EDDY CURRENT IMAGING OF AIRCRAFT USING REAL TIME IMAGE

SIGNAL PROCESSING

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INTRODUCTION

The increased incidence of aircraft component failures as motivated a reassessment of the NDE methods applied to assure fleet airworthiness. In the past, eddy current testing has been limited by the presence of spurious signals, operator error and the lack of permanent test results. An eddy current system using portable precision scanners and signal analysis techniques developed in the nuclear industry has been applied to aircraft inspections. Using custom designed probes, multifrequency mixing, and digital signal processing, the detection criteria of 10% loss of wall on the interior faying surface and cracks 60 mils (1.5 mm) in length have been accomplished. The subtle nature of these flaw conditions and the presence of interfering signals prompted the need for signal processing techniques. To achieve this objective, real time signal processing that requires a minimum of computation has been implemented in an eddy current C-scan imaging system. The signal processing produces spatial displays of amplitude (in phase or quadrature), magnitude, phase of spatial derivatives of these parameters. Permanent images that are more easily interpretable for flaw detection are thus produced.

DISCUSSION

With the aging of the aircraft fleet, there has been an increasing number of component failures. In most cases, the ultimate failure can be attributed to either fatigue cracking, corrosion or a combination of the two. Of course, there are possible precursors that allow the failure mechanisms to occur, such as adhesive joint weaknesses or inadvertent stress risers.[1] The most common inspection method presently utilized is visual with the inherent difficulties of detecting subsurface faults and paint coatings. Additionally, visual inspections are dependent on specific lighting conditions and are subjective.

In this study, inspection personnel from commercial airlines, corporate aviation and military repair depots were contacted to ascertain specific objectives for NDE of aircraft. The consensus was that a reliable technique to detect surface and subsurface cracking 0.06 inch (1.5 mm) long and corrosion wall loss of 10% were required to satisfy safety concerns. These same groups also provided access to aircraft and removed components with known or suspected incipient failures for a test bed. Typical areas that are inspected for corrosion in corporate and small commercial aircraft are shown in Figure 1. In this case, corrosion damage caused by collected moisture was the principal driving mechanism. Both the interior and exterior were subject to attack. In other cases cyclic loading at stress risers were the prime concern.

EDDY CURRENT TEST SYSTEM

A laboratory test system, as shown in Figure 2, was assembled comprising a precision scanner, a commercial eddy current test instrument and a personal computer. Custom application software was written to operate the system, digitize, analyze and display the data.

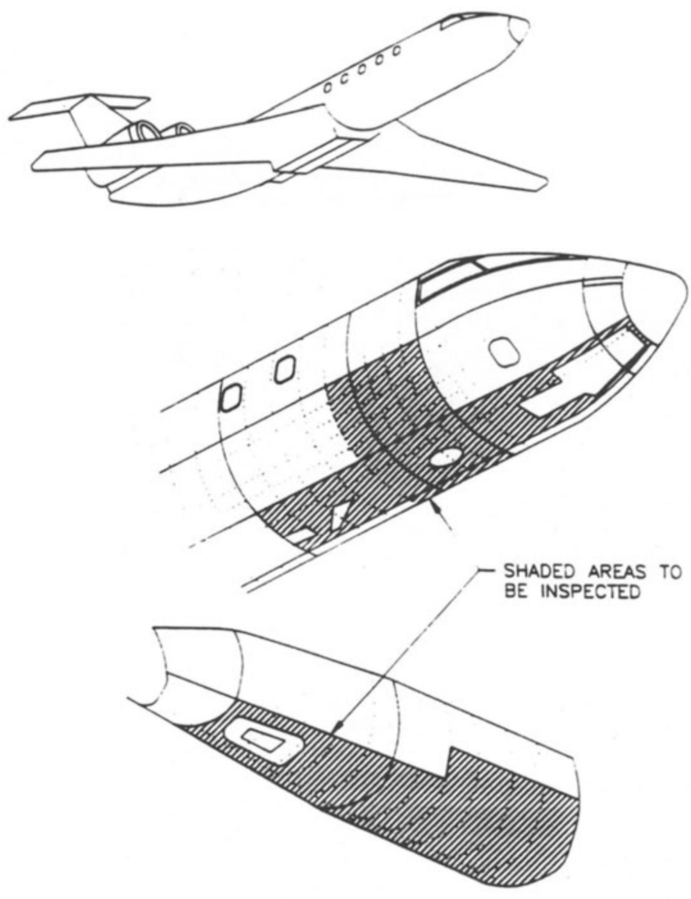

Fig. 1 Typical areas of corrosion requiring eddy current inspection.

