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EDDY CURRENT STANDARDS – CRACKS VERSUS NOTCHES

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ABSTRACT

This article describes eddy current tests to evaluate cracks and electrode discharge machined (EDM) notches in aluminum specimens. It was performed to verify the use of EDM notches for adjusting the eddy current instrument to produce a predetermined response to flaws of known size. The lengths of some of the notches and cracks were less than the probe coil diameter and some were longer.

Each notch and crack was scanned both transversely and axially at an index of 0.05 mm per scan. The vertical output from the NDT-18 was fed into an SRS boxcar averager, then through an IEEE interface to a PC and monitor, and finally to a printer. All tests were conducted at 180 kHz using a 3.175-mm-diameter ferrite-shielded probe. Photographs were taken of each flaw response on the CRT impedance plane.

The results showed good agreement between cracks and notches of similar sizes in 7075-T6 aluminum samples.

INTRODUCTION

"Calibration" of the eddy current system is frequently accomplished by adjusting the eddy current instrument to produce a predetermined response to a flaw of known size. Electrode discharge-machined (EDM) slots or notches of different sizes are frequently used as calibration reference flaws for eddy current tests. The detectable flaw size is assumed to be equivalent to the size of the EDM notch used in setting up the instrument. However, recent reports by Rummel[1] and by Randle and Woody,[2] indicate that these assumptions may lead to confusing or possibly erroneous test results.

Rummel states the following: "Although EDM slots, saw cuts, etc., are convenient and useful for test setup, instrument response 'calibration,' and demonstration of area coverage in automated scanning systems, they *DO NOT* produce eddy current response signals that are equivalent to cracks of equal size. Therefore, they should not be used *exclusively* for evaluating crack detection capabilities or for validation of the performance levels of the eddy current inspection procedures." For NDI probability-of-detection (POD) programs, Rummel and others suggest using various size fatigue-cracked specimens for system calibration.

Randle and Woody used 4340 steel specimens. Most of Rummel's work was with titanium specimens. In this article, the authors evaluated 7075 aluminum specimens because most of their inspections are done on aluminum aircraft structure. The following tests were performed to determine if there were any difficulties in using EDM-slotted specimens and comparing them to cracks of equal size.

PROCEDURE

TEST EQUIPMENT

The authors evaluated a variety of eddy current probes before choosing an NDT Products Engineering Model MP902-50B probe, which gave the best response at 180 kHz. The probe was 3.175 mm in diameter and 127 mm long, had a 90-degree orientation, and was ferrite-shielded. A Nortec NDT-18 eddy current instrument was used for all tests. To achieve maximum response from the notches and cracks, the liftoff was in a horizontal direction on the CRT, and the crack/notch was in the vertical direction. The horizontal gain was set at 1 volt per division and the vertical gain was set at 0.2 volt per division. (The CRT was divided into 8 vertical divisions and 11 horizontal divisions.) The vertical output from the NDT-18 was fed into an SRS boxcar averager, then through an IEEE interface to a PC computer and monitor, and finally to a printer. The probe was attached to the scanning bridge of a Staveley precision ultrasonic C-scan system (Figure 1).

