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Numerical Simulation and Experiment on Magnetic Flux Leakage Inspection of Cracks in Steels

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Abstract

The magnetic flux leakage inspection method is widely used in the detection of pipelines, storage tanks and other steel materials. Especially in corrosion pits detection, it has become a matured technology. As cracks may exist in the steels which may lead to big hazards, its detection becomes very important. Meanwhile, the cracks evaluation by MFL inspection can be determined by many parameters, it has much difficulty to implement due to its weaker signals compared with pits. In this research, the finite element model for cracks' MFL is established and corresponding method are carried out. Furthermore, parameters such as depth, width, angle of cracks and scanning direction are analyzed. Also, the experiments are done which show great reliability comparing with numerical simulations. The results show that the cracks can not be detected when the scanning direction parallels with it. So the cross-scanning method is recommended for MFL inspection on cracks.

Keywords: Magnetic flux leakage (MFL) inspection, Numerical simulation, Experiment; Cracks

1. INTRODUCTION

Magnetic flux leakage (MFL) inspection method is widely used in the detection of pipelines, storage tanks and other steel plates. Especially in corrosion pits detection, it has become a matured technology which is generally considered to be the most cost-effective method for corrosion monitoring. As cracks may exist in the steels which may lead to big hazards, its detection comes urgently. Meanwhile, the cracks evaluation by MFL inspection can be determined by many parameters, it has much difficulty to implement due to its weaker signals compared with corrosion pits [1].

Analytical approaches to model MFL are difficult to achieve due to both the awkward boundaries associated with realistic defect shapes and the lack of generality that ensures when making the necessary assumptions needed to obtain tractable analytical solutions. Viable models are needed in order to understand the ways in which fields and defects interact to produce measurable indications, to help in the design of detection probes for diverse applications, to simulate those inspection environments which are difficult and/or expensive to replicate in the laboratory, and perhaps most important in many of the critical inspection situations facing industries today, to provide training data for automated defect characterization schemes. Recently, 2-D finite element methods have been used to research MFL signals under different defects shapes, materials, magnetizing situation and so on and it is also proved to be an effective method. However, in 2-D FEM defects are also treated as 2-D profile instead of actually 3-D geometry [2-4]. In this article, 2-D and 3-D FEM is adopted to analyze the MFL method. The parameters such as the depth, width, angle of cracks and scanning direction are considered in the simulation, and corresponding curves are obtained. Also, some corresponding experiments are carried out. The experimental results show that the model described here has a high reliability.

2. THEORETICAL MODELS

The MFL problem can be treated as a static magnetic problem. It can be expressed by Maxwell's equations below:

$$\nabla \times \vec{H} = \vec{J} \tag{1}$$

$$\nabla \cdot \vec{B} = 0 \tag{2}$$

where $\vec{H}$ is the magnetic field intensity vector, $\vec{J}$ is the applied source current density vector and $\vec{B}$ is the magnetic flux density vector.

The field equations are supplemented by the constitutive relation that describes the behavior of electromagnetic materials. In permanent magnet region

$$\vec{B} = [\mu]\vec{H} + [\mu_0]\vec{M}_0 \tag{3}$$

where $[\mu]$, $[\mu_0]$ is magnetic permeability matrix, $\vec{M}$ is remanent intrinsic magnetization vector [5-6].

With this theoretical base, the contour results such as those seen in Figure 1 can be obtained. As shown in Figure 1, the magnetic flux leakage exists above or below the location of crack. Also, the model used in this work is shown in Figure 1.

3. SIMULATION RESULTS AND ANALYSIS

3.1 Influence of crack's depth on MFL

The magnetic flux leakage of crack is defined as the MFL value on the position of 2mm above the crack. The curve of density of the magnetic flux leakage as a function of different depth of cracks is shown in Figure 2. It shows the density of MFL increases nonlinearly and with the increasing rate as crack depth increases. That indicates that the method of MFL is more sensitive to detect greater depth cracks than smaller ones.

3.2 Influence of crack's width on MFL

The curve of density of the magnetic flux leakage as a function of different widths of cracks is shown in Figure 3. It shows the density of MFL increases nonlinearly but with a decreasing rate as crack width increases. That indicates that the method of MFL is not sensitive to detect the widths of cracks when it is much larger.

3.3 Influence of crack's angle on MFL

It is shown in Figure 4 that the density of MFL decreases with a decreasing rate as crack angle increases. That indicates the near surface cracks are difficult to detect. As a matter of fact, the near surface cracks have little influence on the performance of components in most instances.

