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PROGRESS ON CHARACTERIZATION OF COMPLEX SURFACE-BREAKING AND SUB-SURFACE DISCONTINUITIES USING EDDY CURRENT NONDESTRUCTIVE EVALUATION AND MODEL-BASED INVERSION

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ABSTRACT

For powder metallurgy nickel-based superalloys, non-metallic inclusions (NMIs) and non-metallic particles are frequently present. If an EC inspection can reliably classify NMI indications from crack indications, there would be great payoff for the USAF. In this work, progress is presented on demonstrating the capability of eddy current inspection with model-based inversion to characterize complex surface-breaking and sub-surface discontinuities. A series of inversion studies were performed to investigate the sensitivity of the technique to varying probe and scan conditions. A number of complex discontinues were also manufactured to further challenge the inversion process. Lastly, both parametric model and emerging voxel-based inversion schemes were considered in the evaluation.

Keywords: eddy current, nondestructive evaluation, model-based inversion, non-metallic inclusions

NOMENCLATURE

EC	eddy current
NDE	nondestructive evaluation
NMI	non-metallic inclusion
NMP	non-metallic particle
ROI	region of interest
USAF	United States Air Force

1. INTRODUCTION

The use of eddy current (EC) nondestructive evaluation (NDE) techniques to detect damage in aircraft structures and propulsion components is a key part of United States Air Force programs to ensure that the risk of failures meets the desired requirements. Building on prior work on eddy current model-based inversion [1], recent progress has demonstrated the capability of characterizing surface breaking cracks and EDM notches of various sizes and aspect ratios under varying probe and scan conditions [2-4]. These results demonstrate advantages over a simple amplitude-based analysis of the data. However, not all eddy current indications in turbine engine component inspections originate from cracks. For powder metallurgy nickel-based superalloys, non-metallic inclusions (NMIs) and non-metallic particles (NMPs) are frequently present [5-6], which can result in the unnecessary removal of engine components from service. If an EC inspection can reliably discriminate NMI indications from crack indications, there would be significant payoff for the USAF. Building on recent work demonstrating feasibility of NMI classification and characterization [6-7], progress is presented on further demonstrating the capability of model-based inversion to characterize more complex surface-breaking and sub-surface discontinuities, under a greater range of probe and test conditions.

2. MATERIALS AND METHODS

2.1 Parametric and Voxel-Based Inversion

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The primary model-based inversion approach leveraged parametric models for three main classes of discontinuity: (a) surface breaking notch/crack, (b) a surface-breaking volumetric discontinuity, or (c) a sub-surface volumetric discontinuity such as an embedded NMI. Surrogate models were created for these three classes using simulated results from VIC-3D® with a D20 (outer diameter ~ 30 mils) probe 2D raster scan resolution of 51 x 64 μm (x and y). Surrogate models using fast interpolators were implemented to provide the means to improve the speed of the inverse methods. A nonlinear least-squares estimator (NLSE) was used to perform the general inversion process in conjunction with an iterative scheme to avoid local minima [1]. Additional information on the inversion scheme addressing crack/notch planar discontinuities can be found in [4]. More details on parametric surrogate models addressing planar and volumetric discontinuities are presented in [6-7].

As an alternative to parametric inversion, voxel-based inversion addresses a class of algorithm where each voxel of the anomaly is to be reconstructed in 3D. There is no a priori assumption as to the shape of the anomaly, as distinct from the idea of model-based inversion, which assumes that the anomaly can be modeled as one or more canonical shapes. By invoking the 'Born approximation,' total electric field within the anomaly is assumed to be defined by the incident field, so that the only unknown is the anomalous current throughout the flaw region. Mathematically, this has the effect of linearizing the problem. Because this has the potential to be a very large system, the algebraic reconstruction technique (ART) is introduced.

2.2 Complex Discontinuities for Challenge Testing

Recent work is presented on attempts to grow fatigue cracks from shallow NMIs, building on prior work [5]. With respect to previous demonstrations, there has been more difficulty in growing cracks from the very shallow discovered NMIs. One issue has been the residual stress state of the specimen. An initial test sample fractured away from the ROI without nucleating any cracking near the NMI. However, a second specimen is being testing and a heat-treatment was applied to reduce the residual stress effect. A possible grown crack indication in the neighborhood of the NMI is shown in Figure 1.

To evaluate inversion capability for sub-surface discontinuities, spark plasma sintering (SPS) was used to create test specimens with NMIs embedded under a thin (500 μm) Waspaloy top sheet. Five alumina particles were placed within a layer of Waspaloy powder between the top sheet and the 6.3 mm bottom plate. Samples used both spherical alumina milling media, with an average size of ~300 μm, and some alumina particles with varying aspect ratios.

3. RESULTS AND DISCUSSION

A primary focus of this work is to demonstrate and verify model-based inversion performance using eddy current NDE under varying probe states and test conditions. An adjustable 'normality probe' was designed to facilitate these sensitivity studies. The tip of probe will enable running scans with the D20 probe tilted in multiple directions. Repeated eddy current tests with different probe tilts will test the reliability of the technique when there are varying probe characteristics. Studies were also performed using a number of different D20 probes, at both 2 MHz and 6 MHz. As well, a number of supplemental specimens including EDM notches with known sizes will be used to evaluate the repeatability of the technique. Lastly, the complex discontinuities will be inspected using different probe states with varying amounts of surface material removed.

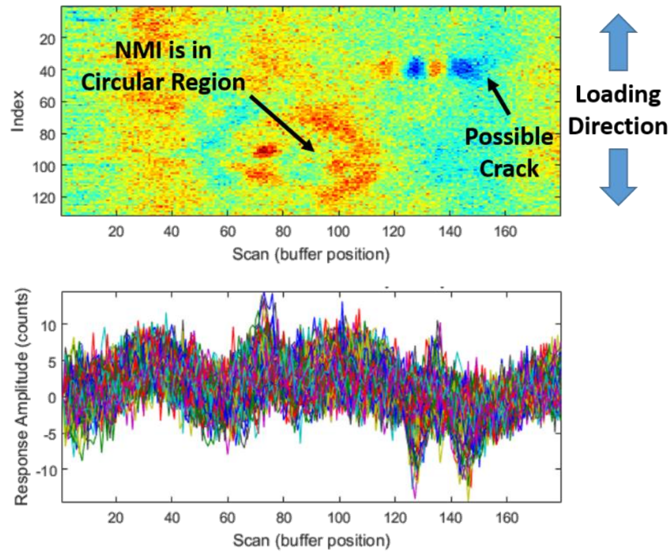

FIGURE 1: LIKELY GROWN CRACK INDICATION IN NEIGHBORHOOD OF NMI RESPONSE.

4. CONCLUSION

In this work, progress was presented on the demonstrating the capability of eddy current inspection with model-based inversion for characterization of complex surface-breaking and sub-surface discontinuities. A series of test studies were used to demonstrate the potential of the inversion scheme for classification and sizing of both cracks and NMIs of varying depth. These results indicate the promise for EC inversion to distinguish shallow NMIs and sub-surface NMIs from surface-breaking cracks. Continued work is planned for growing fatigue cracks from shallow NMIs and also an embedded NMI specimen.

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