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Study on the influence of kinetic parameters of propeller on acoustic and vibration characteristics of propulsion shafting

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ABSTRACT

Propeller in most research on the vibration characteristics of propulsion shafting is simplified, in order to study the influence of kinetic parameters of propeller itself on acoustic and vibration characteristics of propulsion shafting, the propulsion shafting model which contains precise three-dimensional elastic propeller is established, focusing on the mass effect and elastic effect of propeller on shafting longitudinal vibration based on analytical method and finite element method. Results show that the simplified method of propeller has great influence on the propulsion shafting vibration, and the influence of propeller on the acoustic and vibration characteristics of propulsion shafting includes not only mass effect, but also obvious elastic effect. From the point of view of shafting vibration control, increasing propeller mass and blade elasticity are beneficial to shafting vibration control.

Keywords: propeller, mass effect , elastic effect, longitudinal vibration

1. INTRODUCTION

At present, most ships are propelled by propellers. The research results at home and abroad show that[1-3], the longitudinal vibration of propulsion shafting is an important factor affecting hull vibration and noise. In order to study the effect of longitudinal vibration of propulsion shafting on hull vibration and noise, many geometric models of shafting have been established[4-6], including lumped mass model and distributed mass model. Because of the complexity of propeller geometry, the lumped mass point or uniform mass disk are used to simulate propeller geometry[4,5]. Neither of the two modeling methods takes the effect of propeller elasticity on the longitudinal vibration of propulsion shafting into account, which is obviously different from the actual situation.

In order to make the research results of longitudinal vibration of propulsion shafting closer to the actual situation, a propulsion shafting model considering the elasticity of propeller blades is established. The longitudinal vibration characteristics of propulsion shafting considering the elasticity of propeller blades are studied by using transfer matrix method and finite element method, respectively. Then the influence of the simplified method of propeller on longitudinal vibration of shafting is simulated and analyzed and the influence of propeller mass and blade elasticity is further analyzed.

2. Transfer Matrix Method for Longitudinal Vibration of Shafting

2.1 Transfer Matrix Theory of Beams

The one-dimensional beam structure is divided into n elements. The number of elements is increased from 1 to n, and the number of nodes between elements is increased from 0 to n. Each node corresponds to the point transfer matrix, and correspondingly, beam elements from 1 to n correspond to the field transfer matrix, as shown in Figure 1.

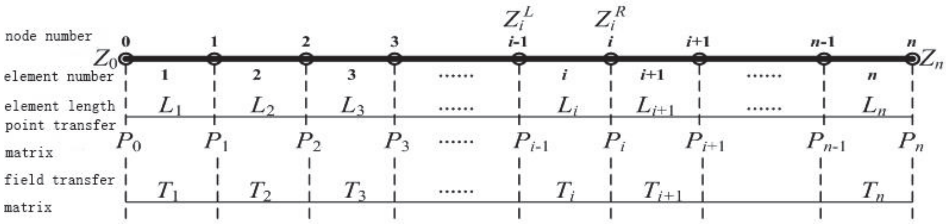


Figure.1 Element division of the beam structure

For the beam element i, the state vector of the left end section is defined as z_i^L, the state vector of the right end section is defined as z_i^R. For the whole beam structure, the state vector of the left end section is defined as z_0, the state vector of the right end section is defined as z_n.

The relationship between the state vector z_n and the state vector z_0 shown in Fig. 1 is obtained by substitution from left to right.

$$z_n = P_n T_n P_{n-1} \cdots P_i T_i \cdots P_1 T_1 P_0 T_0 z_0 = T z_0 \tag{1}$$

in which

$$T = P_n T_n P_{n-1} \cdots P_i T_i \cdots P_1 T_1 P_0 \tag{2}$$

T is the field transfer matrix between the state vectors at both ends of the beam structure. It is obtained by multiplying the point transfer matrix at each node and the field transfer matrix of each beam element in turn.

