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Research on the simulation of factors influencing maximum firing distance of acoustic homing torpedo

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Abstract. In the torpedo attack, the appropriate firing distance is the key to ensure the torpedo hit the target, it's necessary to ensure the firing distance used is within the maximum firing distance. Therefore, under the premise of known firing conditions, it's necessary to determine the maximum firing distance and be familiar with the factors that affect the value and the influencing rules of each factor. Based on the firing model of the acoustic homing torpedo, the expression of the maximum firing distance is established, and the main factors affecting the value are obtained. Through the simulation, the influence factors are analyzed quantitatively, and the rule of their influence on the maximum firing distance is founded out. This research can provide the necessary reference for the commanding officer in battle, in order to make full use of the research results and improve the hit probability of the acoustic homing torpedo.

1 Introduction

In torpedo attack, suitable firing distance and firing direction are the key to ensure torpedo hit the target. The so-called firing distance is the distance between the enemy and our firing platform when firing torpedoes. Sometimes the firing direction of a torpedo determined by the leading angel (the angle at which the firing direction relative to the target's bearing) does not always hit the target. This is because the power energy carried by the torpedo is limited, the maximum firing range (torpedo is stable at the velocity and depth within this range) is also limited, so the firing distance must be limited, its maximum allowable distance is the maximum firing distance. If the torpedo is fired at a distance more than the maximum firing distance, it is impossible for the torpedo to hit the target even if the torpedo is aiming accurately. Maximum firing distance is strictly defined as under certain firing conditions, torpedo from launch to hit the target consumed by the range is just the maximum firing range, then the distance between the firing platform and target is the maximum firing distance[1].

In the past, the research on the maximum firing distance is mainly focused on the straight running torpedo, wake homing torpedo and wire-guided torpedo[2-6]. At present, when using acoustic homing torpedoes, the consideration of the maximum firing distance is

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not enough. Therefore, it is very necessary to study it deeply and find out the main factors that affect its value and the influencing rules of each factor, so as to provide the necessary reference for the commander when using the acoustic homing torpedo to ensure a high hit probability.

2 Maximum firing distance and influence factors

As shown in Fig.1, d_g and W_g are target position and firing platform position when firing respectively, C_m is the course of target, C_l is the firing direction when the torpedo is running out of the tube. θ is the impact angle determined in advance by commanding and control system, φ is leading angle, Q_{mg} is the relative angle of target when firing torpedo. CT is the operationing distance of acoustic homing torpedo, denoted by r , TW_g is the torpedo searching range, denoted by S_{l1} , S_{l2} is homing track range[7], D_{gj} is the maximum firing distance, T is the position point when the torpedo finds the target.

In the triangle $W_g d_g C$, according to the relationship between target velocity and torpedo velocity, we get:

$$d_g C = \frac{V_m}{V_l} S_{l1} \tag{1}$$

V_m is the target velocity, V_l is the torpedo velocity. The ration of target velocity to torpedo velocity can be expressed in m , which is velocity ratio. Then, according to the cosine theorem, the maximum firing distance is:

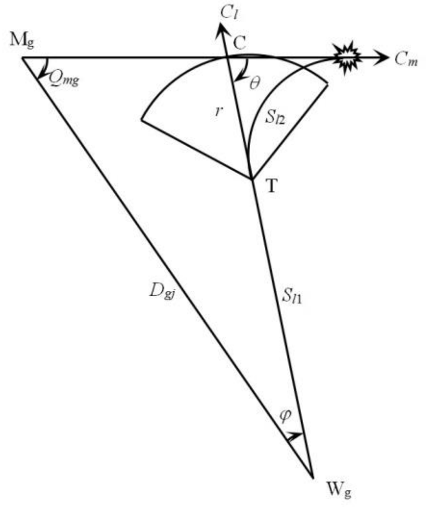

Fig. 1. Acoustic homing torpedo attack picture.

$$D_{gj} = \sqrt{(S_{l1}+r)^2 + (mS_{l1})^2 + 2mS_{l1}(S_{l1}+r)\cos\theta} \tag{2}$$

