AUTOMATED EDDY CURRENT DETECTION OF EDGE DEFECTS IN A COMPLEX GEOMETRY USING A MAGNITUDE APPROACH

Ray T. Ko and Stephen J. Pipenburg
Automated Inspection Systems
Systems Research Laboratories, Inc.
2800 Indian Ripple Road
Dayton, Ohio 45440

INTRODUCTION

The inspection capability on turbine engine disks is important to the safety of an airplane. Eddy current inspection has been widely accepted as an effective tool in detecting small fatigue cracks on engine disks. The inspection of simple geometries such as boltholes, webs and bores in a engine disk is less complicated than those of complex geometries such as antirotation windows, scallops, dovetails and non-circular holes. One of the main difficulties in inspecting complex geometries is due to the presence of irregular edges. Raatz [1] reported the influence of edges in measuring conductivity. Williams, Tilson and Blitz [2] minimized the change of phase angle variation around an edge by the proper selection of inspection frequency and coil size. Elsberry and Bailey [3] enhanced edge defect detection by using a shielded probe to collimate the field. Hoppe and Stubbs [4], on the other hand, used the frequency content of the edge signals to discern the edge defect in antirotation windows. This frequency approach was extended to the inspection of other complex geometries such as antirotation tangs and live rims by Ko [5]. Furthermore, Ko [6] used the edge signals in scallops to position a rotational probe in a scallop prior to inspection. These techniques [4-6] are limited to partial inspection of the geometries; however, a new technique is needed if an entire inspection of a complex geometry is required. This paper discusses the use of a simple mechanical mechanism to adapt to a complex geometry, and a signal processing technique for the detection of edge defects.

EXPERIMENTAL CONDITIONS

Geometry and Probe

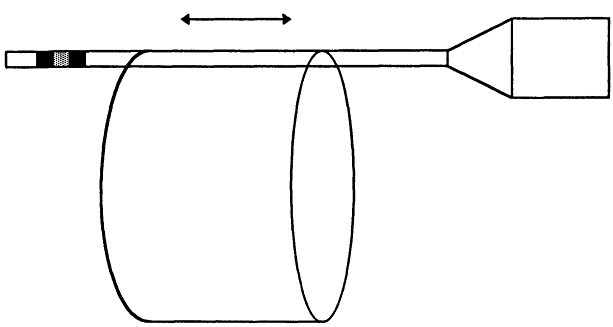
The geometry studied is an elliptical oil drain hole, or simply e-hole, which is part of the F129 fan disk. The material of this disk is Ti-6Al-4V. This geometry is located on a tapered cylindrical surface, thus the thickness varies around the e-hole. A simplified drawing of this geometry is shown in Figure 1a. The inspection area for an e-hole geometry is similar to that of a dovetail geometry; however, the shape of an e-hole is closed, while the shape of a dovetail is open.

Review of Progress in Quantitative Nondestructive Evaluation, Vol. 14
Edited by D.O. Thompson and D.E. Chimenti, Plenum Press, New York, 1995

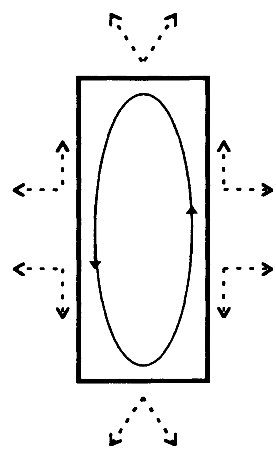
A special eddy current probe, which has little contact area with the geometry, was designed for the inspection of the e-hole. This probe consists of three portions: (1) probe tip (2) compliance mechanism and (3) probe body. On the probe tip a double differential reflection coil, which consists of one transmitter and two receivers, is circumferentially wound at its end, as shown in Figure 1a. This tip is mounted on a compliance mechanism in which two spring-loaded ball slides are perpendicular to each other, and the tip is perpendicular to this compliance mechanism. The probe body connects the probe tip and compliance mechanism to the Retirement For Cause (RFC) inspection system. The coil was driven by a NORTEC NDT-25L eddy current instrument, but the signals were digitized by SRL's 12-bit digitizer. All the data are processed by an INTEL computer while scanning the geometry. The inspection frequency was 2 MHz. The scan speed for this geometry is 1.3 inches per second. A high pass filter of 20 Hz and a low pass filter of 300 Hz were applied to the signals.

