

RFC EDDY CURRENT PROBE TESTS

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INTRODUCTION

An automated, computer controlled inspection system is being developed under the Retirement for Cause (RFC) Program. This inspection system is responsible for the reliable detection of flaws of critical sizes in an assortment of locations and orientations on multiple disks and spacers in the fan, compressor and turbine sections of the F100 aircraft engine. As a result the eddy current inspection modules in the RFC system must incorporate a wide variety of eddy current probes capable of completely inspecting the many required geometries. During the course of development of such a system, tests must be conducted to insure total coverage of the required areas; these tests result in possible redesign of the probes. In addition, tests must be conducted to determine the capability of the inspection system to detect flaws. These tests result in possible adjustments to inspection parameters such as inspection frequency, filter settings, and possible modifications to inspection algorithms. When confronted with similar probes with different coil designs, it is desirable to determine the optimum design of the probe and coil using comparison tests.

Each type of test mentioned above has been conducted during the development of the RFC System. There are other studies conducted in this program which have come about from these tests and from a natural desire to better understand the probes and the inspection environment to produce a more reliable eddy current inspection. One such study concerns the lift off signal in real differential eddy current probes.

This paper will attempt to overview some of the tests described above. When appropriate, at selected points of interest, a more indepth explanation of the tests and results will be given.

COVERAGE TESTS

The tests of coverage necessarily require knowledge of the geometry of the probe, placement of the coils in the probe and the details of the geometry being inspected. To describe these tests without over emphasizing the details, the following types of geometries will be considered: Holes, corners and radii.

Holes require the use of hole probes which spin at 1500 rpm. These probes have the coils mounted on an outer diameter, oriented to detect flaws in the bore or corner of the hole. The inspection is non-contact, the probe being centered automatically before inspection of the hole. Two holes that have been tested are the web bolthole in the 8th high pressure compressor (HPC) disk, and the radial or rim cooling hole in the 2nd high pressure turbine (HPT) disk. Each hole has presented interesting and difficult problems.

The inspection of the 8th disk web bolthole would be straight forward except for a potential problem related to cleaning. There is a deposit found in the bore region of this hole which has been identified by the engine manufacture. This deposit causes eddy current signal responses which are very difficult to separate from the flaw signal. The manufacturer is attempting to solve this problem via cleaning.

The radial cooling hole offers different problems. The first area of concern is the bevelled region on the outer side of this radial hole. Tests have shown decreased sensitivity in this region compared to the bore region of the hole. This is expected. The second area of concern is the inside corner of the hole which intersects a non-planar surface completely masking any signals produced by EDM notches in this area. These two areas have limited the coverage of this hole.

The second type of geometry to be considered is the corner. Typically a corner has a small radius of curvature, on the order of 0.020". The inspection of corners is accomplished with a compliance probe. A compliance probe is a probe with a plastic housing imbedded with Aluminum Oxide. This plastic houses the coil and tubes channelling air to the coil tip for cooling. The housing is attached to the probe body by a structure of springs designed to produce compliance in the desired directions. In the case of corners, the probe initially employed only one spring set giving compliance in a direction parallel to the wall of the corner being inspected. This has been modified to give additional compliance in the direction perpendicular to the wall.

Tests have been conducted with this probe on the snap radius of the 9th HPC seal. As a result of these tests the probe has been modified to give a coil placement at an angle of 30° relative to the wall of the corner being inspected. This gives acceptable sensitivity on the surface perpendicular to the wall, and in the corner. 30° was chosen to allow inspection of the anti-rotation window with the same probe. Various sized notches in various orientations were placed in the snap radius and tests were conducted with the modified coil placement. This modified probe has shown satisfactory signal to noise ratios for 0.020" long EDM notches.

Tests have also indicated coverage limitations in the snap radius in HPC seals due to the anti-rotation windows in these parts. The extent of these limitations are affected by the scanning speed, filter settings and the dimensions of the coil and coil housing.

Another type of geometry to consider is a radius. This is a radius in a surface such as a web or bore, and generally the radius runs out into another radius or a flat surface. Again, compliance probes are used. There are two cases to consider here. First, there is the possibility, if the radius is large enough, to scan using a flat surface compliance probe by simply following the surface. Such is the case in the 8th HPC disk inner web radius (radius of 0.5"). In this case, it was found that a slight extension of the coil housing on the flat surface compliance probe allows the use of this probe in such areas.

