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Non-destructive crack detection by capturing local flux leakage field

Mustafa Göktepe*

Department of Physics, Faculty of Science and Literature, Balikesir University, 10100 Balikesir, Turkey

Abstract

The crack detection in the industrial machine parts is very important. The non-destructive crack detection and evaluation of the these cracks are highly desirable from the viewpoint of safe and economic operation of installed facilities such as industrial factories and power plants. A crack induces local damages in the magnetic flux path in a ferromagnetic material and any change in crack area results in change in the distribution of magnetic flux in the material. In this paper, variation of the magnetic flux distribution in locally magnetised ferromagnetic materials which has discontinuity as a crack, is studied. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Non-destructive; Crack detection; Crack; Leakage field; Sensor; Transducer

1. Introduction

The non-destructive detection and evaluation of the cracks are highly desirable from the view point of safe and economic operation of installed facilities such as power stations, industrial plants and pipe lines. The fatigue cracks or other pre-existing cracks could lead to sudden, sometimes catastrophic, failure of structural components.

Evaluation of the crack area and detection of the crack are critically important for some components that are subjected to cyclic stress. Magnetic techniques have been shown to be useful for crack detection in ferromagnetic materials and to be sensitive to the microstructural changes induced by cyclic stress [1,2]. When the crack is formed, the quantity evaluation of crack area or crack length is important in order to estimate fatigue damage or to study the propagation of fatigue cracks.

Several non-destructive test (NDT) techniques have been developed to capturing cracked regions in the material. These techniques are named as radiographic methods, ultrasound methods, thermographic methods, and Eddy current techniques [3,4].

On the other hand, the appeared discontinuity resulting from a crack also produces disturbance to the distribution of magnetic field in the material, and the magnitude of the disturbance is determined by the size and shape of the crack. Therefore, it should be possible to evaluate the crack area by magnetic measurements under localised magnetisation [5–7].

Magnetic effects explained by the concept of electromagnetic fields, which can be imagined as lines of magnetic force, extending through space. When a specimen is magnetised, the magnetic lines of force (the magnetic flux) are predominantly inside the ferromagnetic materials. If, however, there is a surface breaking flaw, or a sub surface flaw, the field is distorted, causing local magnetic flux leakage fields. Effectively, the flaw causes a sudden local change in relative permeability, μ_r.

Magnetic methods of NDT depend on detection of local magnetic flux leakage field. The results show that the size of the leakage field is dependent on a large number of factors, most of which are irrelevant so far as present-day magnetic methods of NDT are concerned.

The specimen, which is ferromagnetic, is magnetised by suitable methods, and flaws which break the surface, or are just sub-surface, distort the magnetic field causing local flux leakage fields.

2. Experimental

In this study, number of crystalline 3% Si–Fe lamination sheets have been used to simulate cracks in the material. Lamination sheets with 0.35 mm thickness, 30 mm width and 150 mm length have been stacked on each other to simulate full and half cracks, as shown in Fig. 1. A 1 mm wide crack has been made in the middle of the sample, as in Fig. 1(a). Crack was located along the sample of the cross-section as a full crack. A 1 mm wide and 1.40 mm deep half crack is also made in the middle of the sample as shown in Fig. 1(b).

* Fax: +90-266-2390852.
E-mail address: goktepe@balikesir.edu.tr (M. Göktepe).

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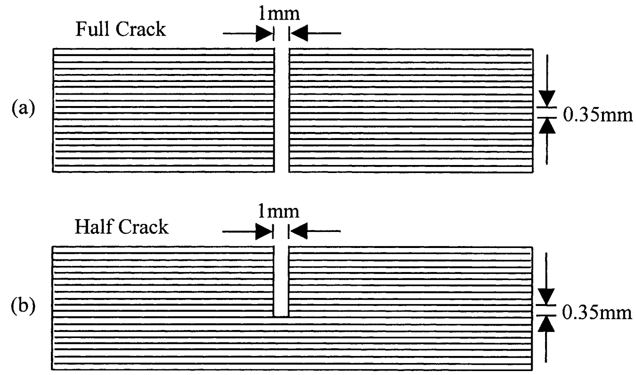

Fig. 1. Simulation of (a) full and (b) half cracks.

A C-core was used to obtain magnetic flux in the material as shown in Fig. 2. Cross-sectional faces of both limbs were touched to the sample surface to allow the transfer of magnetic flux lines and limbs to the sample. C-core was made from 3% Si–Fe laminations with 40 mm average limb length, with 100 mm^2 cross-sectional area of limbs and 40 mm distance between the limbs. An $N_1 = 50$ turn magnetisation coil was located on the C-core to get magnetisation in the core. A linear Hall effect sensor was also positioned between the limbs of the core.

C-core was magnetised by using 50 turn magnetisation winding. When the ac current is applied to the windings, a magnetisation occurs in the core due to re-orientation of the magnetic domains along the flux lines. Because of this, variation of flux density ($\mathrm{d}B/\mathrm{d}t \neq 0$) in time becomes greater then zero.