And then we can get:

$$D_{gj}=\sqrt{S_{l1}{}^{2}(1+m^{2}+2m\cos\theta)+r(r+2S_{l1}+2mS_{l1}\cos\theta)} \tag{3}$$

According to the definition of the maximum range:

$$S_{lj}=S_{l1}+S_{l2} \tag{4}$$

S_{lj} is the maximum range of torpedo, then

$$S_{l1}=S_{lj}-S_{l2} \tag{5}$$

The expression of S_{l2} is explicit:

$$S_{l2}=r\frac{1-m\cos Q_{m}}{1-m^{2}} \tag{6}$$

Q_m is the relative angle of target when the target is founded by the acoustic homing torpedo during the searching phase.

It's obviously to see from Eqn. (3), Eqn. (5) and Eqn. (6) that D_{gj} is related to V_m, V_l, S_{lj}, r and Q_m ,which are the main factors that affect the maximum firing distance.

Among the above parameters, V_m can be calculated by the commanding and control system, V_l and S_{lj} can be obtained according to the type of acoustic homing torpedo used. r is related to Q_m when the target is founded, and it changes with the difference of Q_m. This is because the operationing distance of the torpedo homing device will be quite different when the torpedo approaches the target with different relative angle of target or impact angle.

Usually, the relative angle of target when the homing device detects the target is approximately taken to be the impact angle during the straight running phase, then Q_m is equal to θ. As shown in Fig1, supposed that the midline of torpedo homing sector found the target. As mentioned above, under the known conditions of V_m, V_l, S_{lj}, then D_{gj} can be expressed as a function of Q_m and r. So in order to find maximum firing distance, the key is to get r under different Q_m or θ.

3 Operational distance of acoustic homing device

In the past, in the course of calculating the maximum firing distance, r is usually taken as a fixed value, which usually takes the acoustic homing distance in the transverse direction of target. In fact, r varies with the difference of Q_m, so it is bound to bring some errors. Therefore, it is necessary to obtain r corresponding to different relative angle of target firstly, and then we can calculate the maximum firing distance accurately.

The main factors affecting r are hydrologic condition[8], target noise, target reflection intensity, torpedo self-noise, ocean reverberation, and the performance of torpedo homing devices are closely related to it[9].

For active acoustic homing torpedo, in the process of calculating r , the establishment of the relationship varies with the main background noise. Here the main basis is whether the background noise is isotropic or not.

When the background noise is isotropic ambient noise, the theoretical calculation of r can refer to the active sonar equation:

$$TL = (SL + TS - NL + GL - DT)/2 \tag{7}$$

Where, TL is the sound propagation loss from the source to the target, SL is the sound level, TS is the target reflection intensity, NL is the background noise level, GL is the processing gain, and DT is the detection threshold of the torpedo homing device.

When the main background noise is ocean reverberation, the reverberation is not isotropic, then the active sonar equation becomes:

$$TL = (SL + TS - RL - DT)/2 \tag{8}$$

RL is the equivalent plane wave reverberation level. In ideal hydrologic condition, the active sonar of torpedo homing device is mainly affected by isotropic background noise, so in this paper, we adopt the Eqn. (7).

TL can be expressed as the sum of $20\lg r$ which is the expansion loss and βr which is absorption loss, that is:

$$TL = 20\lg r + \beta r \tag{9}$$

β is the attenuation coefficient of sound propagation.

$$\begin{aligned}\beta = &(1.2488\times10^{-5} - 6.0535\times10^{-7}t + 1.4767\times10^{-8}t^2 \\ &-1.5352\times10^{-10}t^3)\times(1-1.764\times10^{-5}h)\ f^2\end{aligned} \tag{10}$$

Where t is the temperature of seawater, h is the searching depth of torpedo and f is the center working frequency of torpedo.