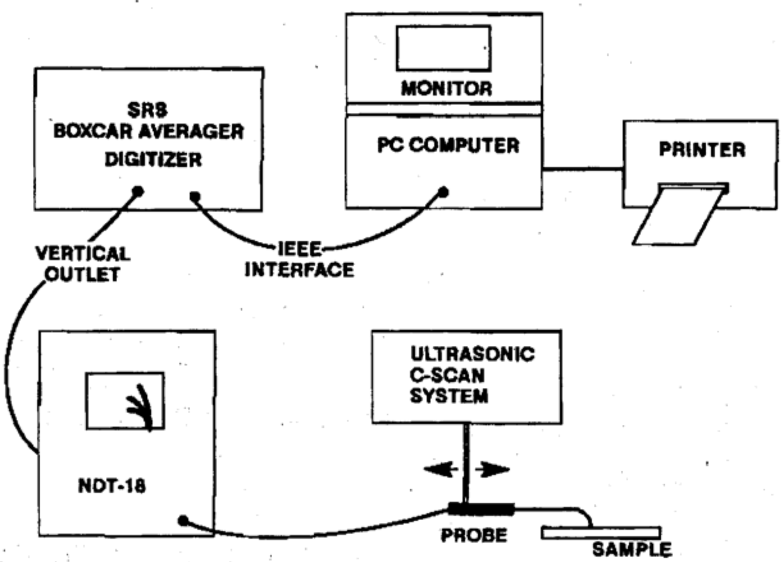

Figure 1. Eddy Current Scanning System

The 152- by 102- by 9.25-mm test specimens were fabricated from 7075-T6 material. EDM starter notches were made at various locations on the blocks, and fatigue cracks were started in the notches by three-point bending. The starter notches were removed by machining, and the specimens were fatigue-tested until cracks of the desired length were produced. Some of the specimens were fractured to determine the shape of the cracks. Basically, all cracks were semicircular with a length-to-depth ratio of 2. To avoid scratching the specimens, 25.4-mm-wide tape was placed over the notches and cracks. The tape was approximately 0.075-mm thick.

Test specimen J71 contained a 2.54-mm-long fatigue crack. To this we added a 2.54-mm U-shaped and semicircular EDM notch and a 1.27-mm semicircular EDM notch. Specimen 30 contained two fatigue cracks, one approximately 2.6 mm long and the other 1.0 mm long. Two additional specimens were used; one contained a through-the-thickness (2 mm) fatigue crack approximately 20 mm long and the other contained a through-the-thickness EDM notch approximately 19 mm long. Finally, an EDM notch 1 mm wide by 2.5 mm long by 0.5 mm deep was added to specimen J71 to study the response from wide notches. The short EDM notches were approximately 0.075 mm wide, and the long EDM notch was approximately 0.125 mm wide.

SCANNING OF SMALL CRACKS AND NOTCHES

The 1.27-mm semicircular notch, 2.54-mm semicircular notch, and 2.54-mm fatigue crack were scanned transversely at an index of 0.05 mm per scan. The impedance plane response from the notches and cracks is shown in Figure 2a. The isometric C-scan results are shown in Figure 2b. The NDT-18 was set at 0.2 volt-per-division vertical gain and 1.0-volt-per-division horizontal gain.

