To cite this article: Yan J X, Xing J H, Zhang J P. Analysis on the influence of submarine's internal tank on the acoustic target strength[J/OL]. Chinese Journal of Ship Research, 2019, 14(6). http://www.ship-research.com/EN/Y2019/V14/I6/73.

DOI: 10.19693/j.issn.1673-3185.01524

Analysis on the influence of submarine's internal tank on the acoustic target strength

*Yan Jiaxiang**, *Xing Junhua*, *Zhang Junping*

China Ship Development and Design Center, Wuhan 430064, China

Abstract: [**Objectives**] The influence of submarine's internal tank on the acoustic target strength control is studied. [**Methods**] The planar element method based on Kirchhoff high frequency approximation was used to calculate and analyze the influence of internal tanks at different positions inside the submarine's pressure hull on the target strength, and their control effects of four tank structure improvement schemes were calculated and analyzed. [**Results**] The results show that the internal tank mainly affects the target strength in the frequency band from 1 kHz to 3 kHz. The internal tank located near the centerline of the broadside has little effect on the original target strength, while the tank at the bottom of the broadside has a great impact on the original target strength. The calculated results show that the inclination of the interior wall of the tank located near the centerline can help reduce the target strength in the normal incidence direction. However, the inclination of the interior wall of the tank located at the bottom can significantly reduce the target strength in the frequency band above 3 kHz, but the reduction effect on that in the low frequency band between 1 kHz and 3 kHz is not enough to make up for the influence caused by the internal tank. [**Conclusions**] In the design of submarine, corresponding measures should be taken to reduce the influence of the internal tank on the target strength.

Key words: submarine design; target strength; internal tank; planar element method

CLC number: U674.76

0 Introduction

Acoustic target strength is one of the important indicators of the stealth performance of submarines. In its early control design, overlays were often used while less consideration was given to the integration design of structure and shape to reduce target strength from the perspective of overall cost-efficiency ratio [1]. With the development of computer technology, forecast software is used to model and predict the target strength of submarines, analyze and test different schemes. In this way, modification of the overall design of submarines and selection of materials, plate thickness and sound-absorbing coating can be realized at the scheme design stage to reduce overall acoustic target strength [2-3].

For the control of acoustic target strength of submarines, it is important to find the scattering source and make clear its influence rules. Classic hydroacoustics mentions that the presence of side lobe around 20° of submarine's bow and stern will cause the target strength to increase by 1-3 dB, which may result from the internal reflection of submarine's cabin structure [4]. By calculating and forecasting, Martin et al.[5] concluded that the hidden reflectors immersed in the water (for example, in enclosure, superstructure deck and inside the light shell) have a great impact on the overall target strength. However, when the line type is perpendicularly incident, the target strength will change greatly. For a long time, due to many reasons including the hidden location, small scale, scattered distribution, uncertain target

Received: 2019-01-25

Authors: Yan Jiaxiang, male, born in 1969, senior engineer. Research interest: general ship technology. E-mail: yanboling@sina.com
Xing Junhua, male, born in 1982, master, senior engineer. Research interest: general ship technology.
E-mail: xjh0315@163.com
Zhang Junping, male, born in 1962, professor. Research interest: general ship technology

***Corresponding author:** Yan Jiaxiang

or strong directivity of these scattering sources, they have often been ignored in the design of submarines and related studies are rare.

The internal tank is mainly located inside the pressure shell of submarines with wide distribution and various forms. It also plays an important role in water storage, diving, surfacing, balancing, and ballasting of submarines. The mechanism analysis believes that the submarine is a complex extended body target with the distribution of multiple bright spots. The scattered acoustic fields of the target components are superimposed in different spaces, causing the changes of echo phase and the fluctuations of the measured target strength, which affects the test results of the submarine.

With the consideration of the layout and structural form of the internal tanks of a typical submarine, we adopted physical and acoustical numerical calculation to analyze the influences and reasons of three typical tanks located near the centerline, at the bottom, and at the stern of the pressure body in the abeam direction, and then calculate and analyze the control effect of optimization scheme for reference of overall design.

1 Calculation method

Numerical methods such as planar element method, finite element method, and boundary element method are often used for the calculation of target scattering engineering. Planar element method has been widely used in engineering due to fast calculation speed, controllable accuracy, and simple algorithm.

In this paper, the planar element method based on Kirchhoff high frequency approximation[6] is used. By approximating the scattering acoustic field equation of the target, we can obtain the acoustic target strength on a non-rigid surface under far-field and transmitter-receiver conditions:

$$TS = 20\lg\left|-\frac{\mathrm{i}k}{2\pi}I\right| \tag{1}$$

where

$$I = \iint_s \mathrm{e}^{\mathrm{i}2k\boldsymbol{\rho}\boldsymbol{r}} \cos\alpha \cdot R(f,\alpha)\,\mathrm{d}s \tag{2}$$

Eq. (2) is to solve surface integral I. In Eq. (2), $\boldsymbol{\rho}$ is the vector from the point of the surface element to the reference point; $\boldsymbol{r}$ is the unit vector from the receiving point to the reference point; k is the wavenumber of the incident wave; $R(f,\alpha)$ is the surface reflection coefficient of the shell material; f is the frequency; α is the angle between the incident direction of the sound source and the surface element normal; s is the symbol of surface integral.

