Analysis of the acoustic scattering properties of underwater objects coated with viscoelastic damping layer

Tang Zhiyin¹, Zhang Jijian²*, Zou Hailong¹, Shen Huijie¹,a* and Li Xiang¹

¹College of Power Engineering, Naval University of Engineering, Wuhan, Hubei, 430033, China
² Wuhan Ronshengqi Technology Co., Ltd., Wuhan, Hubei, 430000
*a*huijie.shen@mail.mcgill.ca

*Corresponding author’s e-mail:shj588@163.com, zhangjj@rsq-tech.com

Abstract. The acoustic software of Actran was used to calculate the sound scattering characteristics of the underwater spherical shell. The accuracy of the numerical calculation was verified by comparing with the theoretical values. Furthermore, a damping layer of viscoelastic material was coated outside the spherical shell, and the sound scattering characteristics of the shell after the damping layer was calculated and analyzed. The calculation results show that the intensity of acoustic target is reduced to a certain extent in most of the analysis frequency bands after the viscoelastic damping layer is laid, especially in the low frequency band has been greatly attenuated. At low frequencies, the distribution of scattered sound pressure field of a spherical shell with a viscoelastic damping layer is much more regular than that of an elastic shell sphere. The interference level of the sound field in front and in back of the spherical target is obviously less than that of the elastic light shell. Study has shown that laying a viscoelastic damping layer helps to reduce the sound scattering intensity of underwater targets to a certain extent and improves the invisibility of underwater targets.

1. Introduction

Since the research on the acoustic scattering characteristics of underwater large targets has significant engineering applications[1-2], the theoretical calculation methods and experimental verification of acoustic scattering characteristics for the underwater targets have been extensively studied at home and abroad. In practical applications, the structure shape of research objects is usually irregular and complex, and the analytical method is difficult to solve the scattering sound field. With the rapid development of numerical simulation, there has been a breakthrough in the study of acoustic scattering calculation. The commonly used mathematical models include Kirchhoff integral equation method[3], truncated total least square algorithm[4], finite elements method[5], finite difference time domain method (FDTD)[6], boundary element method (BEM)[7], etc..

In recent years, the acoustic scattering fields of underwater targets treating with various technologies to enhance the invisibility ability or with different simulation methods to improve the calculation precision receive special interest by lots of scholars. Yu mengsa[8] from 702 Research Institute studied the excited vibration and acoustic radiation of a finite length annular stiffened elastic cylindrical thin shell in an infinite loud medium. Combined with the boundary conditions on the shell surface and inside and outside the sphere, the acoustic vibration coupling equation was established, and the natural vibration frequency and vibration mode of the shell in vacuum were studied. Vasilev G.
et al. combined the finite element software ANSYS and the boundary element software Sysnoise to study the vibration mode in water and acoustic radiation directivity of a finite length cylindrical shell with hemispherical shell caps at both ends[9]. Fan Jun from Shanghai Jiaotong University provided a plate element method which can be used to analyze the high-frequency acoustic scattering of rigid targets[10]. Also, some researches were carried out on the elastic scattering in the low-frequency range.

In this paper, the acoustic scattering characteristics of underwater spherical shell are studied based on the commercial software Actran. The viscoelastic damping layer is laid on the spherical shell to reduce the acoustic scattering intensity. Results show that the acoustic scattering intensity of underwater target in the low-frequency range could be reduced by the viscoelastic damping material layer, such that improving the invisibility performance of underwater targets.

2. Calculation model of an underwater shell with damping layer

The rapid development of computer makes it possible to analyze the scattering of complex shells by finite element method. Numerical simulation technology is the most popular method in industry, and it is also the most appropriate method to predict the vibration acoustics of complex structures. Its advantages are that it is suitable for complex shapes, but it also faces some difficulties: (1) FEA supports the shell structure simulation, such as contact analysis, vibration analysis, etc., but it is unable to carry out the acoustic scattering analysis because it does not provide special acoustic load conditions; (2) the boundary element method (BEM) of acoustic software can simulate the structure with small degree of freedom, but the efficiency is very low when computing large-scale model.

As a professional software, Actran, equipping with structural and acoustic finite element techniques, has been widely used in acoustic research. It provides a possibility for efficient analysis of acoustic scattering characteristics of underwater shells.

2.1. Model introduction

The geometric of the model is shown in figure 1. The inside of the spherical shell is air, the outside of the shell is viscoelastic damping layer and the outside of the damping layer is water. The section diagram of its internal acoustic structure is shown in figure 2.

2.2. Simulation process

Before analyzing the acoustic scattering characteristics of underwater shell, the boundary of underwater shell should be obtained first. The analytical solution of scattering sound field of elastic
spherical shell with air inside is selected as reference. At the same time, the scattering sound field of rigid spherical shell, elastic spherical shell and the elastic shell with damping layer are calculated by using Actran software. Figure 3 shows the analysis flow based on Actran software. The boundary conditions of underwater shell during installation are simulated.