Experimental Procedure

The scanning of the e-hole was carried out by manipulating an eddy current probe inside this complex geometry. By repeating the scan, index and rotation mechanical patterns, a complete coverage of the e-hole was carried out. The inspection started at a position in which the probe tip was in contact with the inside wall of the e-hole with some compliance. The scan started from one end of the edge of an e-hole, passed through the bore area and ended at the other end of the engine. Then the scanner moved the probe to the next position, rotated the probe and scanned again. The purpose of the rotation was to ensure the compliance of the probe on the geometry inspected. Therefore, the movement of the probe tip was in an elliptical shape, although the index pattern of the scanner inside the e-hole was rectangular, as shown in Figure 1b.



(a)



(b)

Figure 1. (a) Geometry of an e-hole and a probe tip in a corner of the e-hole; the arrow indicates the scan direction (b) the end-view from the probe tip: probe tip index pattern (bold line), compliance direction (dash line), and scanner index pattern (solid line).

A MAGNITUDE TECHNIQUE

Typical signals from an e-hole with edges around a corner are shown in Figure 2a. Signals from several indices are plotted together to show the variation of these signals around a corner. In this figure, the signals on the left side were from a notch-free edge while the signals on the left were from a notched edge. The notched edge gives a relatively smaller amplitude as compared to the notch-free edge. However, when the probe tip was away from the corner area to the flat area of the e-hole, a decrease in amplitude was also observed, as shown in Figure 2b.

Both the amplitude reduction and position dependent on the signal were observed when inspecting the e-hole. To focus on the amplitude response, a simple geometry such as a bolthole was examined initially. Results of the amplitude response were applied to the position dependence problem in the e-hole inspection. These bolthole specimens contain either notch or fatigue cracks on the edges. The significance of the fatigue crack is that it represents the real defect in serviced engines. The specimen has two parallel sides and circular edges. Figure 3a shows eddy current signals on the impedance plane which were obtained by plotting the vertical output against the horizontal output. The dotted line represents signal from a notch-free edge while the solid one represents signal from a notched edge. Figure 3b shows the signals of vertical channels of both signals. The amplitude contrast of the vertical channels can be further optimized by rotating the eddy current signal on the impedance plane in Figure 3a. However, an optimized rotation may be good for a certain size of defect, but not necessary good for other sizes.

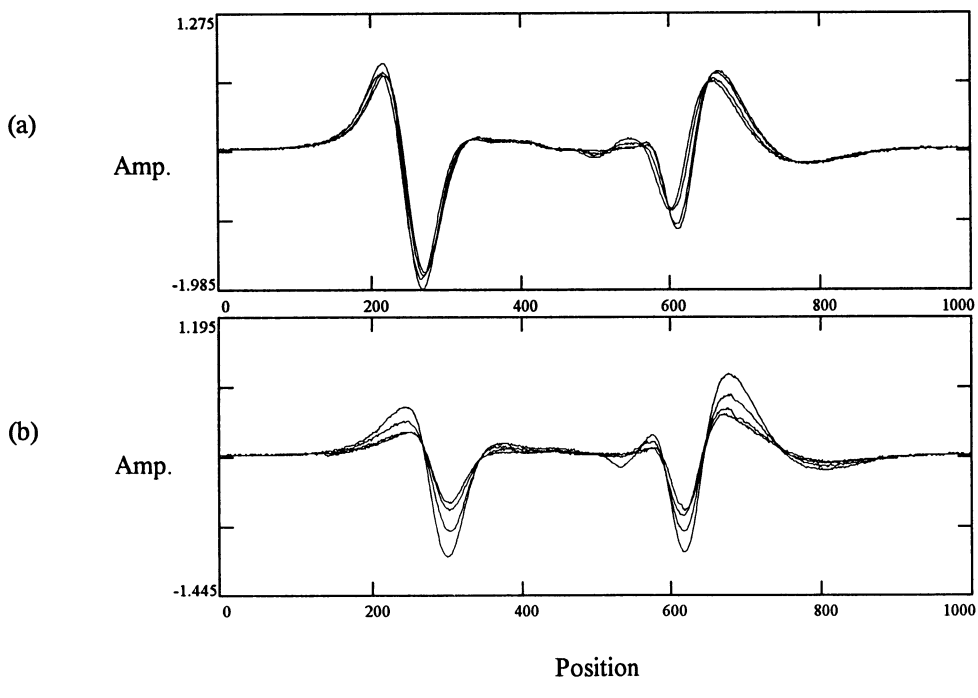
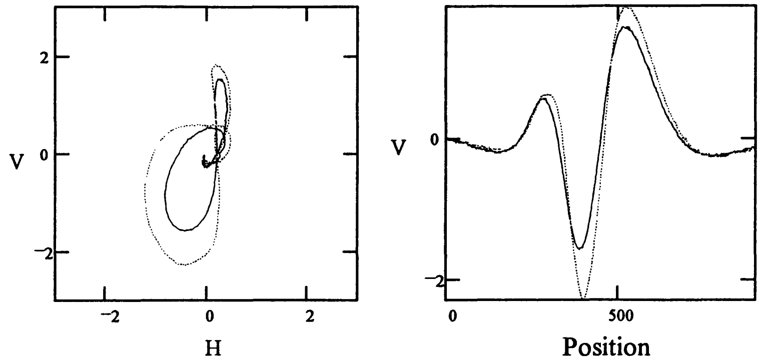