This paper uses Gordon integral algorithm to solve I[7-8]. It is assumed that the surface is meshed and discretized into $M \times N$ meshes and each mesh is approximated as a polygonal small planar element. Then, for each planar element, the Gordon integral formula can be used to convert the surface integral into the contour integral around the region. After coordinate transformation, its simplified vector form is as follows.

$$\boldsymbol{G}_{s(i,j)} = \iint_{s(i,j)} \mathrm{e}^{\mathrm{i}2k\boldsymbol{r}_i\cdot\boldsymbol{r}_0}\mathrm{d}s = \frac{1}{\mathrm{i}2k\left|\boldsymbol{n}_0\times\boldsymbol{r}_0\right|^2}\cdot$$
$$\sum_{n=1}^{N_0}(\boldsymbol{n}_0\times\boldsymbol{r}_0\cdot\boldsymbol{a}_n)\mathrm{e}^{\mathrm{i}2k\boldsymbol{b}_n\cdot\boldsymbol{r}_0}\sin(k\boldsymbol{a}_n\cdot\boldsymbol{r}_0)/(k\boldsymbol{a}_n\cdot\boldsymbol{r}_0) \tag{3}$$

where $\boldsymbol{r}_i$ is the position vector of the planar element; $\boldsymbol{n}_0$ is the unit normal vector of the planar element; $\boldsymbol{r}_0$ is the unit vector in the incident wave direction; $\boldsymbol{a}_n$ is the length and direction vector of the n-th edge of the planar element; $\boldsymbol{b}_n$ is the position vector of the midpoint of the n-th edge of the planar element; N_0 is the number of sides of the divided polygonal planar element.

Therefore, the acoustic target strength of the effective surface area can be obtained as below:

$$TS = 20\lg\left|\frac{k}{2\pi}\sum_{\substack{i=1\sim M\\ j=1\sim N}}\left[R(\alpha_{ij})\cos\alpha_{ij}\boldsymbol{G}_{s(i,j)}\right]\right| \tag{4}$$

where $R(\alpha_{ij})$ is the surface reflection coefficient of the (i,j)-th planar element divided by the meshes, and α_{ij} is the angle between the surface element normal and the incident direction of the sound wave.

First, the three-dimensional model of internal tank is established, and then the model is divided into triangular meshes of shell 181 type. After obtaining the information of nodes and meshes, we import the calculation module of the planar element for calculation.

In the calculation of the internal tank, the shell with the sound transmission of "water-steel-air" is simplified into a rigid target. For the sound transmission of "water-shell-water-inner shell-air", the inner shell is simplified into a rigid target and the transmission situation of shell in water is considered based on its thickness. Then, the target strengths of the shell and inner shell are calculated according to Eq.(4) and the comprehensive acoustic target strength can be obtained based on the principle of incoherent energy superposition [9]:

$$TS_{\mathrm{all}} = 10\lg\left[10^{TS_{\mathrm{w}}/10} + D(f,\alpha)^4 \times 10^{TS_{\mathrm{n}}/10}\right] \quad (5)$$

where TS_{w} is the target strength calculated separately for the shell; TS_{n} is the target strength calculated separately for the inner shell; $D(f,\alpha)$ is the sound pressure transmission coefficient of the shell, which can be obtained using the transfer function of layered medium.

A rigid ball with equivalent size of the tank model and a radius of 3 m is selected for calculation and verification. The comparison with analytical results (Fig. 1) shows that the calculation accuracy of the planar element method is closely related to the mesh size. Smaller meshes result in higher calculation accuracy. Accordingly, larger meshes lead to lower calculation accuracy, and the frequency at which the calculation starts to diverge is also lower. It can be seen from the figure that when the frequency band from 1 to 10 kHz and the mesh size below 100 mm are selected, the calculation error can be controlled within 0.5 dB, which meets the calculation requirements of this paper.

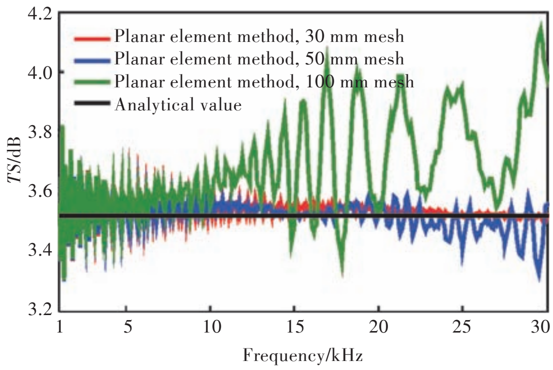


Fig.1 Error checking of planar element calculation method

2 Analysis on influence of internal tank on target strength

2.1 Calculation model of typical internal tank

In view of the stability control requirements of the submarine, the internal tank is generally arranged at the bottom of the submarine, and may also be arranged at a high position. As shown in Fig. 2 and Fig. 3, three typical internal tank schemes are selected and the ratio of the vertical height of the internal tank to the diameter of the parallel midship is taken as 0.2. Scheme 1 and Scheme 2 are respectively located at the centerline and bottom of the parallel midship of the broadside. The plane size of the shell plate of the internal tank of Scheme 2 is the same as that of Scheme 1. Scheme 3 is located at the bottom of the cone of the stern and the length and capacity of the internal tank remain the same with those of Scheme 2.

