REPORT

April 28, 2006
EWI Project No. 47961GTH
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Innovative Welding Processes for Small to Medium Diameter Gas Transmission Pipelines

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

Submitted to:

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

EWI

MATERIALS JOINING TECHNOLOGY

Tasks 3 and 4 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

Improved Root Pass Techniques
(Task 3 Report)

Process Control Systems for Pipeline Girth Welding
(Task 4 Report)

to

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

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Executive Summary

The purpose of this portion of the project was to develop improved root pass automation (Task 3) and process control systems (Task 4) for girth welding of pipeline butt joints. To achieve these goals a motion control module was developed for control of a track-mounted Serimer-Dasa welding tractor (bug). The module includes a software program that can communicate with a motion controller and control all motions of the axes. Most welding bugs can only oscillate and move the welding torch up and down while the welder/operator must manually set his torch push/drag angle before welding and between separate welding passes. An axis was added to a welding bug to automate torch travel (push/drag) angle. Adding this axis helped automate the torch angle and provided more mechanized welding with less operator intervention, which leads to better adaptive control. This is especially useful in pipeline welding of girth welds in the 5G (fixed pipe) position as the welding bug must rotate around all orientations of the pipe. The motion control module includes additional hardware added to the standard welding bug, the control of the Spin Arc torch speed, and an overall software user interface for the operator to use to command the automated welding bug.

A control system for automatically maintaining contact-tip-to-work distance was also developed and integrated into the main control software program developed during this task. This compensates for pipe ovality by maintaining a constant arc voltage when welding. This in turn helps maintain the required heat input and weld bead penetration profile as welding takes place around the fixed pipe.

Acknowledgements

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Legal Notice

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 (RE) GMAW process embodied in the Spin Arc process from Panasonic. Work in Tasks 3 and 4 employed the Spin Arc torch used in Task 1.

2.0 Objectives

The objectives of Task 3, “Improved Root Pass Techniques” and Task 4, “Process Control Systems for Pipeline Girth Welding” were as follows:

- Develop communication software to control a mechanized welding bug through RS232 communication.
- Develop a user-friendly interface for an operator to control the bug from a laptop computer.
- Develop automated torch travel angle control hardware and integrate it with the mechanized bug system.
- Develop automated torch tilt software and integrate it with the mechanized bug system.
- Integrate Spin Arc torch hardware onto the mechanized bug system.
- Develop a control system for the Spin Arc torch and integrate it with the automated torch travel angle control.
- Provide real-time quality monitoring (RTQM) and gather data for future analysis with data acquisition from cost-match project.
- Develop an automatic voltage control system using the RTQM data acquisition system for measuring arc voltage and maintaining a user specified CTWD during welding.

3.0 Improved Root Pass Automation

3.1 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 (MIG) welding applications.

3.1.1 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. 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 1). 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.

3.1.2 STX Controller Box with RS232

The STX bug was delivered with a control box that could be communicated with using ASCII commands and a serial port running RS232 protocol (Figure 2). This is not a standard STX control method. The control box was built by Serimer-Dasa specifically for this project so that EWI could have total control of the axes on the bug. Along with the four axes used by the STX bug itself, the control box also provided three additional servo amplifiers for potentially controlling two wire speed feeders and an auxiliary motor. The auxiliary motor is the one used for torch tilt control that was added onto the STX bug. One of the three additional servo amplifiers was wired up to connect to the auxiliary torch tilt motor. At this point, the STX controller box was able to talk to and control the torch tilt motor. EWI developed a software program to control all five axes now integrated on the STX bug system. The software runs on a laptop computer connected to the control box by serial port. The software will be described in a following section.

3.1.3. 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 3) 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 4 and 5 show the STX bug with the attached torch tilt hardware and torch.

3.1.4 Spin Arc Torch Control System with Motor Amplifier

The motor amplifier required for the Panasonic Spin Arc torch was a Pansonic MINAS controller running on 220 VAC 3-phase power. To convert the 120 VAC power used in the U.S., a phase converter and amplifier were required. The amplifier was used first to convert the 120 VAC to 220 VAC single phase. Next, a single- to three-phase 220 VAC converter was used to make the input power acceptable for the MINAS servo amplifier.

After the servo amplifier was wired correctly and able to accept power, the connections sending signals from the computer to the servo amplifier I/O were wired; in particular, the three channels for the encoder on the motor inside the Panasonic Super Small Spin Arc torch. These three signals contained the information needed to create a seam-tracking feedback loop. General I/O was also wired up for the on/off control of the Spin Arc motion, speed control of the Spin Arc frequency and synchronization with the bug motion during welding.

3.1.5 Laptop Computer System for STX Control

The STX bug system was controlled by RS-232 ASCII commands through a serial port on the 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. Figure 6 shows the system being controlled by the laptop computer.

3.1.6 PXI Industrial Computer System with Data Acquisition

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 7). 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.

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.

3.2 Software

Several software programs were developed or integrated during the course of Task 3. Each software program serves a specific purpose and is discussed individually as it relates to the hardware or control system.

3.2.1 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 a laptop computer connected to the STX control box by serial port (Figure 8). 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 connected to the laptop 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.

3.2.2 Sequence Programming within the STX Control Software

The largest effort within Task 3 was the integration and coordination of the motion between the travel speed and torch tilt axis. Both axes must move in succession in order to achieve proper downhill welding of the pipe joint. The manual welder uses his skill and agility to know how to change both travel speed and the torch angle to ensure a good weld. This sort of intelligence had to be programmed into the software to allow the STX bug to achieve the same result. The STX bug has two inclinometers embedded within the bug that measure angular position. This angular position was sensed by the STX control software many times per second. The bug's "intelligence" was created by mathematical calculations that determined what motion to change when a specific angle or orientation was reached. This algorithm was then integrated into the software program.

After the STX control software had been developed and used during welding, an automatic welding sequence program was begun. In this software development step, the software running on the laptop needed to be able to run a programmed path with programmed changes during the welding sequence. Specifically, automatic changes in the torch travel angle as the STX bug moved its orientation about the pipe. Two software modules were added to the STX control Software running on the laptop, to allow the welder to pre-program a welding path.

3.2.3 Preprogram Welding Path by a Set Travel Distance

The first motion-sequencing program was designed to allow the welder to preprogram a welding path for the STX bug by specifying an end distance or total distance to travel. The welder is required to set a beginning travel speed and a desired ending travel speed, along with a beginning torch travel angle and an ending torch travel angle. Upon initiating the arc, the motion begins and this software module interpolates the correct speed and angles for motion during the welding sequence. Figure 9 is a picture of the software screen where the welder or operator would enter the parameters required to preprogram a welding path by specifying a total distance to travel.

