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RESISTANCE WELD MONITORING

CENTAUR TANKS 55-0501-22, 55-0501-23

(AC 21, AC-22)

NAS 3-11811

GDC-AGD-68-0028

FINAL REPORT

MARCH 1969

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RESISTANCE WELD MONITORING

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ABSTRACT

Two "in-process" methods of determining weld quality were evaluated under actual production conditions in this program:

1) the ultrasonic method using ultrasonic transducers installed in the welding electrodes, whereby the through transmitted sound is monitored for the effect produced by each weld cycle; and

2) the thermal expansion method, which measures the rate of expansion produced by each weld.

Both of these methods were used to monitor actual production welding of Centaur Tanks AC-21 and AC-22. The results are compared with x-rays to determine correlation. Preliminary results, given in an earlier report, GDC-AGD-8-002A, are summarized with results obtained on AC-22 and final recommendations are made.
INTRODUCTION

The use of nondestructive in-process inspection of resistance welds has been under study by General Dynamics Convair Division since early 1965. In 1966, a German ultrasonic unit and a British thermal expansion unit were obtained for evaluation purposes. Tests conducted during 1966 and 1967 indicated the potential of these units to detect substandard welds.

In 1967, the British expansion unit was updated to a solid state configuration and improvements in sensing capability were incorporated. Also, in 1967, a new American-manufactured ultrasonic unit was developed as a result of cooperation between Automation Industries (Sperry Division) and Convair. This unit had increased capability and offered ease of maintenance and parts replacement.

As a result of earlier tests, it was proposed to NASA that these monitors be used to monitor actual production welding of several Centaur tanks for the purpose of determining actual capability under production conditions. The information collected would be for data evaluation only and would not be used for weld acceptance or rejection. Since the Centaur tank is 100% x-rayed, good data comparison could be made. This final report summarizes the results obtained using both the ultrasonic and the thermal expansion methods on Centaur tanks AC-21 and AC-22.

The detection of substandard welds at the time they are produced is the goal of this program. The ultrasonic method should essentially produce the same information as x-ray, relative to weld defects such as cracks, voids, and spits. The thermal expansion method is intended to produce information relative to weld size with particular emphasis on stick welds. X-ray is not capable of detecting this type of defect.
GENERAL DYNAMICS
Convair Division

SUMMARY

The two methods of ultrasonic and thermal expansion monitoring were used on a non-interference basis to monitor all production welding accomplished in the major weld fixture on both Centaur tanks AC-21 and AC-22.

Over 56,000 welds were inspected by x-ray and thermal expansion methods. Approximately 18,000 of these were also monitored with the ultrasonic inspection system. (Seamwelds cannot presently be monitored by the ultrasonic system.)

Ultrasonic Test Method

Comparison of x-ray and ultrasonic data showed that both systems detected the same defective welds, a total of 16. All were spit welds. Seven of these contained voids ranging in size from .020" to .050". One of the 16 contained a crack .020" in length.

Instability of the ultrasonic transmission level experienced during monitoring of AC-21 continued to be a problem during monitoring of AC-22. Turbulence and temperature variation of the electrode cooling water, which was also the sound couplant, is thought to be the cause of signal instability. The high rate of production welding contributed to this problem. Development of a more stable couplant-cooling system will be required in order to use automatic GO/NO-GO gating of signal amplitude for acceptance or rejection.

Thermal Expansion Method

Of the 56,000 welds monitored by this system, a total of 547 welds were considered to be substandard. The expansion rates of these welds were considerably less than the rates normally observed for the given joint configuration.

Variation of expansion rates between test samples and the production part on the heavier builds first noted on AC-21 was also experienced on AC-22. Closing the sensor gap settings did not change this relationship. Variation of fit and part alignment may have a dampening affect on the expansion rates.

Additional instrumented tests to determine exact expansion characteristics produced on large tank structures will be required. This is in order to validate the ability of the expansion monitor to indicate substandard welds.
DISCUSSION

Monitoring and Instrumentation

Figure 1 is a sketch of the Centaur joint configurations which were monitored during this program. It should be noted that Joints A through H and K were monitored with both systems. Joints D1 and K1 are seamwelds which cannot be monitored by the ultrasonic system. Joints L through P were welded on the gantry weld machine which is not presently adapted for the ultrasonic system. The arrangement of the various monitors and recorders is shown in Figure 2. A photograph of the monitors in place on the welding machine is shown in Figure 3.