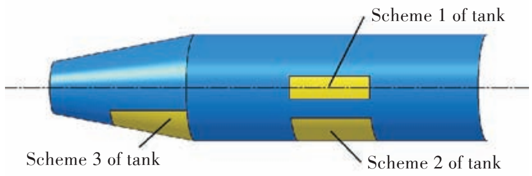


Fig.2 Schematic diagram of three typical internal tank locations

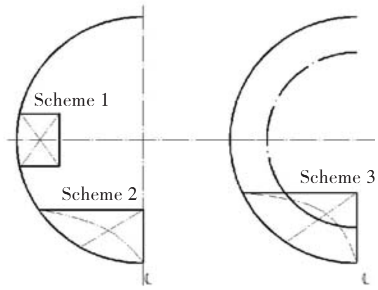
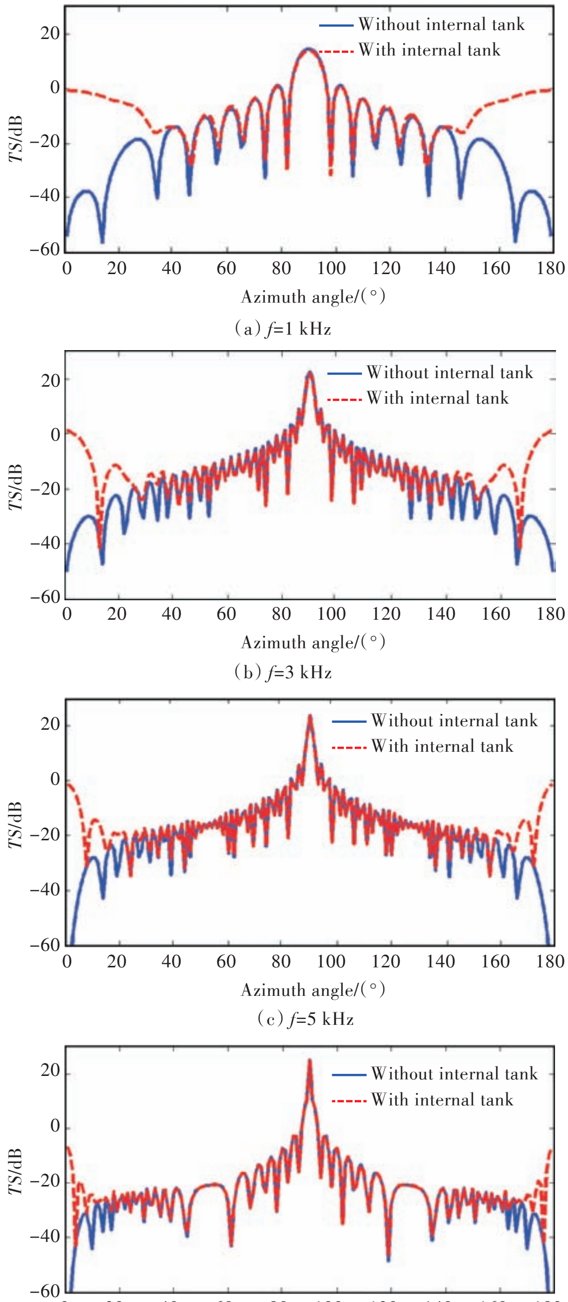


Fig.3 Main profile dimensions of three typical internal tanks

2.2 Target strength comparison with or without internal tank

The effect of the presence or absence of internal tank on the target strength is calculated. As shown in Fig. 4, in all frequency bands near the abeam direction, the difference between the abeam peaks with or without the internal tank is within 1 dB for Scheme 1, and the target strength is basically the same. This is because the target strength is mainly affected by the interior wall of the tank in the low frequency band and the shell in the high frequency band. However, the interior wall of the tank is not much different from the shell in terms of line shape and scale at the centerline. Therefore, from the perspective of this conversion relationship between the internal tank and the shell, the impact of Scheme 1 of internal tank on the target strength is small near the abeam direction.

It can be seen from Fig. 5 that when there exists the internal tank of Scheme 2, the target strength almost greatly improves in all frequency bands and azimuth angles, indicating that Scheme 2 has a great impact on the target strength at this position. In the frequency band of 1–3 kHz, the target strength in the abeam direction is increased by more than 15 dB. The reason is that when there is no internal tank, the shell basically reflects rigid oblique incidence with small echo intensity (up to around 0 dB). When there exists the internal tank as shown in Fig. 6, based on the relative energy relationships of shell and inner



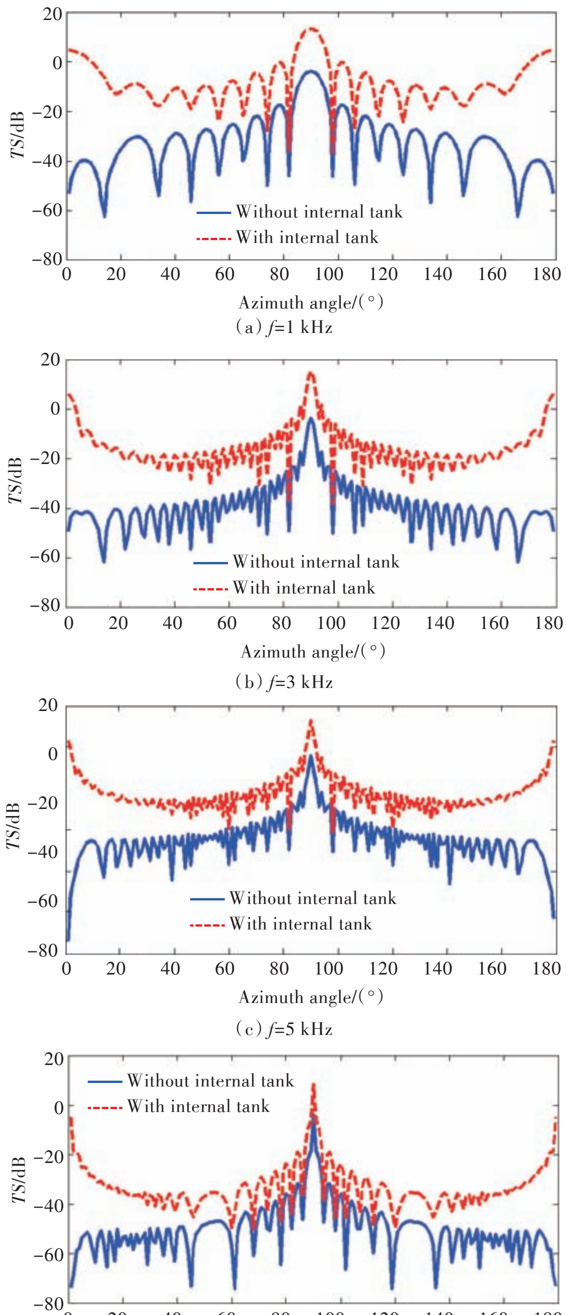
(a) f=1 kHz

(b) f=3 kHz

(c) f=5 kHz

(d) f=10 kHz

Fig.4 The comparison of target strength with or without internal tank of Scheme 1



