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EDDY CURRENT NONDESTRUCTIVE TESTING USING FARADAY INDUCTION TO PRODUCE THE EXCITATION

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Abstract: This paper presents a new nondestructive testing method. The conductive material being tested moves in a time constant magnetic field. Due to the movement the induced currents in the conductor generate a secondary magnetic field. When the eddy current flow pattern is disturbed by the existence of defects, variations of the magnetic field occur and information about the defects can be assessed by measuring the magnetic field.

As far as the authors know this is an original method, that has not yet been reported in the literature, and presents undoubted advantages when the material to be tested is in motion relative to the test sensor (like when inspecting a rail track with a bogie).

Keywords: Eddy currents, velocity induced eddy currents, non-destructive testing.

1. INTRODUCTION

Eddy current based methods are widely used for inspecting conductive materials [1].

These methods are based on eddy currents induced in the conducting sample under test by a time-varying magnetic field generated by time-varying currents that are imposed in an excitation coil located in the vicinity of the sample's surface. Because the eddy currents flow pattern depends on the electromagnetic properties of the material, flaws, welds and other defects can be evaluated by measuring the magnetic field that these currents produce. The amplitude and phase of the magnetic field inform about the material inhomogeneities and can be assessed either using direct or indirect methods.

The simplest form of an eddy current probe implies a single excitation coil used to apply the magnetic field in the conductive material and whose impedance change senses the presence of defects [2]. Pick-up detection coils, either simple or having a differential configuration, can also be used to measure magnetic fields variations [3, 4]. Another procedure is to apply magnetic sensors to measure directly the magnetic field parameters. Some of the most used are anisotropic magnetoresistors (AMR) [5], "giant" magnetoresistors (GMR) [6, 7], SQUIDs [8] and HALL sensors.

Eddy current techniques with sinusoidal excitation field have been employed in several applications, such as the detection of cracks inside aircrafts structures [9], breaks in the printed circuit tracks [10] or to determine the thickness of metallic sheets [11]. Applications with pulsed or multifrequency excitation currents have also been used to determine the thicknesses of sheets [12] or to detect corrosion in aging aircrafts [13].

In conjunction with ultrasonic testing techniques, magnetic flux leakage (MFL) methods are the procedures commonly used today to search for cracks in the rails. These methods produce magnetic flux inside the rail that leaks from the superficial cracks allowing the detection of superficial defects in railway tracks [14, 15].

However given the great sensitivity of eddy current based methods especially for detecting near surface defects and being an inherently non-contact technology, research and development on the subject is being envisaged to become a commercially more viable rail testing. The challenge remains in the operation speed because the inspections must be made in overcrowded railway networks with the movement of trains at increasingly speeds.

The approach described in this paper is the induction of the eddy currents in the material under test with a DC magnetic field moving in the vicinity of the sample under test (Faraday effect) and the use of very sensitive GMRs to infer the presence of cracks by measuring the magnetic field resulting from the currents flow pattern. It is believed that this solution has not yet been reported in the literature. It presents undoubted advantages as the method sensitivity increases as the relative motion between sample to be tested and the sensor speeds up.

2. TESTING METHOD

The block diagram of the testing setup is depicted in Fig. 1.

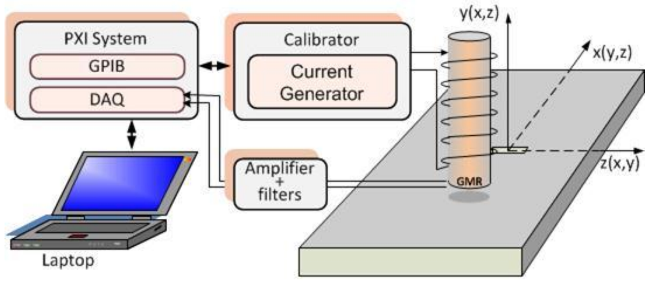

Figure 1. Experimental setup, with ECP and measurement instrumentation.

In order to obtain a signature of a plate defect the eddy current probe (ECP) is oriented perpendicularly above the surface to be tested and displaced at a constant speed. The eddy current probe DC excitation current is provided by a FLUKE 5700A calibrator. Embedded in the ECP is a tiny giant magnetoresistor sensor (436 x 3370) µm (GMR) which measures the magnetic field along its sensing axis. The GMR sensor is mounted on the bottom plane, close to the plate, with the sensing direction perpendicular to the primary excitation field. This sensor, a AA002-02 produced by Non Volatile Electronics, is powered at ±5 V by the power supply module. The output signal from the sensor is amplified 100x with an instrumentation amplifier (INA 118) and acquired using a NI USB-6251 data acquisition board. The board has eight differential BNC analog inputs (16-bit) with a maximum sampling rate of 1.25 MS/s per channel and input range from ±0.1V to ±10V.

