

APPLICATION OF A COMPUTER MODEL TO ELECTRIC
CURRENT PERTURBATION PROBE DESIGN

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INTRODUCTION

The purpose of this paper is to illustrate, by means of two examples, how computer models of electromagnetic NDE probes can be used as an aid in probe design and applications. The type of probe we will consider is of the electric current perturbation (ECP) design, and the computer models employed are those described elsewhere¹, which were developed for ECP analyses. While the numerical results we present are therefore specific to the ECP probe, the suggestion that computer models be used to answer design or implementation questions is applicable to any electromagnetic probe, given an appropriate model.

The first application we address is a true design problem involving miniaturization of the ECP probe for inspecting a certain feature of an F100 engine part. The second is more a question of implementation as it has to do with determining the optimum frequency for subsurface flaw detection in the presence of near surface anomalies in the material.

MINIATURIZATION OF THE ECP PROBE

As part of an Air Force program² to develop the ECP method for retirement-for-cause applications we encountered an inspection problem associated with the engine component shown in Figure 1. This is a second-to-third stage fan seal from an F100 engine and the features of interest are the small notches called antirotation windows, one of which is shown in the inset. The requirement is the detection of edge cracks that tend to grow at the tangency point, where circular "corner" blends into the flat bottom of the window. One way to do the inspection is to simply scan the probe past each window and look for anomalies in the signal that would indicate the presence of a flaw.

Preliminary experiments with this so-called linear scan showed some rather large excursions due to part geometry, but flaw signals that were clearly visible superimposed on the background signal. While the results were considered satisfactory, we thought we might do even better with another type of scan in which background variations are not so severe.

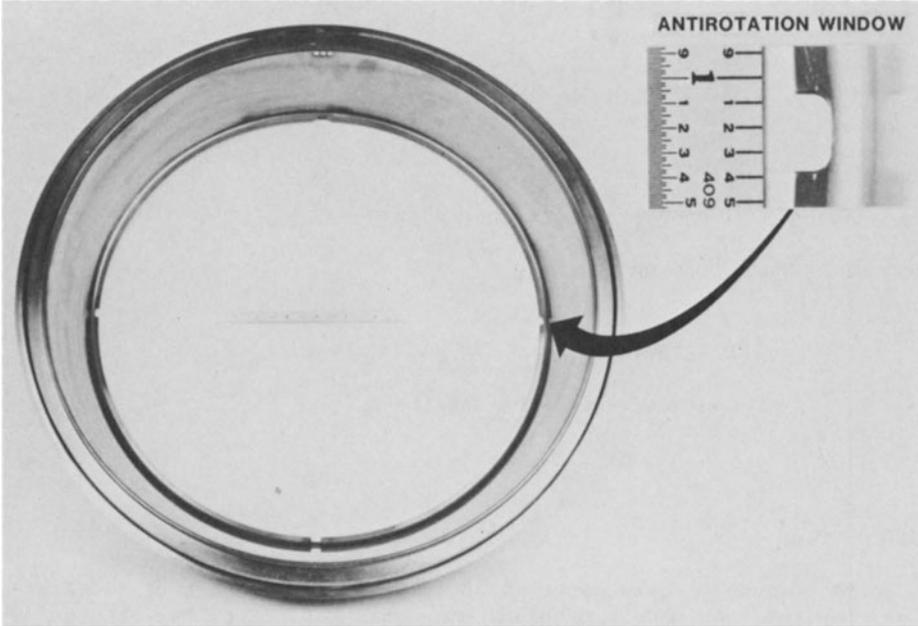


Fig. 1. Antirotation window in the F100 second-to-third stage fan seal.

The second type of scan, which we call a contour scan, is illustrated in Figure 2. The probe fits inside the window and the scanning system is programmed to follow the window contour as indicated in the figure. Because the probe must fit inside the window to do this, and the distance across the window is about 0.3 inches, the antirotation window inspection problem called for the design of a miniaturized ECP probe.

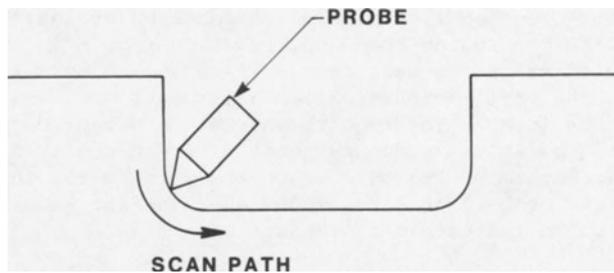


Fig. 2. Contour scan for the inspection of antirotation windows.

One of the steps we decided to take to make the probe as small as possible was to move the sensor from outside the induction coil, which

is it's normal position for most applications, to a position inside the coil as in Figure 3. The question then became, where inside the coil do we get the best response - offset to one side (the offset configuration of Figure 3) or at the center of the induction coil (the centered configuration)?