Figure 2. (a) Notch-free edge signals around a corner of the e-hole on the left side while notched edge signals on the right side (b) variation of notch-free edge signals as probe moves away from the corner of the e-hole.



(a) (b)

Figure 3. Eddy current signals on (a) the impedance plane and (b) vertical channel from a notch-free edge (dotted line) and a notched edge (solid line).

Magnitude Technique

A better way to detect defects in the edge areas is to use the magnitude of the impedance. The advantage of this magnitude approach is that it does not depend on the phase angle of any particular eddy current signal on the impedance plane. The magnitude $M_{i,j}$ for the signal at index i position and scan position j is defined as follows:

$$M_{i,j}=\sqrt{V_{i,j}^2+H_{i,j}^2} \tag{1}$$

where $V_{i,j}$ is the amplitude of the vertical channel and $H_{i,j}$ is the amplitude of the horizontal channel. Figure 4a shows magnitude curves around a notched edge. Similar to the amplitude variation, the peak magnitude decreases as the probe scans across a defect.

Since this reduction of magnitude exists for quite a range when a defect is present at the edge, the magnitude can be summed in the scan direction to discern a flaw in edges with a constant curvature. By integrating the magnitude in the scanning direction j, or integrating the area under the magnitude curve, SM_i is calculated as:

$$SM_i=\sum_{j=1}^{j=nj} M_{i,j} \tag{2}$$

Figure 4b shows the values of SM_i at various indices. It can be seen that SM_i remains constant until a notch appears, then decreases to a minimum, and back up to constant as the probe moves away from the notch location.

Detection of Fatigue Cracks

Similar observations were made on the fatigue crack, as shown on Figure 5. In this study, ten boltholes with twenty fatigue cracks were inspected. The smallest size of edge crack detectable using this magnitude technique was 8 x 4 mils (or .008 inch long by .004 inch deep).

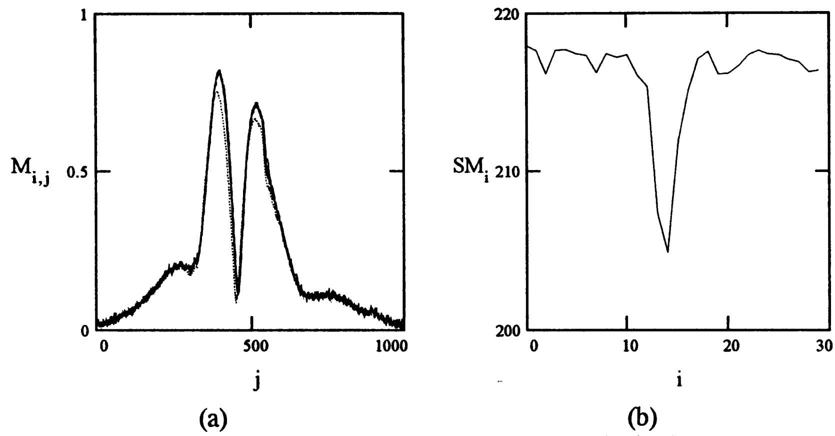


Figure 4 (a) Overlap of magnitude curves around a notched edge (b) sum of the magnitude under the magnitude curve.

