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Welding the AT-400A Containment Vessel

Eldon Brandon

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Eldon Brandon
Mechanical Engineering Department
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0958

Abstract

Early in 1994, the Department of Energy assigned Sandia National Laboratories the responsibility for designing and providing the welding system for the girth weld for the AT-400A containment vessel. (The AT-400A container is employed for the shipment and long-term storage of the nuclear weapon pits being returned from the nation's nuclear arsenal.) Mason Hanger Corporation's Pantex Plant was chosen to be the production facility. The project was successfully completed by providing and implementing a turnkey welding system and qualified welding procedure at the Pantex Plant. The welding system was transferred to Pantex and a pilot lot of 20 AT-400A containers with W48 pits was welded in August 1997. This document is intended to bring together the AT-400A welding system and product (girth weld) requirements and the activities conducted to meet those requirements. This document alone is not a complete compilation of the welding development activities but is meant to be a summary to be used with the applicable references.

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Contents

Overview	1
Partners	2
Section 1. Development of the Welding System and Procedure	3
History	3
Design Requirements	5
Constraints	6
Design of Container	6
Design of Welding System	6
Description of Welding System	8
Description of Safety System	10
Development of Welding Parameters	12
Welding Program	14
Quality Requirements	17
Verifications of Conformance	17
Results	19
Section 2. Implementation of the Welding System at the Pantex Plant	23
Background	23
Demonstrations and Approvals	23
Section 3. Welding the Pilot Lot of Containment Vessels	27
Background	27
Welding Procedure	27
Data Collection	27
Findings	38
Section 4. Results and Conclusions	41
Acknowledgements	42
References	43

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Welding the AT-400A Containment Vessel

Overview

This project was part of a dismantlement activity and was initiated by a Department of Energy Albuquerque Office (DOE/AL) directive to Sandia National Laboratories (SNL) to develop and implement a welding system to perform the closure weld on containers for the shipment and long-term storage of plutonium pits.¹ The first production units (FPUs) were completed in August 1997, and post-FPU support continued into mid-1998. Environmental safety and health issues (especially nuclear safety, industrial safety, and environmental protection) were primary concerns, as were weld quality and welding system reliability and performance.

Several aspects of this program were very significant and visible. The cost of the welding equipment and development ultimately totaled approximately \$2 million over the 3-1/2-year period. The AT-400A constituted the first production arc-welding program at the Pantex (Px) plant. The fact that it was a pit container and the proximity of the weld to the pit added concern for the quality, safety, and reliability of the process. The success of this development effort is best reflected by DOE's and Pantex's acceptance of the process and procedure for pit containerization.

This paper describes the gas metal arc welding system, the safety controls, and procedures necessary to meet the requirements of the applicable federal regulations and the additional agency-imposed requirements.

- Section 1 summarizes the development of the welding equipment and procedure.
- Section 2 summarizes the implementation of the welding activity at Pantex.
- Section 3 summarizes the welding of the pilot lot of containment vessels.
- Section 4 summarizes the results and conclusions.

Partners

The agencies involved in this project were under the direction of the U.S. DOE/AL, Weapon Surety Division (WSD). The following agencies had a variety of responsibilities:

Agency	Responsibility
Sandia National Laboratories (SNL)	Design of container and provide welding system
Allied Signal/FM&T	Provide containers, sample rings, and support fixtures
Mason Hanger Corporation's (MHC) Pantex (Px) Plant	Containerization (production)
Lawrence Livermore National Laboratory (LLNL)	Pit support fixture design, welding process oversight
Los Alamos National Laboratory (LANL)	Pit support fixture design, welding process oversight

Section 1. Development of the Welding System and Procedure

History

Some of the welding-related activities associated with this project were:

- 1/12/94 Dept 2165 requested welding support from Dept. 1484 for the AT-400A.
- 1-4/94 Procured welding equipment and material and prepared sample rings.
Performed initial development using the gas tungsten arc welding process.
- 4/27/94 DOE directed that we change to the gas metal arc welding process.
- 8/16/94 Placed order with Jetline Engineering, Irvine, CA for two GMA welding systems for \$305,000.
- 2/20/95 Received the first system (S/N 34433) at SNL.
- 2-7/95 Conducted the following experiments at SNL:
 - Evaluated various compositions of shielding gas.
 - Evaluated various compositions of backing gas.
 - Experimented with weld joint geometry.
 - Experimented with one and two welding passes.
 - Experimented with welding gun angle.
 - Conducted fractional factorial experiment to optimize the five welding parameters.
 - Performed the welding and testing to qualify the welding procedure and to bracket the parameters.
- 5-7/95 Implemented the following changes to the Jetline system:
 - Added second camera and split screen.
 - Changed from Stenning to Jetline camera system.
 - Built pendant controls into control cabinet.
 - Added 120-volt outlet on control cabinet.
 - Added 120-volt outlet for fume exhaust system.
 - Added shelf to control cabinet.
 - Fixed position of chiller nozzles.
 - Programmed chillers to turn off during arc-on time.

- Added shroud over cabinet cooling fan.
- Added cover over Amphenol connectors on bottom of cabinets.
- Added video editor (to add notes to video).
- Implemented numerous changes to software including a change to do three spot welds and the seam weld as one program.
- Increased air solenoid from 1/4- to 3/8-inch to get adequate flow rate.
- Changed pulse rate monitor circuit to correct reported value and to increase response time.

7/25/95 Second GMA system (S/N 34434) was shipped from Jetline to Pantex Building
11-28 Training Facility.

9/28/95 Shipped first system from SNL to Pantex 12-99 Production Facility.

11/8-9/95 LLNL/SNL/Px performed thermal mockup test in 11-28.

1/10/96 Installed first iteration of spindle rotation sensor for independent safety system.

6/96 Implemented low arc energy welding parameters in 12-99.

7/9-10/96 LLNL/SNL/Px performed second thermal mockup test in 12-99.

9/17/96 Installed new SNL independent safety system in 11-28.

12/18/96 LANL/SNL/Px performed thermal mockup test in 11-28.

1/97 Implemented dynamic spot weld in 11-28.

1-2/97 Evaluated offset welding gun study.

2/97 Development of Safety Dog is underway in 11-28.

5/11/97 Completed System Test Plan in 12-99.

6/19/97 Contractor Operational Readiness Review (C-ORR) began.

7/22/97 DOE-ORR began.

8/25/97 FPU, CV # P000007.

Design Requirements

The federal requirements for the packaging and shipping of nuclear materials are defined in 10 CFR 71, *Packaging and Transportation of Radioactive Material*.² In addition, both Sandia and Pantex imposed supplemental requirements for additional safety and security purposes.

The Safety Analysis Report for Packaging (SARP)³ describes the AT-400A package and packaging procedures and documents conformance of the AT-400A packaging with 10 CFR 71. Sandia drawing 706112, *AT-400A Pit Container System*, lists the system-level specifications and drawings pertaining to this program.

