

Study on Method of Underwater Electromagnetic Target Dimension Recognition

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Abstract—The detection range and the equipment-target encounter speed are key factors to the capability of target dimension recognition in an underwater electromagnetic detection system. In view of that, a novel dimension recognition method based on the detection range and the encounter speed extracting was proposed in this paper. This method is able to suppress interference more effectively and improve the capability of the target dimension recognition in the underwater electromagnetic detection system. The target dimension features were analyzed. The extracting algorithms for the detection range and the encounter speed were deduced. The feasibility of improving the target dimension recognition capability by considering factors such as the detection range and the encounter speed was proved via examples.

Keywords—electromagnetic detection; underwater electromagnetic propagation; feature extracting; dimension recognition

I. INTRODUCTION

The target recognition capability is very important to the underwater electromagnetic detection equipment. However, the energy attenuation in electromagnetic wave propagation process underwater is serious and strongly nonlinear. As a result, the system operating frequency, the signal waveform and the system detection range are more likely to be restricted. Only the signal strength and delay of the electromagnetic wave can be utilized in the underwater target detection system design. If the targets' shape, size, equipment-target encounter distance and speed differ considerably, the accuracy and consistence of the target detection would be affected. Then the certain action control requirement could not be realized easily and reliably.

Recognition by the underwater targets' dimension features can not only improve the capabilities for target detection and recognition in the electromagnetic detection system, but also effectively suppress interference and reject false targets with low similarity or weak relevance to the true ones. So the proposed method has great significance to improve the operation reliability and recognition accuracy of the system.

II. DIMENSION ELECTROMAGNETIC FEATURES OF UNDERWATER TARGET

For the active electromagnetic detection equipments, the target reflected electromagnetic field signal is a kind of

amplitude modulation waveform modulated by $H_{zm} \cdot f(t)$ [1].

$$H_{zp}(t) = H_{zm} \cdot f(t) \cdot \sin(\omega_0 t + \varphi_0) \quad (1)$$

$$f(t) = e^{-\rho t^2} \quad (2)$$

$$\rho = \frac{0.36 V_{TK}^2 \sin^2 \theta_k}{B_k^2 + (1 + 0.063r)} \quad (3)$$

$$B_k = K_B \frac{B}{\sin \theta_k} \quad (4)$$

In the equations above, we defined the H_{zm} as maximum magnitude of the received signal (A/m); the ω_0 as signal frequency (rad); the φ_0 as initial phase of the received signal (rad); the V_{TK} as relative velocity (m/S); the r as detection range (m); the θ_k as encounter angle (rad); the B_k as target equivalent width (m); the K_B as target shape factor; the B as target actual width (m).

From (1) to (4), the target reflected signal waveform is drawn as shown in Fig.1. The target dimension B could be estimated from the signal duration time ΔT . The features of the underwater target electromagnetic dimension could be described as:

$$B_k = \Delta T \cdot V_{TK} \quad (5)$$

$$\Delta T = \sqrt{\frac{0.36 \sin^2 \theta_k}{\rho} - \frac{1 + 0.063r}{V_{TK}^2}} \quad (6)$$

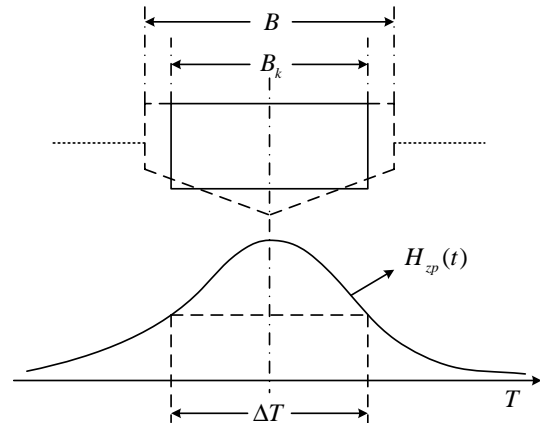


Figure 1. Feature curve of $H_{zp}(t)$

From (5), (6) and Fig.1 we can see that, the target dimension recognition could be realized easily by testing the