![Figure 3. Analysis process.](image)

2.3. Model establish

2.3.1. Acoustic model. The acoustic scattering simulated model is established in Actran, as shown in figure 4. The details of element and properties are as follows: (1) steel shell: the element type is triangular shell element with 2364 nodes; (2) viscoelastic damping layer: the element type is solid shell element with 2364 nodes; (3) air: the element type is tetrahedral mesh with 36163 nodes; (4) water: the element type is prism grid with 55075 nodes; (5) infinite element: the element type is triangular shell element with 2364 nodes.

![Figure 4. Acoustic model.](image)

2.3.2. Material properties. The relevant material properties applied in the calculation are as follows: thicknesses of the steel shell and the damping layer are 30 mm and 50 mm, respectively; diameter of outer shell is 1.5 m; density, elastic modulus and Poisson’s ratio for the steel shell are 7850 kg/m³, 2×10¹¹Pa and 0.33, respectively; while for damping layer, these three parameters are respectively 1136.6 kg/m³, (9.43×10⁶+9.363×10⁵×f⁰.⁴⁸₁⁵)Pa and 0.497; the damping coefficient of such a material can be expressed by -0.1187+0.2918×f⁰.¹⁴⁷¹³, wherein, f is the frequency.

2.3.3. Boundary conditions and loads. The outer of air is defined as infinite element. The infinite element is used to provide non reflective boundary conditions and extract the radiated sound power. The plane wave unit load is applied on the outer side of the infinite element, i.e. the spatial position is (0, 0, -30), as shown in figure 5.

![Figure 5. Plane wave unit load.](image)

2.3.4. Result analysis. According to the results extracted by the commercial software Actran, the sound pressure at any point (including scattered sound pressure and incident sound pressure) within a limited distance outside the shell is calculated, and the frequency range is 0-5000Hz. The intensity of acoustic target is taken as the evaluation index at 15m away from the outer surface of the shell, which is defined as [11]:

\[ I = \frac{1}{2} \rho c S \Phi \]
where $p_{sc}$ is the scattered sound pressure and $p_{in}$ is the incident sound pressure.

$$TS(r) = 20 \times \log_{10} \left( r \frac{|p_{sc}(r)|}{|p_{in}(r)|} \right)$$ (1)

3. Results and discussion

To validate the correctness of the calculation model develop in this paper, the results calculated by Actran is compared with the analytic result first, for an elastic spherical shell. Results are presented in figure 6, as shown by the dotted line and solid line, respectively.

It can be seen from figure 6 that the maximum value and the minimum value of target strength appears near 500Hz and 1340Hz respectively; above the 1340Hz, the scattering intensity of the target tends to rise slightly, and there are peaks and valleys of scattering values at some frequency. The trend of simulation results by Actran is almost consistent with the analytic result for the elastic smooth shell, such that the accuracy of the simulation is validated.

Figure 7 presents the target strength for an elastic smooth shell with and without a covered layer, as shown by the solid and the dotted lines, respectively. It can be seen that after the damp coating is laid on the smooth shell, the target intensity will be reduced to a certain extent in the whole analysis frequency range (except for some frequency range). The average reduction of target intensity is about 4dB. In particular, in the low frequency range it has been greatly attenuated, and the maximum
attenuation value can be as high as 10dB. At the same time, the peaks and the troughs of target strength shift slightly towards the low frequency range.

![Figure 7. Results of target intensity for a smooth shell and a damping layer shell.](image)

Figure 8. Acoustic scattering fields at 540 Hz

![Figure 8. Acoustic scattering fields at 540 Hz](image)

(b) Elastic shell with 50mm damping layer

Figure 9. Acoustic scattering fields at 1340 Hz

![Figure 9. Acoustic scattering fields at 1340 Hz](image)

(a) Elastic smooth shell

(b) Elastic shell with 50mm damping layer

The acoustic scattering fields at several frequencies are presented in figures 8 and 9, respectively for a smooth shell and a damping layer shell. Figure 8 shows the map of acoustic scattering pressure at
540 Hz (i.e. the peak of the target intensity). Obviously, under plane wave incidence, the sound pressure field for the shell with damping material layer is much more regular than that of the smooth shell. Behind the spherical shell, the interference of acoustic pressure field of with damping layer is obviously less than that smooth one. The scattering sound field in front of the spherical target is much smaller than the smooth one. At the valley positions of the target strength curve, i.e. figure 9, the scattered field of the spherical target with damping material layer is also improved to a certain extent. Results show that laying viscoelastic damping layer can reduce the acoustic scattering intensity and improve the stealth performance of underwater targets.

4. Conclusion
In this paper, the acoustic scattering characteristics of underwater spherical shell are studied with the help of Actran software, and the calculation results of acoustic scattering characteristics of underwater shell are validated by the analytic solution. Conclusions of the current research are:(1) it is feasible to use the finite element model in Actran software to solve the scattering characteristics of simple shape targets, which proves the high accuracy of the finite element method; (2) applying the viscoelastic damping layer to the spherical shell, the target intensity can be decreased in most range of the analysis frequency, especially in the low frequency range. The viscoelastic damping layer can reduce the acoustic scattering intensity and improve the invisible performance of underwater target.

A natural extension of this work is the scattering behaviour of the actual engineering model under broadband acoustic excitation, which will be studied by combining the detailed boundary conditions and the complex models.

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