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Comprehensive Automated Welder System - PDRD SR-17-007

J. B. McIntosh, K. W. Burkes

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REVIEWS AND APPROVALS

AUTHORS:

J. B. McIntosh, R&D Engineering Date

K. W. Burkes, R&D Engineering Date

APPROVAL:

Rick Poland, Manager Date
R&D Engineering

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Welding Control and Power System Design & High-Speed DAS and FPGA Programming
Klaehn Burkes

Hardware Assembly and Troubleshooting
George Graham
Larry Powell
Giovanni Ramirez Alicano
Will Priester

Mechanical Design for Automation
Chad Sweeney
Hope Hartman

EXECUTIVE SUMMARY

The Comprehensive Automated Welder System - PDRD SR-17-007 project was initiated to develop hardware and software to eliminate possible error pre-cursor functions of the pinch welding process that require manual manipulation and data entry as well as leveraging 21st century technology advances by replacing obsolete hardware with state of the art maintainable equipment.

The project plan targeted three primary areas for improvement:

1. Replacing the existing welding power supply system with a solid-state power supply
2. Improving the data acquisition system, sensors and controls
3. Updating the software to a FPGA "real-time" program with automated steps

SRNL purchased, designed and installed in 723-A, a system to meet the requirements for these areas. While improvements in hardware controls and sensor selection were achieved and a successful software automation routine was demonstrated, the performance goals were not met with the custom solid-state power transformer.

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LIST OF ABBREVIATIONS

ARMS II	Automated Reservoir Management System II
DACS	Data Acquisition and Control System
FPGA	Field Programmable Gate Array
PDRD	Plant Directed Research & Development
RDE	Research And Development Engineering
SRNL	Savannah River National Laboratory
SRTE	Savannah River Tritium Enterprise
SSWT	Solid-State Welding Transformer

1.0 Introduction

The pinch welding process of loading reservoirs, squeezing the stems and entering the welding results into a data management system has not significantly changed in over 30 years. The Tritium reservoir pinch welding control and data acquisition system has not undergone technological improvements since the late 1990's. Current practices are vulnerable to error due to operator mistakes in data entry and repetitive tasks. Existing hardware has become obsolete and a large amount of useful data that could be acquired is not available in using an antiquated data acquisition and control system.

The Comprehensive Automated Welder System - PDRD SR-17-007 project was initiated to develop hardware and software to eliminate possible error pre-cursor functions of the pinch welding process that require manual manipulation and data entry as well as leveraging 21st century technology advances by replacing obsolete hardware with state of the art maintainable equipment.

The project focus included replacement of the welding power system, employing better sensors to monitor the welding process and eliminating the operator interactive functions for the process using software/hardware automation routines.

2.0 Pinch Welding Process Improvement

The contrast in the pinch welding process steps below demonstrate the vulnerability for operator errors and improvements that result from the automation of pinch welding the stems of tritium vessels:

Welding Procedure

1. Retrieve schedule for loading on a specific loading line from ARMS II
2. Retrieve and follow procedure for performing loading functions
3. Install reservoirs on Loading Line
4. Load reservoirs

Manual Operations (Current Method)

1) Operator enters welding information into Pinch Weld Data Acquisition System
2) Operator adjusts loading pressure valve to set the initial weld force for the loading line
3) Operator adjusts initial welding voltage for the loading line
4) Operator selects station to weld and pinch electrodes
5) Operator runs a pre-weld resistance check for the station
6) Operator selects the option to weld
7) Operator prints local copy of the data
8) Operator releases the pressure to the welded station
9) Operator re-starts the process by entering welding information into the Pinch Weld DAS for the next station
10) Once all welds are completed, the operator takes the printouts to another room and enters data into the correct data fields in the ARMS II system

After reservoir loading, the Comprehensive Automated Pinch Welding system performs all the tasks required to make the closure weld for the load stem:

Automatic Operations (After PDRD Implementation)

1) Select option on the new Pinch Welder Data Acquisition and Control System (DACS) to start the welding program.
2) Computer downloads reservoir information to the local interface from ARMS II
3) Station is selected and electrodes adjusted to the correct force via an automatic pressure regulator for the station
4) Computer performs continuity measurement to ensure proper electrode contact and alignment
5) Computer loads the correct weld current/voltage profile for the type of reservoir

6) Computer performs the weld, making real time adjustments to voltage and current during the weld, as necessary
7) Computer saves data and generates files for upload to the ARMS II system
8) System will continue the process by downloading welding information into the Pinch Weld DACS for the next station and performing weld function until all welds are completed

By automating every manual step required to perform and record the pinch weld data, HPI At-Risk behaviors that can lead to errors in the process are eliminated. Tying the input and output of the DACS system directly to ARMS II improves the accuracy, consistency and security of the weld data information transfer.