2.2 Transfer Matrix Method for Longitudinal Vibration of Shafting Considering the Elasticity of Propeller Blades

The state vector of the longitudinal vibration of the shafting is defined as $Z = [u \quad N]^T$, in which the displacement and the stress of the cross section are defined as u and N. According to the deduction of the author's previous paper [6], the point transfer matrix of the centralized mass points is

$$P = \begin{bmatrix} 1 & 0 \\ -m\omega^2 & 1 \end{bmatrix} \tag{3}$$

The point transfer matrix of a massless linear spring is

$$P = \begin{bmatrix} 1 & \frac{1}{K} \\ 0 & 1 \end{bmatrix} \tag{4}$$

For the convenience of calculation, the thrust shaft is simplified to a uniform section without considering the change of section area. The field transfer matrix of its longitudinal vibration is as follows.

$$T = \begin{bmatrix} \cos(\beta l) & \frac{\sin(\beta l)}{EA\beta} \\ -EA\beta\sin(\beta l) & \cos(\beta l) \end{bmatrix} \tag{5}$$

The propeller is composed of hub and blade. The blade has certain elasticity. The influence of propeller on the vibration characteristics of propeller-shaft coupling system is not only reflected in the mass effect of propeller, but also should include the elastic effect of propeller blade. Therefore, the action diagram of propeller on the shafting system is shown in Figure 2.

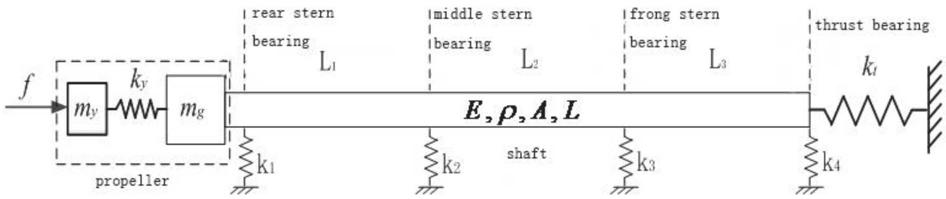


Figure.2 The mechanical model of shafting longitudinal vibration considering the blade elasticity

Among them, m_y and k_y is the equivalent mass and stiffness of the blades; m_g is the mass of propeller without the equivalent mass of the blades, m_y and m_g is regarded as mass point. E , ρ , A and L are elastic modulus, material density, cross-section area and total length of the uniform shaft; k_1 , k_2 , k_3 and k_4 are lateral support stiffness of rear stern bearing, middle stern bearing, front stern bearing and thrust bearing. k_t is the longitudinal support stiffness of thrust bearing.

Thus, the total transfer matrix of shafting longitudinal vibration considering blade elasticity can be expressed as

$$T = P_3 T_1 P_2 P_1 P_0$$

(6)

The left end of the propeller is free, and the cross-section stress is exciting force of the propeller.

$$N_1 = f$$

(7)

The right end of the shaft is rigidly fixed and its longitudinal displacement is zero.

$$u_5 = 0$$

(8)

When the longitudinal excitation force f is applied to the propeller end, the relationship between the state vector of the right end and the left end of the propulsion shafting is as follows.

$$[u \ N]_5^T = [T] \bullet [u \ N]_1^T$$

(9)

Obviously, T is a 4×4 square matrix, so formula (9) can be expressed as

$$\begin{bmatrix} u \\ N \end{bmatrix}_5 = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} u \\ N \end{bmatrix}_1$$

(10)

Substituting formula (7) and (8) into formula (10) can obtain

$$T_{11} u_1 + T_{12} f = 0$$

(11)

Order $f = 0$, the modal frequency of the shafting longitudinal vibration can be obtained by solving equation (11).

Solve equation (11), we can obtain the left-most state vector of the shafting.

$$\begin{cases} u_1 = -\dfrac{T_{12}}{T_{11}} f \\ N_1 = f \end{cases} \tag{12}$$

The longitudinal vibration response of shafting at any section can be obtained by substituting formula (12) into formula (10) and selecting corresponding transfer matrix according to different response positions.

In order to verify the correctness of the above theoretical analysis, the vibration acceleration level at the thrust bearing of the shafting is solved by using MATLAB programming, and the corresponding finite element model is established in Abaqus for simulation analysis. The finite element model is shown in Figure.3, and the specific parameters of the propulsion shafting are shown in table.1.