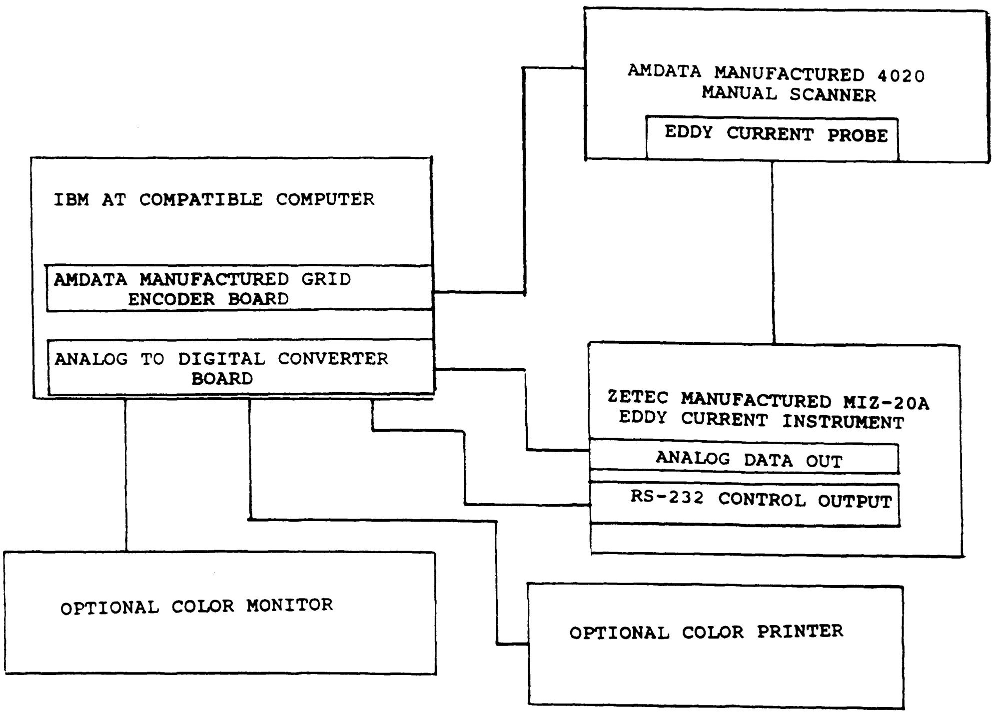

Figure 2. Block Diagram of Laboratory Test System.

The two axes scanner encoders provided the spatial information necessary to plot the data as well as generate the synchronizing pulses for acquiring data on a preset grid. Typically, data was taken in increments of one quarter of the coil diameter. Suction cup attachment tracks were used as guides on the test pieces.

A commercially available eddy current tester was used for the system. In most cases, the Zetec MIZ 20A, a single frequency instrument with an operating range from 100 Hz to 2 MHz, was used. For some tests, the Zetec MIZ 12, a four frequency instrument, was used when multiparameter mixing was beneficial. Three general categories of probe types were evaluated, and each had its special application advantages. Absolute pancake, differential pancake and driver/pickup coil configurations were used.

ABSOLUTE PROBE

- SENSITIVE TO ANY CHANGE IN CONDUCTIVITY, PERMEABILITY, OR GEOMETRY OF TEST SAMPLE
- USED FOR CORROSION MAPPING

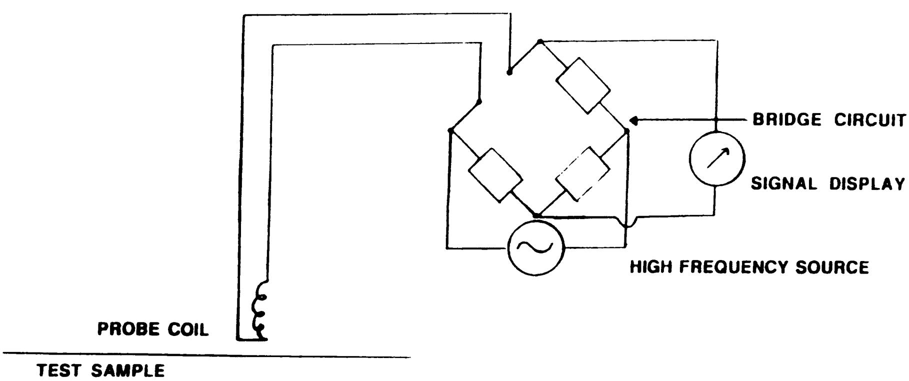

Figure 3. (a) Eddy Current Probe Designs

Absolute coils are the standard design and coil diameters from 0.1 to 0.5 inch were used as the situation warranted. Differential pancake designs were employed when some known component symmetry could be exploited to enhance signal to noise ratio. Concentric driver/pickup coil configurations were used for subsurface flaws when the increased signal power was helpful.

