AUTOMATIC GENERATION AND EXECUTION OF EDDY CURRENT SCAN PLANS

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INTRODUCTION

Eddy current inspection is highly sensitive to the position of the probe relative to the component being scanned. Ensuring that the probe maintains a constant lift-off and remains perpendicular to the surface being scanned is very import to the scanning process, as the signal strength is best under the these constraints. Variations of tilt or lift-off during a scan can introduce large, spurious signals that may mask flaw indications. Earlier work on scan automation used the probe signal to control the lift-off variations so that a constant lift-off could be maintained over a non-planar surface[1]. The present study focuses on achieving probe perpendicularity and constant lift-off all through a given scan, to attain accurate and repeatable eddy current measurements.

Positioning the probe perpendicular to a given surface, especially if the part geometry is modeled as a second or higher order curve, is a non-trivial task. The presence of asymmetry in the geometry complicates the motion and positioning of the probe over the part. Thus, most probe motion and positioning programs are often developed and implemented to scan a particular geometry only. They often incorporate object geometry information peculiar to the scanned object. The above constraint results in the probe orientation becoming a function of object geometry. Further, the scan development time is dependent on object geometry and often increases with the complexity of the geometry. This hard coding results in loss of flexibility and prevents software reusability. Developing a systematic scanning mechanism that is independent of part geometry will clearly, improve the efficiency of the scanning process.

This paper describes the development of an automated eddy current (EC) scanning process and scan results on custom designed test pieces. The aim of the automation process has been to enhance the efficiency of the scanning procedure by developing in-house tools or utilizing already available commercial tools. A kinematics [2,3] based positioning algorithm, which lies at the core of the automation process, has been developed. It uses information from probe motion simulated in software and determines the exact motions of the probe and/or the part under scan and stores this information in a postprocessor file. The latter is used by hardware interface software to execute the actual real world scans. Results from scans conducted using this automated approach on sample test objects with embedded flaws (EDM notches), are presented.

EC TESTBED HARDWARE DESCRIPTION

The Eddy Current (EC) Test Bed Station serves as the hardware platform on which the scans are executed (Fig. 1). The EC Test Bed is built around a computer controlled measurement workstation, and was designed to achieve precise, repeatable EC measurements on parts with

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general 3D geometry. The EC Test Bed comprises of an eight axis scanning machine and an Impedance Analyzer which acquires the data from the probe. These two devices are controlled remotely via an IEEE 488 system. Utilizing the remote capabilities of the system helps in integration of disparate hardware into one integrated system. The two hardware components are described below.

The positioning hardware's function is to position the probe at the desired point on the surface being scanned. It comprises of two sets of four axis machines, providing the scanning system in all with eight degrees of freedom of motion. Each machine has translation capabilities along the three principal coordinate axis and a rotational capability about one of the axis (Fig. 1). The eddy current probe is mounted on one of the machines and the object (material being scanned) is mounted on the other. Each of the machines is controlled by an embedded controller capable of operating in stand alone or in remote mode. The remote mode uses a digital GPIB standard interface and is controlled by a dedicated computer.

The data acquisition hardware is an HP4194A Impedance/Gain Phase Analyzer™ which stores the measurement data from the eddy current probe and transmits the data to the controlling computer on demand. This instrument like the positioning software can be run under console or remote control mode. In the former mode the instrument can be programmed by softkeys. Remote control capability is provided via a HP-IB (IEEE 488 standard) bus system.

AUTOMATED EC SCANNING - OVERALL DESCRIPTION

This section describes a typical EC scanning cycle and describes the reduction in the development time cycle (without reducing accuracy) by the use of software tools. The Scanning process consists of three logical phases. This is shown in Fig. 2.