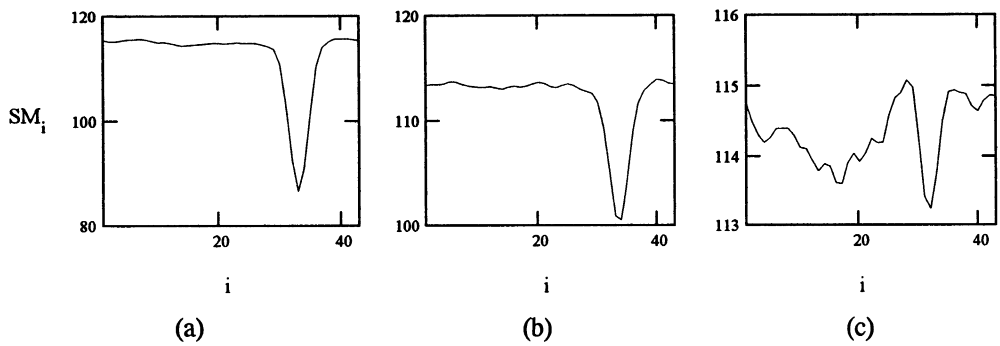


Figure 5 Sum of the magnitude under the magnitude curve for (a) 28 (b) 18 and (c) 8 mils long fatigue cracks.

Application to the e-hole

Finally, this magnitude technique was applied to the edge signals of the e-holes, as shown in Figure 6. It is noticed that the magnitude varies with the position. Furthermore, there are differences between the inner and the outer edges. This is because these edges on both sides of the e-hole are not identical. In addition, when a defect is in an edge, a reduction of magnitude was also observed. Without going to a non-linear method or a complicated method to set a threshold for each edge, a simple application of the magnitude can be applied to the e-hole. This is done by integrating the SM_i over a range from several index directions. Therefore, the summation of magnitude in both scanning and index directions, *ISM*, is calculated as:

$$ISM=\sum_{i=1}^{i=ni} SM_i \quad (3)$$

Therefore, the parameter *ISM* is for the detection of the e-hole. For the eight values of *ISM* in Figure 6, the notched edge gave the lowest value.

Figure 7 shows the result of an automated inspection after integrating the mechanical scan, data acquisition and data analysis into the RFC inspection system.

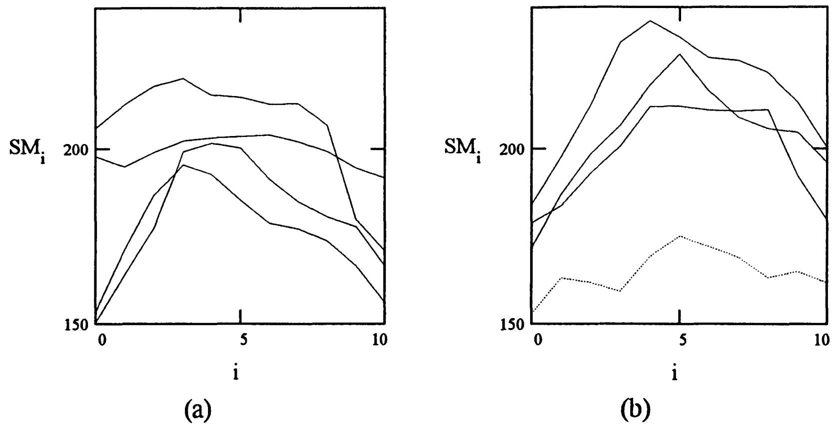


Figure 6 Sum of the magnitude under the magnitude curve for (a) inner edges and (b) outer edges of the e-hole. The dotted line indicates a 20 mils long EDM notch at the corner of the e-hole.