3.0 Project Plan

The Comprehensive Automated Pinch Welding PDRD project plan targeted three primary areas for improvement:

1. Replacing the existing welding power supply system with a solid-state power supply
2. Improving the data acquisition system, sensors and controls
3. Updating the software to a FPGA "real-time" program with automated steps

The project plan was predicated on a three-year schedule:

Year 1 - focus on development of the specifications for the power electronics and data acquisition system design and procurement of this hardware.
Year 2 - focus on installation and deployment on a two-station welding system located in the SRNL Research and Development Engineering facility, 723-A including initial testing and evaluation of the automation software.
Year 3 - focus on fully integrated testing and evaluations and on refinements required to integrate the system into the Tritium facilities concerning facility impacts and the design laboratory qualification and acceptance process.

3.1 Welding Power Supply

The power supply components for the SRTE pinch welder system consists of the items in Figure 3-1.

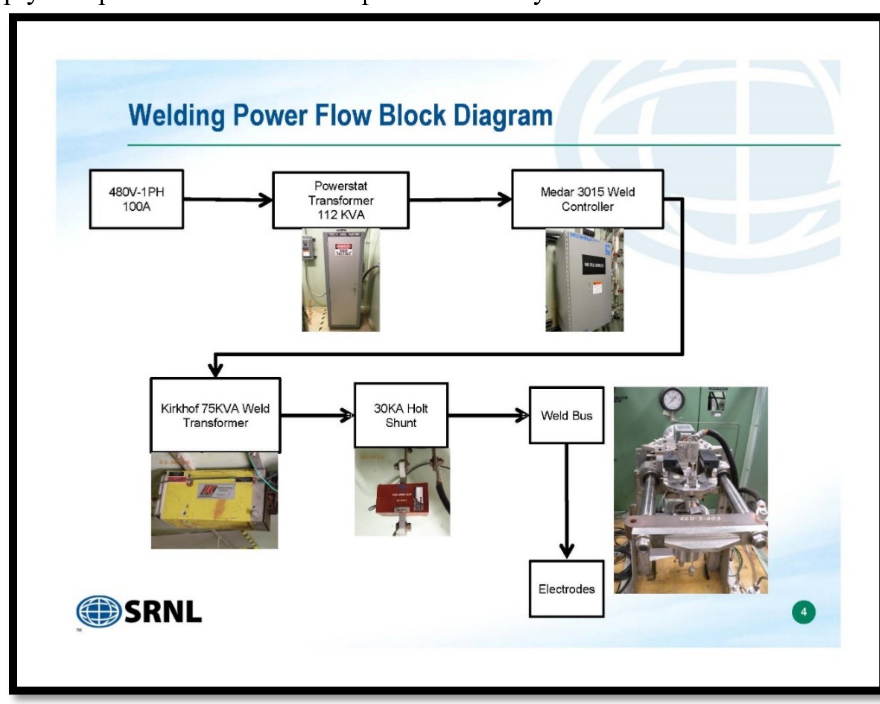

Figure 3-1. SRTE Pinch Welder Power Flow

For the PDRD project, SRNL specified (E-SPP-H-0049) and purchased (PO# 300215) a computer controlled, solid-state, power amplifier-based transformer to replace the powerstat transformer, Medar Weld Controller and Kirkhof weld transformer.

The new transformer was designed to support advanced voltage and current welding capabilities pursued by the Design Laboratories. Capability and quality improvements can be made by using the new power electronics technology. The transformer is digitally controlled by a high-speed processor and provides the exact current and voltage characteristic for a weld that meets the pinch weld requirements. Utilizing real time feedback from the device, current shunt, displacement sensor and electrode voltage measurements, the output can be adjusted to ensure weld quality. In addition, complicated power outputs can be programmed to support adaptive controls for welding metals other than stainless steel, such as aluminum.

Specific requirements for the transformer included:

1. Input Voltage Rating: 480VAC ± 10%, 3ϕ grounded delta (B-phase) input (1ϕ capable)
2. Output Voltage Rating: Maximum 10VAC @ 6000A 1ϕ output
3. Voltage and current output capable of variable frequency range of 60Hz to 1000 Hz
4. Supports weld operations of varying duration from one (1) 60Hz cycle up to (150) 60Hz cycles.
5. Mounted in an NEMA 1 type electrical enclosure with a lockable handle and visible indication of energization
6. Enclosure includes a control transformer with overcurrent protection
7. Transformer output controlled via a wired communication connection
8. Voltage output controllability with changes at rates of up to 12kHz in the output waveform during a weld operation.

The solid-state transformer was delivered to SRS on 8/23/17 including user manual, software programming interface instructions and functional test data.