3.2.4 Preprogram Welding Path by STX Bug Orientation about the Pipe

The second motion-sequencing program was designed to allow the welder to preprogram a welding path for the STX bug by specifying a beginning and ending orientation of the STX bug about the pipe. The welder is required to specify a beginning STX bug orientation and a desired ending orientation, for example, 12:00 to 3:00 o'clock. The welder also specifies a beginning and ending travel speed and beginning and ending torch travel angle. After the arc is initiated and motion begins, this software module interpolates between the beginning and ending orientation to set the correct travel speed and torch travel angle to achieve the desired result. Figure 10 shows the software screen where the welder or operator enters the parameters required to preprogram a welding path by specifying a beginning and ending STX bug orientation relative to the fixed (5G) pipe position.

3.2.5 Software on PXI Computer for Spin Arc Control

A software program was written to talk to and control the Spin Arc torch. This software program, called Intellicontrol, resided on the PXI computer system which had industrial data acquisition capabilities. The Spin Arc torch was connected to a servo-amplifier that controlled the speed of the motor. The motor within the torch had an encoder that can be used to keep track of position and speed of the Spin Arc torch. Using the data acquisition capabilities on this computer, the Intellicontrol software program was written to sense the encoder signals and control spinning speed of the torch. The following signals were used by the software program to control and measure the Spin Arc torch:

- Direction of spin from Encoder Channel A
- Direction of spin from Encoder Channel B
- Frequency of spin from Encoder Channel Z
- Travel speed of the Spin Arc torch from servo-driver voltage.

During welding, the Spin Arc torch speed can be changed at any point. The encoder signals from the torch are continually measured and logged. All control elements are available and can be used in future projects to program the Intellicontrol software system for seam-tracking at high rates of speed; Figure 11 shows a screenshot of the software main panel.

3.2.6 Software on PXI Computer for Data Acquisition

The final software program created during Task 3 was the data-acquisition software. This software module was also part of the Intellicontrol program running on the PXI computer system. The extensive data-acquisition hardware available on this system allows for measuring welding parameters and Spin Arc control during welding. The welding parameters measured with this software program can be used to help create the adaptive control algorithms. This software samples data at extremely high rates (kHz range) depending on the number of channels sampled. Several sensors were purchased and integrated with the PXI data acquisition system including:

- Voltage divider for measuring arc voltage
- Hall effect sensor for measuring DC current
- Gas flow meter for measuring shielding gas flow rate
- Wire feed speed sensor for measuring welding wire feed rate
- Travel speed sensor for measuring travel speed during welding.

The PXI computer system was tested during welding with the Spin Arc torch on a robot system. Several screenshots from the software program are displayed in Figures 12 and 13. Welding trials were performed with the Spin Arc torch controlled by the Intellicontrol software and PXI computer system.

4.0 Development of Process Control Systems for Pipeline Girth Welding

CTWD control to compensate for pipe ovality during girth welding was identified as the primary deliverable for Task 4. This was integrated with the Spin Arc GMAW-RE solution. The same solution can be applied to hybrid laser GMAW root pass welding, if required. The CTWD control uses the torch height axis on the bug, a welding voltage sensor and software to automatically read the set voltage on the power supply and provide automatic voltage control (AVC). These three tasks were involved in developing the AVC control. One software control program reads data from each task and the algorithm for maintaining CTWD was executed by the same software program.

4.1 Industrial Control System

To develop the AVC, the data acquisition system and the STX bug needed to communicate with one another through a common platform. To accomplish this task, all software was combined into one main program and all hardware connected to one main computer. The system was put into an industrial cabinet and the sensor and data signals were wired up to an industrial data acquisition board inside the cabinet (Figure 14).

4.1.1 Integration of Individual Software Programs

The data acquisition software program, Intellicontrol, was integrated with the STX control software and installed onto a single PXI computer system. This involved combining the individual sensors, signal to the power supply contactor, the STX bug control box and analog and digital I/O signal lines with the PXI computer. This also involved integrating the individual software components into one software program controlling the entire system. Once the hardware and software was integrated onto one main system, the STX bug, data-acquisition sensors, Spin Arc torch, power supply, and the automatic voltage control shared data and worked together to complete the system for welding process control.

4.1.1.1 STX Control Software

The STX control software developed in Task 3 was transported from the laptop computer to the industrial PXI computer system now residing inside the industrial cabinet. The software also needed to change communication protocol from the PCMCIA-based data-acquisition card that was used when the STX control software was on the laptop, to the more powerful PXI-based data acquisition board.

4.1.1.2 Data Acquisition Software

The Intellicontrol software written for the data acquisition required in Task 3 needed to be integrated with the STX Control software. This involved changing the Spin Arc control hardware from control by the Intellicontrol software to control by the new, combined STX control software. The Spin Arc torch required several hardware changes via signals from the data acquisition hardware. These signals were placed under the control of the STX control software. The remaining item from this task was to allow the user to change the Spin Arc parameters from the STX control software screen during welding.

4.1.1.3 Spin Arc Power and Frequency

The Spin Arc frequency was a parameter that needed to be adjusted during welding. The frequency can be changed from 1 to 100 Hz and the operator needed a quick way to adjust the torch parameters during set-up and welding. A software program was developed to allow the operator to adjust the spin frequency of the Spin Arc torch during welding. The STX control software was amended with the Spin Arc control which is selectable from the STX software screen (Figure 15). The Spin Arc software screen displays the current spin frequency and the input voltage to the torch. The software allows the operator to set the spin frequency during welding, to immediately halt the spin and to reset the torch in case of a fault condition.

4.1.1.4 Power Supply Contactor

The welding arc needed to be integrated with several items so that all would begin synchronously. First, the STX software needed to have a way for the welder to start the arc by clicking a button on the computer screen. Second, any preset spin frequency and spinning motion needed to begin once the arc was initiated. Last, the STX bug travel motion needed to begin once the arc was initiated. All of these items were synchronized by the STX Control software program at the instant that the operator hit the Arc Start button (Figure 16). This generated an analog I/O signal from the data-acquisition board to trip a relay, which then caused the contactor on the power supply to close allowing the arc to start.

4.1.1.5 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 16). 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 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.

4.1.2 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.

4.1.3 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 17). 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 18).

5.0 Discussion

The results and conclusions from this work have already been used within this project for development of welding procedures within Task 1, "Development on Innovative Root Pass Welding Procedures."

5.1 Development of Improved Root Pass Automation

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

5.2 Development of Process Control Systems for Pipeline Girth Welding

This task involved the development of an industrial process control system which integrated the hardware and software systems developed in Task 3. Once the integration was complete, further process control was developed including the synchronization of arc initiation with a software user interface button, STX bug travel motion, Spin Arc frequency, and arc initiation. 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.

6.0 Conclusions

The work conducted within Task 3, "Improved Root Pass Techniques" and Task 4, "Process Control Systems for Pipeline Girth Welding" met the objectives set. The results of this work can be concluded as follows:

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

2 A user-friendly interface was developed for an operator to control the bug from a laptop computer.

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

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

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

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

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

8 An automatic voltage control system was developed using the RTQM data acquisition system for measuring arc voltage and maintaining a user specified CTWD during welding.