The container design and construction quality was based on 10 CFR 71, Subpart H, *Quality Assurance*, and DOE/AL QC-1. 10 CFR 71, in turn, recommends the application of the ASME Boiler and Pressure Vessel Code Requirements for the Construction of Nuclear Power Plant Components for a Category B weld (which includes circumferential welded joints within the main containment shell). The Code and other supplemental requirements are summarized as follows:

Sandia specification SS706212⁴ lists the overall programmatic requirements and the container design requirements. This specification lists the design criteria and the normal and hypothetical accident condition tests defined in 10 CFR 71.71 and 71.73. Some specific requirements of SS706212 are:

- Design will conform to ASME Boiler and Pressure Vessel Code Section III, Division 1, Subsection NB whenever practicable. Any nonconformance will be documented in the SARP.
- Use austenitic stainless steel, no organic materials.
- Minimum inside height 17.82 inches, minimum inside diameter 13.25 inches.
- Design container for maximum temperature of 600 degrees F, no pressure requirement.
- 150 degrees F maximum allowable temperature at the surface of the pit.
- Fifty-year design life.
- Welded, tamper-resistant container.
- No melt-through of the weld joint during welding.
- Weld soundness, no cracks, limited internal indications, complete penetration.
- Maximum weld convexity of 0.050 inch (to provide radial clearance with outer container (overpack)).
- Leak tight per American National Standards Institute standard ANSI N14.5.
- Structural integrity as proven by a variety of destructive tests.

- Positive control of the container and pit during assembly and welding.
- Probability of breach of the containment vessel (CV), during and subsequent to assembly, of less than 10^{-7} .
- Maintain minimum radiation exposure of personnel by the principles of minimum exposure time, maximum distance, and proper shielding.

Constraints

The DOE directed that the gas metal arc welding process would be employed for this project.

In the interest of repeatability of the procedure and minimum radiation exposure, we designed the process to be fully automatic under computerized numerical control (CNC). Pantex stipulated that the welding operators were to not be in a decision-making position, i.e., after the initiation of the automatic welding cycle, they could only stop the welding cycle by actuating a sequence stop.

Obviously, any scenario that could result in the release of radioactivity was unacceptable. Prevention and mitigation of any release of radioactivity were paramount concerns. Not only did the container have to meet stringent design integrity requirements, but the processing equipment and procedures had to be fail-safe.

Design of Container

The container that was designed for this project had a 1/4-inch wall, 14-inch diameter, and 19-inch height with elliptical ends. The container was forged in two halves (shells) from 304L stainless steel (Figure 1).⁵ After inserting the contents (internal support structure and pit), the two shells were gas metal arc welded together. A 3/8-inch tube, which was previously welded in the upper container shell, was used to leak check, evacuate, and backfill the completed container.

Design of Welding System

Sandia was directed by DOE to deliver the welding system to the Pantex plant as government furnished equipment (GFE) through the Weapons Quality Division (WQD).⁶ A subsequent memo⁷ clarified some of the ASME weld quality references, especially with regard to the NDE requirements.

Figure 1. AT-400A containment vessel, designed by Sandia for off-site shipment and long-term storage of plutonium pits.

- Positive physical control of the container during all stages of the assembly.
- Minimum radiation exposure to personnel (ALARA concept).
- Fully automatic operation.

Description of Welding System

A gas metal arc welding system (Figure 2) was fabricated by Jetline Engineering, Irvine, CA, based on Sandia Purchase Order AL6630 and the associated technical specification⁸ for this application using primarily off-the-shelf components. The system was subsequently defined by Pantex drawing sets VT0030 (welding system) and VT0033 (independent safety system) and consists of the following components:⁹

Fixture. A vertical-axis welding fixture supports the container in the vertical position (plane of the weld is horizontal). The container rotates while the welding gun remains stationary. An electromechanical seam follower serves to move the welding gun both in-out and up-down to maintain a constant position relative to the weld groove. A pneumatic cylinder applies an axial loading of approximately 500 pounds to ensure that the weld joint is closed for welding.

Welding Power Supply. A standard Miller Maxtron 450-ampere constant current/constant voltage (CC/CV) DC welding power supply was modified to switch modes from constant current to constant voltage during the pulse cycle. Specifically, during the low-current portion of the cycle, the power supply operates in a constant voltage mode. It switches to a constant-current mode during the high-current portion of the cycle. This modification was done by Jetline to optimize the control of the welding arc, i.e., to keep the arc directed at the bottom of the U-groove and to maximize the weld penetration.

CNC. The computerized numerical control was designed and built by Jetline using a 386-based controller. The programmer/controller provides CNC control of the weld sequence and the welding parameters using a resident program. The welding program is entered by keyboard input and then stored or can be programmed off-line and then entered by a floppy disk. Provisions are also provided to communicate remotely via an RS-232 port.

Data Acquisition System. The data acquisition system is an integral part of the CNC and samples each of the five primary welding parameters at the rate of 10 samples per second. It then stores the data to the hard drive for later downloading to a floppy or to a remote location via the RS-232 port. The data are used only for statistical process control and diagnostics, not for product acceptance.

Figure 2. The gas metal-arc welding system that was implemented at the Mason Hanger Corporation Pantex Plant for the girth weld on the AT-400A containment vessel.

Primary System Monitor. The primary system monitor is also integral with the CNC. It samples each of the five welding parameters and five secondary conditions at the rate of 30 to 50 samples per second and stops (or prevents a start of) the weld if an abnormal condition exists.

Video System. Two charge-coupled device cameras view the weld area during the welding, one from the front and the other from the trailing side. The output is displayed on a split screen monitor and is also recorded on a video recorder for later observation and documentation. The date, weld number, and any other pertinent information are recorded on the video. The video is used only for diagnostics, not for product acceptance.

Vortex Cooler. Two commercial vortex tubes, Exair Model 5215 Cold Guns, are attached to the welding fixture and are directed toward the weld joint to cool the weld area before and after welding. The program turns on the cold guns 5 minutes before the weld begins, turns them off during the arc-on time (to avoid disturbing the arc shielding gas), and turns them on again at the end of the weld time for an additional 5 minutes while the fixture continues to rotate.

Description of Safety System

Primary System Monitor. The primary system monitor is integral with the Jetline CNC and samples the five welding parameters at a rate of 30 to 50 samples per second and stops the welding if any of the five welding parameters is out of its allowable limits for greater than 1/2 second.

The primary welding monitor (the Jetstar computer) will initiate shutdown if any of the primary welding parameters is abnormal for > 0.5 second:

- peak welding current exceeds $\pm 10\%$ from set value of 240 amperes,
- wire speed exceeds $\pm 15\%$ from set value of 460 ipm,
- travel speed exceeds $\pm 5\%$ from set value of 13 ipm,
- background voltage exceeds $\pm 30\%$ from set value of 21 volts,
- pulse rate exceeds $\pm 5\%$ from set value of 160 Hz;

or if any of the following secondary conditions are abnormal:

- assembly cart is not in correct position for welding,
- welding fixture is not in the full up (welding) position,

- cooling water flow is too low,
- cover gas flow is too low,
- backing gas flow is too low.

Independent Safety Monitor. During the course of testing abnormal events, we found that if we forced the fixture to stop rotating and the welding arc/wire feed to continue, a melt-through of the weld joint would occur after about 10 seconds. Similarly, melt-through could occur if the fixture rotation slowed, and at the same time, the welding current increased uncontrollably. To further preclude this event from happening (which would require a simultaneous failure of the fixture drive, the CNC monitor, and of the operator to react to the abnormal sight and sound for an extended period of time), a totally independent monitor and shutdown system was designed and added for additional safety.