(a) f=1 kHz

(b) f=3 kHz

(c) f=5 kHz

(d) f=10 kHz

Fig.5 The comparison of target strength with or without internal tank of Scheme 2

shell with integration, it is found that the acoustic target strength is mainly affected by the interior wall of the tank in the frequency band of 1–3 kHz. Besides, due to high transmission and normal incidence of the rigid plane at the interior wall of the tank, the target strength increases significantly and is much larger than that without internal tank of Scheme 2. In the frequency band of 3–6 kHz, the effects of the shell and the interior wall on the acoustic target strength are equivalent. In the frequency band above 6 kHz, the acoustic target strength is mainly affected by the shell of the tank.

It can be seen from Fig. 7 that the result of Scheme 3 is similar to that of Scheme 2, namely that the target strength is low without internal tank. After the internal tank is arranged, the target strength significantly increases due to the normal incidence of the rigid plane at the interior wall of the tank in the low frequency band. The target strength increases by more than 15 dB in the abeam direction of the 1–3 kHz band. It is worth noting that due to the interaction between the shell and inner shell, a peak appears near abeam 90° direction in the low frequency band, and the peak value at the original 78° azimuth

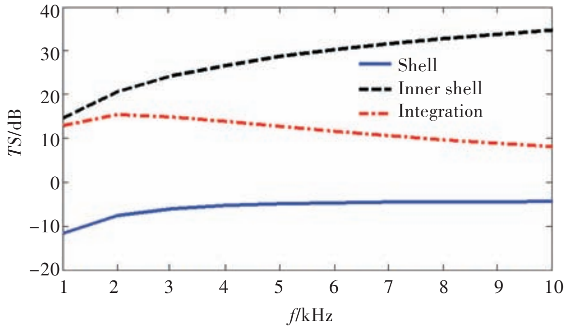
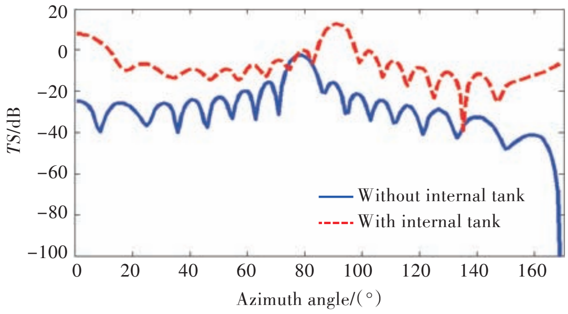
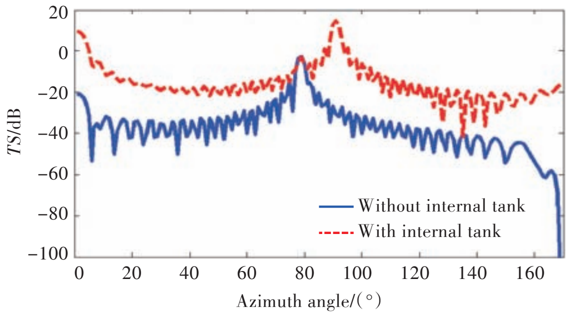


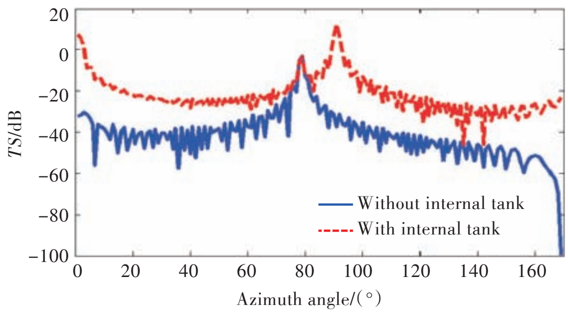
Fig.6 The comparison of target strength abeam affected by interior wall and shell of Scheme 2



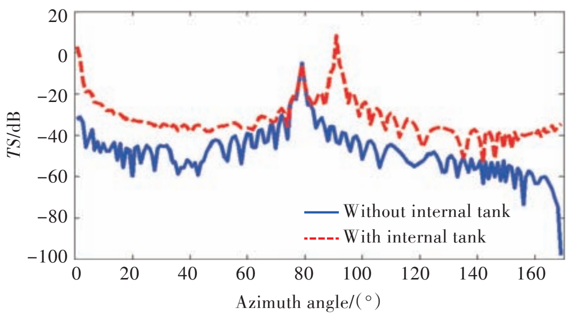
(a) f=1 kHz



(b) f=3 kHz



(c) f=5 kHz



(d) f=10 kHz

Fig.7 The comparison of target strength with or without internal tank of Scheme 3

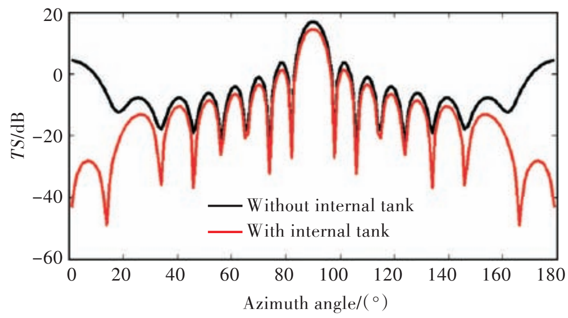
angle in the middle and high frequency bands gradually becomes prominent, and a double peak phenomenon appears.