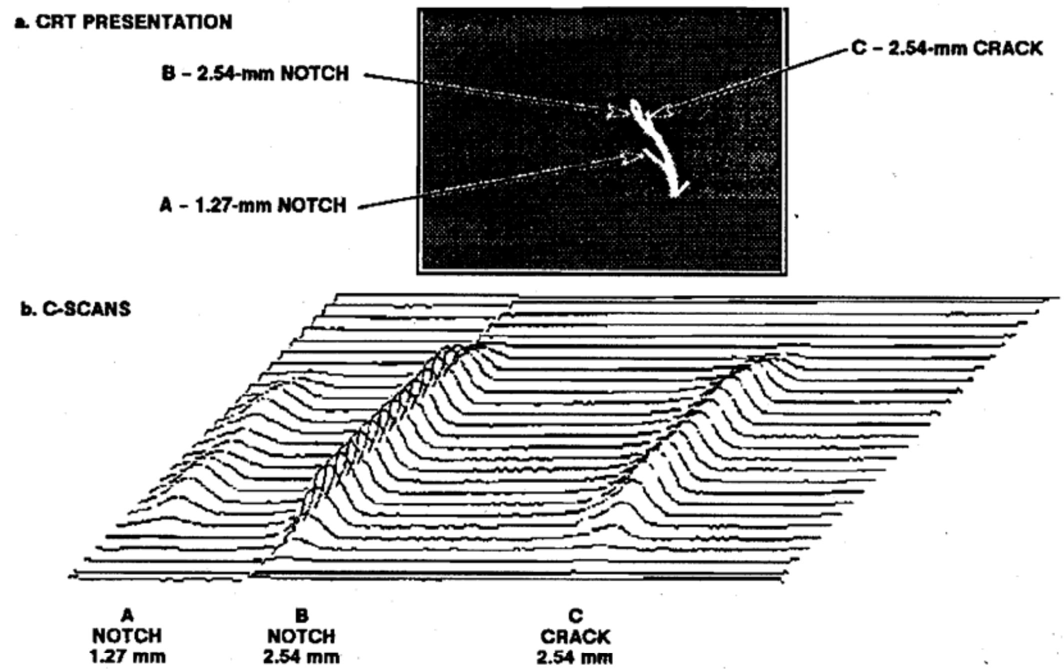

Figure 2. Eddy Current Results for Small Notches and Crack

The isometric C-scans in Figure 2 provide useful qualitative information but do not provide quantitative data that can be compared. Therefore, each notch and crack was scanned both transversely (across) and longitudinally (along the length). Typical results from the 2.54-mm-long fatigue crack are shown in Figure 3. The amplitude of the peak signal is recorded in volts, and the general topography of the crack is shown in the longitudinal scan. However, for comparison of results, it was decided to select a single line scan with the highest voltage from each flaw. Before doing this, a 2.54-mm U-shaped notch was added to the specimen to determine if there was any difference between a U-shaped and a semicircular-shaped notch of equal size.

Figure 4, shows the results obtained from a transverse scan of the three notches and one crack. Figure 5 shows the results obtained from a longitudinal scan of the same flaws.

To obtain additional data, we selected Specimen 30, which contained two cracks. Crack No. 1 was reported to be 2.6 mm long, and crack No. 2 was reported to be 1.0 mm long. Transverse scans, at about 2.5 mm per second, were made of Cracks No. 1 and 2 in Specimen 30 and of the two 2.54-mm notches and 2.54-mm crack in Specimen J71. The results are shown in Figure 6. The peak amplitude of each trace compares favorably with the size of the flaws.

SCANNING OF LARGE CRACK AND NOTCH

All the instrument settings were kept the same when scanning the large crack and notch. The notch was through the thickness (2.0 mm) and 19 mm long. The crack was through the thickness (2.0 mm) and 20 mm long. The natural fatigue crack was closed, whereas the large notch was about 0.25 mm wide. The transverse scans and CRT traces are shown in Figure 7.

