Study on low frequency sound absorption characteristics of cavity coating with local resonance

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Abstract. It is of great significance to study the low frequency acoustic absorption characteristics of acoustic cover for improving the acoustic stealth performance of submarine. Considering the sound absorption performance of cavity coating and local resonant thin film structure, a finite element model of cavity acoustic coating with local resonance is established. The sound absorption characteristics of the composite structure in the range of 10-1000Hz are studied. The influence law of the sound absorption performance was obtained by adjusting the geometric parameters of the composite structure. The results show that :(1) The coupling between the local resonant structure and the cavity coating can produce a sound absorption peak, and the sound absorption coefficient can be increased by 30% at most; (2) The first sound absorption peak produced by the composite structure is mainly related to the cavity overburden; (3) The second sound absorption peak is mainly generated by the coupling between the cavity coating and the local resonance structure. The results can provide a theoretical basis for the design and application of acoustic coating.

1. Introduction
The low frequency active detection sonar emits sound wave, and the echo is generated when the acoustic wave meets the target. The intensity of echo reflects the acoustic stealth performance of the target. As a sound absorbing material, the acoustic covering layer is laid on the surface of underwater vehicle to absorb the sounding sound waves emitted by the enemy active sonar, reduce the self-radiated noise[1], enhance the acoustic stealth performance and improve the combat effectiveness. However, due to the limitation of the law of mass action, it is difficult to control the low frequency acoustic waves with a single structure of acoustic absorbing cover. It is of great significance to develop an acoustic absorbing cover with good low frequency acoustic absorbing performance for improving the acoustic stealth performance of submarines.

At several cavity type in coating, such as a cylinder or cone cavity cover layer[2-4], combination cavity cover layer, multilayer cavity cover[5], the performance of sound absorption and noise reduction of high frequency sound waves is improved mainly through isolation of acoustic coating, but its low frequency suppression and isolation ability are still very weak, so it is difficult to have effective sound absorption performance. The emergence of locally resonant thin films provides a new research scheme for this purpose [6-8]. In 2014, Ma et al.[9] designed a thin-film composite resonant sound absorption structure that can absorb single or even multiple frequencies. Therefore, applying the local resonant film material to the cavity acoustic coating provides a new research idea for improving the low frequency sound absorption characteristics.

In view of the limited low frequency sound absorption effect of the cavity type cladding and the long-term stability problem of the local resonance structure, a composite structure with local resonance...
structure embedded into the cavity type sound absorption cladding is proposed in this paper. Through the simulation of COMSOL Multiphysics, it is found that the sound absorption peak is generated by the coupling of cavity structure and local resonance structure, which improves the sound absorption effect. In addition, by analyzing the sound absorption mechanism of the composite structure and adjusting the structural parameters, the laws of influence on the sound absorption performance are obtained. The research results can provide a theoretical basis for the design of acoustic coating.

2. Materials and Methods

2.1. Calculation of sound absorption coefficient

When the plane wave is incident vertically to the interface between the liquid medium and the solid medium, due to the different impedance and large gap between the liquid medium and the solid medium, the acoustic wave will produce reflection at the interface, and the sound pressure reflection coefficient is

$$ R = \frac{Z_m - Z_0}{Z_m + Z_0} $$

Among them, \( Z_0 = \rho_0 c_0 \), which is the wave impedance of the medium in which the incident sound field is located. \( \rho_0 \), \( c_0 \) denotes the density of the incident sound field and the sound velocity respectively. \( Z_m = \frac{p}{v} \), which is the mechanical impedance per unit area of the surface of solid medium. \( p \) is the nodal sound pressure at the fluid side of the fluid-solid coupling interface in the sound field. \( v \) is the normal velocity of the node on the solid side.

When the backing is rigid, such as air, the transmission coefficient is very small, approximately 0. Therefore, when the reflection coefficient is known, the sound absorption coefficient can be obtained by the principle of energy conservation

$$ \alpha = 1 - |R|^2 $$

Among them, \( |R| \) is the amplitude of the sound pressure reflection coefficient.