The personal computer was modified by the addition ofan A/D board and an encoder board interface to the scanner.

The analog in-phase and quadrature components of the eddy current signal were digitized from the eddy current instrument output. Although the eddy current instrument had some filtering options, none were used since the outputs would be scanner speed dependent due to the nature of

DIFFERENTIAL PROBE

- SENSITIVE TO LOCALIZED CHANGES IN CONDUCTIVITY, PERMEABILITY OR GEOMETRY OF TEST SAMPLE

- USED FOR CRACK DETECTION

- COIL 1 WOUND IN OPPOSITION TO COIL 2

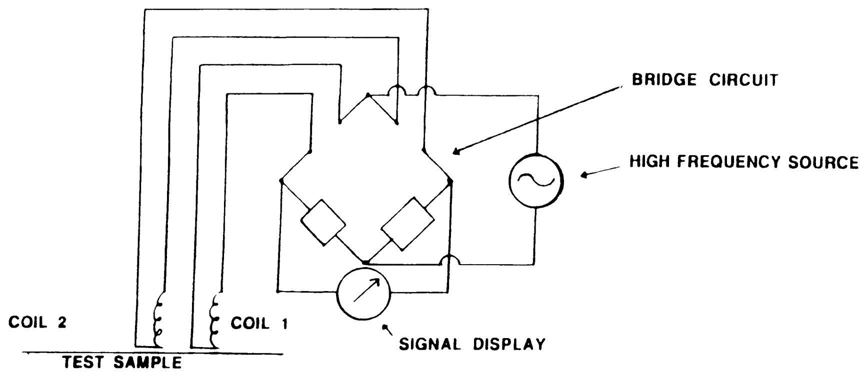

Figure 3. (b)

DRIVER/PICKUP PROBE

- SENSITIVE TO LOCALIZED CHANGES IN CONDUCTIVITY, PERMEABILITY OR GEOMETRY

- MORE SENSITIVE THAN DIFFERENTIAL PROBE

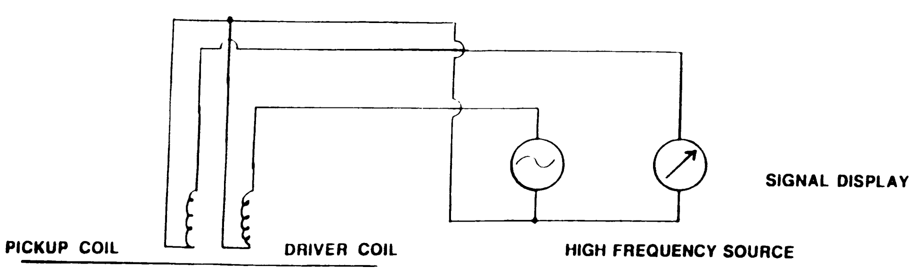

Figure 3. (c)

the filters. Only the spatial dependence of the eddy current response is of interest in this application. The data file then consisted of the two signal voltage components and the X and Y position coordinates.

The computer software constructed a C-scan image similar to those commonly used in ultrasonic inspections. The image display had several options including:

- In-phase or Quadrature Voltage
- Signal Vector Magnitude
- Complex Voltage Phase
- Instantaneous Complex Voltage Phase.

Previous programs concerning automated detection and characterization of flaw signals in eddy current testing of nuclear power plant steam generator tubing had indicated that a spatial derivative of the complex voltage phase was one of the optimum parameters[2]. A phase measurement alone would not be adequate because the summation of noise (usually from probe lift off or wobble) would affect the value to an unacceptable degree. The instantaneous phase again proved to be one of the best indicators of flaws, especially for subsurface cracks and corrosion.

The instantaneous phase can also be some what erratic, especially when dealing with low level and noisy signals. Consequently, a magnitude threshold was established empirically as part of the phase measurement algorithm. The combined displays of amplitude (or magnitude) and instantaneous phase proved to be the most useful for detection of flaws in these applications.

