STUDY ON LOW FREQUENCY EXCITATION CHARACTERISTICS OF MARINE PROPULSION SYSTEM-BASED NOISE SOURCE

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The marine propulsion system radiated noise sources mainly include noise of propeller, noise of propeller shaft support structure and noise of auxiliary machinery, among which the former two have direct correlation with rotational speed of the propulsion system. In order to study the low frequency excitation characteristics of three kinds of noise sources at different rotational speeds, the subscale experimental model of marine propulsion system is established. In addition, the inherent characteristics of the modal parameters of the static propeller shaft support structure are measured by using the impact excitation testing method. Under different rational speed conditions of the marine propulsion system, this study analyzes the low frequency radiation noise characteristics and change law of the propeller-shaft support structure, the auxiliary equipment and the propeller. The experimental results show that under the normal variable speed condition, the low frequency excitation characteristics forms of the auxiliary equipment are single, which are mainly the axial frequency and harmonic frequency. The natural frequency of the propeller and the propeller-shaft support structure is not easily excited. The dominate frequency, blade frequency and harmonic frequency produced by the propeller and the shaft system are the major contributors of marine propulsion system low frequency radiation noise.
Keywords: low frequency radiation noise,inherent structural characteristics, mass effect

1. Introduction

Propeller noise is one of the main noise sources radiated during ship navigation. With the increasingly urgent requirements of the ship noise control, the propeller occupies a central position in the ship's vibration and noise reduction technology. In recent years, abnormal propeller shaft vibration noise has frequently occurred when the ship sails in the ocean. These abnormal vibration noises bring a great harm to the ship itself and health of the crew. Targeting at abnormal vibration noise of the shaft, the following methods are often used in the process of examining abnormal vibration noise of the propeller shaft: The first method is the sensory experience method, which detects the noise source by using sensory awareness such as ear or eye on the site. The second method is the theoretical calculation method. According to the parameters characteristics of abnormal phenomena, the numerical model is used to calculate the possible noise source. The third method is the engineering test method, which tests the noise source date with a professional vibration noise meter and uses data analysis to position and investigate the noise source. The above three methods have their own advantages and disadvantages, but the third method is the most effective and most practical method in terms of engineering applications. Combined with the actual engineering test experience, this paper carries out presentation analysis and research on the inherent submarine characteristics of the propeller, and the underwater vibration characteristics of the propeller in an unsteady state. The analysis and research results will accumulate the experience in judgment of the artificial sensory awareness, and plays the role of verifying scientific theoretical calculation and numerical simulation calculation.

2. Study on mass effect of single blade of composite propeller

During engineering test, due to the material particularity of the composite propeller, acquisition of the modal parameter of the single blade needs to consider the impact of the sensor quality on the composite propeller, which is the so-called mass effect. By mapping single blade model of the composite propeller, the single blade geometric model of composite propeller is established. 38 nodes are established for the single blade, and numbers of nodes on leading and following edges are the same, as shown in Fig1. By deploying different sensors on the 38 nodes, and using the single-point impedance excitation technique, modal parameters of single blade are acquired under a number of different sensors, with the test results shown in Table 1.

The results of the engineering modal test show that the composite propeller has a significant mass effect on the arranged sensors. When the number of sensors arranged is below 7, the first four order natural frequencies of the single blade are basically identical. Considering the requirements of the engineering test method to the layout of the sensors, seven sensors are selected as the test model for the research. Testing results and modal parameters of composite propeller single blade are shown in Fig. 2 and Fig. 3.

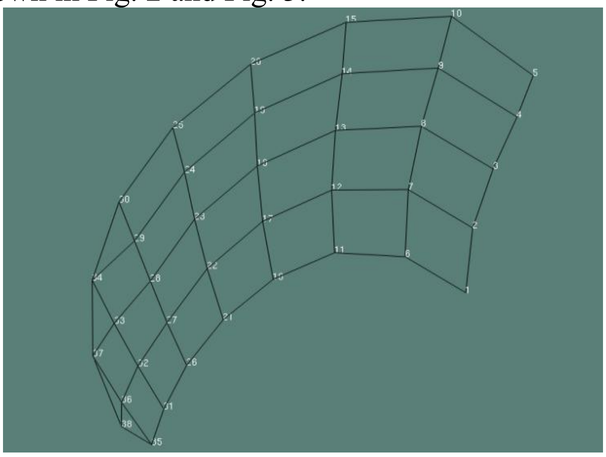

Fig. 1: Net model of composite propeller.