The independent safety monitor is totally independent of the Jetline computer and, except for the sensors, is housed in a separate, stand-alone cabinet. It was designed and built by Pantex and is designated by tool numbers VT0033 (the cabinet and associated circuitry) and VT0034 (the calibration adapter). It serves as a redundant system (i.e., totally separate and independent from the Jetstar CNC) and monitors the welding current and travel speed and stops the welding in the event of an undercurrent, overcurrent, or an underspeed condition. Two independent travel speed monitor circuits—one that monitors the speed of the drive spindle (upper welding chuck) and one that monitors the rotation of the container via an idler wheel/encoder which runs on the surface of the container. Also, there are two independent current monitors. Both sense the RMS current in the welding cable via separate Hall-effect devices.

The independent safety system will terminate welding if:

- The spindle rotation speed slows to < 10 ipm.
- The CV rotation speed slows to < 10 ipm.
- The RMS welding current A rises to > 200 A for > 2 seconds.
- The RMS welding current A rises to > 260 A for > 200 milliseconds.
- The RMS welding current B rises to > 200 A for > 2 seconds.
- The RMS welding current B rises to > 260 A for > 200 milliseconds.
- The RMS welding current A drops to < 70 A for > 100 milliseconds.
- The RMS welding current B drops to < 70 A for > 100 milliseconds.

Notes: Welding currents A and B are redundant monitors on the same circuit. The low welding current condition may indicate an arc outage as might happen if a melt-through occurred.

Development of Welding Parameters

High Arc Energy Welding Procedure. The initial welding development was performed at SNL using high arc energy welding parameters (this term is used to distinguish from the subsequent low arc energy parameters), based on the observation that those parameters resulted in optimum weld quality. Those parameters were optimized by running a face-centered cubic design five-factor, three-level fractional factorial experiment based around parameters that had been found to produce acceptable welds in preliminary welding tests. The experiment consisted of making 29 weld segments using predefined combinations of the independent variables. The independent variables were the five welding parameters, and the levels of each were as follows:

- Peak current 250, 300, 350 A
- Background voltage 20, 23, 26 V
- Travel speed 16, 22, 28 ipm
- Wire speed 550, 650, 750 ipm
- Pulse rate 80, 120, 160 Hz

The resultant welds were subjectively rated by three welding personnel (E. Brandon, F. Hooper, T. Marquez) using criteria of visual appearance, penetration, and fill of the weld groove. The data were normalized and analyzed by Steve Crowder, 12323. His model indicated that the resulting optimum parameters (based on criteria of weld smoothness, weld profile, weld width (fill of groove), and penetration) were as follows:

High Arc Energy Welding Parameters

308 amperes
24 volts
20 ipm travel speed
770 ipm wire speed
157 Hz pulse rate

We qualified the welding procedure by making and evaluating three sample weld rings.

Low Arc Energy Welding Procedure. The possibility of melt-through brought about the concern regarding nuclear safety, and we were directed to try to perform the weld at parameters that would not cause a melt-through if the CV stopped rotating and the welding arc continued.

Hence, we proceeded to develop and optimize the parameters to perform the weld at about 30 percent less arc energy. This development was performed in Pantex Building 11-28.

In optimizing the low arc energy parameters, the independent variables were the same five welding parameters as before. Also, the criteria for evaluating the results were the same as before—weld smoothness, weld profile, weld width (fill of groove), and penetration. Again, the new parameters were optimized by running a face-centered cubic design five-factor, three-level fractional factorial experiment based upon parameters that had been found to produce acceptable welds in preliminary welding tests. The experiment consisted of making 29 weld segments using predefined combinations of the independent variables. The independent variables were the five welding parameters and the levels of each were as follows:

- Peak current 230, 240, 250 A
- Background voltage 21, 23, 25 V
- Travel speed 12, 14, 16 ipm
- Wire speed 460, 480, 500 ipm
- Pulse rate 120, 140, 160 Hz

The resultant optimum parameters:

Low Arc Energy Welding Parameters

240 amperes

21 volts

13 ipm travel speed

460 ipm wire speed

160 Hz pulse rate

In accordance with SS706178, the welding procedure was documented as WPS-2¹⁰ and PQR-2.¹¹ We subsequently made three more sample ring welds in Building 12-99 to confirm the results of the prior qualification performed in 11-28. The confirming qualification was documented as WPS-2a¹² and PQR-2a.¹³

It turned out that the heat input (amps x volts / travel speed) was approximately the same for the two welding procedures, but the hypothetical time-to-melt-through at zero travel speed would be longer for the low arc energy condition (because of the lower arc energy). The heat inputs were:

	<u>Volts × Amps / Travel Speed = Heat Input / Length of Weld *</u>				
High Arc Energy	24	×	308	/	20 = 24.6
Low Arc Energy	21	×	240	/	13 = 22.9

*Note: These values are shown for comparison only. The heat input value shown above is not the true heat input (i.e. joules) because the voltage and amperage values are background and peak, respectively, not RMS values.

Welding Program

The welding program, SEAM, makes three tack welds that are used to hold the upper and lower halves of the CV together for the seam weld. The three tack welds are automatically positioned at 90-degree intervals and the seam weld starts at the fourth 90-degree position. The vortex coolers then come on and the weldment rotates at 1 rpm for 5 minutes to precool the weld area before welding. The coolers turn off and the part rotation slows to 13 ipm for the one-pass seam weld. With a container circumference of 44 inches, the resultant weld time is 3 minutes 23 seconds. The welding current is pulsed at a rate of 160 hertz between a peak value of 240 amperes and a background of approximately 140 amperes. The arc voltage varies to produce the programmed welding current but is programmed to be 21 volts during the background portion of the pulse. (The resultant RMS current and voltage values are about 168 amperes and 23 volts, respectively.) The wire speed is programmed at a constant 460 ipm. At the conclusion of the weld, the vortex coolers come back on for 5 minutes while the weldment again rotates at a rate of 1 rpm.

To meet the 0.050-inch maximum weld convexity requirement at the weld overlap, the parameters are programmed to produce an up-slope taper at the start of the weld and a down-slope taper at the end of the weld (at the overlap).

A printout of the SEAM weld program is given as Table 1.