Ultrasonic Method

Standard electrode holders and electrodes were modified to allow for installation of the ultrasonic transducers and connecting cables. The cooling water is also the sound couplant and is introduced and removed at the base of the electrode through tubes fitted to the electrode holder. (See Figures 4 and 5.) Water was prevented from reaching the cable connection by the "O" rings mounted on the transducer adaptor body. Electrodes were removed by displacement accomplished by turning the large screw at the end of the electrode holder shown in Figure 5. This method of electrode removal prevented damage to the transducer as well as electrodes and the tapered electrode seat in the holder.

As shown in the above sketch, ultrasonic through transmission was accomplished by the use of two transducers, one acting as the pulser and the other as the receiver. The weld pressure negated the need for a wet couplant between the electrodes and the workpiece. Preweld signal amplitude was established by inserting test samples representative of the joint between the electrodes and...
bringing the electrodes together on the test sample at the pressure required by the weld schedule. Signal amplitude was adjusted by sensitivity control to 50% of scale to allow excursion during the weld cycle. (See Figure 6.) "A" scan presentation was used and this signal was fed to an oscillographic recorder for permanent record. Previous tests have shown that for a good weld, a general increase in signal amplitude over the weld period will occur. Drastic loss of amplitude indicates a defective weld.

**Thermal Expansion Method**

The thermal expansion sensor was mounted on the stationary portion of the upper electrode assembly and the rack was attached on one end via ball socket to the movable ram assembly. (See Figures 7 and 8.) The rack passed through the sensor and was meshed with a pinion attached to a lever arm positioned between two stops, as shown in the sketch below. The pinion was mounted on an electromagnetic clutch so that no lever movement took place until the clutch was energized. The lever was spring loaded to one side to provide return. Clutch energization and count gate start were triggered simultaneously. This initiation pulse was obtained from the heat-cool panel of the weld machine control. Thermal expansion digital information was in milliseconds (ms), counting from the left, hundreds, tens, units and tenths. In general, once the expansion rate for a good weld was established, via test samples, then variations were interpreted as follows: shorter expansion rates (lower number) indicated a hotter or larger weld; longer expansion rates (higher number) indicated a colder or smaller weld.

As a basis for comparison of all data, the complete weld cycle was recorded via inductive pickup from the throat of the weld machine and fed to the oscillographic recorder. Figure 9 illustrates the relation between the basic weld cycle and the two monitoring systems.
Observations

Ultrasonic Method

As noted in the preliminary report, the pattern of the ultrasonic signal trace varied according to the weld cycle configuration used for a given joint. This configuration evolved as a result of the techniques required to weld the widely varying sheet thicknesses and combinations of thicknesses. The technique involved everything from single impulse single phase for two thin gauge sheets, to multiple impulse three phase, including use of preheat and temper for the heavier sheet buildups.

Since the weld electrodes acted as lenses for the ultrasonic signal, some change occurred in ultrasonic signal trace configuration throughout the monitoring of a single joint configuration. This was so because of wear on the electrode face. However, in those instances where defective welds were made, the change in the ultrasonic signal was dramatic and easily recognizable.

Instability of the ultrasonic signal caused by turbulence and rapid temperature change in the electrode cooling water, which was also the sound couplant, must be minimized in order to make automatic control practical.

Thermal Expansion Method

Correlation of thermal rates between the 1" x 4" samples used as production control by inspection and the production part was very good for the thin thickness combinations, but degraded on the heavier builds, the greatest deviations occurring on the heavy machined rings. In some cases, the rates on the production part were two and a half times as slow as the test sample, indicating a colder or smaller weld. Since an exact simulation of large tank fit and alignment conditions cannot be made on test samples, more exact test instrumentation will be required to determine validity of the expansion indication.
Ultrasonic Method

Excellent correlation may be seen between x-ray and ultrasonic results as shown in Table I. However, all defects experienced during the manufacture of two tanks were of the spitting or blown spot variety. This type of defect was accompanied by a loss of metal (expelled) and subsequent surface concavity. The concavity resulted in loss of contact area by the electrode and therefore reduction of ultrasonic signal amplitude. Internal defects such as cracks and voids may occur without metal expulsion (spit) or noticeable surface concavity. None of these were experienced during the welding of AC-21 and AC-22, so that the capability of the ultrasonic system to detect such defects under production conditions was not determined. Examples of defective welds detected during the welding of AC-22 and the x-ray verification are shown in Figures 10 and 11.

Fit, alignment, and electrode cleanliness all had an effect on the amplitude of the ultrasonic transmission. Therefore, the monitor indicated changes in these parameters during the squeeze period prior to heat passage for each spotweld. The use of the monitor transmission level to optimize these parameters is definitely feasible.

Instability of the ultrasonic signal caused by coolant turbulence and temperature variation indicated the need for improvement of the electrode cooling system. This will not only benefit the monitor, but also improve electrode cooling, especially significant at high production welding rates.

