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Research articles

Non-destructive scanning for applied stress by the continuous magnetic Barkhausen noise method

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ABSTRACT

This paper reports the use of a non-destructive continuous magnetic Barkhausen noise technique to detect applied stress on steel surfaces. The stress profile generated in a sample of 1070 steel subjected to a three-point bending test is analyzed. The influence of different parameters such as pickup coil type, scanner speed, applied magnetic field and frequency band analyzed on the effectiveness of the technique is investigated. A moving smoothing window based on a second-order statistical moment is used to analyze the time signal. The findings show that the technique can be used to detect applied stress profiles.

1. Introduction

Mapping surface stresses in industrial parts is very important, as the levels and distribution of applied stresses directly influence the performance and safety of such parts. For example, an uncontrolled increase in the stresses in a mechanical component may increase the possibility of nucleation of surface cracks and therefore reduce its fatigue resistance. Ideally, the methods used for this purpose should be non-destructive.

Suitable non-destructive testing (NDT) techniques make use of a variety of phenomena, including ultrasound, X-ray diffraction, neutron diffraction and Barkhausen noise. Of these, testing based on Barkhausen noise has the greatest potential for innovation because of its simplicity and low cost.

Measurement of magnetic Barkhausen noise (MBN), an NDT technique, has been the subject of a wide range of studies for the last two decades, and research continues to be carried out into suitable applications, equipment and measuring procedures [1–3]. MBN was discovered by Henry Barkhausen in 1919 [4] when he was performing experiments with earphones. He found that if ferromagnetic materials are magnetized by variable fields, a “noise”, known as Barkhausen noise, can be detected in the voltage induced in a pickup coil near the material. Magnetic emissions, which can be detected by a coil as a series of voltage pulses, have been shown to be generated by reversible and irreversible movements of the 180° magnetic domain walls and by domain rotation [5].

MBN is known to be sensitive to several material and mechanical properties, such as grain size [6–8], carbon content [9], stress state [10], hardness [11] and plastic deformation [12,13]. Consequently, the potential for using MBN in the non-destructive measurement of microstructural and mechanical parameters has been the subject of many studies.

The classical way to measure MBN signals involves the use of a probe consisting of a magnetic excitation system and an MBN sensor (pickup coil). Cyclic magnetic excitation is generated in the material, and the resulting Barkhausen noise is measured by the sensor. Instead of being produced uniformly throughout the magnetization cycle, Barkhausen noise is concentrated in two bursts of activity per cycle near the coercive field. Hence, when measurements are being taken, the probe should be kept still on the surface for not less than half an excitation cycle. It follows that the use of cyclic magnetic excitation for continuous surface scanning based on Barkhausen noise has some limitations.

Magnetic flux leakage (MFL) is a traditional NDT technique for volumetric-flaw detection in steel surfaces [14–16] that is widely used in pipeline inspection. A constant magnetic field is produced in the material, and when a defect is present, the resulting

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perturbation in the magnetic field can be measured with a Hall sensor. The method is highly sensitive when used to detect grooves, gouges, cracks and mass loss due to corrosion but its sensitivity is limited when it is used to detect microstructural changes caused by thermal effects, plastic deformation or applied stress.

When an MFL probe is moved over a sample, the constant sliding magnetic field also produces a magnetic field in the material that varies with time. If this magnetic field is strong enough, it will produce Barkhausen emissions, and a pickup coil placed near the magnetic source will detect Barkhausen noise continuously. This signal is known as continuous magnetic Barkhausen noise (CMBN) and was first studied by Alfred E. Crouch [17]. There is a dearth of other studies on CMBN in the literature.

A previous study by our research group showed how CMBN can be applied to volumetric flaw mapping [18] to detect the size and thickness of artificial grooves produced in a 1070 steel. The influence of probe configuration, scanning speed and frequency band analyzed on the effectiveness of the technique was investigated, and the magnetic behavior of the probe was analyzed by numerical simulation using the finite element method (FEM). The results showed that the use of a ferrite core in the coil favors emission and detection of CMBN. Another study by our group described a device that uses permanent magnets to create a precise rotating magnetic field [19]. The MBN pickup coil is fixed in the center of the rotating magnetic field, and the device measures CMBN signals as the angle of magnetization changes to determine the direction of the macroscopic magnetic easy axis.

The aim of this paper is to show how CMBN measurement can be used as the basis of a scanning method to detect applied stress on steel surfaces. The influence of different variables (pickup coil type, scanner speed, applied magnetic field and frequency band analyzed) on the effectiveness of the technique is investigated. The results suggest that MBN technology could profitably be used in non-destructive flaw mapping of steels.