Table 1. Weld Parameters Program - Production Welder

Jetline Engineering

Jetstar GMAW

Date: 5/9/97

Weld Program: SEAM

Description: AT-400A, 360-Degree Weld, Normal Parameters

Date Created: 5/30/96

Last Modified: 5/09/97

Created by: Eldon

Modified by: Eldon

Back Preflow(s):	300.00
Back Postflow(s):	1.00
Torch Gases Preflow(s):	10.00
Torch Gases Postflow(s):	10.00
Part Diameter:	14.00 in
Weld Direction:	0
Monitor Weld:	1
Acquire Data:	1

1st Channel:	PEAK CURRENT
2nd Channel:	WIRE FEED SPEED
3rd Channel:	WELD TRAVEL
4th Channel:	BACKGRND VOLTAGE
5th Channel:	FREQUENCY
6th Channel:	TEMPERATURE 1

Part Number:	Various
Arc Transfer:	Pulsed Spray
Filler Material:	0.035 E308L
Base Metal:	304L
Weld Process:	P-GMAW
Weld Joint:	Narrow U-Groove
Current Type:	DCRP
Shield Gas:	Ar-5C0 ₂
Note:	240 A-21V-13 ipm

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Table 1. (Continued)

Chan- nel Note 1	Seg- ment	Start Value	End Value	Seconds/ Degrees Note 2	Monitor Level (%)	Stop Level (%)	Acquire Time (s)	Pulse Rate (Hz)	Peak Time (%)	Seam Tracker Note 3
1	0	180.0	240.0	3.0 DP	20.0	20.0	0.1	160.00	40.00	0
1	1	240.0	240.0	342.0 DP	10.0	10.0	0.1	160.00	40.00	0
1	2	240.0	240.0	21.0 DP	10.0	10.0	0.1	160.00	40.00	0
1	3	240.0	225.0	3.0 DP	20.0	20.0	0.1	160.00	40.00	0
1	4	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
1	5	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
1	6	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
1	7	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
1	8	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
1	9	240.0	0.0	0.2 SN	10.0	50.0	1.0		50.00	0
2	0	460.0	460.0	5.0 DN	100.0	100.0	1.0		50.00	0
2	1	460.0	460.0	340.0 DN	15.0	15.0	1.0		50.00	0
2	2	460.0	460.0	21.0 DN	15.0	15.0	1.0		50.00	0
2	3	460.0	300.0	3.0 DN	40.0	40.0	1.0		50.00	0
2	4	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
2	5	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
2	6	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
2	7	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
2	8	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
2	9	480.0	0.0	0.2 SN	10.0	50.0	1.0		50.00	0
3	0	44.0	13.0	5.0 DN	20.0	20.0	1.0		50.00	1
3	1	13.0	13.0	333.0 DN	5.0	5.0	1.0		50.00	1
3	2	13.0	13.0	32.0 DN	5.0	5.0	1.0		50.00	0
3	3	13.0	44.0	3.0 DN	80.0	80.0	1.0		50.00	0
3	4	44.0	44.0	300.0 SN	100.0	100.0	1.0		50.00	0
3	5	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
3	6	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
3	7	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
3	8	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
3	9	13.0	10.0	0.2 SN	10.0	50.0	1.0		50.00	0
4	0	20.0	21.0	3.0 DN	40.0	40.0	1.0		50.00	0
4	1	21.0	21.0	342.0 DN	30.0	30.0	1.0		50.00	0
4	2	21.0	21.0	21.0 DN	30.0	30.0	1.0		50.00	0
4	3	21.0	23.0	3.0 DN	50.0	50.00	1.0		50.00	0
4	4	0.0	0.0	0.0 SN	10.0	50.00	1.0		50.00	0
4	5	0.0	0.0	0.0 SN	10.0	50.00	1.0		50.00	0
4	6	0.0	0.0	0.0 SN	10.0	50.00	1.0		50.00	0
4	7	0.0	0.0	0.0 SN	10.0	50.00	1.0		50.00	0
4	8	0.0	0.0	0.0 SN	10.0	50.00	1.0		50.00	0
4	9	25.0	25.0	0.2 SN	10.0	50.00	1.0		50.00	0
5	0	160.0	160.0	6.0 DP	100.0	100.0	1.0		50.00	0
5	1	160.0	160.0	7.0 DP	50.0	50.0	1.0		50.00	0
5	2	160.0	160.0	345.0 DP	5.0	5.0	1.0		50.00	0
5	3	160.0	160.0	11.0 DP	5.0	5.0	1.0		50.00	0
5	4	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
5	5	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
5	6	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
5	7	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
5	8	0.0	0.0	0.0 SN	10.0	50.0	1.0		50.00	0
5	9	160.0	160.0	0.2 SN	10.0	50.0	1.0		50.00	0

Note 1 Ch 1 = peak current, Ch 2 = wire speed, Ch 3 = travel speed, Ch 4 = background voltage, Ch 5 = pulse rate

Note 2 D = degrees, S = seconds, P = pulsed, N = not pulsed

Note 3 0 = seam tracker locked out, 1 = seam tracker operative

Quality Requirements

The quality assurance program for the AT-400A container is described in QP706211.¹⁴ This Sandia document defines the general quality practices applicable to (1) the overall project, (2) the design of the container and internal support fixtures, (3) the production practices for the container and internal support fixtures, and (4) the support of Pantex assembly processes.

In addition, both Sandia and Pantex imposed supplemental requirements on the welds for additional quality, safety, and security purposes. The ASME B&PV Code Section IX¹⁵ and ANSI/AWS B2.1¹⁶ were used as guides in controlling the weld quality. SS706178¹⁷ defines the procedure for qualifying the operators, the welding system, and the welding procedure.

During the AT-400A pilot lot production welding, Pantex made and evaluated a sample weld ring at the start of each day's production.¹⁸ The test results were used as a partial monitor of the performance of the welding equipment for that day and also used to build up a data base of the measured welding parameters. The sample welds were evaluated visually, radiographically, and metallographically.¹⁹ Visual examination included a check with a go/no go gauge of the overall weld diameter (must be less than 14.100 inches) and also a check of any undercut/lack-of-fill condition. Radiographic requirements are based on ASME B&PV Code Section III²⁰ for rounded indications and by SS706213¹⁸ for linear indications. Metallographic requirements are based on requirements similar to the radiographic requirements.¹⁸

Evaluation/acceptance of the CV welds was by visual, leak check, and ultrasonic inspection in accordance with the requirements of SS706451.²¹

Verifications of Conformance

Weld Quality. As one measure of product quality, the ASME Boiler and Pressure Vessel Code was employed as a standard for product quality to the extent possible. Because certain ASME Code requirements such as radiographic inspection could not be performed on the AT-400A container because of the presence of the plutonium, we took compensatory steps to ensure quality. For example, ASME Section IX—Welding Qualification—requires that one weld be made and examined to qualify the welding procedure. We required that three welds be made and examined.

To arrive at a welding process suitable for ASME Code qualification, the welding parameters were optimized through an iterative series of box-centered cubic factorial design experiments. The desired weld characteristics were 100 percent joint penetration, a flat weld profile, complete joint fill, minimum internal defects, and minimum heat input. The first iteration employed a fairly wide range of parameters. We used the results of the first iteration to conduct a second experiment using a narrower range of parameters in

order to get a better optimization of welding parameters, in particular, improving on the requirement for a flat weld profile. The third iteration was necessary to further reduce heat input to the weld to give a greater margin of safety. By this iterative approach we arrived at a combination of welding parameters that resulted in the best welds. These welding parameters were used to produce the three welds for welding procedure qualification. The resulting three welds passed the ASME Code required mechanical and nondestructive tests.

Qualification. The SEAM welding program was qualified by making and evaluating three sample welds in accordance with the requirements of ASME Section IX, which specifies tensile and bend tests, and radiographic and metallographic evaluations.²² In addition, each welding operator was qualified by making one weld that was evaluated in the same manner as the procedure qualification welds, except that mechanical tests were not required.