In conclusion, after the internal tank is arranged, the target strength is mainly affected by the interior wall of the vertical plane of the internal tank. The impact of Scheme 1 is small, while the impacts of Scheme 2 and Scheme 3 are large. Specifically, in the low frequency band of 1−3 kHz, Scheme 2 and Scheme 3 have great effects on the target strength near the abeam direction. The target strength in the low frequency band is generally difficult to control, which needs to be fully considered during the design process of the internal tank scheme.

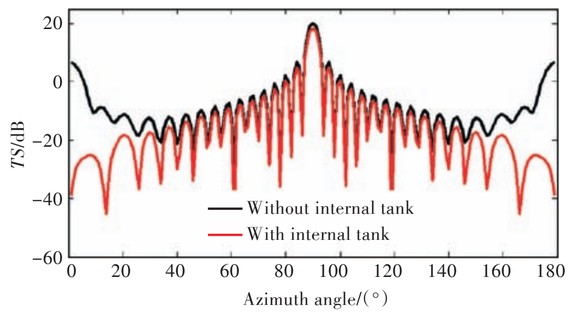
2.3 Influence of the internal tank on the whole section of parallel midship

When the tank is located at the bottom (similar to Scheme 2 and Scheme 3), the impact extent of the tank on the target strength is further analyzed. Aiming at avoiding the loss of generality, the overall calculation of the parallel midship of Scheme 2 is carried out. The parallel midship is set as long as Scheme 2. As shown in Fig. 8 and Fig. 9, the target strength of the parallel midship with or without internal tank can be obtained. The data analysis result shows that the internal tank mainly affects the low frequency band of 1−3 kHz. When the frequency is lower, the impact is greater. The target strength at 1 kHz in the abeam direction increases by more than 2 dB.

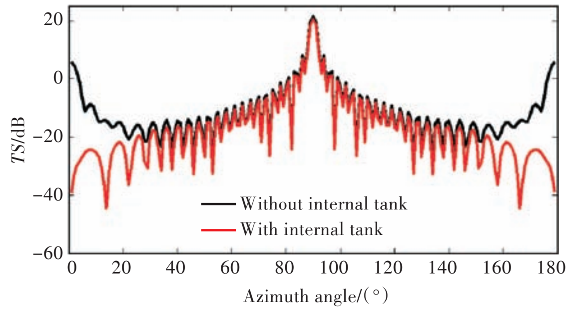
According to the energy contribution, when there



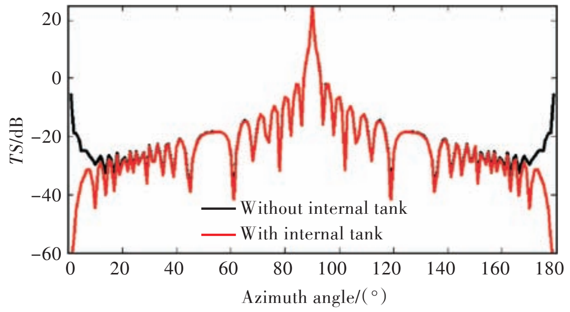
(a) f=1 kHz



(b) f=2 kHz

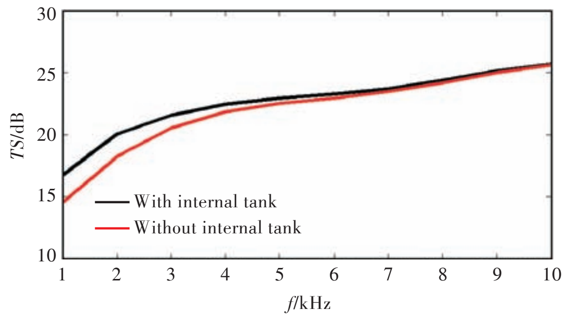


(c) f=3 kHz

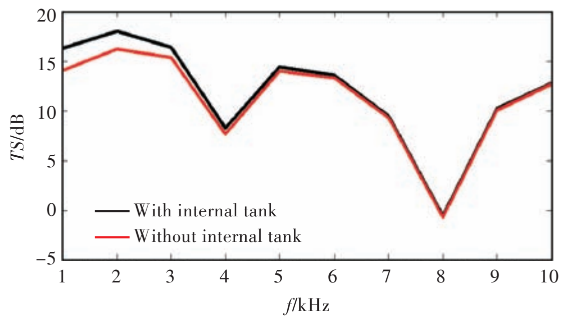


(d) f=10 kHz

Fig.8 The comparison of target strength with or without internal tank of the whole section of parallel midship



(a) Abeam 90°



(b) Average value within abeam 90°±5°

Fig.9 The comparison of target strength abeam with or without internal tank of the whole section of parallel midship

is no internal tank at the location of Scheme 2 at the frequency of 1 kHz in abeam direction, the only acoustic energy reflected by the shell accounts for 1.4% of that of the whole section of parallel midship. However, after the internal tank is arranged, the acoustic energy reflected by the internal tank accounts for 41% of that of the whole section of parallel midship. Thus, it can be seen that if there are a large number of internal tanks similar to Scheme 2 in the whole ship, their impact on the overall target strength (especially in the abeam direction) cannot be ignored.

