THE INFLUENCE OF CALIBRATION AND ACCEPTANCE CRITERIA ON CRACK

DETECTION AND DISCRIMINATION BY EDDY CURRENT TECHNIQUES

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INTRODUCTION

Use of linear elastic fracture mechanics in design and in life-cycle management of engineering systems has increased the demand for quantitative NDE and for quantification of NDE performance capabilities. Demonstrated performance capabilities by eddy current methods have increased the focus on eddy current applications for the detection of small cracks in critical hardware. Although eddy current methods have an extensive history of application, characterization of critical factors in application and quantification of the output has received little attention. Work described herein was performed to increase understanding of critical eddy current probe characteristics, to quantify performance in support of detection theory development, and to demonstrate the effects of established eddy current procedures on overall performance.

Variability in eddy current probe performance is easily recognized by response to "calibration standards" and actual performance on test hardware. Probes that are built at the same time, using special care, do not perform equally in actual application. This difficulty was evident when two identical sets of air core and ferrite core probes were produced for our laboratory, and demonstrated variable response characteristics. In the course of evaluation and characterization, differences in response characteristics were measured using methods that have been previously discussed in detail [1,2]. In summary, the electrical characteristics of each probe were measured over a range of frequencies in free air, coupled to typical conductive materials and as a function of scanning over known flaws in materials. This work was extended to demonstrate the effects of probe variations on response using typical production eddy current procedures.

TYPICAL INDUSTRY APPLICATION OF EDDY CURRENT PROCEDURES

The mode of application for probe type eddy current procedures in industry is that of establishing a technique that yields a desired response to a flaw of interest. "Calibration" of the eddy current system is frequently accomplished by adjusting the eddy current instrument to produce a predetermined response to a flaw of a known size. Linearity of the instrument system may then be verified by reproducing response to flaws of varying sizes. Electrodischarge machined (EDM) slots are frequently

used as calibration reference flaws. It is, however, difficult to precisely duplicate an EDM slot and it is therefore necessary to compare response from a slot to the response from a "master slot" in order to assure reproducibility and consistency in a test set-up. The detectable flaw size is assumed to be equivalent to the size of the EDM slot used in set-up. The EDM slot is assumed to be conservative with respect to response from a crack. A larger amplitude response from a crack, then the response from an equivalent size EDM slot, has been reported [3]. This relationship is valid for large cracks, but is not valid when the flaw size approaches that of the core (air or ferrite) in the eddy current probe. Since the problem of greatest current interest is the detection of very small cracks, some characterization is in order.

COMPARATIVE RESPONSES FROM EDM SLOTS AND CRACKS

If a long crack or EDM slot is scanned axially along the length of the crack, an amplitude response profile is generated similar to that shown in the upper trace of Fig. 1. The peak amplitude and axial length from which a response was obtained is a measure of the actual crack length. The test frequency, and the depth and shape of the crack, will cause some variation in the rate of increase and in the amplitude of the response.

If a short crack or EDM slot is scanned axially along the length of the crack, an amplitude response profile is generated similar to that shown in the lower trace of Fig. 2. The double peak profile occurs as the size of the crack approaches the size of the core in the eddy current probe. The probe frequency and the depth and shape of the crack will cause some variation in the rate of increase and in the amplitude of the response.

A quantitative and qualitative assessment of probe response to cracks and EDM slots of approximately equal sizes was completed by recording the amplitude response as a function of position by successively scanning over various size flaws in two materials. The flaw depths in all cases were approximately one-half the length. An Automation Industries, EM-3300 instrument was used in conjunction with a precision bridge to scan over the flaws. The instrument was balanced on the plate material, away from an edge, and the lift-off was fixed by the use of a single layer of "Teflon" tape placed over the probe face. Data were taken and recorded every 0.010 inch. An 80 turn, bobbin wound, 0.050 inch ferrite core probe was used for all scans performed at 1 MHz. A 235 turn, pancake wound with a 0.060 inch air core probe was used for all scans performed at 200 KHz. The scan data were then plotted in plan, side, end and isometric views. The changes in probe electrical characteristics were also measured and plotted along the axis of each crack.
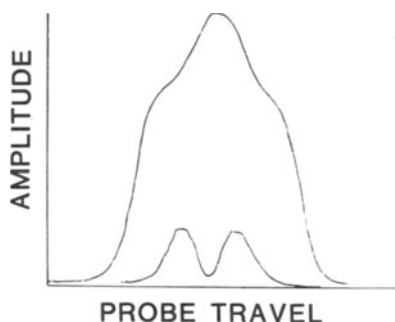

