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Procedure for Automated Eddy Current Crack Detection in Thin Titanium Plates

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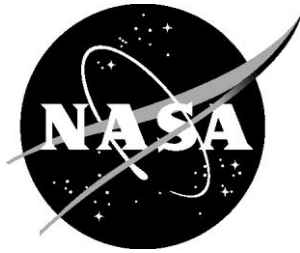
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Procedure for Automated Eddy Current Crack Detection in Thin Titanium Plates

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1.0 Purpose

1.1 This procedure provides the detailed instructions for conducting Eddy Current (EC) inspections of thin (5-30 mils) titanium membranes with thickness and material properties typical of the development of Ultra-Lightweight Diaphragm Tanks Technology (ULTT). The inspection focuses on the detection of part-through, surface breaking fatigue cracks with depths between approximately 0.002" and 0.007" and aspect ratios (a/c) of 0.2-1.0 using an automated eddy current scanning and image processing technique.

2.0 Scope

- 2.1 This procedure is applicable to the inspection of thin titanium membranes at NASA Langley Research Center. The procedure may be implemented at other locations as per discretion of the ULTT Development Team.
- 2.2 Where the procedure allows for equivalent processes or equipment to be used, the ULTT Development Team must review those processes and/or equipment. Any equivalency determination and rationale for allowance of use shall be documented.

3.0 Personnel

- 3.1 Only personnel qualified and certified as Level II or higher in Eddy Current Method of inspection per the requirements of NAS-410 or ASNT-SNT-TC-1A shall perform this inspection. Personnel qualified and certified to Level II or Level III, per the requirements of NAS-410 or ASNT-SNT-TC-1A shall make accept/reject decisions per the requirements of this procedure. Additional training specific to the automated eddy current scanning and data analysis shall be documented as part of the qualifications for Level II and Level III personnel conducting these exams. Any deviation from these personnel requirements must be reviewed and accepted by the ULTT Development Team.
- 3.2 All personnel performing this inspection shall demonstrate a working knowledge of crack detection using an MIZ-27 SI or equivalent impedance plane eddy current instrument.

4.0 Equipment

- 4.1 The following equipment or equivalent is required to perform this procedure.
- 4.2 Any substitutions to the equipment list shall require review and approval by the ULTT Development Team.
 - 4.2.1 MIZ-27-SI Eddy Current Impedance Plane Instrument
 - 4.2.2 Uniwest ETC-2446 3-6 MHz Swivel Probe
 - 4.2.3 Spring loaded probe carrier ensuring constant force contact between probe face and sample under test
 - 4.2.4 National Instruments USB-6259 Multifunction Data Acquisition Device
 - 4.2.5 Compumotor model 4000 Stepper Motor Controller
 - 4.2.6 Minimum two-axis stepper motor controlled scanning table with minimum 0.010" position accuracy
 - 4.2.7 Desktop computer with motion control and data acquisition software
 - 4.2.8 Data analysis computer with data analysis software
 - 4.2.9 Calibration sample with known defect

5.0 System Configuration

- 5.1 Position the sample under test on the scanning table, ensuring no potential obstructions exist between the sample surface and the probe scan path.
- 5.2 Place a thin nonconductive protective tape, not to exceed .0025 inch thickness, on the probe face. Inspect the tape between all scans and replace at the first sign of wear.
- 5.3 Mount the ETC-2446 probe in the probe carrier and position the probe on the sample under test. Ensure the probe face sits with the eddy current coils normal to the sample surface. The probe should be rotated such that split between the two coils is parallel (perpendicular) to the anticipated crack growth direction (high stress direction). Figure 1 displays an image of the probe face showing the coil dimensions and the split between the differential pickup coils.
- 5.4 Connect the probe to the MIZ-27-SI eddy current instrument. Use probe and cable adapters as required.
- 5.5 Connect analog outputs 1-8 of MIZ-27-SI to NI 6259 DAQ device.
- 5.6 Configure the MIZ-27-SI in Differential Driver Pickup (DD-a) mode; 500 samples/sec; Average on 16; 20dB Driver Pickup Gain. Configure each channel as per the following table:

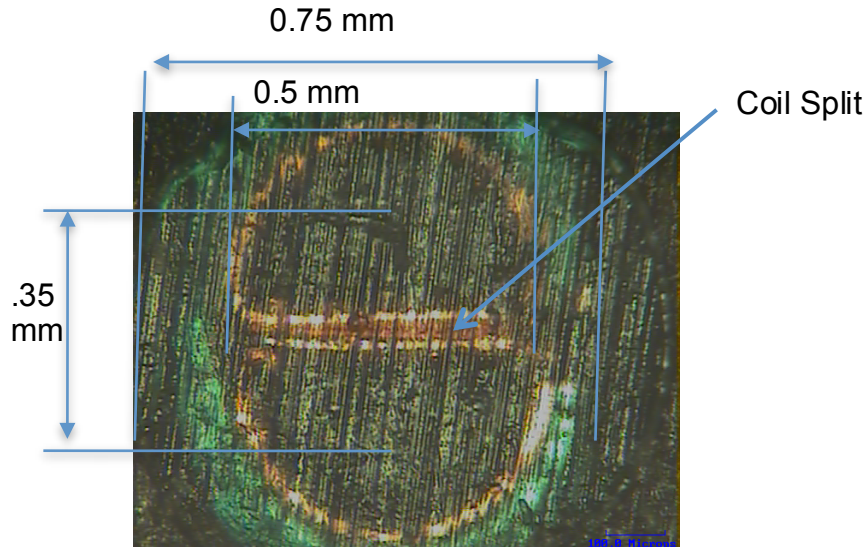


Figure 1. Image of probe face of the ETC-2446 probe showing split between the differential pick-up coils.

Table 1: Eddy Current Configuration for Crack Detection in Thin Titanium Plates

Channel Number	Drive Frequency (MHz)	Drive Voltage (V)	Gain (db)	Rotation Angle (deg)
Ch1	1	12	40	23
Ch2	2	5	40	322
Ch3	4	2	40	213
Ch4	5	1	40	116

5.7 Configure the MIZ-27-SI analog outputs as per the following table:

Table 2: Analog Output Configuration for MIZ-27-SI Eddy Current Instrument

Analog Outputs	Channel	Multiplier	Screen Equivalent
1-2 H-V	1	1	+/- 10 volts
3-4 H-V	2	1	+/- 10 volts
5-6 H-V	4	1	+/- 10 volts
7-8 H-V	5	1	+/- 10 volts

5.8 Under motion control, move the probe to a central area of sample and null all channels.

6.0 System Calibration

6.1 Rotation Angle Calibration

6.1.1 Under motion control, scan the probe over the calibration defect and note probe response. If probe response is not vertical adjust rotation angle such that all channels produce a vertical response similar to that shown in Figure 2.

6.2 Calibration Scan

6.2.1 Under motion control, perform a pre-scan of the sample edges to check for obstructions and to ensure consistent contact between the probe and the sample under test.

6.2.2 Position the probe at the start position of the scan.

6.2.3 Adjust the scan control software to acquire data at a scan speed no greater than 1.5"/second and a sampling distance no greater than 0.010"/sample. Configure the scan control software for unidirectional scanning during data acquisition in order to minimize hysteresis in data due to scan direction effects.

6.3 Perform a two-dimensional scan over the calibration defect and save the probe response on all channels.

6.4 Calibration Data Analysis

6.4.1 Perform data analysis on C-Scan images developed from the eddy current vertical channel amplitude versus (x,y) position. Figure 3 displays a plot of the raw C-Scan data for the calibration flaw in calibration sample number 19.

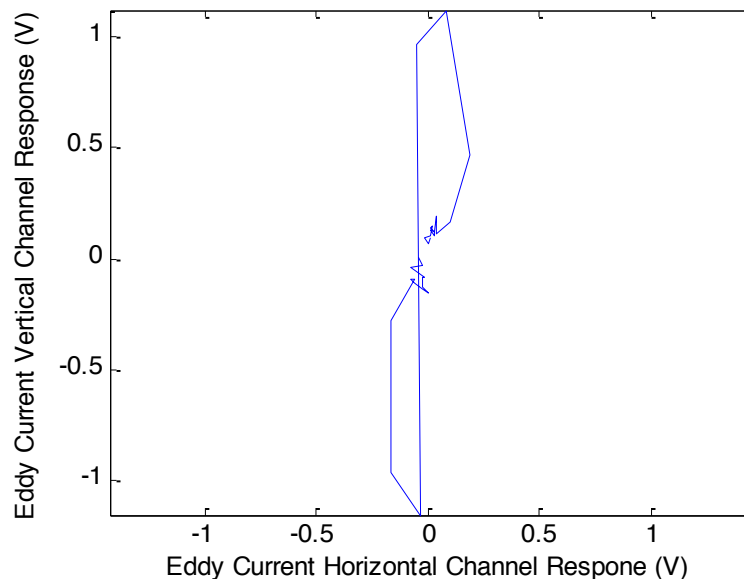


Figure 2. Probe response for scan over calibration flaw in calibration sample 19 at 4 MHz drive frequency.