3 Calculation and analysis of the optimized scheme

3.1 Scheme optimization

According to the above analysis, the acoustic target strength of the internal tank is mainly affected by the normal incidence of the interior wall of the tank. Therefore, the internal tank is modified and optimized based on Scheme 1 and Scheme 2. The interior wall of the tank is inclined by 6°, 8°, 10°and 30° respectively, as shown in Fig. 10. Considering the feasibility of the project realization, the interior wall of the 30° inclination scheme is divided into two equal parts: the upper part and the lower part, which are symmetrically inclined. The other schemes incline downward along the external normal line of the interior wall. All inclination schemes have the same internal volume as the original Scheme 1 or Scheme 2.

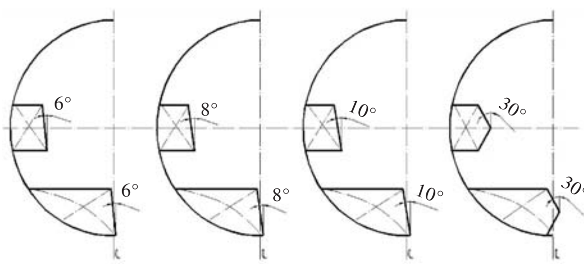
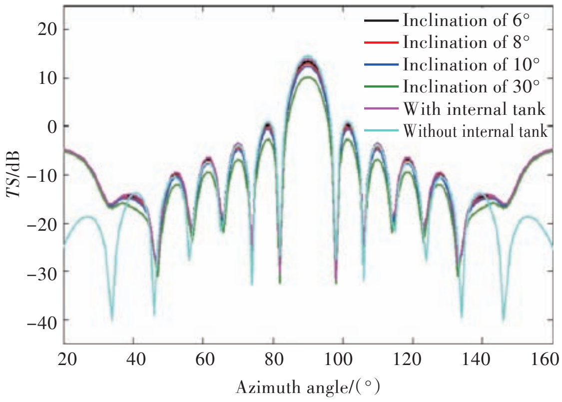


Fig.10 The optimized inclination schemes of tank interior wall

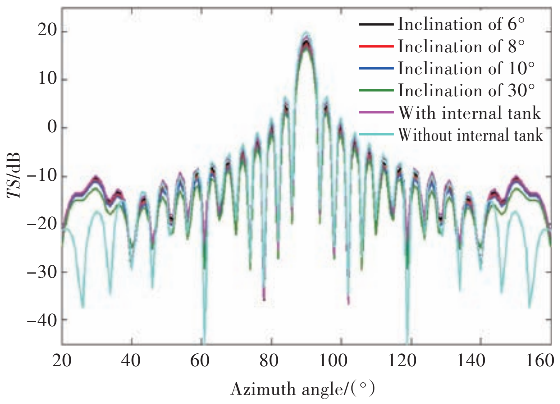
3.2 Comprehensive comparison of effects

The above inclination schemes are calculated, and the results show that the target strength of Scheme 1 in the frequency band below 4 kHz decreases in varying degrees with the increase in inclination angle. The larger inclination angle results in more obvious reduction. However, there is basically no effect above 4 kHz (Fig. 11).

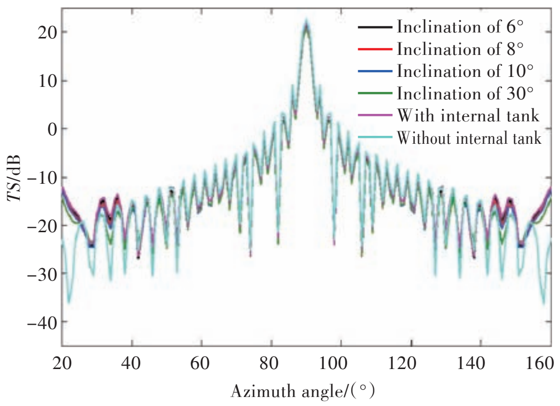
In order to evaluate its actual impact on the project, the average target strengths of different schemes within the range of abeam 90° ± 5° are compared. The results in Fig. 12 show that at the frequency of 1 kHz, inclination of 8° resulted in the effect close to 1 dB, inclination of 10° the effect close to 1.5 dB, and inclination of 30° the effect above 3.5 dB. In a word, it is beneficial to the reduction in the target strength abeam to incline the internal tank of Scheme 1 by more than 8°.