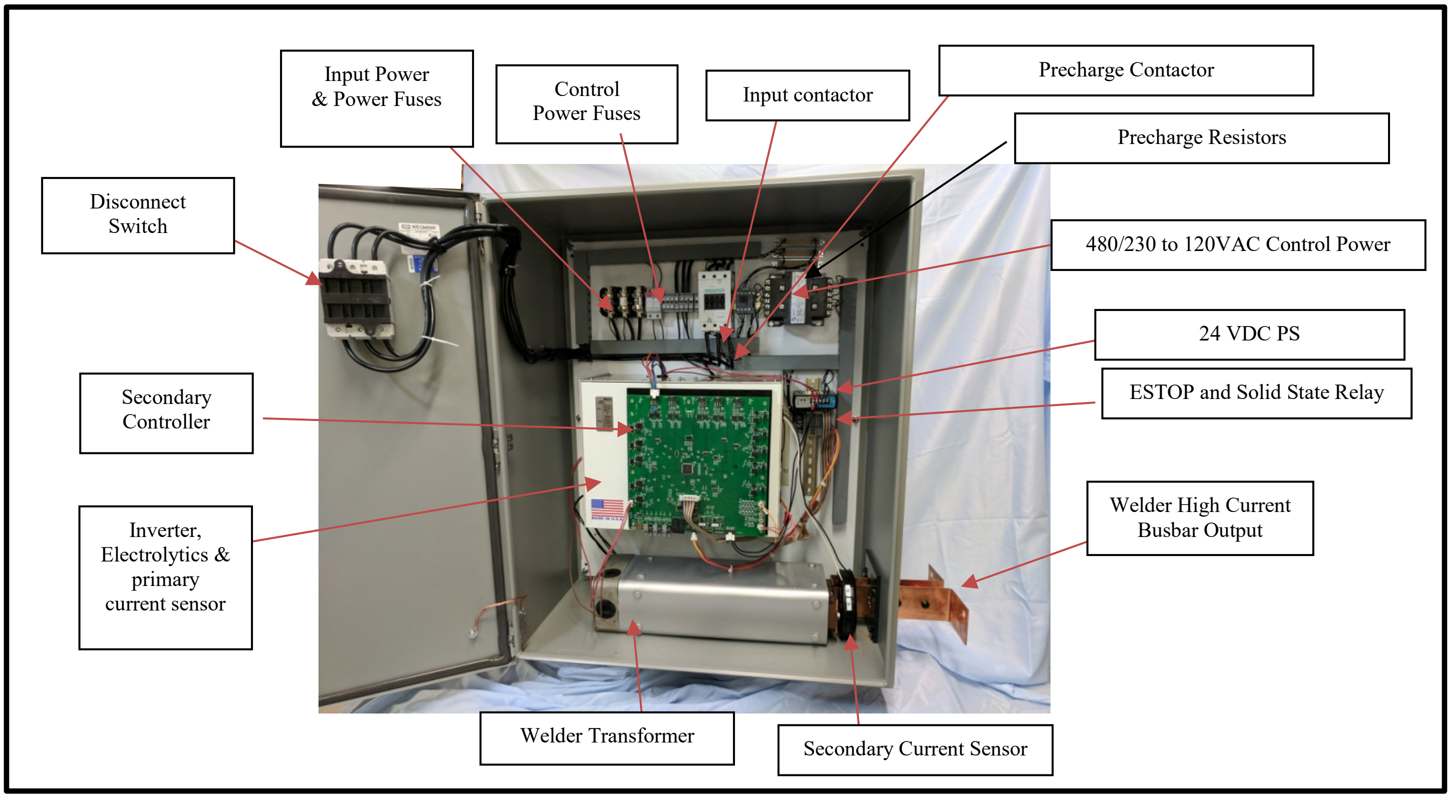

Figure 3-2. Solid State Welder Transformer Interior

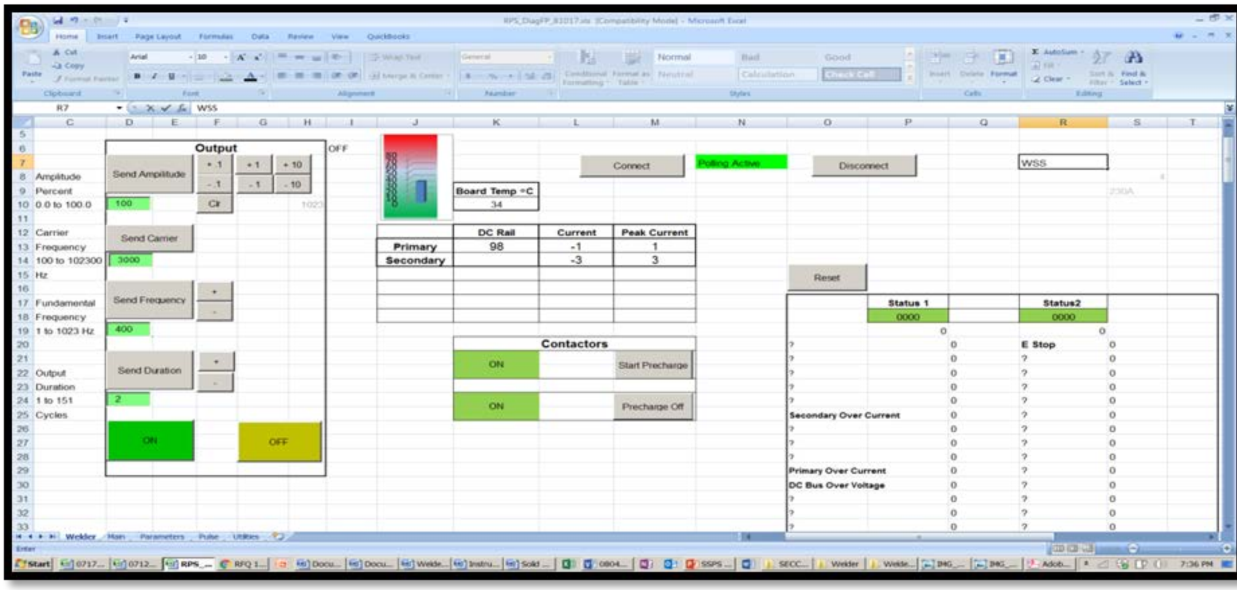

Figure 3-3. SSWT Welder Test Interface Programming Screen

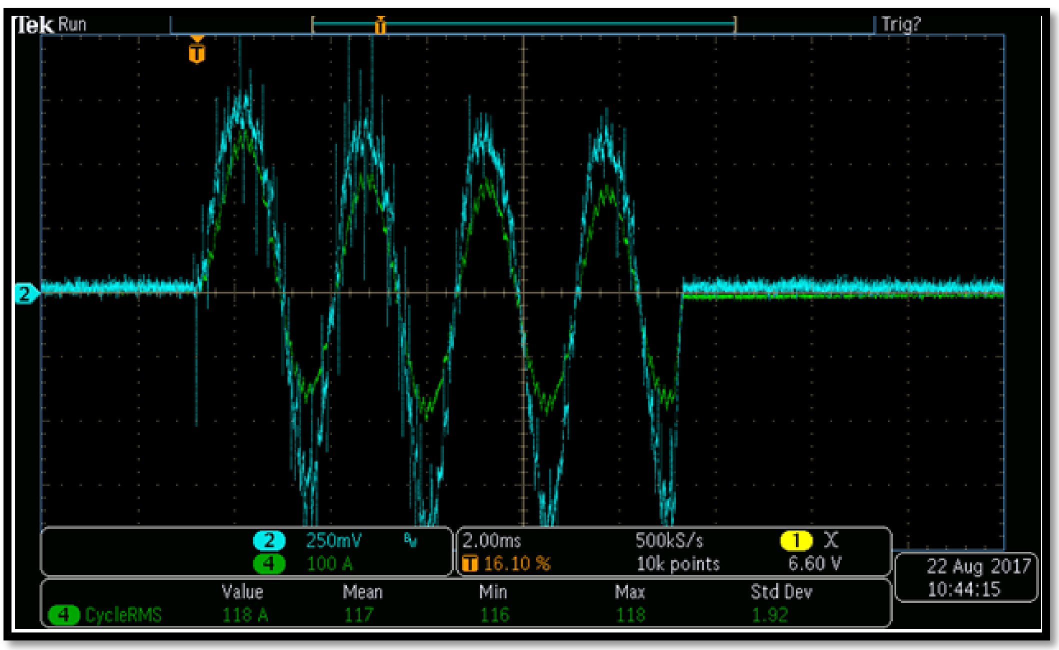

Figure 3-4. High Speed Snapshot of SSWT Output

SRNL RDE designed an 80/20 frame to mount the SSWT and worked with SRNL Facilities Engineering to have the electrical power supply modified to accommodate the new system.

In May of 2018, the solid-state transformer was installed and connected to a two-station welding system located in Cubicle G of the SRNL Research and Development Engineering 723-A facility. To support the installation, electrical safety evaluations of the facility wiring power distribution (E-ESR-A-00190) and the SSWT (E-ESR-A-00191) were performed along with an 8Q-51 FAI for R&D Welder Upgrades.

Figure 3-5. Installed SSWT in 723-A, Cubicle G

In June of 2018, upon initial calibration of the output for the Solid-State Transformer, at a current level over 6000 Amps, approximately 30% of the IGBTs failed preventing the functional test of the system. Funding to perform system configuration, calibration and weld studies was returned to the PDRD overall budget for FY18. New components were ordered, the SSWT as repaired in late FY19, limiting the amount of testing performed with the hardware.