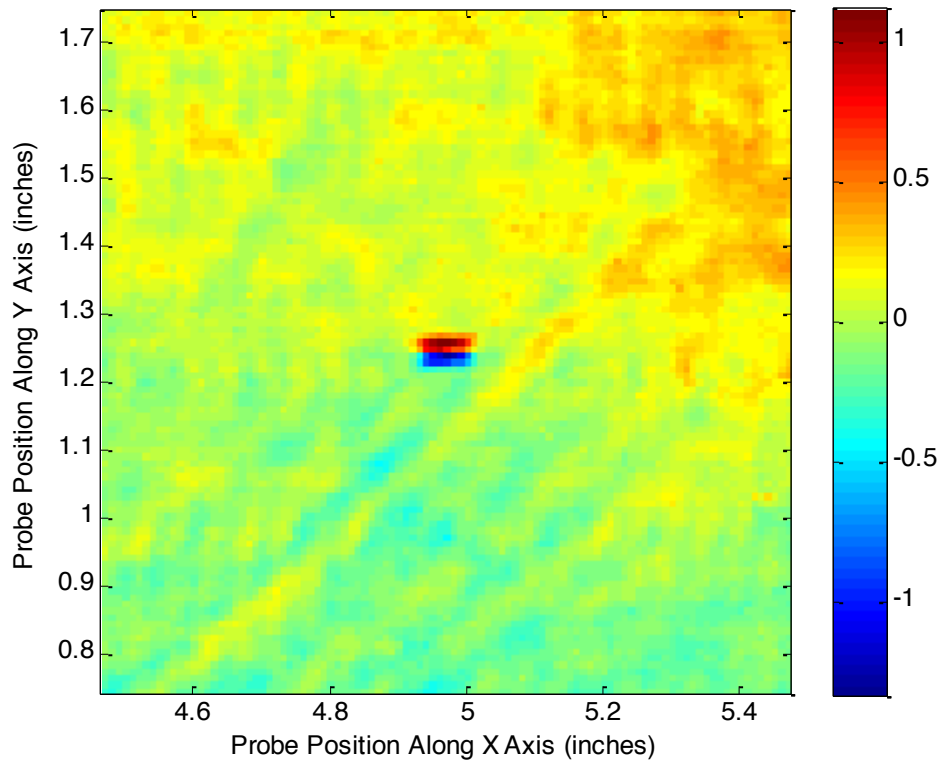


Figure 3. Eddy current vertical channel C-Scan data for calibration flow in calibration sample 19 at 4 MHz drive frequency. Color axis unit is volts.

6.4.2 Signal processing of the C-Scan image may be applied to enhance contrast in the flaw response. In particular, the flaw response can be significantly enhanced by the application of a differential filter in the direction perpendicular to the coil split of the eddy current probe. Additional processing such as interpolation of data between acquired data points and background subtraction may also be applied as required.

6.4.2.1 Standard data processing includes application of a differential filter perpendicular to the coil split direction and one point interpolation of data between acquired data points.

6.4.2.1.1 Differential filtering is performed by shifting data array a distance of 0.020" (approximate coil spacing of ETC-2446 probe) and then subtracting shifted array from original data.

6.4.2.1.2 Data interpolation is performed using a linear interpolation between every two nearest neighbor data points to define the amplitude of a new data point equidistant from the two neighbors.

6.4.2.2 Figure 4 displays an image of the processed vertical channel C-Scan at 4 MHz for sample number 19 (raw C-Scan data displayed in Figure 3) following the procedure of section 6.4.2.1.

7.0 Analysis and Sizing of Calibration Flaw

7.1 Following the data processing of section 6.4.2.1 crack analysis and sizing may be performed. Automated crack detection and sizing is based upon the amplitude of the processed vertical channel C-Scan as shown in Figure 4.

7.2 A threshold indication is set in the automated crack detection routine.

7.2.1 The noise floor in the data is defined as 3x the standard deviation of the processed signal level (from section 6.4.2.1) on an unflawed sample (or away from a defect in a flawed sample). Using this definition calibration studies at NASA LaRC found the noise floor at 4 MHz to be 0.225 Volts.