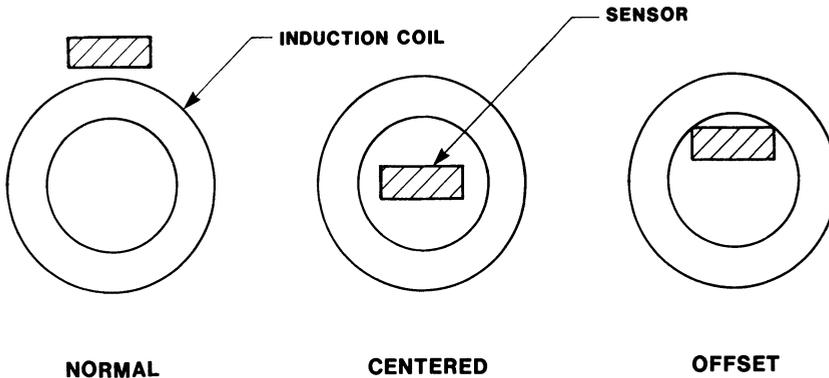


Fig. 3. Alternative ECP probe configurations.

Actually, when the window inspection problem came up we already knew the answer because we had already completed an experimental investigation of the centered probe in connection with another program. But the question does give us an opportunity to show how our ECP model could have been used to provide the answer.

Before looking at the results for a centered probe, let us first recall that when we scan along a crack or slot with the sensor outside the coil in it's normal position we obtain a bipolar signal, with peak-to-peak amplitude proportional to the area of the crack face. However, with the same type of scan using the centered probe we obtain signals like those shown in Figure 4.

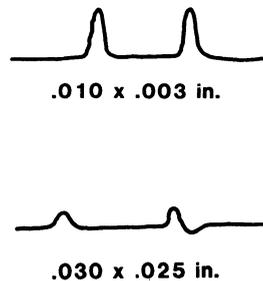


Fig. 4. Experimental data on flaw response with the centered probe configuration. Scales are not the same in the two traces.

These are scans back and forth along the flaw and that's why there

are two peaks. The signal itself has only one peak, and shows an unexpected behavior as a function of flaw size. The trace on the bottom, which is on a different scale, has a flaw signal that is about the same amplitude as the upper trace even though the flaw area is about 30 times larger in the lower trace. This type of behavior was enough to cause us to abandon the centered probe idea.

Given these experimental results the calculations described below were undertaken to see if our computer model would have told us the same thing. One result of our calculations is shown in Figure 5, which contains plots of calculated flaw signals for an EDM slot for the three probe configurations shown on the bottom of the figure. As is evident from the figure, the centered configuration gives the weakest signal and also has the same single-peaked shape as the experimental signal. With the offset configuration, however, the flaw signal is nearly the same as in the normal configuration, and is therefore the preferred design. Experimental evidence that the offset configuration provides adequate flaw sensitivity in the contour scan mode is presented elsewhere³.

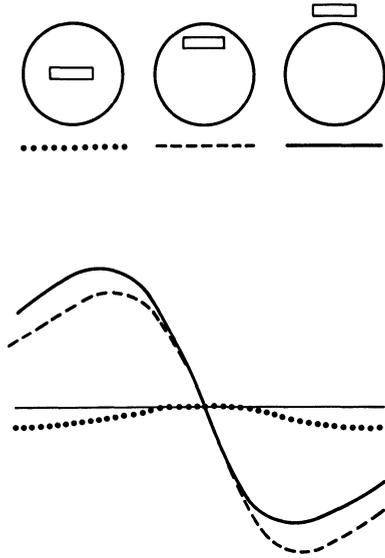


Fig. 5. Calculated flaw response for the normal, offset and centered probe configurations.

To see if we could explain the very weak centered probe response to large flaws, we also did two more calculations using the same probe and flaw dimension as were used in the centered probe experiment, and obtained the results shown in Figure 6. The calculated response is somewhat greater for the larger flaw and both curves show a dip in the center that was not evident in the experimental data, but the calculated results are at least qualitatively the same as the experimental results.

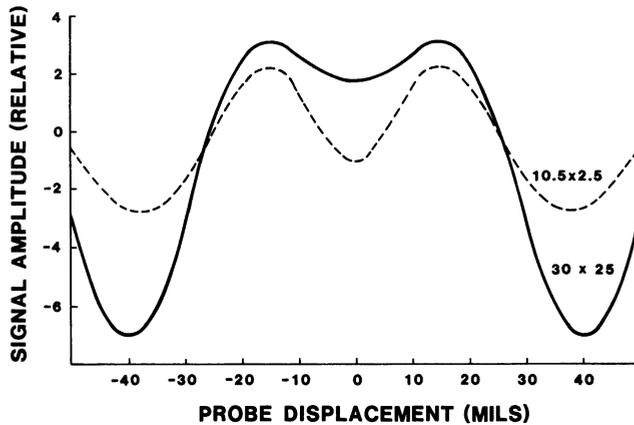


Fig. 6. Calculated response to EDM slots with the centered probe configuration. Flaw sizes are in units of 0.001 inch.

We conclude, therefore, that the computer model used here can provide a reliable guide to probe performance. Thus, the ECP model, as well as other models appropriate to other types of probes, offer an inexpensive way to explore the relative merits of various probe designs for specific flaw detection problems.