3.2 Data Acquisition and Control Hardware

Data Acquisition and Control Processor

To support the new pinch welder controllable power electronics capabilities, SRNL researched various computer and data acquisition solutions and eventually purchased a National Instruments FPGA based PXI system (Purchase Order #303895).

The new pinch weld data acquisition and control system (DACS) is a "real time", deterministic, low latency, high reliability, embedded controller. The controller is the same type used for production/life cycle testers at SNL, NSC, LANL, Y12 and LLNL. Field programmable gate arrays (FPGA) and fiber optic communication links ensure the fastest throughput available for control and acquisition. Using input modules with data rates of 204,000 samples per second and controllers with data transfers of 24GB per second, the DACS can dynamically control the welding process. In practical terms, an almost quarter second weld can have its characteristic parameters measured and sliced into a million separate data points and the controller can calculate and adjust the power output over one hundred times during the welding operation.

Sensor Hardware

SRNL researched and purchased a precision pressure regulator for the automated system made by Equilibar (Purchase Order # 337557). The Equilibar electronic pressure regulator (QPV1) allowed for ultra-high-resolution control to +/- 0.0005% of full scale (300psig) and was integrated into the National Instruments PXI system via the analog I/O PXI-7842R card.

Figure 3-6. Equilibar Pressure Regulator

A reflectance compensated, fiberoptic distance sensor (RC-100Q) with 20 Khz Bandwidth made by Philtec Inc. was installed to measure weld displacement (Purchase Order # 337784). During the weld, the metal closure thickness can vary from 0.06 to 0.04 inches. Typical weld tubing is nominally 0.125 inches and total movement including pre-weld compression is approximately 0.085 inches (2.2 mm). To ensure the DACS captures the displacement during the weld, the chosen sensor has an optimum resolution of 30μin over a range of 0.2 inches. This sensor was also connected to the National Instruments PXI system via the analog I/O PXI-7842R card.

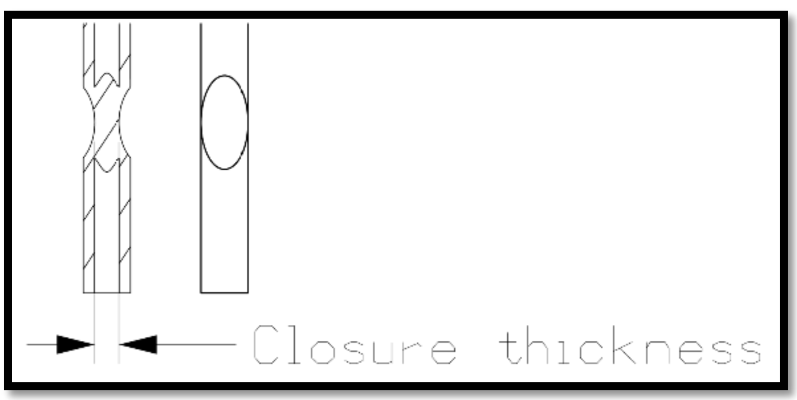

Figure 3-7. Pinch Weld Stem Closure

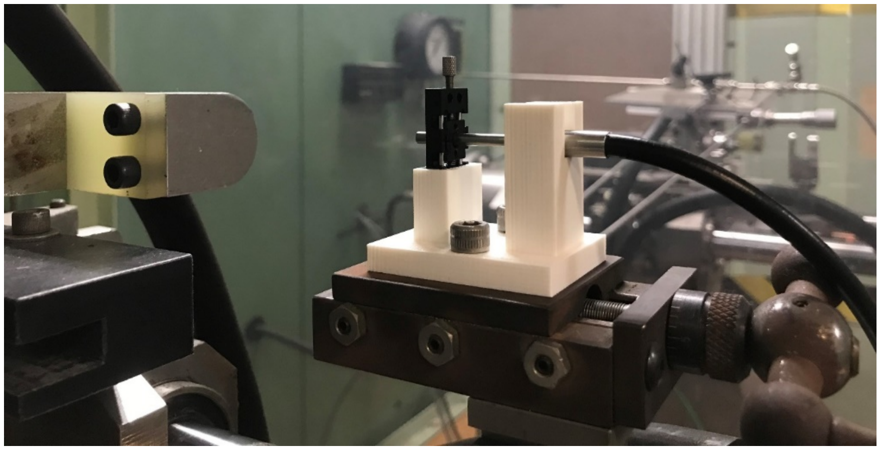

Figure 3-8. Displacement Sensor Assembly

SRNL designed an additive manufactured assembly to electrically isolate, allow zero-position adjustments and secure the displacement sensor.

