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High sensitivity rotating alternating current field measurement for arbitrary-angle underwater cracks

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ABSTRACT

Alternating current field measurement (ACFM) technology has been used for sizing underwater structure cracks. However, conventional ACFM is more sensitive to cracks perpendicular to the induced current than cracks with other angles. In this paper, a rotating alternating current field measurement (RACFM) method and underwater test system are present for the detection of arbitrary-angle cracks with high sensitivity. The RACFM is proved by simulations and experiments. Arbitrary-angle cracks detection results obtained from ACFM and RACFM have shown that the RACFM method overcomes the limitation of directional detection of ACFM and effectively achieves high detection sensitivity for arbitrary-angle cracks on underwater structures.

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1. Introduction

In the past few decades, with the development in offshore oil & gas exploitation industry, the demand for key equipment, such as offshore platforms and pipelines, has increased dramatically. During the equipment's lifetime, they are suffering from a number of hazards including extreme storms, complex loads, and corrosions. Even a small crack will diminish the overall capacity of the key equipment significantly. In the past few years, several serious incidents were caused by key equipment failures in offshore oil and gas industry [1–4]. U.S. mineral management service reported [5] that 1443 incidents occurred in offshore during 2001–2007.

According to the results of the industry and government research programs [6–8], it is important to prevent future failure of underwater structures by providing cracks information using inspection technologies in early stages. However, there are lots of challenges in underwater inspections, because the marine environment is always coming with physical, chemical, biological factors and the complex surface situations, such as attachments on underwater structures, which influence the operations and cracks inspection results [3,9–13].

For underwater cracks inspection, visual inspection is a very useful and economical method, which relies on inspectors' ability and experience [14,15]. However, small and narrow cracks, such as stress corrosion cracks (SCC), are not visible to the unaided eye in most cases. Magnetic particle inspection (MPI) [16,17] is the most widely used method for underwater surface cracks inspection. MPI uses small magnetic particles, such as iron filings, to reveal and locate the surface cracks. However, its effectiveness depends on the situation of structures surface, which is similar to liquid coupled ultrasonic inspection methods [18,19]. But high levels of surface cleaning will be costly for underwater equipment. As a non-contact inspection technology, magnetic flux leakage (MFL) technology [20] does not require high level surface cleaning before inspection. MFL is based on magnetizing the equipment and sensing the flux leakage. About 90% of metal loss detections for underwater pipelines are performed with MFL. But it is difficult to detect tight cracks as the flux will flow around these cracks without leakage. Eddy current testing (ECT) is widely used for the detection of surface and subsurface flaws in conductive materials. Conventional ECT is highly sensitive to lift-off because of the variations in sensing coil's impedance [21]. In the underwater environment, the surface of structures is often uneven due to coatings and attachments. Therefore, constant lift-off is difficult to achieve, which affects the accuracy and detectability of conventional ECT.

ACFM is originally developed by University College of London (UCL) for sizing underwater cracks as an alternative to MPI, which based on the alternating current potential drop (ACPD) technology [22]. When the measurement is performed, the induced uniform alternating electromagnetic field will be disturbed by crack on structures. As shown in Fig. 1, two components of the disturbed magnetic field are measured to calculate the crack depth and length via mathematical models. The magnetic field in X direction

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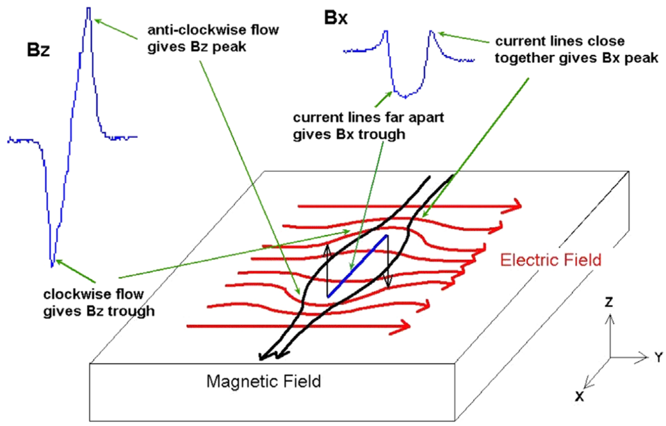

Fig. 1. Perturbations of electric field and magnetic field around a crack and ACFM signals obtained.

(B_x) shows a reduction for the decrease of current density, which reflects the crack depth, while magnetic field in Z direction (B_z) shows a negative and positive peak at both end of the crack, which indicates the crack length [23,24]. With the advantages of high tolerance to lift-off, no or little surface cleaning and accurate mathematical model, ACFM has been widely used for sizing cracks on underwater structures without calibration in the offshore oil and gas industry [25,26].