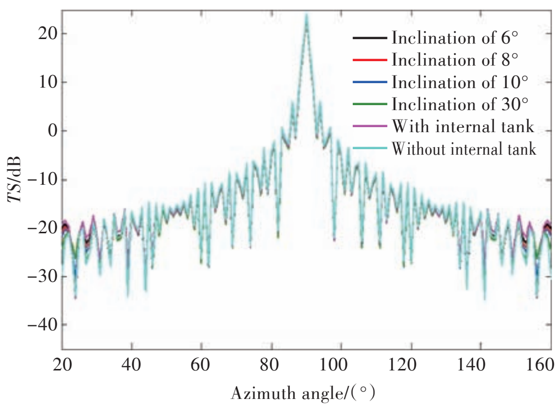
(a) f=1 kHz



(b) f=2 kHz

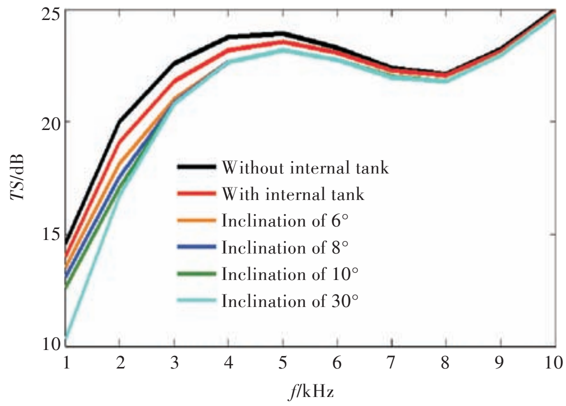


(c) f=3 kHz

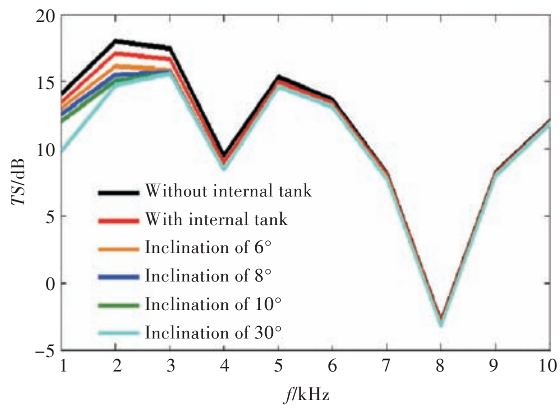


(d) f=5 kHz

Fig.11 The comparison of target strength with the inclined optimized schemes of Scheme 1



(a) Abeam 90°

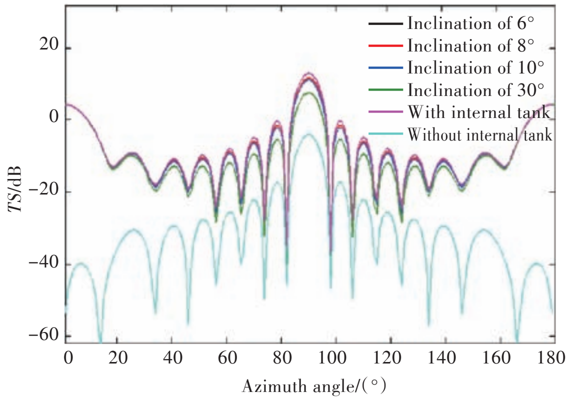


(b) Average value within abeam 90°±5°

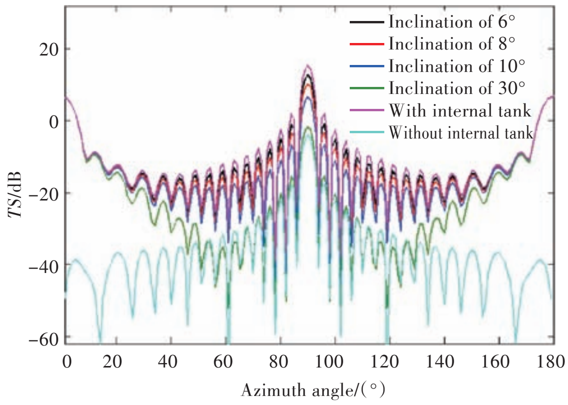
Fig.12 The comparison of target strength abeam with inclined optimized schemes of Scheme 1

The data analysis results of Scheme 2 are shown in Fig. 13. It can be seen from the figure that the target strength after inclination is between the situation with and without the internal tank. As the inclination angle increases, the target strength gradually returns to the state without the internal tank. However, in terms of the frequency band, the inclination of the internal tank only helps to reduce the target strength above a certain frequency band, and the effect of reduction is limited in the low frequency band of 1–3 kHz.

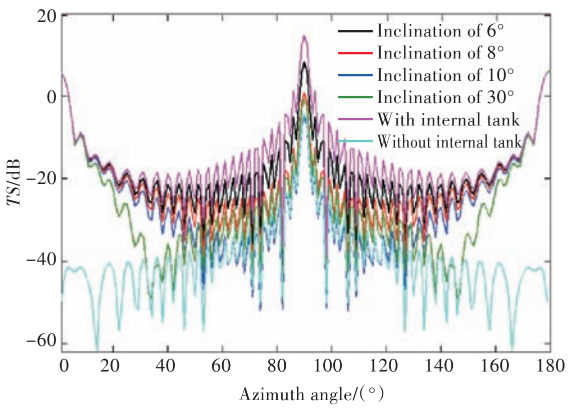
Fig. 14 shows the comparison of the average target strength of each scheme in the range of abeam 90° ± 5°. It can be seen from the figure that at the frequency of 1 kHz, the inclination of 8° has an effect of about 1 dB; the inclination of 10° has an effect of about 2 dB; the inclination of 30° has an effect of more than 5 dB. However, referring to the state without the internal tank, especially in the low frequency band of 1–3 kHz, there is still a large gap in the target strength. Therefore, for Scheme 2, although the inclination of the internal tank can alleviate this gap to a certain extent, it cannot counteract the impact of the internal tank on the target strength in the low frequency band.



