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# Research on Vibration of Ship Coupling Beam

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**Abstract:** With the continuous progress and development of the military strength of various countries, the concealment performance of submarines has received more and more attention from various countries. It has gradually become an effective way to reduce vibration and noise by studying the vibration and sound radiation characteristics of the propeller-shaft-boat coupling structure. The previous research methods for the vibration and sound radiation characteristics of simple and uniform structures are insufficient in meeting current actual engineering needs. Therefore, it is necessary to explore a more accurate and efficient method for modeling and calculating the complex non-uniform structure of the propeller-shaft-boat.

## 1. Introduction

Plate and shell structures are widely used in aerospace engineering and marine engineering. They are important basic structures for rockets, aircraft, missiles, submarines and torpedoes. Therefore, the study of its dynamic characteristics has important theoretical and practical application value.

As an important part of national defense, the performance of nuclear submarines will directly affect national security. Good concealment performance makes the submarine's attack more sudden and maximizes its combat effectiveness, which has important military significance. Therefore, concealment is one of the most important issues in the submarine design process. Plate and shell structure is the most important part of nuclear submarine. Under normal circumstances, in order to reduce weight while meeting the requirements of rigidity, strength and stability of the structure, many stiffeners are arranged in the circumferential and axial directions of these shells. Such as the ring ribs of a single shell, the solid ribs and top longitudinal trusses connecting the double shells. The stern of a nuclear submarine can be approximately simplified as a conical shell with circumferential stiffeners; the middle body can be regarded as a ribbed cylindrical shell with different lengths divided by multiple bulkheads; the bow is a revolving shell. In addition, there are pedestals of different sizes inside the submarine, on which there are various power equipment installed through the vibration isolation system. It is precisely because of the existence of these structures that the mechanism research on its vibration and sound radiation characteristics becomes particularly complicated and difficult. Therefore, the research on the vibration and sound radiation of such structures is almost simplified to the research on beams, plates, stiffened plates, cylindrical shells and stiffened cylindrical shells. The geometric parameters, material parameters, and connection methods of these structures will directly determine the mass matrix, stiffness matrix and damping matrix of the structure, thus profoundly affecting its dynamic characteristics. Therefore, research and interpretation of the vibration and sound radiation



characteristics of these structures, and to find out the main causes of vibration and sound radiation, are of great significance for reducing the vibration and noise of the submarine and improving its concealment. The noise of submarine mainly comes from three parts: mechanical noise, propeller noise and hydrodynamic noise.

### 2.1 Structural vibration of combined shell

When modeling the composite shell structure, not only the mechanical modeling of the sub-structures is involved, but also the interface coordination conditions and boundary conditions between the sub-structures are also considered. Commonly used composite structure modeling and solving methods include sub-structure method, dynamic stiffness method, admittance method and finite element method. The sub-structure method adopts the analysis idea of first part and then whole. Firstly, the entire complex composite structure is divided into several sub-structures, and then the dynamic equations of each sub-structure are solved, and finally according to the interface coordination relationship and boundary of each sub-structure Condition, the dynamic characteristics of the overall structure can be obtained by assembly. Due to different mechanical assumptions, different coordinate systems, and different structures, such as beams, plates, shells and other structures, when mechanical modeling of substructures are introduced, their boundary conditions are also different, making the modeling of complex composite shell structures. There are certain difficulties. The dynamic stiffness method and the admittance method also start from the perspective of domain division. The differential equations of each substructure are converted into algebraic equations by the method of separation of variables or the integral transformation method to obtain the dynamic stiffness or admittance matrix of each substructure. The dynamic stiffness or admittance matrix of the entire structure is obtained from the interface matching conditions. These three methods are all based on analytic or semi-analytic solutions. Due to the limitation of boundary conditions, they are not conducive to the application of complex structures. The finite element method is based on numerical solutions and is easy to analyze the vibration characteristics of complex composite structures and different types of boundary conditions. In addition, the influence of parameters such as some openings and additional discrete masses is also easy to analyze. However, in view of the large amount of calculation, large calculation memory and space occupation, and too slow solution characteristics, the finite element method is still obviously weaker than the analytical method for the mechanism of structural vibration.

### 2.2 Natural vibration analysis

This section gives an example of the vibration modal characteristics of the coupled beam to verify the effectiveness and reliability of the method and the program written in this paper, and discusses and analyzes the vibration modal distribution of the coupled beam. Here we first consider the vibration characteristics of the coupled beam under the boundary conditions of fixed-supported at both ends, free at both ends, and simply supported at both ends when the coupling angle of the two beams is zero.