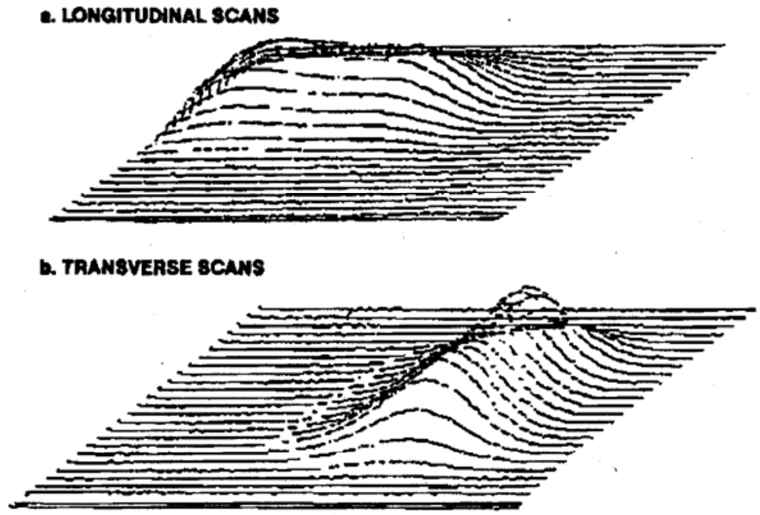

Figure 3. Eddy Current Scans of 12.54-mm Crack in Specimen J71

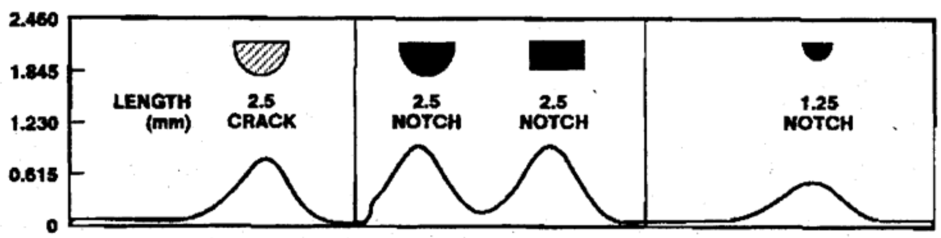

Figure 4. Transverse Scans of Notches and Crack in Specimen J71

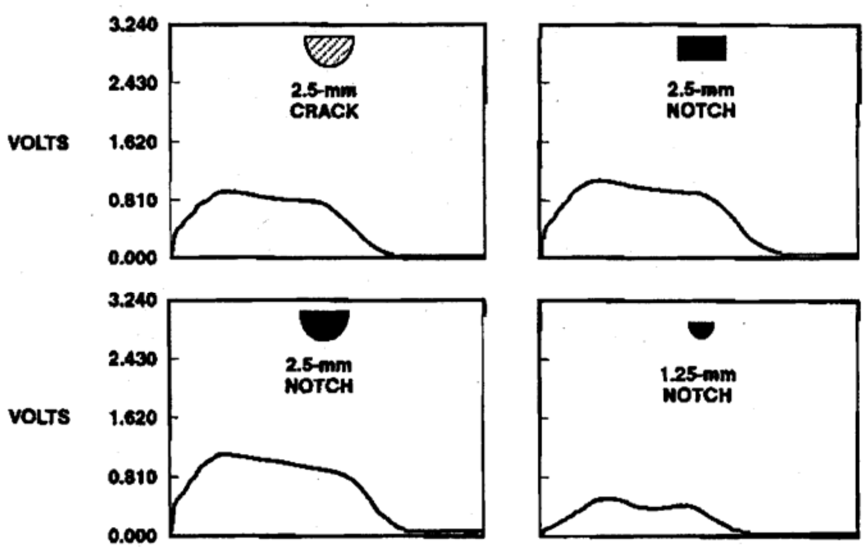

Figure 5. Longitudinal Scans of Notches and Crack in Specimen J71

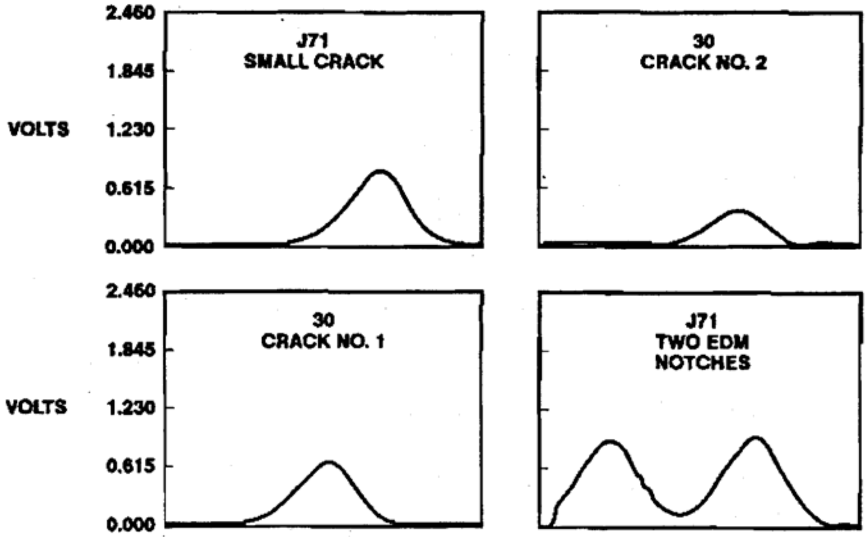

Figure 6. Transverse Scans of Cracks and Notches in Specimens J71 and 30

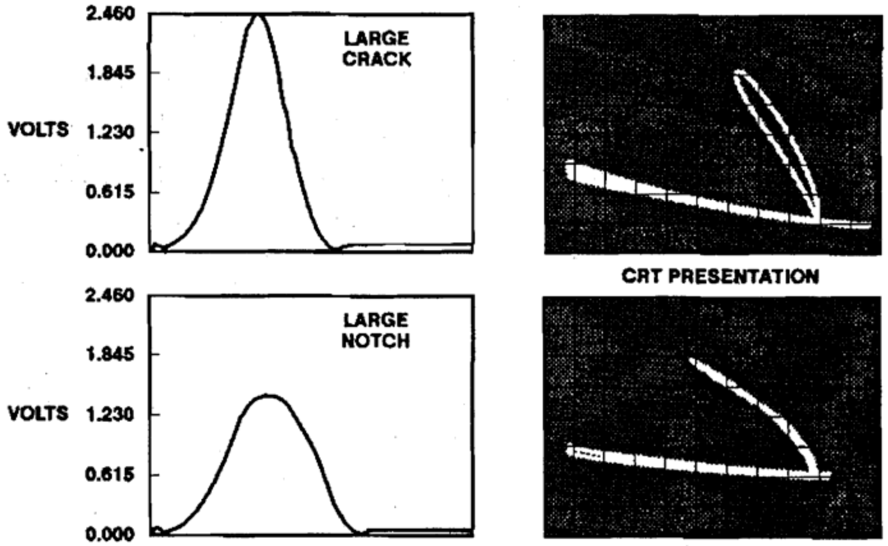

Figure 7. Transverse Scans and CRT Presentations for Large Crack and Notch

RESULTS

The combined results for all flaws are shown in Figure 8. The comparison in Figure 8 was made by plotting the peak voltage from the transverse scans with the flaw length. There is excellent