Phase 1

This phase is the scan-path visualization and scan generation phase. Here, the probe path on the object is first generated to the user's requirement. A commercial milling machine Computer-Aided Machining (CAM) package was chosen. For each probe position on the simulated scan path,

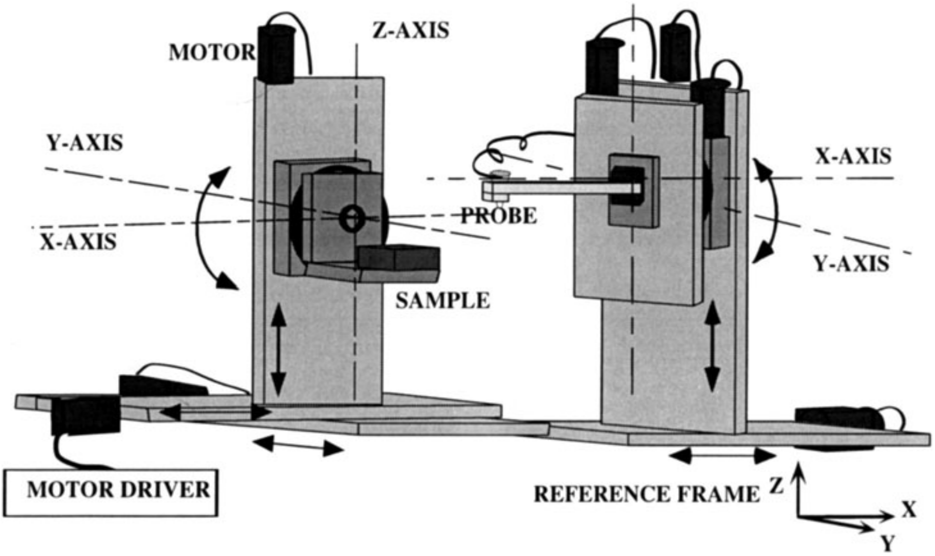

Fig. 1 Schematic of the scanning hardware.

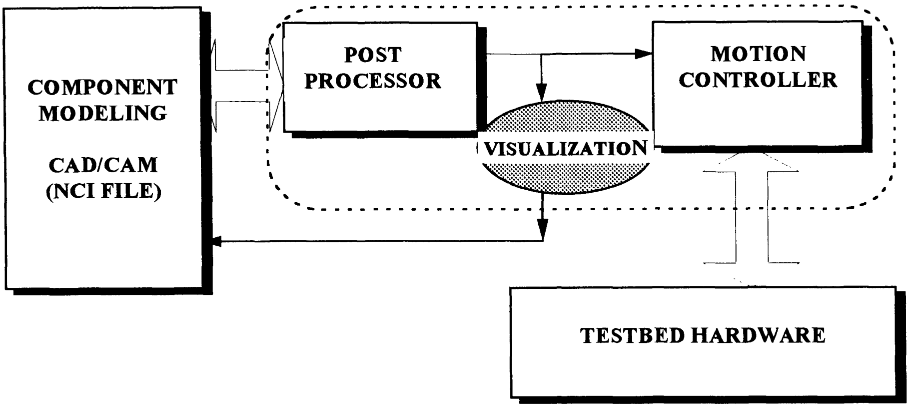

Fig. 2 Overview of the scanning process.

the software, provides two pairs of three coordinates which describe the probe in 3D (or $\Re^3$) space.[1] Visualization features provide user-friendly feedback and the optimum probe path can be generated quickly. Once the probe path is finalized in the CAM package, a postprocessor processes the scan path (which describes only probe positions) and then generates the exact motions (translations and rotations) of the probe and the object along the three principal axis. An overview of the postprocessor algorithm is presented in the next section.

Phase 2

This is the actual scan realization phase. This phase translates the visualized motion of the probe into actual physical motion. The scan is executed by the testbed hardware in remote mode under computer control. A hardware interface program reads the motion parameters generated by the postprocessor and communicates with the remote devices. The interface program is designed to read in the hardware configuration at run time. This feature allows the program to adapt to hardware modifications, thus providing flexibility and allowing for hardware reconfiguration. The interface program controls the individual motion segments that comprise a scan and coordinates data acquisition from the measuring unit. The data acquired is stored in a binary format (for storage efficiency) for post scan off-line analysis.

Phase 3

This is the post scan phase. In this phase the data acquired from the data acquisition unit is processed on the computer off line, after the scan is completed. This processing essentially subtracts the background signal and noise from the raw data set. The resulting impedance map will then more clearly reflect the presence of flaws. Typically a commercial data visualization and analysis package is used.