QE/EE. The welding process, including the welding system and welding procedure, was formally qualified for production through a joint Qualification Evaluation/Engineering Evaluation (QE/EE) conducted by a Product Realization Team comprised of AT-400A project representatives and welding engineers from SNL, LLNL, LANL, and Pantex. The QE/EE plan required demonstrations of the welding process under production conditions and evaluation of the resulting welds for conformance to the weld acceptance requirements specified for sample welds¹⁹ and CV welds,²¹ as well as the welding procedure qualification requirements.¹⁶

The QE/EE plan also required a formal equipment qualification of the welding system to ensure that the welding system and related controls and documentation, i.e., welding system drawings, calibration and maintenance procedures, and software quality plan, were in place for production. The equipment qualification plan²³ also required satisfactory completion of the System Test Plan (STP)²⁴ as evidence of acceptable system performance and reliability. This STP was designed to exercise all normal and abnormal operational scenarios of the welding system by conducting a series of 274 tests. The response of the built-in safety systems when the welding system was operated under forced off-normal conditions was a prime factor in system acceptance or failure. To meet the target of $<10^{-7}$ probability of failure of the safety systems to operate properly, no failures were allowable during this STP.

Because of iterative changes made to the welding system to reduce the failure probability to $<10^{-7}$, the STP was conducted three times. Even though no failures occurred in any of the three test series, several anomalies were found and corrected and the particular test run repeated. For example, during one series of normal welds, the safety system initiated a shutdown when it sensed an underspeed condition. The cause was traced to a weak spring on the speed sensor (tachometer) and was corrected. During another normal weld the operator did not detect a mechanical problem during the setup and the system initiated a shutdown. This was corrected by adding a step to the operating

procedure. By the third test series, there were no failures and no anomalies, ultimately resulting in an acceptable QE status for the welding system.

Product Acceptance. As one step for product acceptance, a sample weld is made at the beginning of each production shift. The sample weld is evaluated visually, radiographically, and metallographically in accordance with the requirements for sample welds.¹⁹ The successful results of that weld are used for partial acceptance of the product welded during that shift. This requirement was deleted at the completion of the first 20 pilot lot welds (see subsequent heading: *Results. Sample Weld Ring*).

In addition, each product weld is examined visually and by a helium leak test prior to crimping and welding the fill tube on the upper CV shell. Each CV weld is subsequently ultrasonically tested.²¹

Results

Effectiveness of Heat Sinking.^{25, 26} We evaluated the effectiveness of air-cooled and water-cooled welding chucks at SNL by measuring the temperatures on the inside of sample weld rings during gas tungsten arc welding. Three conditions of chuck cooling were employed: (1) no supplemental cooling, (2) finned copper heat sinks with compressed air impinging on the fins, and (3) water-cooled heat sinks on the welding chucks. The welding program consisted of four passes at 18 ipm and the use of 260 and 300 amperes welding current.

The results indicated that both methods of supplemental cooling significantly reduced the weldment temperatures and that the effectiveness was about the same for the two methods. Because of the strong desire to avoid water in the production welding facility at Pantex and the extra complexity of the water cooling, we chose to pursue air cooling in subsequent welding development. In fact, the next step was to implement vortex coolers and a copper finned extension on the aluminum welding chucks.

Thermal Mockup Tests. At the direction of LLNL, a thermal mockup test was performed at Pantex 12-99 Bay 4 on November 8-9, 1995 under simulated production welding conditions using an electrically heated unit to simulate the thermal output generated by a pit. Thermistors were placed inside the containment vessel on the surface of the simulated pit and at various locations on the support fixture. After implementing a lower arc energy welding procedure, the thermal mockup test was repeated on July 9-10, 1996.²⁷ A peak temperature of 105 degrees F was reached after the welding was completed. (The maximum allowable temperature at the surface of the pit was 150 degrees F.)

A similar thermal mockup test was performed on December 18-19, 1996, in Building 11-28 for LANL.²⁸ The temperature measurements were similar to those

given above and the conclusion was that the welding would not result in an excessive temperature of the pit.

Safety. We demonstrated that the original weld program could result in melt-through of the weld joint if several very unlikely events occurred simultaneously. Specifically, (1) if the welding control system failed, and (2) the parameter monitor system failed, and (3) the fixture stopped rotating for a long period of time, and (4) the operator failed to respond to the abnormal sight and sound of the arc, and (5) the welding arc continued uninterrupted. The safety enhancement concentrated on minimizing the possibility of these events, despite the fact that the occurrence of a melt-through of the CV followed by melt-through of the pit casing was never proven or even explored, and that the likelihood of a string of simultaneous failures that could allow such an event to occur was incredibly low.

In a series of activities to minimize the possibility of a melt-through, we (1) developed an new set of welding parameters and qualified the new procedure, and (2) designed and built a new, redundant, monitor system for the welding current and travel speed.

The new welding parameters resulted in about the same heat input but less arc energy with the result that the weld penetration was only slightly less, and the time-to-melt-through was several seconds longer.

Using lessons learned from the first iteration of a safety system, Pantex designed and built a new, stand-alone safety system. The new system has two independent current monitors and two independent travel speed monitors. Including the Jetline computer monitor, we now have four independent travel speed monitors and three independent current monitors.

We have performed hundreds of welds under controlled conditions to verify the system reliability, repeatability, and safety. Each of the off-normal conditions was simulated many times on each of the safety circuits to demonstrate that all of the safety systems terminated the welding action reliably. We can confidently state that the containers can be safely and reliably arc welded with an acceptably low probability of system failure and consequent melt-through.

Sample Weld Ring. The rationale for implementing the sample weld ring was that this test would verify the performance of the welding system on inexpensive, non-WR hardware. Also, since the CVs could not be radiographed, the results would be used as a partial acceptance of the lot of CVs welded during the day. Also, the weld parameter data that would be collected by the welding of the rings would accelerate the accumulation of a data base that would be used for the subsequent design of a statistical process control tool.

This requirement for the daily sample weld ring was dropped at the conclusion of the first 20 pilot lot CVs. The rationale for deleting this requirement was based on the long time required to perform the sample weld (due to the lengthy Pantex operation procedure) and the lack of proven correlation between the sample weld and the subsequent CV weld.

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Section 2. Implementation of the Welding System at the Pantex Plant

Background

Mason Hanger Corporation's Pantex Plant was named by DOE to perform the containerization of the pits upon weapon disassembly. The production welding system and the pit imaging, assembly, gross leak check, laser marker, a code reader, and a contingency cut-apart station were set up in Building 12-99 Bay 4. In addition, a functionally identical welding system for operator training was set up in Building 11-28.

The gas metal arc (GMA) welding system was procured from Jetline Engineering, Irvine, CA, based on SNL purchase order AL-6620 dated August 18, 1994, and the associated technical specification. The first system (serial number 34433) was installed at SNL and was used to develop the initial welding procedure. Experience with the first system led to several changes in the hardware and software. The changes were incorporated into the first system and a second welding system was ordered from Jetline Engineering. The first system was subsequently shipped to the production facility at Pantex as GFE.⁶ The second system (serial number 34434) was shipped directly from Jetline to Pantex and installed in Building 11-28.

