New Advances in Detecting Cracks in Raised-Head Fastener Holes Using Rotational Remote Field Eddy Current Technique

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ABSTRACT

Rotational remote field eddy current (RFEC) method has shown its outstanding capability in detecting cracks under raised-head fasteners [1]. Recent years NDT society has noticed the conductivity condition between a fastener and hole material tremendously alters the eddy current signal. Therefore, new study has been carried out by the authors on verifying the ability of the RFEC technique in detecting cracks in some harsh conditions which effect the fastener-hole material conductivity. These include:

1. Detect-ability with alodined and anodized fasteners;
2. Detect-ability with tightly installed fasteners;
3. Detect-ability with fasteners with scratched surface at different locations relative to fastener shaft circumference.

A large number of specimens/standards were built by FAA AANC and a big amount test has been carried out by the authors.

Description of the specimens and the test along with test results will be presented in the paper.

INTRODUCTION

Increasing niche applications, growing international markets, and the emergence of advanced rotorcraft technology are expected to greatly increase the population of helicopters over the next decade. In terms of fuselage fatigue, helicopters show similar trends as fixed-wing aircraft. The unsteady loads experienced by rotating wings not only directly affect components in the dynamic systems but are also transferred to the fixed airframe structure. Expanded use of rotorcraft has focused attention on optimization of maintenance practices. The FAA's Airworthiness Assurance Center (AANC) at Sandia National Labs has joined with Bell Helicopter and other agencies in the rotorcraft industry to evaluate nondestructive inspection (NDI) capabilities for an assortment of rotorcraft structural components. Rotorcraft components accumulate fatigue cycles much faster than fixed-wing aircraft which are mainly driven by constant amplitude pressure cycles. Thus, more accuracy is required for crack growth predictions - and greater sensitivity is required of NDI - since times to failure can be on the order of a few flight hours instead of numerous flights. As the helicopter industry adopts the damage tolerance philosophy, the appropriate application of nondestructive inspection (NDI) equipment will play a critical role in managing safety.

Currently the capabilities for nondestructive inspection and evaluation (NDI/E) of rotorcraft components are essentially limited to the techniques established for fixed wing aircraft. The regime in which rotorcraft NDI/E work must be conducted is significantly different because a very large number of cycle loads are generated in a short time. Additionally, the ability of rotorcraft to hover makes them more weight critical than fixed wing aircraft.

To address some of the stringent crack detection requirements and to expand some of the inspection intervals with very small flight hours, new NDI methods are developed to detect cracks before they extend out from under the head of the fastener. Among them rotational flat geometry remote field eddy current (FG_RFEC) method has shown its outstanding capability in detecting cracks under raised-head fasteners [1]. Recent years NDT society has noticed the conductivity condition between a fastener and hole material tremendously alters the eddy current signal. Therefore, new study has been carried out by the authors on verifying the ability of the RFEC technique in detecting cracks in some harsh conditions which affect the fastener-hole material conductivity. These include:

4. Detect-ability with alodined and anodized fasteners;
5. Detect-ability with tightly installed fasteners;
6. Detect-ability with fasteners with scratched surface at different locations relative to fastener shaft circumference.

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FG_RFEC TECHNIQUE AND SUPER-SENSITIVE-EDDY-CURRENT (SSEC) SYSTEM

The original Remote Field Eddy Current (RFEC) has used in NDI of conducting tubing for years. The RFEC technique is characterized by its features of deep penetration and the linear relation of its signal phase to the total wall thickness under inspection. The signal phase to wall thickness relation is independent of probe lift-off and the location of a flaw in respect to the wall thickness.

IMTT has expanded the applications of RFEC techniques to the inspections of conducting objects of flat or nearly flat geometries with the help of specially designed probes called FG_RFEC probes, Figure 1. The probe blocks the direct coupling path. The electromagnetic energy released from the drive unit is forced by the FG_RFEC probe to go along the indirect coupling path. Therefore, the entire signal received by the pickup unit has passed the wall twice and carries the whole information about the wall condition. The signal can be extremely weak, but is very clean without noise coming from the driving unit.

An SSEC system is developed to deal with the weak signals obtained from an FG_RFEC probe. SSEC system is a modified version of a conventional eddy-scope. It has comparatively high gain and low noise level, so that it can bring the weak pickup signal to a level that is readable on a computer screen.

