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The Numerical Calculation and Laboratory Model Validation Analysis of Mechanical Noise Based on Benchmark Submarine Model

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The Numerical Calculation and Laboratory Model Validation Analysis of Mechanical Noise Based on Benchmark Submarine Model

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Abstract. The mechanical noise analysis of ship structure based on finite element method has been an important means of mechanical noise assessment in the initial design stage of ships. This article is based on the Benchmark standard submarine model, carrying out the numerical simulation of the Benchmark submarine scale model, and obtaining the first-order and second-order natural vibration characteristics of the model. At the same time, we establish a laboratory test system of the Benchmark submarine scale model, and test the natural vibration characteristics of the model under laboratory conditions. We compare numerical simulations and experimental laboratory test results, optimize the numerical modeling method and find the reliability of the numerical simulation calculation. Based on the above research, modeling a true-scale Benchmark standard submarine model, calculate the natural vibration characteristics of the Benchmark submarine model in the ocean flow field environment. Then calculate the value of mechanical radiation noise under the excitation of mechanical equipment based on the natural vibration characteristics results.

1. Introduction

The submarine's radiated noise is one of its main characteristics in the marine environment. Submarine radiated noise includes mechanical noise, propeller noise and hydrodynamic noise[1-2]. The radiated noise characteristics of submarines directly affect the stealth performance of submarines. As an important component of submarine radiation noise, mechanical noise has always been the research direction of all countries in the world. The finite element method can be used to simulate the mechanical noise of submarines[3-6]. The research on the mechanical noise characteristics of underwater vehicles such as submarines is of great significance both for the mechanical noise control of domestic submarines and for the study of mechanical noise characteristics of foreign submarines.

2. Laboratory modelling research

Based on the benchmark submarine model， establish a scaled simulation model， and process a scaled physical model. Simulate the natural vibration characteristics by finite element method. At the same time, built an inherent vibration characteristic test system of the physical scale model under laboratory conditions. Carry out laboratory test research on the inherent vibration characteristics of the scaled model and numerical modeling and calculation of the scaled model.

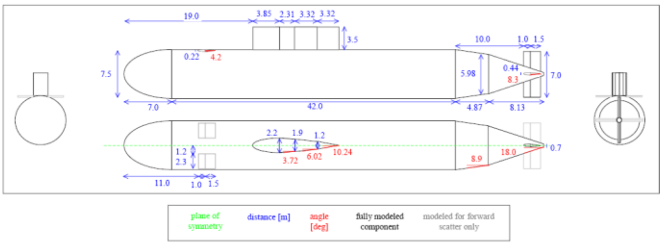

Figure 1. Schematic diagram of Benchmark standard model scale

2.1. Building a submarine scale model test system

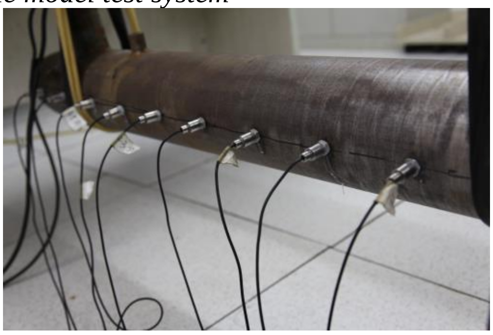

Figure 2. Laboratory Test System

As shown in Figure 2, the entire test line system includes the Benchmark submarine scale model, the shaker device, the vibration sensor, and the data acquisition display system(including industrial computer, collector and other equipment). Simulating the excitation of submarine machinery through a vibration exciter, apply axial excitation force and vertical excitation force to the scaled model, and analyze the inherent vibration characteristics of the test model.

Different working conditions were set in the test, and the vibration characteristics of a large number of Benchmark submarine scale models were obtained through multiple working conditions, and the vibration characteristics of the model were analyzed.

2.2. Comparison of the results of the scaled model test with the simulation calculation

Using the scaled simulation model the numerical simulation of the natural vibration characteristics in the air is carried out by the finite element method. The natural vibration characteristics of the model air are obtained by calculation, as shown in Fig. 3.

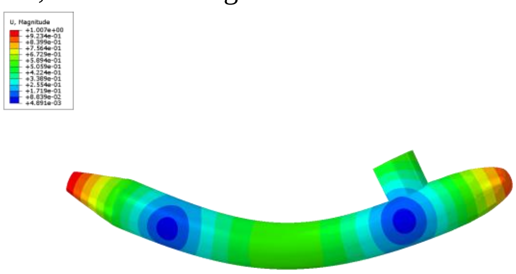

Figure 3. Schematic diagram of the first-order mode of the scaled model

The first-order and second-order mode in the air of the scaled model is obtained by numerical simulation, as the natural vibration frequency is 378.42 Hz. And 1156.7 Hz.