agreement in the correlation for small notches and cracks because they basically yielded the same phase angle. However, there is a disagreement between the voltages from the large crack and large notch because the phase angle was 40 degrees for the notch and 55 degrees for the crack. (The phase angle is the angle between the liftoff trace and flaw trace.)

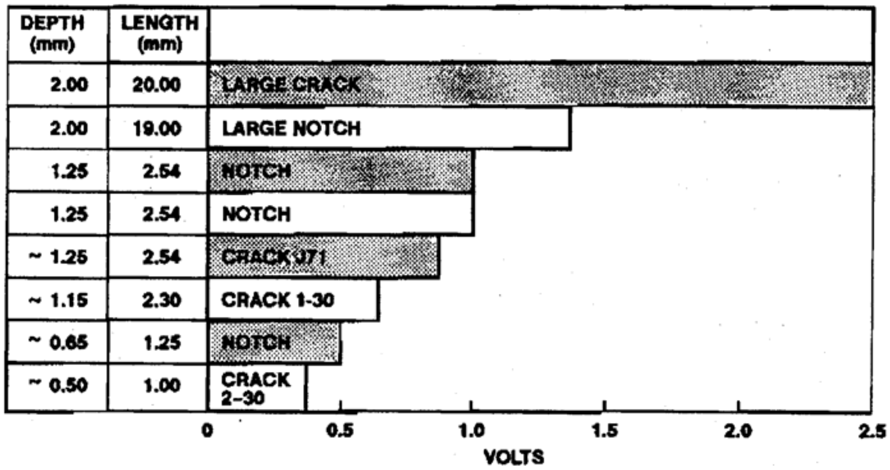

Figure 8. Combined Results for Cracks and Notches — Volts Versus Flaw Size

Figure 9 is an illustration made from the actual CRT presentations for the 1-mm and 2.6-mm cracks in Specimen 30, the 2.54-mm notch and crack in Specimen J71, and the large notch and crack. Again, there is good agreement between the amplitude of the signal and the size of the flaws.