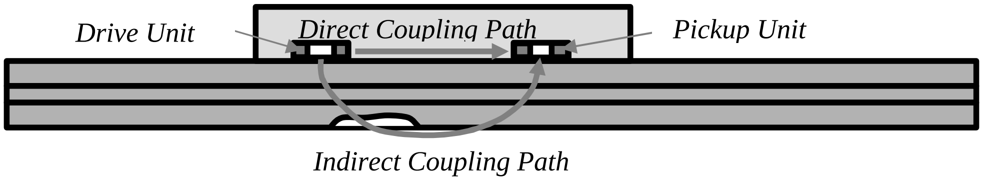

Figure 1: Simplified Drawing of An FG RFEC Probe And the Energy Coupling Paths.

Current version of an SSEC system, SSEC RF01, consists of a piece of software and a Printed Circuit Board (PCB) that are installed/inserted into a regular personal or industrial computer, see the left picture in Figure 2. It utilizes the fundamental features of a computer as the base of an SSEC system. Figure 2 (right) is the second version of the system where it becomes a small box and can be connected to a customer preferred computer through a universal serial port (USB).

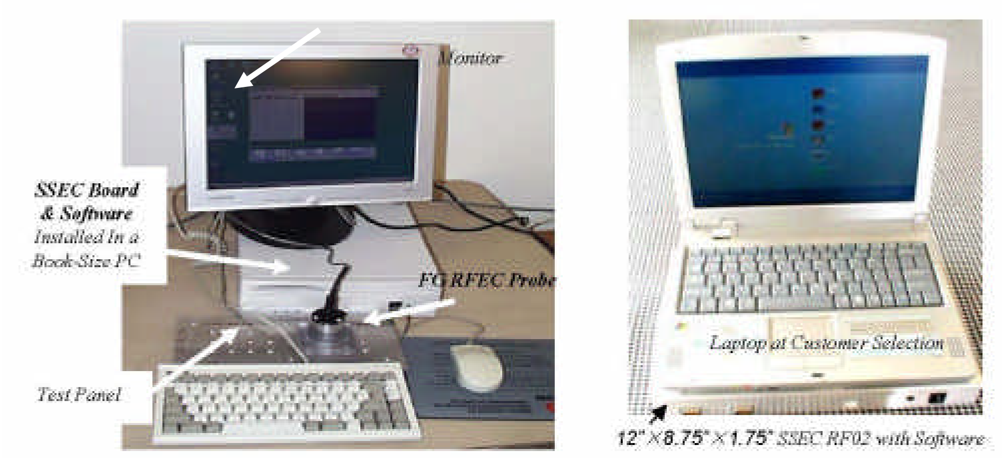

Figure 2: Current (left) and Second (right) Versions of An SSEC System.

CRACK DETECTION MODES: RASTER SCAN VERSUS ROTATIONAL SCAN

For the purpose of accurate and fast detection of fastener hole cracks a series of rotational RFEC probes with accompanying software have been developed.

Traditionally a raster scan mode is used for crack detection. In such a mode a probe moves in X and Y direction over entire area of interest. The raster scan mode has a disadvantage as inner-layer crack signals are submerged by the fastener signals/noises, which may be tens or hundreds times greater than the crack signals, Figure 3. A rotational probe consists of a centered excitation coil and an off-set differential sensor, Figure 4. The probe minimizes the noises when it is rotating right at the fastener center because of the geometric symmetry. As it is shown in Figure 3, when the rotation center of such a probe coincides with fastener center, we should have a zero signal from the differential sensor when there is non crack. A signal appears in the differential sensor only when it passes a crack.

To have a rotational FG RFEC probe work with high sensitivity the probe must be centered well with the fastener under inspection.