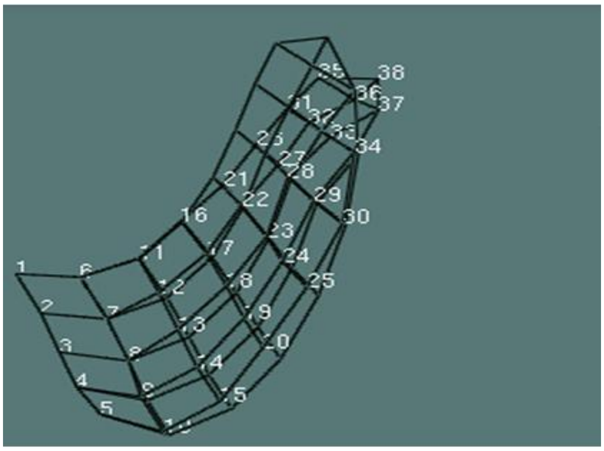

Fig. 2: First order model of composite propeller.

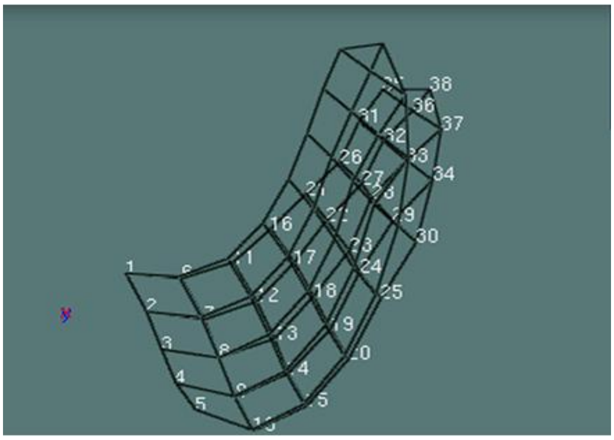

Fig. 3: Second order model of composite propeller.

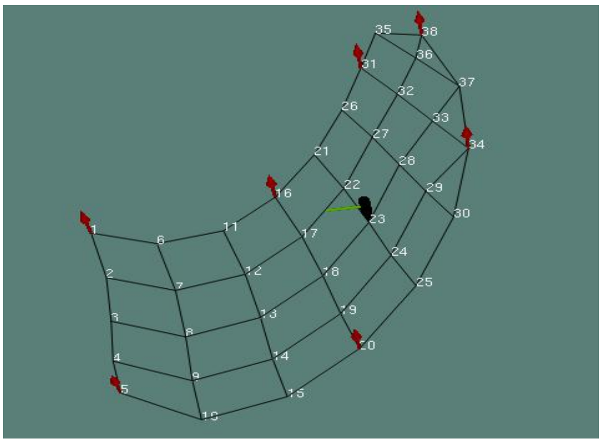

Fig.4: Test model of composite propeller.

Number of sensors	Natural frequency/ Hz			
	First order	Second order	Third order	Fourth order
38	f1-9	f2-9	f3-3	f4-21
26	f1-9	f2-8	f3-4	f4-21
16	f1-8	f2-7	f3-1	f4-19
11	f1-2	f2-4	f3-2	f4-6
9	f1-2	f2-4	f3-2	f4-6
7	f1	f2-1	f3-1	f4+1
5	f1	f2-1	f3	f4
3	f1	f2	f3	f4

Table 1: The relationship between number and frequency

3. Study on parameter difference among 5 blades of composite propeller

Composite propeller layering has a close relationship with the hydrodynamic performance of propeller, and composite propeller's ability to automatically adjust the blade deformation can achieve the goal of improving its hydrodynamic performance. After a reasonable layering, a composite propeller whose propulsion efficiency is higher than metal propeller under multiple operating conditions can be designed. Australian scholars have designed an adaptive lightweight marine propeller diagram that reflects the relationship among layering material, angle and thickness. This indicates that the composite propeller's adaption to fluid and flow field can be improved by adjusting the angle and thickness of the layer. Aiming at the differences in layering material, angle and thickness among 5 blades and combined with the conclusions of the single blade mass effect study, the differences in the modal parameters of the blades are studied.

Using the impedance co-excitation method, the same excitation model is established, as shown in Fig. 4. The modal parameters of each blade are obtained by conducting the modal testing for seven blades. The results are shown in Table 2, Table 3 and Table 4. The results show that there are big differences in the natural frequencies of the blades, and the damping ratio is also different. The vibration modes of the blades are basically the same, which shows that there are some difference in layering material, angle and thickness of each blade of the composite propeller.

