NDT&E International 42 (2009) 369–375

Contents lists available at ScienceDirect

NDT&E International

journal homepage: www.elsevier.com/locate/ndteint

A fast method for rectangular crack sizes reconstruction in magnetic flux leakage testing

Yong Zhang [a,*], Zhongfu Ye [b], Chong Wang [b]

[a] School of Computer and Information, Hefei University of Technology, Hefei, 230009 Anhui, People's Republic of China
[b] Institute of Statistical Signal Processing, University of Science and Technology of China, Hefei, 230027 Anhui, People's Republic of China

ARTICLE INFO

Article history:
Received 23 June 2008
Received in revised form
6 November 2008
Accepted 13 January 2009
Available online 29 January 2009

Keywords:
Magnetic flux leakage
Magnetic dipole model
Crack sizes reconstruction
Particle swarm optimization algorithm

ABSTRACT

Magnetic flux leakage (MFL) testing is widely used to examine ferromagnetic materials. For the reason of estimating the sizes of cracks in metals is important in piping industries, a fast method based on particle swarm optimization algorithm is proposed for reconstructing the sizes of rectangular crack in this article. Considering the magnetic leakage field intensity is related to the air gap between the inspection specimen and the sensor, we give the reconstruction results in different lift-off values. Besides, the influence of different magnetic conditions to the reconstruction effectiveness has been investigated. The simulation results have shown the rapidity and accuracy of the proposed method.

1. Introduction

The magnetic flux leakage method is one of the most important and sensitive method for the examination of surfaces and near-surface areas in ferromagnetic materials [1]. One of the essential roles of non-destructive testing is to detect the sizes of cracks in the critical parts of industrial devices [2].

Forster investigated the shapes of 128 cracks whose width within 50 μm, and the analysis results show that the shapes of these cracks are mainly composed of rectangular and "V"-shaped crack. [3]. Therefore, the rectangular crack as a basic but important defect form has obtained a lot of attention. Ramuhalli et al. used wavelet basis function neural networks as a forward model to predict the crack's sizes [4,5]. Minkov et al. divided the crack into many small rectangular cracks and reconstructed the crack with complex profiles by the Nelder–Meade simplex search method [6,7]. Hari et al. solved the inverse problems using the finite element model and the genetic algorithm [8].

In this article, we give the expression for predicting the magnetic leakage field intensity based on magnetic dipole model and introduce the particle swarm optimization (PSO) algorithm into the problem of estimating the defect sizes from the vertical component magnetic leakage field intensity. With given parameters of a crack, the magnetic leakage field intensity is determined by two factors. The first one is the air gap between the specimen and the sensor, i.e. the lift-off value of the sensor. And the other one is the magnetic condition [9]. We reconstruct the sizes of two rectangular cracks with different lift-off values and magnetic conditions. The FEM software ANSYS 5.7 simulates the data of magnetic leakage field intensity.

2. Reconstruction approach

2.1. The crack model

The length, width and deepness of the rectangular surface crack are $2l$, $2a$ and d, respectively. And define the applied magnetic field direction as the positive direction of the x-axis, which is shown in Fig. 1.

The magnetic dipoles distributed on the walls ABCD and EFGH generate the magnetic leakage field out of the crack. The z-component magnetic leakage field intensity at the point (x, y, z) is predicted by the following equation [6,7,10].

$$H_z(x,y,z) = \int_{-l-y}^{l-y}\int_0^d \frac{m(u)}{4\pi\mu_0} \times \left\{\frac{(z+u)}{[(x+a)^2+y^2+(z+u)^2]^{3/2}} - \frac{(z+u)}{[(x-a)^2+y^2+(z+u)^2]^{3/2}}\right\} du\,dy \quad (1)$$

* Corresponding author. Tel.: +86 5513601314; fax: +86 5513601305.
E-mail address: zhangyong2003@ustc.edu (Y. Zhang).

0963-8695/$ - see front matter
doi:10.1016/j.ndteint.2009.01.006

where $m(v)|_{v\in[0,u/d]} = m_1+m_2v$ is the surface density of the magnetic charge at the crack walls while u and v are the depth variables, m_1 and m_2 are magnetic charges per unit area. At the crack mouth, i.e. $v=0$, $m(0)=m_1$, and the distribution change rate is m_2. Minkov et al. have explained the dipole model and the parameters detailed and compared the measured value with the predicted value of the magnetic leakage field intensity [10]. Integration of Eq. (1) gives the following analytical expression [10]:

$$\begin{aligned} H_z(x,y,z) = \frac{m_2}{4\pi\mu_0 d}\Big\{&\left(\frac{m_1 d}{m_2}-z\right)[A_1(l-y,x+a)\\ &+A_1(l+y,x+a)-A_1(l-y,x-a)-A_1(l+y,x-a)]\\ &+[-(x+a)A_2(l-y,x+a)-(x+a)A_2(l+y,x+a)\\ &+(x-a)A_2(l-y,x-a)+(x-a)A_2(l+y,x-a)]\\ &+[(l-y)A_3(l-y,x+a)+(l+y)A_3(l+y,x+a)\\ &-(l-y)A_3(l-y,x-a)-(l+y)A_3(l+y,x-a)]\Big\} \end{aligned} \tag{2}$$

where

$$\begin{aligned} &A_1(l-y,x-a)\\ &=\ln\left[\sqrt{\frac{(x-a)^2+(z+d)^2}{(x-a)^2+z^2}}\times\frac{(l-y)+\sqrt{(x-a)^2+(l-y)^2+z^2}}{(l-y)+\sqrt{(x-a)^2+(l-y)^2+(z+d)^2}}\right] \end{aligned} \tag{3}$$