7.2.2 The indication threshold is then defined as 3x the noise floor for the system. Using this definition calibration studies at NASA LaRC defined the indication threshold to be 0.675 Volts for 4 MHz drive frequency.

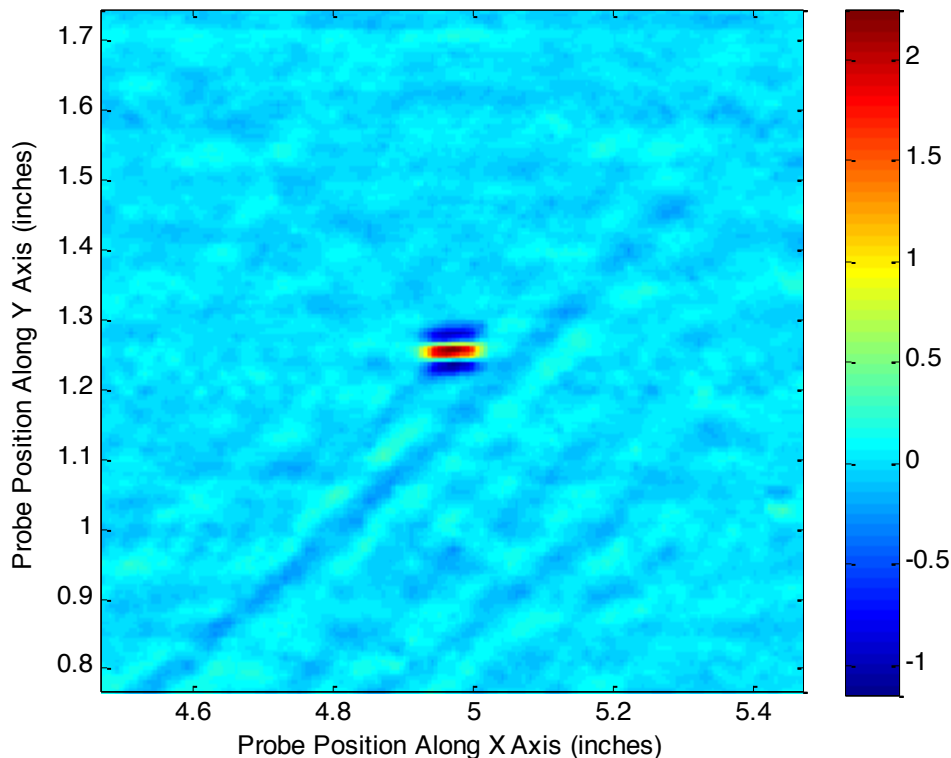


Figure 4. Processed C-Scan data for calibration flaw in calibration sample 19 at 4 MHz drive frequency. Color axis unit is volts.

7.3 The processed C-Scan data (as per section 6.4.2.1) is compared to the indication threshold to perform automated crack detection and sizing. All pixels above the threshold are set to unity while all pixels below the threshold are set to zero.

7.3.1 The crack length is calculated as the positional difference between the nonzero pixels with the largest and smallest positions.

7.3.2 The crack depth is calculated based upon the peak indication strength. Figure 5 displays a plot of the 4 MHz peak indication for the C-Scan data processed as per section 6.4.2.1 for a series of fatigue crack panels. The crack depths of these panels have been estimated by the vendor based upon measured surface crack lengths during processing (Engineering Materials Laboratory (EML) Report Nos. 1008-10, 1103-9, and 1107-4). The slope of the best fit to the data is inverted to calculate the predicted crack depth from the eddy current response.

7.4 A C-Scan plot of the threshold data can be generated for automated flaw detection. The plot can also be annotated with measured crack length and depth as per section 7.3. Figure 6 displays a C-Scan plot of the automated crack detection and sizing for sample number 19.