SUBSURFACE FLAW DETECTION

As our second example of the use of computer models we examine the problem of subsurface flaw detection in the presence of near surface irregularities that tend to mask the flaw signal. For this purpose we have taken the flaw to be a small cubic void located 0.050 in. below the surface, while surface perturbations are also modeled as a small void, but located at the surface. Calculations show that the flaw is deep enough to produce significant differences in phase between surface and subsurface signals, and that phase sensitive detection can be used to distinguish subsurface flaw signals from surface noise. The next question we address is, then, that of choosing the operating frequency and phase shift so as to maximize signal-to-noise.

If we calculate only the real parts of signal and noise as a function of frequency we obtain the two curves shown in Figure 7. These data tell us that if phase differences are ignored, then lower frequencies give better signal-to-noise figures than higher frequencies. However, the oscillations in the flaw signal as a function of frequency indicate that the phase undergoes large changes over the range of frequencies used here, which suggests the use of phase sensitive detection, as noted above. The idea is to choose an operating frequency such that signal and noise are 90° out of phase, and then adjust the detection system to read only the component of the mixed signal that is in phase with the flaw signal. This should tend to minimize noise, but will not entirely eliminate it because the phase of the noise component varies from point-to-point during a scan and is, therefore, not always orthogonal to the flaw signal.

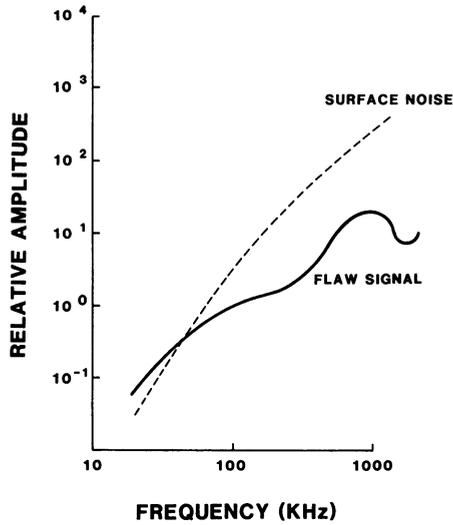


Fig. 7. Real parts of the flaw and surface noise signals.

Figure 8 shows plots of the signal phase at maximum amplitude and the difference between signal and noise phases, also at maximum amplitude, as a function of frequency. These curves tell us that signal and noise components are orthogonal at about 400 kHz, and that the phase of the flaw signal at this frequency is slightly greater than 90° . When this information is used to calculate signal-to-noise at this "optimum" phase, as described above, we obtain the solid curve shown in Figure 9. Also shown for comparison is the signal-to-noise curve obtained using only the real parts of the signal and noise components. For this particular case, the improvement realized by using optimized phase sensitive detection is about a factor of two.

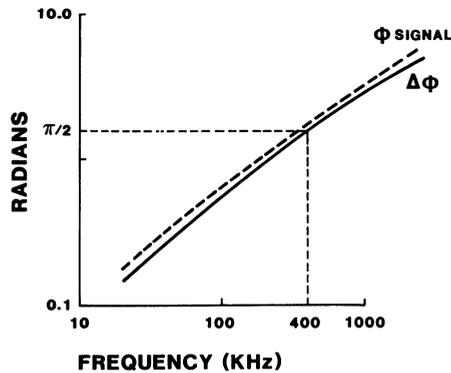


Fig. 8. Flaw signal phase (ϕ) and signal-noise phase difference ($\Delta\phi$) as a function of frequency.

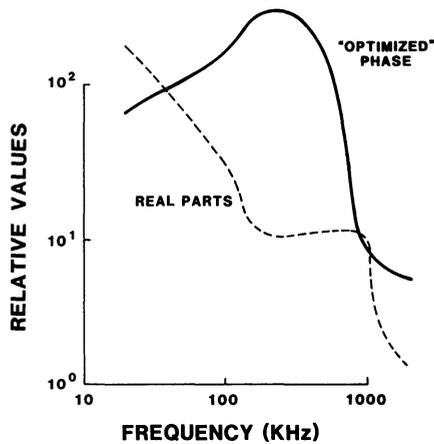


Fig. 9. Signal-to-noise ratios for a flaw 0.05 inch below the surface.

The use of phase sensitive detection to maximize signal-to-noise is, of course, common practice. What we are suggesting by the example given here is that one can use computer models as a guide in selecting the frequency that makes such detection most efficient for a given probe and flaw geometry. Again, as was the case in the probe design study described earlier, computer models offer a relatively inexpensive and flexible alternative to preliminary experimentation.

CONCLUSION

The calculations described above are only two examples of ways that computer models can be applied to practical problems in electromagnetic NDE. Many of the difficulties that made earlier models unreliable or too specialized to be useful, are being systematically eliminated. Theory has now advanced to the point where it is possible to model, with reasonable accuracy, the effects of probe geometry, frequency, liftoff, material inhomogenities, and, with some restrictions still remaining, the types, sizes and locations of flaws. We believe that continued advances in theory, coupled with advances in computer technology, will soon encourage the widespread use of such models in the solution of electromagnetic NDE problems.

ACKNOWLEDGEMENT

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