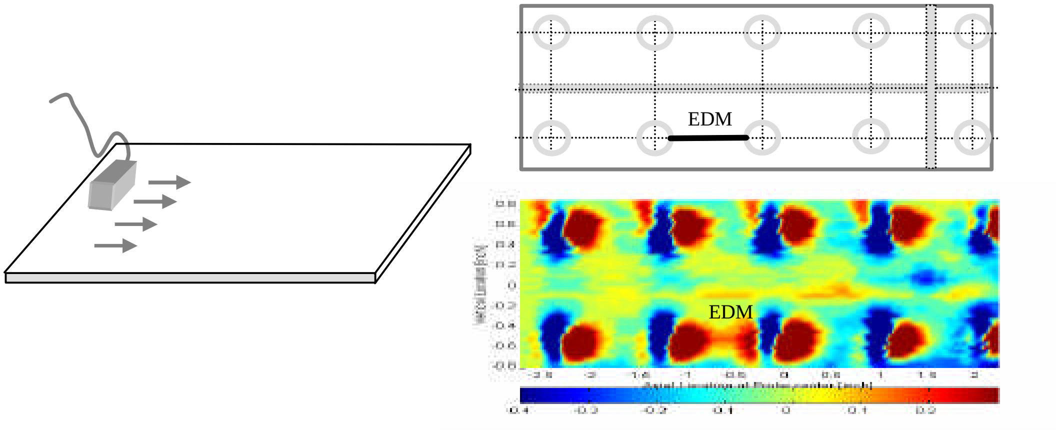

Figure 3: Raster Scan – Inner Layer Crack Signals Are Submerged By Strong Fastener Signals.

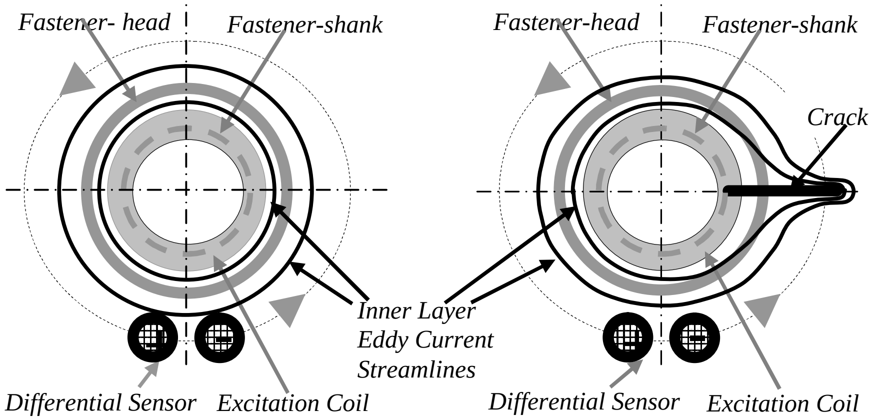

Figure 4: Rotating Probe Minimizes Noises From Fastener Because Of Geometrical Symmetry. No-Crack Case (Left) and With An Inner Layer Crack (Right).

INSPECTION OF RAISED-HEAD FASTENERS

One example of application of rotational FG RFEC probe in aircraft crack detection is the inspection of raised-head fasteners, Figure 5.

Raised-head fasteners are often used in helicopter structures. They are also seen on non-aerodynamic surfaces of conventional airplanes. The round fastener head can work as a guide for the probe rotation if a pocket, that closely matches the outer diameter of the fastener head, is made on an FG RFEC probe head.

Figure 6 shows a typical commercial available FG_RFEC probe, RF2_ROT_ RH_DP, working on a panel with raised head fasteners.

The IMTT FG RFEC probe for inspection of raised-head fasteners have been extensively tested on different panels provided by Airworthiness Assurance NDI Validation Center (AANC), Federal Aviation Administration (FAA) of The United States. So far the probe keeps the best Probability Of Detection (POD) record in detection inner-layer cracks for two layer, 1.0mm + 1.0mm or 0.040” + 0.040”, aircraft aluminum structures. A brief of the POD study report is shown in Figure 7.

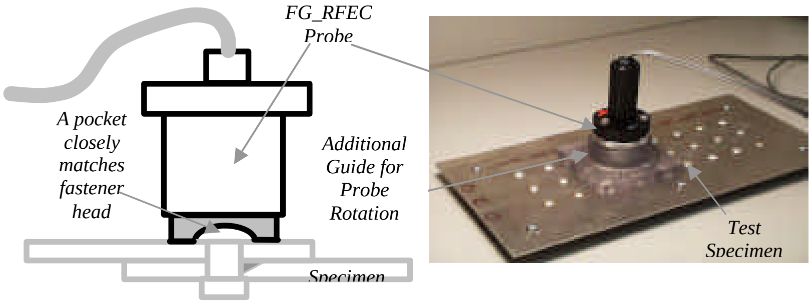

Figure 5: Rotational FG RFEC Probe Applied To Raised-Head Fastener.