7.0 Recommendations

The results and conclusions from this work have already been used within this project for development of welding procedures within Task 1 – Development on Innovative Root Pass Welding Procedures. They will also be used in subsequent tasks within this project as noted below:

1 Real-time quality monitoring
2 Technology demonstration
3 Further use of the outcome from Tasks 3 and 4 should be made to advance the mechanization of pipeline girth welding for hot, fill, and cap passes.

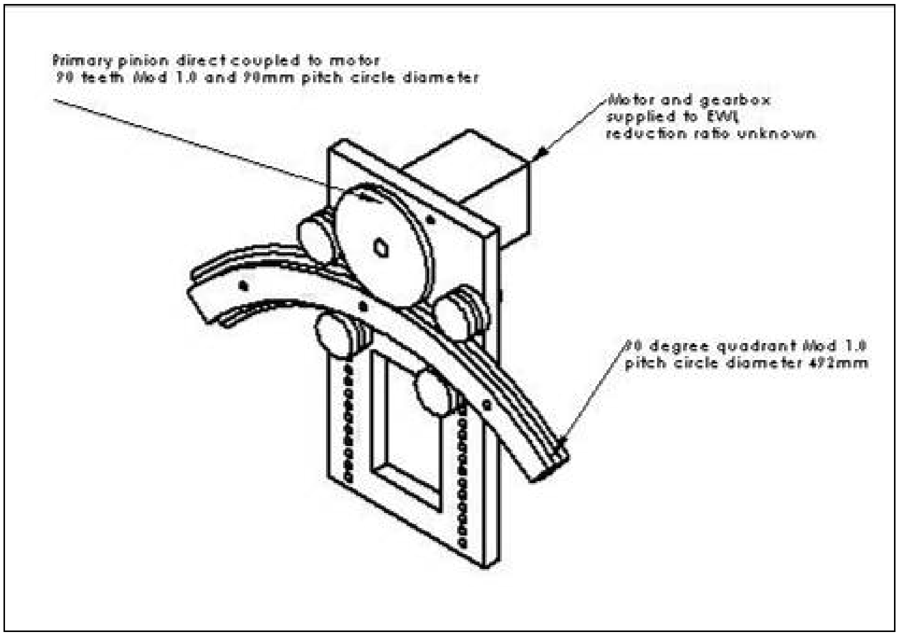

Figure 1. Mounting Bracket and Design for Torch Travel Angle Bracket