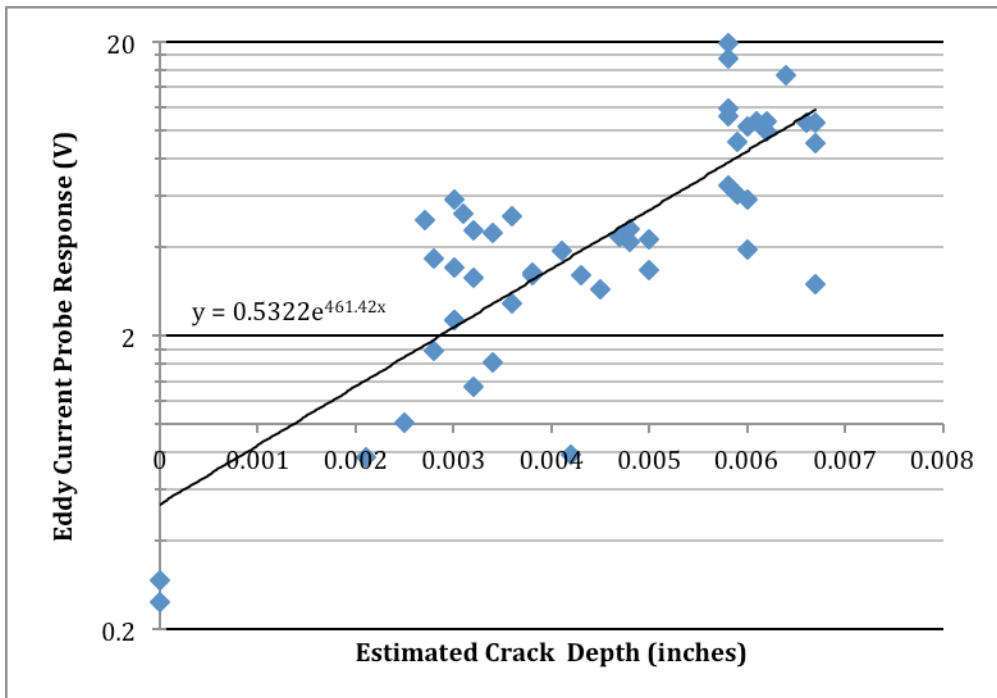


Figure 5. Eddy Current response versus estimated crack depth for 4.0 MHz inspection frequency.

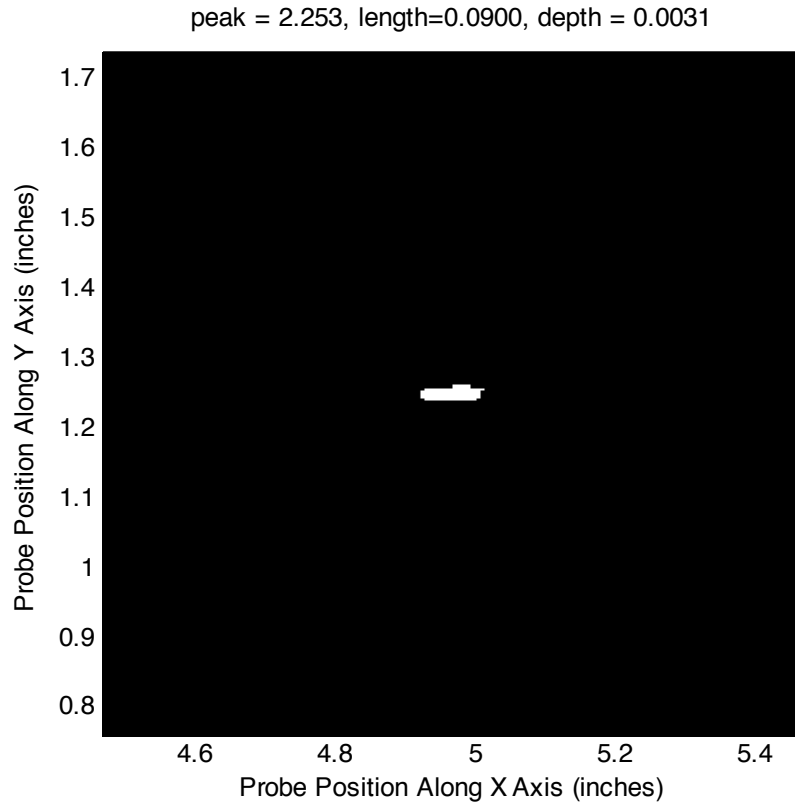


Figure 6. Automated crack detection and sizing for calibration flaw in sample 19 at 4 MHz drive frequency.

7.5 Upon successful calibration and sizing of the calibration flaw the system configuration shall be noted and held constant during inspection of samples under test.