HARDWARE MODELING

This section gives an overview of the algorithm (implemented as the postprocessor), that interprets the CAM scan information and determines the individual motion components (rotations and translations). The postprocessor algorithm models the scanning hardware. The algorithm essentially determines how the next position of the probe is to be attained given "current" and

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[1] The CAM generates 6 coordinates for each tool position on the object.. These coordinates generated by the milling machine CAM package are perpendicular to the object's surface at that point. The perpendicularity of the probe is ensured by interpreting these coordinates as corresponding to the two ends of the probe.

"target" positions. It thus works on a pair of 6 coordinate information. This feature allows the algorithm to remain independent of the type of scan (raster scan, zigzag scans etc.). In those scans for which the probe requires rotation about more than one axis (say x and y axis), the algorithm transfers the rotation of the probe about one of its axis to the object, and then compensates the object rotation by appropriate probe translation. The only dependencies are that the probe scan paths generated by the CAM package be 5-axis scan paths and the probe shape be modeled as a vector in $\Re^3$ space. There are no inherent assumptions regarding the shape of the sample. The implementation of the algorithm required no modification to the existing hardware (Fig. 1). The algorithm was integrated into the testbed hardware and was tested on two custom designed aluminum blocks. The next section describes the experimental evaluation in more detail.

EXPERIMENTAL EVALUATION OF THE MOTION ALGORITHM

The goal of developing a scanning system that does not include any object geometry specific features, was tested by designing two test pieces with curved surfaces. The test pieces are shown below (Fig. 3 and Fig. 4). Two test pieces (aluminum blocks) were manufactured with one block having a uni-directional curvature and the other having a bi-directional curvature (Block 1 and Block 2 as shown in Fig. 3 and Fig. 4). On each of these blocks, three sets of EDM notches were machined. The dimensions of the notches were 40x20 mils, 20x10 mils and 10x5 mils. The detection of these EDM notches on the complex surfaces serves as a good test for the automation system.

TYPES OF SCAN

To test the scanning system three types of scans were conducted on the two blocks. The three types of scans are here classified as, Flat, No-tilt and Full scans. Each of these scan procedures is described below.

Flat scan

In the flat scan the probe scans the material surface in a flat plane over the material surface. In this scan the probe does not follow the object's surface contour. Hence, in this scan the air gap is non-uniform and varies greatly over the scan surface.

No-tilt scan

Here, the probe follows the surface, in the up-down direction as the scan progresses, but there is no attempt to orient the probe perpendicular to the material surface. Thus, the surface at a given scan point could be at a relative angle other than 90 degrees.

Full scan

In the third type of scan, the probe follows the object surface with its orientation perpendicular to the object's surface through the scan.

SCAN RESULTS AND EVALUATION

This section describes the scans conducted on the two test pieces and the data obtained from these scans.

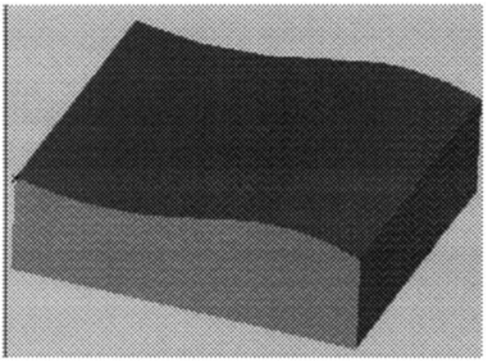

Fig. 3. Block 1--single curvature.

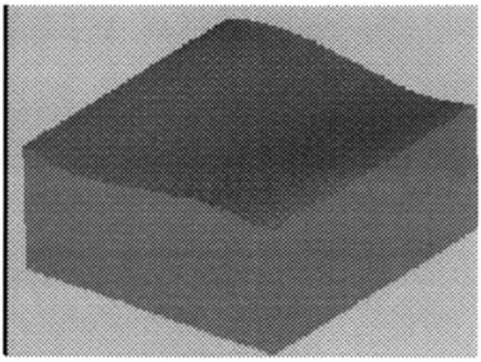

Fig. 4. Block 2--dual curvature.

Figures 5.1, 5.2 and 5.3 show the surface plots for Block 1. These provide three dimensional views of the impedance data as it varies over the surface of the object. Figure 5.1 and Fig. 5.2 show the impedance plot for a flat and no-tilt scan[2] respectively. As is seen from the plots the background surface in these two plots is not flat. The background signal presence is very clear in Fig. 5.1 where the lift-off variation is more drastic. In both cases, there exists a relative non-perpendicular orientation between the probe and the sample surface at the scan points (as the probe is not constrained to be perpendicular to the scan point).