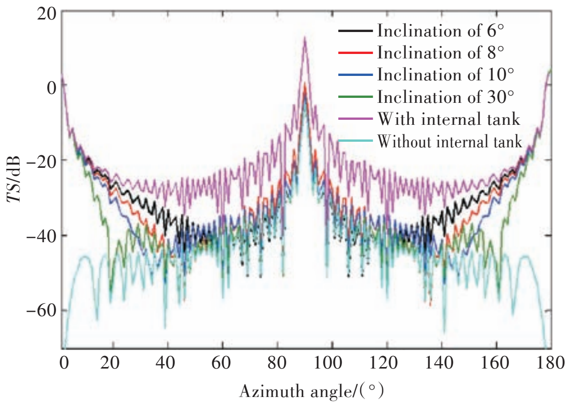
(a) f=1 kHz



(b) f=2 kHz

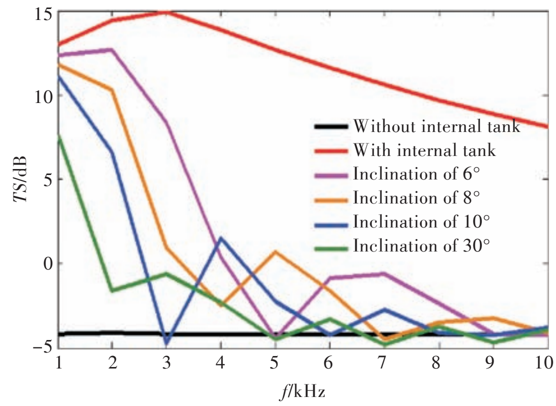


(c) f=3 kHz

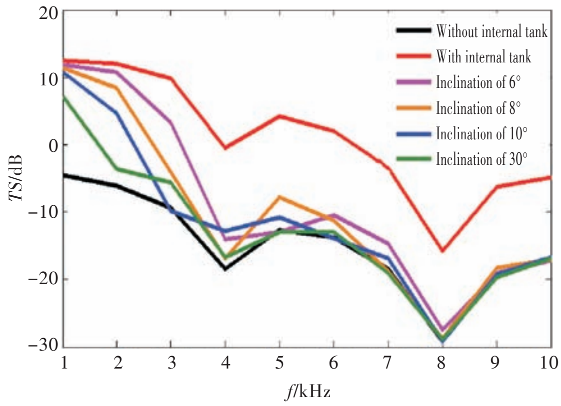


(d) f=5 kHz

Fig.13 The comparison of target strength with optimized inclination schemes of Scheme 2



(a) Abeam 90°



(b) Average value within abeam 90°±5°

Fig.14 The comparison of target strength abeam with inclined optimized schemes of Scheme 2

4 Conclusions

The calculation and analysis of the internal tanks at typical positions show that the internal tank located near the centerline has little effect on the target strength, while the internal tank located on the bottom of the broadside has a large impact. The main impact is in the abeam direction and the low frequency band of 1–3 kHz, which cannot be ignored when compared with the whole section of parallel midship of the broadside and needs to be considered in the later design.

Optimized inclination with different angels is carried out for the scheme of tank interior wall. The calculation result shows that the inclination of the interior wall near the centerline is beneficial to the reduction in the target strength, while the inclination of the interior wall at the bottom can significantly reduce the target strength in the medium and high frequency bands above 3 kHz. However, the reduction in the low frequency band of 1–3 kHz is not enough to counteract the influence of the internal tank.

In the design of the submarine, it is necessary to evaluate the internal tank. The tank interior wall near the centerline should be inclined and the tank located at the bottom of the broadside should connect and be symmetrically arranged on the left and right sides as far as possible, so as to reduce its impact on the acoustic target strength.

References

[1] Randolf T. Acoustic coating for submarines[C]//Proceedings of the European Conference on Undersea Defence Technology (UDT Europe 2011). London, UK, 2011: 89-91.

[2] Maxit L, Oudot G, Audoly C. Target strength modelling of submarine[C]//Proceedings of the European Conference on Undersea Defence Technology (UDT Europe 2004). Nice, France, 2004: 513-522.

[3] Anders E. Acoustic target strength design for submarines-modeling and measurements[C]//Proceedings of the European Conference on Undersea Defence Technology (UDT Europe 2008). Glasgow, UK, 2008: 1-5.

[4] Liu B S, Lei J Y. Principles of underwater acoustics [M]. 2nd ed. Harbin: Harbin Engineering University Press, 2009: 160-161 (in Chinese).

[5] Almgren M, Kallman M. Acoustic target strength prediction of underwater objects[C]//Proceedings of the European Conference on Undersea Defence Technology (UDT Europe 1997). Hamburg, Germany, 1997: 24-26.

[6] Fan J, Tang W L, Zhuo L K. Planar elements method for forecasting the echo characteristics from sonar targets[J]. Journal of Ship Mechanics, 2012, 16(1/2): 171-180 (in Chinese).

[7] Liu C Y, Zhang M M, Cheng G L, et al. Improved planar element method for computing target echo[J]. Journal of Naval University of Engineering, 2008, 20(1): 25-27, 31 (in Chinese).

[8] Wang H Y. The research on target characteristics of composite cylindrical shell[D]. Harbin: Harbin Engineering University, 2012 (in Chinese).

[9] Hu B, Zhang J P. Effect analysis for the shape of submarine bow pressure bulkhead upon the acoustic target strength[J]. Chinese Journal of Ship Research, 2016, 11(6): 22-27 (in Chinese).

潜艇内部液舱对声目标强度的影响分析

严家祥*, 邢军华, 张均平

中国舰船研究设计中心,湖北 武汉 430064

摘 要:[**目的**]研究潜艇内部液舱对声目标强度控制的影响。[**方法**]采用基于Kirchhoff高频近似的板块元方法,计算并分析处于潜艇耐压壳体内部不同位置的液舱对目标强度的影响规律,研究4种液舱结构改进方案的目标强度控制效果。[**结果**]结果表明:内部液舱主要在1~3 kHz频段对目标强度有影响,其中处于舷侧中心线附近的内部液舱对目标强度影响不大,而处于舷侧底部的内部液舱则有较大影响;位于中心线附近的液舱内壁倾斜有利于降低正横目标强度,而位于底部的液舱内壁倾斜虽可大幅降低3 kHz以上频段的目标强度,但对1~3 kHz低频段目标强度的降低效果仍无法抵消存在内部液舱带来的影响。[**结论**]在潜艇设计中,需对内部液舱采取相应措施,减小其对目标强度的影响。

关键词:潜艇设计;目标强度;内部液舱;板块元法