (Task 3) of this project achieved the objective of incorporating hardware onto an existing mechanized bug and creating mechanized torch travel angle control as a fourth axis.

Task 4: Objectives

- The primary deliverable for Task 4 was identified as AVC or constant torch height control to compensate for pipe ovality and mismatch during girth welding

- In order to complete the AVC control, the hardware and software developments of Task 3 needed to communicate through one common hardware and software platform.

3

Task 4: Hardware Industrial Control System

- **Integration of Individual Software Programs**
  - STX Control Software
  - Data Acquisition Software
  - Spin Arc Control and Frequency
  - Power Supply Contactor
  - Power Supply Pendant
- **AVC Functionality**
  - Software Algorithm for constant torch height control

Task 4: Industrial Control System

Task 4: AVC Functionality

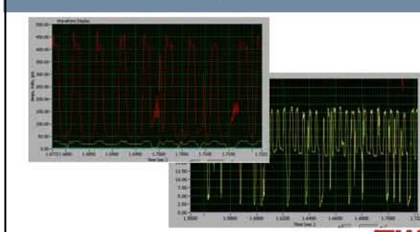
- Automatic torch height adjustment to maintain proper contact tip to work distance
- Sensor monitors average welding current
- Compares to a desired current level for a 5/8-inch contact tip to work distance
- Maintains desired current setting by adjusting torch height during welding by issuing commands to the mechanized bug

Task 4: Software AVC - Constant Torch Height

Seam Tracking Study

- Seam Tracking with Spin-Arc Torch
  - Seam tracking can normally be accomplished using the encoder signals from the spin arc torch
  - Encoder signals representing spin position can be correlated to the welding current to determine position of the wire in relation to the right or left sidewall in the joint
  - The Dip-Pulse power supply was studied with high speed video and welding current signals to assess the potential for seam tracking
  - Results from the study indicated that seam tracking with the current/voltage signal from the Dip-Pulse power supply would be difficult due to inability to discern proximity to sidewall within the signals
- Seam Tracking Capabilities on STX Bug
  - Only available for weaving
  - Based on programmed weave setting

Seam Tracking Signal Analysis



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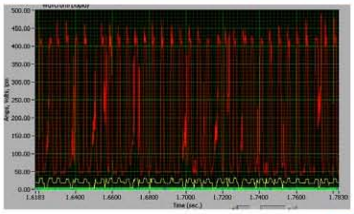
Seam Tracking Signal Analysis



Task 4: Conclusions

- This task involved the development of an industrial process control system which integrated the hardware and software systems developed in Task 3.
- The synchronization of these items made it possible to develop the AVC functionality, which achieved the objective for the development of process control systems (Task 4) within this project.

EWI THE MATERIALS JOINING EXPERTS

Questions?

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Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines

David Yapp, Cranfield University

EWI Project 47961GTH
DOT Transaction Agreement DTRS56-05-T-0001

Final Project Meeting

EWI, Columbus, Ohio

April 6th, 2006

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The drivers for cross-country pipelines

- Rapid growth worldwide of natural gas: use expected to double in next 20 years
- Predicted investment in new pipelines of $20 billion every year for next 20 years
- Sustained investment in new and replacement pipelines in North America – Trans Alaska Gas Pipeline alone will cost $18 billion

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Pipeline CAPEX Cost Reduction

- Increased use of high strength steels: X80 and X100
- Increased pipe lay rate: controlled by root run rate
- Reduced equipment and labor costs: controlled by fill pass productivity

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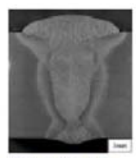
High Strength Low Alloy Pipeline Steels



Dual Tandem Gas Metal Arc in X100 Pipe, internal root

- Increased strength = thinner wall
  - Trans Alaska Gas Pipeline saves 0.5 million tons of steel for X100 compared to X80
  - Reduced welding and transport costs
- Complex thermo-mechanical processing to achieve weldable high strength steel
- Much more sensitive to welding thermal cycle than lower strength grades

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Fill Pass Productivity

- CAPS (Cranfield Automated Pipe-welding System) developed for application of tandem and dual tandem welding
- CAPS system reduces number of welding stations by factor of four – large reductions in labor and equipment costs)
- Tandem welding now established, and adopted by contractors

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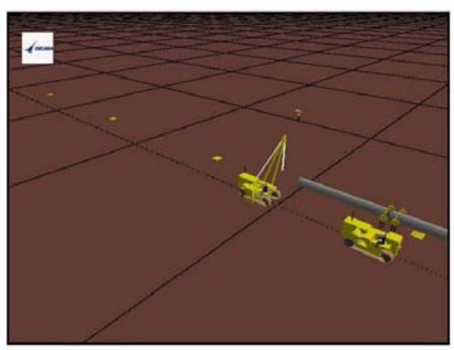