Table 1 Parameters and data of each section of beam

Parameter	Unit	Girder 1	Girder 2
$L$	m	0.24	0.8
$S$	m <sup>2</sup>	0.0009	0.0009
$I$	m <sup>4</sup>	6.75e-8	6.75e-8
$E$	N/m <sup>2</sup>	2.1e11	2.1e11
$\rho$	kg/m <sup>3</sup>	7780	7780

Table 2 shows the first eight natural frequencies of the horizontal coupled beam structure under different boundary conditions. It can be seen through observation that the calculation method in this paper is in good agreement with the results obtained by ANSYS simulation. And can verify the reliability of this paper using spring groups to simulate arbitrary boundary conditions. In the calculation process of this paper, the displacement expansion of the coupled beam adopts the cutoff number  $n=10$ . In order to verify the convergence of the solution method in this paper, Table 3 shows the natural frequencies calculated with different values of the cutoff number  $n$  when the two ends of the horizontal coupled beam are fixedly supported. It can be observed from two aspects that the method used in this

article has good convergence: (1) When the cutoff number is only a small value, the method can obtain sufficiently accurate results at low orders; (2) As the number of cutoff items increases, The consistency of the solution results is improved, which shows that the method in this paper has good numerical stability. In the subsequent analytical calculations, the number of truncated items  $n=10$  is used accordingly.

Table 2 Comparison of natural frequencies of horizontal coupled beams under different boundary conditions

Boundary conditions		1	2	3	4	5	6	7	8
Fixed at both ends	Current	85.49	235.57	462.01	763.73	1140.76	1593.23	2180.26	2466.51
	ANSYS	85.65	237.19	468.27	781.46	1181.40	1674.10	2266.70	2490.50
	Error%	0.18	0.69	1.36	2.32	3.56	1.88	1.18	0.97
Free at both ends	Current	85.32	235.29	462.36	764.72	1141.88	1633.82	2221.59	2925.99
	ANSYS	85.56	236.79	467.15	779.02	1176.80	1666.10	2253.90	2948.10
	Error%	0.28	0.64	1.04	1.87	3.06	1.98	1.45	0.76
Simply supported both ends	Current	37.87	149.61	334.66	608.43	948.14	1204.27	1389.05	1943.06
	ANSYS	37.75	151.56	343.15	615.37	972.35	1234.50	1419.50	1963.60
	Error%	0.31	1.31	2.54	1.14	2.55	2.51	2.19	1.06

Table 3 Comparison of natural frequencies of horizontal coupled beams under different intercepts

Model	M=2	M=4	M=6	M=8	M=10	M=12	Ansyz	Ansyz
1	85.50	85.50	85.50	85.52	85.49	85.45	85.46	85.646
2	235.49	235.47	235.47	236.26	235.57	236.57	230.60	237.19
3	475.61	462.03	462.03	461.94	462.01	462.13	462.08	468.27
4	797.90	797.85	763.78	764.26	763.73	764.53	764.49	781.46
5	1090.23	1207.90	1207.91	1140.97	1140.76	1140.84	1140.83	1181.4
6	2181.40	2181.40	2180.41	1592.49	1593.23	1594.11	1594.77	1674.1
7	2466.73	2466.53	2466.53	2180.29	2180.26	2180.26	2180.26	2266.7
8	3371.10	3274.10	3274.10	2466.50	2466.51	2466.51	2466.51	2490.5

For any given order of modal frequency, the corresponding modal shape can be easily obtained through the formula. For horizontal coupled beams, after normalizing the mode shapes, the first four modes are selected for comparison with the finite element simulation model under three boundary conditions: fixed at both ends, simply supported at both ends, and free at both ends, blue The dashed line represents the original position of the coupled beam, the green solid line represents the modal shape obtained by the method in this paper, and the red circle represents the ANSYS simulation value. Through comparison, it can be seen that after normalization, the method in this paper is in good agreement with the simulated value of the modal shape.

