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Report No. RN-S-0470

CORRELATION STUDY OF ULTRASONIC
SHEAR-WAVE INSPECTION OF
NOZZLE COOLANT-CHANNEL BRAZE SHEAR-JOINTS
PHOEBUS-2 NOZZLE S/N 880600

To

AEC-NASA Space Nuclear Propulsion Office

NERVA Program

Contract SNP-1

June 1968

NUCLEAR ROCKET OPERATIONS

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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SHEAR-WAVE INSPECTION OF
NOZZLE COOLANT-CHANNEL BRAZE SHEAR-JOINTS
PHOEBUS-2 NOZZLE S/N 880600

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ABSTRACT

This report describes the correlation study of the ultrasonic shear-wave inspection of nozzle coolant-channel brazed shear-joints. The tooling requirements, test setup, and technical data obtained are also described. Results show a direct correlation of ultrasonic-signal amplitude to the measured amount of unbrazed. A computer analysis of the data is also presented. It is recommended that additional data be obtained from a nozzle that has machined grooves for comparison with data obtained from grooves made by the electrical discharge machining method. The data would then be evaluated to further establish the confidence level of the ultrasonic shear-wave technique. A decision could then be reached whether to proceed with a quantitative, computerized system for the ultrasonic inspection of future NERVA nozzle coolant-channel braze shear-joints.

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I. PURPOSE

The purpose of the study was to determine the degree of correlation of the ultrasonic signal-amplitude recorded from nozzle coolant-channel braze shear-joints and signals from a calibration standard. The results will be used to further develop the technique of ultrasonic shear-wave inspection of nozzle coolant-channel braze shear-joints. Data collection for the future system would be recorded on magnetic tape. The data would then be digitized and reduced by computer to provide a quantitative evaluation of future NERVA nozzle coolant-channel braze shear-joints.

II. CONCLUSION

Visual information has been provided of the actual measurements of the amount of unbrazed in the coolant-channel braze shear-joints as related to the ultrasonic signal-amplitude. The comparison of data recorded on the strip chart with the measured amount of unbrazed shows a direct relationship between signal amplitude and amount of unbrazed. In all cases where there was a completely unbrazed joint, a 90 to 95% signal-amplitude was seen on the strip chart as compared with the signal from the 0.100-in. deep reference slot. The ultrasonic signal of the completely unbrazed joint is not equal to that of the reference slot because the rounded bottom of the groove in the nozzle does not have the same amount of reflecting surface as the square slot in the reference standard. In addition, the side of the groove produced by the electrical discharge machining (EDM) method is rough and scatters some of the ultrasound, causing a loss in signal amplitude. It can be concluded that, when a signal with an amplitude of 90 to 95% of the signal from the reference standard is recorded, a completely unbrazed joint exists. Where lesser amounts of unbrazed were recorded, the ultrasonic signals were proportional to the measured unbrazed. There was no unbrazed detected visually or ultrasonically in the cross-sections of the 0.100-in. deep groove area of the shim-to-coolant-channel braze joint.

All data for this study were obtained from the tube-leg-to-nozzle-jacket braze shear-joint. However, it must be pointed out that a signal from an unbrazed shim-to-tube-leg cannot be differentiated from a signal received from the tube-leg-to-jacket braze joint. Nevertheless, if a total unbrazed occurred between the shim-to-tube-leg braze joint, a signal of 60% would be recorded. This has been demonstrated experimentally in the laboratory by selecting a sample with a sound braze joint and removing the shim by the EDM method. A signal of approximately 60% was recorded.

It can be shown mathematically that 0.040 in. of the shim-to-tube-leg braze joint is not inspected by the sound beam. This is due to the 48-degree angle of the shear-wave sound beam as it scans the braze joint. It can be seen in the photographs of the sample that no unbrazed exists between the nickel-plated shim to nickel-plated tube leg braze joint in the area of the 0.100-in. deep nozzle-jacket groove. While it appears in the photographs of the samples that the tube legs are bent, this is due to the parting tool used to remove the sample from the nozzle and did not occur at the time of installation.