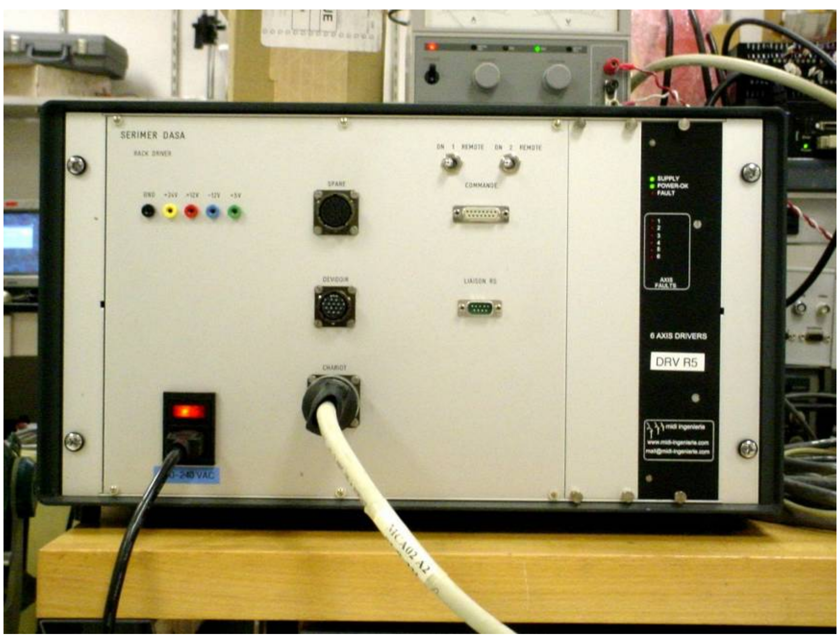

Figure 2. Saturnax Bug (STX) Controller Box with RS232

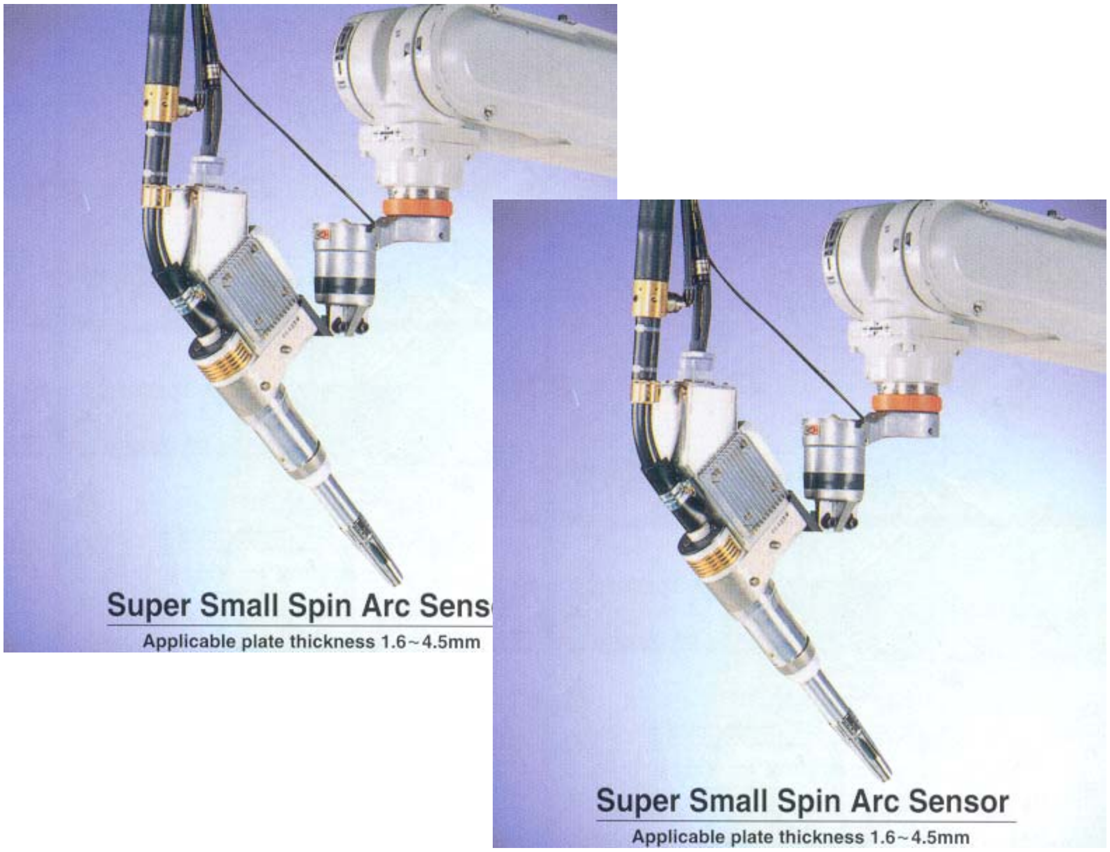

Figure 3. Panasonic Spin Arc (GMAW-RE) Torch

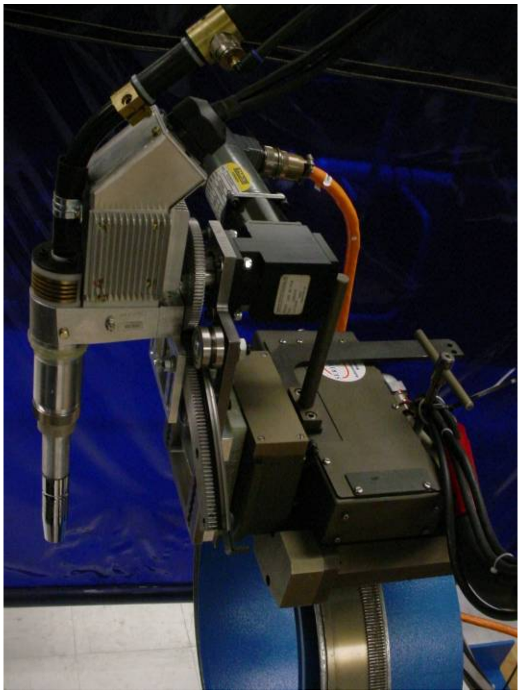

Figure 4. Torch Travel Angle Hardware Added to Standard STX Bug

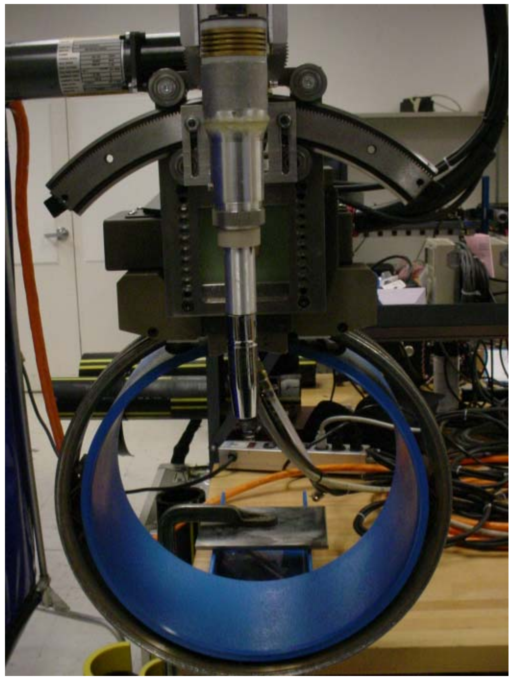

Figure 5. Front View of Torch Travel Angle Hardware Added to Standard STX Bug

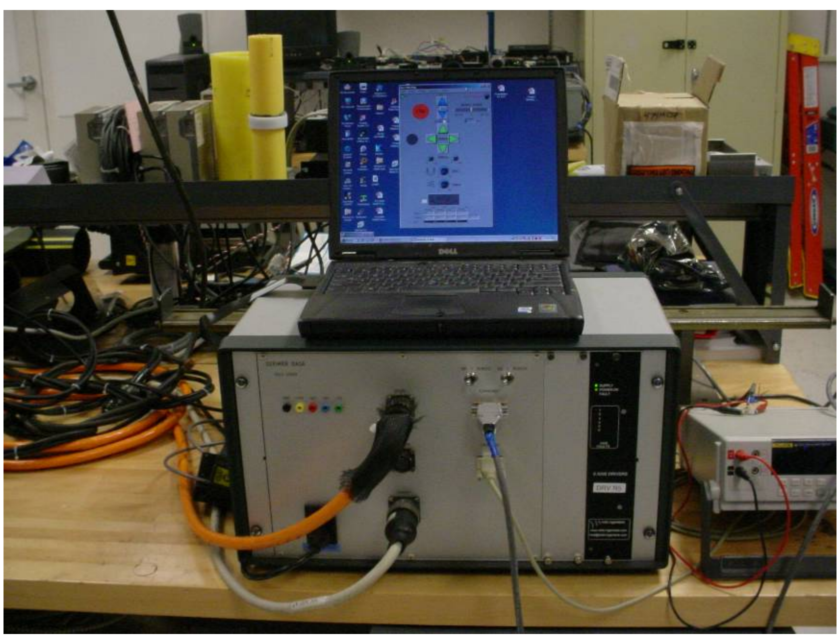

Figure 6. STX Control Box being Controlled by Laptop Computer Running Pendant-Like Software