TEST RESULTS

Initial tests with the eddy current imaging system were conducted on laboratory simulations of aircraft corrosion. Test sample included aluminum plates riveted to structural aluminum stringers. Electric discharge machine notches and machined wall loss were used to simulate cracks and corrosion damage. In the second phase, removed portions of commercial, military and corporate aircraft with service induced corrosion were obtained for further laboratory tests. A limited number of field tests were then conducted on flight line aircraft. The results of these several tests are summarized below.

Laboratory Results

The first samples fabricated were made of 0.040 inch thick aluminum plate riveted to an aluminum stringer. Various EDM notches emanating from the rivet holes were fabricated as well as machined back surface wall loss of 0.004 and 0.008 inch depths. For the wall loss samples. an absolute probe operating at 12 kHz provided adequate sensitivity to detect the 0.004 inch wall loss. For the rivet notches, the shortest notch was 0.060 inch long and was detectable using a differential probe operating at 500 kHz. The differential coil design aided the detection by partially suppressing the rivet signal due to cancellation between the two coils. For both cases, simple amplitude plots sufficed for detection.

A commercial airline provided a similar sample removed from service because of corrosion. This sample contained back surface corrosion and surface cracking obscured by paint. The results from this sample, shown in Figure 4, are similar to the lab sample. Again, an amplitude plot was sufficient for the detection. The test frequency was lower, 2 kHz, because the component skin was thicker. Note that the subsurface flaws appear most readily in the vertical channel data while the surface cracks appear best in the horizontal data channel. (The standard convention of setting probe wobble signals at 0 degrees was followed throughout.)

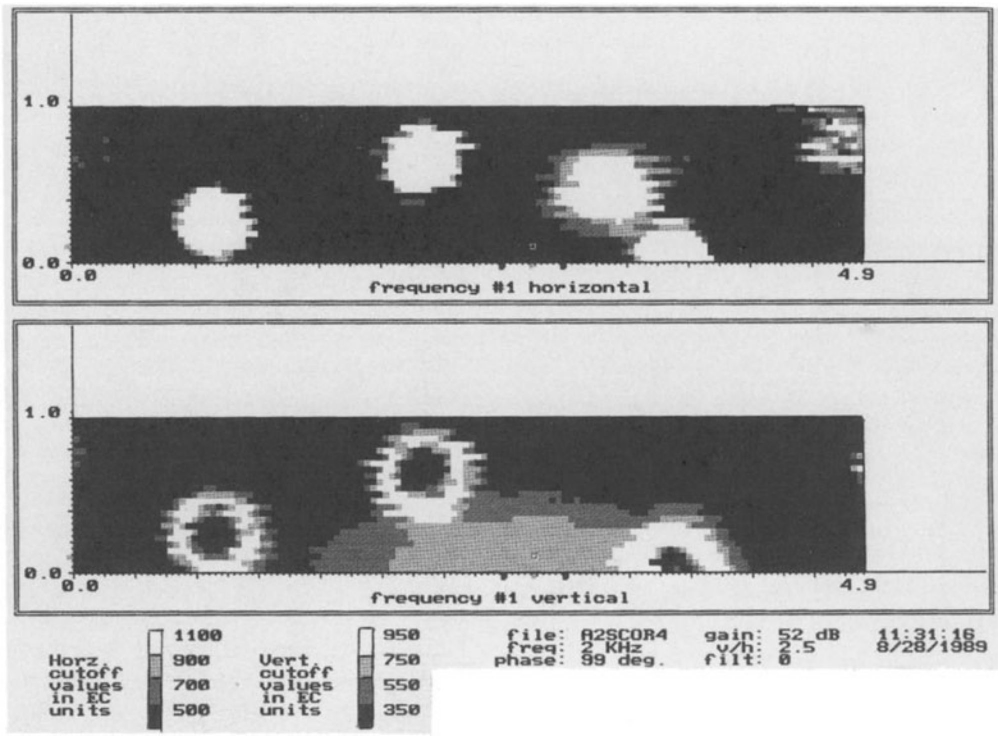

Figure 4. Corroded Stringer Sample (50% wall loss) From Commercial Airliner

Circular indications are drilled holes. The corrosion is the large indications on the vertical C-scan.

Another sample received was a 16 inch landing wheel with a small crack originating at one of the holes in the hub. In this sample, a 0.12 inch absolute probe was used at 150 kHz to image the crack. This particular crack was not visually detectable, but had been found using dye penetrant methods.