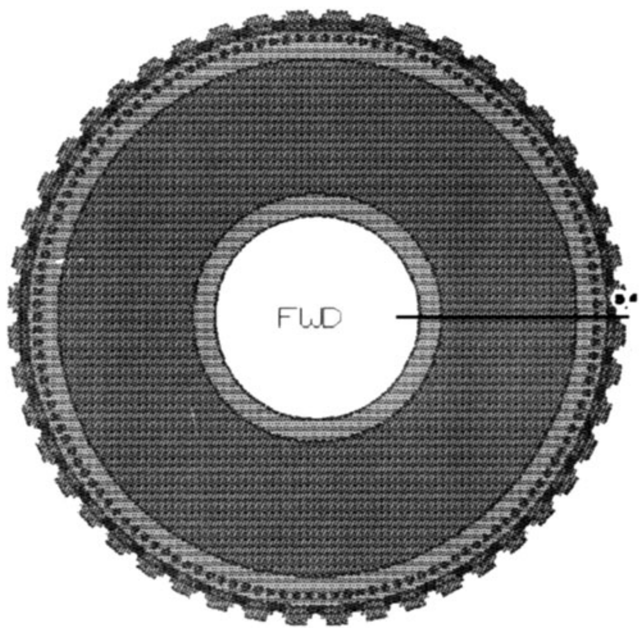


Figure 7 Automated inspection results from an engine disk. Both the edge and bore notches were detected and indicated as solid circles on the right most side of the graph.

DISCUSSION

The reduction of magnitude on edge signals in this study can be attributed to at least two reasons. The first reason is related to the position dependence observation in the inspection of an e-hole. Since the coil is circumferentially wounded around the probe tip, a change of the curvature in the geometry can affect the magnitude of the signal. In the large curvature area of the e-hole, the coil is closer to metal so that the magnitude is higher. When the probe is in a small curvature area, the periphery of the coil is away from the surrounding metal, thus the magnitude is smaller. The second reason is the reduction in magnitude of the edge signal when a defect is in the edge area. A possible explanation is the change in impedance in the edge area. When a flaw is present in the edge area, the flow path of the induced current along the edge of the geometry is increased. Therefore, difference of eddy currents received by two receiver coils became less than that in the notch-free case, and caused the magnitude to decrease.

SUMMARY

A magnitude technique has been developed for inspection of imperfect edges on the engine part and specimens. Inspection results from both notches and fatigue cracks indicate that the magnitude technique is a promising technique for the inspection of edge defects in a complex geometry. RFC/NDE Eddy Current Inspection Module software using this technique has been installed for automated detection of edge defects in a complex geometry.

ACKNOWLEDGEMENT

This work was conducted under USAF contract F33657-88-C-2189 and subcontract DOEO3317.

REFERENCES

1. C. F. Raatz, "Eddy Current Testing in Determining Metal Alloy Type and Heat Treatment," Boeing Company, Air Plane Division (August 1966).
2. D.J.A. Williams, J.P. Tilson and J. Blitz, "Effects of the Edges of Samples on Eddy-current Flaw Evaluation," in *Proceedings of the 14 Symposium on Nondestructive Evaluation*, pp. 41-44 (1983).
3. R.T. Elsberry and D.M Bailey, "Characterization of Shielded Eddy Current Probes," Material Evaluation, 44, pp. 984-988 (July 1986).
4. W.C. Hoppe and D.A. Stubbs, "Automated Eddy Current Inspection of Antirotation Windows in F100 Engine Compressor Air Seals," in *Review of Progress in Quantitative Nondestructive Evaluation*, D.O. Thompson and D.E. Chimenti, eds., (Plenum Press, New York, NY), Vol. 4A, pp. 463-474, 1985.
5. R.T. Ko, "Detecting Flaws in the Presence of Strong Geometry Signals in F100 Gas Turbine Engine Components," in *Review of Progress in Quantitative Nondestructive Evaluation*, D.O. Thompson and D.E. Chimenti, eds., (Plenum Press, New York, NY), Vol. 8B, pp. 777-784 (1989).
6. R.T. Ko, W.C. Hoppe, D.A. Stubbs, D.L. Birx, B. Olding and G. Williams, "An update on automatic position, inspection, and signal processing techniques in the RFC/NDE inspection system," in *Review of Progress in Quantitative Nondestructive Evaluation*, D.O. Thompson and D.E. Chimenti, eds., (Plenum Press, New York, NY), Vol. 6A, pp. 975-985 (1987).