FLAW DETECTION IN ALUMINUM WELDS BY THE ELECTRIC CURRENT PERTURBATION METHOD

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INTRODUCTION

The integrity of the Space Shuttle external fuel tank is vital to the success of each shuttle mission. These giant tanks (154 ft long and 28 ft diameter) are manufactured for NASA by Martin Marietta Aerospace, New Orleans, LA. An important part of the quality assurance for each tank is detection of defects in the welds using nondestructive evaluation (NDE) methods. The tank is manufactured from aluminum panels which are welded together, and due to the large physical size of the tank, several thousand feet of weld must be inspected for each tank. Therefore, to be cost effective, the NDE methods used must not only be reliable but also must be rapid.

The electric current perturbation (ECP) method is being investigated for possible application to flaw detection in "unshaved"* welds joining aluminum panels having a thickness of 0.250 in. or less which are typical of those used in some sections of the external tank. The ECP method offers the potential for a rapid, semi-automated inspection of the entire weld thickness with access required from only one side. The primary objective of the work reported here was to demonstrate a new two-frequency ECP method to allow discrimination of ECP signals produced by simulated internal (back-surface) defects from the background signal produced by the weld bead.

EXPERIMENTAL APPROACH

The ECP method consists of establishing an electric current flow in the part to be inspected (usually by means of an induction coil) and detecting the magnetic field associated with perturbations in the current flow around defects using a separate magnetic field sensor[1]. In the usual configuration an ECP probe consists of an induction coil and a

*The term "unshaved" refers to the as-welded condition, i.e., the weld bead has not been machined to obtain a smooth surface.

sensor which are scanned together as a unit. In this research, an elongated induction coil was used to provide linear current flow in the region of the sensor. Figure 1 shows the experimental setup with the probe positioned over a welded specimen. Emphasis was placed on the probe orientation that provided current flow parallel to the weld. In this case, maximum ECP sensitivity is obtained for defects oriented from approximately 45° to 90° with respect to the weld (and current flow) direction. Detection of flaws from approximately 0° to 45° with respect to the weld direction is based on the same principles except the probe is oriented for current flow perpendicular to the weld, i.e., rotated by 90°.

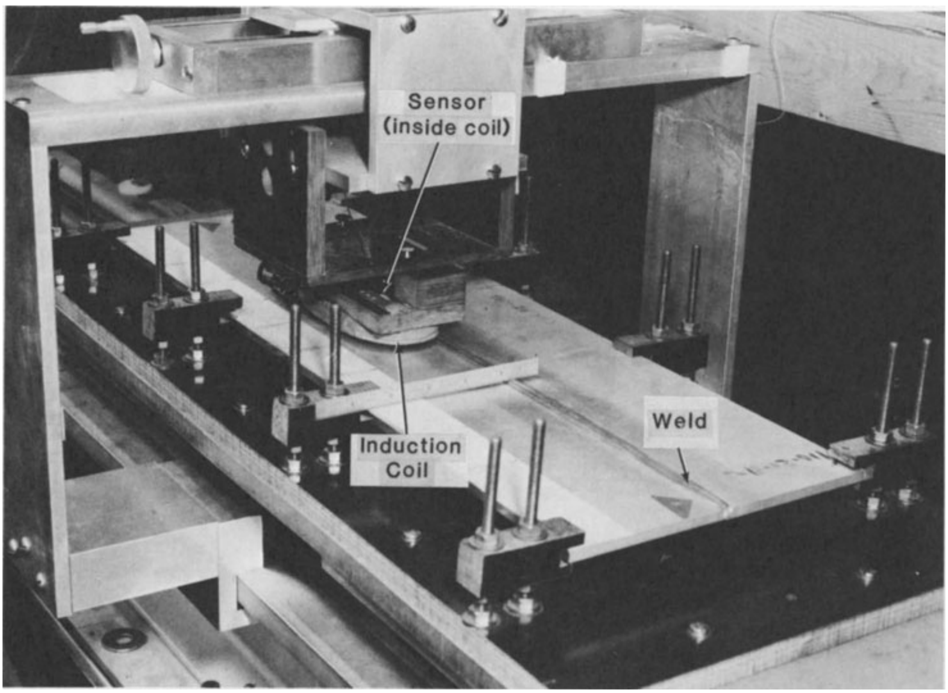

Fig. 1. ECP experimental setup for welded panel investigation.

A block diagram of the ECP instrumentation is shown in Figure 2. A signal generator set to a single excitation frequency drives a power amplifier which in turn is connected to the induction coil in the ECP probe. Output from the ECP sensor goes to an amplifier and phase sensitive detector which is referenced to the oscillator signal phase. The phase sensitive detector provides two outputs, A and B, which are the in-phase and quadrature components of the ECP signal. These signals are fed to a digital oscilloscope. By using a position encoder attached to the scanning system, the ECP signals are digitized with respect to the true spatial position of the probe. The digitized data are then transferred to a computer for signal processing. The magnitude of the ECP signal is computed from the in-phase and quadrature components.

