EDDY CURRENT PROBE PERFORMANCE VARIABILITY

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INTRODUCTION

Eddy current testing is used extensively by the Air Force for nondestructive inspection of many aircraft structural components. Although the reliability and consistency of inspections depends to a large extent on the characteristics of the eddy current probes used, no adequate specifications or certification methods presently exist for assuring probe performance. Because of the variability in probe performance, a need exists for establishing a means to control probe performance characteristics which will eventually lead to improved test results.

The primary objective of the work reported in this paper was to determine the degree of variability in eddy current probe performance for a group of probes representative of those presently in use by the Air Force for inspecting aircraft structural components. By presenting the data in terms of probability distributions, an assessment can be made of how many probes would be rejected if acceptance criteria were based on requiring probe performance to be within a desired range. A determination of the percentage of rejectable probes based on the probes presently in use would allow the acceptance range to be set to a reasonable value without rejecting an excessive number of probes. An additional objective was to provide a comparison between probe performance on artificial flaws (slots) and a fatigue crack as an initial step for estimating probe performance on cracks based on performance on slots.

EXPERIMENTAL PROCEDURE

Thirty nonshielded and thirty shielded probes were tested. These probes were obtained from many different Air Force bases and are representative of probes typically in routine use. Probe coil diameters were limited to less than approximately 1/8 in., since these would be most commonly used for small flaw detection. Typical probes are shown in Figure 1.

The probes were characterized by measuring their responses to four slots in a prototype Air Force (AF) general purpose eddy current standard, NSN 6635-01-092-5129, P/N 7947479-10. The slots measured 1 in. long with depths of 0.05, 0.02, 0.01, and 0.005 in. A piece of 0.0025-in. thick mylar tape was positioned on the standard for measuring the probe response...
Fig. 1. Typical eddy current probes evaluated in this program to liftoff. The probe responses were also measured for a fatigue crack (0.050 in. long by approximately 0.012 in. deep). Both the standard and the fatigue crack specimen were aluminum.

A block diagram of the laboratory setup is shown in Figure 2. A Hewlett Packard 4194A impedance/gain-phase analyzer was used to measure the impedance characteristics of each probe as it was scanned over the specimens. Impedance data were taken at 200 kHz since this frequency is commonly used by newer Air Force eddy current equipment for inspection of aluminum structures.
Each probe was spring-loaded against the specimen using a double cantilever spring arrangement which assured that the probe was always perpendicular to the test specimen regardless of the amount of spring deflection. The probes were scanned by a precision scanning system driven by high-resolution microstepper motors. Impedance measurements were digitized at 0.01-in. increments as the probes were being scanned. Both the scanning system and the impedance analyzer were controlled by a desktop laboratory computer. The digitized data were transferred to the computer for analysis and storage.

The probe scan path is shown in Figure 3. The probe was first scanned over the center of each slot in the standard. Since the slots were much longer than the probe diameter, it was not necessary to position the probe exactly in the center of the slot length. After scanning each probe over the slots, it was moved onto the tape to generate a change in liftoff. The probe was then moved onto the fatigue crack specimen and scanned over the crack. Because of the relatively small size of the crack, probe positioning was more critical, and it was not possible to obtain the maximum crack response in a single scan. Therefore, a raster scan was used, as shown in Figure 3. This resulted in multiple scans across the crack in increments spaced 0.005 in. apart until the maximum crack response was obtained.

Measurements of the following parameters are reported in this paper:

1. **Flaw Response**: A typical probe response to the four slots and liftoff is shown on an impedance plane plot in Figure 4. Note that the liftoff response is in a different direction from the flaw responses. In a typical eddy current inspection, the liftoff response is minimized by adjusting the instrument to respond only to the components of signals which are perpendicular in direction to the liftoff response. A similar approach was used in this program. A computer routine was used to calculate the signal component perpendicular to the liftoff direction. The probe impedance component perpendicular to the liftoff direction is plotted in Figure 5 as a function of probe position with respect to the slots. The flaw response is the maximum impedance change obtained from each flaw. This measurement was made on each of the slots as well as the fatigue crack.

