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Features extraction of sensor array based PMFL technology for detection of rail cracks

Ping Wang [a], Longhui Xiong [a,*], Yinchun Sun [a], Haitao Wang [a], Guiyun Tian [a,b]

[a] College of Automation Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
[b] School of Electrical and Electronic Engineering, Newcastle University, Merz Court, Newcastle upon Tyne NE1 7RU, UK

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ABSTRACT

Pulsed magnetic flux leakage (PMFL) testing is a new emerging and effective electromagnetic non-destructive testing (NDT) technology which combines the conventional magnetic flux leakage (MFL) technology with the theory of pulsed current. Compared with single sensor, the sensor array can scan larger areas with higher speed and lower lapsus.

Finite element method (FEM) is used to get the ideal signal of MFL with defects, including signal horizontal and vertical. According to the analysis of different signal of MFL with defects, the relation between magnetic signal and defect size is received. Then a full set of PMFL system based on sensor array is used to detect the standard specimens. In order to eliminate the noise and extract the feature, the detecting signal is analyzed and processed by some pre-treatments. In the process of time-domain analysis, every peak value of sensor signal is extracted as analyzing signal, then peak values are lined as output signal of the sensor array. By analyzing different characters of curve under different defect sizes, and getting corresponding characteristic quantities, the reasons of the errors are discussed.

1. Introduction

As China's speed up its railway operations, the risks of major accidents such as broken rail and derailment caused by rail damage are greatly increasing. The defects of high-speed and heavy haul railway are mainly oblique contact fatigue cracks which is a hidden risk. As maintenance time being shortened, its rapid inspection and fault monitoring have became a major issue of non-destructive testing around the world [1,2]. The study about pulsed eddy current thermography for imaging multiple cracks caused by rolling contact fatigue has also been in progress [3]. The research work of this paper is to inspect the rail in the application background of rails damage detection. It is very important to discover defect in the initial stage of the formation of surface and shallow surface cracks [4–6]. The main work of this paper is the early technology research on tracks online detection.

In recent years, with the study of the theory of the pulse signal continues to develop, magnetic flux leakage field of non-destructive testing presents a new opportunity for development. There have been substantial researches in the feature extraction technique in pulsed electromagnetic-NDT [7–9]. At the same time, with the process and accuracy of the sensor measurement continuously improved, array detector are more and more introduced into the design aspects of the detection system due to its high-rate and being rich in information. A pulse signal can expand into sum of infinite plurality of harmonic components by Fourier transform and thus it has a very wide spectrum. When using a pulse current as the excitation signal to detect, it can obtain a large number of parameter information to the test piece [10,11]. The pulsed magnetic flux leakage detection technology (PMFL) came into being a new branch of magnetic flux leakage, which improves the penetration depth of the excitation field in the realization of the magnetization of the ferromagnetic material, and enhances the effect of the penetration of excitation field and detection effect of deep defect by using of the advantages of rich

* Corresponding author. Tel.: +86 15365129529.
E-mail address: 15365129529@163.com (L. Xiong).

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frequency components of pulse excitation [12]. It is the major significance of the study for detection for oblique contact fatigue cracks of high-speed and heavy haul railway.

In this paper, magnetic flux leakage detection system with array probe that can rapidly detect flaw of ferromagnetic material has been established using pulsed magnetic flux leakage nondestructive testing technology, combined with the advantages of the sensor array [13]. We make some quantitative and qualitative identification to unknown defects according to array detection signal of the different magnetic field components, and put forward a method of quantitatively determining the defect geometry size according to characteristic value of the curves extracted.

2. Combination of pulse excitation and MFL

The alternating magnetic flux leakage in the detection will produce skin effect and eddy current, the magnetic lines of flux are concentrated at the surface and near surface of the material and the magnetization depth will decrease with excitation current frequency elevated. Therefore, the alternating magnetic flux leakage method has a high sensitivity for the detection to the defects at surface and near surface of material.