SRNL installed the DACS into a cabinet that contains a mock-up of the current field deployed pinch welder data acquisition system. In addition to the pressure regulator and displacement sensor, inputs for weld voltage, weld current, weld force and other I/O were connected to the new DACS. All shared inputs and outputs are selected using isolation relays so that either system can be used for R&D in support of the PDRD or other SRNL weld development work or for SRTE fielded system process support.

3.3 <u>Welder DACS Software</u>

SRNL used National Instruments LabView 2014 to develop a high speed "real-time" program with automation routines built-in to read downloaded weld parameters, apply pressure, verify permissives, initiate a weld and record weld data to a format that can be uploaded to ARMS II. Computer routines integral to the LabView software were written and tested to interact directly with solid-state transformer through a high speed fiberoptic link, setting target voltage/current weld waveform outputs and other system parameters.

The automated welding routine begins by uploading a configuration file (previously downloaded from ARMS II) with the parameters for performing a weld run on a loading line which can consist of up to 8 stations. For the two-station setup in the test bed, a sample file looks like this:

```
[Info]
Num Runs=1
Operator="J. Wallace"

[Run # 9-24-19A]
Station=1
Reservoir Type="1X"
Fixture="Fixture 1X-211"
Serial Number="12345"

[Run # 9-24-19A]
Station=2
Reservoir Type="1X"
Fixture=" Fixture 1X-211"
Serial Number="12346"
```

Once the data has been entered, the automatic steps proceed as detailed in Section 2.0 unimpeded unless a system parameter is outside a pre-set limit. In that case, operator interaction is required to bypass or abort the weld.

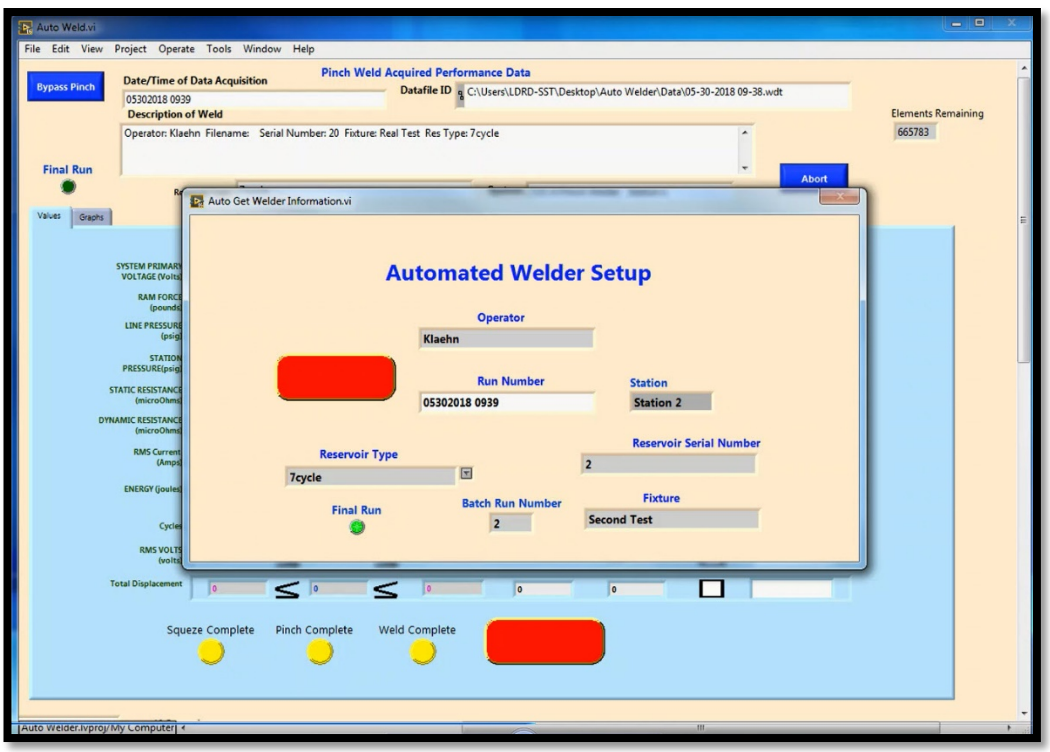

Figure 3-9. DACS Automation Screen

For each weld, the DACS software collects and stores high speed weld data that can be used by the welding engineer, SNRL scientists and the design labs in evaluating weld quality and aid in assuring the prevention of non-conformances in the pinch weld.

After all the reservoirs on all selected stations have been welded, the DACS automatically prints a hard copy of the results and saves a text file with weld specific data for upload to the ARMS system.