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Pipeline Root Welding

- High speed root welding controls pipe lay rate
- New root welding processes have potential for widespread application for mechanized welding of pipe roots in small and medium diameter pipelines
  - Internal welding not possible for small diameters
  - copper backing rings can cause problems

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Cranfield Tasks 1 and 2

- Task 1: evaluate hybrid laser-arc welding for pipe root welds
- Task 2: Evaluate properties for Laser root / Tandem GMA fill

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Fiber Lasers

- Major advance in solid state laser processing
- Fiber lasers offer:
  - High power
  - High beam quality
  - Delivery via fiber
  - Robustness
  - Predicted long life
  - Low running costs
  - High wallplug efficiency (20 to 30%)
  - Small Footprint

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Laser Installation at Cranfield

- IPG YLR-8000 Ytterbium Fiber laser, 8kW, 300µm fiber
- Precitec lens
- Fanuc Robot
- Lincoln 455M Pulsed welding power supply

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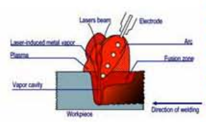
Main Hybrid Laser/ arc process variables



- Laser Power
- Laser Focus Point
- Shielding gas
- Arc Power /Wire feed speed
- Laser to arc distance
- GMAW torch to laser angle
- CTWD
- Weld preparation
- Travel speed
- Welding position

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Development strategy

1. **High speed root runs: target 160 inches / minute (4 m/min), hybrid laser-GMAW**
2. **Laser weld at high root face thickness / tandem fill: deeper laser weld, capable of affecting properties, especially for X100**

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Laser Weld Speed vs Penetration

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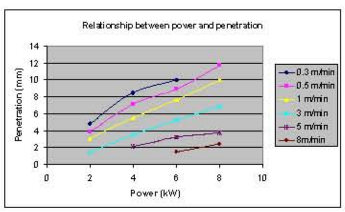
Laser power vs penetration



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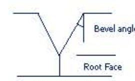
High speed root runs: variables matrix

- **Laser power:** **4 to 6.75 kW**
- **Focus Point:** **Plate surface +0 /-2 mm**
- **Arc power:** **5 to 7.5 kW**
  - Wire feed speed 10 to 15 m/min
- **CTWD:** **12 to 17 mm**
- **Bevel angle:** **12°, 18°, 45°**
- **Root face:** **0, 1, 2 mm**
- **Laser/arc distance:** **2 to 5 mm**
- **Laser / torch angle: 19°**
- **Wire diameter** **1 mm**
- **Plate thickness** **6 mm**
- **Shielding gas:** **Trimix** (82.5%Ar, 12.5%CO2, 5%He)



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Effect of travel speed

Travel speed 2.5 m/min

Travel speed 4 m/min

Laser power:	6.25 kW
Wire feed speed:	10 m/min
Bevel angle:	12°
Root face:	1 mm
CTWD:	14 mm
Laser / arc distance:	2 mm

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Effect of wire feed speed

Wire feed speed 10 m/min

Wire feed speed 12.7 m/min

Laser power:	6.25 kW
Travel speed:	4 m/min
Bevel angle:	12°
Root face:	1 mm
CTWD:	14 mm
Laser / arc distance:	2 mm