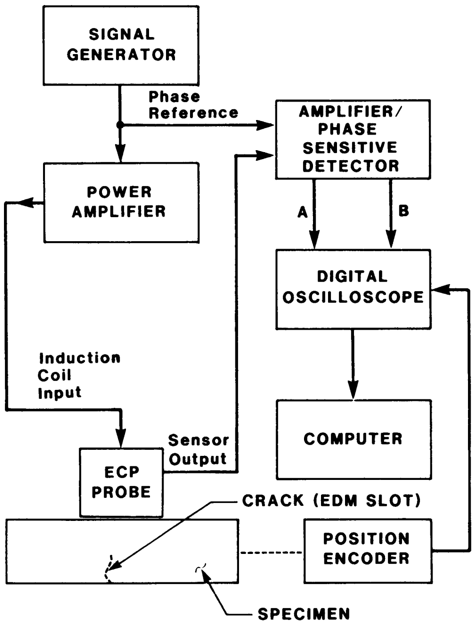

Fig. 2. Block Diagram of ECP Instrumentation.

By choosing an initial excitation frequency for the ECP probe of 150 Hz, current density on the back surface of the weld bead was sufficient to produce ECP signals from back-surface flaws. The irregularities of the "unshaved" weld bead on the near-surface of the panel also produce signals. By increasing the excitation frequency, the current penetration depth is decreased and signals from the weld bead and also from near surface flaws become prominent while the back-surface flaw signals decrease. The amplitude of the weld bead response in the high excitation frequency signal can be normalized to that of the weld bead response in the low excitation frequency signal to produce equal amplitude weld bead signals. By using a digital, point by point subtraction of the high frequency normalized signal from the low frequency signal, only the flaw response should remain.

For two-frequency measurements, one scan of the specimen is made at the first excitation frequency, then the instrument is set to the second excitation frequency and the scan is repeated. Since the signals are digitized with respect to the spatial position of the probe, signal processing operations can be performed on data samples from each of the two separate frequencies which are digitized at precisely the same location. In an actual application on the external tank the ECP probe would be excited at the two frequencies simultaneously and the resulting signals would be measured simultaneously by two separate phase sensitive detectors, each set to its respective frequency.

SPECIMENS

A 0.375 in. thick x 6 in. wide x 24 in. long non-welded aluminum panel was used for initial setup and optimization of excitation frequencies without the influence of the weld bead. The 0.375 in. thickness was chosen to simulate the total weld bead thickness in a 0.250 in. thick welded panel. Subsequent evaluations were performed on a 0.250 in. thick x 8 in. wide x 24 in. long welded panel. Both panels were fabricated from 2219-T87 aluminum alloy. A schedule of nominal defect sizes, orientations and locations for both panels is shown in Figure 3. Since flaws must be detected in all orientations, EDM slots were machined at 0 °, 45°, and 90° with respect to the weld bead direction. The welded panel also contained several flat-bottom holes; however, these were not of primary interest in this investigation since the goal was detection of cracks.

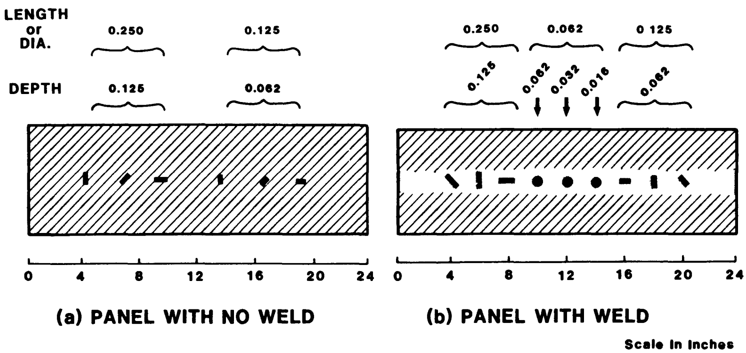

Fig. 3. Flaw sizes and orientations in non-welded and welded panels.

SUMMARY OF RESULTS

Non-Welded Panel - Current Flow Parallel to "Weld"*

Initial ECP evaluations were performed on the 0.375 in. thick non-welded panel. This allowed preliminary data to be obtained for optimum probe position and excitation frequencies and a determination of the ECP sensitivity without the complicating influence of the weld.

Optimum overall results for the two-frequency method were obtained by using 150 Hz and 350 Hz excitation frequencies. The ECP signals obtained at these two frequencies are shown in Figure 4a and 4b. ECP signals from edge effect at each end of the panel have been removed in the figures for clarity.