![Diagram of scan path for slot standard and fatigue crack specimen](image-url)
Fig. 4. Impedance plane plot for typical eddy current probe response from slots 1-4 (1 in. long with depths of 0.05, 0.02, 0.01, and 0.005 in. respectively) and from 0.0025-in. liftoff

Fig. 5. Change in probe impedance component perpendicular to liftoff vs. position for slots 1-4 (1 in. long with depths of 0.05, 0.02, 0.01 and 0.005 in. respectively)
(2) Absolute Probe Impedance: The total impedance of each probe (without regard to the liftoff direction) was measured at a position in the scan away from any flaw. The probe resonant frequency was also checked to make sure it was not close to the operating frequency.

EXPERIMENTAL RESULTS AND DISCUSSION

For determining the variability in probe performance, the data are presented as histograms showing distributions of the number of probes vs. flaw response (probe impedance change from a flaw). A Gaussian curve has also been fitted to the data, and the mean and standard deviation data are shown. The Gaussian curve was used for convenience; the use of other curves that may provide a better fit to the experimental data was beyond the scope of the project.

The distribution of flaw responses from EDM slot No. 3 (1 in. long x 0.010 in. deep) is shown in Figure 6 for the group of thirty shielded probes. The data from this slot were selected because they were similar to the data from the fatigue crack and would be more representative of smaller flaws. The shapes of the distributions from the other slots are similar except that the distributions are shifted to higher impedance values for the deeper slots and to smaller values for the shallower slots. The probe impedance changes from slot No. 3 are shown on the horizontal axis. The width of each box in the histogram represents an impedance change of 0.025 ohm. The percentage of the total number of probes having an impedance change from the flaw within the range shown by each box is represented by the height of the box. For example, 16.7% of the group of thirty probes had an impedance change from slot No. 3 within the range of 0.225 to 0.250 ohm, as shown by the height of the single box representing this range on the horizontal scale. The percentage of probes having impedance changes within a range represented by more than one box can be obtained simply by adding the number of probes represented by all the boxes in that range.

It is apparent that a wide variation in flaw response exists, as shown in Figure 6. The flaw responses ranged from a minimum of 0.080 ohm to a maximum of 0.533 ohm, or a variation by approximately a factor of 7. The mean (or average) response was 0.242 ohm. Two-thirds of the probes had flaw responses within the range of 0.150 to 0.300 ohm. If acceptance criteria for probes were set to include only this range, for example, then 67% of the probes would be accepted and 33% would be rejected.

Data from slot No. 3 for the group of thirty nonshielded probes are shown in Figure 7. Here the variation in flaw response is from 0.044 to 0.280 ohm or approximately a factor of 6. This is about the same amount of variation as with the shielded probes, but the responses are shifted to smaller values, showing that the nonshielded probes generally give a smaller response to the flaw.

Overall trends in the flaw response data indicate that the responses to each of the four slots and the fatigue crack varied by a factor of 6 to 7 for each probe type (shielded and nonshielded). In each case, this variation could be reduced to a factor of 2 by rejecting approximately one-third of the probes.

Relationship Between Slot and Crack Responses

In order to use a slot in a standard to set up an eddy current probe and instrument for an inspection, the slot response must be representative of the response obtained from a crack in the size range anticipated. In
Fig. 6. Distribution of flaw response impedance change from slot No. 3 (1 in. long x 0.01 in. deep) for shielded probes

Fig. 7. Distribution of flaw response impedance change from slot No. 3 (1 in. long x 0.01 in. deep) for nonshielded probes
this program, data were obtained from four slots of different depths and one fatigue crack. Although the data from a single crack are too limited to allow an adequate correlation to be made between slots and cracks of different sizes, some valuable conclusions can still be drawn.