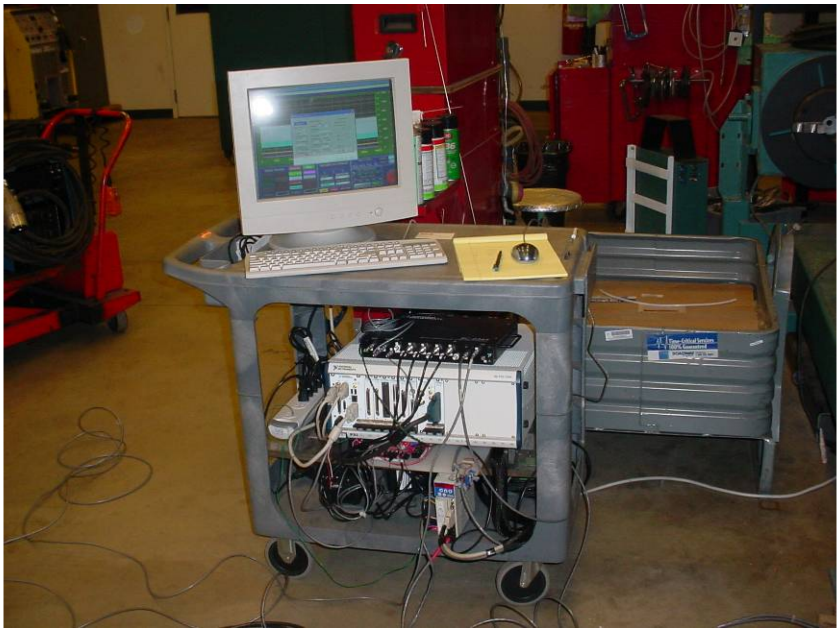

Figure 7. PXI Industrial Computer System Controls Spin Arc and Data Acquisition

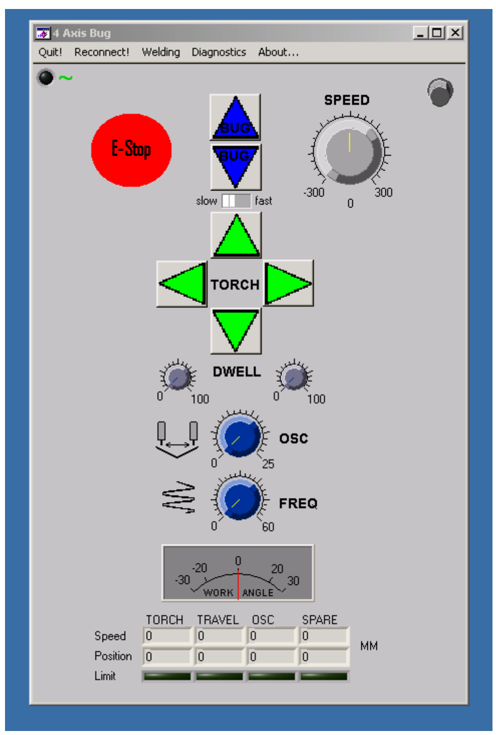

Figure 8. User Interface on STX Control Software Developed for Pendant-Like Control of the STX Bug

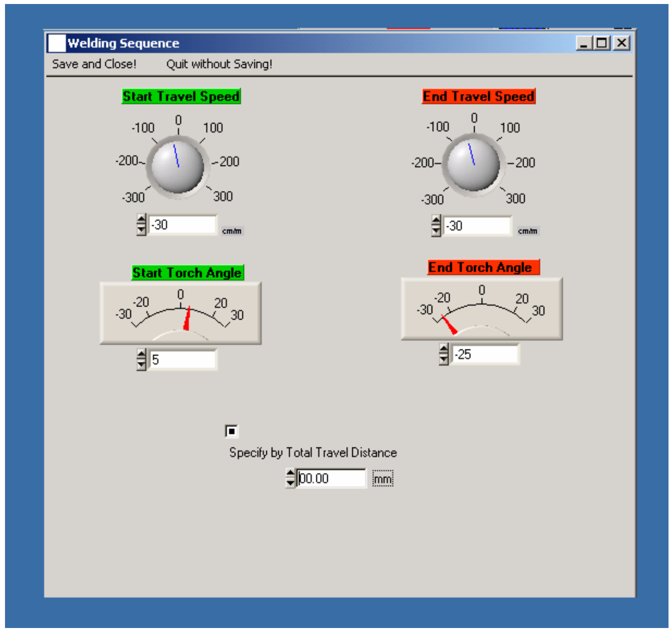

Figure 9. Software User Interface for Programming a Welding Sequence by Specifying a Total Distance

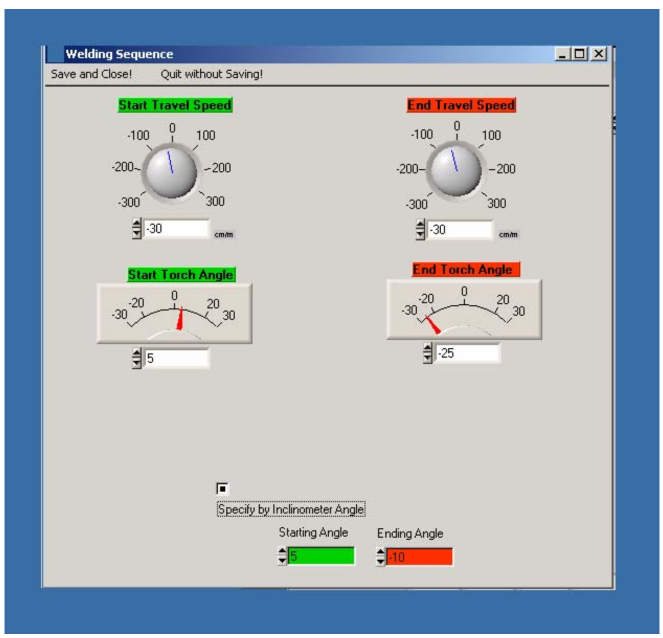

Figure 10. Software User Interface for Programming a Welding Sequence by Specifying a Beginning and Ending STX Angle of Orientation about the Pipe