No essential differences were noted in signal configuration for a given joint between AC-21 and AC-22.

Thermal Expansion Method

Total substandard welds indicated by this system are shown in Table I. These welds exhibited expansion rates considerably slower than either the production control test or the normal rate for that particular joint.

The relation between expansion rate and weld heat is graphically shown in Figure 12. Excellent correlation has been evidenced on all 1" x 4" production control test samples and the thinner gauge joints on the production part.
The expansion rates for the heavy thickness combinations encountered on the machined rings at Stas. 219 and 413 deviated by a factor of up to 2.5 from the production control test. Varying the sensor gap did not change this relation. In most cases the expansion rates for the production part were slower than those obtained on the test sample. Examples of typical expansion rates for thin and heavy joints are shown in Table II. Joint "A" expansion rates, although considerably slower than the test sample, were consistent within 10 milliseconds. Joint "B" exhibited some expansion rates that would be considered satisfactory based on test samples, but the slower rates would seem to indicate substandard size and penetration. The same holds true for Joints "M" and "N".

The reasons for these deviations are not understood at this time. Although the weld cycle was recorded for each weld, it is felt that the recording instrument was not sensitive enough to indicate all heat changes. Large heat changes, such as those caused by machine malfunction, were easily understood and correlation was exact. Figure 13 shows such a malfunction and the resulting weld trace and expansion rate.

Since the exact conditions of mass, fit and alignment, such as exist on large tank structures, cannot be simulated on small test samples, verification of expansion rate indications of substandard welds was lacking.
CONCLUSIONS

Ultrasonic Method

Production testing on a wide range of material thicknesses readily proved the ability of the ultrasonic weld monitor system to detect gross weld defects. However, because of the low defect level, consistent with the high quality of resistance welding on the Centaur tank, the monitoring of 18,000 welds did not permit adequate evaluation of the full capability of this system to detect all types of defects. In addition to the spit welds noted, the system also indicated deficiencies in fit, alignment and surface condition which may lead to the production of substandard welds.

Instability of the ultrasonic signal caused by couplant turbulence must be minimized in order to realize the system's full capability and to utilize the automatic GO/NO-GO alarm and shut-off circuitry.

Expansion Method

Excellent correlation was obtained on the thin thickness joints. Expansion rates for the production control samples and the production part were the same. Excellent response to heat changes on test samples was obtained on all thickness combinations.

The deviations of expansion rates on the heavier thickness joints on the production part indicate that the production test samples do not provide sufficient assurance of good welds. Correlation of weld energy levels with expansion rates on 1" x 4" test samples, as shown in the preliminary report, support this view. Additional testing on the heavier joint thicknesses is required to resolve this item.
RECOMMENDATIONS

Ultrasonic Method

Efforts should be continued toward making this system fully automatic. This would include provisions for disabling the weld machine firing circuit when the preset high or low limit of the monitor is exceeded. This method would then provide the means for further reduction of defect levels, since detection is immediate and corrective measures can be made on-the-spot.

In order to do this, it is necessary that the signal instability caused by the electrode cooling water be resolved. To this end, it is recommended that the following system be procured: a closed loop self-contained electrode cooling and ultrasonic couplant system. This system must produce minimum turbulence and stability of temperature. Sufficient heat dissipation would be provided to assure adequate electrode cooling at highest production welding rates.

When procured, run calibrated instrumented test to verify temperature, flow and ultrasonic transmission stability. Verify system stability and reliability on one production tank. Correlate to x-ray results and report.

Expansion Method

Conduct a test program to determine the exact weld electrical energy required to produce an acceptable weld on test samples. Determine the affect on this energy level imposed by the several conditions of the production part (mass, fit, alignment). Obtain actual expansion traces of test and production welds and the affect on the expansion characteristics imposed by the various energy levels.

This instrumentation is required in order to validate the expansion indications of substandard welds. It would also provide a more realistic approach to producing the weld strength required on the production part, which is now restricted by the use of small test samples.

It is also recommended that expansion monitoring be continued on any tank welded prior to completion of the above recommended test program.
#### TABLE I

**SUMMARY OF RESISTANCE WELD MONITORING**

**OF CENTAUR TANKS (AC-21 & AC-22)**

<table>
<thead>
<tr>
<th>INSPECTION METHOD EMPLOYED</th>
<th>X-RAY</th>
<th>ULTRASONIC MONITOR</th>
<th>THERMAL EXPANSION MONITOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL WELDS INSPECTED</td>
<td>56,412</td>
<td>18,000</td>
<td>56,412</td>
</tr>
<tr>
<td>CRACK</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>VOID</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>SPIT</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>UNDERSIZE</td>
<td>0</td>
<td>0</td>
<td>547</td>
</tr>
<tr>
<td>TOTAL SUBSTANDARD</td>
<td>16 (a)</td>
<td>16 (a)</td>
<td>547 (b)</td>
</tr>
</tbody>
</table>

**NOTES:**

(a) Defects indicated by x-ray and ultrasonic are the same welds.