The system is controlled using a personal computer running LabVIEW. The results of the experiment are processed using MATLAB software.

3. WORKING PRINCIPLE

In traditional eddy current methods for nondestructive testing (NDT) the eddy currents are generated in the sample under test by time-varying magnetic fields produced by time-varying excitation currents. In the study described in this paper, eddy currents are due to Faraday effect. The DC current that runs in the probe excitation coil creates a time constant magnetic field (similar to magnetic fields produced by permanent magnets). The relative motion between the conductive sample to be tested and the static magnetic field probe induces currents that have a distribution related to the material characteristics and to the movement.

Some of the equations that govern the phenomenon are derived from Faraday's law considering the flux change composed of two parts:

$$-\frac{d}{dt}\int_A \boldsymbol{B}.\, d\boldsymbol{A} = -\int_A \frac{\partial \boldsymbol{B}(t)}{\partial t}.\, d\boldsymbol{A} + \oint_s (\boldsymbol{v} \times \boldsymbol{B}).\, \boldsymbol{ds} \qquad (1)$$

Where the flux density is $B(x,y,z,t)$ and the surface $A(t)$ is bounded by the curve $s(t)$. The first term of the right side is due to the time variation of $\boldsymbol{B}$ and for a time constant magnetic fields is null. The second term is the change flux due to the motion and to the variation of the contour $\boldsymbol{s(t)}$ corresponding, in the application under study to the total magnetic flux change and to the induced emf in the plate under study. The resulting currents that flow in the material are time-varying for the same position and generate a magnetic field that is measured by the GMR sensor embedded in the probe. The presence or absence of defects is inferred by the analysis of this magnetic field.

4. TESTING CHARACTERISTICS

To investigate the performance of the testing method to detect defects in a plate, some experiments were carried out.

A. Description of the Samples

Three metallic plate specimens with machined notches simulating defects have been used. Two of them are made out of an aluminium alloy, one 1 mm and another 1.5 mm thick, both having 6 notches with different depths and widths as illustrated in Fig. 2. Notches identified with numbers 2 and 4 only reach half the plate thickness while the others (1, 3 and 5) are 1 mm depth. The third plate is made of stainless steel (AISI 304) 1 mm thick where only one notch with 10 mm length, 1 mm width and 1 mm depth was machined.

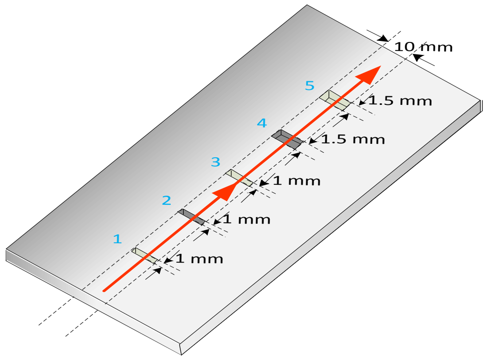

Figure 2. 3-D view of one crack of the plate to be tested.

B. Conditions of Experiments

In this application tests were conducted with a DC current having different magnitudes depending upon the material and the scanning speed. All measurements are taken with a sampling frequency of 100 kS/s and the scanning was made at different scanning speeds too. Fig. 2 depicts also the scanning path considered. The cracks tested were superficial, meaning that the probe was moved above the surface with the machined notches. The GMR sensing axis was oriented perpendicularly to the crack and thus, the sharp variation produced in the output signal enables the crack detection.

4. EXPERIMENTAL RESULTS

Fig. 3 presents the results obtained for two different speeds when the 1 mm crack at the stainless steel sample is scanned with a 50 mA excitation current.

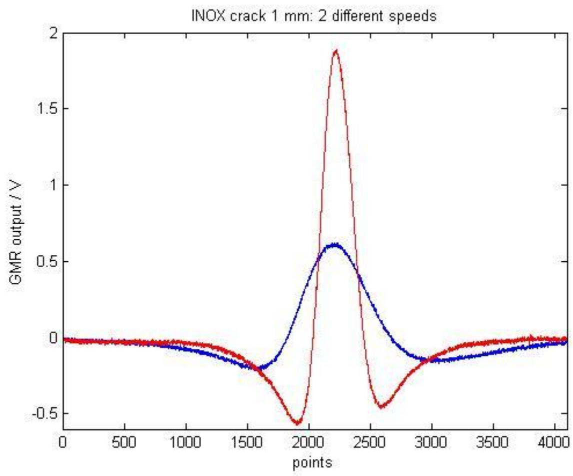

Figure 3. Result for the 1mm crack in the stainless steel sample.

Fig. 4 presents the oscilogram obtained for the scanning of the same crack at the highest speed (0.22 ms^{-1}).