A statistical fit was made to the ultrasonic signal-amplitude values and the corresponding measured amount of unbrazed by the method of least squares. The straight line fitted to the data is graphically presented in Figure 1 together with data points used in the mathematical calculations. In addition, 90% upper and lower confidence limits are provided. These limits indicate the interval within which 90% of the unbrazed amounts could be expected for any observed ultrasonic signal-amplitude. For example, if an ultrasonic signal-amplitude of 0.50 (50%) was recorded, 90% of the unbrazed depths were observed between the values 0.0358 and 0.0672. Therefore, 90% of the data was calculated to be within the two limits.

The 90% limits were based on ± 1.64 standard deviation of the average about the fitted line. Table 1 presents the relationship of the observed data to the unbond depth showing the accuracy within the 90% confidence limits.

Figure 1 - Statistical Data Plot of Ultrasonic Signal Amplitude and Measured Unbraze

TABLE 1

CONFIDENCE INTERVALS ON THE OBSERVED DATA OF THE
UNBOND DEPTH

Observed Ultrasonic Signal Amplitude (%)	Unbond Depth (in.)		
	Lower 90% Limit	Expected Unbond Depth	Upper 90% Limit
10	0.000	0.011	0.027
20	0.005	0.021	0.037
30	0.015	0.031	0.047
40	0.026	0.041	0.057
50	0.036	0.052	0.067
60	0.046	0.062	0.077
70	0.056	0.072	0.088
80	0.066	0.082	0.098
90	0.076	0.092	0.108
95	0.081	0.097	0.113

The scatter in the data, in part, can be attributed to the following factors:

1. The depth of the grooves in the nozzle is 0.100 in., ± 0.010 , and no allowance was made for the variation in groove depth.
2. The recorded ultrasonic signal amplitude was based on an estimate made from the strip chart as related to the calibration slots. The proper quantitative system would provide that the data be collected on magnetic tape and then reduced by computer to eliminate the errors of estimating signal amplitude. Reference standards also would be made with a greater range in depth of the calibration slots (0.020 - 0.100 in.).
3. The vertical amplifier of the Spray UM-700 unit is not truly linear. Newly developed ultrasonic units (e.g., Sperry Mimerscope 725) have a more linear amplifier which would provide greater accuracy and reduce the amount of data scatter.
4. In addition, the groove in future NERVA nozzles is expected to be produced by conventional machining rather than by the EDM method. The depth of the groove will be 0.095 in., ± 0.005 , and will be square at the bottom rather than rounded as now produced by the EDM method. The closer depth tolerance and the square bottom will both contribute to improved accuracy.

III. DISCUSSION

Ultrasonic shear-wave inspection is not new and has been used in many applications to determine the quality of plate material. The use of shear waves for the evaluation of braze joints is another application of this method. The ultrasonic waves are generated when the piezoelectric element in the search unit is excited by a high-voltage pulse. The search unit acts both as a generator and received of the ultrasonic wave. The ultrasonic waves are

transmitted into the material by means of a suitable couplant (e.g., water or oil). Reflection of the ultrasonic vibrations will occur at the boundary between two different materials if a mismatch of acoustic impedance is encountered. In the case of a completely unbrazed joint, there is a high acoustic-impedance mismatch and most of the ultrasound will be reflected and returned to the search unit. This sound wave is then converted to an electrical signal by the piezoelectric element in the search unit, amplified, and displayed on a cathode ray tube or recorded on a strip chart. Where there is a completely brazed joint, a small acoustic-impedance mismatch occurs and only a small signal is generated and recorded. In ultrasonic testing, the sound beam, when passing at an angle from one material to another, is comparable to the refraction of light when passing from one medium to another. The extent of the refraction and the angle can be calculated by Snell's law:

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{V_1}{V_2} ,$$

where the $\sin \theta_1$ is the incident angle, $\sin \theta_2$ the resultant angle, V_1 the velocity in the first medium (water couplant), and V_2 the velocity of the second medium (Hastelloy X).

