DETECTING FLAWS IN THE PRESENCE OF STRONG GEOMETRY SIGNALS

IN F100 GAS TURBINE ENGINE COMPONENTS

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INTRODUCTION

The inspection of F-100 gas turbine engine components using the Retirement For Cause (RFC) Eddy Current Inspection Station includes the requirement to scan three common but critical geometries: Antirotation windows (ARW), antirotation tangs (ART) and the live rim (LR) area at the component rim, as shown in Figures 1 and 2. These geometries have a common feature -- edges, as shown in Figure 3 -- that presents a challenge to successful inspection. The edges are sources of strong geometry signals that often have a higher amplitude than flaw signals, thus making a conventional amplitude inspection technique difficult. Therefore, a "frequency select" technique was developed which uses the frequency difference as a flaw determination criteria [1,2]. Using this technique, the RFC System has successfully detected both EDM notches and fatigue cracks in these geometries located in engine components fabricated of IN-100, waspaloy and titanium.

EXPERIMENT SET-UP

The frequency select technique was implemented on an RFC eddy current station with a NORTEC NDT-25L eddy current instrument and a double-ended differential coil probe. All data were collected, digitized, and analyzed in an Intel 86/380 microcomputer. Experiments consisted of execution of a typical inspection sequence, in which the engine disk or seal is mounted on the station's turntable, and the probe is coupled to the EC instrument via a rotary scanner attached to the mechanical manipulator. During a typical inspection, instrument phase and gain are calibrated using the probe and a calibration plate or block. During phase calibration the "wobble" signals on the impedance plane are rotated into a horizontal direction, and gain calibration ensures a proper gain setting.

For inspection of geometries with edges, the manipulator moves the probe to the part, and a dimensioning check routine is executed to locate the edge of the geometry on the engine disk. The edge of interest is the side of the geometry perpendicular to the rotation direction. Once the edge is found, the frequency select mode is executed on a group of ARW, ART or LR, depending upon the part being inspected. The data are acquired while the turntable is rotating, and analyzed while the scanner is
Figure 1. Location of antirotation windows on compressor seal.

Figure 2. Location of antirotation tangs and live rim on turbine disk.

indexing. This rotation-index pattern is executed repeatedly until the desired area in the geometry is completely scanned, as shown in Figure 3. This scanning pattern is critical to achieving reliable inspections since it is tolerant to dimensional variations among probes, probe positioning, engine components, and inspection stations.

TIME DOMAIN

In the frequency select mode each edge is treated as a unit when processing with the Fast Fourier Transform (FFT) routine. Thus, a time domain separation scheme is applied on the waveforms so that each small section of waveform corresponds to an edge. The number of geometries
encountered in a given inspection depends upon the particular seal or
disk, and each geometry may contain a different number of edges. For
example, an ARW may have only two edges, an ART has four edges, and the
LR has two edges on each of the more than 90 LRs typically situated
side-by-side around a disk. Data are analyzed one geometry at a time for
ARWs and ARTs, but for convenience, nine LRs (18 edges) are analyzed
together. Typical waveforms for ARWs, ARTs and LRs are shown in Figures
4, 5, 6, and 7. Initially, this time domain waveform separation scheme
was based on an experimentally determined parameter called "first index,"
which is the first minimum-amplitude index in the time domain waveform.
But, since the edge conditions of the geometry are not identical from seal
to seal or disk to disk -- and the instrument, scanner and probe may vary
slightly -- this pre-determined first index was not always consistent with
the actual first index of the waveform.

To compensate for this variation, a peak-detection subroutine was
developed. This subroutine is used to find the peaks and determine the
first index automatically. Once the first index is determined, the
separation of each time domain waveform is processed with the known
separation of edges and the waveform shape. Furthermore, a minimum­
amplitude searching subroutine is called during the separation of waveform
sections to ensure no sharp drop occurs at either end, thus minimizing
any uncertainty in the frequency calculation.

FREQUENCY DOMAIN

Each small time domain data is processed with the FFT routine. To
save time without sacrificing accuracy in FFT processing, every fifth
point of time domain data is used. After both the vertical and horizontal
data are processed with the FFT routine, the mean frequency (rather than
the peak frequency) of the spectrum of each channel is calculated and
compared to a "frequency limit" parameter, which ensures that the signal
is not too small (this situation usually occurs after the probe has moved
away from the geometry and flaw area). After the frequency limit check,
Figure 4. Time domain waveforms from waspaloy ARW showing the second edge with a 0.050-in. x 0.035-in. (length x depth) EDM notch. Note that the geometry signals decrease gradually in the index direction, as the notch signals increase.

Figure 5. Time domain waveforms for titanium ART, showing first edge with a 0.015-in. x 0.015-in. (length x depth) EDM notch.
Figure 6. Time domain waveforms from IN-100 LR, showing four EDM notches with lengths of 0.015-in., 0.015-in., 0.005-in. and 0.010-in., on edges 5, 9, 10 and 11, respectively.

Figure 7. Time domain waveforms for two waspaloy ARW fatigue cracks, with lengths of 0.035-in. and 0.021-in. on the first and second edge, respectively.
the frequency difference is calculated. By definition, the frequency difference is the difference between the mean frequency of the horizontal channel and the mean frequency of the vertical channel. Figure 8 is an example of the frequency difference calculation for an edge. Tests showed that in ARW and ART inspections, the FFT process was so fast that the limiting factor of the inspection was the mechanical scan speed; in LR inspections, which involve larger quantities of data, the FFT process caused a slight delay in the inspection process. A recent upgrade of the computer system eliminated this delay problem.

When inspecting a flaw-free geometry, the frequency domain remains quite constant as the probe scans over the edge area. As the probe begins to move away from the edge, the frequency difference begins to decrease. As the probe moves further away, the signal frequency becomes so small as to be negligible for frequency difference calculation, as shown in Figure 9; note that the signal frequency at the last three indices are too low to allow frequency difference data to be calculated. When inspecting a flawed geometry, the presence of flaw in the edge area perturbs the frequency, producing a higher frequency difference compared to those at different index positions. As the probe moves further away from the edge, the presence of flaws usually results in a lower frequency difference, as shown in Figure 10.

To detect flaws in the presence of such strong geometry signals, two types of threshold techniques were developed -- absolute and relative. The absolute threshold technique is a comparison of the frequency difference at each index with the upper and lower bounds, as shown in Figure 9. The relative threshold technique is the comparison of the frequency difference variation along the index direction with a relative
Figure 9. Typical frequency difference plot from a flaw-free ARW edge, along the index direction.

Figure 10. Typical frequency difference plot from a flawed ARW edge along the index direction.

Figure 11. Four frequency difference plots from four waspaloy ARW edges.
SUMMARY

The "frequency select" technique was developed for detecting flaws in the presence of strong geometry signals in F100 gas turbine engine disks. This technique was implemented in the Retirement For Cause (RFC) Eddy Current Inspection Station for inspecting antirotation windows, antirotation tangs, and the live rim at the component rim area. This technique treats each geometry edge as a unit; it processes signals from both the vertical and horizontal channels of the impedance plane with a Fast Fourier Transform (FFT) routine, and calculates the mean frequency and frequency difference of both channels. Based on this frequency data, two threshold techniques (absolute and relative) are used for flaw determination.

Tests to date have shown that the frequency select technique can be used to reliably detect flaws (EDM notches and fatigue cracks) in IN-100, waspaloy, and titanium components that otherwise might remain hidden within the strong geometry signals caused by the antirotation windows, antirotation tangs, and the live rim.

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REFERENCES