signal duration time ΔT in condition of a known target and encounter situation. Based on that method, the conventional electromagnetic detection equipment usually sets a value ΔT to judge the target recognition and locate it for a further action. However, in a practical application, the target dimension factors (B 、 K_B), encounter conditions (V_{TK} 、 θ_k) and system capability (r) are usually unknown and nonlinear. If the dimension factors mentioned above are heterogeneous and could not be achieved beforehand, the conventional target dimension recognition method would cause a serious deviation. As a result of that, the optimal action time controlling would fail. Even an omission or a misoperation would happen [2-4].

III. TARGET DIMENSION FACTORS

In the process of the system and the target encountering, there are many objective factors influencing the electromagnetic wave receiving and the target dimension recognition, such as target shape factor K_B , encounter angle θ_k , and so on. Those factors can be given as experience values, and would not cause a serious deviation in dimension recognition. But the encounter speed V_{TK} and detection range r are more critical to the dimension recognition as shown in Fig.2. Considering certain electromagnetic detection equipment and a known target, we assume that the effective received signal duration time is ΔT_A in a situation of a longer equipment-target encounter distance and a higher relative velocity. Accordingly, the effective received signal duration time is ΔT_B in a condition of a shorter encountering distance and a lower relative velocity. Obviously, ΔT_A and ΔT_B are different even for the same target. If the system still recognizes the target by judging the invariable duration time set beforehand, there must be a serious mistake in the target dimension recognition [5].

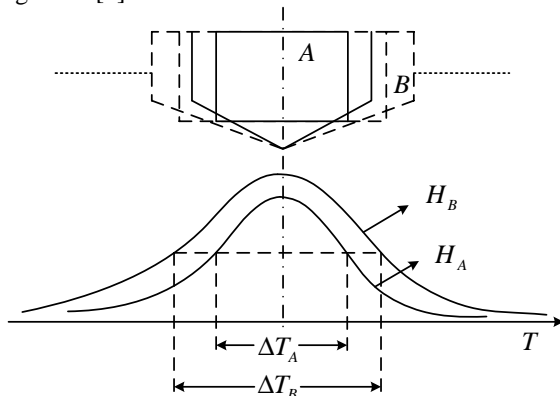


Figure 2. r 's and V_{TK} 's influences on ΔT

Considering the calculation of encounter speed V_{TK} and detection range r , it is very convenience to achieve the values via Doppler velocimetry and pulse ranging in the air. However, the underwater electromagnetic wave propagation features limit the detection system operation parameters. If

the overall platform is taken into consideration and an improvement is obtained in the system redesign, the value of encounter speed V_{TK} could be provided by a self-guided system. But it is more favorable for the detection system to solve that problem. As we known, the self-guided system is more likely to be blind in the near range of the target. But the underwater electromagnetic wave only can be utilized in near field. As a result, the parameter r could not be provided by the self-guided system in practical application.

A. Parameter r Acquisition

According to the propagation features^[1] of the electromagnetic wave in a conductive media, the magnitude of the electromagnetic wave will exponential decay and the phase lag will increase as the propagation distance increases. We define the magnitude attenuation coefficient as K_r and the phase shift coefficient as Φ_r :

$$K_r = \frac{|E|}{E_0} = \frac{|H|}{H_0} = e^{-\beta r} \quad (7)$$

$$\Phi_r = -\alpha r \quad (8)$$

In (7) and (8), α and β are defined as follows:

$$\alpha = \omega \sqrt{\frac{\mu \epsilon}{2} \left[\sqrt{1 + \frac{\sigma^2}{\omega^2 \epsilon^2}} + 1 \right]^{\frac{1}{2}}} \quad (9)$$

$$\beta = \omega \sqrt{\frac{\mu \epsilon}{2} \left[\sqrt{1 + \frac{\sigma^2}{\omega^2 \epsilon^2}} - 1 \right]^{\frac{1}{2}}} \quad (10)$$

The ϵ , μ and σ are defined as basic parameters describing the media electromagnetic features^[1]. The α and β are respectively defined as phase shift constant and magnitude attenuation constant [6, 7].