Thus, Eqn. (7) can be written as:

$$20\lg r + \beta r = (SL + TS - NL + GL - DT)/2 \tag{11}$$

The above equation is also called the active acoustic homing equation for torpedo, where:

$$NL = 96\lg V_l - 33\lg f - 23.5\lg h \tag{12}$$

For active acoustic homing torpedo, TS is very important which affects r directly. TS depends on the size, the material of target as well as the angle of incident. The larger the geometric size of the target, the stronger the reflection is. The larger the reflection coefficient of the reflector is, the stronger the reflection is. The reflection is strong when sound wave incident from the target transverse. The reflection is week when sound wave incident from the front or rear of the target. In order to estimate the target reflection intensity, the target can be equivalent to an ellipsoid, whose long and short semi-axes A, B, C correspond to the length, width and draft depth of the target. For underwater target, C is the height. The target strength estimation equation is:

$$TS = 10\lg(G^2 U) \tag{13}$$

$$G = \frac{KABC}{2(A^2\cos^2 Q_m + B^2\sin^2 Q_m)} \tag{14}$$

$$U = \{0.251635Q_m^2 - 0.18555Q_m + 0.0365\sin[3(Q_m + 0.174537)] + 0.015X_m^2 \sin(9Q_m/2)\}^{-1} \tag{15}$$

K is the acoustic reflection coefficient, which is 0.94 for ships made of steel.

By substituting the above parameters into Eqn. (11), r corresponding to different Q_m can be obtained, and then the maximum firing distance under different θ can be calculated according to the Eqn. (3).

For passive acoustic homing torpedo, under ideal hydrological conditions, r depends on the sound propagation loss. The theoretical calculation of r can refer to the passive sonar equation:

$$TL = SL - NL + GL - DT \tag{16}$$

Thus, Eqn. (16) can be written as:

$$20\lg r + \beta r = SL - NL + GL - DT \tag{17}$$

The above equation is also called the passive acoustic homing equation for torpedo, where:

$$SL = 60\lg V_m + 9\lg T - 20\lg f + 20\lg k(Q_m) + 35.8 \tag{18}$$

T is the weight of target, $k(Q_m)$ is the sound level of target, which is related to relative bearing of target.

$$k(Q_m) = 0.3 + 3.9655\sin Q_m - 105.1651\sin^2 Q_m + 1093.9709\sin^3 Q_m - 5596.9957\sin^4 Q_m + 16776.5741\sin^5 Q_m - 31451.003\sin^6 Q_m + 37358.4773\sin^7 Q_m - 27319.4625\sin^8 Q_m + 11221.651\sin^9 Q_m - 1981.3219\sin^{10} Q_m \tag{19}$$

Approximate form is:

$$k(Q_m) = \sin|Q_m| + 0.3 \tag{20}$$

By substituting the above parameters into Eqn. (17), r corresponding to different Q_m can be obtained, and then the maximum firing distance under different θ can be calculated.

4 Simulation and analysis

Supposed the maximum firing distance is 20 km, torpedo velocity is 40 kn, SL is 140 dB, GL is 20 dB, DT is 10 dB, the center working frequency of torpedo is 24 KHz, h is 15 m. The attacking area is an isothermal layer with a temperature of 5 $°C$. The displace of target vessel 3000 ton. The target is submarine, whose intensity is according to the example [4.1] in the reference literature[10]. The target velocity is divided into three cases, namely12kn, 16kn, and 20Kn. Firstly, the opertioning distance of acoustic homing torpedo with different relative angle of target can be calculated. The simulation results are shown in Fig.2 and Fig.3 .

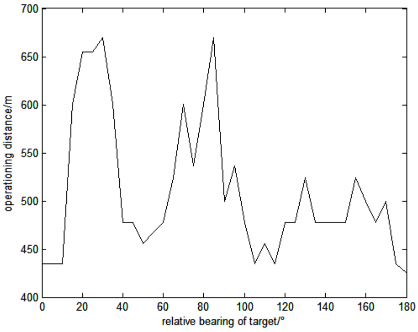

Fig. 2. Operationing distance of active acoustic homing torpedo.

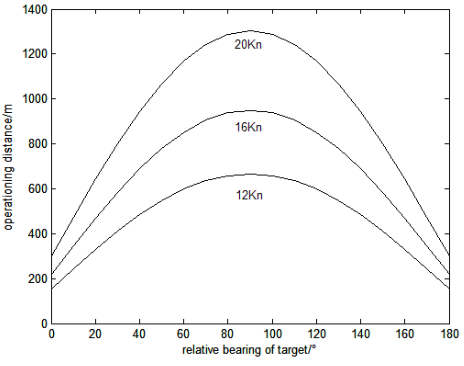

Fig. 3. Operationing distance of passive acoustic homing torpedo.

