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Magnetic sensors assessment in velocity induced eddy current testing

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ABSTRACT

This paper presents an enhancement in the probes to be used on a new nondestructive testing method with eddy currents induced by velocity. In this method, a permanent magnet that is attached to a moving carriage creates eddy currents in the conductive material to be inspected. By measuring the opposing magnetic field generated by the eddy currents, it is possible to obtain information regarding the presence of defects. Different magnetic field sensors, such as, differential pick-up coils, giant magneto resistors (GMR) and Hall sensors have been used and compared. A permanent magnet moving above a plate was studied using a numerical model to allow further improvements to be made in the probe. Depending on each sensor's geometry, sensing axis and range, its position and orientation must be strategically chosen in order to increase defect sensitivity. The best probe's position is the one that guarantees the highest sensibility to the defects' presence.

1. Introduction

Nondestructive testing (NDT) is a topic of significant relevance for several industries, such as aeronautics, railroad, petrochemical or nuclear. There is currently a demand for NDT progress due to maintenance and safety needs in such industries. This factor has driven a recent growth in the development of new NDT methods.

This paper is a step toward the development of a NDT system capable of being applied to cases where the velocity factor is used to its benefit by increasing its sensitivity. Examples of industrial manufacturers that can benefit from these inspection systems are electrical cable manufacturers or producers of aluminum plates and foils using cold rolled lamination.

Eddy current testing (ECT) is a commonly used technique to inspect conductive materials for defects [1] caused by material stress or corrosion. It uses a time-varying magnetic field, generated by an excitation coil with a sinusoidal [2] or transient current regime [3], to induce eddy currents in the material. By measuring the disturbances in the path of the induced eddy currents this method is able to detect, locate and characterize the defect [4]. Some of the most used magnetic field sensors are based on Hall effect [5], anisotropic magnetoresistor (AMR) [6], giant magnetoresistor (GMR) [7] and pick-up coils [8].

Recent work showed that a modified ECT method using a permanent magnetic field fixed in a moving medium and a GMR is able to detect defects on an aluminum plate [9]. The advantage of this method relies of the fact that its sensitivity increases with the speed of the probe. This was proved for an aluminum sample for a speed range from 0 to 6 m/s [10,11].

Other authors [12] also used the same physical principle to detect the presence of cracks on a conductive material but instead of measuring the magnetic field as our approach does, the quantity being assessed is the Lorentz force experienced by the sample. They call the method “Lorentz force eddy current testing” (LET).

The monitoring and inspection of metal surfaces for defects in moving media are an area where ongoing research is still paramount. In order to understand the effect of speed in the detection of defects using electromagnetic NDT techniques, some authors developed numerical models [13,14] applied to actual testing solutions. Modeling velocity in NDE is a non trivial problem that can only be solved is particular situations.

This paper is a step forward essential to increase the performance of the method. It reports and analyses in detail the data measured with different magnetic sensors when a sample with machined cracks perpendicular to the eddy currents induced in the material is inspected. The sensors used are a differential pick-up coil, a commercial magnetic sensor based on giant magnetoresistors (GMR) and a Hall sensor.

From a preview of the magnetic field pattern in the vicinity of a conductive plate with defects one is able to decide, based on the quantity (i.e. the magnetic field component) to be measured, which is the best position for the sensor.

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The paper is organized as follows: in Section 2 a small theoretical introduction to the working physical laws of the method is presented; Section 3 introduces the experimental set up and the conditions of the experiments; Section 4 previews the results being measured in order to position the probes for the best outcome; Section 5 describes the probes; Section 6 presents and concludes about the details of the experimental data obtained by each probe and finally in Section 6 conclusions are drawn.

2. Modified ECT method

The work described in this paper allows the detection and location of defects in a metallic plate using a modified eddy current testing method. In the traditional ECT eddy currents are induced in the sample plate by a time-varying magnetic field created by an excitation coil placed closely to the sampled material. The flow of the eddy currents is disturbed when a defect exists and the resulting magnetic field contains the information concerning the perturbation. In this work eddy currents are induced by moving a constant magnetic field in the vicinity of the surface of the sample plate. This constant magnetic field is created by a permanent magnet that, as it moves, creates a relative magnetic field variation in the metallic plate surface.

From the derivation of the Maxwell equations, assuming the magnetic field from the permanent magnet is constant in time, it is possible to obtain a relation between the magnetic field density and velocity:

$$\frac{1}{\mu\sigma}\nabla^2 B + \nabla(v \times B) = -\frac{1}{\mu\sigma}\frac{\partial B}{\partial t} \tag{1}$$

where B represents the total magnetic field that is a superposition of the primary magnetic field due to the permanent magnet and of the secondary magnetic field produced by the induced eddy currents, v is the velocity of the permanent magnet and μ and σ are respectively the magnetic permeability and the conductivity of the material being tested.