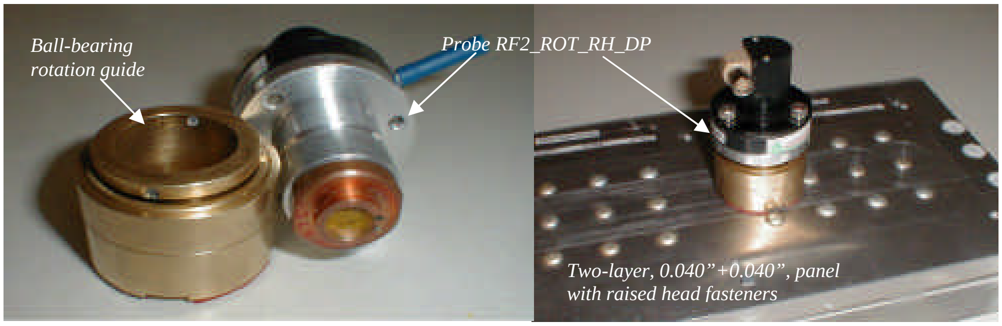

Figure 6: A Typical Commercial Available Rotational FG_RFEC Probe.

JOINT CONDUCTIVITY VARIATIONS

Field inspections on helicopters showed that the eddy current (EC) signals from various regions of similar rivet sites and joints may vary drastically. This phenomenon can mask signals from cracked rivets sites and can greatly reduce the flaw detection sensitivity. Focused laboratory tests revealed that there two are the main contributors to the conductive path between the fastened layers:

1) The EC signals change in accordance with the level of conductivity between the surface and subsurface skins, and
2) Specific features of the rivets, such as anodized and alodined rivet coating, tight fastener installed fasteners, and surface scratch.

Figure 8 provides a rough explanation on how joint conductivity of a fastener alters the streamlines of the eddy currents induced by drive coil currents right above the fastener. If the coil center coincides with the fastener center, Figure 8 A, the joint conductivity has no effect to the eddy current streamlines at all. When the drive coil moves a distance to the right, the eddy current streamlines are going cross the joint without significant change in their paths if the joint is well conductive, as shown in Figure 8 B. The reaction from the eddy currents to the coil impedance keeps about the same as it was in case A. Hence, we don't see significant changes in the impedance plane. However, if the joint is not conductive, the eddy current streamlines are not able to go cross the joint. They extend their paths to loops longer than they were in Case A. We know, the longer the eddy current paths are, the weaker the eddy current values will be. Hence, their reaction to the coil impedance plane becomes less the change in the coil impedance plane will be more pronounced.

Similar phenomenon happens with a cracked fastener hole. The conductive joints provide more pronounced crack signals more pronounced that those from non-conductive joints. Figure 9 shows the impedance variation in conventional EC techniques.