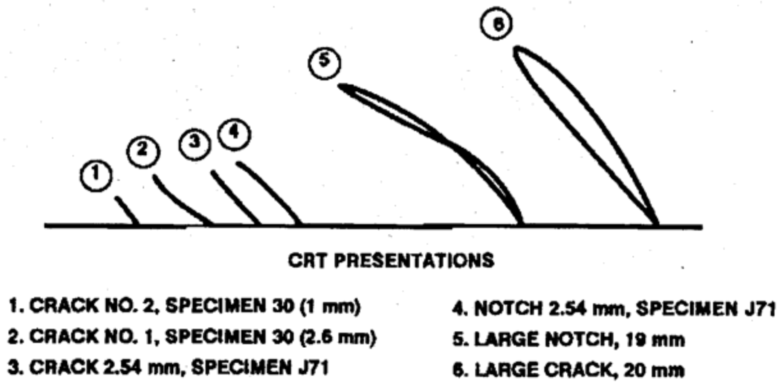

Figure 9. CRT Impedance Plane Presentations for Different Size Flaws

DISCUSSION

In 1988, an airliner experienced an in-flight structural failure when the upper fuselage ripped open and a large section of the skin peeled away. This failure was precipitated by the link-up of small fatigue cracks extending from adjacent rivet holes in aluminum fuselage lap-joint splices. This failure, brought about by multisite damage (MSD), helped focus attention on problems associated with in-service inspections and especially with eddy current inspection. During the past 3 years, the aircraft manufacturers and the FAA have been conducting investigations into the reliability of eddy current tests.

There are a variety of eddy current techniques for detecting MSD (cracks) adjacent to fastener holes. These include hand-held eddy current probes guided by a circle template, sliding probes, rotating surface probe, and more recently the EddyScan 30 (Nortec) and Magneto-Optic Imager (Physical

Research). In all cases, researchers have used EDM notches for flaw size evaluations and instrument setup (calibration). In a recent Boeing study,[3] where more than 15,000 fastener locations were examined, a probability of detection (POD) was obtained for four techniques (Figure 10). They had naturally cracked panels and EDM notched panels containing flaws ranging from 0.5 to 4.06 mm. The test involved some 20 inspectors. Similar results were obtained in a previous study at Douglas Aircraft Company.[4]