In Figure 4a signals from the 0.250 in. x 0.125 in. flaws can be seen in the 150 Hz data. Note that a unipolar signal shape is obtained from the flaw oriented 90° to the "weld" (and current flow) direction while a bipolar signal shape is obtained from the flaw at 45°. These signal shapes are typical for flaws with these orientations. Other ECP background signals also appear which are not associated with the back-surface flaws and may be caused by conductivity variations in the aluminum panel. In Figure 4b the 350 Hz data show that the signals from the 0.250 in. x 0.125 in. back-surface flaws have decreased in magnitude relative to the background signals which are not associated with the flaws. This indicates that many of the background signals are caused primarily by near-surface effects.

*The non-welded panel was considered to contain an imaginary weld along the row of defects, i.e., in the same orientation as the welded panel.

To remove the background signals from the ECP data, subtraction of the high excitation frequency data from the low excitation frequency data was performed. Since the absolute amplitude of the ECP signals varies as the frequency is changed, it is necessary to normalize the high frequency signal to the low frequency signal before subtraction. The normalization scale factor was determined by measuring the amplitude of a background signal due to a near-surface anomaly at each excitation frequency and computing the ratio of these amplitudes. The high frequency data were then multiplied by the scale factor to yield the same amplitude as the low frequency data. In Figures 4a and 4b, which show ECP data taken at 150 Hz and 350 Hz, a region of the signal has been designated where the background signal must be due to a near-surface anomaly since it is still present when the frequency is increased to 350 Hz. The scale factor was computed from the peak-to-peak signal amplitude in this region.

The normalized and subtracted data are shown in Figure 4c. Signals from the 0.125 in. x 0.062 in. flaws are now more evident and a signal from the 0.250 in. x 0.125 in. flaw oriented parallel with the "weld" is also recognizable. (Note that for maximum sensitivity to the flaw parallel to the "weld" , it would be necessary to rotate the probe by 90°.) Since the data still contains slowly varying fluctuations in the baseline, a high-pass digital filtering routine was utilized to remove these components. The filtered data are shown in Figure 4d. The filtering dramatically improves the record, thus making the flaw signals more apparent. These results indicate that the ECP method has the inherent sensitivity required for detection of 0.125 in. x 0.062 in. back-surface flaws through a thickness (0.375 in.) equivalent to that of the weld bead in a 0.250 in. thick aluminum panel.

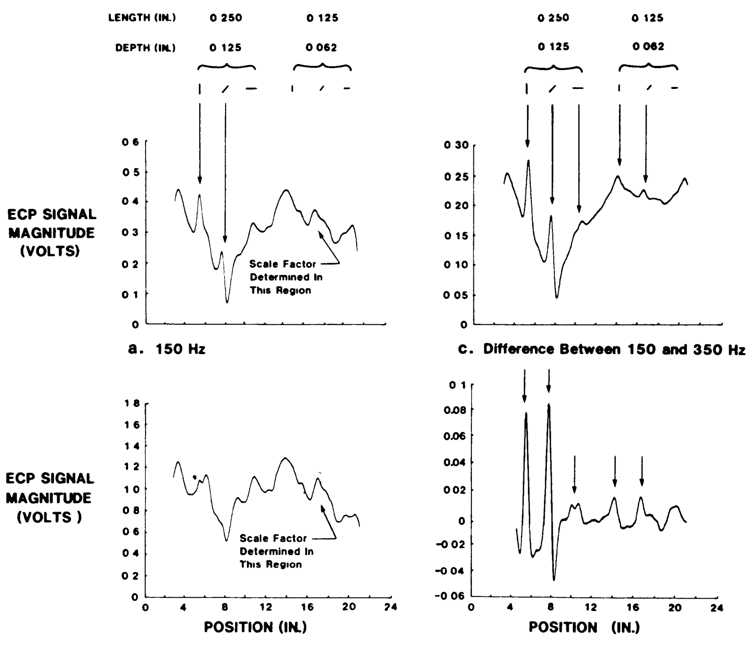

Fig. 4. ECP signals from non-welded panel with current flow parallel to "weld".

Welded Panel - Current Flow Parallel to Weld

ECP evaluations were performed on the 0.250 in. thick welded panel with the ECP probe oriented the same as for the non-welded panel, i.e., current flow parallel to the weld. The 150 Hz and 350 Hz data are shown in Figures 5a and 5b.

Notice that a very significant background signal is obtained from the weld bead and that distinct flaw signals cannot be recognized for even the larger flaws (0.250 in. x 0.125 in.). As with the non-welded panel, optimum results were obtained by subtracting the normalized 350 Hz data from the 150 Hz data as shown in Figure 5c. Signals from the 0.250 in. x 0.125 in. flaws are now recognizable.