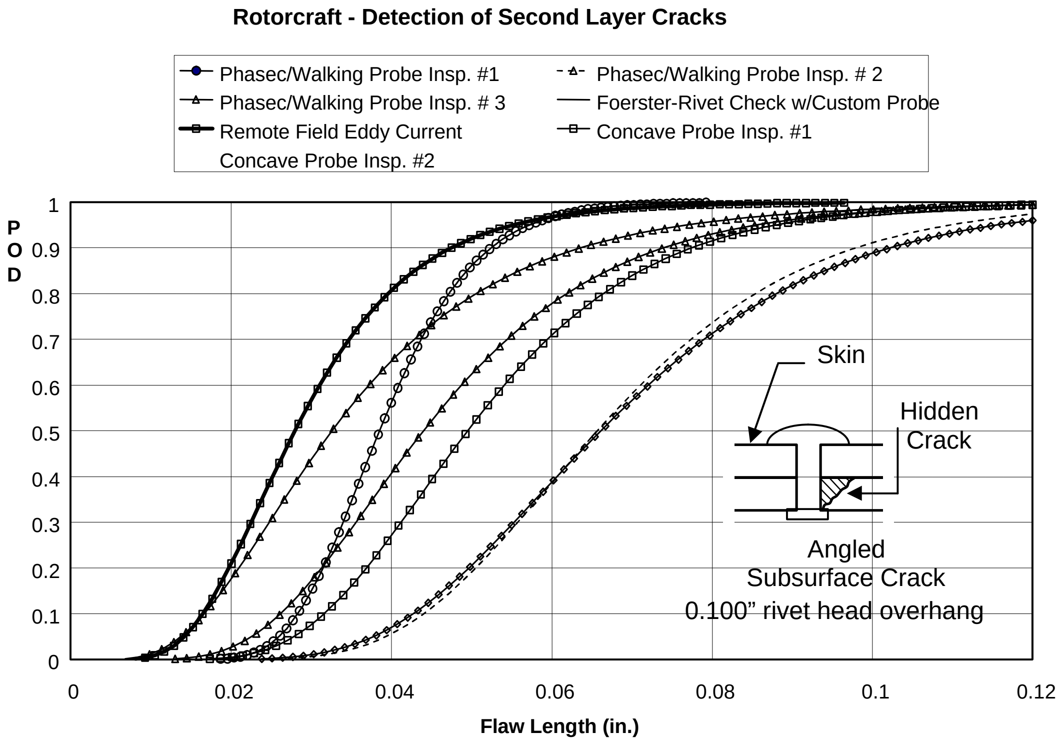

Figure 7: FAA AANC POD Record For A Number Of NDT Techniques In Detecting Second Layer Cracks.

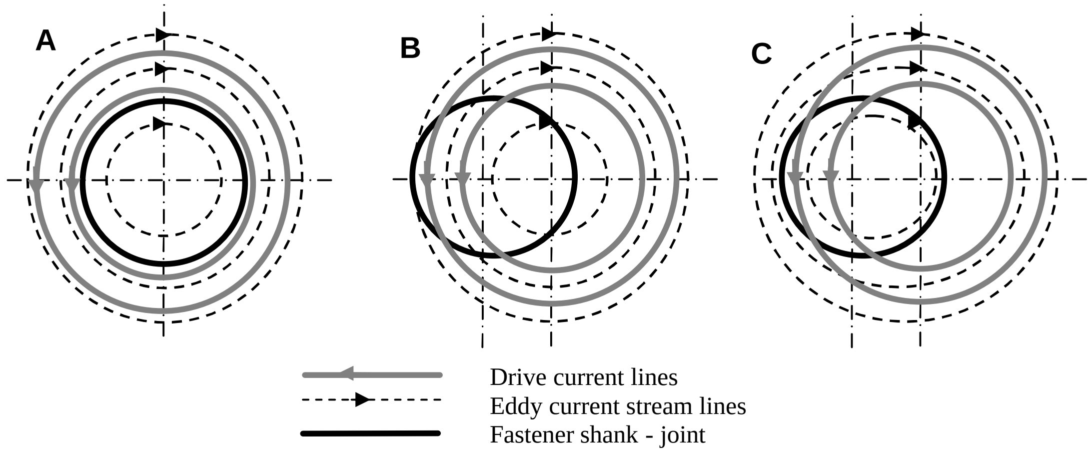

Figure 8: Effect From Conductive And Non-Conductive Joints To Coil Impedance Variation

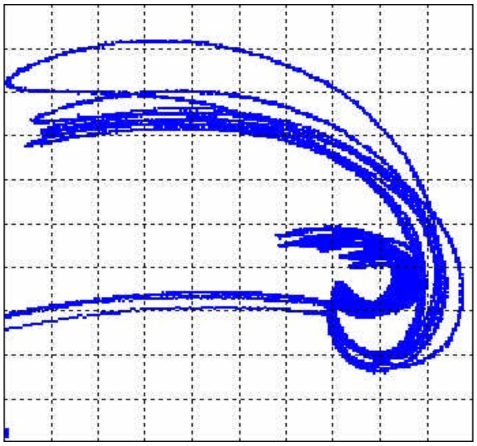

Figure 9: Decrease In Conventional EC Impedance Signals Caused By Varying Levels Of Conductivity At Rivet.

INITIAL FATIGUE CRACK PROBABILITY OF DETECTION STUDY

In-service fatigue crack inspections were simulated using typical joints from the rotorcraft tail boom. Multiple configurations of lap joints with various edge distances, rivet types and rivet sizes were assembled with a statistically-relevant flaw distribution. Results from these tests were used to produce Probability of Detection (POD) and false call assessments for the general joint with raised head fasteners.