The detection of defects using this method is therefore possible by measuring the magnetic field density as it contains all the information of the eddy currents perturbation due to the presence of defects.

3. Experimental setup and conditions of experiments

A probe installed in a carriage moves above the sample as depicted in Fig. 1. The probe contains a permanent magnet to produce the eddy currents in the conductive material and a magnetic sensor to measure the magnetic field in the vicinity of the sample. A LCB060 belt drive actuator from Parker with a 3.5 m long sliding glide system was assembled to move the 150 mm long carriage that holds the probe. The actuator is powered by a Parker SMH100 brushless servomotor which can accelerate the carriage at a rate of 20 m/s^2, to achieve a maximum speed of 6 m/s. A Parker Compax3 driver/controller controls the motor, using the encoder as feedback, according to a programmed PLC algorithm. The encoder contains 2048 points per revolution, providing a maximum carriage position resolution of 0.083 mm. A National Instruments USB-6251 DAQ is used to measure the output voltage of the magnetic sensor in the probe with 16 bit resolution. The whole experimental setup is depicted in Fig. 1 where it is visible the drive belt actuator, the actuator driver/controller, the probe, the DAQ a personal computer and the aluminum plate with defects.

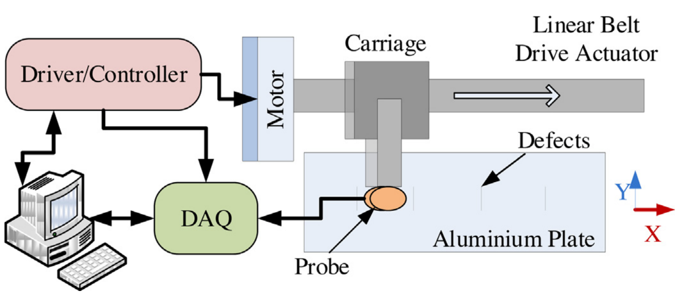

Fig. 1. Block scheme of the experimental setup.

Each 0.083 mm step the probe is moved, the drive belt controller outputs a pulse that triggers the ADC included in the DAQ board to digitize the probe's output voltage.

To analyze the effects of velocity and defect depth on the acquired signals, a 4 mm thick aluminum 1050 plate with eight machined defects was inspected. All defects are 50 mm long, 0.5 mm wide and depth varies from 0.5 mm to 4 mm (through plate) with intervals of 0.5 mm.

Tests were performed by programming the controller to accelerate the carriage to the desired speed, to maintain the speed while conducting the measurement, to decelerate the carriage to a full stop and finally makes it to return to the initial position at a rate of 0.5 m/s.

Each experiment is performed at a constant speed. The output voltage from the magnetic sensor that denotes the presence of a defect is an instantaneous peak. Considering that the probe in testing situations shall be attached to a moving carriage with considerable inertia, the velocity derivative is always much lower that the one related with the amplitude change due to the defect. Thus, the defect is always detectable even if during the measurement an incident occurs that causes a variation of speed.

4. Measurement preview and probe positioning

Considering that the final target of this ECT-based technique is to detect cracks in a material when there is a relative movement between the probe and the material then, in order to maximize the output signal from the magnetic sensor included in the probe, the position of the permanent magnet was chosen to create eddy currents directed perpendicularly to the cracks' line on a limited area. This situation is depicted in Fig. 2. It was obtained using the commercial finite element numerical model COMSOL simulating the eddy currents distribution on the surface of a 4 mm thick aluminum sample 1050 without defects when a permanent magnet moves along x at a constant speed of 20 m/s above the sample.

In Fig. 2 it is possible to observe that the eddy current density in front of the magnet is higher than the one behind the magnet. This justifies the location of the magnetic sensors in front of the magnet.

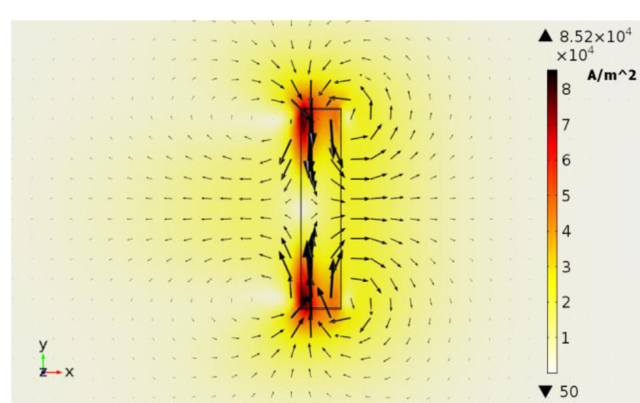

Fig. 2. Eddy currents distribution on the Al surface when the magnet moves along x at 20 m/s.