$$A_2(l-y,x-a)=\tan^{-1}[A_{21}(l-y,x+a)] \tag{4}$$

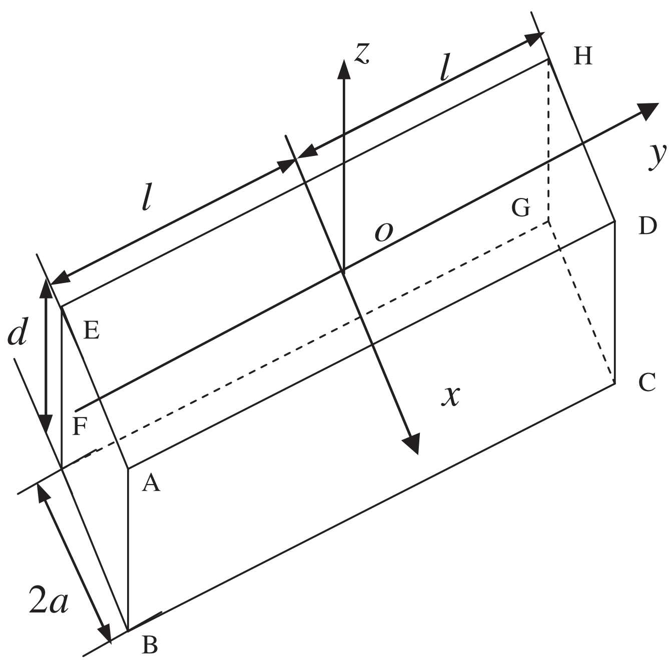

Fig. 1. The sizes of a rectanglular crack and its coordinate.

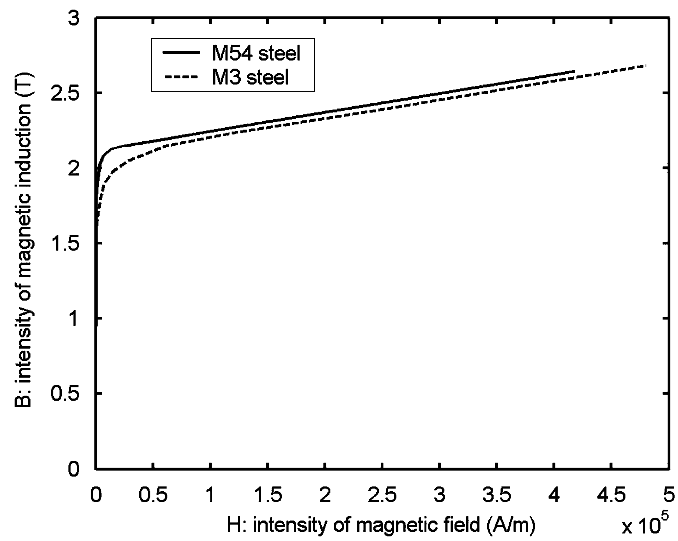

Fig. 3. The B-H curves of the M54 and M3 steel.

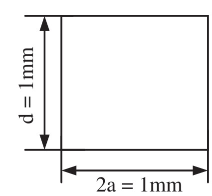

Fig. 4. The cross-section in the x–z plane of a rectanglular crack.

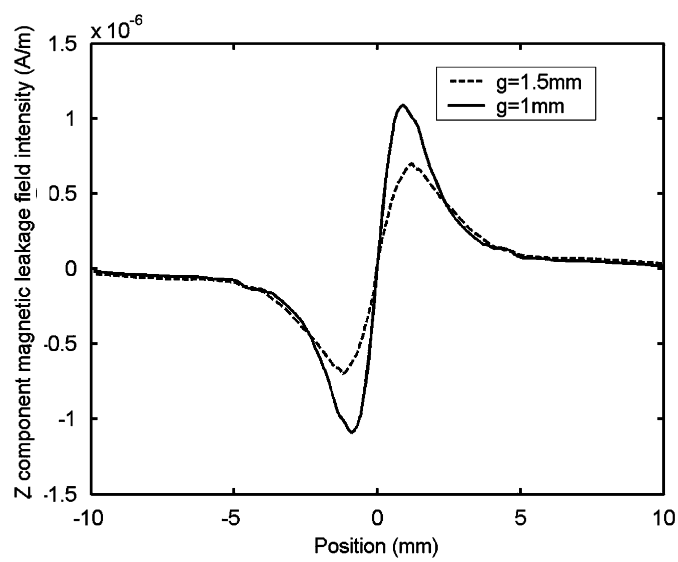

Fig. 5. The z component magnetic leakage field intensity in different lift-off value.

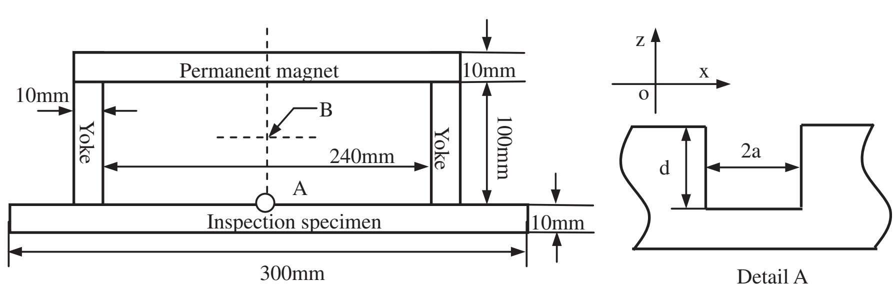

Fig. 2. The 2-D inspection model.