Field Tests

Field tests were conducted at a corporate aircraft maintenance facility, a commercial airline and a military depot.

In one test, the routine maintenance inspection for the aircraft had just been completed and no corrosion had been detected. The eddy current system was then used in selected areas of the lower fuselage.

The amplitude plots did not reveal and damage in these sections. However, the instantaneous phase plots did detect subsurface corrosion, as shown in Figure 5. The corrosion occurred at the edge of the backing stringer and this boundary obscured the amplitude data. (It is possible that multiparameter mixing algorithms would improve detection in this region and this approach will be pursued in the future work.) Subsequent internal inspections confirmed the presence of this corrosion caused by a small hydraulic leak. Neither the routine visual inspection nor a conventional eddy current inspection approach would detect this damage. Only the phase C-scan plot was able to pinpiont this damage.

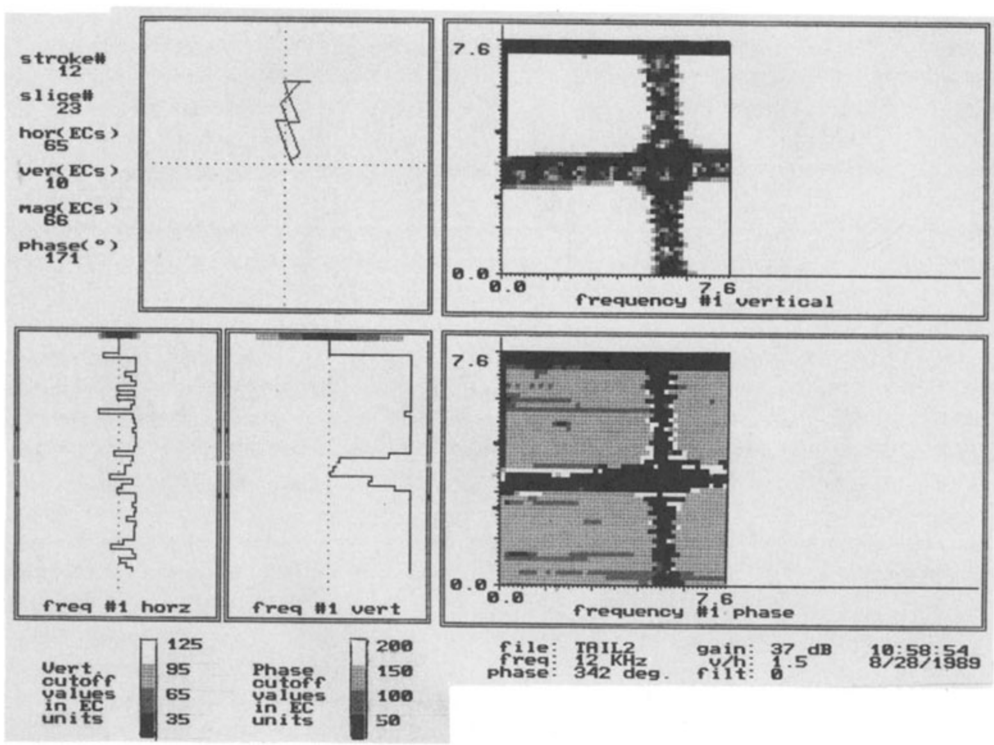

Figure 5. Corporate Aircraft With Subsurface Corrosion Along Stringer.

Corrosion detected using phase display.

Probe: 1/2" diameter absolute probe.

Another tested component had surface cracking in the stringer rather than the skin. In this case, it was necessary to use a driver/pickup coil design to increase the signal strength. In this test the conventional amplitude plots provided marginal detection of the cracking. Again, the phase plots provided an unambiguous image revealing the cracking.

CONCLUSION

The design objectives of detection subsurface corrosion at 10% of wall and surface cracking at 0.06 inch were met using an eddy current imaging system.

Judicious selection of probe style, absolute, differential or driver/pickup, is essential for optimum test results.

Although conventional amplitude data plots served for detection in most cases, the availability of signal phase plots enhanced the flaw detection capability. In actual field tests, the phase plot was the only successful technique for flaw detection.

REFERENCES

1 "Aging Aircraft", DeMeis, Richard, Aerospace America, July, 1989.

2 Signal Processing for Steam Generator Inspection, Jackson, P. S., Endter, R. K., Sapia, M. A., and Lareau, J. P., Electric Power Research Institute Publication NP-5773, April, 1988.