First order	Frequency /Hz	Damping/ %
1#blade	f +4	0.42
2#blade	f -5.9	0.94
3# blade	f -5.9	0.78
4# blade	f +0.4	0.71
5# blade	f	0.95

Table 2: The relationship between modal parameter and first order in air

Second order	Frequency /Hz	Damping/ %
1#blade	f +6.3	0.90
2#blade	f -1.4	0.84
3# blade	f -7.6	0.95
4# blade	f +3.9	1.0
5# blade	f	0.89

Table 3 :The relationship between modal parameter and second order in air

Third order	Frequency /Hz	Damping/ %
1#blade	f -2.9	1.34
2#blade	f -5.6	1.12
3# blade	f -3.5	1.33
4# blade	f -2.9	1.80
5# blade	f	1.66

Table 4 :The relationship between modal parameter and third order in air

4. Comparative study on modal parameters of composite propeller single blade for both dry and wet conditions

Lightweight property contributes to a higher stiffness-weight ratio and better vibration performance. Compared with the propeller made of metal materials, the composite propeller has large deformation and is lightweight, which increases the difference of modal parameters in air medium and in water medium. The author uses engineering test method to carry out the modal test against the composite propeller in water medium. The under-water modal test excitation model for 5 blades is shown in Fig. 4, and the test results are shown in Table 5, Table 6 and Table 7. Combining the results obtained in the previous section, and comparing the modal parameters of the 5 blades in the air and in the water, the results shows that there are difference in the natural frequency and the damping ratio of each blades in the water, and the first three order vibration mode in the water is basically the same with that in the air. Impact of the attached mass of water medium on the lightweight natural frequency is obvious.

First order	Frequency/Hz	Damping /%
1#blade	f +0.9	2.27
2#blade	f -2.5	2.22
3# blade	f -2.3	1.91
4# blade	f -0.2	1.50
5# blade	f	2.53

Table 5: The relationship between modal parameter and first order in water

Second order	Frequency/Hz	Damping /%
1#blade	f +1.9	1.38
2#blade	f -1.4	2.10
3# blade	f -4.5	1.98
4# blade	f +3.2	1.27
5# blade	f	2.15

Table 6 : The relationship between modal parameter and second order in water

5. Underwater inherent characteristics of metal propeller

The underwater inherent characteristics of the propeller are an important parameter in the propeller designing. The inherent characteristics of the propeller include the natural frequency, damping ratio and vibration mode of the propeller single blade. In real engineering applications, it is necessary to obtain the inherent characteristics of each propeller blade in order to study the vibration characteristics of the propeller in an unsteady state. The engineering test method is used to identify modal parameters of those two kinds of propeller blades in locations 1m under water. Those blades are defined as composite and metal ones. By using the physical mapping method, the geometrical models of the composite blade and the metal blade are established. 38 nodes are established for the single blade, and numbers of nodes on leading and following edges are the same. By deploying different sensors on the 7 nodes, and using the single-point impedance excitation technique, modal parameters of single blade are acquired. As there are differences in quality structure and material properties between two types of blades in the process of designing and processing, results of identifying underwater modal parameters are different from two blades. The underwater modal parameters for two kinds of single blades are shown in Table 7 and Table8.

Modal of metal propeller blades		
First order	Frequency/Hz	Damping /%
1#blade	f -1.2	2.1
2#blade	f -0.8	2.2
3# blade	f -0.1	2.5
4# blade	f -0.8	2.3
5# blade	f	2.5

Table 7: The relationship between modal parameter and first order in water（metal propeller）

Modal of metal propeller blades		
Second order	Frequency/Hz	Damping /%
1#blade	f	0.68
2#blade	f +0.1	0.71
3# blade	f +0.2	0.70
4# blade	f +0.1	0.69
5# blade	f	0.67

Table 8: The relationship between modal parameter and second order in water（metal propeller）

6. Study on vibration characteristics of composite propeller for the cavitation condition

As we all know, the propeller works in the ship's wake stream. Because the hull line and the accessories are not symmetrical, the ship's wake speed has obvious circumferential non-uniformity. Thus, within the rotating interval of each blade, the relative velocity of the fluid which contacts the blade (equal to the vector sum of the velocity of the wake where the blade lies and the rotational speed of the blade) is periodically changed. Thus, the degree of cavitation intensity is also periodically changed. In addition, due to the rotation of the blade, the hydrodynamic pulsating pressure field with the blade frequency is formed in the seawater around the propeller. Under the action of this pulsating pressure, the large number of bubbles existing in the area is pressed for volume fluctuation due to periodic variation from ambient pressure. With the rotation of the propeller, a large number of transient vacuoles are collapsed and bounced the within the blade area, accompanied by strong acoustic radiation; Within the propeller area, a large number of stable bubbles can also radiate sound waves due to the periodic forced vibration. All of these constitute a propeller cavitation noise.