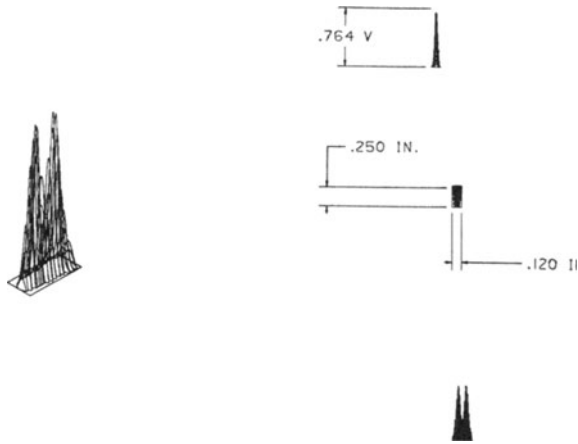Fig. 1. Response from two fatigue cracks of different size (0.290"L and 0.0.067"L).

.764 V

.250 IN.

.120 II

Fig. 2. Response from a 0.076 inch EDM Slot in 6061-T6 Aluminum; 200 KHz, Air Core Probe.
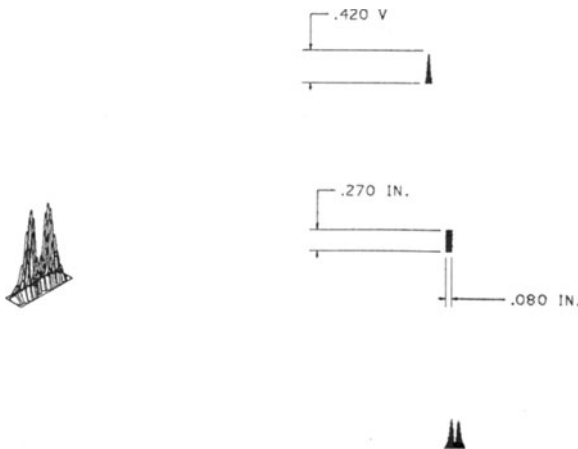

.420 V

.270 IN.

.080 IN.

Fig. 3. Response from a 0.070 inch Fatigue Crack in 6061-T6 Aluminum; 200 KHz, Air Core Probe.
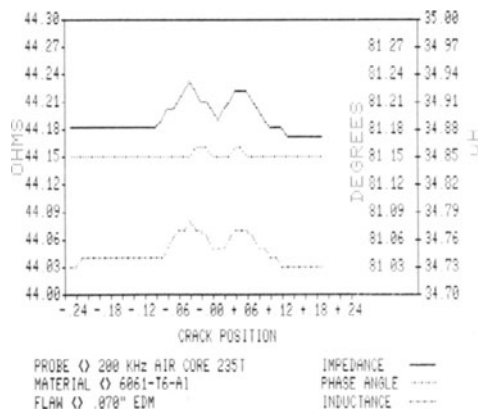

Fig. 4. Change in Probe Electrical Characteristics over an 0.076 inch EDM Slot.

Figure 2 shows the three dimensional plot of the response of the 200 KHz air core probe to a 0.076 inch long EMD slot in aluminum. Figure 3 shows the response to a 0.070 inch long fatigue crack in aluminum. Figure 4 is a plot of the electrical characteristics of the 200 KHz air core probe obtained by scanning axially along the length of the 0.076 long EDM slot in aluminum. Figure 5 shows the response to the 0.070 inch long fatigue crack in aluminum. Figure 6 shows the three dimensional plot of the response of the 1 MHz, ferrite core probe, to the 0.076 inch long EDM slot in aluminum. Figure 7 shows the response to a 0.070 inch long fatigue crack in aluminum. Similar responses were obtained from 0.125 inch long flaws in titanium at 1 MHz (Figures 8 and 9). The methods used in measurement of electrical properties and response to flaws were similar to those described by other workers [4,5].

All scans show the double peak characteristic and the peaks are symmetrical. The scans clearly illustrate the difficulty in selecting a single peak amplitude response for purposes of instrument "calibration"
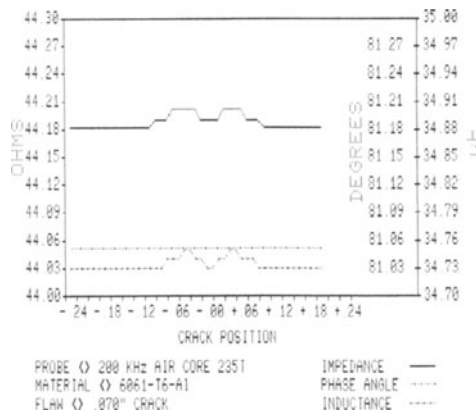

