FAST PATTERN RECOGNITION METHOD FOR EDDY CURRENT TESTING

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INTRODUCTION

One of the benefits of eddy current (EC) testing is the attainability of high testing speeds while maintaining high sensitivity and requiring little with regard to material preparation. For this reason it is commonly automated and integrated in production lines of semi-finished products such as bars, tubes and wires. Because of the requirements of high throughput on-line digital analysis of EC signals is rarely applied, in contrast to ultrasonic testing. However, the usual methods of analog filtering and phase-selective or phase-insensitive threshold evaluation of EC signals are limited in regard to the suppression of false or pseudo-defect indications, classification of defect types, quantitative assessment of defect features and the suppression of signals originating from manmade structures.

When testing tube and bar products high sensitivity is required, which is equivalent to requiring a low quantity of pseudo-defects [1]. Additionally, defect classifications can be useful in drawing conclusions about the condition of a production line. In the automotive industry, the testing of components requires high sensitivity, as well as the ability to distinguish defects from component structures, such as openings or reinforcements. Similar requirements exist in aircraft maintenance testing. Here, quantitative determination and documentation of defect features is necessary for observations of defect propagation and determinations of critical stages of defects.

Our primary objective was to develop a digital analysis method that surmounts the limitations of analog evaluations stated above and is suitable as well for high speed testing of semi-finished products.
ANALYSIS METHOD

In order to accommodate different areas of application, which usually demand differences in the analysis system, we base our approach on software, even though dedicated processors would increase the processing speed. When limiting the digital signal sampling rate to a rather coarse 4-5 samples per characteristic probe width (base width, BW) we obtain raw data rates of typically 300 kb/sec at a data resolution of 8 bits, which is quite satisfactory in most cases.

Various authors have discussed signal classification schemes [2], flaw reconstruction methods [3,4], EC imaging methods [5,6] and associated factors [7]. Also a whole range of methods known from image processing [8,9] may be used. Particularly effective are binary operations, such as, in the simplest case, a threshold evaluation. While this approach leads to a relatively large loss of information regarding signal shape it permits one to include the areal extent of an object in the evaluation. This is not possible with methods such as frequency analysis.

Procedure

Our analysis approach, initially developed for signals from differential probes, is shown schematically in Fig. 1. The signal from the probe is filtered, presently still analog, then digitized and stored in a data array corresponding to the location of the probe on the surface to be tested. The resultant image is then searched for objects and their features and extent determined. The prior elimination of signals originating from structures, as described below, is only required if the test item contains manmade structures, such as openings, supports etc., and if these structures can contain defects. From the geometry of the objects we extract characteristic features using the binary image as well as the original data. Based upon these features, which now represent a reduced data set,
and optional additional parameters obtained from frequency analysis, we can classify the objects and separate defects from noise or pseudo-indications.

Object tracing

The presence and extent of an object in an image is determined by using two thresholds (Fig. 2). A signal crossing the upper or trigger threshold indicates the presence of an object and activates the tracking of the objects' edge using a tracking threshold. The latter is set 2 to 3 times lower than common thresholds, at about 2 to 3 times the noise level. Suppressing crossovers of the tracking threshold outside the object and connecting gaps smaller than 2 data samples results in closed, simply connected objects.

The scan of the inner surface of a hole drilled in aluminum, shown in Fig. 3a, displays signals from a simulated vertical crack which becomes shallow towards the bottom. Using standard threshold methods alone at best half of the cracks' total length can be determined (Fig. 3b). However, the object tracking algorithm recognizes the areal extent down to signal amplitudes of 1/3 of the threshold yielding almost the entire length (Fig. 3c).

This enhanced recognition of a defects' extent is a first step to higher sensitivity, which can be increased further by reducing the trigger threshold and eliminating

Fig. 2. Object tracing using a trigger and tracing thresholds to determine the extent of an object in an image.
Fig. 3. Evaluation of signals from a covered crack of decreasing depth in a hole drilled in aluminum: a) Original scan data, b) values above the trigger threshold, c) extent after object tracing, d) evaluated crack geometry.

the then occurring pseudo-defect indications by the following classification scheme.