2.2. Establishment of composite model

The structure of the underwater locally resonant cavity overburden established in this paper is shown in Fig. 1. The radius of the bottom circle of the conical cavity is 7.5mm and the height is 20mm. The film mass block is embedded into the cavity, the thickness of the film is 0.2mm, and the shape is round platform. According to the thickness of the cavity \( B \) is 1mm, the large radius of the circular table film is 7.125mm, the small radius is 7.05mm, and the material is silicon rubber. Its physical parameters are: The real part of young’s modulus \( \text{Re}(E) = 1.9 \times 10^6 \text{ Pa} \), The fitting formula of the imaginary part changing with frequency is \( \text{Im}(E) = 7.96 \times 10^{-2} \times 2\pi f \). Among them, \( f \) is the frequency of the incident wave. Poisson’s ratio is \( \nu = 0.48 \). The density is \( \rho = 980 \text{ kg/m}^3 \). The initial stress in the \( x, y \) direction of film is \( \sigma_x = \sigma_y = 2.2 \times 10^5 \text{ Pa} \). The covering rubber material and the backing material are the same as above. The sound absorption effects of the composite structure, the cavity structure of the same size and the local resonance structure are compared as shown in Fig. 2. It can be seen that after the cavity structure and the local resonance structure are coupled, two sound absorption peaks are generated at 130Hz and 445Hz, and the peak values are about 0.4 respectively.
3. Discussion
In order to obtain the influence rule of the composite structure on the sound absorption performance, the influences of the thickness of rubber material, perforation coefficient (the ratio of the radius of the bottom circle of the cavity and the radius of the bottom circle of the overburden), the size of the film and the thickness of the mass block on the low frequency sound absorption performance are analyzed and calculated. The calculated results are shown in Fig. 3.
As shown in Fig. 3 (a), with the increase of the thickness of rubber material, the two sound absorption peaks move slightly to the high frequency, the bandwidth becomes wider and the sound absorption coefficient becomes larger. As shown in Table 1, for every 5mm increase in the thickness of the covering layer, the second sound absorption peak moves to the high frequency by 5Hz. When the covering layer is 45mm and 50mm, the reason for the same position of the sound absorption peak is that the frequency change step of the incident sound wave set in the simulation is large.

| Thickness of rubber material (mm) | Sound absorption peak (Hz) | Absorption coefficient |
|----------------------------------|---------------------------|-----------------------|
| 25                               | 440                       | 0.366                 |
| 30                               | 445                       | 0.381                 |
| 35                               | 450                       | 0.396                 |
| 40                               | 455                       | 0.404                 |
| 45                               | 465                       | 0.416                 |
| 50                               | 465                       | 0.426                 |

As shown in Fig. 3 (b), the radius of the bottom circle of the covering layer is kept constant while the radius of the bottom circle of the cavity is increased, and the two sound absorption peaks gradually move to the low frequency. The peak value of the first sound absorption peak has no obvious change, but the high frequency sound absorption coefficient decreases, so the bandwidth becomes narrower. As shown in Table 2, when the radius of the bottom circle of the cavity increases by 1mm, the moving range of the second sound absorption peak to the low frequency gradually decreases. When the radius of the bottom circle of the cavity is 5mm, that is, when the perforation coefficient is 1/3, the second sound absorption peak increases by about 30% compared with the acoustic covering layer of the cavity type. The cavity bottom radius gradually increases, indicating that the perforation coefficient increases, so the sound absorption peak moves to the low frequency.

| Perforation coefficient | Sound absorption peak (Hz) | Absorption coefficient |
|-------------------------|----------------------------|-----------------------|
| 5/15                    | 620                        | 0.621                 |
| 6/15                    | 540                        | 0.540                 |
| 7/15                    | 445                        | 0.381                 |
| 8/15                    | 415                        | 0.360                 |
| 9/15                    | 365                        | 0.320                 |
| 10/15                   | 330                        | 0.298                 |
As shown in Fig. 3(c), with the increase of the thickness of cavity B, the high frequency sound absorption effect is slightly improved. As shown in Table 3, when the thickness of cavity B increases by 1mm, the second sound absorption peak moves to the low frequency by 5Hz-10Hz, and the sound absorption coefficient increases by about 10%. As the thickness of the cavity B increases, that is, the local resonance structure moves up, the film becomes smaller and the resonance effect of the mass block of the film becomes stronger, so the sound absorption coefficient gradually increases.

| Cavity B thickness (mm) | Sound absorption peak (Hz) | Absorption coefficient |
|------------------------|---------------------------|-----------------------|
| 0.5                    | 455                       | 0.243                 |
| 1                      | 450                       | 0.248                 |
| 1.5                    | 450                       | 0.325                 |
| 2                      | 445                       | 0.381                 |
| 2.5                    | 440                       | 0.438                 |
| 3                      | 440                       | 0.476                 |