Figure 5.3 shows the impedance plot for Block 1 with the probe perpendicular to the object surface. To orient the probe perpendicular to the curvature, the postprocessor program calculates the probe translation and rotation angles such that the probe is always perpendicular to the material surface at all the scan points. As is seen, the data from the scan reveals the EDM notches (40-mil and 20-mil long EDM notches) more clearly than the previous data (Fig. 5.1 and Fig. 5.2).

The next two plots (Fig. 6.1 and 6.2) pertain to the flat, no-tilt and full scan for Block 2. Comparing the two plots clearly demonstrates the effect of probe tilt. In this case, too, the background data hides the flaw data effectively. The relative probe-sample curvature non-perpendicularity is seen as a non-planar background. In Fig. 6.3, however, the probe is maintained at a perpendicular orientation to the object surface at all times and as expected, the background is a flat plane. In this case the signals from the notches are clearly visible-Even one of the 10-mil EDM notch signals (not seen in prior plots) is visible in Fig. 6.3.

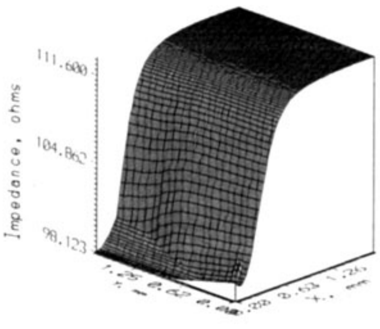

Fig. 5.1 Flat scan on Block 1.

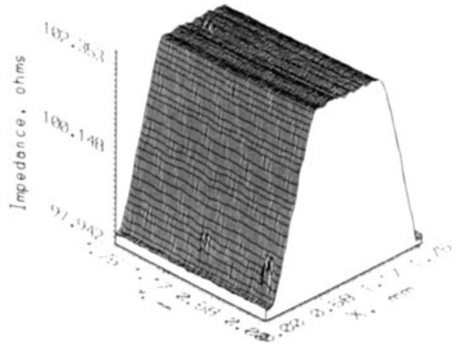

Fig. 5.2 No-tilt scan on Block 1.

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[2] The three types of scan have been described earlier

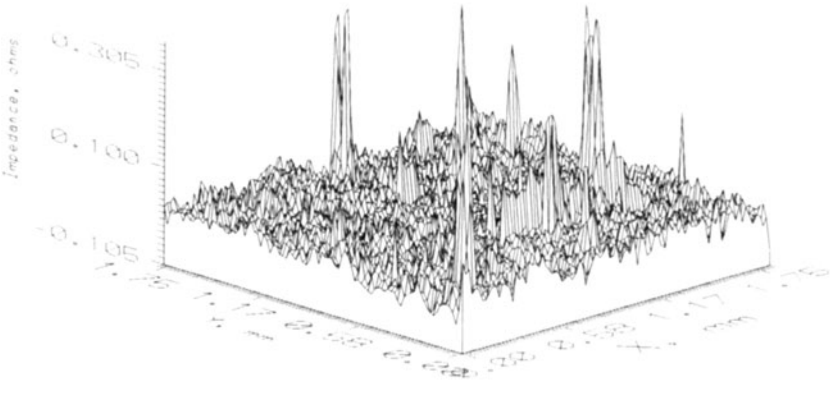

Fig. 5.3 Full scan on Block 1.

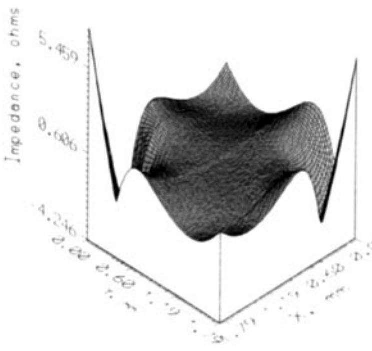

Fig. 6.1 Flat scan on Block 2.