Magnetic flux lines follow closed magnetic circuit, than pass to the sample from the C-core limbs. A 10 turn search coil is located one of the core limb, to measure variation of dB/dt. Fig. 3 presents the behaviour of the magnetic flux lines in the C-core and around cracked (its for full crack) region. According to this picture, flux flows in the core up to meet crack. The normal component of flux gets bigger in the cracked region. A linear Hall effect sensor has been used to read normal component of the magnetic flux lines. If there is no crack or scratch on the sample, there is no expectation to read normal component of magnetic flux (because, all flux lines pass trough in the material due to its higher permeability). When a crack or scratch somehow occurs on the material, a discontinuity suddenly appears and normal component of the magnetic flux becomes greater than zero instead of a signal becoming big enough to read as a output signal of the Hall effect sensor.

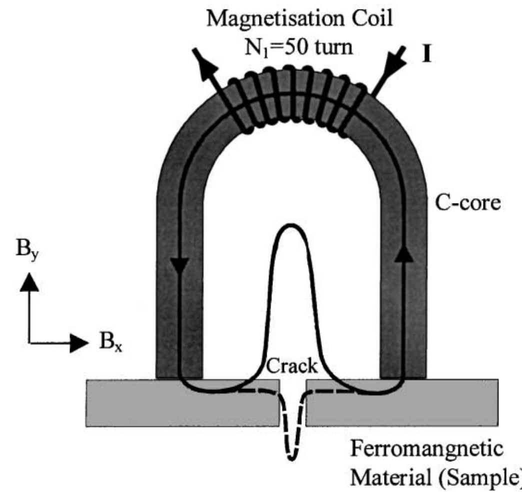

Fig. 3. Schematic diagram of the flux path.

In the laboratory, study number of crack simulations were tested by using this system. Fig. 4 shows variation of the sensor outputs versus sample length. Crack is shown located in the 0 mm position of the sample length axes of the graph. Crack inspections were carried out for magnetisation frequencies 50, 100, 300 and 500 Hz to see influences of magnetisation frequencies on the sensor outputs. Different

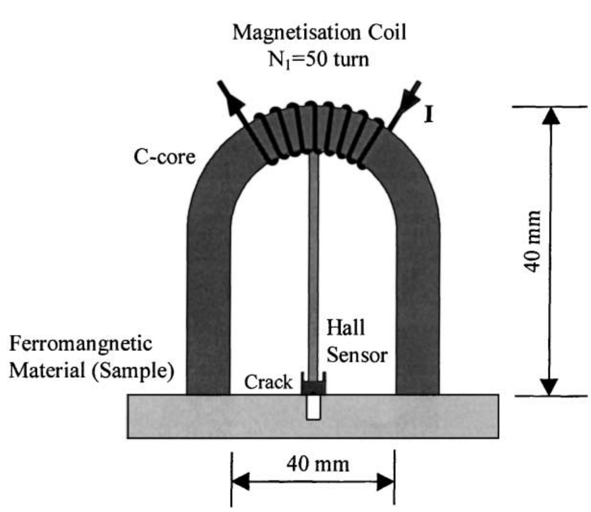

Fig. 2. Schematic diagram of crack detector.

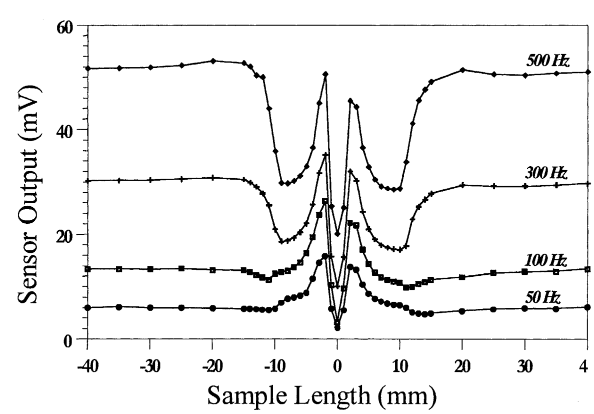

Fig. 4. Variation of output characteristics of the sensing element around crack region.

background signals were obtained at 6–52 mV for different magnetisation frequencies. Amplitude of the background signal increased with increasing frequencies. When the sensor approaches to about 15 mm of the centre of the crack region, the amplitude of sensor output suddenly drops instead of increasing gradually. When the sensor reaches 0 mm position, amplitude of the signal drops to its minimum value. This point gives us the centre point of the cracked region.

3. Conclusion

In conclusion, proposed sensor is suitable for industrial applications. Amplitude of the output signal of sensor increases with increasing magnetisation frequency. The sensor is capable to capture the cracks in the material.

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Biography

Mustafa Göktepe was born in Ankara, Turkey, in 1961. He received his BSc degree in Physics Engineering from the Hacettepe University, Engineering Faculty, Department of Physics Engineering, Ankara, Turkey, in 1986. MSc degree in Physics from the Uludag University, Bursa, Turkey, in 1989. PhD degree from the University of Wales, College of Cardiff, School of Engineering, Wolfson Centre for Magnetic Technologies, Cardiff, UK, in 1994, He is a member of IEEE and TFD Turkish Physics Association. Research topics of interest are sensors and transducers, 2- and 3D magnetisation problems, magnetic domains and magnetic measurements, non-destructive crack detection, theoretical simulation of ferromagnetic domains and MOKE. Dr. Göktepe is in charge of Magnetic Technologies Laboratory and director of the Computer Centre of Balikesir University.