Specimen assemblies, used in this study, featured rivet installation variations, alodined rivets, rivets with coatings removed in select regions, and tighter rivet holes that required some force to assemble. All of these changes increased the conductivity between the first and second layer which changed the eddy current signals drastically. The followings are major parameters for part of the test specimens:

- Material: 7075-T6
- Surface skin: t = 0.040".
- Subsurface skin: $t_{(sub)}$ = 0.040".
- Bolt hole: D_1 = 0.196" diameter.
- Rivet shaft diameter, head diameter, crack profiles, and installation layout are described in Table 1.
- Rivet type/part no.: MS20470.
- Rivets: button-head; 1" spacing.

Table 1

Rivets Used in POD Test Specimens

Item	Number	Installation	Head Dia.	Shaft Dia.	Shaft Length	Mat'l
1	MS20470 E6-7.5	Bucked	0.375	0.188	0.470	Alum.

Multiple Configurations (studies):

1 Angle on Top – Surface Crack

2 Angle on Bottom – Surface Crack

3 Angle on Top – Subsurface Crack

4 Angle on Bottom – Subsurface

Figure 10: Profile Possibilities For Probability Of Detection Test Specimens.

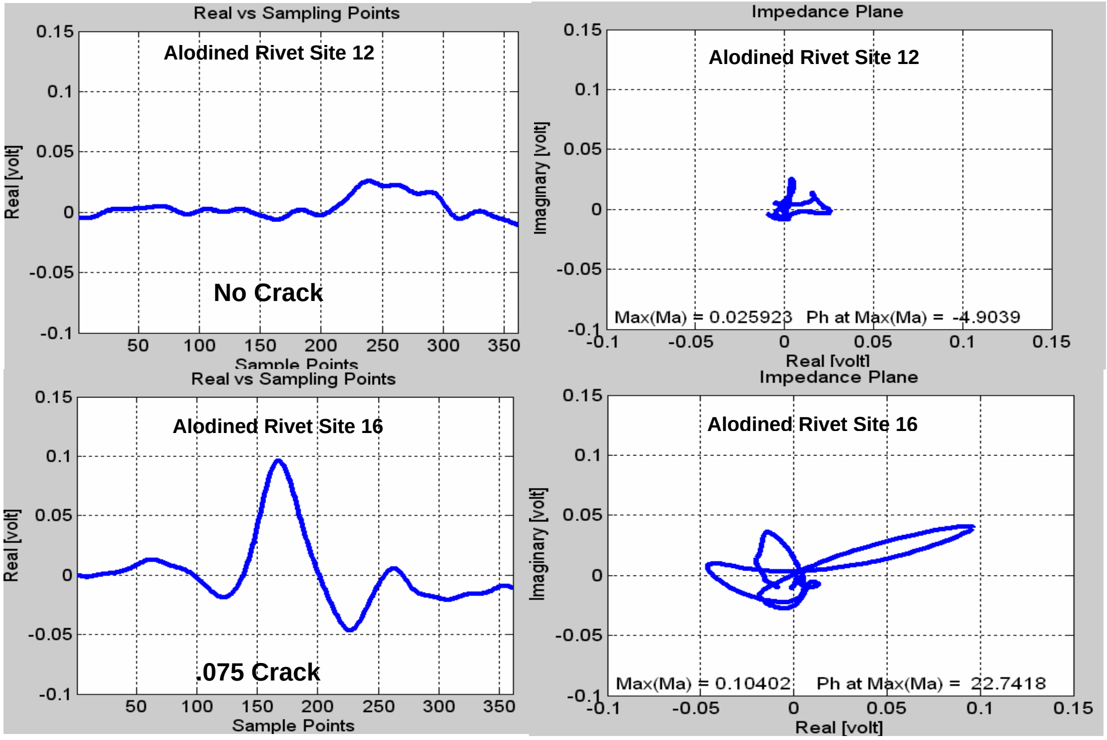

Figure 11: Signals From 1st Layer Cracks Using FG_RFEC Technique