In order to understand the hydrodynamic noise low frequency characteristic line spectrum at moment of propeller cavitation and the excitation representation of the inherent characteristics of the blade, the propeller cavitation hydrodynamic noise testing is carried out from the point of view of engineering test. Class I tested propeller is installed to the 1: 2 subscale experimental model, and the hydrophone is installed on accessories of the propeller. Start the speed motor to make the propeller's velocity gradually ascended from 25 r/min to 120 r/min. Record hydrodynamic noise data of the propeller at each rotational speed in a real-time basis. When the propeller rotates at 116 r/min, the surface of the blade is cavitated. The hydrodynamic noise data of the propeller are recorded for cavitation and non-cavitation conditions, and the spectrum characteristic chart is plotted. Comparing the low frequency noise line spectrum in the cavitation state and the non-cavitation state, it can be found that the frequency characteristics line spectrums for two states are the same. The frequency corresponding to the characteristic line spectrum is 13Hz, 27Hz, 54Hz, 81Hz, 94Hz and 104Hz respectively, which are the multiples of the characteristic line spectrum frequency 13Hz. However, the amplitude of the excitation spectrum of the propeller in the cavitation state is much higher than that in the non-cavitation state. At 116 r/min, the propeller's blade frequency is just 13 Hz, indicating that in the cavitation state, the propeller blades can radiate more line spectrum energy and amplify the amplitude of the blade frequency. Combining the underwater inherent characteristics of the propeller blade, the underwater characteristic line spectrum radiated by the propeller blade in the cavitation state is mainly the blade frequency and its multipliers, and the natural frequency of the blade is excited.

7. Study on vibration characteristics of metal propeller in a sliding state

The study on the vibration characteristics of the propeller in the high speed stopping and sliding mode can not only play a key role in identifying the noise source of the tail structure, but understand the excitation characteristics of the propeller under different speeds. The stopping and sliding test method is a commonly used and efficient test analysis method for ship mechanical fault diagnosis and noise source identification separation.

Similarly, by using the engineering test method, the testing model disconnects the coupling between the spindle and the host in the high-speed navigation state, so that the model can separate from the propeller and slide. Record vibration acceleration time response spectrum of the testing model during the period from separation to stopping of the propeller. It can be seen from the spectrum that the spectrum frequency is mainly distributed at 20Hz to 100Hz, among which at 20Hz to 30Hz, a strong line occurs 60 seconds after the ship stops and slides; 25Hz exists in the entire sliding stage, but the amplitude in the first 60 seconds is stronger than that in the later 60 seconds; 49Hz and 98Hz always run through the entire stopping and sliding stage, and the amplitude remains unchanged. As for characteristic frequency of 49Hz and 98Hz with the constant amplitude, the main source of the frequency can be analyzed according to the open status and the characteristic spectrum of the device. For the characteristic frequency of 2Hz to 30Hz with the variable amplitudes, the flow-induced vibration is the noise source of the characteristic frequency of the changing amplitude according to the recorded rotational speed of the propeller, speed of model, and local transmission characteristics of the model structure.

8. Conclusions

The modal parameters of two types of propellers in the water are obtained by means of engineering modal test. Comparative analysis of the spectral characteristics of the propeller for cavitation condition is carried out by means of the engineering test method of the scaled model. The stopping and sliding condition of the real ship at a high speed is simulated, the time series characteristics of the testing model in this state are analyzed. In addition, the present characteristic frequency is analyzed. The main conclusions are as follows:

There is an obvious mass effect relationship between single blade composite propeller and the number of arranged sensors. When the sensors with the number below 7 are arranged, the first four natural frequencies of single blade are basically the same.

There is a big difference in the first three natural frequencies and the damping ratio among 5 blades of the composite propeller. But, the vibration pattern of each blade is basically the same, indicating there are some differences in laying material, angle and thickness among each blade.

In the water, the natural frequency and damping ratio are also different from each blade of the composite propeller. In the air, the first three order vibration mode is basically the same with that in the water, and the impact of attached mass of the water on the natural frequency of each blade is obvious.

The propeller in a cavitated state can directly induce and amplify the corresponding amplitudes of blade frequency and its double frequency, and the natural frequency of the blade is not been induced in this state.

As for the time-frequency characteristics of the propeller at the high-speed stopping slide stage, there are characteristics frequency with constant amplitude, and characteristics frequency with variable amplitudes. The main cause for characteristics frequency with variable amplitudes is the flow-induced vibration.

9. Acknowledgement

The work is founded by the National Science Foundation of China under grant numbers 61503354.

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