On the other hand, the modal analysis was carried out for the vibration test data of the benchmarked submarine scale model obtained by the test.

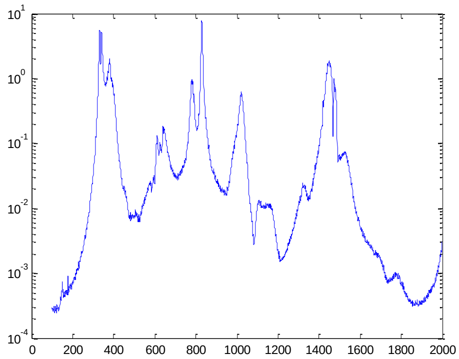

Figure 4. modal peak

The experiments for each working condition were separately analyzed. The singular value decomposition results of the cross-spectrum matrix and the power spectrum of each measuring point were used to pick up the suspected modal peaks. The results are shown in Table 1.

Table 1 Suspected modal frequencies

No.	Frequency /Hz	No.	Frequency /Hz	No.	Frequency/ Hz
1	331.4	5	642.7	9	1451
2	340.6	6	781.3	10	1473
3	380.2	7	828.9		
4	612.8	8	1022		

Based on the above data analysis, the following conclusions are obtained:
According to the mode distribution, 380.2 Hz is suspected to be the first-order bending mode.

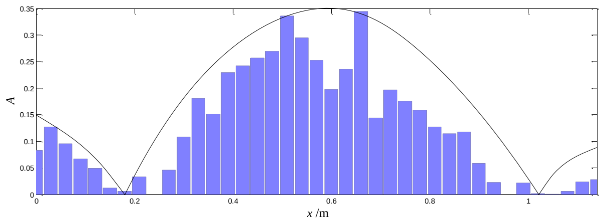

Figure 5. First-order bending mode shape distribution

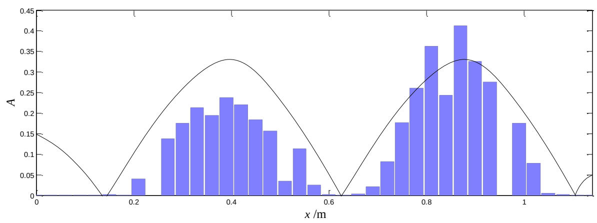

Figure 6. Second-order bending mode shape distribution

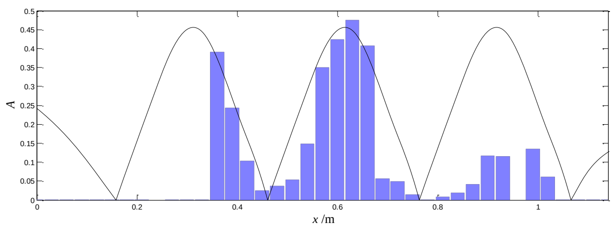

Figure 7. Third-order bending mode shape distribution

The test analysis results are compared with the numerical simulation results, as shown in Table 2. The error between the numerical simulation results and the experimental test analysis results is about 10%. Considering the factors such as the processing error of the test model and the laboratory test error, the error value is within the acceptable range and the calculation reliability is high.

Table 2 Comparison of test results with numerical calculation results

Modal order	Modal frequency		error/%
	Test	Numeral caculations	
1	340.6Hz	378.42Hz	9.99
2	1022 Hz	1156.7Hz	11.64
3	1451 Hz	--	--

The above research verified the simplification and modeling method of submarine numerical model by the Benchmark submarine scale model test, the same as the numerical calculation method of the natural vibration characteristics of the submarine structure. It provides a comparison basis for the numerical calculation of vibration characteristics and the reliability of mechanical noise calculation for more complex submarine models.

3. Numerical calculation and analysis of mechanical noise

Based on the above numerical simulation and model verification analysis, the finite element model of the benchmark submarine in the ocean flow field environment is established, and the natural vibration characteristics of the model under this condition are analyzed, and the mechanical noise characteristics after load excitation are analyzed.