Though the features of magnitude attenuation and phase shift in underwater electromagnetic wave propagation are nonlinear, the value of propagation distance still can be obtained from the features mentioned above. Comparing the methods of distance extracting from magnitude to the method from phase shift, the method of ranging from the propagation phase shift is better in stability and accuracy [8].

B. Parameter V_{TK} Acquisition

According to the parameter V_{TK} from the received signal $f(t)$ or $H_{sp}(t)$, we could derivate the ρ calculation equations as follows in condition of sampling at equal time intervals Δt , as shown in Fig.3. It can be realized in the electromagnetic detection system design.

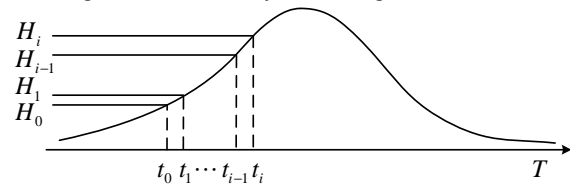


Figure 3. V_{TK} feature in $H_{sp}(t)$

$$f(t_i) = e^{-\rho t_i^2} \quad (i = 0, 1, 2, \dots) \quad (11)$$

After processing the sample data, the further calculations are as follows:

$$\ln \frac{f(t_{i-1})}{f(t_i)} = \rho(t_i - t_{i-1})(t_i + t_{i-1})$$

$$= \rho \cdot \Delta t(t_i + t_{i-1}) \quad (12)$$

$$\ln \frac{f(t_{i-1})}{f(t_{i+1})} = \rho(t_{i+1} - t_{i-1})(t_{i+1} + t_{i-1})$$

$$= \rho \cdot 2\Delta t(t_{i+1} + t_{i-1}) \quad (13)$$

$$\rho = \frac{B - A}{t_{i+1} - t_i} = \frac{B - A}{\Delta t} \quad (14)$$

In (14), the variable A and B are defined as follows:

$$A = \frac{1}{\Delta t} \ln \frac{f(t_{i-1})}{f(t_i)}; \quad B = \frac{1}{2\Delta t} \ln \frac{f(t_{i-1})}{f(t_{i+1})}$$

The target dimension recognition in uncertain conditions could be realized by using (5) and (6) according to the dimension factors [9, 10].

IV. EXAMPLES ANALYSIS

A. Example A

In this example we assumed that the target shape and the encounter speed V_{TK} had been known beforehand, and discussed the dimension estimation in condition of different detection range r ($0.5 \text{ m} \leq r \leq 6 \text{ m}$, $r_{i+1} = r_i + \Delta r$, $i = 0, 1, \dots, \Delta r = 0.5 \text{ m}$).

As we known, the encounter situation changes randomly as the underwater electromagnetic detection equipment passing through the target. This uncertain situation varies the value of target signal duration time ΔT and makes the problem of target dimension recognition more complex. In view of that, this paper defined the vertical encounter angle φ_{TK} , as shown in Fig.4, as the angle between the equipment voyage direction and the equipment-target connection as the equipment detected the target for the first time as getting close to it. Considering the most adverse encounter condition, as the detection equipment passing through the bottom of a cylindrical target in an abeam direction, the corresponding relationships between the distance traveled or the signal duration time and the value of φ_{TK} are shown in Fig.4.