Another possibility is that the radius is too small to practically scan across. In such cases a compliance probe must be used which has a coil housing which matches the radius of interest. This happens in the 1st and 2nd HPT disks and the 3rd and 4th low pressure turbine (LPT) disks in the inner web regions. In these cases the probes must have the same radius as the geometry. There is no scanning allowed because of this constraint, so multiple probes must be used, each having the coil placed at a different angle in the coil housing. Tests have been conducted to determine the proper placement of the coils in the housing and the number of probes required to accomplish complete coverage.

Specifically, tests were conducted on the 4th LPT disk inner web radius. See Figure 1 for drawing of probe and geometry. EDM notches were placed at three different angles in this radius with two different orientations for a total of six EDM notches. The two orientations used were circumferential and radial relative to the axis of the disk. Each notch was to be 0.015" x 0.007" x 0.005" (l x d x w).

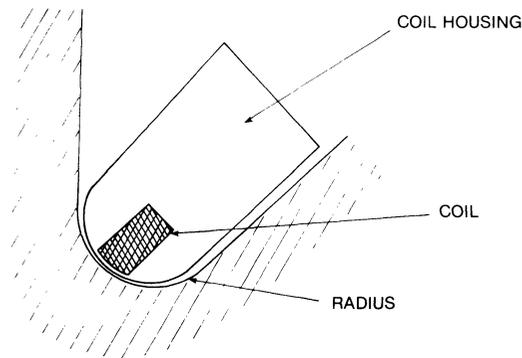


Figure 1. COMPLIANCE PROBE USED TO INSPECT SMALL RADIUS

For the purpose of explaining relative angles of the notches and the coils, the axis of the probe in its inspection position will be considered the reference. Three frequencies were used to determine the optimum frequency for the test; 500, 1000 and 2000 KHz. 2000 KHz was found to consistently give the larger signal-to-noise ratio for each notch. The probes used had differential split-ferrite cores. The core diameter was approximately 0.080". LO was made horizontal, and the signal-to-noise was based upon the vertical channel.

Figure 2 shows the signal-to-noise ratio plotted versus coil-notch separate angle. Primarily the data confirms the expected behavior. Theoretically, one might expect that the coverage of the coil is

approximately equal to the angle that the coil subtends. In this case that angle is 40° .

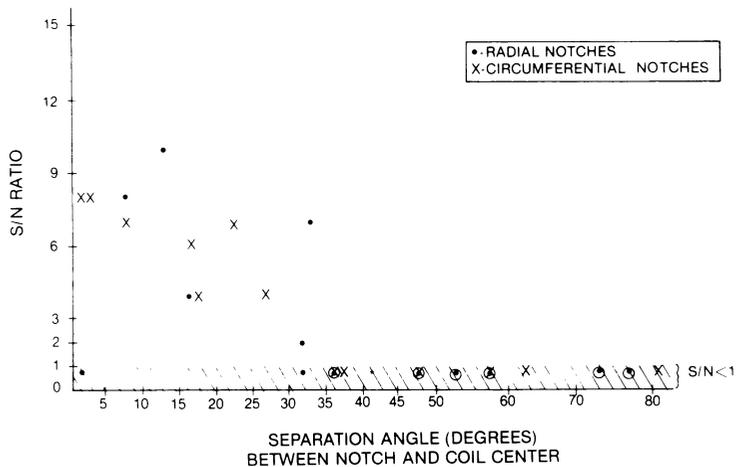


Figure 2. COVERAGE EXPERIMENT ON 4TH LPT DISK: SIGNAL-TO-NOISE RATIO VERSUS SEPARATION ANGLE (DEGREES) BETWEEN NOTCH AND COIL CENTER

There is one very important point to make which can be observed from this data. When the differential coils are scanning in a direction parallel to the segment connecting the center points of each coil, and a notch is encountered which is perpendicular to the scan direction, for small notches, there is minimum in the probe response when the coil path crosses directly over the center of the notch. In this situation (radial notches), there is a maxima on either side (in a direction normal to the scan direction). In the case where the notch is oriented parallel to the scan direction (circumferential notches), the maximum occurs when the coil path crosses directly over the notch center. The result is that to insure complete coverage of this radius and similar radii, the coil placement and number of probes should be chosen such that there is a 50% overlap of the angles that successive coils subtend. This of course multiplies the number of probes.

