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NONDESTRUCTIVE INSPECTION OF GENERAL PURPOSE HEAT SOURCE (GPHS) GIRTH WELDS

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Abstract

The General-Purpose Heat Source (GPHS) provides power for space missions by transmitting the heat of ^{238}Pu decay to an array of thermoelectric elements. The GPHS is fabricated using iridium capsules, TIG welded, to contain the $^{238}PuO_2$ fuel pellet. GPHS capsules will be utilized in the upcoming Cassini mission to explore Saturn and its moons. The physical integrity of the girth weld is important to mission safety and performance. Since experience in the past had revealed a potential for initiation of small cracks in the girth weld overlap zone, a nondestructive inspection of the capsule weld is required. An ultrasonic method was used to inspect the welds of capsules fabricated for the Galileo mission. The instrument, transducer, and method used were state of the art at the time (early 1980s). The ultrasonic instrumentation and methods used to inspect the Cassini GPHSs was significantly upgraded from those used for the Galileo mission. GPHSs that had ultrasonic reflectors that exceeded the reject specification level were subsequently inspected with radiography to provide additional engineering data used to accept/reject the heat source. This paper describes the Galileo-era ultrasonic instrumentation and methods and the subsequent upgrades made to support testing of Cassini GPHSs. Also discussed is the data obtained from radiographic examination and correlation to ultrasonic examination results.

INTRODUCTION

Because many of the spacecraft used for planetary exploration operate at extensive distances from the sun, solar power cannot be effectively used to generate electric power. The United States civilian space program has employed radioisotope thermoelectric generators (RTGs) to power the systems and components of the deep space platforms. The General-Purpose Heat Source (GPHS) provides power for space missions by transmitting the heat of ^{238}Pu decay to an array of thermoelectric elements inside the RTG. The RTGS are designed to maximize immobilization of the fuel during all mission phases, including transportation and handling, launch, and any launch abort or reentry event.

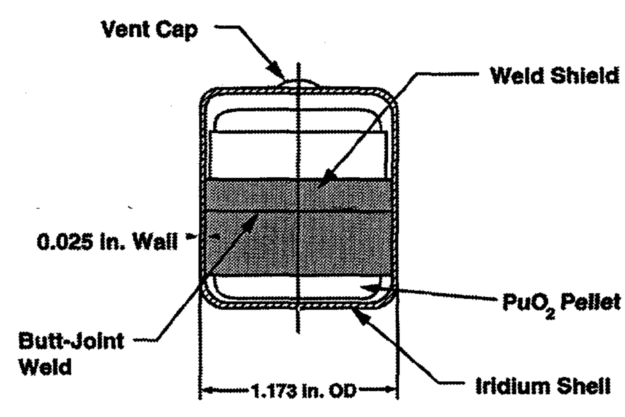

Figure 1. General-Purpose Heat Source (GPHS)

The GPHS (Figure 1) is fabricated using iridium capsules, gas tungsten arc (GTA) welded, to contain the $^{238}PuO_2$ fuel pellet. GPHS capsules will be utilized in the upcoming Cassini mission to explore Saturn and its moons. The physical integrity of the girth weld is important to mission safety and performance.

In the early phases of GPHS production by the Savannah River Plant for the Galileo and Ulysees space programs, cracks were occasionally observed in production GPHS girth welds in the underbead of the weld overlap region. Upon examination of the cracks, it was concluded that they were a result of thorium-induced hot cracking in the presence of thermal and solidification stresses. The cracks were not visible on the external surface of the weld and, if left undetected, could compromise the containment of $^{238}PuO_2$ in the unlikely event of an aborted launch or reentry into the earth's atmosphere.

An ultrasonic inspection methodology was developed during the Galileo/Ulysses program to detect and measure underbead cracks. This methodology was upgraded and further refined for inspection of GPHS girth welds produced for the Cassini mission by Los Alamos National Laboratory.

GALILEO/ULYSSES ULTRASONIC INSPECTION

The ultrasonic test (UT) inspection system developed for the Galileo/Ulysses programs was designed to hold the GPHS capsule with the axis of rotation in the horizontal position as shown in Figure 2 (Moyer 1994). A positioner was used to rotate the capsule and an arm held the transducer at a fixed angle, 31 degrees from the normal to the capsule surface, for a circumferential scan of the capsule. The axial position of the transducer was adjusted manually. A 5.0 Mhz KB-Aerotech gamma transducer with a 0.75-in focal length in water was used for the inspection and an Automation Industries S-80 instrument was used for data aquisition.