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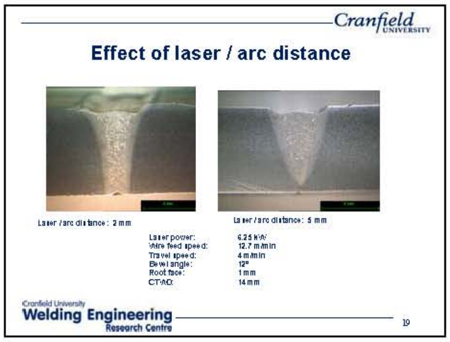
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Effect of laser / arc distance
Laser / arc distance: 2 mm
Laser / arc distance: 5 mm
Laser power: 6.25 kW
Wire feed speed: 12.7 m/min
Travel speed: 4 m/min
Bevel angle: 12°
Root face: 1 mm
CTWD: 14 mm
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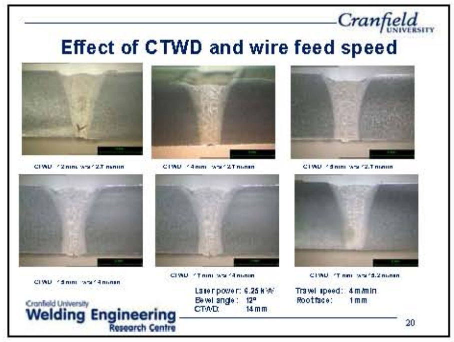
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Effect of CTWD and wire feed speed
Laser power: 6.25 kW
Bevel angle: 12°
CTWD: 14 mm
Travel speed: 4 m/min
Root face: 1 mm
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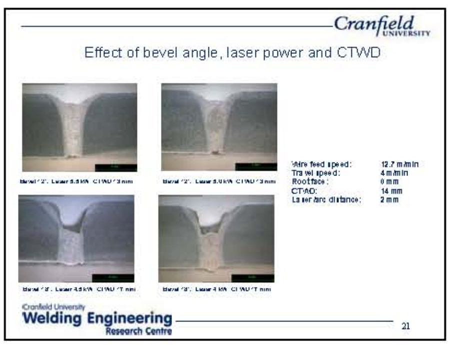
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Effect of bevel angle, laser power and CTWD
Wire feed speed: 12.7 m/min
Travel speed: 4 m/min
Root face: 0 mm
CTWD: 14 mm
Laser /arc distance: 2 mm
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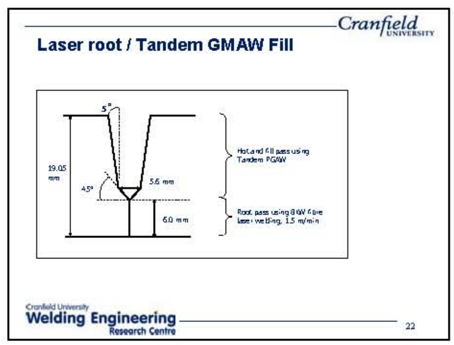
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Laser root / Tandem GMAW Fill
5°
19.05 mm
45°
5.6 mm
6.0 mm
Hot and fill pass using Tandem PGAW
Root pass using 8 kW fibre laser welding, 1.5 m/min
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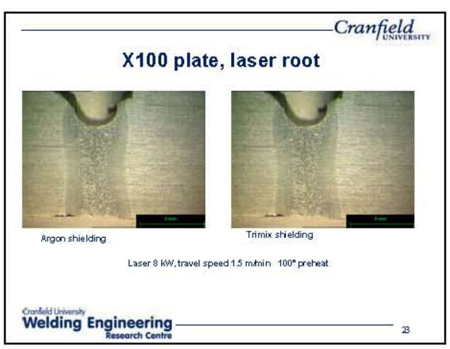
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X100 plate, laser root
Argon shielding
Trimix shielding
Laser 8 kW, travel speed 1.5 m/min 100° preheat
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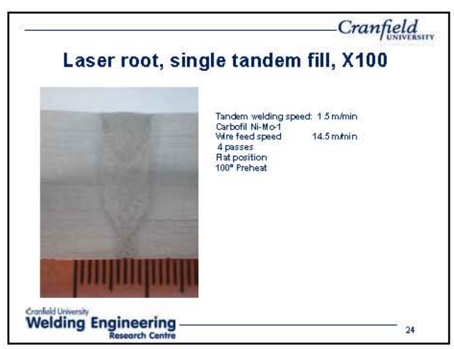
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Laser root, single tandem fill, X100
Tandem welding speed: 1.5 m/min
Carbofil Ni-Mo-1
Wire feed speed 14.5 m/min
4 passes
Flat position
100° Preheat
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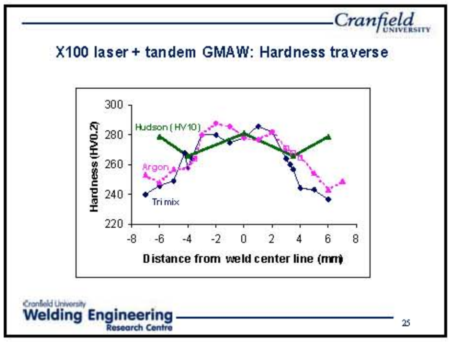