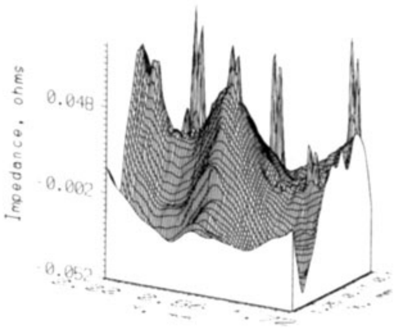

Fig. 6.2 No-tilt scan on Block 2.

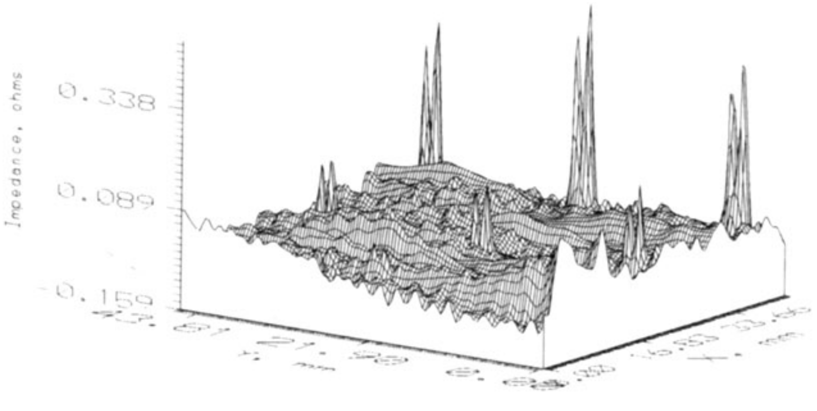

Fig. 6.3 Full scan on Block 2.

The effect of probe tilt on flaw data can be further illustrated by the two surface plots (Fig. 7.1 and 7.2). These two plots were of a small area scanned around the 40-mil EDM notch for Block 1. In Fig. 7.1 the surface was scanned with the probe in a flat plane. The effect of increasing lift-off (along the x axis) results in a non-planar background while in Fig. 7.2 the probe is positioned to be always perpendicular to the sample at the scan point. As is seen, the average signal variation in the latter case is less than 0.5 ohms. The EDM notches stand out clearly against the background signals.

SUMMARY

We have described the design of an automated scanning system and discussed the results from scans on two test pieces, designed in-house. The design of the two test blocks aimed at providing a general geometry which would be known to the scanning system at run time only. This last condition ensures that the software is generic enough to handle arbitrary 3D curves. The experimental results show that such a system can provide accurate scan data without the overhead of developing custom programs to handle specific geometry. Further, the effect of probe tilt on the flaw data was shown. The background effect, due to the tilt of the probe relative to the object's surface, hides the flaw signals and reduces the probability of detection. By ensuring that the probe scans the surface at right angles at all scan points, it was shown that even the 10-mil EDM notches on a complex curved surface could be detected.

This paper presents a systematic solution to speed up the eddy current scanning process. This automated system integrates inverse kinematics models, CAD/CAM and visualization techniques to build an efficient system that reduces the cycle development time without sacrificing the accuracy of measurements. Future work will incorporate real-time data visualization utilizing the multi-tasking features of modern operating systems, providing less turn around time and better utilization of resources. We intend to use commercial software tools to integrate the scanning process components, to realize the goal of an efficient and flexible automated scanning system.

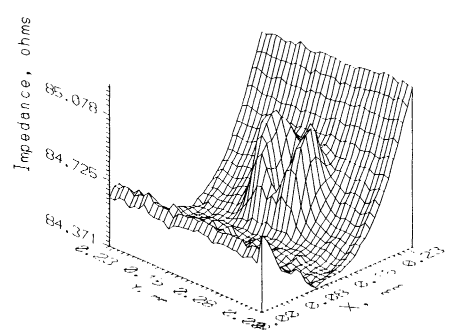

Fig. 7.1 Flat scan over 40 mil EDM notch.

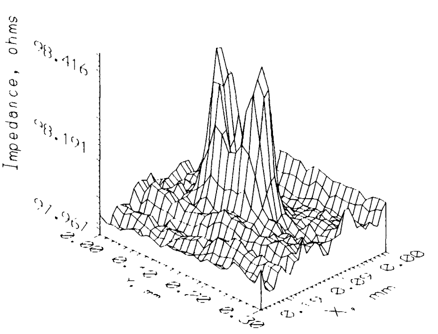

Fig. 7.2 Full scan over 40 mil EDM notch.

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