4.0 Testing Process

The testing process of the welder consisted of several important steps. First the protection settings were required to make sure that no damage would happen to the welder. These were done by directly driving current through the CT and Hall effects sensor that were on the input and output of the welding transformer. Once these setting were established then incremental operation of the welder was performed. First the output of the welder was shorted in order to do initial characterization/calibration of the output using a current shunt and current transformer. This was done first at 1000 Hz and then at 60 Hz. Next, the output of the welder was connected to the weld head. This led to final characterization which was when an attenuation of the output was detected (Figure 4-1 and 4-2). Using the hardware on hand and purchasing additional welding cable, attempts to help reduce the attenuation were exhausted. These include running parallel cabling between the weld head the SSWT to reduce the secondary resistance in half. Finally, the cables were rerouted to the shortest distance to the weld head. This helped obtain the maximum amplitude shown in the figures below, but the attenuation was still present. Welded samples with the attenuation included were analyzed, and as shown in Figure 4-3 below, closure was not achieved.

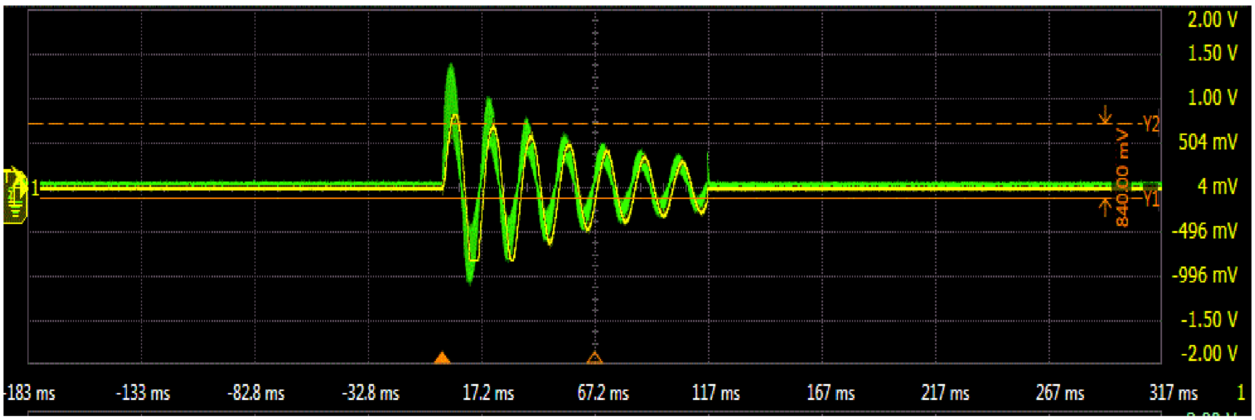

Figure 4-1. Attenuation of Welding during 7 Cycles Peak 4165A

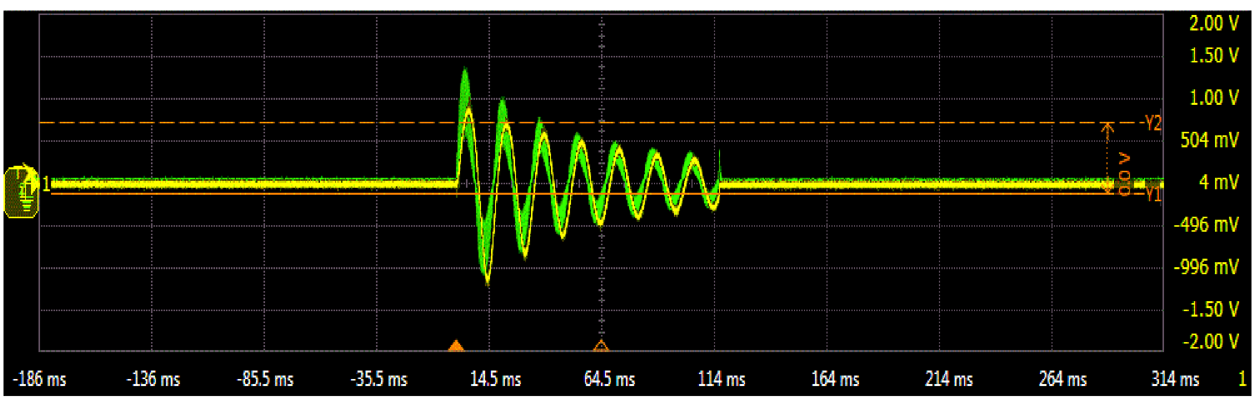

Figure 4-2. Attenuation of Welding during 7 Cycles Peak 5077A

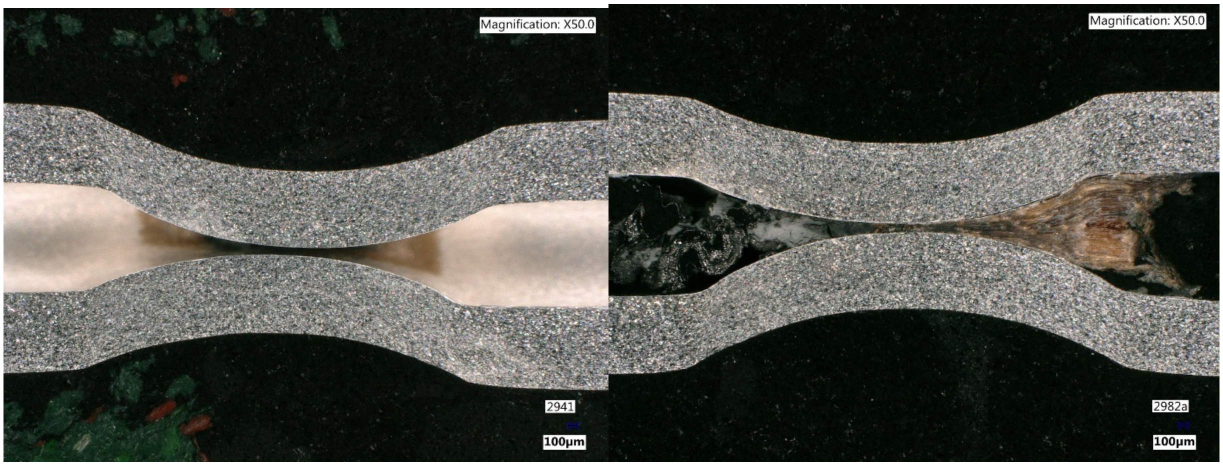

Figure 4-3. Cross Sections of Welds Performed with SSWT

5.0 Results and Discussion

The PDRD SSWT did not perform to the needs of the project for two main reasons. The first is that the step-down transformer was designed so that welds of up to 1000 Hz could be tested. This causes the transformer to saturate to under smaller amplitudes of current. The reason it was rated to 1000 Hz is because a 60Hz transformer would have never allowed for testing of 1000 Hz at high currents. However, the 1000 Hz transformer needed to be over designed to prevent saturation from happening or two transformers could have been used with a switch between the two depending on the test being performed. However, the increased cost would not fit in the existing budget and schedule of the PDRD and this modification would prevent the automatic operation of the welder.

The second reason the SSWT did not perform acceptably is because a constant amplitude could not be maintained due to the design of the DC bus capacitor for the system. This was evident only when adding the long connections to the weld head. During preliminary functional testing, when the welder leads were shorted the current lag was not present. This added resistance in longer cable leads causes the capacitor to discharge faster by requiring more power to drive current to the weld head. When the leads to the weld head are shortened it allowed for the reduction of DC discharge and a constant amplitude can be maintained. In the field, long bus bars connect the welder to the weld heads. This results in very low secondary resistance and could help with keeping the amplitude constant through the total amount of cycles.

