EDDY CURRENT PROBE PERFORMANCE CHARACTERIZATION*

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INTRODUCTION

Single-coil, absolute eddy current probes are used extensively by the Air Force for inspection of aluminum airframe structures. Because of the large variations in probe performance [1], a specification is needed to ensure that probes meet minimum performance criteria. In order to develop these criteria for the specification, it was necessary to assess the probe performance factors that limit flaw detectability and then to determine the response of typical probes used by the Air Force so that reasonable thresholds can be established without rejecting a large number of probes.

An experimental evaluation of thirty shielded and thirty non-shielded surface probes (typical of those used by the Air Force) was conducted to determine probe performance with a specific eddy current instrument being adopted for widespread use by the Air Force. This paper describes preliminary results of the investigation and shows the results of measurements of the following parameters for shielded and nonshielded probes: (1) liftoff "noise", (2) tilt "noise", (3) effect of liftoff on flaw response, and (4) effect of tilt on flaw response. The data show the range of variation in each parameter for the typical probes tested, the response to EDM slots of four sizes and fatigue cracks of two sizes, and a comparison of the responses from shielded and nonshielded probes. Suggested acceptance criteria are given for the four measured parameters, as well as the percentages of probes which could meet the criteria.

PROBE PERFORMANCE PARAMETERS

Major factors which limit flaw detectability with hand-held, absolute (single-coil) eddy current probes are associated with probe liftoff and tilt. This is based on the assumption that the probe impedance is properly matched to the instrument and that adequate signal level is obtained from a flaw so that electronic noise in the instrument is not a factor.

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When a probe is scanned over the surface of a part to be inspected, liftoff variations typically occur because of factors such as variations in the thickness of paint on the part. It is also difficult for the probe axis to be maintained perpendicular to the part surface when performing a manual inspection and thus the probe is often tilted, so that the angle between the probe and the part is less than 90 degrees. The probe liftoff results in two effects: (1) fluctuations (noise) in the signal from the eddy current instrument; and (2) reduction in the magnitude of the flaw response. Probe tilt results in similar problems: (1) noise signals; and (2) reduction in flaw signal amplitude.

The noise signals produced by variations in liftoff and tilt can mask flaw signals and reduce the detectability of flaws. The reduction in flaw signal amplitude caused by liftoff and tilt can be detrimental because the eddy current instrument is often adjusted to obtain a given response to a flaw in a nonpainted test block. The inspection, however, may be performed on a painted surface or with the probe tilted. Therefore, the flaw response obtained during an inspection may be smaller than expected, based on the test block signal.

The absolute magnitude of the probe liftoff and tilt effects is not of primary importance; the factor that limits flaw detectability is the magnitude of the liftoff or tilt effect compared to the signal obtained from a flaw. For example, the liftoff noise can be large as long as the flaw signal is significantly larger so that the noise does not mask the flaw signal. Therefore, in this investigation the liftoff and tilt effects are expressed as ratios; the liftoff or tilt measurement is divided by the flaw signal for each of the probes tested. This normalizes the measurements for all of the probes so that they can be compared directly.

**EXPERIMENTAL SETUP**

Thirty shielded and thirty nonshielded probes were tested. These probes were obtained from numerous Air Force bases and are representative of probes in routine use. Probe coil diameters were limited to approximately 0.25 inch or less since these would be most commonly used for small flaw detection.

The probes were connected to a Hocking UH-B eddy current instrument which has a nominal operating frequency of 200 kHz. The UH-B is a meter type instrument, and the signal output is normally displayed as a meter indication. For each probe tested, the instrument was adjusted to minimize liftoff effects in the same manner as in a normal setup for flaw detection. Instead of recording the meter indication, the analog output of the instrument (which is directly proportional to the meter reading) was recorded with a digitizing oscilloscope and transferred to a computer for analysis. Probe scanning and tilt were accomplished by a precision, three-axis scanning system driven by stepper motors under computer control. The probes were spring-loaded against the specimen surface.

The flaw response of each probe was measured by scanning over four slots in an Air Force eddy current test block and over two laboratory-grown fatigue cracks. The slots were 1 inch long with depths of 0.005, 0.010, 0.020, and 0.050 inch, and the cracks had surface lengths of 0.05 and 0.10 inch and estimated depths of approximately 0.012 and 0.025 inch, respectively. Both the test block and crack specimens were made of 7075 T6 aluminum.
Liftoff noise was measured by first placing the probe in contact with the test block surface and then recording the signal obtained by scanning it onto a 0.006-inch-thick layer of tape placed on the block surface. The effect of liftoff on the flaw response was determined by placing a 0.006-inch-thick plastic shim on the test block and fatigue crack specimen surfaces and then scanning the probe over the flaw and measuring the flaw response.

Tilt noise was measured by placing the probe perpendicular to the test block surface and then recording the signal obtained by tilting it 10 degrees. The effect of tilt on the flaw response was determined by scanning the probe over the flaw with the probe tilted 10 degrees from perpendicular. The direction of tilt was in the same direction as the scan direction.

EXPERIMENTAL RESULTS

Liftoff Noise

The ratio of the liftoff noise signal amplitude to the amplitude of the flaw signal indicates the effectiveness of the probe in detecting flaws where liftoff variations are encountered. An ideal ratio would be zero, where no liftoff noise signal is obtained. The largest practical value would be approximately 0.5, where the liftoff noise signal amplitude is one-half that of the flaw signal. A value of 1 indicates that the liftoff signal is the same amplitude as the flaw signal; flaw detection would be difficult in this case since the flaw signals could not be readily distinguished from liftoff signals on the basis of amplitude.

