Automated Eddy Current Inspections of Complex, Irregular Surfaces

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Background

• Wyle’s 7-axis Eddy Current Inspection System (ECIS) is used by the USAF and allied nations to inspect military engine components for:
  – Small surface cracks
  – Machining-induced surface anomalies

• Fully automated – operator loads the part and necessary probes, enters part number identification information, and presses start

• All steps of the inspection are independent of the operator:
  – Instrument setup / standardization of sensitivity
  – Part scanning and data collection
  – Data analysis
  – Data archiving
  – Accept / Reject of part
New Challenge

• Most geometries can be programmed using a few simple equation-based axis movements

• Most engine components have tight dimensional tolerances

• Recent more complex geometries require:
  – up to 6 coordinated axes
  – probes with an automated indexing axis

• Attention is required to ensure:
  – Probe stays normal and in contact during inspection
  – Sufficient coverage with the expected flaw sensitivity
Overview

An inspection development method was created to automate robot manipulation programming and inspection of complex surfaces:

- Scan contours mapped from solid model of part
- Part coordinate data are extracted to text files
- Automated creation of scan plan software
- Recent ECIS hardware/software improvements allow inspection of complex regions and shapes
- Results in an easier implementation for high resolution scanning of complex surfaces
Example Inspection Area

- Cylindrical feature that is askew from the conical OD
- Must inspect the non-uniform fillet radius and around the base of the fillet
- Not easily defined by Cartesian coordinate equations
- Many possible ways to transform scanning into machine axes
Approach

1. Define scans in the 3D solid model cad file
2. Extract scan coordinates to a massive text file
3. Parse the file to obtain part local coordinates
4. Matlab-based development program:
   - analyzes and organizes the scan points
   - calculates machine coordinates based on the specific probe dimensions
   - creates CNC commands and ECIS code to control the probe scanning and inspection processing
Scan Definition

- 3D solid model of the part is used to define scan coordinates that cover the requirement area
- Unigraphics NX6 with Advanced Designer Bundle
Scan Definition Procedure

- Extract isocline curves at the required index spacing
- Each isocline curve is defined by the fixed probe tip angle and probe body axis angle
Scan Definition Procedure

- Abnormal ovoid curve isocline created near base of the fillet
- This fillet angle is small enough angle that the compliance of the shoe will keep it normal to the surface
- Abnormal cluster is removed
Scan Definition Procedure

- Continue scan curves by offsetting by the index distance to encompass the required inspection surface area.
- The probe and sensor are aligned normal to the part side wall.
Scan Definition Procedure

• Local working coordinate system is created for the feature
• Coordinate system origin is located at bottom center of the part
• Z-axis is aligned to the part axis of rotation
• X-axis is aligned along the axis of the desired feature
Scan Definition Procedure

• Create point sets along each curve at a specified incremental arc length
• These points are then queried for their locations with respect to the working coordinate system
• Results in a large text file with a lot of needless data
Raw Output File

- As an example, there are 24,562 coordinate points for this feature.

A lot of extra information is included (most already deleted here).

A search for XC, YC, ZC gives needed data.
Part Scan Coordinates

• The output file is parsed and re-organized into individual scans
  – Minimize the number of simultaneous scanning axes
  – Keep the sensor normal to the part

• This geometry requires 4 axes to scan and 4 additional axes (including one on the probe) to index between scans and geometries
Machine Scan Coordinates

• Part coordinates must be transformed into machine coordinates
• Account for the probe dimensions and variable tip angle
• Specify active and inactive axes
Inspection Probe and Sensor

- Probe has a small footprint with an adjustable angle shoe to match the isoclines as extracted from the solid model.
- The probe tip angle can be adjusted between scans but not while scanning.
- A split D differential reflection sensor is used to minimize environmental and geometrical signals while providing sensitivity to small surface cracks.
Inspection

• The tip angle and probe axis angle is incremented each scan to keep coil normal to surface
Inspection Results

• A notched feature was inspected, resulting in a somewhat confusing set of eddy current “A-scans” or scan buffers of varying lengths:
Inspection Data C-scan

- An easier visualization of the data would be a transformed rectangular C-scan plotted in degrees to align radial features.
Data Processing

- Filtering is performed to improve the flaw S:N ratio and suppress geometry-related signals.
- Analog HP filter is applied to avoid DC saturation of the digital signal sampler.
- A filter similar to a rectifying bandpass is applied prior to signal thresholding for flaw detection.
Data Visualization

• A polar 3D plotting tool has been created to view the data in a more intuitive display
• Allows easy identification of location of indications
Data Visualization (3D)

• With registration of the inspection data into part coordinates, the data can be plotted on a solid model.

• The inspection data can provide feedback on:
  - machining issues
  - lifing model
  - potential crack initiation sites
Future Application

• Some geometries may have large dimensional tolerances, yet require inspection for small surface defects or cracks
  – IBR / Blisk blade repairs, for example

• In this case, we could use the presented algorithm to generate automated scan patterns from CMM data, obtained on the ECIS or from customer-supplied data

• The inspection scanning would be automatically customized to the dimensions of each specific part
Data Presentation

• As the collection of data becomes more complex, there is an increasing need for tools to display, process, and analyze the data more intuitively

• With the permanent digital record of inspection data, many new capabilities are enabled
ECView Program

• New Matlab-based program created for:
  – Data Visualization, Manipulation, and Analysis
  – Inspection Development and Debugging
  – Displaying Data on CAD Models
  – Performing Signal Measurements and Analysis
  – Flaw Characterization
  – Offline Signal Processing and Algorithm Development
  – Virtual Re-Inspection of Archived Data

• Comprehensive capabilities for importing and exporting of data or images into common formats
  – Images (.png, .jpg, .bmp, .tif, .pdf)
  – Data (.csv, .txt, .prn, .mat)
  – Customer-driven automated flaw reports
ECview – Visualization

- Movable pointer
- Movable zoom window
- Polar plotting of surfaces
ECview – Development/Debugging

- Coverage Verification
- Signal Processing
  Algorithm Development

S:N = 0.3
S:N = 3.1
ECview – 3D Plotting

- Plotting of data on solid part models
- Could be used with FEA models
- Helps visualize machining issues
ECview – Measurements

- Signal Statistics
- Linear Distance
- Frequency
- Signal to Noise
ECview – Signal Processing

• Hardware/software frequency filter simulation
• Replication of ECIS-proprietary filters
• Platform for new signal processing development
ECview – Virtual Re-Inspection

- Capability to re-process archived raw inspection data while effectively changing:
  - calibration characteristics (notch values, phase rotation, processing)
  - inspection threshold / flaw size requirements
  - signal processing algorithms
- Enables retroactive requirement changes
- Enables more efficient algorithm development
  - collect once, then optimize processing
- Easily modified for various re-inspection goals

Max indication: 137  Max size: 0.0044

Peak = 136.9  Peak/Peak = 136.9
ECview – Input / Output

• Input Options:
  – All ECIS raw data files (.prn)
  – Delimited text files (.csv, .txt)
  – Matlab files (.mat)
  – Binary ECIS database files (.dat, .#)
  – Aerotech Nscope files (.nsc)

• Output Options:
  – Delimited text files
  – Excel workbook
  – Matlab files
  – Image files (.png, .jpg, .bmp, .tif, .pdf)
Summary

• A generalized inspection routine has been developed to inspect along curves defined in a 3D solid model.
• The approach has been validated on complex fillets.
• A new postprocessing / data visualization program has been developed that will allow for further indication characterization.
Questions?

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