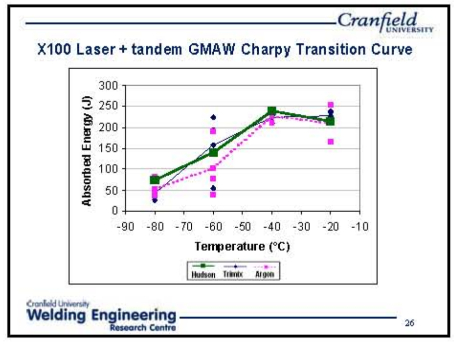

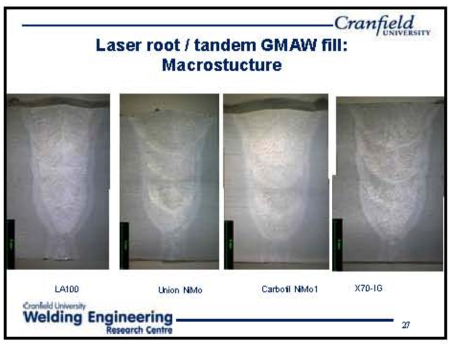

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Laser root / tandem GMAW fill: mechanical properties

Weld code	Consumable	UTS N/mm²	Tensile failure location	Side Bend test	Fracture test	Charpy Weld root -18°C J	Charpy Fusion line root -18°C J	CTOD -18°C mm
L1	Lincoln superarc LA100	786	Parent	Acc.	Acc.	207	257	0.36
L2	Bohler Thyssen Union NiMo	779	Parent	Acc.	Acc.	219	231	0.19
L3	Oerlikon Carbofil NiMo1	786	Parent	Acc.	Acc.	238	245	0.11
L4	Bohler X70-IG	783	Parent	Acc.	Acc.	181	240	0.10

Tests to API 1104. Bend test 180°, former 45 mm radius

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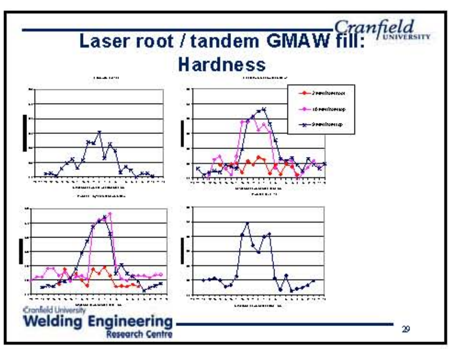

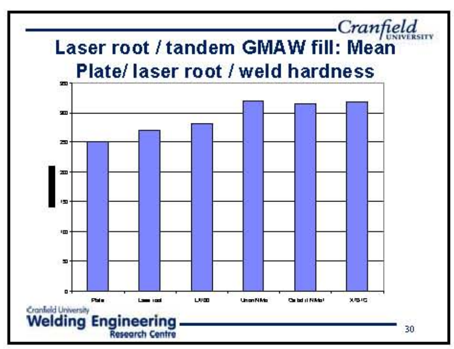

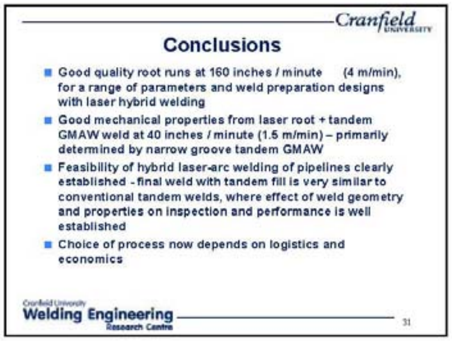
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Conclusions
Good quality root runs at 160 inches / minute (4 m/min), for a range of parameters and weld preparation designs with laser hybrid welding
Good mechanical properties from laser root + tandem GMAW weld at 40 inches / minute (1.5 m/min) – primarily determined by narrow groove tandem GMAW
Feasibility of hybrid laser-arc welding of pipelines clearly established - final weld with tandem fill is very similar to conventional tandem welds, where effect of weld geometry and properties on inspection and performance is well established
Choice of process now depends on logistics and economics
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Forming Projects in Pipeline Welding and Inspection
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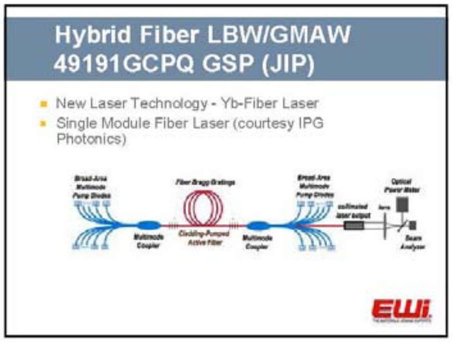
Hybrid Fiber LBW/GMAW 49191GCPQ GSP (JIP)
New Laser Technology - Yb-Fiber Laser
Single Module Fiber Laser (courtesy IPG Photonics)
Broad-Area Multimode Pump Diodes
Fiber Bragg Gratings
Multimode Coupler
Cladding-Pumped Active Fiber
Multimode Coupler
Broad-Area Multimode Pump Diodes
collimated laser output
Optical Power Meter
Beam Analyzer
EWi