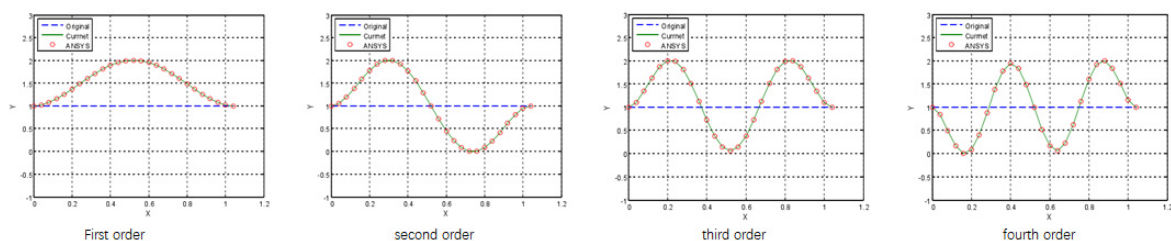


Figure 1 Formation ratio of the first four modes of horizontal coupling beam fixed at both ends

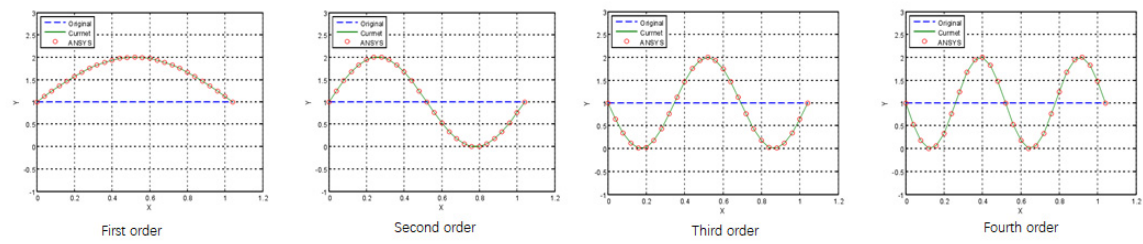


Figure 2 The ratio of the first four modes of the horizontal coupled beam simply supported at both ends

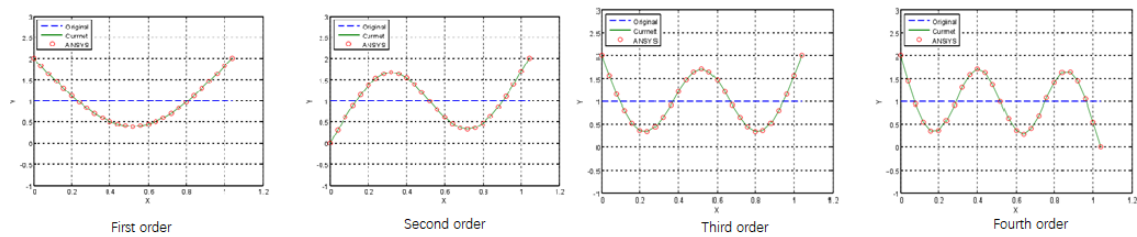


Figure 3 Formation ratio of the first four free modes at both ends of a horizontal coupled beam

Table 4 Comparison of natural frequencies of right-angle coupled beams

		1	2	3	4	5
$\Theta=45^\circ$	Current	86.63	128.99	219.10	362.03	430.76
	ANSYS	86.15	128.54	217.32	358.03	425.28
	Error%	0.56	0.35	0.82	1.12	1.29
		6	7	8	9	10
	Current	718.88	762.77	1106.60	1177.80	1191.00
	ANSYS	703.84	755.18	1096.20	1154.53	1170.87
	Error%	2.14	1.00	0.95	2.02	1.72