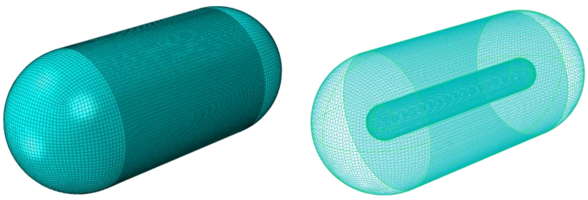

Figure 8. Ocean environment flow field model

As shown in Fig. 8, in the modeling process, it is necessary to comprehensively consider the accuracy of the model and the efficiency of numerical calculation. When establishing the ocean flow field, in order to fully couple the flow field grid with the submarine model grid, while keeping less The number of meshes is used to increase the calculation speed, and a two-layer flow field is established. The inner flow field has a dense mesh, and the submarine model meshes the scale. The outer flow mesh can be appropriately adjusted according to the flow field size.

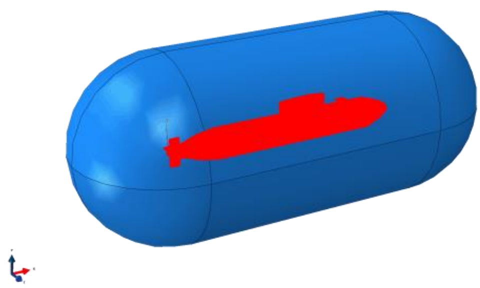

Figure 9. Benchmark submarine model in the flow field environment

Finally, a benchmark submarine model in the ocean flow field environment as shown in Fig. 9 is established.

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The mechanical noise characteristics of the submarine have many influencing factors, and the inherent vibration characteristics of the submarine itself is one of the main factors. The natural vibration characteristics of the benchmark submarine model in the ocean flow field environment are calculated based on the finite element method.

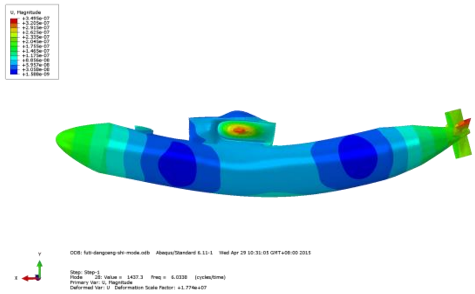

Figure 10. Benchmark submarine model first-order mode

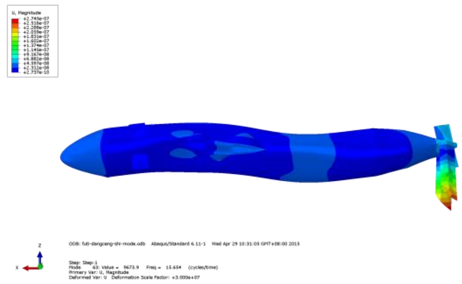

Figure 11. Second-order mode of the Benchmark submarine model

As shown in Fig. 11 and Fig. 12, the first-order and second-order natural vibration modes of the model in the ocean flow field are calculated by the finite element method.

Based on the natural vibration characteristics of the submarine, the excitation effect caused by the simulated propulsion shafting at the tail of the submarine is calculated, and the mechanical noise of the model in the ocean flow field environment is calculated.

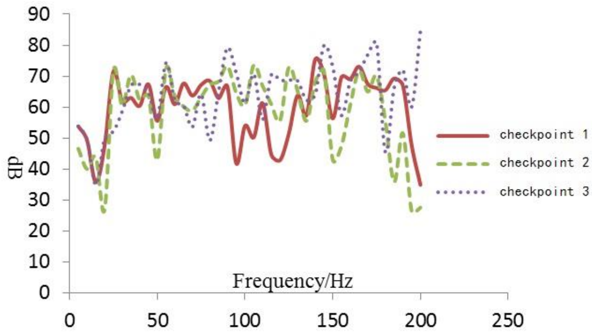

Figure 12. Schematic diagram of mechanical noise distribution of submarines in different locations

Based on the finite element method, the numerical model of the submarine is established, and the natural vibration characteristics of the submarine in the ocean flow field are calculated. The mechanical noise generated by the submarine under the excitation of the power equipment is calculated. The above research content can provide technical support for the design and analysis of submarine noise characteristics, the detection of submarine targets and the propagation of submarine noise in ocean channels.

4. Conclusion

In this paper, the laboratory test system for the inherent vibration characteristics of the submarine scale model is built. The reliability of the numerical simulation method for the submarine mechanical noise based on the finite element method is verified by the laboratory test and numerical simulation. Based on the above research, the natural vibration characteristics analysis and mechanical noise simulation calculation of the complex submarine structure are carried out, which can provide support for the performance evaluation and mechanical noise analysis of the ship during the design stage.

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