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Non-destructive evaluation of magnetic metallic materials using Hall sensors

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Abstract

In this paper we present a laboratory developed Hall sensor for non-destructive testing of ferromagnetic surfaces, based on magnetic anomaly detection phenomena. The principle of operation is based on the detection of the magnetic flux leakage in the dimensional boundaries of a gap, mainly of the vertical component Bz referring to the surface plane. Hall sensor is set parallel and very close to the magnetized surface, so as to increase the sensitivity, since the present fields are relatively weak. Small changes in its direction and lift-off movements result in decreasing and noisy output signal. Sensor properties in combination with an appropriate signal processing unit and an effective and fully controlled inspection technique can be used to applications where a rapid and qualitative inspection is needed.

Keywords: Non-destructive evaluation; Magnetic flux leakage; Hall sensor

1. Introduction

Recent demands in industry concerning the failure of structural components concerns, as well as the increasing need for quality control in domestic products have resulted in the development of many new non-destructive techniques. For this purpose various methods are widely used, such as ultrasonic, eddy current, X-ray radiography, infrared and thermographic methods. Extensive use of ferromagnetic materials in engineering applications makes the magnetic flux leakage technique [1] a widely used principle to determine the presence of surface and sub-surface discontinuities. The disturbance of magnetic flux near the discontinuities permits the contactless sensing of the vertical component of the leaking magnetic field. Detection of the size and the position of cracks are very important from the point of view of safety and economy of structural operation. Moreover, technology of sensor manufacturing including electronic circuit may be used for production with low cost.

Many efforts have been made to develop and establish an algorithm for the evaluation of the size and the location of cracks in magnetic materials [2]. The interesting parameter is the precise description of the magnetostatic and electrodynamic response of the under test samples caused by the presence of cracks, for different ac and dc excitation fields. It allows the analysis and the modeling of cracks and their propagation in pipelines, fatigue cracks, inspection in ferromagnetic sheets and rods and even rust detection. Hall sensors have been proved to be sensitive in sensing of surface gaps in magnetic metallic materials, mostly under dc excitation. MR sensors which are usually used for surface inspection [3] are out of interest of this framework because they may cause signal reading problems due to magnetic circuit changes.

2. The experimental set-up

The integrated working standard NDT is illustrated in Fig. 1. A PC controlled *x–y* positioning stage is driven by two step motors, one for each axis, and has a repeatability of 10 μm for a scanning area of 25 mm × 25 mm. Such a repeatability decreases to 100 μm for a maximum scanning capability of 300 mm × 300 mm. This *x–y* stage is laying on a bulk granite basis which absorbs vibrations down to 8 Hz that could add noise to output signal and is illustrated

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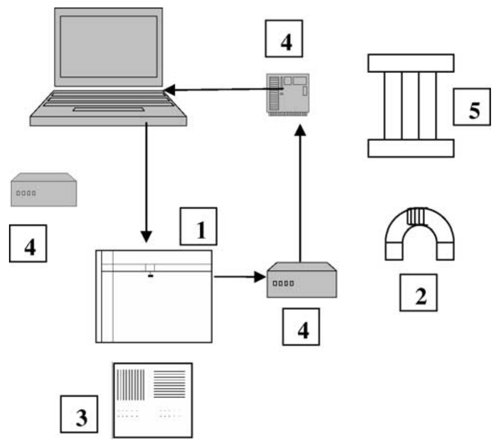

Fig. 1. Experimental NDT set-up: (1) *x*–*y* stage; (2) electromagnet; (3) premachined samples with groups of gaps and holes; (4) power supply, amplifier, data acquisition card; (5) Helmholtz coils.

in Fig. 2. An ac core electromagnet with a magnetizing coil of 100 turns and 150 mm distance between the two poles, is forming a closed magnetic circuit in combination with the plates under testing. Two groups of gaps and holes have been machined on two parallepipeds of Fe and Al, which are used as standard testing specimen. The first group has a constant depth and varying width (radius for holes respectively) from 0.1 to 1 mm. The second group is characterized by constant width or radius and varying depth from 0.1 to 1 mm. A signal generator and a power supply are used to magnetize the under test sample, a pre-amplifier and an amplifier and a data acquisition card are used to detect the output signal and control the excitation. A pair of Helmholtz calibration coils of 230 mm diameter with 1000 turns on each coil in which homogeneous magnetic field of approximately 1000 Oe can be created, is used to calibrate the Hall sensors. Helmholtz coils are illustrated in Fig. 3. The NDT set-up is calibrated in the Laboratory of Physical Metallurgy at NTUA.