Fig. 5. Change in Probe Electrical Characteristics over a 0.070 inch Fatigue Crack.
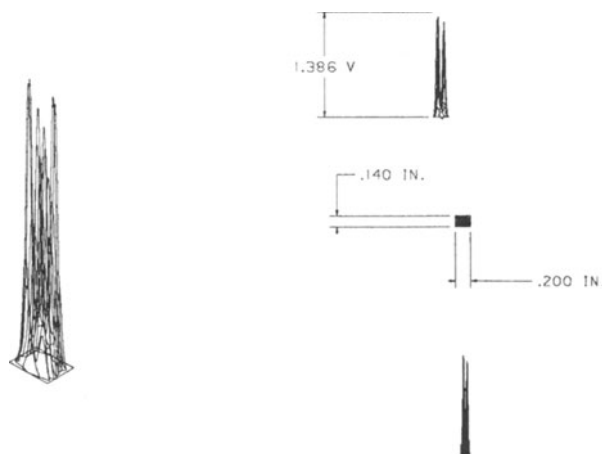

Fig. 6. Response from a 0.076 inch EDM Slot in 6061-T6 Aluminum, 1 MHz, Ferrite Core Probe.
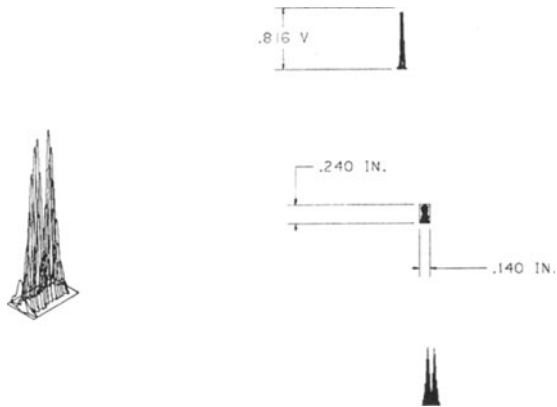
Fig. 7. Response from a 0.070 inch Fatigue Crack in 6061–T6 Aluminum;
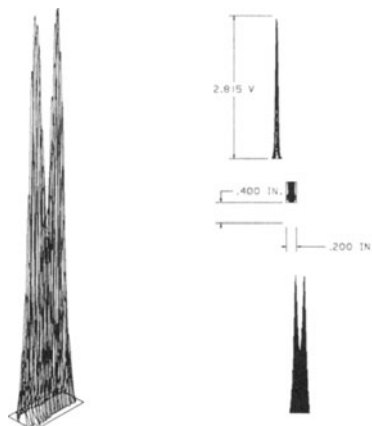1 MHz, Ferrite Core Probe.

Fig. 8. Response from a 0.124 inch EDM Slot in 6A1–4V Titanium; 1 MHz,
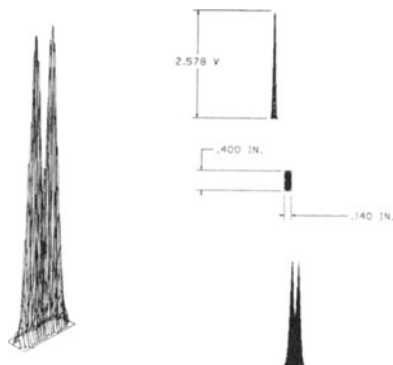Ferrite Core Probe.

Fig. 9. Response from a 0.125 inch Fatigue Crack in 6061–T6 Aluminum;
1 MHz, Ferrite Core Probe.

and procedure set-up and the lack of conservatism in using an EDM slot as
a measure of an equivalent crack size response level. The double peak
response accounts for some of the scatter in repetitive assessments of
flaws when the peak amplitude is used as the basis for acceptance.

IMPACT OF EDM AND CRACK RESPONSE VARIATIONS

      The impact of eddy current response variations to EDM slots and to
fatigue cracks is evident in analysis of a production NDE evaluation
sequence. In this case, an EDM slot was used as the reference standard
for instrument set-up. Instrument response linearity was verified by
responses to two EDM slots of larger size. NDE was performed on a series
of components that contained known flaws of varying size. Instrument
responses to the known flaws were recorded and the signal distributions
were plotted as shown in Fig. 10. Acceptance of the components was based
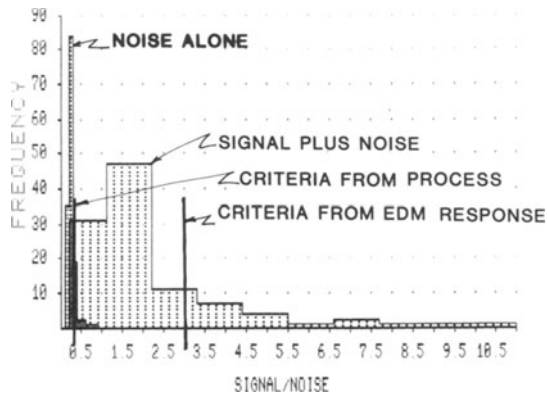

