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Study on offset measurement of underwater high-speed moving body based on single induction coil

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ABSTRACT

In this paper, a new offset measurement method for underwater rod-shaped high-speed moving body has been presented. Based on the principle of electromagnetic induction, the offset test reference model of the underwater detection sensor was developed to analyze the influence of offset on the induced electromotive force of the underwater inductive sensor. Moreover, simulations by MATLAB was carried out to analyze the influence of offset on the induced electromotive force of the measurement system while underwater high-speed moving body passing through the induction coil in different direction. Two important factors correlated closely with the offset were obtained, which are the amplitude and the width between the adjacent peak and peak-valley of the induced electromotive force caused by the high-speed moving body through the induction coil. And most importantly, an offset measurement experiment of underwater high-speed moving body based on single induction coil was conducted to validate the simulation results obtained above. By comparing the experiment results with the simulation data, the new offset measurement method put forward in this work was proved to be feasible.

1. Introduction

When the rod-shaped moving body moves underwater at the speed of quicker than 100 m/s, it is necessary to observe whether the moving target will deviate from the pre-calculated position or not. The current approach is that putting one board perpendicular to the predetermined trajectory in the sealed cabin filled with water, on which perforation will be left after the rod-shaped moving target moved through the board, thus the location where the rod-shaped moving body moved through the wood can be determined. However, there are a few problems about the method for judging the motion offset of rod-shaped movement: (1) inconvenient observation for the reason that the test shall be performed underwater, (2) generally the offset of a set of data cannot be distinguished due to the board removed from underwater only after a group of tests; (3) poor real-time characteristic. When the common photoelectric coordinate targets on the land are used underwater, there are some problems caused such as sealing difficulties, the impact of water quality, light path refraction and reflection in the propagation. Therefore, the paper is intended to carry out the study of the automatic test method for underwater high-speed moving body offset.

This provides a theoretical basis and experimental data for the offset automatic testing of underwater high-speed moving body, while seeking a kind of simple and inexpensive test equipment.

2. Detection principle

Following questions should be considered when designing the test equipment: (1) non-contact measurement method should be adopted in order to avoid interfere with

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the moving body; (2) measurement sensors and equipment should be waterproof for the sake of installation convenience underwater and low requirement for the water quality; (3) when high-speed moving body moves through the sensor side, test equipment should sense with no distortion in real time, that is the test equipment has certain response rate. Underwater high-speed moving body made from the steel structure in the test can be magnetized or carry magnetic bead, while the induction coil is often used to measure the velocity of underwater high-speed moving body, which could not interfere with the projectile motion underwater. Meanwhile, aqueous medium's influence on magnetic induction intensity can be negligible. Consequently, offset test device of underwater high-speed moving body is an ideal device as long as reliable moisture proof and insulation is taken on the induction coil [1].

According to the principle of the induction coil, for purposes of analysis, allowing for the diameter of the general high-speed moving body is much smaller than the diameter of the induction coil and the length is much smaller than the radius of the coil, magnetized high-speed moving body is simplified to one magnetic dipole with the positive and negative points magnetic charge where magnetic moment $\vec{p}$ is magnetic properties of magnetic dipole and regarded as a point dipole. Furthermore, suppose the orientation of magnetic moment $\vec{p}$ coincided with the direction of movement and coil axis. Thus, to the induction coil, analysis of the coil mechanism can be converted to the analysis of the induced electromotive force ε generated by a point magnetic dipole with magnetic moment $\vec{p}$ going through a coil with radius R and N turns along the central axis, where coordinate system is shown in Fig. 1. In the Fig. 1c is the offset between the trajectory of the moving body relative and the coil target axis and μ_0 is the magnetic permeability [2–5].

The magnetic flux ϕ_0 through a single coil of the induction coil is [2]:

$$\begin{aligned}\phi_0 &= \oint_l U_\kappa dl \\ &= \int_0^{2\pi} U_\varphi R d\varphi \\ &= \frac{\mu_0 p R}{2\pi}\int_0^{\pi} \frac{R - c\cos\varphi}{(R^2+c^2+z^2-2Rc\cos\varphi)^{3/2}} d\varphi\end{aligned} \quad (1)$$

When the high-speed moving body with velocity v goes through the single coil, the induced electromotive force in the coil is expressed as:

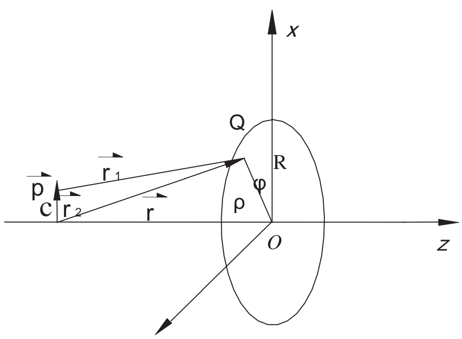

Fig. 1. Coordinate system.

$$\varepsilon_0 = -\frac{d\phi_0}{dt} = \frac{d\phi_0}{dz}\cdot v \quad (2)$$

The relationship between induced electromotive force of induced coils and the displacement of high-speed moving body could be gained through simulation in Eq. (2) by MATLAB, where R is 150 mm, c is 0, 80 mm, and 120 mm respectively and other parameters are normalized, shown in Fig. 2.

The simulation curve in Fig. 2 shows that as the offset increase between the through position and the geometry axis of the induction coil, the following phenomena will happen when high-speed moving body go through the induction coil:

(1) Under the same conditions, bigger the offset is, greater the induced electromotive force amplitude is.
(2) Bigger the offset is, smaller the width between the two peaks (peak and peak-valley) is.
(3) The rate of change of the induced electromotive force $d\varepsilon/dz$ will increase significantly, as the increase of offset.
(4) No matter how much the offset of high-speed moving body passing through the induction coil is, the waveform midpoint (A in Fig. 2) corresponding to the induced electromotive force is always zero (see Fig. 2).

Therefore, study on how offset influence induced signal could be performed from the amplitude and waveform width.

3. The relationship between the offset and amplitude

The parameters irrelevant with structural parameters in Eq. (2) should be normalized, while l_1 is 0.091 mm, l_1 is 0.024 mm, a is 0.0025 mm, b is 0.0008 mm, and R is 150 mm. RM's change rule with the change of the offset c is shown in Fig. 3, where RM is the ratio of the maximum of the induced electromotive force caused by the offset

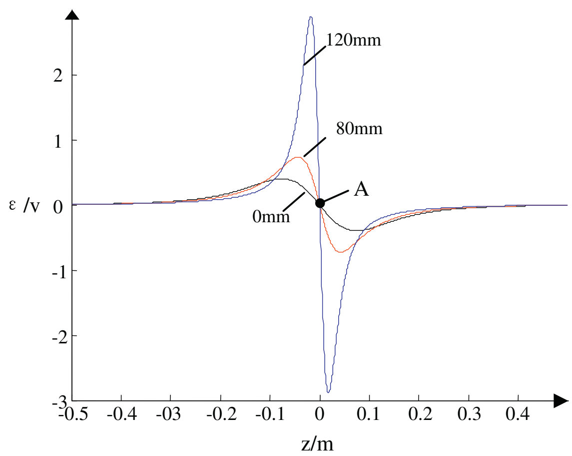

Fig. 2. The relationship between the induced electromotive force and high-speed moving body displacement under different offsets.