As mentioned in the previous section, the data from slot No. 3 (1 in. long x 0.01 in. deep) more closely represented the 0.05-in. long x approximately 0.012-in. deep fatigue crack than the data from the other slots. The relationship between the flaw responses from slot No. 3 and those from the fatigue crack is shown in Figure 8 for both the shielded and nonshielded probes. Here, the impedance change from the crack is plotted as a function of the impedance change from slot No. 3 for each probe. The line drawn on the plot represents a one-to-one correspondence between the crack and slot data. For example, if the data point for a probe falls on this line, then the response for that probe is the same for the crack as it is for the slot. The data show the same wide variation in responses as shown previously in the distributions. However, the slot and crack responses for most of the data are reasonably equivalent since the data points fall close to the line representing a one-to-one correspondence. The shielded probe data generally fall above the line while the nonshielded probe data are generally grouped below the line. This indicates that the shielded probes tend to give a somewhat greater response from the crack as compared to the slot while the nonshielded probes give a smaller response from the crack.

These data provide a degree of confidence that the response of a probe to a crack can be approximated by its response to a slot. Although additional data are needed for other crack sizes, this provides a preliminary indication that probe response acceptance limits can be established on slots in Air Force standards such as the one used here.

Fig. 8. Response from crack (0.050 in long x approximately 0.012 in. deep) vs. response from slot No. 3 (1 in. long x 0.010 in. deep) for shielded and nonshielded eddy current probes. The line at 45 degrees represents a one-to-one correspondence between slot and crack responses.
Fig. 9. Distribution of absolute probe impedance from shielded probes at 200 kHz

Fig. 10. Distribution of absolute probe impedance from nonshielded probes at 200 kHz
Absolute Probe Impedance

In addition to the impedance change from a flaw, another parameter of importance is the absolute probe impedance. This measurement is significant because eddy current instruments require that probes have an impedance within a certain range or the instrument will not balance properly and will not function with that probe. Also, since the impedance becomes very large at the resonant frequency of a probe, it is not desirable to operate a probe at a frequency close to resonance.

For all of the probes, the resonant frequency was well above 200 kHz and was not a significant factor in the impedance measurements. The distributions of probe impedances at 200 kHz for the shielded and nonshielded probes are shown in Figures 9 and 10, respectively. The variation in impedance for the shielded probes ranged from 73 to 258 ohms while the nonshielded probe impedances ranged from 23 to 225 ohms. For the shielded probes, 73% had impedances between 80 and 140 ohms while only 50% of the nonshielded probes had impedances in this range. Acceptance criteria for probe impedance would require evaluation of instrument specifications to determine the range of impedance values over which the instruments would balance.

CONCLUSIONS

For the probes tested in this program, the flaw responses from the shielded probes were generally greater than those from the nonshielded probes. The responses within each of these probe groups varied by a factor of 6 to 7 for each of four slots (1 in. long with depths ranging from 0.005 in. to 0.05 in.) and a fatigue crack (0.05 in. long x approximately 0.012 in. deep).

By rejecting approximately one-third of the probes, the variation in flaw responses for the shielded probes or for the nonshielded probes could be reduced to a factor of 2.

A relatively good correspondence was obtained between the probe responses to the 0.05-in. long x approximately 0.012-in. deep fatigue crack and the 1-in. long x 0.01-in. deep slot. The crack signal was generally slightly larger than the slot signal for the shielded probes and slightly smaller than the slot signal for the nonshielded probes.

The absolute probe impedance values varied by a factor of 3.5 for the shielded probes and by a factor of almost 10 for the nonshielded probes.

A first step toward obtaining more consistent probe performance could be to establish probe acceptance criteria based on (1) the impedance change from slots in a standard such as the Air Force general-purpose eddy current standard and (2) the absolute probe impedance.

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