(b) The 547 welds indicated as undersize had expansion rates considerably below the rates normally recorded for that joint (colder weld).

Since the expansion rate is taken only from the initial part of the weld cycle, internal defects are not indicated unless accompanied by a change in energy input during this time.
## TABLE II
### TYPICAL EXPANSION RESULTS

<table>
<thead>
<tr>
<th>MATERIAL COMBINATION</th>
<th>JOINT</th>
<th>TEST SAMPLE 1&quot; x 4&quot;</th>
<th>TANK 1&quot; x 4&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LO</td>
<td>HI</td>
</tr>
<tr>
<td>Thin Joints</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>010/014/016/010</td>
<td>D</td>
<td>074.3</td>
<td>073.6</td>
</tr>
<tr>
<td>010/014</td>
<td>E</td>
<td>058.7</td>
<td>058.5</td>
</tr>
<tr>
<td>014/014</td>
<td>G</td>
<td>075.8</td>
<td>060.0</td>
</tr>
<tr>
<td>018/014/032</td>
<td>P</td>
<td>058.0</td>
<td>052.5</td>
</tr>
<tr>
<td>Heavy Joints</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>070/016/010/026</td>
<td>A</td>
<td>116.9</td>
<td>103.6</td>
</tr>
<tr>
<td>110/010/014/016/010/026</td>
<td>B</td>
<td>121.9</td>
<td>115.4</td>
</tr>
<tr>
<td>070/032/032/016/026</td>
<td>M</td>
<td>089.4</td>
<td>067.6</td>
</tr>
<tr>
<td>100/018/014/032</td>
<td>N</td>
<td>090.6</td>
<td>079.9</td>
</tr>
</tbody>
</table>

All expansion times are in milliseconds.

### COMPARISON OF EXPANSION RATES FOR 1" x 4" TEST SAMPLES AND ACTUAL PRODUCTION PART
THICKNESS COMBINATIONS
MATERIAL 301 1/2 H & UP

A **.070/.016/.010/.026
B & C **.110/.016/.014/.016/.010
D & D1 .010/.014/.016/.010
E & F .010/.014
G & H .014/.014
K & K1 .014/.014/.032/.026
L .032/.032/.016/.026
M **.070/.032/.032/.016/.026
N **.100/.018/.014/.032
O **.070/.018/.014/.032
P .018/.014/.032

**321 Annealed

STA. 218

STA. 288 AND 344

STA. 410

FIGURE 1

CENTAUR WELD JOINTS EVALUATED

TOTAL WELDS: 28,206

* THERMAL EXPANSION MONITOR ONLY
FIGURE 3

MONITORS IN PLACE ON WELD MACHINE
FIGURE 9
MONITORS RESPONSE TO WELD CYCLE
ABOVE: OSCILLOGRAPHIC TRACE OF THE ULTRASONIC TRANSMISSION DURING WELDING OF JOINT "E". THE FIRST AND THIRD WELDS ARE NORMAL. THE SECOND WELD EXPERIENCED A SPIT AND SUBSEQUENT LOSS OF SIGNAL AMPLITUDE IN THE POST WELD PERIOD.

RIGHT: PHOTO OF X-RAY SHOWING THE THREE WELDS ABOVE.

FIGURE 10
WELD DEFECT JOINT "E"
ABOVE: ACTUAL OSCILLOGRAPHIC TRACE OF THE ULTRASONIC
TRANSMISSION DURING WELDING OF JOINT "D". THE
FIRST TWO WELDS ARE NORMAL AND SHOW A MARKED
INCREASE IN SIGNAL AMPLITUDE IN THE POST-WELD
PERIOD. THE THIRD WELD EXPERIENCED A "SPIT"
AND THE POST-WELD PERIOD SHOWS COMPLETE LOSS
OF SIGNAL.

RIGHT: PHOTO OF THE X-RAY SHOWING ONE OF THE NORMAL
WELDS AND THE DEFECTIVE WELD.

FIGURE 11
WELD DEFECT JOINT "D"
FIGURE 12
EXPANSION VERSUS WELD HEAT
JOINT "M" 1" X 4" TEST SAMPLES

NOTE NEARLY PERFECT CORRELATION
General Dynamics
Convair Division

Normal Weld
Expansion 055.4 ms

Malfunction-Defective Weld
Expansion 036.4 ms

Expansion Diagram

X-ray of Defect

Figure 13
Weld Control Malfunction