NDT&E International 53 (2013) 31–35

Contents lists available at SciVerse ScienceDirect

NDT&E International

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

Analysis of the lift-off effect of a U-shaped ACFM system

Li Wei *, Chen Guoming, Yin Xiaokang, Zhang Chuanrong, Liu Tao

Centre for Offshore Engineering and Safety Technology, China University of Petroleum, Shandong Qingdao 266555, People's Republic of China

ARTICLE INFO

Article history:
Received 22 June 2012
Received in revised form
10 September 2012
Accepted 1 October 2012
Available online 17 October 2012

Keywords:
ACFM
Lift-off
U-shaped probe
Simulation ANSYS
Experiment

ABSTRACT

Non-contact inspection is the main advantage of the alternating current field measurement (ACFM). The lift-off effect lowers the mutual-inductance between the ACFM probe and the test sample. The lift-off value has a significant influence on electromagnetic signal and the measurement accuracy of a U-shaped ACFM system. To optimize the U-shaped ACFM system, the lift-off value is determined through simulation analysis and experimental study in this paper. The distribution and intensity of the alternating magnetic field signals above the crack at different lift-off values for the U-shaped ACFM probe are simulated in ANSYS. The relationship between the lift-off value and the amplitudes of the electromagnetic signals is studied using a linear least squares fitting method. By analyzing the simulation results, 4 mm is selected to be the optimal lift-off value for the U-shaped ACFM probe. To verify the analysis of lift-off effect, real crack inspection experiments are conducted using the U-shaped probe of an ACFM prototype in laboratory. The results show that a 4 mm lift-off value is acceptable for this U-shaped ACFM probe considering both inspection sensitivity and stability.

1. Introduction

Alternating current field measurement (ACFM) was developed for the detection and sizing of surface-breaking cracks. It is now used in many applications [1]. ACFM functions through non-conductive coatings applied at underwater welds, and is an alternative nodestructive test (NDT) technique of the conventional Magnetic Particle and Penetrant Testing. ACFM measures the alternating magnetic field disturbances. The disturbances increase when the induced electric current is disturbed by the presence of a surface breaking crack. The main advantage of ACFM, compared to the conventional eddy current (EC), is that it requires no contact with the workpiece. This eliminates the need to clean and brighten the metal surface for testing, which saves enormous cost and time. However, when the surface of the workpiece is covered with layers of coating or marine growth, it may not be possible to achieve a close proximity between the probe and the metal surface [2]. The lift-off is the distance between the ACFM probe and the workpiece. This distance influences the desired characteristics of the ACFM signals [3]. This influence leads to significant errors in crack depth measurement. On one hand, the amplitudes of alternating magnetic field disturbances become lower as the lift-off increases. On the other hand, the signals induced and received by ACFM probe are unstable when the lift-off is too small. A small variation of lift-off, which may be due to varying coating thickness, irregularities on sample surface or movement of probe, will lead to a large change in the signal response [4]. It is crucial to find an appropriate lift-off value for optimal signal response.

The lift-off effect is similar to the eddy current NDT. Several methods are widely applied to compensate the lift-off effect in EC inspections [5,6]. But a such method is not available for the lift-off effect in ACFM. The effect of lift-off distance was investigated in [3,7] with a mathematical model. Amineh et. al [2] proposed a method for sizing long surface breaking crack at a stable lift-off distance in ACFM. These compensation methods and model mentioned above are based on the signals received by the ACFM probe with a stable lift-off distance, whereas the actual lift-off distance always varies. This paper aims to determine an optimal lift-off value for a specific U-shaped ACFM system, which helps the probe receive stable signals with a small lift-off variation.

This paper is organized as follows. In Section 2, based on a brief description of the U-shaped ACFM probe structure, the distribution and intensity of the alternating magnetic field signals above the crack at different lift-off values are simulated in ANSYS. To verify the analysis of lift-off effect and obtain the optimal lift-off value for this specific U-shaped ACFM probe, experiments are discussed in Section 3.

2. Simulating lift-off for a U-shaped ACFM probe

2.1. U-shaped ACFM probe

The U-shaped ACFM probe consists of an inducing component and a detecting component, as shown in Fig. 1. The inducing

* Corresponding author. Tel.: +86 186 7891 0863.
E-mail address: ronald8044@163.com (L. Wei).

0963-8695/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ndteint.2012.10.001

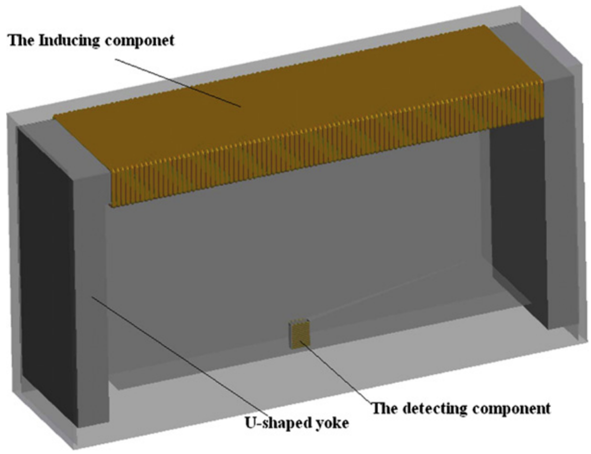

Fig. 1. Structure of U-shpaed ACFM probe.

