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Engineering Evaluation and Thermal Analysis of the
W79 Diaphragm Seal Weld

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Summary

Five diaphragm seal specimens for the W79 retrofit program were welded and burst tested to meet requirements for the Engineering Evaluation (EE). The average burst pressure for these five diaphragm specimens was 11500 psi. All failures greatly exceeded the drawing requirements placed upon the system. After burst testing the specimens, we performed scanning electron microscopy on all five specimens to ensure ductile failure and cross-sectioned two specimens to characterize the weld morphology. The metallographic analysis showed these parts to be typical of high quality thin-section weldments. Analysis of heat flow during welding also has been included in this report. Thermal profiles easily meet those required by assembly specifications. Maximum temperatures achieved during welding were 520 °C in the diaphragm area and 80 °C on the bottom of the block.

Equipment and Procedure

Engineering Evaluation

Five diaphragms were laser seal welded at Pantex Plant (PX) using a 400 watt Lumonics laser welding system. The welding parameters, listed in Table 1, were developed during an extensive weld development effort and will be used in production. After welding, each welded diaphragm specimen was leak and burst tested. The specimens were then shipped to LLNL for evaluation. For historical purposes, we performed scanning electron microscopy on all samples to make records of the failure location and morphology. We metallographically cross-sectioned two of the diaphragm welds to determine the morphology and geometry of the fusion and heat affected zones of the weld.

Thermal Analysis

One diaphragm was welded with four Type K thermocouples attached to the block part as shown in Figure 1. Five data acquisition channels were used including one that recorded ambient air temperature conditions. Data was accumulated and plotted by a computer data acquisition system equipped to take one temperature reading per second. The normal production welding equipment and parameters were used during this testing.

Results

Engineering Evaluation

We leak tested all five EE specimens and each exhibited a better than 2×10^{-8} atm cc He/sec leak rate. This level of leak-rate is acceptable for the diaphragm assembly. After leak testing, all parts were burst tested.

The failure requirement placed on these diaphragms during burst testing was a minimum pressure of 7.5 ksi. The 7.5 ksi failure pressure has a large safety factor compared to the actual working pressures found in the system. The average failure pressure for the five EE specimens was 11500 psi and all exceeded the minimum failure pressure by at least 2.5 ksi. Table 1 lists burst pressure, failure type and diaphragm thickness of the EE and several development specimens. Figure 2 shows a plot of the failure pressures of the EE and, for comparison, several development diaphragm specimens plotted as a function of the diaphragm thickness to show that the specimens were typical of those during development.

The scatter in failure pressures among the EE specimens was much less than that found in the development specimens. This is probably caused by tighter quality control and inspection of the diaphragms in the EE lot. Three different types of failures were found in the EE lot of diaphragms: 1) weld, 2) partial diaphragm and 3) full diaphragm. In general, as the diaphragms became thicker, the failure mode shifted from diaphragm failures to weld failures. We would expect the shift in failure modes to progress in this fashion for these parts. The larger scatter in development data is probably due to a dimensional measurement not known about any of the specimens. This is the radius between the diaphragm and the plug on the diaphragm. Sharp radii in this area will tend to cause failures at lower pressures than when more rounded features are found.

Scanning electron micrography was performed on all specimens to show the ductility of the failure surfaces. A typical ductile dimple failure surface from specimen 348058 is shown in Figure 3. This specimen failed in the partial diaphragm manner. For comparison, Figure 4 shows the failure surface from specimen 286439, which also had the typical ductile dimple failure pattern. This specimen failed in the weld fusion zone. Figures 5 through 9 show low magnification micrographs of the failures for historical purposes.

Metallography was performed on specimen 163523 that failed in the weld area and specimen 721151 that failed in the diaphragm area. Etching of these specimens shows flow lines in the failure and deformed areas of both. The flow lines are indicative of the plastic deformation during testing. The reduced cross-sections in the specimens indicates good ductility present in both the diaphragm material and the weld metal. Figure 10 shows the failure in specimen 163523 with associated reduction in area in the weld fusion zone. Figure 11 shows the weld fusion zone in specimen 721151. A large amount of plastic deformation occurred in this area even though failure occurred in the diaphragm. Figure 12 shows plastic deformation that occurred in the failed diaphragm of specimen 721151.