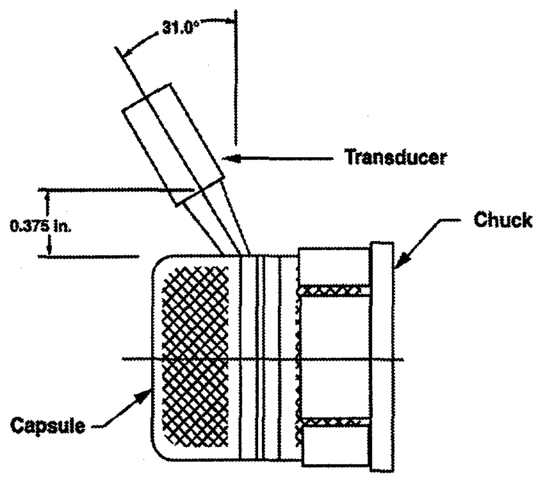

Figure 2. Horizontal GPHS Scan Orientaion

The UT methodology was developed to reject capsules with large cracks in the weld overlap area. The ultrasonic inspection was used to indicate the weld quality, rating each weld in terms of a reference slot in a standard. The UT standard used was fabricated with three electro-discharge machined (EDM) slots 0.003, 0.006, and 0.0012 in. deep by 0.010 in. wide by 0.050 in. long. The signal threshold was set by adjusting the S-80 instrumentation so that the signal from the 0.006-in. deep slot produced a full-scale signal. The reject threshold was set at "8", which represented 80% of full scale. Each capsule was given a rating from 1 to 13 on the basis of signals reflected from the weld bead.

CASSINI ULTRASONIC INSPECTION METHODOLOGY

The procedures used to inspect the Galileo/Ulysses GPHS capsules were reviewed and recommendations were made on the requirements for inspecting the Cassini capsules. It was recommended to upgrade the UT instrumentation/methodology of the Galileo/Ulysses-era GPHS inspection. The original instrumentation used for the Galileo/Ulysses programs was, by the time of the Cassini mission, obsolete and inoperative. The part fixturing was extremely difficult to set up and adjust. The instrument output was relatively crude, with output recorded on a strip chart recorder. Calibration of the equipment was conducted using a single reference EDM slot on a standard. Calibration against several reference slots spanning the range of expected defect sizes would have verified the linearity of the instrumentation and provided confidence in the testing procedure. A Lamb wave inspection technique was chosen as this was shown to be sufficiently sensitive to the small EDM reference defect slots as well as having a linear response to different slot sizes.

The equipment configuration used to inspect GPHS capsules produced for the Cassini mission consisted of a Panametrics A3367 3.5-Mhz transducer with a 1.5-in. spherical focus in water, a Panametrics model 5055UA ultrasonic analyzer, a Panametrics Multiscan Waveform Digitizer, a Tektronix model 2235A 100-Mhz dual channel oscilloscope and a 486-processor computer.

The Cassini UT inspection methodology incorporated many enhancements and improvements. The scans were performed from both sides of the weld, not just one direction. The method demonstrated excellent reproducibility.

The "top scan" methodology used (Figure 3) offered time-of-flight enhancements that were used to indicate the location of the UT reflector relative to the weld centerline. The data generated was entirely digital and was consequently easily stored, retrieved, and more precise than the analog data obtained with the Galileo/Ulysses-era equipment. The scans were controlled and collected by a computer; this minimizes the amount of time the operator spends handling the GPHSs. Figure 4 shows the immersion tank with a GPHS mounted in the fixture and the transducer in measurement position.