6.0 Conclusions

The SSWT performance did not meet expectations, however, a next generation unit incorporating the recommended modifications above, would allow for generating welds that could be characterized and evaluated for use in the field. A replacement weld transformer would need to have a higher rating for the output current along with a better capacitor for keeping the charge during longer welds.

The design of the automation of the software and improved controls and sensors can be readily applied to the pinch welder systems deployed at SRTE. The automatic pressure regulator can be installed on the N_2 supply line and computer operated relays could be incorporated in the existing weld select switch boxes that apply pressure to move the weld head electrodes against the weld stem. There are additional cable penetration feed-throughs in the gloveboxes that can support the addition of the fiber-optic displacement sensors. Ethernet cable runs for the ARMS II interface are available in each welder cabinet. The fielded systems are National Instruments PXI chassis and are compatible with the automation software developed for this project.

7.0 Recommendations, Path Forward and Future Work

Open items that were not able to be finished for this project include:

- Fully integrated testing, evaluation, and weld qualifications performed and documented for standard tritium pinch welds and developmental welds using alternate tubing metals and methods.
- Testing of real-time feedback from sensors to change weld performance.
- Formal demonstration of data download/upload using an ARMS II sandbox system
- This project is to develop a direct replacement for existing systems under the purview of the Sandia and Los Alamos design laboratories. Development of this system requires design laboratory approval and alignment with corresponding projects at the laboratories and at the Kansas City National Security Campus. Consultation will need to occur with the Design Laboratories about the new design and possible integration into a Tritium process at SRS.

8.0 References

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Determination of Pinch Weld Quality Metrics using Data Fusion Methods, Paul Korinko
Aluminum Resistance Welding - Sandia National Laboratory, J. Puskar
Current Resistance Force Welding Activities at Sandia-Livermore, M. Maguire
Weld Evolution as a Function of Cycles, Paul Korinko, Bill West

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