As shown in Fig. 3(d), the change of mass block thickness only has an impact on the value and position of the second sound absorption peak, while the other peaks have no significant changes. As shown in Table 4, as the thickness of the mass block increases by 0.5mm, the moving range of the second sound absorption peak to the low frequency gradually decreases, and so does the increase range of the peak. While the film remains the same, the thickness of the mass block increases, that is, the density of the unit mass surface increases, and the resonance of the film mass block is enhanced, so the sound absorption coefficient increases. According to \( \omega = \sqrt{k / m} \), where \( \omega \) is the antiresonance frequency, \( k \) is the acoustic wave number, and \( m \) is the mass, so the sound absorption peak moves to the low frequency.

| Mass block thickness (mm) | Sound absorption peak (Hz) | Absorption coefficient |
|--------------------------|----------------------------|-----------------------|
| 0.5                      | 615                        | 0.305                 |
| 1                        | 445                        | 0.381                 |
| 1.5                      | 365                        | 0.439                 |
| 2                        | 315                        | 0.474                 |
| 2.5                      | 285                        | 0.504                 |
| 3                        | 260                        | 0.536                 |

4. Conclusion
In this paper, a composite structure embedded in the local resonance structure into the cavity covering layer was established, and the influence laws of the geometric parameters of the composite structure on the sound absorption performance are analyzed by using the finite element software COMSOL Multiphysics. The results show that:

(1) The local resonant film structure and the cavity acoustic cover structure will produce coupling, forming the sound absorption peak, and enhancing the sound absorption effect. By adjusting the structural parameters, it is found that when the perforation coefficient is 1/3, the peak value of the second sound absorption peak is the largest, which is increased by about 30%.

(2) The first sound absorption peak is mainly generated by the cavity covering layer after coupling, which mainly moves to high frequency with the increase of the thickness of the covering layer and the decrease of the perforation coefficient, and the peak value of the sound absorption peak has no obvious change.
(3) With the increase of the perforation coefficient and the thickness of the mass block, the second peak of sound absorption moves to the low frequency, and the amplitude of the shift decreases gradually. The peak value increases with the decrease of the film area and the increase of the mass thickness. Although the composite structure produces sound absorption peak at low frequency, the sound absorption band is narrow and needs to be further improved. For example, the method of series local resonance structure is adopted. The research results can provide a theoretical basis for the structural design of acoustic absorbing cladding and have a guiding significance for solving practical engineering problems.

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References:
[1] ZHU Beili, HUANG Xiuchang. The key technology of submarine stealth-design of acoustic overlay[M]. Shanghai: Publishing house of Shanghai Jiaotong University, 2012.
[2] TAO Meng, TANG Weilin. Analysis on the Mechanism of Alberich type sound absorption coating at low frequency[J]. Journal of vibration and shock, 2011, 30(1): 56-60.
[3] YE Hanfeng, TAO Meng, LI Junjie. Analysis of acoustic absorption performance based on COMSOL cavity Acoustic Overlay at oblique incidence[J]. Journal of vibration and shock, 2019, 38(12): 213-218.
[4] Valentin Leroy, Anatoliy Strybulevych, Maxime Lanoy, Fabrice Lemoul, Arnaud Tourin, et al. Super-Absorption of Acoustic Waves with Bubble Meta-Screens. Physical Review B: Condensed matter and materials physics, American Physical Society, 2015, pp. 020301(R).
[5] LIU Guoqiang, LOU Jingjun, HE Shiping, ZHANG Chong. Analysis of sound absorption characteristics based on COMSOL multilayer material sound absorption overlay[J]. Journal of ship science and technology, 2016, 38(4): 35-37.
[6] YE Chao, SU Jilng. Influence of microstructure parameters on sound insulation performance of thin-film acoustic metamaterials[J]. Journal of noise and vibration control, 2017, 37(1): 163-166.
[7] Naify C J, Chang C M, Mcknight G, et al. Membrane-type metamaterials: transmission loss of multi-celled arrays[J]. Journal of Applied Physics, 2011, 109: 104902.
[8] Naify C J, Chang C M, Mcknight G, et al. Transmission loss of membrane-type acoustic metamaterials with coaxial ring masses[J]. Journal of Applied Physics, 2011, 110(23): 124903.
[9] Ma G, Yang M, Xiao S, et al. Acoustic metasurface with hybrid resonances[J]. Nature Materials, 2014, 13(9): 873-878.