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Studies to optimize the probe response for velocity induced eddy current testing in aluminium

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ABSTRACT

Detection and localization of surface and near surface defects in metallic objects using faster and simpler methods is always a matter of great interest in non-destructive testing (NDT). Early defect detection is of utmost importance to maintain safety of the structure and to reduce the maintenance costs. This work proposes a NDT method based on velocity induced eddy currents to detect the surface defects in electrically conductive metal. The approach used is original as it is the resultant magnetic field generated by the eddy currents of the test material induced by the permanent magnet motion, that is measured in order to detect defects. For this purpose new kind of moving magnetic probes were designed and fabricated. Each probe consists of permanent magnets which, due to the movement, induces eddy currents in the sample and a Hall effect sensor able to measure the resultant magnetic field. The total magnetic field has the information of the perturbation of the induced currents produced by the defect. Commercial simulation software was used for the optimization and design of the probe. In order to test the performance and feasibility of the proposed method several experiments were performed on an aluminium plate specimen having linear defects machined with different orientation and depths. The results were obtained by scanning the probe on test specimen at a constant speed. Experimental results confirm that the proposed method with the proposed sensing solution can be an NDT tool to detect the defects in the electrically conductive materials where motion is involved, for example in the inspection of railroads.

1. Introduction

A precise inspection of metallic objects for the detection of defects at high accuracy and resolution is still a problem of interest in nondestructive testing (NDT). Several NDT methods including flux-leakage [1,2], ultrasound [3] and optical inspection [4] are capable of detecting defects in metallic structures. However these methods have some disadvantages, such as, low inspection speed, need of a couplant or preparation of inspection surface that requires costly maintenance. This paper describes enhanced contributions to the implementation of an inspection method based on eddy current testing (ECT). The method described in this paper induces eddy currents in the test material in the same way as the Lorentz force eddy current testing (LET) method [5], but differs in the measured physical quantity. In LET, force disturbances caused by induced currents are detected, whereas in the original approach proposed within this paper, the eddy current's magnetic field perturbations are measured directly using a magnetic field sensor [6,7].

Eddy current testing (ECT) method [8–10] commonly known as the electromagnetic NDT method is widely used

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and a well understood technique particularly for the testing of conducting metals. In this method the current in the coil that constitutes the probe induces eddy currents in the test material based on the basic principle of electromagnetic induction. When a crack interrupts the eddy current flow the result is a change of the coil impedance, by measuring these impedance changes or by measuring a resultant magnetic field using a magnetic sensor it is possible to detect the cracks in the test material. This is the traditional ECT method. However, ECT requires skilled operators, use of different probes for different applications, need of continuous excitation with alternating current which may cause heating, moreover it is difficult to attain the data at high speeds. Thus, our study is devoted to study an alternative version of eddy current testing which is based on the velocity induced currents. Unlike conventional ECT this method uses permanent magnets, thus does not require excitation currents. This technique is contactless and its sensitivity to detect defect increases with speed [7].

The monitoring and inspection of metal surfaces for defects in moving media is an area where ongoing research is fundamental. It is paramount to understand the velocity effects as high velocities can compromise the ability to detect and characterize defects with magnetic flux leakage techniques. Other applications as the testing of aluminium foil and sheets during their production or aluminium cable's inspection can be referred. Another very important application is railroads monitoring. Since the trains are very heavy, run at high speeds and have continuous contact with the wheels it may cause rolling contact fatigue (RCF) cracks. The RCF cracks are one of the most common causes of train derailment [11] that needs to be prevented with precise inspection using trusted NDT methods. It attains a paramount importance due to the trains having direct relation with public transportation.

The probe in the velocity induced eddy current method consists of a permanent magnet to induce the eddy currents in the test specimen during the motion and a Hall-effect sensor to detect the resultant magnetic field. The orientation of permanent magnet with respect to the surface of the test object and distance of the Hall-effect sensor relative to permanent magnet play a critical role in the design and optimization of the probe in order to increase induced eddy current density and defect detection. The present manuscript contributes to describe the designing and optimization of two kinds of probes in the proposed NDT method. The probes were named as 'sleeping magnet probe' and 'standing magnet probe' to detect the defects in a metallic surface.

The remainder of the paper is structured into four sections. In the following section a brief introduction to the NDT method using velocity induced eddy currents is made. In Section 3 numerical modelling for different probe configurations using a finite element program to compute the stationary study, is described. Section 4 contains the experimental validation that confirms the improvement of the method with the use of new probes by detecting four defects in an aluminium plate. Finally the conclusions and future work are summarized in Section 5.

2. Velocity induced eddy currents method

The velocity induced eddy current method belongs to ECT group. In this method a constant magnetic field is used (a permanent magnet or DC current though a coil) to generate induced currents, while moving this magnet source at a constant speed over the metallic plate. The constant magnetic field contributes to induce the eddy currents in the material. Perturbation in the total magnetic field generated in the vicinity of the plate can be detected by a Hall-effect sensor. When using eddy current based methods to detect the defects, detection can be improved if the induced eddy currents have a direction perpendicular to the span of the crack, so that a greater perturbation occurs when the probe crosses over the crack. As discussed before, basically RCF defects are initiated on the surface or very close to the surface due to over stressing of wheel on the rail. Thus, orientation of magnet in the probe which causes eddy currents in the material is important, in order to maintain higher density of the induced currents perpendicular to the crack direction.

In order to characterize the geometrical characteristics of a crack such as its length, a wide area has to be scanned. This area should contain a wide zone of induced currents with a similar intensity and oriented in the same direction as motion of magnetic source. At the same time, the measurement of the resultant magnetic field can be done simultaneously by an array of magnetic sensors placed in the vicinity of this zone of uniform current density, which speeds up the assessment of large areas.

A study of the influence on the current density created by different configurations of the magnets included in the probe with numeric modelling and experimental validation is given below not only to understand the physical phenomenon involved but also to optimize the detection capabilities of the probe.

Two types of probe configurations have been considered: (1) 'Sleeping magnet probe' includes a single permanent magnet with its magnetization perpendicular to the motion axis and parallel to the surface under inspection. Using this configuration there are two zones with uniform current density which are oriented along the motion axis (perpendicular to the direction of the crack) on each side of the magnet, as depicted in Fig. 1(a); (2) 'Standing magnet probe' composed by multiple magnets having opposing magnetizations perpendicular to the surface under inspection. This configuration creates multiple zones of uniform current density with the current direction perpendicular to the cracks as depicted in Fig. 2(a). Both probes, (1) and (2), are integrated with Hall sensors to determine the resultant magnetic fields.

3. Numerical modelling based studies

A commercial finite element program (COMSOL) was used to gain better awareness about how geometrical changes in the probe configuration influences both the induced eddy current flow patterns and the crack detection sensitivity. Simulations were carried out to