There is a signal excitation coil driven by AC current to induce alternating current and magnetic field on metal surface in conventional ACFM technology, as shown in Fig. 2. The induced current perturbation will be the maximum when the crack is perpendicular to the induced current (known as perpendicular crack in this paper). But it will be the minimum when the crack is parallel to the induced current (known as parallel crack in this paper), as shows in Fig. 3. Due to this phenomenon, the sensitivity of conventional ACFM is directional, high sensitivity for perpendicular cracks and low sensitivity for other angle cracks and almost no signal for parallel cracks. Therefore, traditional ACFM has to scan the same area several times along different directions to avoid missing the cracks, which significantly increases the cost of underwater inspections. In our previous work, an optimized double U-shaped orthogonal inducer is present to detect perpendicular crack with sensor array. In this paper, a rotating alternating current field induced by the double U-shaped orthogonal inducer and an underwater test system are present for the detection of arbitrary-angle cracks on underwater structure with one pass scanning.

This paper is organized as follows: Section 2 shows the theoretical model of RACFM and FEM analysis of rotating alternating electromagnetic field. The RACFM system is described in Section 3. Arbitrary-angle underwater cracks detection experiments are conducted and discussed in Section 4. Conclusion is made in Section 5.

2. Induced rotating alternating current field

2.1. RACFM theoretical model

According to the ACFM principle, it is sensitive to the perpendicular crack as the distortion of induced alternating current field is most significant when the perpendicular crack presents, as shown in Fig. 3. If the induced alternating current rotates periodically, the arbitrary-angle cracks in any direction will be perpendicular to the induced field at one moment in a period, which makes it possible to have high detection sensitivity for arbitrary-angle cracks. A rotating magnetic field can be constructed using

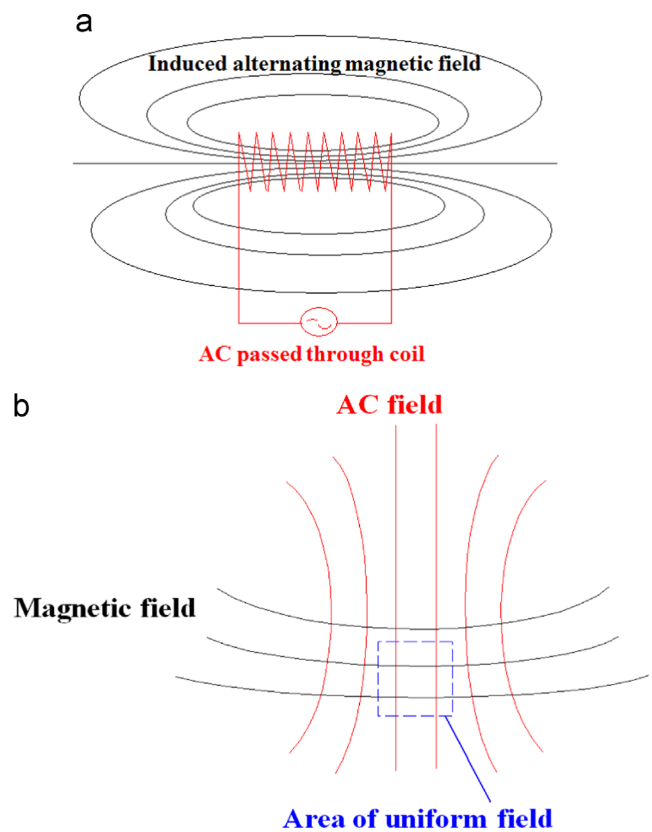

Fig. 2. Induced AC current and Magnetic field using a signal excitation coil in traditional ACFM (a) around the excitation coil, and (b) on the metal surface.

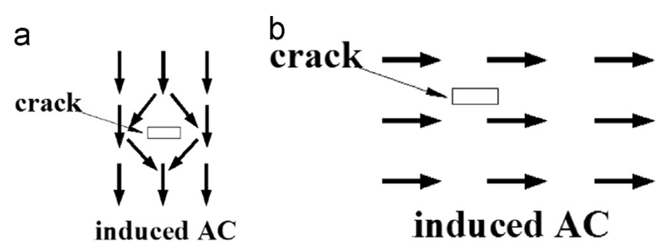

Fig. 3. Inducted AC current field perturbation caused by, (a) perpendicular crack, and (b) parallel crack.

two orthogonal excitation coils with 90° phase difference alternating currents [27,28]. In this way, two same excitation coils winding on the U-shaped MnZn ferrite yokes are placed orthogonally along X direction (excitation X) and Y direction (excitation Y) as the double U-shaped orthogonal inducer of RACFM [29], as shown in Fig. 4. Excitation X and excitation Y are driven by one pair alternating currents, $i_x(t)$ and $i_y(t)$ respectively, which are defined as follows.

$$i_x(t) = I_0 \sin(\omega t + \alpha_0) \tag{1}$$

$$i_y(t) = I_0 \sin(\omega t + \alpha_0 + 90^\circ) \tag{2}$$

where I_0 is the amplitude of the alternating current, ω is the frequency of the alternating current, and α_0 is the initial phase of the $i_x(t)$. Amplitudes and frequencies of them are the same, while the initial phases are with 90° delay.

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