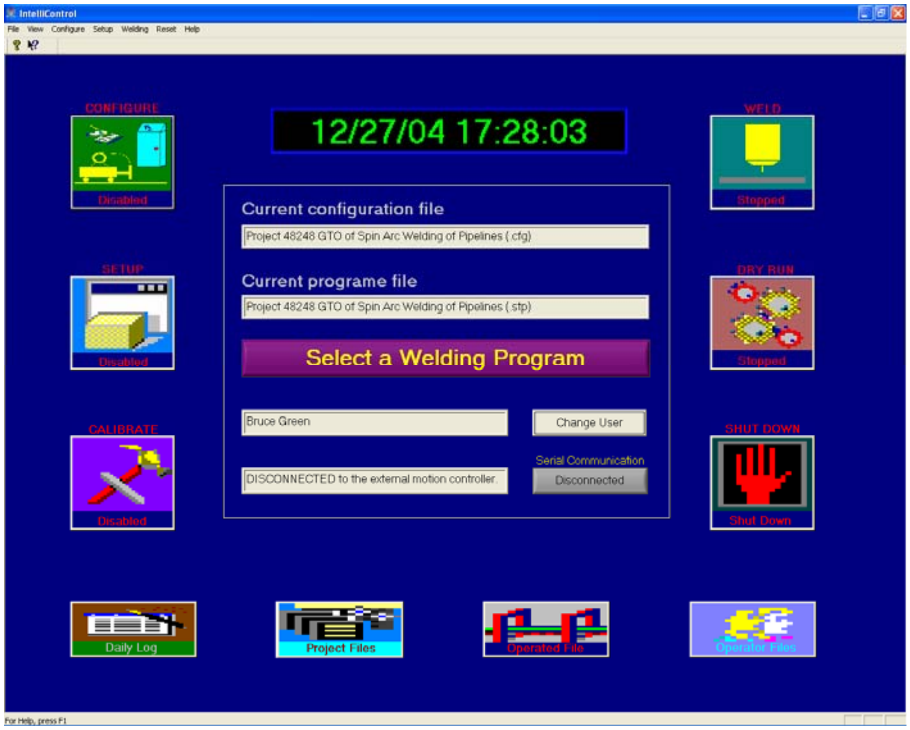

Figure 11. Intellicontrol Software Main Panel

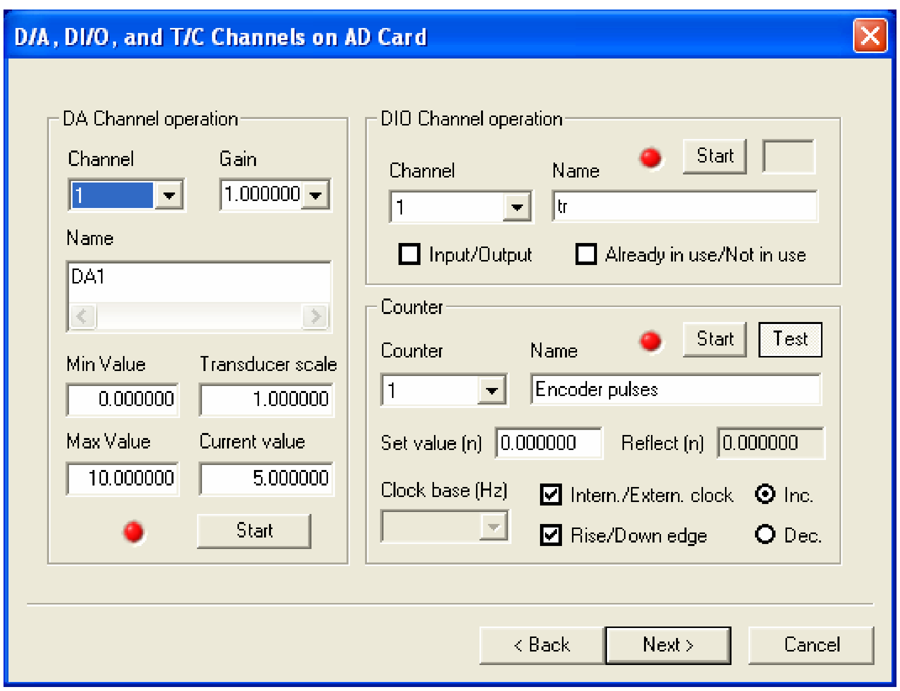

Figure 12. Intellicontrol Software Interface Module for Setting Up Spin Arc Control

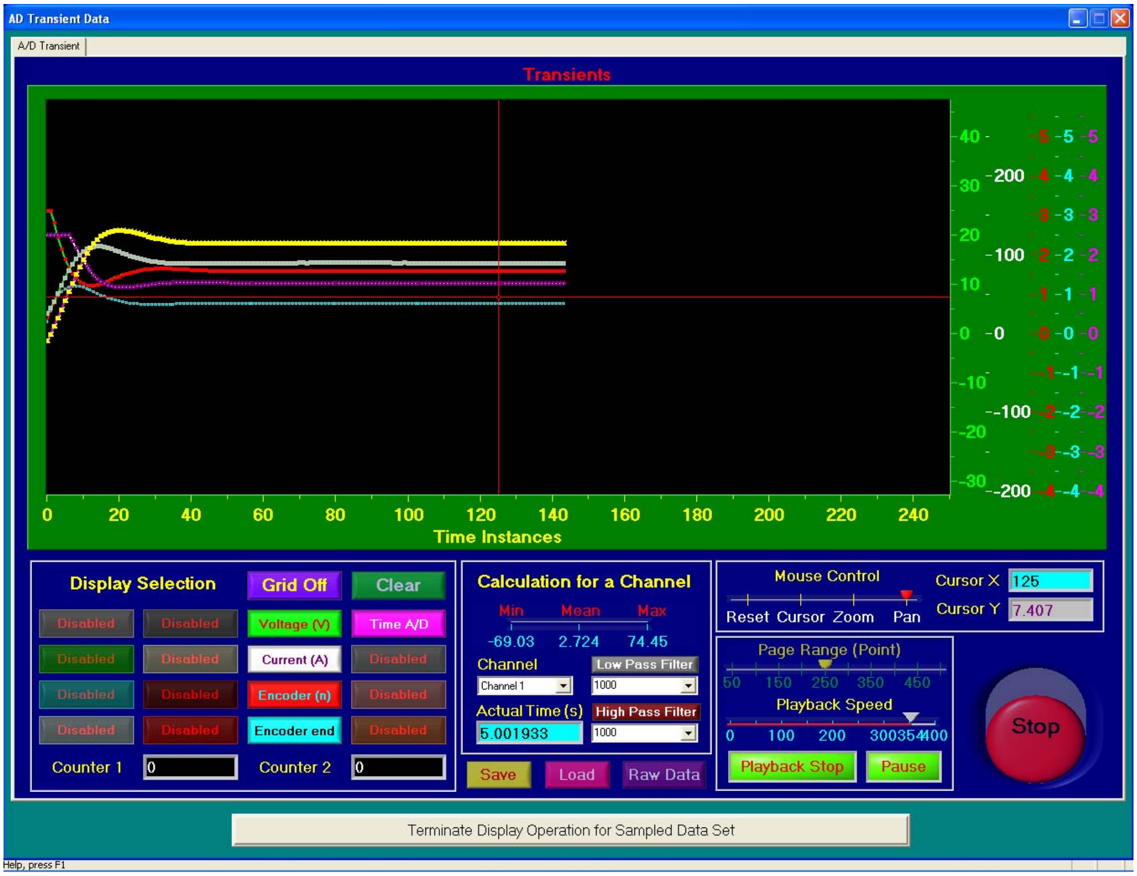

Figure 13. Intellicontrol Software Interface Module During Data Acquisition of Welding Parameters and Spin Arc Control

Figure 14. Operator at the Industrial Control Cabinet Housing the Integrated Hardware and Software for Process Control