8.0 Inspection of Samples Under Test

- 8.1 Following successful calibration, inspection of the sample under test may be performed.
- 8.2 Any deviations from the system configuration shown in Table 1 shall be documented in a notes file attached to inspection data.
- 8.3 Position the sample under test on the scanning table, ensuring no potential obstruction exists between the sample surface and the probe scan path.
- 8.4 Inspect the protective tape on the probe face and replace if any signs of wear are present.
- 8.5 Position the ETC-2446 probe on the sample under test. Ensure the probe face sits with the eddy current coils normal to the sample surface. The probe should be rotated such that split between the two coils is parallel (perpendicular) to the anticipated crack growth direction (high stress direction).

- 8.6 Under motion control, perform a pre-scan of the sample edges to check for obstructions and to ensure consistent contact between the probe and the sample under test.
- 8.7 Under motion control, move the probe to an area of sample away from any edges and null all channels.

- 8.8 Position the probe at the start position of scan.
- 8.9 Configure the scan control software to cover the entire inspection area. Maintain scanning speed and sampling distance equal to the calibration scan as set in section 6.2.3.
- 8.10 Perform a two-dimensional scan over the sample under test and save probe response on all channels.

9.0 Data Analysis

- 9.1 Data analysis is performed using the data acquired and stored in section 8.
- 9.2 A data analysis computer is used to read in the stored data file. Data analysis software shall be able read the horizontal and vertical eddy current response from each eddy current channel (see tables 1 and 2) and display the recorded voltages as a function of probe position to generate C-Scan images. Figure 3 displays a plot of the unprocessed vertical channel C-Scan at 4 MHz for Sample number 19.
- 9.3 The unprocessed data may be filtered to improve the signal to noise ratio. Any applied filtering technique must be demonstrated on a calibration sample before being used for accept/reject decisions on an unknown sample under test.
 - 9.3.1 Standard data processing includes differential filter perpendicular to the coil split direction and one point interpolation of data between acquired data points.
 - 9.3.1.1 Differential filtering is performed by shifting data array a distance of 0.020" (approximate coil spacing of ETC-2446 probe) and then subtracting shifted array from original data.
 - 9.3.1.2 Data interpolation is performed using a linear interpolation between every two nearest neighbor data points to define the amplitude of a new data point equidistant from the two neighbors.
 - 9.3.2 Figure 4 displays an image of the processed vertical channel C-Scan at 4 MHz for Sample number 19 following the procedure of section 9.3.1
- 9.4 Indication analysis and sizing is performed based upon the amplitude of the vertical channel C-Scan data processed as per section 9.3.1.
- 9.5 Image thresholding may be applied using the indication threshold defined in section 7.2.
- 9.6 The processed data can be compared to the indication threshold to perform automated indication detection. All pixels above the threshold are set to unity while all pixels below the threshold are set to zero.

- 9.6.1 The preliminary indication length is calculated as the positional difference between the nonzero pixels with the largest and smallest positions.
- 9.6.2 The preliminary indication depth is calculated based upon the peak indication strength as discussed in section 7.3.2.
- 9.6.3 As more information becomes available on the eddy current amplitude versus actual crack depth the plot in Figure 5 should be updated to incorporate actual crack depth data. The inversion function for crack depth from measured eddy current response should likewise be updated at that time.
- 9.7 A C-Scan plot of the data after application of the indication threshold can be displayed for rapid visualization of any indications above threshold. Figure 6 displays such a plot for calibration sample number 19.
- 9.8 Further data analysis such as analyses of the eddy current lissajous signatures of the data should be performed to validate automatically detected indications. Such lissajous plots can be constructed by combining the horizontal and vertical eddy current amplitudes along a line crossing an indication.
- 9.9 The location, length, indication strength, and predicted depth of all indications shall be reported for the sample under test.
 - 9.9.1 The location of the scan start position as well as the orientation of the scan axes shall be noted on the part under test and recorded in an inspection report.
 - 9.9.2 The location of all indications shall be noted on the part under test.
 - 9.9.3 The distance of all indications in (x,y) coordinates from the start position shall be reported along with indication strength and length.
- 10.0 If it is necessary to screen for fatigue cracks in directions away from the primary crack growth direction, or if no primary direction exists, bi-directional scanning shall be required.
 - 10.1 Rotate probe 90 degrees such that split between the differential pickup coils is perpendicular to the direction defined in Section 8.5.
 - 10.2 Inspect the protective tape on the probe face and replace if any signs of wear are present.
 - 10.3 Position the ETC-2446 probe on the sample under test. Ensure the probe face sits with the eddy current coils normal to the sample surface.
 - 10.4 Acquired data as per sections 8.8 – 8.10.
 - 10.5 Analyze acquired data as per section 9. Report all indications as per section 9.9.

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