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Research on the stress-magnetism effect of ferromagnetic materials based on three-dimensional magnetic flux leakage testing

Li Xiao-meng [a], Ding Hong-sheng [a,*], Bai Shi-wu [b]

[a] Department of Physics, University of Science and Technology Beijing, Beijing, China
[b] Pipeline Research Institute of China National Petroleum Corporation, Langfang, Hebei, China

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ABSTRACT

Metal magnetic memory is a non-destructive testing technique in which the stress-magnetism effect of ferromagnetic materials is applied to evaluate the stress-concentration zone. A test platform was developed to measure the three-dimensional magnetic flux, based on leakage flux theory, in order to realize real-time display, processing, and storage of magnetic signals by using LabVIEW programs. The distribution of the two-dimensional spectrum entropy of detection signals is intuitively displayed by Fourier transform and support vector machines model. Our results demonstrate that data acquisition can be realized accurately using magnetic flux leakage inspection technology based on LabVIEW and that the distribution of the spectrum entropy can provide a method for monitoring crack growth through diagnosis of internal stress concentrations in materials.

1. Introduction

Metal magnetic memory (MMM), which was first presented at the 50th International Welding Conference in 1997 [1–3] and originally developed by Russian researchers [4], is a new, non-destructive testing (NDT) and diagnostic method for assessing ferromagnetic material stress concentrations [5–7] and fatigue damage. MMM is primarily based on the magnetic irreversible phenomenon that appears in stress concentrations and plastic deformation areas within ferromagnetic working pieces under load conditions. The direction of magnetic domains in these areas undergoes reorganization and reorientation, which results in the magnetic field emerging on the surface of such areas. The produced magnetic field H_p can be preserved even after the applied load has been removed. The strength of the magnetic flux leakage (MFL) field H_p depends on the maximum working stress. The tangential component $H_p(x)$ has a maximum value of field strength, while the normal component $H_p(y)$ crosses the zero point [8]. However, H_p depends on many factors, such as the location of anomalies relative to the measurement plane as well as the environmental magnetic field, stress distribution, and materials [9].

MMM technology has a number of outstanding merits and is widely studied by Eastern European [10–12] and Chinese [13,14] scholars for its high magnetic field sensitivity, which does not require application of man-made magnetic fields. However, the physical mechanism underlying MMM remains unclear. In particular, no reliable theoretical model has yet been proposed. In practice, the technique is typically used only as a qualitative testing method and no quantitative results can be obtained from it [15,16]. In addition, establishing a general standard among different fields is proving to be difficult.

In the current study, a three-dimensional (3D) MFL detection system was developed using the virtual instrument LabVIEW. MFL signals were collected and stored in real time using a stepper motor which controlling a HMR2300 digital magnetometer to scan ferromagnetic materials. Simultaneously, the distribution of the two-dimensional (2D) spectrum entropy [17], which is extracted from magnetic signals by Fourier transform, was investigated. This method can be used to estimate internal stress concentrations by classification of sampling points using a support vector machines (SVM) [18] model.

2. System structure

A 3D MFL detection system involves three main parts: a scanning console system, a digital magnetometer, and a computer for data acquisition and processing. A schematic of the system is shown in Fig. 1.

The digital magnetic signal is received by a personal computer through a serial port in real time and can be post processed using LabVIEW procedures or functions. For example, the magnetic

* Corresponding author. Tel.: +86 13121752587.
E-mail address: dingdinghs@sas.ustb.edu.cn (D. Hong-sheng).

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signal values can be plotted, filtered, or saved in order to reference them at any time while the system runs, or they can be used as inputs for further mathematical procedure. Fig. 2 shows the front panel display of the detection system based on LabVIEW procedures.

3. Experiments

Testing material used was Q235 low-carbon steel, which is commonly used in engineering structures. The material's chemical composition and mechanical properties are listed in Table 1. Fig. 3 illustrates the shape and size of the 4-mm-thick tensile specimens used in the experiments. A small hole was machined in the middle of the specimen in order to produce local stress concentration during the loading process. Before executing the experiment, the residual stress induced in the machining process was eliminated by demagnetization of the specimen through stress relief annealing. The test was carried out using the 3D MFL system.

Before testing, separate measurements obtained yield stress of 38 kN for the material and tensile loads were thereby selected as 15, 25, 30, 36, 40, 43, 46, and 48 kN. Environmental magnetic field used in the testing was the earth's magnetic field. The specimens were fixed on the tensile machine and the predetermined load values were applied to them. The specimens were evaluated offline as well so as to remove any possible effect of the tensile machine fixture. The magnetic field was measured in 2-mm steps along the 54-mm-long dashed line shown in Fig. 3, located in the middle of the specimen. Measurements began at the left endpoint of the line, whose center is denoted by the circle (as shown in Fig. 3). In the current study, the zero position of the normal component $H_p(y)$ was mainly used to determine stress concentrations, leading to some information loss. Therefore, this report focuses mainly on analysis of the tangential component $H_p(x)$ so as to improve the reliability of MMM.

Fig. 4 presents the tangential and normal components of the magnetic flux densities relative to the scanning coordinate under

Table 1
Chemical composition and mechanical properties of Q235 low carbon steel.