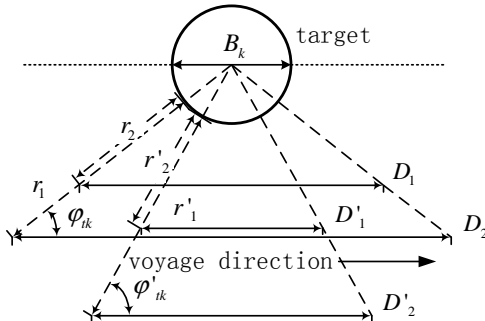


Figure 4. The sketch map of encounter situation

In order to estimate the target dimension when the r and the φ_{TK} vary, this paper assumed that the value of the

vertical encounter angle φ_{TK} varied in 75° , 60° , 45° , 30° , 15° and 0° . In addition the signal traveled journey D should be described as the equation below:

$$D = 2 * (r + \frac{B_k}{2}) * \sin(\frac{\varphi_{TK}}{2}) \quad (15)$$

This paper used the signal duration time ΔT to reflect the dimension estimation in (16):

$$\Delta T = \frac{D}{V_{TK}} \quad (16)$$

The simulation results were shown in the Fig.5.

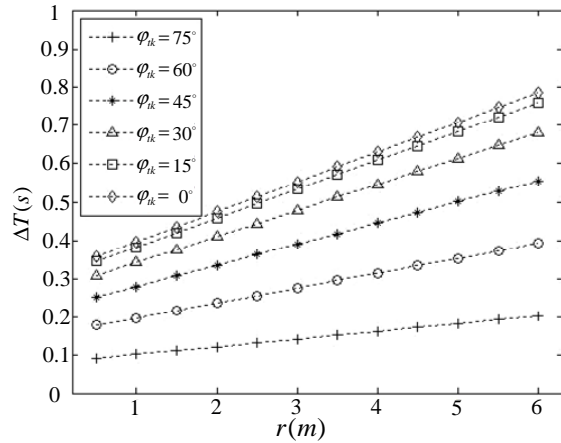


Figure 5. Example A simulation results

B. Example B

In this example we assumed that the target shape and the detection range r (5m) had been known beforehand, and discussed the dimension estimation in condition of different encounter speed V_{TK} ($20 \text{ kn} \leq r \leq 50 \text{ kn}$, $V_{i+1} = V_i + \Delta V$, $i = 0, 1, \dots, \Delta V = 5 \text{ kn}$).

The dimension estimation results could be calculated by (16) when the traveled journey was a constant as shown in Fig.6.

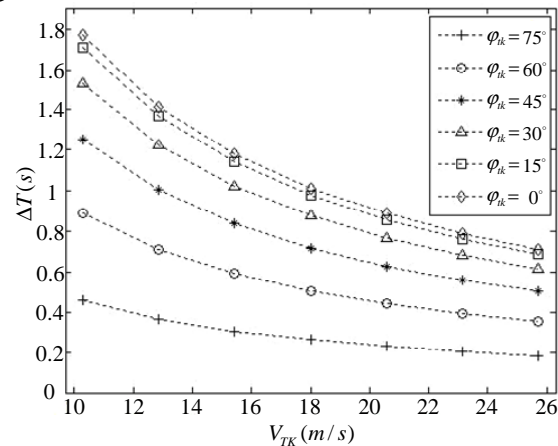


Figure 6. Example B simulation results

From the simulation results, we could draw the conclusions that the value of signal duration time ΔT varies as the detection range r , the encounter speed V_{TK} and the vertical encounter angle φ_{TK} varying. When V_{TK} is a

constant, the ΔT increases linearly as the r increasing. In addition, the smaller φ_{TK} the longer ΔT , and the ΔT increases faster. When r is a constant, the ΔT decreases nonlinearly as the V_{TK} increasing. The smaller φ_{TK} the longer ΔT , and the ΔT decreases rapidly.

V. CONCLUSIONS

The system detection rang and the equipment-target encounter speed are the key factors to the dimension recognition in underwater electromagnetic target detection. Those parameters affect the target dimension calculation and judgment directly. Therefore, the method, proposed in this paper, that recognize the target dimension by extracting the parameters r and ΔT in real-time is able to improve the capability of target dimension recognition in underwater electromagnetic detection system. It achieves the purpose of eliminating the interference from the false target and suppresses interference effectively.

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