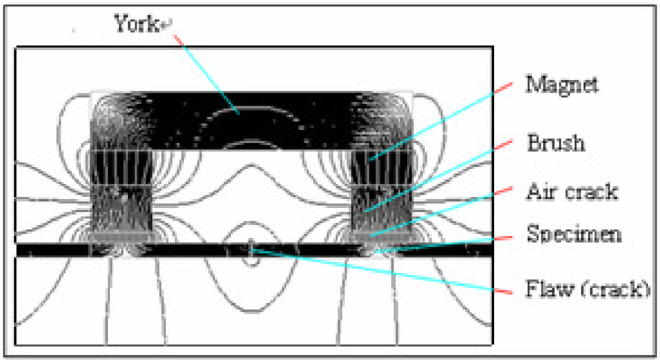

Figure 1. Magnetic flux distribution by 2-D simulation

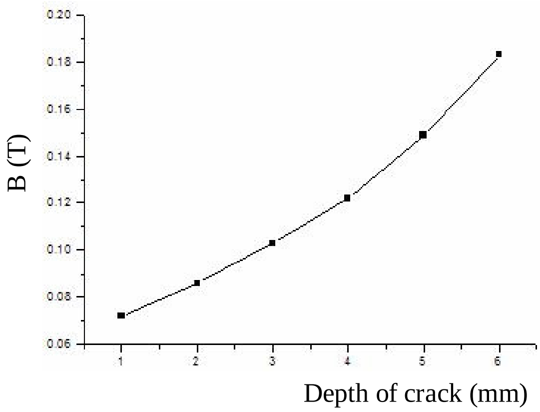

Figure 2. Density of MFL in the cases of different creak depths

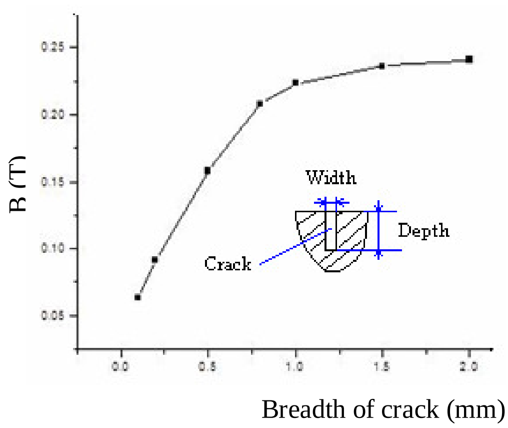

Figure 3. Density of MFL in the cases of different crack widths

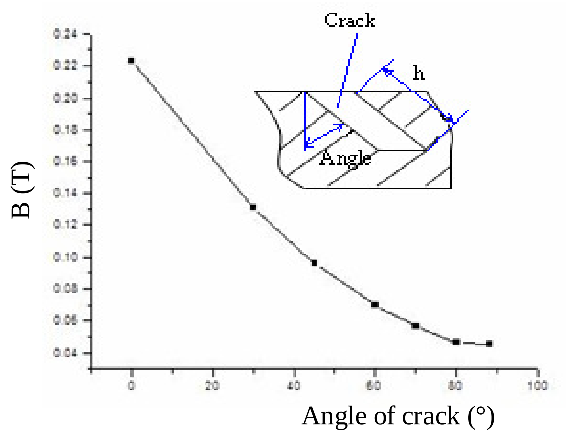

Figure 4. Density of MFL in the cases of different angles of cracks

3.4 Influence of scanning direction on MFL

As shown in Figure 5, the density of MFL decreases with a decreasing rate as the scanning angles increases. When the scanning angles is 90°, the value of MFL density is almost zero. It indicates the cracks may be not detected when the scanning direction parallels the cracks direction.

4. EXPERIMENTS AND ANALYSIS

In order to verify the numerical model presented in this paper, the experiments on influence of depths and scanning directions of cracks were carried out. The device used in experiment is shown in Figure 6.

4.1 Experiment on depths

The test sample was steel plate with 6mm thickness. As shown in Figure 7, the breadth of signals increases with the increasing of depths of cracks from 1 mm to 6 mm. These show the same trend as the results of the numerical simulation.