It can be seen from the solution of r that its value is not related to the target velocity. In Fig.2, r is obviously discrete, which is consistent with the discreteness of submarine's strength. That is to say, if the intensity of the submarine is large in one direction, the operationing distance of active acoustic torpedo in that direction is large. The intensity of the target in the transverse direction caused by the reflection of the hull mirror is strong. The intensity of the target in the bow and tail direction affected by the shielding effect of hull and wake is weak. The intensity near bow $\pm 30°$is strong, probably due to internal reflection of cabin structure.

As can be seen from Fig.3, when target velocity is fixed, r in the transverse direction is maximum, and r is decreasing gradually in the bow and stern directions. This fully shows that the torpedo homing device has a definite directivity, which is greatly affected by the relative angle of target. In addition, the higher the target velocity is , the bigger r is when the relative angle of target is fixed, because the higher target velocity, the more radiation noise, the easier torpedo homing device will find the target at a longer distance.

According to the above results, we can calculate the maximum firing distance under different target velocity and impact angle. The simulation results are shown in Fig.4 and Fig.5.

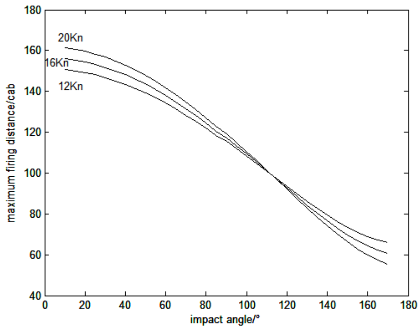

Fig. 4. The maximum firing distance of active acoustic homing torpedo.

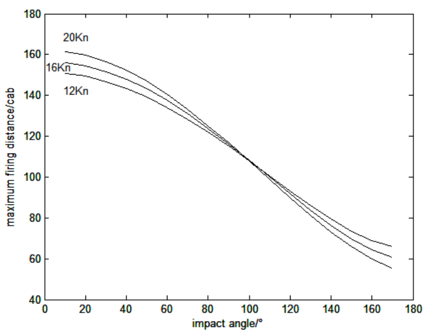

Fig. 5. The maximum firing distance of passive acoustic homing torpedo.

As can be seen from Fig.4 and Fig.5, we can get the same conclusions. D_{sj} decreases gradually with the increase of θ , when the target velocity is fixed. In addtion, when θ is small, D_{sj} increases gradually with the increase of target velocity. When θ is large, D_{sj} decreases gradually with the increase of target velocity.

As can be seen from Fig.3, the impact angle is 110°, when there is inflection point (here let's call it inflection point impact angel), and this inflection point impact angle will vary with the hydrologic environment and firing conditions.

According to the above simulation results, when the commanding officer is determined to use the acoustic homing torpedo, if the impact angle calculated by the commanding and control system is θ_0 ,and the corresponding maximum firing distance is more the distance between target and out platform, then we can take measures to reduce impact angle, so that the maximum firing distance is appropriately increased to meet the firing condition. Or when θ_0 has been determined, if the actual target velocity is more than the one calculated by commanding and system, measures can be taken to reduce θ (when θ_0 is less than the inflection point impact angle),or increase θ (when θ_0 is more than the inflection point impact angle), so that the maximum firing distance is appropriately increased to meet the firing condition.

5 Conclusion

The maximum firing distance of acoustic homing torpedo is related to many factors, only a few main factors are researched here. When using the acoustic homing torpedo, the commanding officer must consider the situation, target velocity and torpedo performance. Besides determining the firing direction, the maximum firing distance must be considered to the firing distance within the maximum firing distance. This requires the commanding officer to fully be familiar with the factors that affect the maximum firing distance, and be familiar with the rules, so that he can be sure when using the acoustic homing torpedo to improve the hit probability.

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