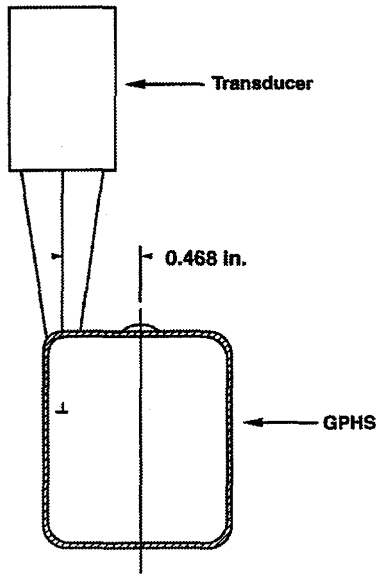

Figure 3. Top Scan Orientation

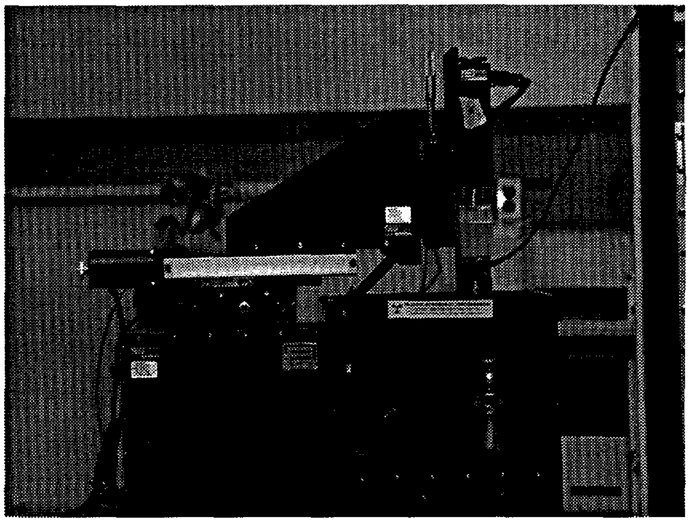

Figure 4. UT Immersion Tank

New UT standards were developed to calibrate the instrumentation. Three standards were produced, each with several EDM slots. Three of the slots, measuring 0.003, 0.005, and 0.007 in. are used to calibrate the instrument. A least-squares fit of the ultrasonic responses to these slots was used to calculate UT reflector sizes, reported in equivalent mils. The three standards were subjected to round robin testing with three identical UT inspection systems (configured for Cassini) at three national laboratories; Los Alamos National Laboratory, Westinghouse Savannah River Corporation, and Oak Ridge National Laboratory. The systems were calibrated with each of the three standards followed by measuring the ultrasonic responses to the unused slots on the standards and actual parts that had known flaws. Based on the calculated slot sizes, the within calibration standard deviation was 0.16 mil.

A correlation with standards used during the Galileo/Ulysses GPHS inspection campaigns to the Cassini inspection methodology was performed. All ultrasonic data from the earlier campaigns were referenced to a number 8 flaw. This represented approximately 80% of the ultrasonic response to a 0.006-in. deep slot. A capsule was identified with a ultrasonic signal level of 8.1. This capsule was opened, decontaminated, and inspected at LANL. After evaluating the ultrasonic data using the current methodology, the response appeared to be equivalent to a 0.0052-in. slot. The reject level was set at signals representing the response to > 5.2 equivalent mils.

RADIOGRAPHIC EXAMINATION OF GPHSs

During the beginning of Cassini GPHS production at LANL, a relatively high percentage of GPHSs were being rejected by the UT girth weld examination. Geometric anomalies in or near the weld, such as fusion of the weld shield foil with the weld, the formation of a step caused by dissimilar wall thickness, or a crack or porosity, caused a relatively large UT response. Radiographic examination of GPHSs rejected by UT was used to further screen the clads and to provide engineering data to support the acceptance of GPHSs that had UT reflectors that did not adversely affect girth weld integrity. Table 1 lists the results of the radiographic examinations of GPHSs that had UT reflectors greater than 5.2 equivalent mils. Of the total 34 examined, only two of the capsules showed evidence of questionable weld integrity. The majority of the reflectors, 58%, were determined to be caused by fusion of the weld shield with the clad weld. Dissimilar wall thickness in the weld area accounted for 38% of the reflectors and porosity in the weld area was 4%.

Several of the radiographic examination results were confirmed with metallographic examination. Figure 5 is a micrograph showing weld shield fusion, confirming the radiographic examination results of the 160 degree area of FC0149. Figure 6 is a micrograph of the weld area located 44 degree from the weld start of GPHS FC0234. The weld porosity shown in this figure confirms the results of the radiographic examination.