In addition, excitation signal of the alternating magnetic flux leakage inspection is usually single-frequency sinusoidal signal with the less frequency component, which is not conducive to reflecting the defect information from the detection signal. For the lack of traditional magnetic flux leakage inspection technology, the solution is the introduction of a pulse technology, since the pulse signal is a periodic square-wave that contains rich frequency component.

Provided cycle of pulse signal is T, and the pulse width is Λ, the amplitude is V.

$$g(t) = A_0 + \sum_{n=1}^{\infty} A_n \sin(n\omega_1 t + \varphi) \tag{1}$$

where $\omega_1 = 2\pi f_1$

$$A_n = \frac{2V}{n\pi}\left|\sin\left(\frac{n\pi\Lambda}{T}\right)\right| \tag{2}$$

As can be seen from the formula: (1) The effect of pulse excitation detection equivalent to the multi-frequency excitation detection with non-equal amplitude, which makes dominant frequency obtain greater excitation frequency, lets the magnetization structure excite energy to penetrate specimen as much as possible. (2) The frequency component of the pulse signal is relatively rich, and thus the sensing signal is more conducive to reflecting the defect information [14,15].

3. Simulation of array pulse magnetic flux leakage inspection

COMSOL Multiphysics is a large-scale numerical simulation software, it is applied to simulation in this article. The 2D transient analysis model under the electromagnetic module is adopted. The area between the U-shaped yoke and specimen should be split up into secondary fine-grained finite element so as to improve the accuracy of the calculation of the region. In this model, the first boundary condition referred to the vicinity of the planar region, which represents the range of the region to solve. For this class boundary, magnetic bit should be taken as zero. For the second boundary condition, when its area between boundary is set to the continuous changes, we can automatically meet its conditions from the extremum obtained by fonctionelle [16]. From the U-shaped yoke, we choose a current density of $4 \times 106\ \text{A/m}^2$ and a square wave having a frequency of 20 Hz as the excitation source. The defects mainly involved the vertical and oblique cracks. In the simulation model, each defect lies in the midfield axis of the yoke and the oblique crack is inclined to the right direction. The horizontal component (x) and the vertical component (y) of leakage magnetic field can be taken as detectable amount, this paper will respectively analyze peak curve of the two components. The simulation model is shown in Fig. 1 and Table 1 has shown the information of model.

In the simulation analysis, the position whose distance from the surface of the test piece is 2 mm was chosen as observation place of the leakage magnetic field, we can identify the defect by analysis of the distribution of magnetic field on this section. The excitation signal is a square wave with certain frequency (Fig. 2(a)), the excitation frequency referred hereinafter is the frequency of the square wave. Simulation findings: In the same excitation frequency, the moment of the peak of the curve which was periodically responded on each point of the horizontal plane is basically the same. Therefore, in the time-domain analysis below, the moment of peak of curve (Fig. 2(b)) was regarded as a parameter, and the connection line of the magnetic field response value of time point extracted from the surface of observation is our observation value. We call it the peak curve of the horizontal magnetic field component (X) in this surface, and peak curve of the vertical magnetic field component (Y), depending on the different component of the magnetic field. Therefore, in the time-domain analysis, the peak value of the sensor signal is regarded as a feature point, and the peak point of each sensors of the array is connected to as characteristic curve of magnetic field distribution.

If these signals of array sensor compose a three-dimensional figure, the defect can be directly shown. As shown in Fig. 3, it is analyzing situation which the rail test-piece with the inclined crack being detected by the sensor array, among which, Fig. 3(a) shows the response

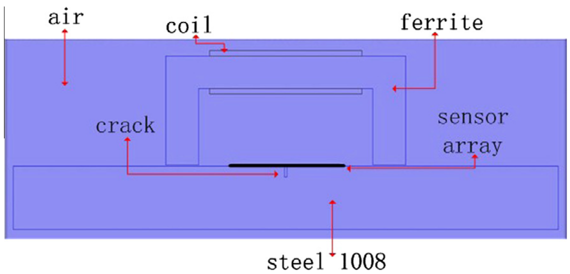

Fig. 1. Simulation model.