Demonstrations and Approvals

Unreviewed Safety Question. The welding of pit containers was a new process for Pantex. Consequently, Pantex determined that the use of the GMA welding system for pit packaging constituted an Unreviewed Safety Question (USQ).²⁹ As such, additional safety measures were identified and implemented to ensure a negligible probability of failure, i.e., an airborne release of radioactive material during the welding. Consequently, a series of formal demonstrations and approvals were required to formally demonstrate the safety of the new system and procedure.

Engineering Evaluation. The engineering evaluation consisted of a joint QE/EE activity run by a Product Realization Team comprised of SNL, LLNL, LANL, and Pantex representatives. The QE/EE was conducted in accordance with standard NWC practices.^{30, 31} The QE/EE resulted in a conditional Qualification Evaluation Release³² allowing Pantex to start AT-400A production, but requiring incorporation of an automated ultrasonic weld inspection system during the initial production of 50 units. There were no conditions on the welding process or the welding system.

System Test Plan. A formal series of tests was conducted on the Production welding system in Building 12-99 per the tests and demonstrations defined in the system test plan,²⁴ which describes the plan in detail and also includes the results as appendices.

The system test plan was based on some of the requirements of the EE/QE and was conducted in partial fulfillment of those requirements.

The tests were used for the initial qualification of the welding system and are to be used for retesting following any subsequent changes to the welding system. The tests are also to be conducted following any calibration and maintenance operations as indicated in the calibration procedure³³ and the maintenance procedure.³⁴

Specifically, the test plan evaluates the welding system and ancillary components in their normal range of operation. The normal range of operation is defined by the welding parameters which were developed for the girth weld and the control bands of the welding parameters as defined by the requirements for the welding system.⁸

The test plan also evaluates the safety features of the welding system in the range of safe operation as defined by the welding parameters and the shutdown limits in the production weld program and the VT0033 Girth Weld Safety System.³⁵

The test plan does not address the suitability of the weld program to produce quality welds.

The tests and the number of replications of each test are listed in Table 2.

The results of the testing are detailed in the System Test Plan,²⁴ Appendices C, D, and E. Several "no tests" were experienced during the testing. The explanations for each "no test" are also given in detail. In summary, the welding and safety systems performed normally, and the test results were acceptable.

C-ORR. The contractor operational readiness review was performed at MHC's initiative to verify readiness for the DOE-ORR. All findings were satisfactorily resolved.

DOE-ORR. The DOE operational readiness review was conducted as a DOE requirement to verify complete operational readiness of the production facility and processes. All findings were satisfactorily resolved.

Table 2. Summary of Tests Performed for the System Test Plan

Demonstrate Normal Operation

Normal seam weld process	23 complete welds
Normal tack weld process	23 tack welds

Demonstrate Jetstar Monitor/Shutdown System

Peak current (high)	5 runs
Peak current (low)	5 runs
Background voltage (high)	5 runs
Background voltage (low)	5 runs
Travel speed, high	5 runs
Travel speed, low	5 runs
Wire speed, high	5 runs
Wire speed, low	5 runs
Pulse rate, high	5 runs
Pulse rate, low	5 runs

Demonstrate Independent Safety System (VT000033)

Overcurrent, moderate, monitor A	23 runs
Overcurrent, moderate, monitor B	23 runs
Overcurrent, high, monitor A	23 runs
Overcurrent, high, monitor B	23 runs
Low travel speed, spindle	23 runs
Low travel speed, CV	23 runs

Demonstrate Secondary System Interlocks

Pre-weld	
Torch gas off	5 runs
Backing gas off	5 runs
Torch water off	5 runs
Fixture out-of-position	5 runs
During-weld	
Torch gas off	5 runs
Backing gas off	5 runs
Torch water off	5 runs
Fixture out-of-position	5 runs

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Section 3. Welding the Pilot Lot of Containment Vessels

Background

A Conditional Qualification Evaluation Release, C/QER 960007LL³² was issued by LLNL to authorize the start of AT-400A production. The initial production consisted of 20 CV units which were for the containment of W48 pits. The FPU, serial number P000007, was welded on August 25, 1997, and the twentieth was welded on December 10, 1997.

The log of those twenty CVs and the twenty sample welds that supported the CV welds is included as Table 3. (The log shows a total of 41 welds since CV P000024 was cut open and the pit repackaged as P000058.)

Welding Procedure

The welding system, calibration, and welding procedure were unchanged throughout the pilot lot production. Only the configuration of the purge tube was modified during this time to improve the vent path for the backing gas from the CV (see the following section, *Findings—Weld Ripple*).

The Jetstar software upgrade diskette was dated 11/18/96 by Jetline Engineering. The software upgrade was installed in the Jetstar computer on 3/4/97 and was automatically assigned version number 748968. The SEAM weld program is employed for all production welds. It was created on May 30, 1996, and was last modified on May 9, 1997, by Eldon Brandon. This software configuration was used throughout the contractor and DOE Operational Readiness Reviews and the pilot lot production. The SEAM program that was employed was presented earlier as Table 1.

Data Collection

Note that the weld parameter data are used only as an aid for diagnostic purposes and not as an indicator of product quality.

The weld parameter data are collected by the Jetstar computer at a rate of 10 samples per second for each of the five welding parameters. These data are then compiled and analyzed in a variety of ways to evaluate:

- (1) the correlation of the average (measured) value with the set (command) value for each parameter for each weld,
- (2) the range of each of the parameters (the standard deviation) during each weld, and

(3) the trend of each parameter during a series of welds.

The mean and standard deviation values of each of the five parameters for the 41 welds were calculated. The results are listed in Table 4. As an aid in interpretation of the data, the mean and standard deviations are plotted in Figures 3a-3d.

As an example of the weld parameters during each weld, the five parameters of weld number P000052 are plotted in Figures 4a-4c. (P000052 was the first CV welded after the purge tube was changed.) These plots are given only to show the general appearance of the data of a typical weld.

Table 3. AT-400A Weld Log

Weld Number	W48 Pit #	Weld Date & Time	Engrg Technician	Notes
S000006		8/25/97 8:28	D. Bull	1
P000007	8834	8/25/97 16:25	L. Fussell	2
S000010		8/26/97 10:32	P. Sena	
P000009	3252	8/26/97 14:52	L. Fussell	
S000011		8/28/97 9:48	P. Sena	
P000012	7431	8/28/97 17:55	P. Sena	
S000014		9/5/97 7:26	D. Bull	
P000015	1833	9/5/97 14:57	D. Bull	
S000019		9/22/97 8:10	K. Teter	
P000020	4324	9/22/97 12:56	K. Teter	
S000021		9/23/97 9:26	T. Flowers	
P000022	6583	9/23/97 14:50	T. Flowers	
S000023		9/24/97 9:41	K. Teter	
P000024	7615	9/24/97 14:00	J. Ramirez	2, 3
S000031		10/7/97 8:26	L. Fussell	
P000032	9837	10/7/97 14:44	P. Sena	2
S000034		10/8/97 14:56	K. Teter	
P000033	4458	10/8/97 17:21	D. Bull	
S000035		10/9/97 9:13	J. Ramirez	
P000036	8796	10/9/97 13:57	T. Flowers	
S000038		10/16/97 9:18	L. Fussell	
P000037	4626	10/16/97 13:16	J. Ramirez	2
S000040		10/17/97 9:32	D. Bull	
P000039	6877	10/17/97 14:41	D. Bull	2
S000041		10/20/97 9:22	K. Teter	4
P000042	7270	10/20/97 13:47	P. Sena	2
S000044		10/24/97 9:26	J. Ithaca	
P000043	8641	10/24/97 14:09	J. Ithaca	2
S000046		10/27/97 10:28	J. Ramirez	
P000045	8681	10/27/97 15:47	L. Fussell	
S000048		10/28/97 11:07	L. Fussell	
P000047	7686	10/28/97 15:10	L. Fussell	2
S000049		10/29/97 10:29	J. Ramirez	
P000050	3509	10/29/97 14:23	J. Ramirez	2
S000051		12/5/97 10:38	L. Fussell	5, 6
P000052	8312	12/5/97 15:35	D. Bull	
S000054		12/8/97 9:59	D. Bull	
P000053	8964	12/8/97 14:51	L. Fussell	
S000057		12/10/97 10:14	J. Ramirez	
P000056	5335	12/10/97 15:58	P. Sena	
P000058	7615	12/10/97 19:13	D. Bull	7