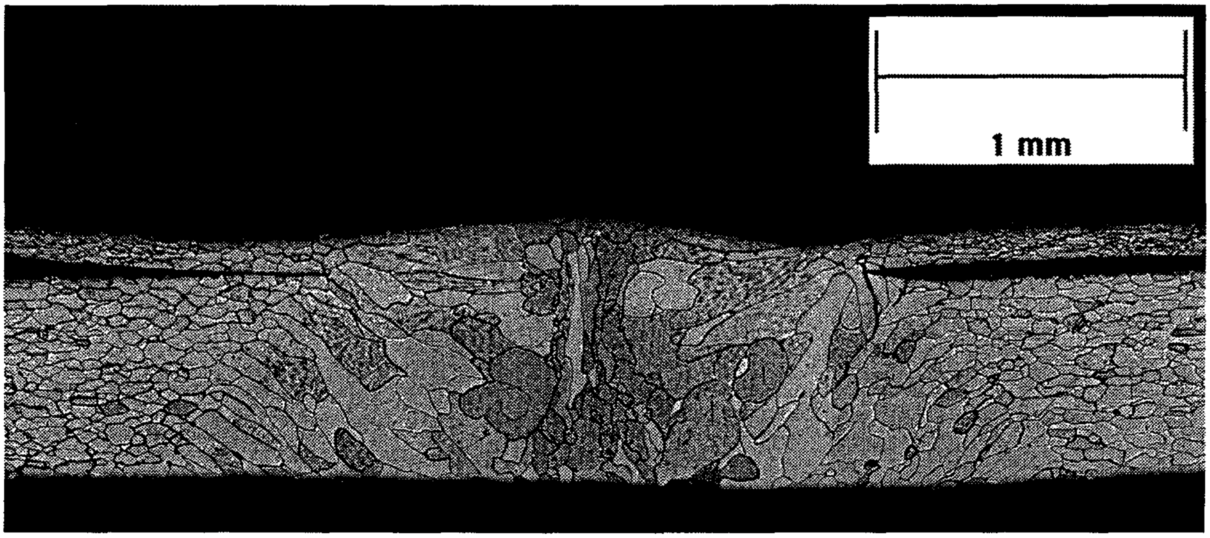

Figure 5. Weld Shield Fused to Weld Area (FC0149)

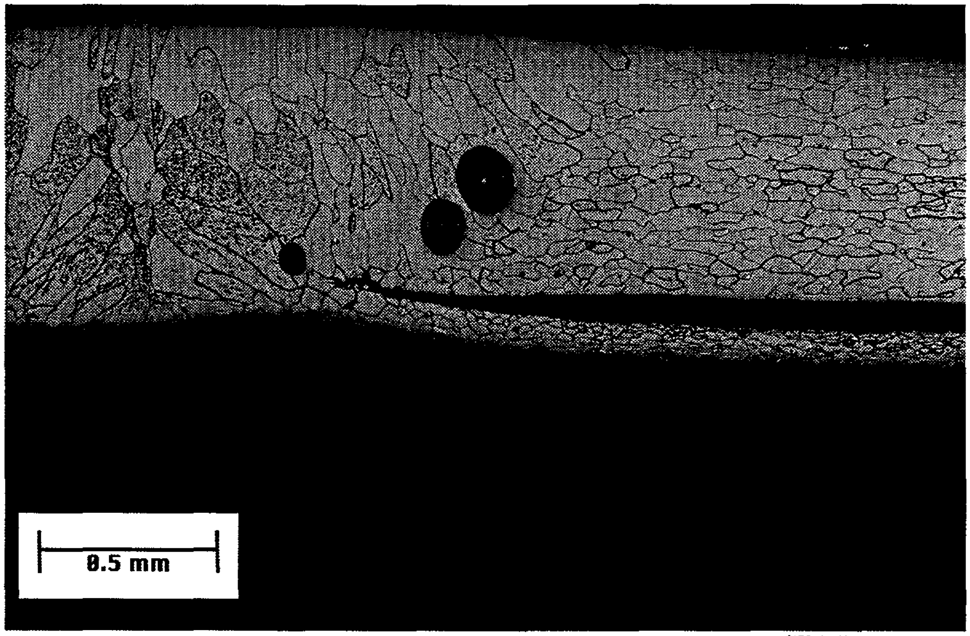

Figure 6. Porosity in Weld Area (FC0234)

CONCLUSIONS

The ultrasonic inspection technique was successful at identifying geometric anomalies in the girth weld area. The presence of these anomalies were confirmed with radiography. The ultrasonic method, however, was not truly effective at identifying welds with decreased integrity. The use of radiography in conjunction with UT lowered the overall weld rejection rate of GPHSs by identifying geometric anomalies not detrimental to the weld.