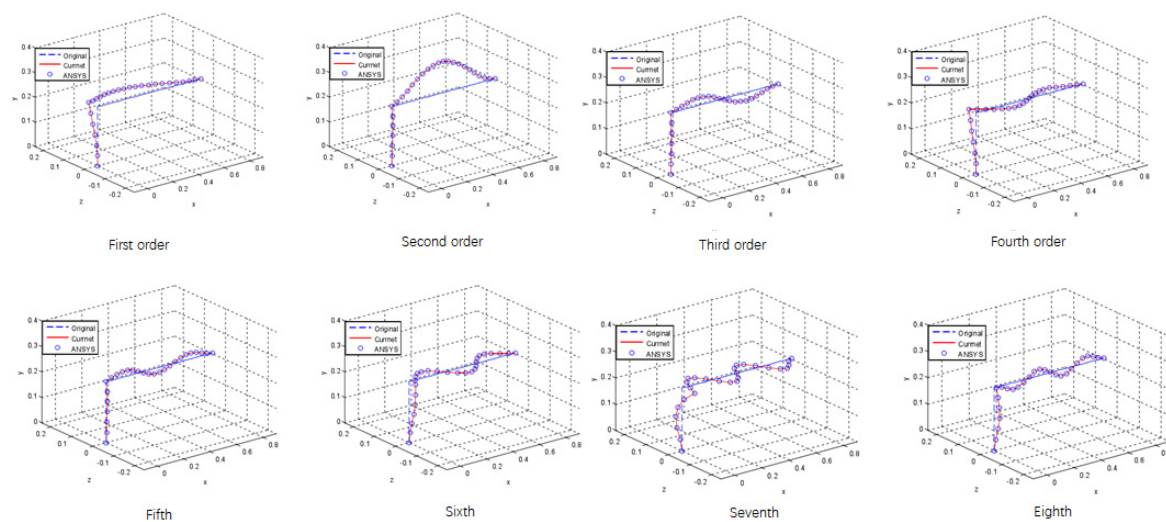


Figure 4 Comparison of the first four modes of a  $90^\circ$  coupled beam with fixed support at both ends

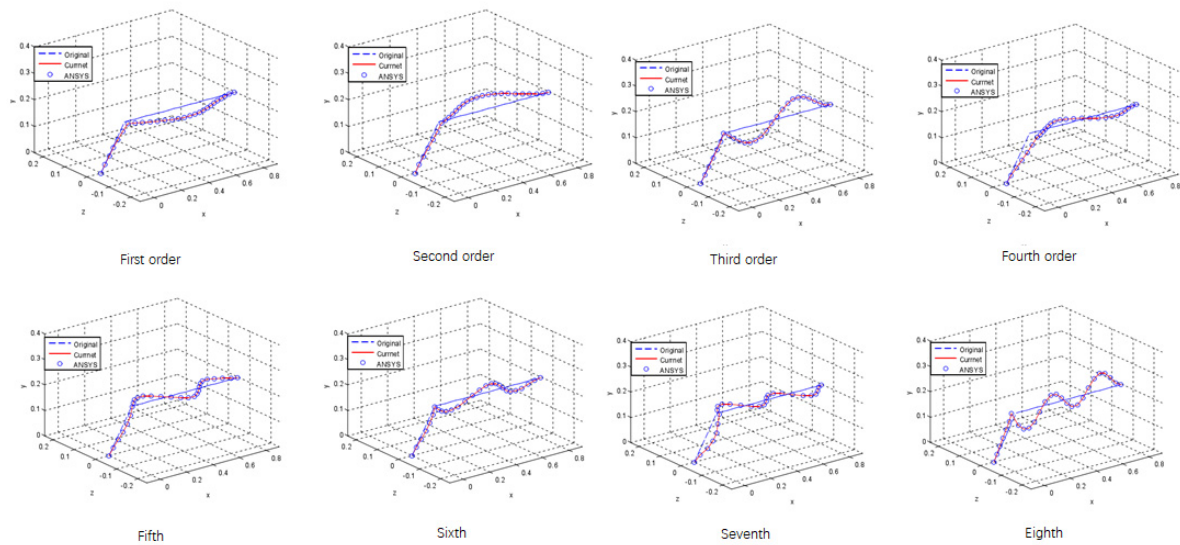


Figure 5 Comparison of the first four modes of the  $45^\circ$  coupled beam with fixed support at both ends

The coupling beams are connected by spring elasticity, and the spring stiffness in each direction is  $1E10$ . It can be seen from Figure 4 and 5 that the coupling beams are coupled at different angles under the three fixed-end boundary conditions. The situation is intact, and there is no sudden change in displacement between the coupling points. The coupling beam is connected as a whole through the coupling spring group, realizing the simulation of the rigid connection. In this paper, the accuracy of the coupling connection of coupling beams at any angle is completed by the coupling spring group.

### 3. Conclusion

(1) A dynamic model of the coupled beam structure with arbitrary angles and arbitrary boundary conditions is established. The improved Fourier series is used as the displacement allowable function of structural vibration, and the analytical solution of the coupled beam vibration is derived using the Rayleigh Ritz method.

(2) Calculate the natural vibration characteristics of horizontal coupled beams under different boundary conditions. By comparing with the calculation results of Ansys, the correctness of the method in this paper to solve the coupled beams with arbitrary boundary conditions is verified. The influence of the number of series expansion terms on the convergence of the results is discussed.

(3) Calculate the vibration characteristics of the coupled beam structure at different angles under the condition of fixed support at both ends. By comparing with the calculation results of Ansys, the correctness of the method in this paper to solve the coupling beam at any angle is verified.

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