New Laser Technology - Yb-Fiber Lasers
4 kW Yb Fiber Laser
4 kW Nd:YAG Laser
EWi


Field Deployed 4-kW Yb-Fiber Laser
EWi


Concrete Cutting with Field Deployed 4-kW Yb-Fiber Laser
EWi

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Objectives

- Determine the necessary steps required to create a production hybrid girth welding system.
- Determine basic productivity limits relative to specific fiber laser powers. Demonstrate quality improvements of the production hybrid system when compared to conventional GMAW systems.
- Develop and qualify weld procedures using the system with accepted deepwater riser, flow line, and tendon requirements (including metallurgical evaluation and full-scale fatigue testing) for a minimum of one pipe size.

Approach

- Task 1
  - Determine candidate pipe, pipe sizes, and welding orientation
  - Specify welding environment (barge versus cross country)
  - Determine hardware needs for fiber laser-based hybrid system
    - At the joint
    - Parallel to pipeline
  - Using industry standard equipment, modify into prototype system
  - Develop operating procedures for welding with fiber-based hybrid system
  - Address hardware/procedure issues such as set-up, alignment, and seam tracking
- Task 1 Deliverables
  - Preliminary design
  - Prototype system
  - Task report

Approach

- Task 2
  - Determine candidate materials
  - Determine hybrid welding limitations using Yb-fiber lasers
    - Power
    - Speed
    - Minor versus major root pass (or single pass)
    - Weld joint geometry
  - Relate production rate to laser size and joint geometry
- Task 2 Deliverables
  - Table with recommended laser for specific processing rates
  - Task report

Approach

- Task 3
  - Using results from Tasks 1 and 2 accomplish the following:
    - Fabricate complete welds (hybrid plus GMAW as needed) using various approaches
      - "Fast" versus "Thick" root
      - Many low power versus one big laser
    - Inspect welds using standard methods to determine any
    - Test welds to standards (tensile, bend, CVN)
    - Compare with standard GMAW approach to pipe welding
  - Task 3 Deliverables
    - Task report

Approach

- Task 4
  - Using the results from Task 1 through 3, develop "parking lot" demonstration of field pipe welding with prototype system
    - Candidate pipe and orientation
    - Use prototype manipulation
    - Laser in "portable state"
      - Local power and cooling
  - Task 4 Deliverables
    - Demonstration
    - Task report

Benefits

- **Program would validate the capabilities of the Yb-fiber lasers to be used in field welding of pipe.**
- **Proposed program would provide process rates, equipment costs, operating costs, and other information needed to determine the economics of laser-welded pipe.**
- **Produce preliminary designs and prototype hardware that would be needed for field welding of pipe.**
- **Demonstrated portability of the hybrid welding of pipe with prototype system.**

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Cost and Duration

- Duration: 1 year
- Total cost of $200,000
- 8 Sponsors sought, each contributing $25,000
- Project will commence once 6 Sponsors have joined
  - If additional Sponsors do not join, the work scope will be reduced in discussion with Sponsor Group

DOT PHMSA-OPS Welding Workshop Results

January 25, 2006
NIST
Boulder, CO

Construction

- Top Goals Identified
  - Laser Hybrid Welding
  - Advanced GMAW Automation Technology
  - Fabrication Standards for High Strength (≥X80) Steel Pipelines
  - Improved End Preparation Technology

Weld Inspection

- Top Goals Identified
  - Global AUT Study – POD/Sizing Accuracy Data Generation
  - Investigate / Develop / Quantify Digital Image Capture Radiography
  - Applicability of AUT Matrix Phased Array Probes and 3-D Imaging

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- Hybrid Laser/GMAW GSP First Sponsor Meeting to be held in mid May – date TBA
- DOT BAA expected to be issued in mid-late April
- Coordination and leveraging of programs to maximize benefit to GSP sponsors, and DOT/stakeholders

Questions?

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Appendix C

List of Attendees and Presenters

List of Attendees

Joe Kiefer	Conoco Phillips
Jeff Schroeder	Miller/Hobart
David Dorling	TCPL (via MS Meeting)
Harvey Haines	PRCI (via MS Meeting)
Doug Hoyt	Exxon Mobil (via MS Meeting)
Anthony Rallis	DOT (Project COTR) (via MS Meeting)

List of Presenters

David Yapp	Cranfield University
Ian Harris	EWI
Connie Reichert	EWI
Jim Russell	EWI (Demonstration)
Suhas Vaze	EWI