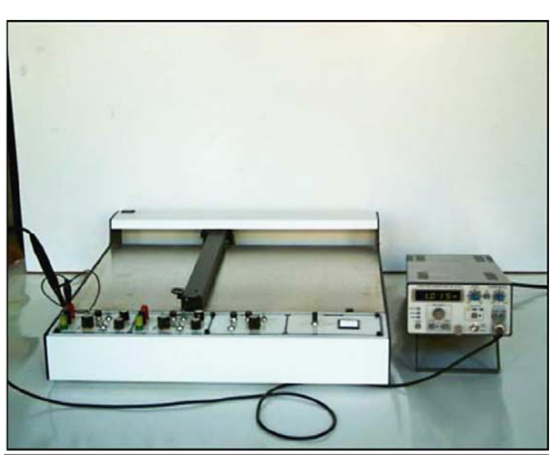

Fig. 2. The *x*–*y* positioning stage.

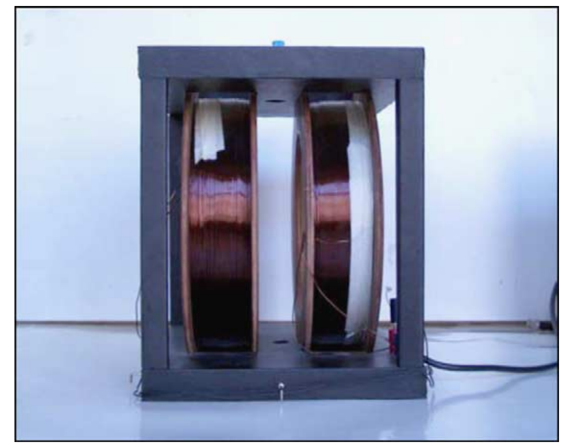

Fig. 3. Helmholtz calibration coils.

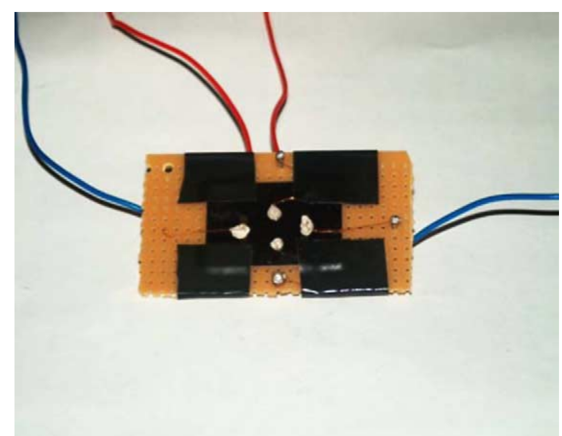

Fig. 4. Hall sensor.

3. The operation

In order to simulate cracks and defects in various depths 0.35 mm thick laminated sheets of Fe–Si 2% oriented mild steel, with or without 1 mm width pre-machined cuts were used. That is, the desired cracks were created by putting together 10 laminated sheets, hence, generating a stack including gaps of various dimensions. These gaps can be either surface or sub-surface. Laminated sheets were used because of the intension to evaluate magnetic cores. The electromagnet is placed on top of the surface under test and on the same side of the crack. Right below it the Hall sensor is free to move parallel to the surface being adjusted on an appropriate non-magnetic probe that is controllably moved by the *x*–*y* stage. A Si-Hall device was fabricated using n-type Si [1 0 0] wafer with nominal resistivity of 2–3 kΩ cm. The wafer was chemically cleaned, dipped in HF solution in order to remove the native thin oxide. Four 1 mm × 3 mm ohmic contacts were made by thermal evaporation of Au–Sb (1%) alloy through the appropriate four holes mask. The alloy sintering was performed by thermal annealing at 500 °C for 15 min in a vacuum chamber. Hall sensor is illustrated