Notes

1. Weld Number Sxxxxxx identifies a sample weld ring, Weld Number Pxxxxxx identifies a production CV weld.
2. Weld exhibited rippled surface for a portion of the circumference.
3. Weld exhibited blowhole at approximately 2 inches from overlap, CV was cut apart, pit repackaged as P000058.
4. Failed X-ray.
5. The backfill purge tube was changed between welds P000050 and S000051 (see text).
6. The new tube was employed for the remainder of the welds.
7. Repackage of pit 7615 from P000024.

Table 4. AT-400A Pilot Production

Weld Number	Ch 1 Current		Ch 2 Wire Speed		Ch 3 Travel Speed		Ch 4 Voltage		Ch 5 Pulse Rate	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
S000006	240.0	2.6	447.8	4.5	12.9	0.0	21.0	1.0	157.9	0.1
P000007	240.0	2.9	458.5	5.8	12.9	0.0	21.0	0.7	158.1	0.1
P000009	240.0	1.7	463.1	5.1	12.9	0.0	21.0	0.7	158.1	0.1
S000010	240.0	1.6	461.4	4.6	12.9	0.0	21.0	1.1	157.9	0.1
S000011	240.0	2.1	463.5	4.5	12.9	0.0	21.0	0.7	157.9	0.1
P000012	240.0	1.5	455.8	2.7	12.9	0.0	21.0	0.8	158.0	0.1
S000014	240.0	0.9	451.9	6.7	12.8	0.0	22.3	1.1	157.9	0.1
P000015	240.0	1.1	463.5	3.3	12.9	0.0	21.0	0.9	158.0	0.1
S000019	240.0	1.1	461.2	3.6	12.9	0.0	21.6	0.9	158.0	0.1
P000020	240.0	2.3	455.3	2.2	12.9	0.0	21.0	0.6	158.1	0.1
S000021	240.0	1.0	455.1	2.2	12.8	0.0	21.7	0.9	157.9	0.1
P000022	240.0	3.0	460.8	5.7	12.9	0.0	21.0	0.9	158.0	0.1
S000023	240.0	0.9	456.1	4.3	12.8	0.0	21.4	1.0	157.9	0.1
P000024	240.1	3.1	454.6	2.3	12.9	0.0	21.0	1.2	158.0	0.1
S000031	240.0	0.9	450.9	2.3	12.8	0.0	21.8	0.8	157.9	0.1
P000032	240.0	1.8	463.0	3.7	12.9	0.0	21.0	0.9	157.9	0.1
P000033	240.0	2.2	458.5	3.7	12.9	0.0	21.0	0.9	158.1	0.1
S000034	240.0	0.7	454.3	3.3	12.8	0.0	22.5	0.8	157.9	0.1
S000035	240.0	1.7	453.1	5.8	12.8	0.0	21.8	0.8	157.9	0.1
P000036	240.0	1.3	456.1	4.7	12.8	0.0	21.0	0.9	158.0	0.1
P000037	240.0	3.0	459.4	3.5	12.8	0.0	21.0	0.9	158.0	0.1
S000038	240.0	1.9	456.7	2.4	12.8	0.0	22.1	0.9	157.8	0.1
P000039	239.9	3.1	465.9	2.6	12.9	0.0	21.0	1.0	158.1	0.1
S000040	240.0	2.3	465.4	2.9	12.8	0.0	21.4	1.2	157.8	0.1
S000041	240.0	0.9	458.6	2.5	12.8	0.0	23.4	0.9	157.9	0.1
P000042	240.0	1.3	458.8	3.2	12.9	0.0	22.3	0.8	158.0	0.1
P000043	240.0	2.1	465.2	2.5	12.8	0.0	22.1	0.9	158.0	0.1
S000044	240.0	1.6	465.7	2.7	12.8	0.0	21.7	1.1	157.9	0.1
P000045	240.1	3.0	457.3	5.6	12.8	0.0	21.1	1.1	158.0	0.1
S000046	239.8	3.1	453.9	3.4	12.8	0.0	21.3	1.1	157.9	0.1
P000047	240.0	2.2	456.0	6.7	12.8	0.0	22.2	1.0	158.0	0.1
S000048	240.0	1.3	464.3	2.5	12.8	0.0	23.3	0.8	157.9	0.1
S000049	240.0	1.2	442.6	3.9	12.8	0.0	22.6	0.7	157.9	0.1
P000050	240.0	1.6	452.6	5.7	12.8	0.0	22.5	0.8	158.0	0.1
S000051	240.0	1.8	433.4	5.8	12.8	0.0	22.4	0.9	157.9	0.1
P000052	240.0	2.5	444.9	6.6	12.9	0.0	21.0	0.8	158.0	0.1
P000053	239.9	2.6	458.4	3.8	12.8	0.0	21.0	1.0	158.3	0.1
S000054	240.0	1.4	456.9	5.9	12.8	0.0	23.2	0.7	158.0	0.1
P000056	240.0	1.9	466.5	4.2	12.8	0.0	21.8	0.8	158.3	0.1
S000057	240.0	1.1	448.0	8.2	12.8	0.0	23.1	0.6	158.0	0.1
P000058	240.0	1.9	459.7	2.8	12.8	0.0	21.9	0.9	158.2	0.1
S-AVG	240.0	1.5	455.0	4.1	12.8	0.0	22.0	0.9	157.9	0.1
P-AVG	240.0	2.2	458.7	4.1	12.9	0.0	21.3	0.9	158.1	0.1

Figure 3a. Summary of Pilot Lot Data —Current

c:\2excel\at-400a\data\summary\current

Figure 3b. Summary of Pilot Data —Wire Speed

c:\2excel\at-400a\data\summary\current

Figure 3c. Summary of Pilot Data —Travel Speed

c:\2excel\at-400a\data\summary\current

Figure 3d. Summary of Pilot Lot Data —Voltage

c:\2excel\at-400a\data\summary\current

Figure 4a. Plot of Weld Data —Weld Current and Arc Voltage

zip:p000052

Figure 4b. Plot of Weld Data —Wire Speed and Travel Speed

zip:p000052.plt

Figure 4c. Plot of Weld Data-Pulse Rate

Findings

Weld Ripple. Upon beginning the production welding, some of the finished welds exhibited a 4- to 8-inches-long rippled surface. In one case (P000024) the rippling ended when a blowhole occurred.³⁶ The rippling never occurred in the sample welds.