In this study, water was the couplant. The incident angle at the nozzle was 22 degrees, resulting in a shear wave of approximately 48 degrees in the nozzle jacket. In this inspection, only the coolant-channel leg to nozzle-jacket braze joint was evaluated. It has been demonstrated in the laboratory that, if a complete unbrazed occurs at the shim-to-tube-leg, a maximum signal equal to that from a 0.060-in. deep slot will be generated. No information from the bottom of the brazed joint is recorded when using shear waves. This test was performed on Phoebus-2 nozzle S/N 880600 to determine the relation of the amplitude of the ultrasonic signal to the amount of measured unbrazed in the nozzle coolant-channel leg joint. The ultrasonic signals from the brazed joints were compared to the signal received from a calibration-test sample with

EDM slots of known depth and width that simulated an unbrazed joint. The calibration sample was the same as the one used in earlier inspections.* It is of the same material, Hastelloy X, and has the same thickness and contour of the area inspected in the nozzle. The dimensions of the EDM slots are 0.012-in. wide and 0.500-in. long, with depths of 0.040, 0.070, and 0.100-in. The depth of the slots simulate a braze joint with a known amount of unbrazed. The ultrasonic unit is calibrated by scanning the three EDM slots and recording the signal amplitude of each on a strip chart. The relation of the amplitude of the signal as related to the depth of slots is seen in Figure 1.

The dimensions of the nozzle grooves are 0.100-in., ± 0.010 , deep and 0.040-in., ± 0.001 , wide. There are 320 grooves in the circumferential direction, each groove extending the full length of the nozzle. After completion of EDM grooving, the grooves and channel walls are chemically cleaned. Each channel and shim is nickel-plated to prevent formation of AL_2O_3 on the Hastelloy-X faying surface. The nozzle groove-walls, however, are not nickel-plated.

IV. PROCEDURE

The nozzle was scanned with the same tooling and equipment employed during earlier inspection of nozzles S/N 880604 and 880605 (see Figure 2). The ultrasonic unit was calibrated as described in Report RP-TR-0014. The aft portion of the nozzle was scanned and a section approximately 5-in. in width was located, beginning 10.5-in. aft of the center line of the nozzle throat (see Figure 3). This section was chosen because of the large number of signals having a range of high and low amplitude that would provide a good statistical sample for evaluation. The section was coated with layout ink and scribe lines were made to define the area of interest. The scan chosen for evaluation was in the center of the section. The section was then machined from the nozzle and forwarded to the metallurgical laboratory for cross-sectioning. Figure 4 is a photograph of the removed section.

*See RP-TR-0014, Ultrasonic Braze Joint Inspection, Phoebus-2 Nozzle, September 1967

Figure 2 - Nozzle in Tooling Setup for Ultrasonic Scanning

Figure 3 - Area Scanned and Location of Sample Removed for Cross-Sectioning

Figure 4 - Removed Section

Before cross-sectioning, each coolant-channel leg groove was numbered with metal impression-stamps so a specific groove could be located and related to the ultrasonic signals on the strip chart.

Six areas were selected, based upon the range of signal amplitude as shown on the strip chart (see Figure 5). Signals from the 0.040, 0.070, and 0.100-in. deep calibration slots are also shown in Figure 5. The numbers of the grooves selected in each sample were 86 through 99, 100 through 112, 149 through 155, 208 through 219, 220 through 235, and 236 through 249. While only one side of the groove was inspected for this study, both sides of each groove would be examined during a nozzle inspection. The ultrasonic shear-wave beam was directed at the side of the groove as shown in Figure 6. The nozzle was rotated so the beam was always directed toward the side of the groove toward the increasing number (e.g., from groove 86 toward 99).