The liftoff noise data for the groups of thirty shielded and thirty nonshielded probes are shown in Fig. 1. The vertical axis represents the value of the liftoff noise signal divided by the flaw signal amplitude; the square represents the mean value for all thirty probes; and the + symbols at the ends of the vertical lines represent the mean value ± one standard deviation. (For data having a normal distribution, the length of the vertical lines would represent values from approximately 67% of the probes.) The liftoff noise data are plotted as a function of flaw depth for the four EDM slots and two fatigue cracks. A positive liftoff noise value represents an upscale meter deflection from the liftoff variation and a negative value indicates a downscale deflection.

The experimental data show mean values of -1 and -1.8 for the 0.005-inch flaw for the nonshielded and shielded probes respectively. The mean values decrease to -0.05 and -0.19 for the 0.050-inch-deep flaw. The smaller values obtained with the nonshielded probes indicate that these probes would be more effective for detection of flaws in the presence of liftoff variations.

A reasonable threshold for acceptable probe performance would be 0.5 (absolute value), where the liftoff noise is 50% of the flaw signal amplitude. For a 0.02-inch-deep slot, 83% of the shielded and 93% of the nonshielded probes would fall within the acceptable range for this threshold.

Tilt Noise

The ratio of the tilt noise signal amplitude to the amplitude of the flaw signal indicates the effectiveness of the probe in detecting flaws where the probe angle varies during scanning. As with the liftoff noise, the ideal value would be zero; the largest practical value would
be approximately 0.5; and a value of 1 would indicate that the tilt signal is the same amplitude as the flaw signal, thus tending to mask the flaw indication.

The tilt noise data for the shielded and nonshielded probes are shown in Fig. 2. The vertical axis is the ratio of the tilt noise signal to the flaw signal; these data are plotted as a function of flaw depth.
for the slots and cracks. The mean values for the nonshielded probes range from -6.1 for the 0.005-inch-deep slot to -0.3 for the 0.050-inch-deep slot. The mean values for the shielded probes range from -0.18 for the 0.005-inch-deep slot to approximately zero for the 0.050-inch-deep slot. These data indicate that the tilt noise for nonshielded probes can be severe, while the noise is significantly less for shielded probes.
The shielded probes would therefore be more effective for flaw detection where tilt variations are encountered. A threshold of 0.5 (absolute value) for a 0.02-inch-deep slot could be met by 93% of the shielded probes, but only by 76% of the nonshielded probes.

**Effect of Liftoff on Flaw Response**

The amplitude of the flaw signal obtained with the probe lifted off 0.006 inch divided by the flaw signal amplitude with no liftoff is shown in Fig. 3. Ideally, this ratio would have a value of one, where no degradation in signal amplitude occurs when the probe is lifted off and the same flaw signal amplitude is obtained with or without liftoff. Values of less than one indicate that the flaw signal amplitude has decreased when the probe is lifted off.

The experimental data show that this ratio is not strongly affected by flaw size, although differences exist between the values obtained from slots and from cracks. The mean values for the shielded probes range from 0.25 to 0.36 for the slots and from 0.45 to 0.50 for the cracks. The mean values for the nonshielded probes range from 0.59 to 0.69 for the slots and from 0.71 to 0.77 for the cracks. The shielded probes are more strongly affected by liftoff than the nonshielded probes.

A reasonable value for the ratio of flaw response with liftoff to flaw response without liftoff would be 0.5, where the flaw signal is reduced by 50% with liftoff. For a 0.02-inch-deep slot, 97% of the nonshielded probes would meet this criterion; however, only 10% of the shielded probes would be acceptable.

**Effect of Tilt on Flaw Response**

The amplitude of the flaw signal obtained with the probe tilted 10 degrees divided by the flaw signal amplitude with the probe perpendicular is shown in Fig. 4. As with the effect of liftoff, an ideal value for this ratio would be 1 where the same flaw signal amplitude is obtained with or without the probe tilted. Values of less than one indicate that the flaw signal has decreased when the probe is tilted. Note that in some cases a value greater than one can be obtained, thus indicating that the flaw response is larger with the probe tilted.

The data show that this ratio is not strongly affected by flaw size, for the shielded probes. The mean values for the shielded probes range from 0.58 to 0.77 for all of the flaws. The mean values for the nonshielded probes are similar to those obtained with the shielded probes for the three largest flaws (>0.02 inch deep) with values ranging from 0.68 to 0.82. The nonshielded probes are more strongly affected by flaw size for the three smallest flaws (<0.012 inch deep) with values ranging from 0.27 to 0.49.

As with the liftoff effect, a reasonable threshold for acceptable probe performance would be 0.5 (absolute value). This criterion would be met by 77% of the shielded and 73% of the nonshielded probes.

**CONCLUSIONS**

Shielded probes were shown to be more susceptible to liftoff noise and the flaw signal was more strongly affected by liftoff than with nonshielded probes. Nonshielded probes were shown to be more susceptible to tilt noise and the flaw signal was more strongly affected by probe tilt than with shielded probes. A relatively high percentage of typical
shielded probes could meet suggested acceptance criteria for liftoff noise, tilt noise, and the effect of tilt on flaw signal amplitude; however, significant probe improvements would be required to meet criteria for the effect of liftoff on flaw signal amplitude. A high percentage of typical nonshielded probes could meet suggested criteria for all four of the above parameters.
Fig. 4. Ratio of flaw response with probe tilted (10 degrees from perpendicular) to flaw response with probe perpendicular vs. flaw depth for (a) shielded and (b) nonshielded probes

REFERENCE