CAPABILITY TESTS

To test the capability of the system requires an extensive set of specimens of various geometries containing flaws of an assortment of dimensions. During the development of the RFC system many tests have been conducted along this line. Most of these tests have, of necessity, been on specimens with EDM notches. In these cases, often, a feeling for the capability of the system can be derived from the coverage tests. When the opportunity arises, real service flaws in engine parts are examined. This has been done for radial cooling holes in the 2nd HPT disk, and cooling holes in the 1-2 HPT spacer. Finally, as part of the RFC program, a series of specimens have been designed and fabricated by Pratt and Whitney, Garrett and G.E. These specimens are of selected geometries with fatigue cracks generated by three-point-bend cycling.

These specimens are a part of the RFC Reliability Tests to be conducted in part in the near future, and in full in approximately 6 months.

A limited number of these reliability specimens have been available for testing. These specimens are a part of the specimens used for optimizing the system and will not be used in any statistics. Tests have been conducted on a V-notch specimen, a scallop specimen and a bolthole specimen. Extensive tests have been conducted on a number of flat plate specimens including some from GE generated under another contract or program. Figure 3 gives the results from these tests; the data was unaveraged and the flaw sizes were given by the corresponding manufacturers. The results as given in the figure seem completely in accord with the expected capability of a conventional eddy current inspection.

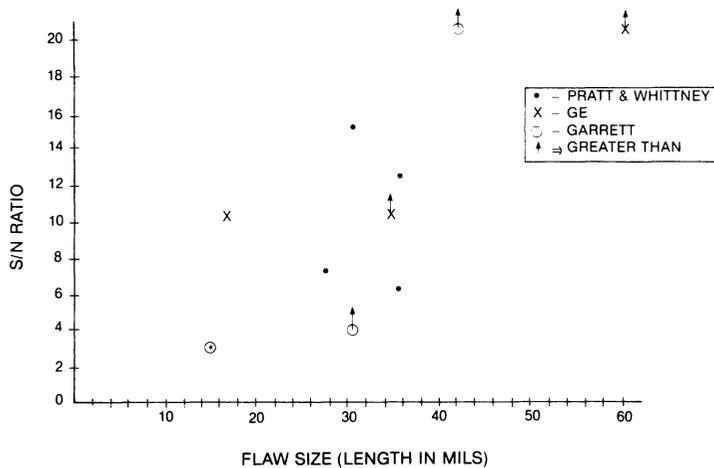


Figure 3. FLAT SURFACE RELIABILITY SPECIMENS: SIGNAL-TO-NOISE RATIO VERSUS FLAW LENGTH

In these experiments, when appropriate, the frequency of inspection was varied to optimize this parameter. One other observation is that in the case of the flat plate specimen from Pratt and Whitney it was observed that the flaw signal was very nearly horizontal. This fact coupled with the fact that as the probe would index across the flaw the response would change in phase, the peak amplitude recorded did not occur when there was a maximum probe response. This observation has led to the investigation of using the vector magnitude of the probe response in the impedance plane to determine the position of the peak response. Tests along this line continue.

COMPARISON TESTS

These tests include comparison of like probes from different manufacturers and like probes from the same manufacturer with different coil designs. Both types of test have been conducted. One such test has been a comparison of two different types of differential coils in three different probe configurations. The coil types are single-ended differential and double-ended differential. A single-ended differential

probe is one in which the two receive coils are wired in series, but wound opposite to each other so that when no flaw is present the voltage induced in each coil is opposite to that of the other; the subtraction is done at the coil. A double-ended differential coil is one in which the two receive coils are wired in parallel, the subtraction being done in the electronics away from the probe.

The three types of probe configurations are a type of rotary hole probe, and two different geometry compliance probes. In the case of the compliance probes the notches were surface notches on a flat surface, with dimensions of 0.010" x 0.009" x 0.003" (unreplicated) (1 x d x w). In the case of the rotating probe, the notches were bore notches in a hole with dimensions 0.010" x 0.009" x 0.003" (unreplicated) (1 x d x w). Table I summarizes the signal-to-noise ratio of the unaverage data. The LO was made horizontal.