2. Experimental setup

An AISI 1070 steel sample measuring 27 × 240 × 3 mm was used. Its chemical composition (weight percentage) was 0.67C, 0.22Si, 0.003S, 0.69Mn, 0.018P and 0.043Al. To eliminate possible residual stresses generated in the rolling process, the sample was subjected to heat treatment at 850 °C for 4 h in a controlled atmosphere. The yield limit of the material after heat treatment was 310 MPa.

The sample was subjected to bending stresses using the scheme shown in Fig. 1a. Equal deflections were generated at each end of the sample, and the resulting maximum stress, located at the midpoint, was 250 MPa. The stress profile and the region in which CMBN was measured are shown in Fig. 1.

The CMBN probe consisted of a magnet, which produces the constant field referred to earlier, and a coil with a ferrite core to measure the MBN. The probe is shown in Fig. 2. The characteristics of the coil, applied magnetic field and scanning speed were varied during the experiments. The characteristics of the various coils, which were wound with 0.05 mm diameter wire, are indicated in Table 1. Parallelepiped magnets measuring 16 × 12 × 5 mm were used in stacks 1, 2, 3 and 4 magnets high to generate magnetic flux densities of 0.26 T, 0.36 T, 0.41 T and 0.45 T, respectively. Scanning speeds of 9, 13, 23 and 33 mm/s were used, and the coil was placed behind the magnet in relation to the direction of movement of the probe over the surface of the sample in all the tests.

The probe was kept in a fixed position during the experiments, and the samples were moved under it on an xyz table. The signal was measured with equipment developed in our laboratory that first amplifies the signal and then filters it in a 1-100 kHz bandpass filter. The sampling frequency was 200 kHz. The xyz table and measurements were controlled by a computer. Measurements were taken six times with each configuration.

2.1. Signal processing methods

As this study sought to investigate the use of a surface-scanning technique, the aim in analyzing the signals was to obtain a signal amplitude profile that would allow the position of faults on the surface of the material to be identified. To this end, the CMBN signals were analyzed using two processing methods [18].

The first involves calculating the parameter $M2_{CMBN}$, which can be expressed as:

$$M2_{CMBN}[i] = \frac{1}{2M+1}\sum_{j=-M}^{M} s^2[i+j] \tag{1}$$

where 2M is the size of the sliding time window and s[*i*] is the CMBN signal. This calculation is effectively a smoothing operation and can be thought of as a low-pass filter. The frequency response

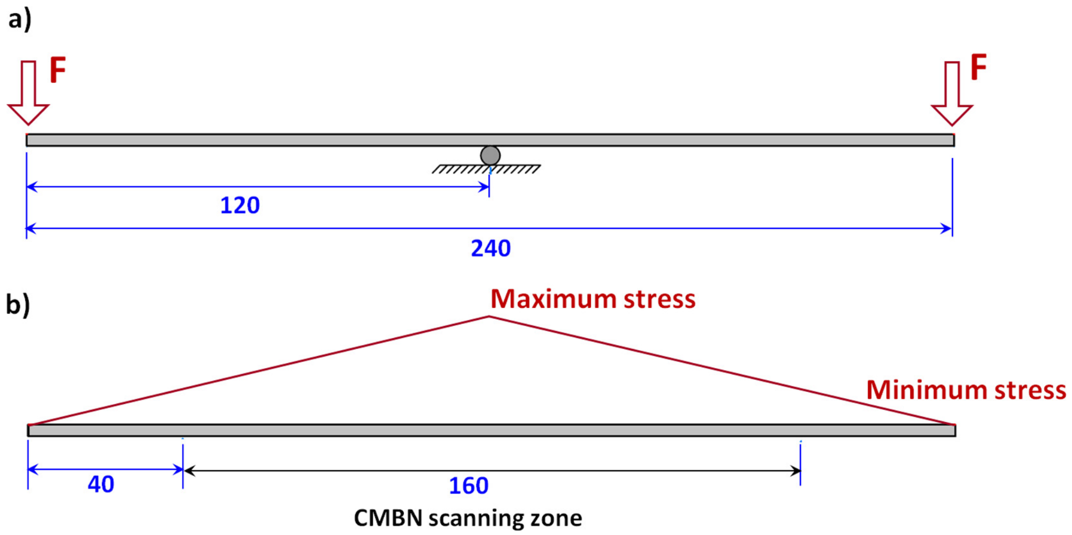

Fig. 1. (a) Applied load and (b) stress profile generated in the sample. Maximum stress = 250 MPa. At x = 40 and x = 200 mm the stress generated is 83,33 MPa. Dimensions in mm.