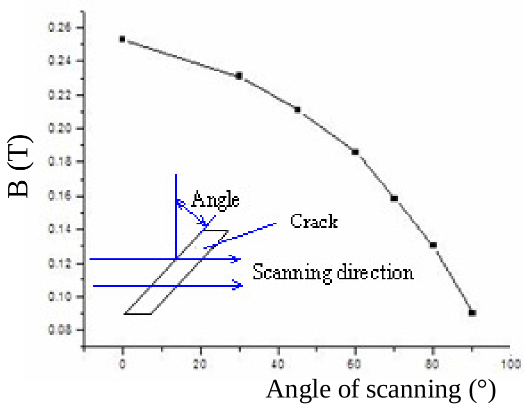

Figure 5. Density of the MFL in the cases of different scanning angles

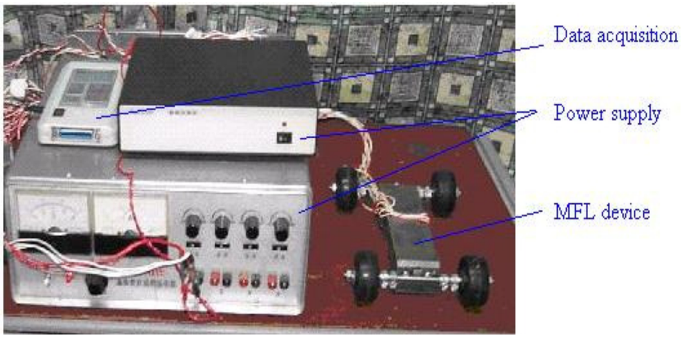

Figure 6. MFL device

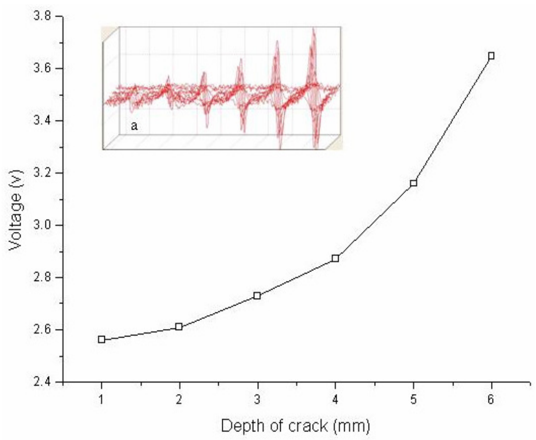

Figure 7. Experiment on crack depth influence a: experimental signals

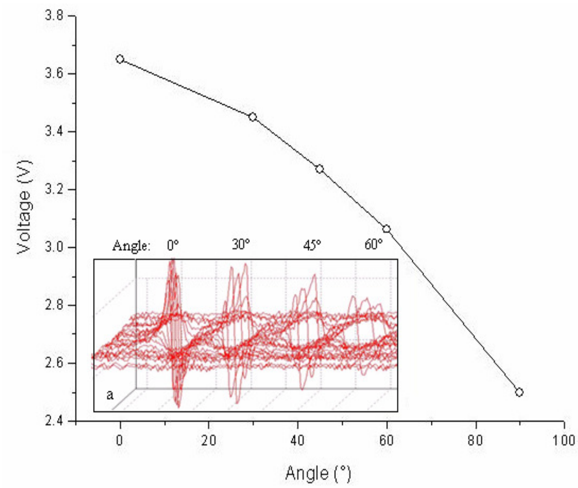

Figure 8. Experiment on influence of scanning directions a: experimental signals

4.2 Experiment on scanning directions

The experiment on scanning direction was carried out with 6mm thickness plate and 6mm depth cracks. As shown in Figure 8, the breadth of signals decreases with the increasing of angles from 0°to 90°between cracks and scanning directions. These signals also show the same trend as the results of the numerical simulation.

So, the cross-scanning method is recommended for MFLT when there may be cracks in the specimen.

5. Conclusions

In this paper, numerical simulations were carried out to analyze the MFL on the crack inspection basing a finite element method. The parameters influencing the MFL of cracks are considered and the corresponding curves are obtained. Also, experiments are done to verify the model. The experimental results show high consistency with simulation results. It is concluded that:

(1)The method of MFL is more sensitive to greater depth cracks than shallower ones. The breadth of inspection signals increases with increasing depths of cracks, and the rise rate is more and more rapid. The relationship between the depths of cracks and the inspection signals is not linear.

(2)The breadth of inspection signals increases with increasing widths of cracks, but the rise rate is more and more slow. Also, the relationship between the widths of cracks and the signals is not linear.

(3)The cracks may be not detected by MFL inspection when the magnetic flux parallels with it. So, the cross-scanning method is recommended for MFLT when there may be cracks in the specimen.

References

[1] G. DAI, Y.L. LIU, Z.J. YANG, W.M. YANG. Analyzing the influence of different parameters on the crack magnetic flux leakage based on the finite element method [J], Chemical machinery. 2005,(32):279-282

[2] Z.Y. HUANG, P.W. QUE, L. CHEN. 3D FEM analysis in magnetic flux leakage method[J]. NDT&E International, 2006 ,(39):61-66

[3] G. DAI, Y. TU, Z.J. YANG. Dynamic Simulation of Magnetic Flux Leakage Field of Columniform Surface Corrosion Defect Based on 3D Finite Element Analysis[J]. Nondestructive Inspection. 2007, 29(01):01-08

[4] G. DAI, Y.D. WANG, Z.J. YANG. Development and experimental result analysis of the magnetic flux leakage inspection instrument [J]. Journal of Daqing Petroleum Institute. 2004, 28(01):89-90

[5] G. KATRAGADDA, J.T. SI, W. LORD. A comparative study of 3D and axisymmetric magnetizer assemblies used in magnetic flux leakage inspection of pipeline [J]. IEEE Transaction on Magnetics, 1996, 32 (3):1573-1576.

[6] J. PHILIP, C.B.RAO, T. JAYAKUMAR, B. RAJ. A new optical technique for detection of defects in ferromagnetic material and components. NDT&E International [J]. 2000, (33)289–295