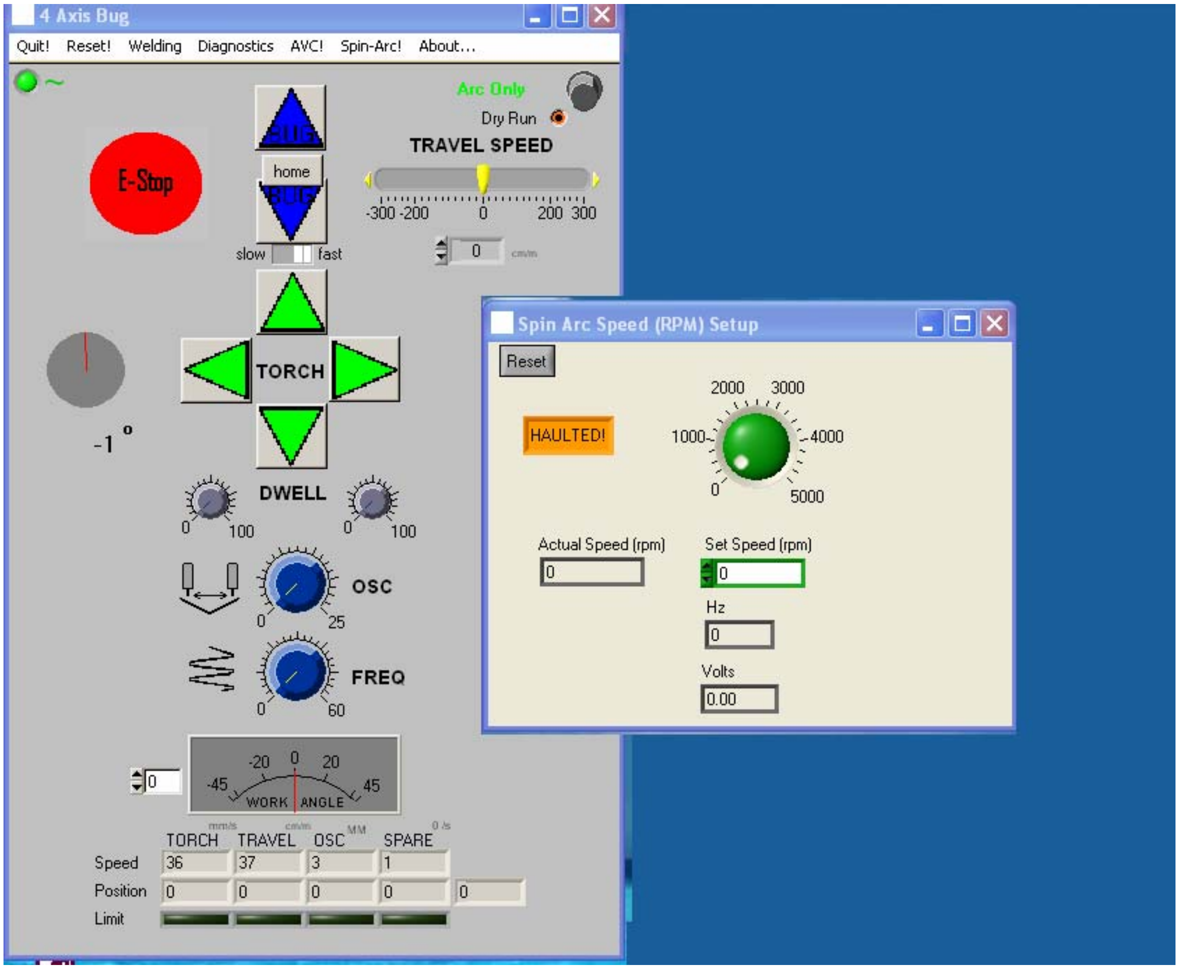

Figure 15. Spin Arc Control Software for Adjusting Spin Arc Frequency During Welding

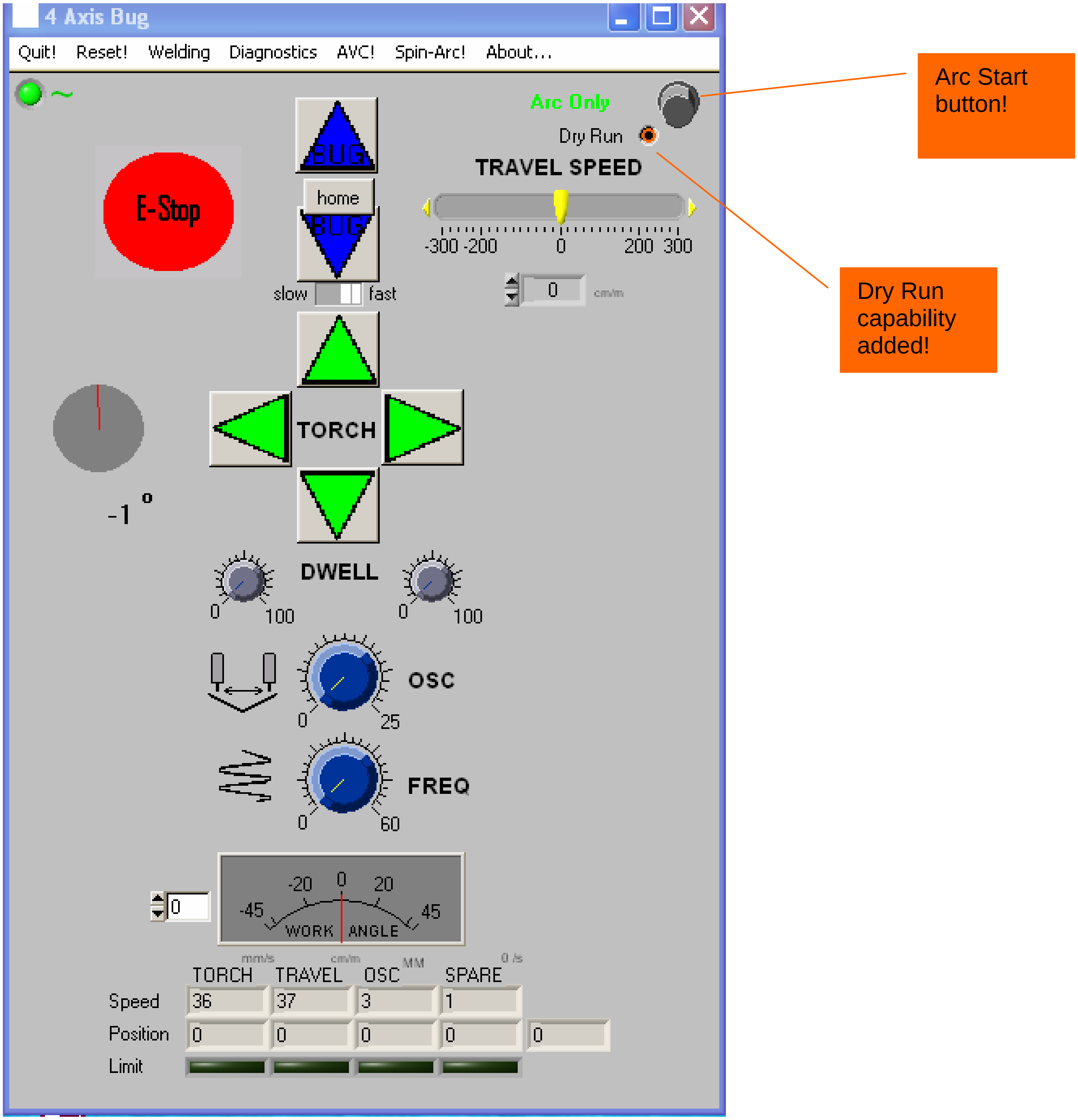

Figure 16. Additions to the Integrated STX Control Software Include Synchronizing Arc Start to Travel and Capability to Perform a Dry Run