Fig. 10. Signal and Noise Response Distributions from Cracks of Varying
          Sizes in Production Test Specimens.
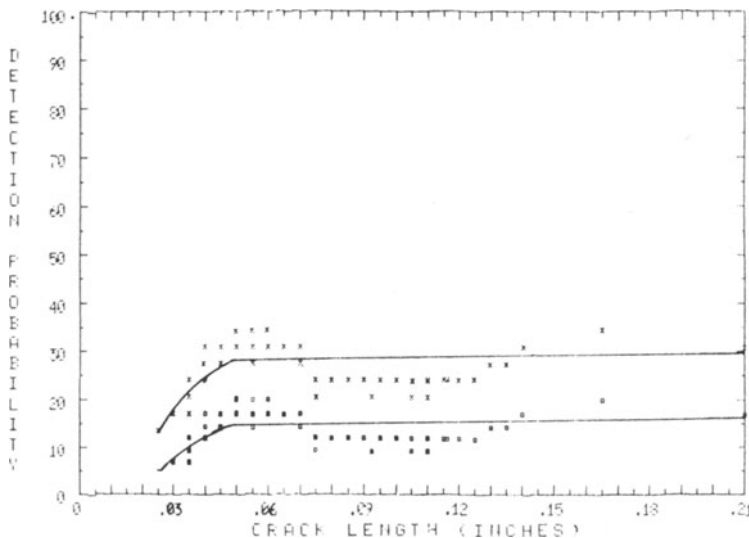

Fig. 11. Probability of Detection for a Production NDE Procedure using
          Acceptance Criteria based on Equivalent Response from an EDM Slot.
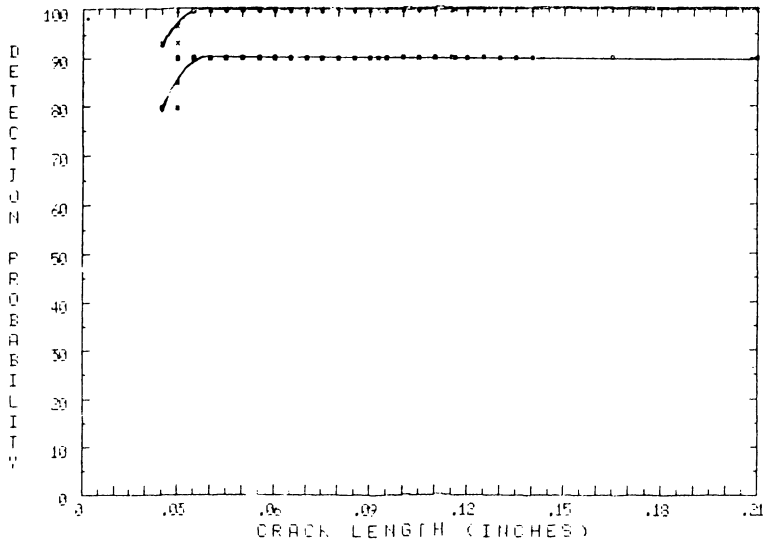
Fig. 12. Probability of Detection for a Production NDE Procedure using
Acceptance Criteria Based on Signal/Noise Process Analysis.

on the response for the EDM calibration reference slot that was equivalent
to the structurally acceptable crack size. A plot of the probability of
detection (POD) for acceptance at the established criteria level is shown
in Fig. 11. It is clear, from analysis of the response signal distribu-
tions, that better discrimination could be obtained from the NDE procedure.
The data were reprocessed using a second acceptance criteria level that
was obtained from the signal distribution response data (Fig. 10). The
result of a change in criteria is shown in the POD curve in Fig. 12. The
change in acceptance criteria resulted in a significantly improved crack
detection capability but also increased the potential for false alarms
(rejection due to noise that is inherent to the application of the NDE
procedure). The increase in false alarm rate can be predicted from the
noise distribution data and the number of acceptable components being
processed through a NDE station.

CONCLUSIONS

    Eddy current probe production, characterization and subsequent
requalification are not well understood and may account for significant
variation in the performance level of a specific NDE procedure. Probe
characterization, by electrical characteristics and reflector (flaw)
response profile, provides a means of discrimination with respect to
performance characteristics and provides a reference for comparison of
probe performance.

    It is clear that EDM slots are useful for eddy current system base-
line set-up and response linearity verification but are not equivalent
to fatigue cracks of equal size. Acceptance criteria must be based on
validated responses from the flaw types of interest. One approach is
through characterization of application noise and signal plus noise
response distributions, from representative flaws of the size of interest,
and determining the acceptance criteria level from the response distribu-
tions obtained. This method has an additional advantage in providing a
method of modeling not only the probability of detection (POD) but also

the level of false alarms that would be expected from service application of the method and the established acceptance criteria. This data may also be used to plot a relative operating characteristic (ROC) curve [6] and thereby provide a tool for assessment and control of the production application of an NDE process.

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