The welding procedure called for an internal purge (backing) gas flow rate of 20 cfh before and during the girth weld to provide an inert gas shield at the weld root. We hypothesized that the purge gas caused a differential gas pressure between the inside and the outside of the container, which, in turn, caused the rippling when the purge gas vented through the weld pool. A subsequent test confirmed that an internal gauge pressure of several inches of water was created during welding. We concluded that this pressure was primarily a result of an insufficient vent path for the gas to escape. Secondary factors were the heating resulting from the welding and the reduced vent path as the weld progressed around the joint.

A brief investigation was performed in 11-28 to quantify the internal pressure resulting from the original (1/4-inch OD) purge tube/welding procedure compared to the use of a smaller (3/16-inch OD) purge tube. The pressure developed with the original tube was 6.1 inches water and was 0.5 inches water with the 3/16-inch tube.³⁷

Consequently, the corrective action was to increase the size of the vent path by using a smaller purge tube. The flow rate of 20 cfh was not changed. This change was incorporated between welds P000050 and S000051. The rippling did not occur after this change was made.

Radiography confirmed the presence of scattered voids in the regions where the rippling occurred. (These voids were significantly larger than the typical scattered porosity often seen in GMA welds.) The voids did not occur in post-pilot lot CV welds after the purge tube was replaced. Hence, we concluded that the increased vent path that was created by the smaller purge tube effectively eliminated the rippling and the coincident voids.

Correlation Between Setting and Actual Values. The precision with which each parameter tracks the set value is largely a function of the calibration of that parameter. Based on practical considerations, a small amount of imprecision is normal. It would be unnecessarily time-consuming and expensive to calibrate to a perfect correlation. Also, nonlinearity of the input command-to-response signal contributes to imprecision of calibration and correlation.

With that background, the following comments are made with respect to each of the weld parameters given in Table 4:

Weld Current

- (average) – Insignificant difference between set and measured values (difference is less than 0.2 ampere).
- (std dev) – Insignificant range of values during each weld (standard deviation is less than 3.1 amperes (1 percent)).

Wire Speed

- (average) – Although it is typically much less, the greatest difference between set and measured values was 26 ipm, which is less than 6 percent. That difference is acceptable based on results obtained during development. Also, it appears that the difference is less for the CVs than for the sample ring welds.
- (std dev) – The standard deviation values are as high as 8.2 ipm but are typically in the range of 4 ipm.

Travel Speed

- (average) – The calibration is slightly on the low side, running about 12.8 to 12.9 ipm compared to the set value of 13 ipm. This difference is acceptable.
- (std dev) – The data show an insignificant range during a weld.

Voltage

- (average) – The set voltage is 21 volts. The measured value begins at 21 volts for the first pilot lot weld but increases during production to about 23 volts for the sample ring welds and 22 volts for the CV welds.
- (std dev) – The standard deviation is about 1 volt, which for a gas metal arc weld, is remarkably stable.

Pulse Rate

- (average) – Presumably due to a slight difference in calibration, the offset in pulse rate is about 2 hertz with the set value being 160 hertz and the measured value being 158 hertz.
- (std dev) – The standard deviation is about 0.1 hertz out of 160 hertz.

Parameter Drift. The average voltage plot (Table 5d) shows a gradual drift upward during the production lot, starting at 21 volts and ending at 22 to 23 volts after 40 welds. This parameter should be monitored closely to determine whether this drift continues.

The average travel speed also shows a drift during the production lot, starting at about 12.9 ipm and ending at 12.8 ipm. This parameter was recalibrated at the conclusion of the production lot.

Correlation Between Sample Ring Weld and Container Weld Parameters. While one would expect there to be no difference between the measured welding parameters from CV and sample ring welds, that was not entirely true. The voltage data shows a noticeable difference in the data. Both types of welds exhibit about the same voltage (21 volts) at the start of the pilot lot, but after 40 welds, the ring welds exhibit about 23 volts and the CVs about 22 volts. In the absence of better information, it is difficult to speculate what the difference may be. One possibility is the added resistance introduced by the weld fixture used for the sample ring welds, which would result in a higher voltage (which is measured at the welding power supply).

Section 4. Results and Conclusions

Two gas metal arc welding systems were designed, built, and set up at Mason Hanger's Pantex Plant. The qualification and training were completed and the nuclear and industrial safety requirements were satisfied. Approvals were granted to produce a pilot lot of twenty AT-400A containment vessels with W48 pits. The pilot lot was satisfactorily completed under production conditions at Pantex and the manufacturing process was released to Pantex.

Nuclear Safety. Initial fault tree analyses performed by Pantex and checked by Sandia showed that the probability of an unplanned release of radioactivity due to a credible combination of failures of the original welding system was approximately 2×10^{-5} . This exceeded the target of $<10^{-7}$ and was not acceptable. By adding a supplementary safety system we achieved a calculated probability of 7×10^{-7} . A reconfiguration of the shutdown circuit and a reduction of the welding heat input resulted in a calculated probability of approximately 10^{-7} . Final enhancements were added to reduce the risk below 10^{-7} .

Process Safety. Pantex performed a formal Job Safety and Health Assessment of the containerization process to ensure compliance with DOE and Pantex operational safety requirements and concerns. The review team comprised Subject Matter Experts (SMEs) from Industrial Hygiene, Industrial Safety, Risk Management, Medical, Ergonomics, Nuclear Safety, Nuclear Explosives Safety, and DOE. The assessment resulted in no significant findings associated with the welding system, but there were several observations. For example, preventing weld spatter from scorching the floor tile, repositioning the video monitor to minimize neck and eye strain, covering the terminals on the welding power supply, and reducing exposure to arc infrared light. We addressed each of the observations and performed corrective actions, if warranted. All of the issues were satisfactorily resolved.

Process Readiness. Pantex performed a formal management self-assessment (MSA) of the containerization process to ensure readiness for the Operational Readiness Reviews. All of the issues raised were addressed and satisfactorily resolved.

The C-ORR was performed by personnel from Mason Hanger Corporation to ensure that the containerization process would receive full approval in the subsequent DOE review. Their critique was particularly stringent, primarily in the area of documentation procedures. Their many observations relative to the Pantex facility and operations were addressed and satisfactorily resolved. There were no findings relative to the welding system or welding process.

The DOE Operational Readiness Review (DOE-ORR) team consisted of DOE/Headquarters (HQ) personnel, many of whom were SMEs. They observed a complete containerization operation and conducted separate interviews with many of the Sandia and Pantex personnel. Vic Loczi was the DOE/HQ welding SME. His only

observation pertaining to the girth weld was regarding the ASME Code requirement for the use of radiography to examine the weld. We noted to him that we required ultrasonic examination in lieu of radiography, and that it would be performed on 100 percent of the completed containers prior to off-site shipment. He agreed with our arguments that the ultrasonic inspection was equivalent to radiography and this became a non-significant observation. No other observations were noted relative to the welding system or the welding process.

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