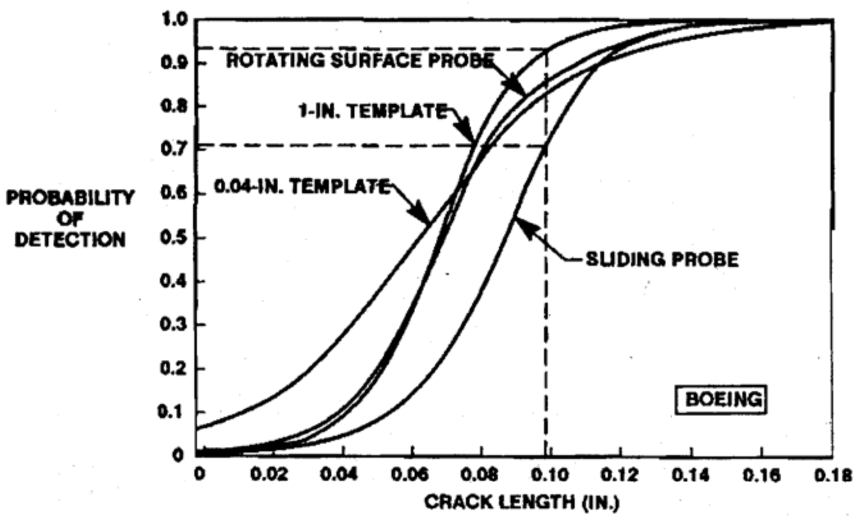

Figure 10. Probability of Detection versus Crack Length

FLAW SHAPE AND SIZE

It is important to know the flaw shape and size because the various NDT tests respond differently to flaw characteristics. For instance, tight (closed) cracks are difficult to detect by radiography, penetrant, and ultrasonic tests. Magnetic particle and eddy current tests are less affected by the tightness of the crack opening but not completely, as reported by Rummel.[1] Figure 11 shows that fatigue cracks range in shape from a depth-to-length ratio (a/2c) of 0.5 to 0.05. Corrosion pitting will have a flaw shape of $a/2c = 1$ or greater. Tension fatigue will generate cracks having an $a/2c = 0.5$, whereas bending stresses tend to propagate the length dimension at a faster rate, especially as the crack depth approaches the neutral axis of the flat sheet material. Damage tolerance engineers are usually more interested in crack length than crack depth. For open cracks, the nondestructive inspection (NDI) response usually increases with flaw length and depth. Unfortunately, it is difficult to detect short, deep flaws (pits) and long, shallow flaws (scratches) by NDI methods.

Where the NDI response (signal) distribution from a flaw is normal or Gaussian and process noise is well separated from the signal, the inspection has a high specificity for discrimination of signals (good signal-to-noise ratio). (See upper portion of Figure 12.)

Where the NDI response (signal) distribution from the flaw is normal, with process noise signals overlapping the flaw response, a discrimination level must be set. Some flaws will be missed (Type I error) and some false calls (Type II error) will be inherent in the inspection (see middle portion of Figure 12). This process is said to have a poor signal-to-noise ratio.

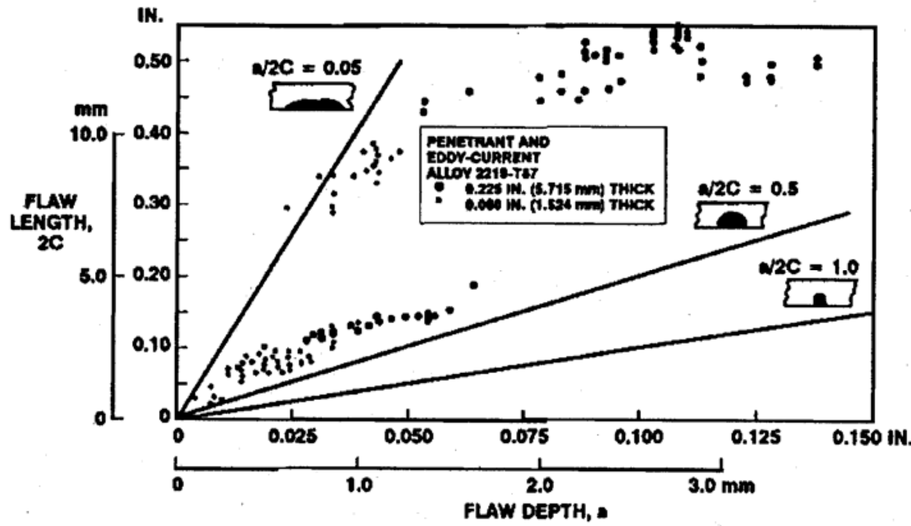

Figure 11. Detectable Flaw Size Data

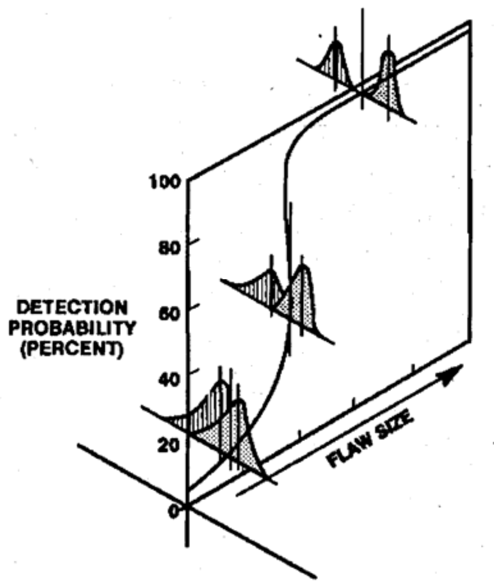

Figure 12. Interaction of Signal/Noise Discrimination and the Probability of Detection (POD)