A slowly varying background signal is again evident in the subtracted data (Figure 5c) as was the case with the non-welded panel. To remove this signal, the data was filtered and the result is shown in Figure 5d. Signals from the 0.250 in. x 0.125 in. back-surface flaws are very evident. Although signals are obtained in the regions near the smaller slots and holes, they do not occur at the precise locations of the flaws and therefore cannot be positively identified as flaw signals.

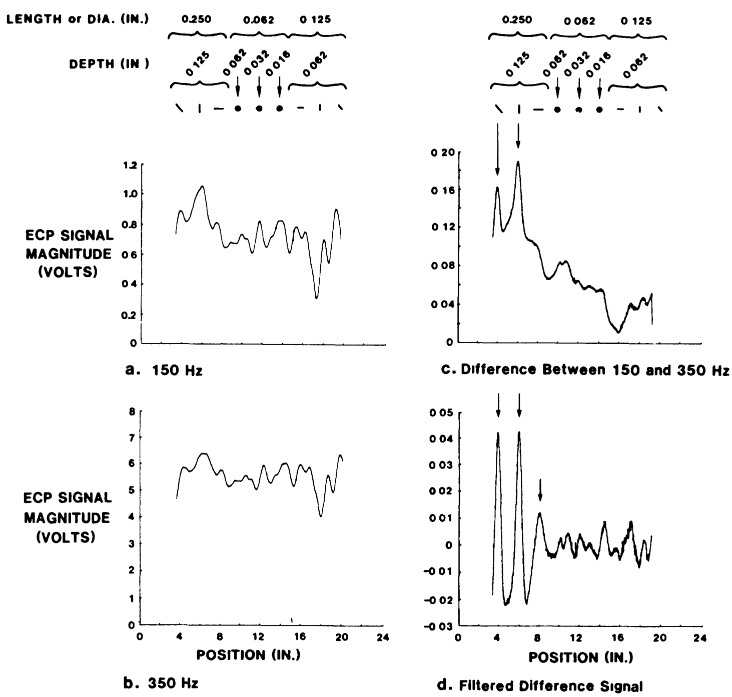

Fig. 5. ECP signals from welded panel with current flow parallel to weld.

Welded Panel - Current Flow Perpendicular to Weld

For this limited experiment, the ECP probe was rotated 90° from the orientation in the previous section. It was found that excitation frequencies of 150 Hz and 1 kHz gave optimum results for this configuration. The processed data in Figure 6 show a prominent signal from the 0.250 in. x 0.125 in. flaw oriented parallel with the weld. The 0.250 in. x 0.125 in. flaw at 45° was too close to the end of the panel for detection with this probe orientation. Although it was not possible to optimize the setup for current flow perpendicular to the weld, these data indicate that it is indeed possible to detect flaws in all orientations.

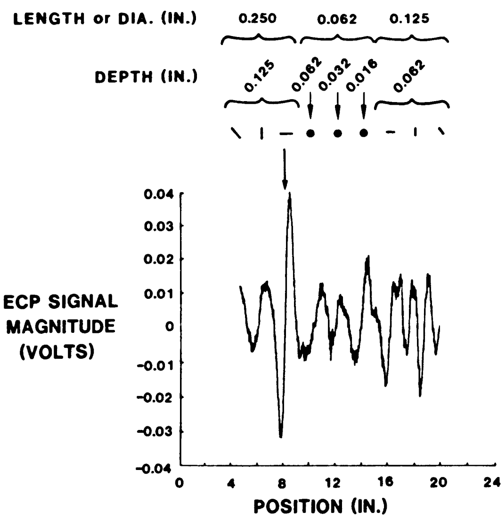

Fig. 6. Filtered difference signal (150 Hz - 1 kHz) from welded panel with current flow perpendicular to weld.

CONCLUSIONS

1. The newly developed two-frequency ECP method effectively reduces background signals from the "unshaved" weld bead and improves detection of back-surface flaws.

2. Back-surface EDM slots as small as 0.125 in. x 0.062 in. were successfully detected in a 0.375 in. thick non-welded aluminum panel equivalent to the weld thickness in a 0.250 in. thick welded panel.

3. Back-surface EDM slots measuring 0.250 in. x 0.125 in. located in the weld of a 0.250 in. thick panel were readily detected in all orientations.

4. The ECP method is very promising for inspection of "unshaved" aluminum welds.

REFERENCES

1. C. M. Teller and G. L. Burkhardt, "Detection and Characterization of Defects by the Electric Current Perturbation Method," Proceedings of the DARPA/AFML Review of Progress in Quantitative NDE, La Jolla, California, July 1980, AFWAL-TR-82-4080, pp. 477-483, published September 1981.