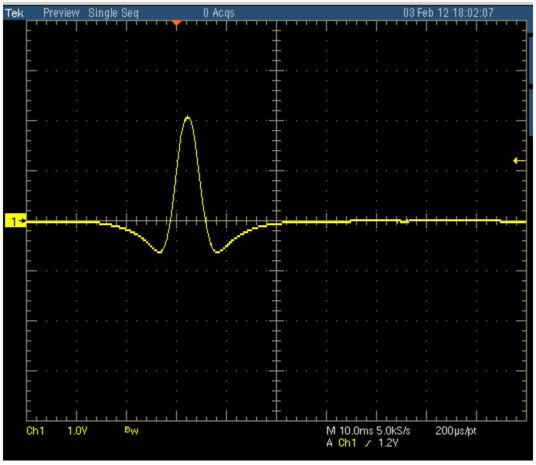

Figure 4. Oscilogram for the 1mm crack AISI 304 scan.

From the experimental data depicted at Fig. 3 for the stainless steel sample using the 50 mA excitation current the sensibility dependence with the speed is evident.

Fig. 5 shows the data obtained when the area over cracks 1, 2 and 3 of the duraluminum 1.5 mm thick plate is scanned at 0.2 ms^{-1} with an applied excitation current I_{exc} = 1.5 A.

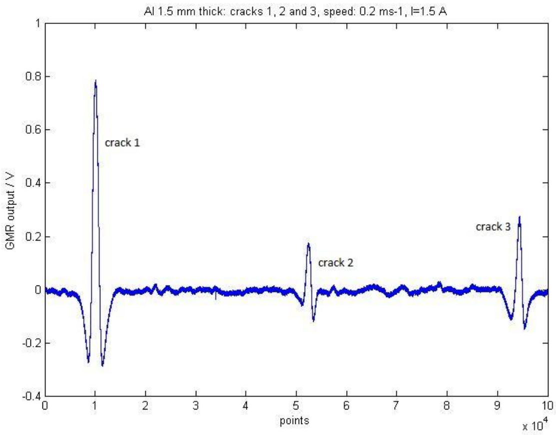

Figure 5. Magnetic field component obtained when the area over cracks 1, 2 and 3 of the Al 1.5 mm thick plate is scanned, with v = 0.2 ms^{-1} and I_{exc} = 1.5 A.

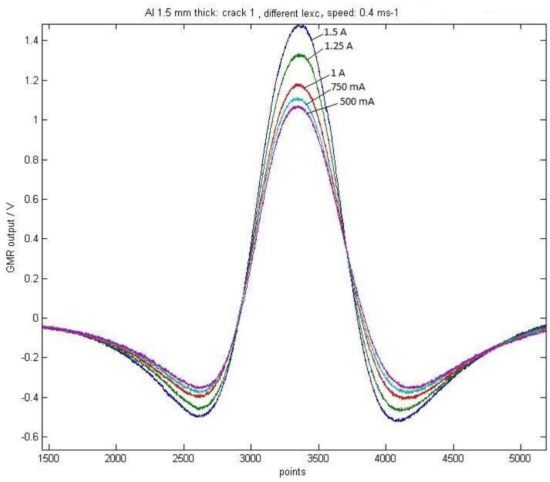

Figure 6. Experimental data obtained for crack 1of the Al 1.5 mm thick plate, with v = 0.4 ms^{-1} at different I_{exc}.

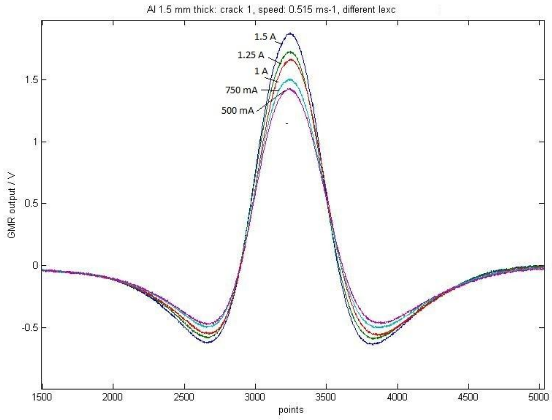

Figure 7. Experimental data obtained for crack 1of the Al 1.5 mm thick plate, with v = 0.515 ms^{-1} at different I_{exc}.

Figs. 6 and 7 represent the raw data measured for crack 1 of the same duraluminium plate (1.5 mm thick) at two different scanning speeds (0.4 ms^{-1} and 0.515 ms^{-1}) with different excitation currents. The sensibility increases with the scanning speed and with the applied current. The high dependency of the signal magnitude with the material properties is also evident.