Table I. COMPARISON OF TWO TYPES OF COILS

SERIES	SINGLE-ENDED ^(a)		DOUBLE-ENDED ^(a)	
	S/N	SENSITIVITY (V) ^(b)	S/N	SENSITIVITY (V) ^(b)
9 Compliance	9	0.5	42	2.4
33 Compliance	20	2.0	38	4.6
0.388 Bolt Hole	3	0.23	7	0.6

(a) Optimum Frequency

(b) Peak-to-Peak Voltage

As is easily seen in the table, the double-ended differential probes seem to out perform the single-ended differential probes. Each signal-to-noise ratio given is the best ratio determined by varying the frequency over a range of about 200 KHz and 2000 KHz. Because of these tests it has been decided to use double-ended differential coils in the RFC probes. This does not exclude the possibility of using absolute probes in selected geometries.

LIFT OFF IN DIFFERENTIAL PROBES

At this point it seems appropriate to discuss a phenomenon which has been observed in the course of the above tests. Since the RFC system will employ mostly differential probes, it is necessary to understand the lift off (LO) signal from a differential probe.

Under ideal circumstances - ideally balanced electrically differential probe, with no tilt - a differential probe will not have an LO response. In reality no differential probe is ideally balanced, nor is it possible to be free from all tilt. Consequently differential probes have an LO response. Tests have shown that the direction of this response in the impedance plane varies. The two parameters, imbalance and tilt, both play a role. For a given probe, implying a given imbalance the probe tilt can be adjusted to give LO responses varying in angle over approximately 180°, as shown in Figure 4. Apparently tilt may help to compensate for imbalance, but not totally.

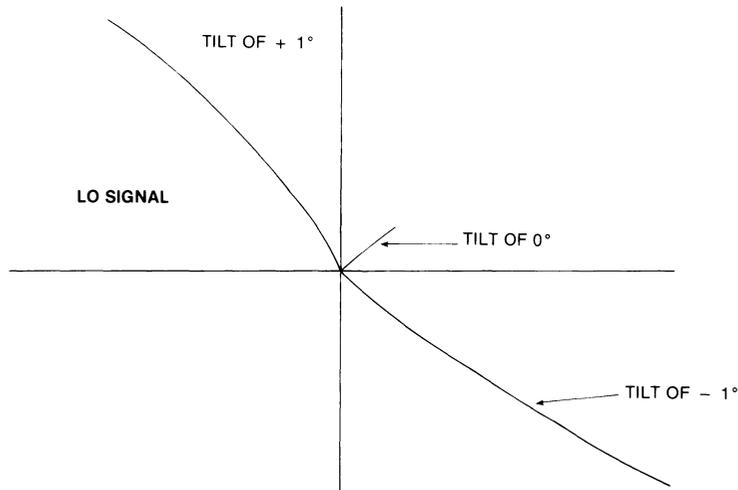


Figure 4. EXAMPLE OF IMPEDANCE PLANE LO RESPONSE OF DIFFERENTIAL EDDY CURRENT PROBE FOR DIFFERENT TILT ANGLES

The problem arises when the question is asked as to the direction of LO in a case such as this. This is essential for any sizing algorithm to be implemented in the future which uses the flaw signal phase angle relative to the LO phase angle. It is also crucial to producing repeatable detection results of an inspection. The solution to this problem is expected to arise from a capability developed for another reason, altogether. The present RFC eddy current inspection module has the ability to automatically select to receive an eddy current signal from only one of two receive coils in the differential probes provided the probe is a double-ended differential probe. In this case the probe can be temporarily made to be an absolute probe. The LO response can be determined from this condition and the probe automatically switched back to a differential probe. Testing on this algorithm is not complete.

SUMMARY

Many tests have been conducted under the RFC program to insure a reliable, repeatable inspection of the many different areas required to be inspected on the F100 Engine. These tests have included coverage, capability and comparison tests. The coverage tests have helped to define the limits of coverage of our inspection techniques, such as the radial cooling holes on the 2nd HPT disk. They have also helped to improve coverage by indicating areas of redesign of probes, such as the 4th LPT disk inner web radius.

The capability tests have helped to confirm to a limited degree, based mostly on EDM notch detection, but partly on fatigue crack specimens, that the capability of the RFC system is about what might be expected of a conventional eddy current inspection system. In qualitative terms, the detection of 0.010" x 0.005" (1 x d) flaws will be near the limit of the range of detectability. In difficult geometries the capability may be degraded.

Comparison tests have shown improved behavior in double-ended differential probes as opposed to single-ended differential probes. This will result in the use of mostly double-ended differential probes in the RFC system. But as pointed out, this has the additional advantage of aiding in the determination of the LO response phase angle. Other tests will continue in the above areas until the RFC system is finalized, and the full reliability test begins.