Thermal Analysis

We sampled temperatures at the rate of one reading per second. Plots of all of the temperature profiles are shown in Figure 13. The results indicate that the maximum temperature was achieved on the diaphragm part and was approximately 520 °C. This was expected since the inside bore thermocouple was closest to the weld and the thin diaphragm part provides very little heatsinking during the welding sequence. The block bottom never exceeded 80 °C which indicates that no deleterious effects would be expected to any internal parts of the system lying under the block. The maximum temperatures were achieved within one minute of the weld start and the part was cool enough to handle with bare hands within two minutes of the weld start.

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Table 1
W79 Diaphragm Seal Welding Parameters

<u>Parameter</u>	<u>Setting</u>
Pulse Energy (Tack)	20 Joules per Pulse
Pulse Energy (Weld)	15 Joules per Pulse
Pulse Energy (Maximum)	30 Joules per Pulse
Pulse Width	9 Milliseconds
Pulse Rate	8 Pulses per Second
Peak Beam Energy Density (Tack)*	201 kW/cm ²
Mean Beam Energy Density (Tack)*	143 kW/cm ²
Peak Beam Energy Density (Weld)*	157 kW/cm ²
Mean Beam Energy Density (Weld)*	114 kW/cm ²
Beam Spot Size (Tack)	1.31 mm X 0.62 mm
Beam Spot Size (Weld)	1.34 mm X 0.62 mm
Lens Focal Length	120 Millimeters

- * - Energy density measured with Prometec Laserscope Model UFF flying wire instrumentation. Beam spot size measured at 86% of peak energy.

Table 2
W79 Diaphragm Burst Test and Failure Data

Engineering Evaluation Samples

Serial Number	Diaphragm Thickness (In.)	Leak Rate (10⁻⁹atm cc He/sec)	Failure Type	Burst Pressure (psi)
721151	0.0108	4.6	Full Diaphragm	10892
371671	0.0112	3.5	Weld	11298
348058	0.0114	4.6	Partial Diaphragm	11192
286439	0.0115	4.6	Weld	11976
163523	0.0117	15	Weld	12046

Development Samples

Serial Number	Diaphragm Thickness (In.)	Leak Rate (10⁻⁹atm cc He/sec)	Failure Type	Burst Pressure (psi)
	0.0109			11946
	0.0105			10109
	0.0114			12543
	0.0114			11623
	0.0115			12271
	0.0115			11986
9201802/1-8	0.0114			11148
9201802/1-5	0.0111			10806
9201802/1-9	0.0118			11569
9201802/1-4	0.0111			13061
9201802/1-1	0.0111			11378
9201802/1-3	0.0118			12698

Figure 1. Thermocouple Arrangement for Weld Thermal Analysis

Figure 2. W79 Diaphragm Burst Test Results

Figure 3. SEM photomicrograph showing the ductile nature of the 304 stainless steel used for the diaphragm material. Area shown is from the partial diaphragm failure of specimen 348058 during burst testing.

Figure 4. SEM photomicrograph showing the ductile nature of the 304 stainless steel weld metal. Area shown is from the weld failure of specimen 286439 during burst testing.

Figure 5. SEM photomicrograph showing the type and location of burst failure in specimen 348058. This is a partial diaphragm failure.

Figure 6. SEM photomicrograph showing the type and location of burst failure in specimen 371671. This is a weld failure.

Figure 7. SEM photomicrograph showing the type and location of burst failure in specimen 721151. This is a full diaphragm failure.

Figure 8. SEM photomicrograph showing the type and location of burst failure in specimen 286439. This is a weld failure.

Figure 9. SEM photomicrograph showing the type and location of burst failure in specimen 163523. This is a weld failure.

Figure 10. Metallographic cross-section of the weld failure in specimen 163523. Note ductility of the weld metal exhibited by necking in the failure region.

Figure 11. Plastic deformation which occurred in weld metal of specimen 721151. Note the good ductility of the material. This specimen failed in the diaphragm area.

Figure 12. Plastic deformation which occurred in diaphragm area of specimen 721151. Note the necking which occurred before failure.

Figure 13. W79 Diaphragm Weld Temperature Profiles

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