For the experimental data signals depicted in the aforementioned examples there isn't any noticeable noise and the cracks are marked clearly. Nevertheless, for some materials and always depending on the scanning speed, the output signal can be noisy and cracks are not identified so easily as in the previous situations. Figs. 8 and 9 depict the magnetic field component measured (in red) when the area including notches 5, 4 and 3 is scanned at 0.2 ms^{-1}. Fig. 8 shows the result for the 1.5 mm thick duraluminium with an excitation current of 1 A and Fig. 9 for the aluminium having 1 mm thickness and 1.5 A.

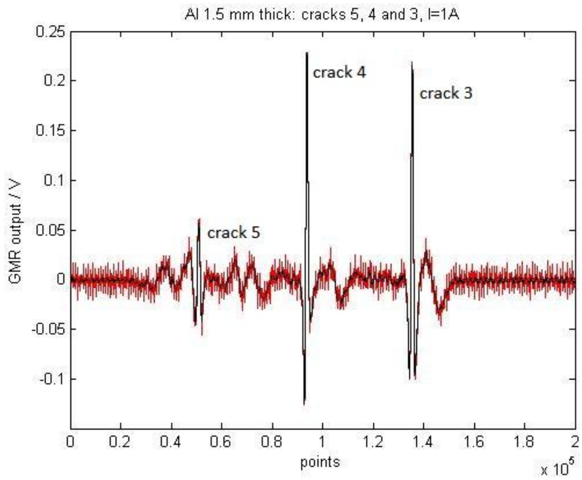

Figure 8. GMR output signal (red) when cracks 3, 4 and 5 of the 1.5 mm Al plate are scanned and corresponding denoised signal (black).

During the testing the signal becomes corrupted by continuous noise making difficult to detect the defects due to the poor signal to noise ratio (SNR). The wavelet transform was used to provide a time-frequency signal analysis. In Figs. 8 and 9 the signal obtained experimentally and the result after removing the noise is also depicted.

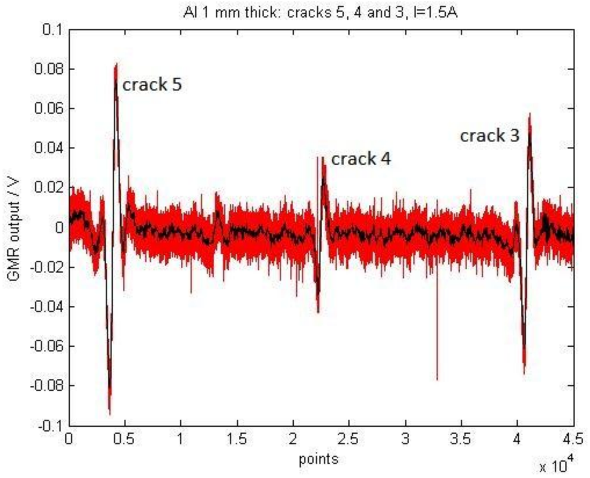

Figure 9. GMR output signal (red) when cracks 5, 4 and 3 of the 1.5 mm Al plate are scanned and corresponding denoised signal (black).

To remove the noise the nearly symmetrical wavelets symlet was selected as the mother wavelet (Sym4). Fig. 10 presents a plot of the wavelet coefficients showing the exact location of the cracks as the positions where the highest magnitudes occur.

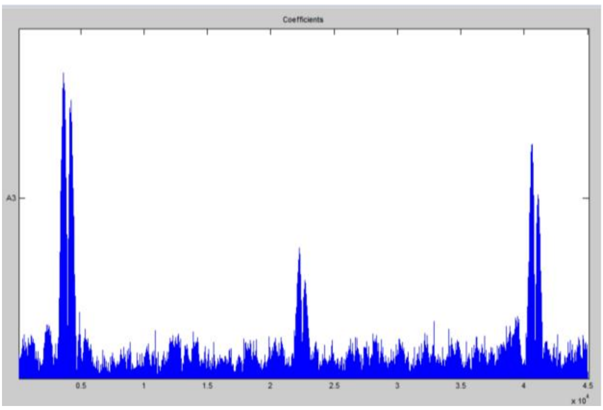

Figure 10. Coefficient magnitudes (A3) obtained for Sym4 illustrating the crack pattern.

5. CONCLUSIONS

This paper presents a new nondestructive testing method. The conductive material being tested moves in a time constant magnetic field. The current flow pattern is disturbed by the existence of defects and the variations that occur in the magnetic field created by those currents provide the information about the defects location.

The experimental results reported in this paper demonstrate that the method is direct and simple enough to be used for crack detection. It has a good detection performance and is particularly well suited to situations where the speed is a factor to be considered as the sensibility increases with the moving speed. It was also proved that the wavelet transform presents good results as a noise reduction algorithm and to identify successfully the patterns corresponding to the cracks.

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