Each sample was polished and then stained with Schantz's etch to define the area of the braze joint. The samples were then photographed at 2X magnification and the amount of unbrazed measured with a Bausch & Lomb measuring-comparator.

A comparison of the ultrasonic signal-amplitude on the strip chart and the amount of measured unbrazed taken from the cross-sectioned sample is listed in Table 2. Photographs of each sample are shown in Figures 7 through 12.

Figure 5 - Recorder Strip Chart with Calibration Signals

Figure 6 - Direction of Ultrasonic Beam

TABLE 2

Comparison of Signal Amplitude to Measured Unbraze

<u>Groove No.</u>	<u>Ultrasonic Signal Amplitude</u> %	<u>Measured Unbond</u> in.
86	5	0.012
87	5	0.005
88	10	0.005
89	15	0.005
90	30	0.050
91	5	0.005
92	45	0.050
93	80	0.100
94	95	0.090
95	10	0.005
96	35	0.040
97	60	0.065
98	95	0.100
99	15	0.010
100	10	0.015
101	10	0.005
102	0	0.010
103	95	0.100
104	70	0.075
105	5	0.010
106	65	0.075
107	95	0.100
108	40	0.020
109	70 "	0.080
110	15	0.010
111	45	0.045
112	55	0.055

TABLE 2 (cont.)

<u>Groove No.</u>	<u>Ultrasonic Signal Amplitude %</u>	<u>Measured Unbond in.</u>
139	10	0.005
140	95	0.100
141	60	0.050
142	65	0.060
143	65	0.060
144	55	0.030
145	45	0.040
146	20	0.015
147	15	0.015
148	90	0.100
149	55	0.040
150	40	0.030
151	5	0.005
152	55	0.060
153	35	0.020
154	5	0.005
155	45	0.040
208	65	0.080
209	0	0.005
210	0	0.005
211	0	0.005
212	15	0.010
213	60	0.060
214	60	0.055
215	95	0.095
216	95	0.100
217	35	0.040
218	0	0.010
219	0	0.010

TABLE 2 (cont.)

<u>Groove No.</u>	<u>Ultrasonic Signal Amplitude</u>	<u>Measured Unbond</u>
	%	in.
220	10	0.010
221	10	0.015
222	60	0.070
223	30	0.040
224	0	0.010
225	30	0.035
226	35	0.040
227	15	0.010
228	0	None
229	55	0.060
230	40	0.025
231	30	0.035
232	.05	None
233	55	0.070
234	0	None
235	45	0.070
236	40	0.035
237	45	0.045
238	15	0.010
239	0	0.005
240	60	0.065
241	65	0.055
242	10	0.030
243	40	0.055
244	45	0.045
245	95	0.100
246	75	0.055
247	80	0.100
248	0	0.0
249	0	0.0

Figure 7 - Samples Cut From Removed Section, Grooves 86-99

2X

Figure 8 - Samples Cut From Removed Section, Grooves 100-112

Figure 9 - Samples Cut From Removed Section, Grooves 139-155

Figure 10 - Samples Cut From Removed Section, Grooves 208-219

Figure 11 - Samples Cut From Removed Section, Grooves 220-235

Figure 12 - Samples Cut From Removed Section, Grooves 236-249

2X

V. RECOMMENDATIONS

To further prove the reliability of the technique, a nozzle with machined grooves which has completed the required testing should be inspected and sections removed and evaluated. This would provide valuable data related to both methods of nozzle grooving and ultrasonic shear-wave inspection. In addition, tube braze-joint development samples should be ultrasonic inspected and the results correlated by cross-sectioning. All data would then be evaluated and the confidence level of the ultrasonic shear-wave technique established. This would provide the necessary information to proceed with the quantitative, computerized system for ultrasonic inspection of future NERVA nozzle coolant-channel braze shear-joints.