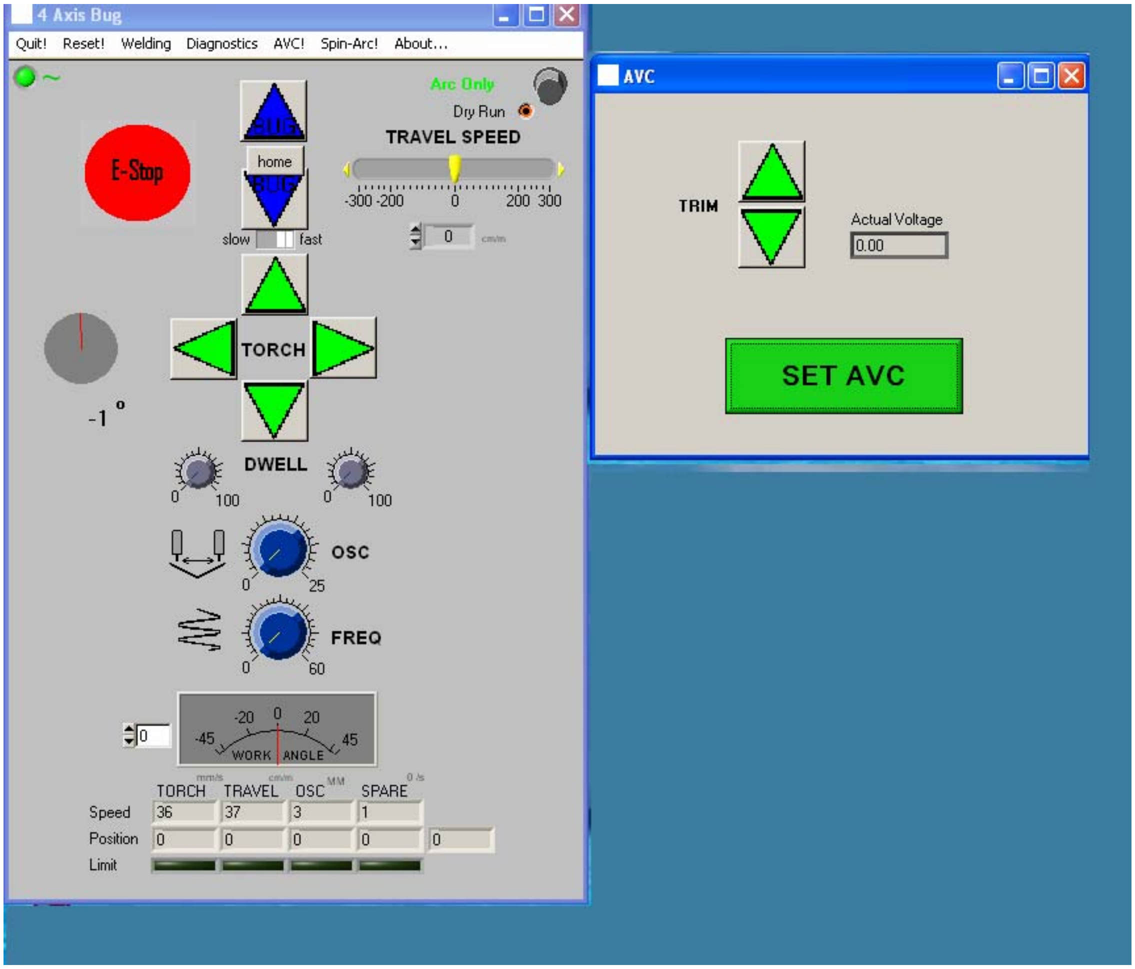

Figure 17. STX Control Software with AVC Control Panel Before Arc Initiation

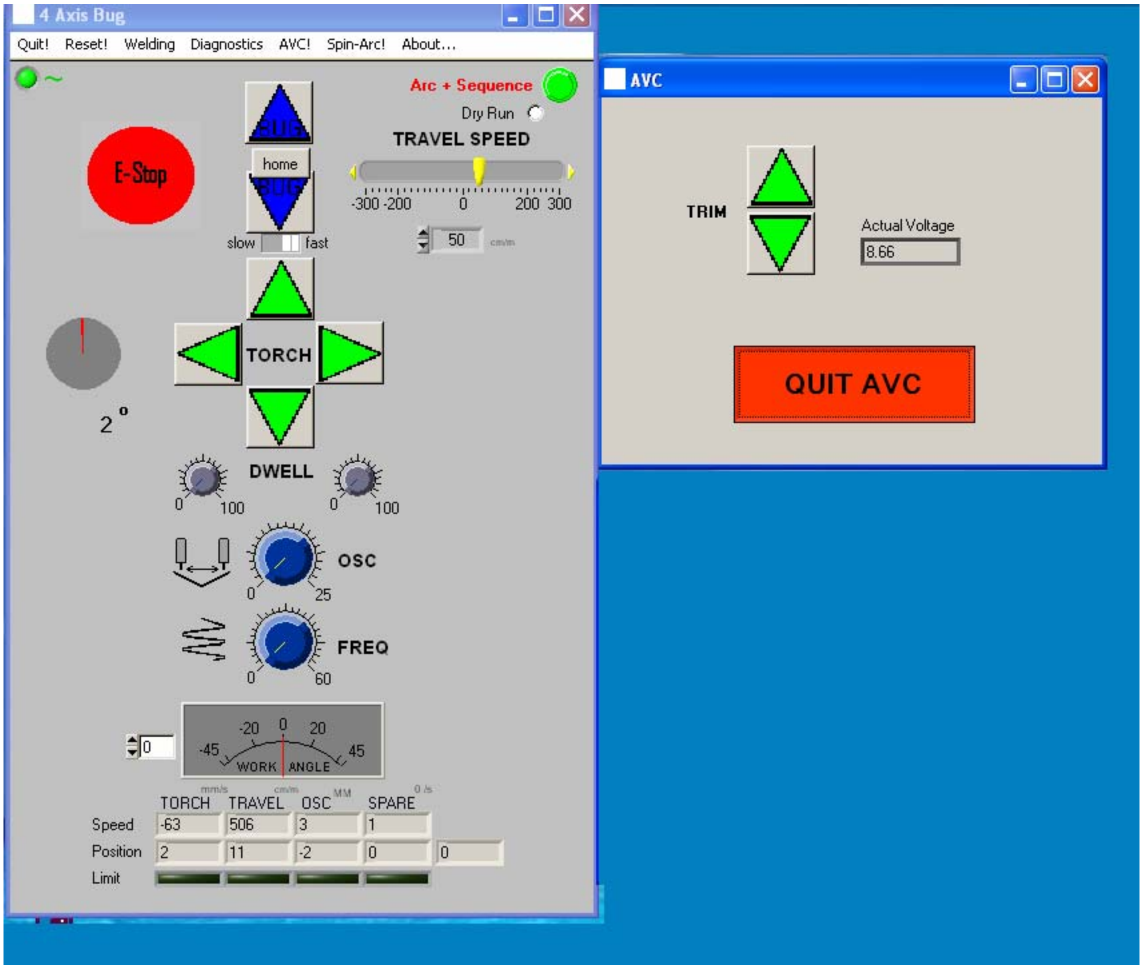

Figure 18. STX Control Software during Welding with AVC Engaged