Where the NDI response (signal) distribution from a flaw is coincident with the process noise signals, there is no discrimination and the inspection is not valid — hence, the difficulty in detecting small cracks where the noise overlaps the signal.

In Figure 9, only a narrow liftoff line is shown; however, if repeated scans were made, the liftoff line would become broad on the CRT and the small crack (No. 2) might be missed.

Consideration must also be given to the depth and width of EDM notches. In Figure 13a, three notches with similar length (about 2.54 mm) and different widths (0.10, 0.25, and 1.0 mm) were scanned using the same conditions for the previous studies. The 0.10-mm-wide notch has a 40-degree separation between the liftoff and flaw trace and the signal is fairly straight. The 0.25-mm-wide notch has a 30-degree separation, but the flaw signal is slightly curved. The 1.0-mm-wide notch has a 40-degree separation at the right side, which curves to 10 degrees at its termination. In Figure 13b, there are three long notches, all 0.10 mm wide but at three different depths (0.25, 0.50, and 0.75 mm). The 0.25-mm response is so close to the liftoff line that it is basically not detectable. However, the two deeper notches yield discernible responses.

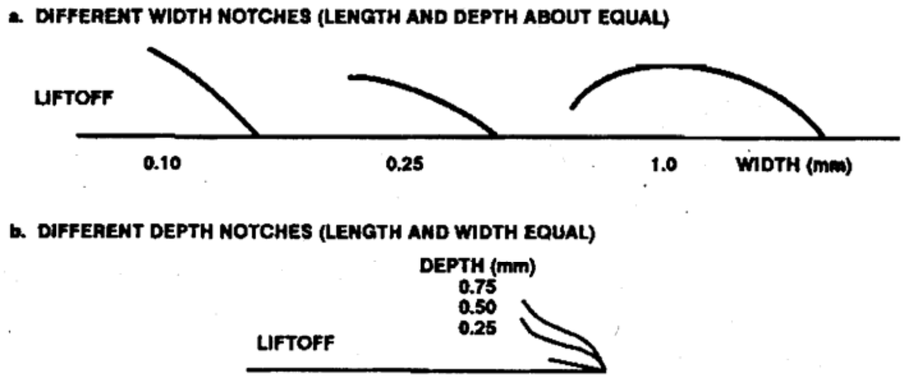

Figure 13. CRT Impedance Plane Response for Various Notch Widths and Depths

SUMMARY

This study was conducted to verify the use of EDM notches for adjusting the eddy current instrument to produce a predetermined response to flaws of known size. The lengths of some of the notches and cracks were less than the coil diameter and some were longer. All the specimens were 7075-T6 aluminum and were tested at 180 kHz using a 3.175-mm ferrite-shielded probe. The NDT-18 settings for all tests were gain = 20, volts per division vertical = 0.2, and volts per division horizontal = 1.0. The results showed good agreement between cracks and notches of similar sizes in aluminum samples. The only significant difference in results was shown for notches having varying widths. Basically, EDM notches should not have widths greater than 0.25 mm for crack simulation at frequencies from 100 to 500 kHz.

During this study, the authors did not encounter the problems reported by Rummel[1] or Randle and Woody.[2] However, we were not concerned with measuring flaw depth but rather flaw length. Basically, our studies have shown that the minimum detectable flaw length is approximately equal to one-half the coil diameter.

REFERENCES

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