Acknowledgments

We thank Rose Gray for assisting with the radiography. We also thank Walter Bast for the design and fabrication of the fixture used to orient the GPHSs at the correct angular location for radiography and metallographic sectioning.

REFERENCES

Moyer, M. W. (1994) *Ultrasonic Inspection of General Purpose Heat Source Clad Vent Set Closure Welds*, Y/DW-1310, Oak Ridge Y-12 Plant, Oak Ridge TN.

Table 1. Radiographic Examination of UT-Rejected GPHSs

Capsule ID	UT Reflector Details[1]	Radiography Results[2]	Capsule ID	UT Reflector Details[1]	Radiography Results[2]
FC0005	230 deg, 5.7 equil mils	WSF	FC0071	210 deg, 6.8 equil mils	WSF
				240 deg, 6.5 equil mils	STEP
FC0024	16 deg, 8.2 equil mils	WSF			
			FC0076	280 deg, 6.3 equil mils	WSF
FC0025	134 deg, 8.7 equil mils	WSF		320 deg, 5.4 equil mils	STEP
	165 deg, 6.2 equil mils	WSF			
			FC0080	243 deg, 8.1 equil mils	STEP
FC0026	130 deg, 8.0 equil mils	STEP		293 deg, 7.8 equil mils	STEP
	200 deg, 5.4 equil mils	STEP			
			FC0081	285 deg, 6.2 equil mils	WSF
FC0030	131 deg, 9.1 equil mils	STEP		352.5 deg, 5.9 equil mils	WSF
	186 deg, 6.3 equil mils	STEP		260 deg, 5.3 equil mils	WSF
	234 deg, 5.5 equil mils	STEP		350 deg, 5.9 equil mils	WSF
FC0033(36)	224 deg, 6.1 equil mils	WSF	FC0089	82 deg, 5.5 equil mils	STEP
	265 deg, 6.4 equil mils	STEP		180 deg, 4.9 equil mils	WSF
	303 deg, 7.5 equil mils	STEP			
			FC0120	88 deg, 5.3 equil mils	WSF
FC0034	276 deg, 7.0 equil mils	WSF		100 deg, 5.3 equil mils	WSF
FC0037	174 deg, 6.1 equil mils	STEP	FC0134	140 deg, 9.2 equil mils	STEP
	201 deg, 7.1 equil mils	STEP		115.5 deg, 6.2 equil mils	WSF
FC0040	126 deg, 8.5 equil mils	STEP	FC0149	85 deg, 9.2 equil mils	STEP
	220 deg, 6.0 equil mils	STEP		159.5 deg, 7.2 equil mils	WSF
	290 deg, 6.4 equil mils	STEP			
			FC0182	135 deg, 6.8 equil mils	WSF
FC0041	108 deg, 8.0 equil mils	STEP			
	270 deg, 6.6 equil mils	STEP	FC0188	287 deg, 9.1 equil mils	WSF
				271.5 deg, 8.9 equil mils	WSF
FC0045	162 deg, 5.4 equil mils	WSF			
	220 deg, 6.1 equil mils	WSF	FC0190	213 deg, 5.9 equil. mils	WSF
FC0048	270 deg, 6.0 equil mils	WSF	FC0197	295.5 deg, 7.7 equil mils	WSF
				320.5 deg, 6.4 equil mils	WSF
FC0049	205 deg, 5.5 equil mils	Porosity/Step			
			FC0208	70.5 deg, 9.3 equil mils	WSF
FC0050	107 deg, 6.8 equil mils	WSF		135 deg, 9.0 equil mils	Porosity/Reject
	124 deg, 5.6 equil mils	WSF		93 deg, 6.0 equil mils	WSF
FC0053	31 deg, 7.6 equil mils	WSF	FC0212	18 deg, 6.1 equil mils	WSF
FC0056	195 deg, 5.4 equil mils	STEP	FC0234	44.5 deg, 5.4 equil. mils	Porosity/Reject
FC0062	112 deg, 5.3 equil mils	WSF	FC0334	250 deg, 6.2 equil. mils	WSF
FC0065	240 deg, 5.9 equil mils	WSF			

[1] Angular location of relflector, degrees from weld start and equivalent slot size of reflector.
[2] WSF = weld sheild fusion; fusion of weld to weld shield, STEP = step due to dissimilar wall thicknesses in weld area.