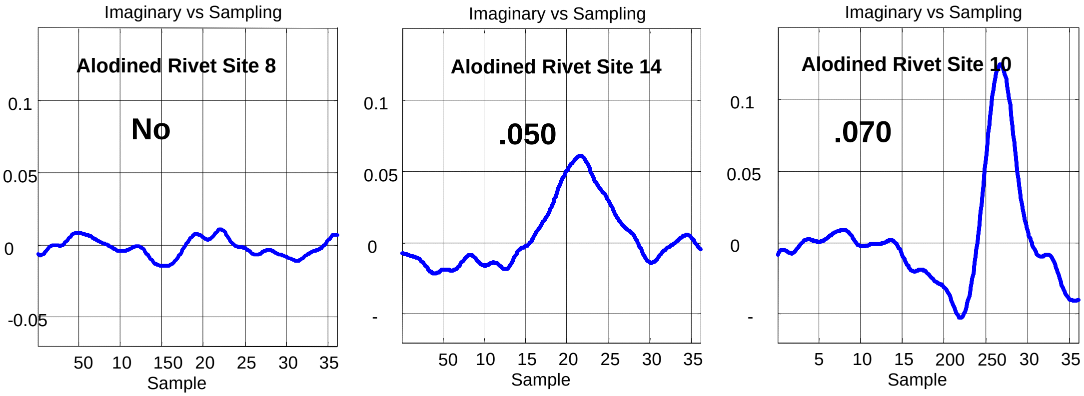

Figure 12: Signals From 2nd Layer Cracks Using FG_RFEC Technique.

SUMMARY

1. Appropriate application of nondestructive inspection (NDI) equipment will play a critical role in helicopter managing safety.
2. In helicopter applications more accuracy is required for crack growth predictions and greater sensitivity is required of NDI.
3. Among currently available EC techniques FG_RFEC technique shows good promise in POD study and in detecting raised head fastener hole cracks with alodined and very conductive fastener joints.

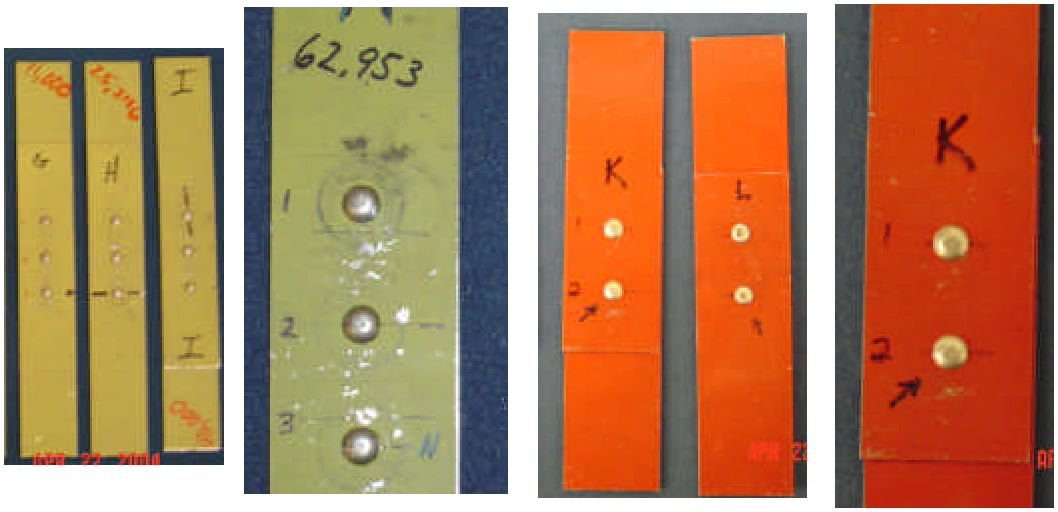

Figure 13: Twelve specimens with natural fatigue cracks – crack lengths ranged from 0.020” to 0.210”

- **Pencil Probe – found only cracks extending beyond rivet head**
- **Walking Probe – found 20 out of 24 cracks; 2 false calls**
- **Concave EC Probe – found all 24 cracks; 3 false calls**
- **RFEC – found all cracks; 1 false call**

REFERENCES:

[1]. Yushi Sun, Dennis Roach and others, “Rotational Remote-Field Eddy-Current Method for Detecting Cracks under Raised Head Fasteners”, Proceedings of Joint Conference on Aging Aircraft 2003, 8-11 September 2003, New Orleans, Louisiana