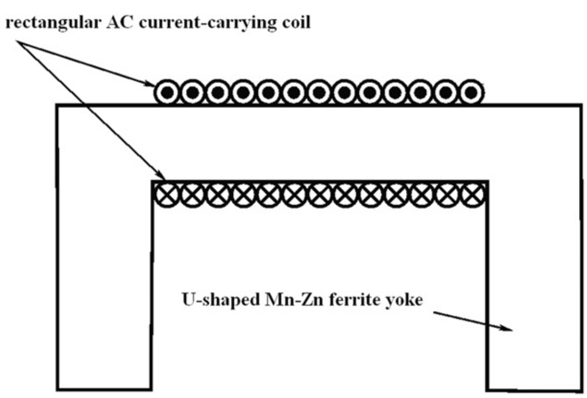

Fig. 2. Structure of inducing component.

component has a rectangular AC current-carrying coil and a U-shaped Mn–Zn ferrite yoke, as shown in Fig. 2. Previous works [8,9] have shown that a rectangular coil and a U-shaped yoke can provide a stronger uniform induction electromagnetic filed in the workpiece. The attenuating percentage of this uniform field transmitting in the workpiece is less than that of the field induced with other shapes— thus the detection sensitivity is increased [10,11]. The detecting component consists of B_X and B_Z detecting coils, which are designed to be orthogonally winded on one yoke, as shown in Fig. 3. The detecting component is used to simultaneously pick up the magnetic-field components in X and Z directions at the same point

When the U-shaped ACFM probe scans the surface of a workpiece along X direction, the current-carrying coil excites a uniform alternating current field and the uniform field is introduced to the surface of workpiece by the U-shaped yoke. If there is no surface defect in the workpiece, the excitation current distributes uniformly in the $y$direction, and the induced magnetic field is uniformly distributed in perpendicular to the current in the x-direction. When the probe scans over a surface defect of the workpiece, the presence of defects diverts current away from the deepest part and concentrates in a place near both ends of the defect, as shown in Fig. 4. This effect produces strong peaks and troughs in B_Z at the ends of defect, whereas B_X shows peaks at the ends and trough at the deepest point of defect. The detecting coils of the ACFM probe generally pick up the signals of B_X and B_Z for defect recognition and quantification [12–14]. The lift-off value affects the interaction between the ACFM probe and the workpiece, and causes error in defect recognition and quantification.

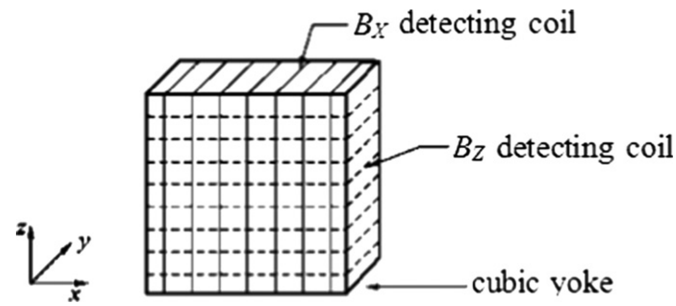

Fig. 3. Structure of detecting component.

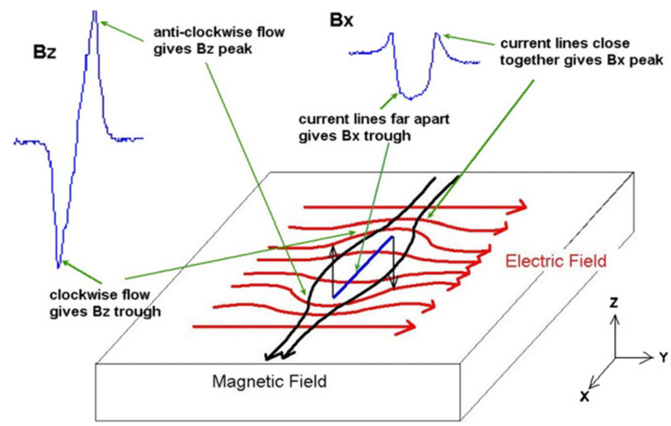

Fig. 4. Trinciple of ACFM.

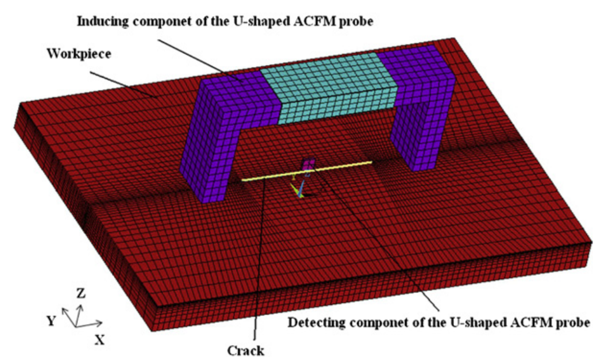

Fig. 5. FEM model of lift-off effect analysis for *U*-shaped ACFM probe.

2.2. Model development in ANSYS

Based on the configuration of the U-shaped ACFM probe and the ACFM principle, a finite element method (FEM) model is built in the electromagnetic module of ANSYS, as shown in Fig. 5. This model is used to analyse the relationship between the lift-off distance and the magnetic-field components B_X and B_Z. The FEM model consists of the *U*-shaped ACFM probe and the mild steel sheet workpiece with a crack. The longitudinal section of the crack is rectangular with a 20 mm length and a 4 mm depth. The inducing coil of the ACFM probe carries an alternating current of 1 V at the initial phase of zero, and the analysis frequency is 6 kHz. The material parameters are given in Table 1.

2.3. Lift-off effect analysis

To find out the lift-off effect of the U-shaped ACFM probe, simulations were performed 36 times using the FEM model