Object classification

Once the extent of an object has been established characteristic features can be determined. The requirement again is, that these may be rapidly computed and that they apply generally. Empirical laboratory studies showed that satisfactory values regarding object length, width and orientation can be obtained from the signal extrema. Thus a peak-to-peak distance of less than 1.5*BW is indicative of a possible crack, while objects with widths larger than 1.5*BW indicate holes, voids or laps. Signals occurring on only one scan line are considered spurious noise and are excluded from evaluation. Fig. 3d shows the shape and orientation of the crack as obtained from the signal extrema in Fig. 3a and corrected for the base width of the probe.

The classification scheme was tested on natural and manmade defects. Fig. 4a displays the results from drilled holes, Fig. 4b from saw cuts. Using a probe with 1 mm BW, holes of 1 mm diameter could be well distinguished from 0.1 mm wide saw cuts and 1 mm long, 50 μm wide EDM notches, based on the above width criteria alone.

The object features used in our analysis and listed in Figure 4 are center position in polar coordinates (Z [cm], phi [deg]), mean and maximum signal amplitude (A_{\text{mean}}, A_{\text{max}}), mean and maximum object width (B_{\text{mean}}, B_{\text{max}} [cm]), object length (L [cm]) and orientation (\alpha [deg]) relative to the
The problem of crack orientation and covered cracks can be solved without major computational demands by using the orientation feature and the phase of the signal. To assess the problem of multiple cracks we evaluated notches of 1 to 10 mm width, shallow grooves of equal dimensions, and double saw cuts of 0.1 mm width and a separation of 1 to 10 mm in austenitic steel. The probes' BW was 1.5 mm. Cuts with less than 5 mm spacing could not be separately detected nor distinguished using the above algorithm. By performing a Fourier analysis on the raw data of the objects in the image, we found, that the position of a spectrum's maximum allows one to differentiate between double saw cuts and notches or
grooves. Testing this approach on other manmade and natural defects showed a significant increase in classification reliability, albeit at some cost to processing speed.

Applications

The method described above is currently being integrated in an EC instrument for maintenance inspection, in particular for the manual testing of the inner surface of drilled holes, such as rivet holes on aircraft. An indexing scanner provides complete coverage by advancing the probe by 0.5 mm per revolution, up to 64 revolutions. Each revolution or scan line is sampled 192 times. The Motorola 68000 microprocessor in the instrument performs the analysis in less than 1.5 sec. For on-line testing of semi-finished products, scan segments consisting of 100 lines must be analyzed in less than 300 ms. Initial studies show this to be achievable using high speed distributed processing systems.

Test objects with structures

Special consideration must be given to test items whose manmade structures cause EC signals larger than cracks or other defects. One possibility is to use the above classification method to recognize the structures and ignore them. Difficulties arise if these structures must be examined for defects. An example of such an item is an airplane wheel rim as shown in Fig. 5. A low frequency EC scan of the inside surface from the outside wheel well using an absolute probe shows the responses from the inside structures, such as drive keys, valve and thermofuse holes, as well as from the manmade cut across a drive key (Fig. 6).

![Fig. 5. Schematic of a typical aircraft wheel rim.](image-url)
Fig. 6. Y-component of EC signal as a function of the probes' position on the tube well surface of inboard half of the wheel. The low frequency scan is performed with an absolute probe.

Fig. 7. Data from Fig. 6 after elimination of symmetric structures and prior to object classification.
The signal from the cut, embedded in the signal from the drive key, can not be separated out using threshold methods. A possible solution consists of determining and subtracting "signal prototypes" of geometrically symmetric objects. This is done by first establishing the symmetry of various structures, e.g. by autocorrelation of each scan line. Subsequent correlation of symmetric segments allow one to build a prototype segment, e.g. of a drive key, by averaging these segments. This prototype segment is then eliminated from the raw data, such that only irregular objects remain. The cut and valve hole signals remain (Fig. 7) after this method is applied to the raw data from Fig. 6. Objects with imperfect symmetry, such as the screws holding the heat shields, cause signal remainders at their edges. These, as well as the non-symmetric objects, may be differentiated by subsequent application of the above classification scheme. Since the elimination of structures requires relatively long computing times this type of analysis is currently only suited for maintenance or semiautomatic inspection.

SUMMARY

The analysis method described above is based on a combination of classic image analysis techniques as well as signal processing methods and recognizes simply connected geometric objects in an eddy current scan. Quantitative geometric analysis leads to characteristic features and classification of the objects detected in the image. This results in an effective increase in sensitivity, even at high testing speeds. Signals from symmetric structures within a test item can be eliminated, which, however, requires longer processing times. The method is being integrated in an EC instrument.

REFERENCES