Chemical composition (%)						Mechanical properties (MPa)	
C	Si	Mn	P	S	Cu	σ_b	σ_s
0.22	0.27	0.61	0.035	0.017	0.08	≥ 235	375–460

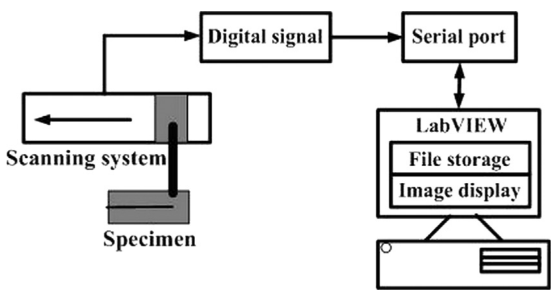

Fig. 1. Overall design of the 3D MFL detection system.

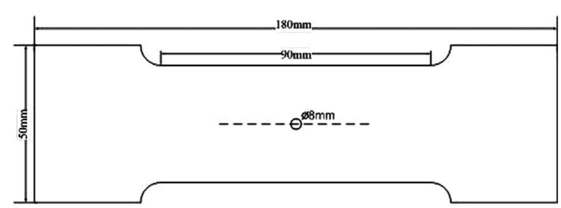

Fig. 3. Specimen dimensions (in mm).

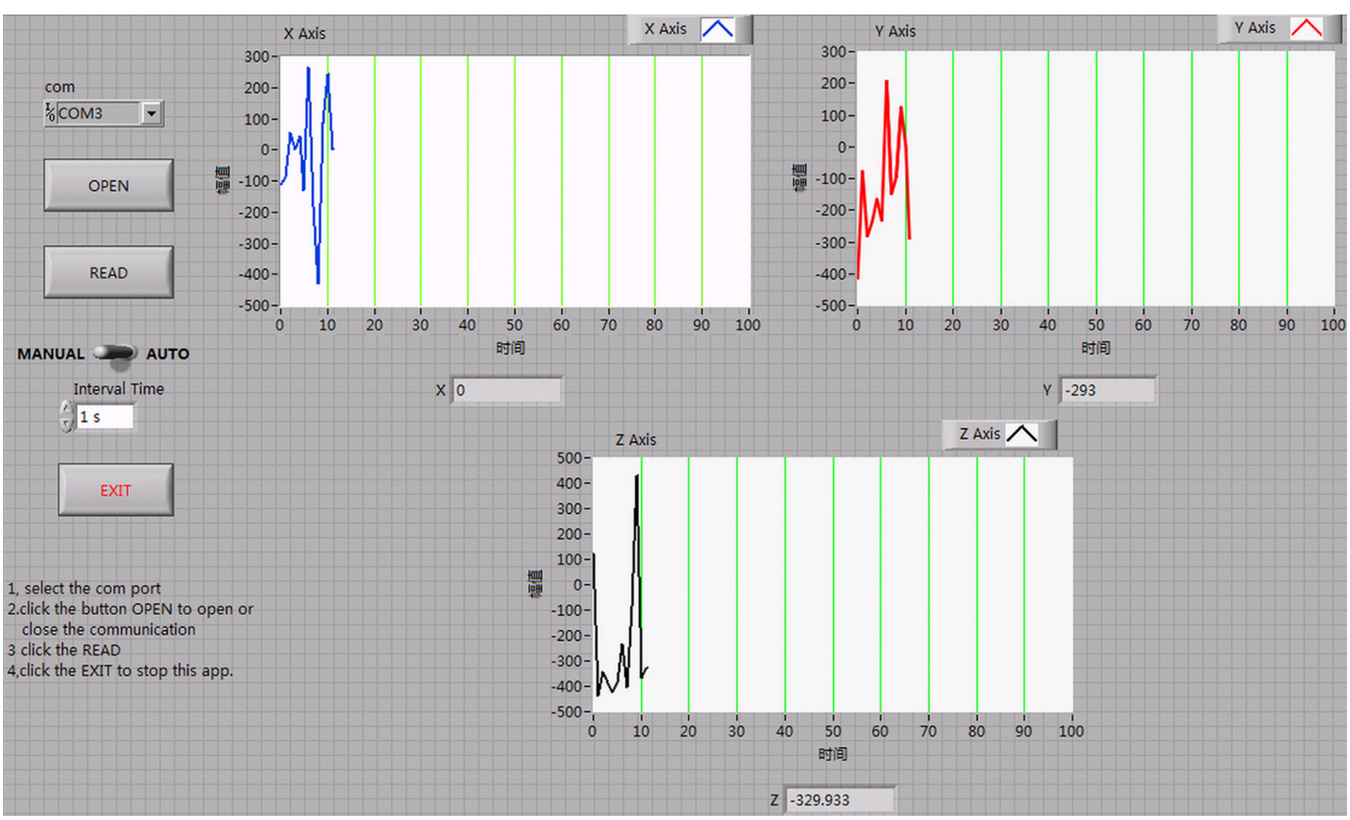

Fig. 2. LabVIEW front panel display of the detection system.