Figure.3 The finite element model of shafting

Table.1 Parameters of shafting

parameters		unit	value	parameters		unit	value
shaft length	L	m	14.92				
shaft outer radius	R	m	0.135	bearing stiffness	k_y	N/m	1.28e8
shaft inner radius	r	m	0.06		k_1	N/m	3.5e7
equivalent mass of propeller blade	m_y	kg	2626		k_2	N/m	2.0e7
					k_3	N/m	2.0e7
equivalent mass of propeller hub	m_g	kg	1314		k_4	N/m	1.0e8
					k_t	N/m	1.8e9
Young modulus	E	Pa	2.1e11				
density	ρ	kg/m^3	7800	Poisson ratio			0.3

The above transfer matrix method and finite element method are used to calculate the vibration acceleration of the propulsion shafting at the thrust bearing, respectively. The results are shown in Figure. 4. It can be seen from the figure that the calculation results of transfer matrix method and finite element method are basically the same, which shows the accuracy of finite element method in calculating the influence of propeller on shafting vibration. The vibration acceleration spectrum at thrust bearing have two peaks at the first longitudinal vibration frequency (63.56 Hz) of the shaft and the first longitudinal vibration frequency (30.57 Hz) of the blade, which indicates that the elasticity of propeller blade has great influence on shafting vibration.

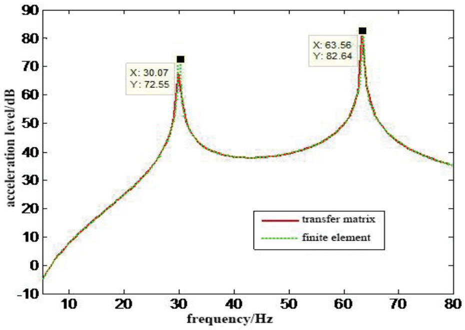


Figure.4 The results contrast of analytical method and finite element method

3. Influence of Propeller on Longitudinal Vibration of Shafting System

3.1 Influence of Propeller Simplification on Longitudinal Vibration of Shafting System

In the related research of shafting vibration, because of the complexity of the actual shafting structure, most models simplify the propeller by using lumped mass points or homogeneous disks of equal mass instead. Because of the different simplification methods, the results are also different. The finite element model of the propulsion shafting with an accurate three-dimensional elastic propeller is shown in Figure. 5. The effect of propeller modeling on the longitudinal vibration modes of shafting is shown in Table.2.

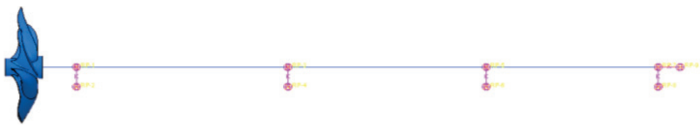


Figure.5 Finite element model of propulsion shafting

Table.2 The longitudinal vibration modal frequency of shafting

modal order	no propeller	lumped mass	homogeneous disk	elastic propeller
1	55.38 Hz	41.09Hz	39.68Hz	41.02Hz
2	106.08 Hz	94.04Hz	89.44Hz	99.50 Hz

It can be seen from the table that after installing propeller, the first and second order longitudinal vibration modal frequencies of the shafting system decrease, and the longitudinal vibration modal frequencies of the shafting system are different under the three modeling modes of the propeller. The first order frequency of lumped mass model is closer to the elastic propeller model, and the shafting longitudinal modal frequencies are lower than those of the other two simplified modes.

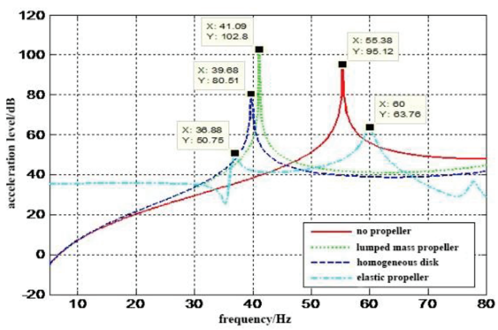


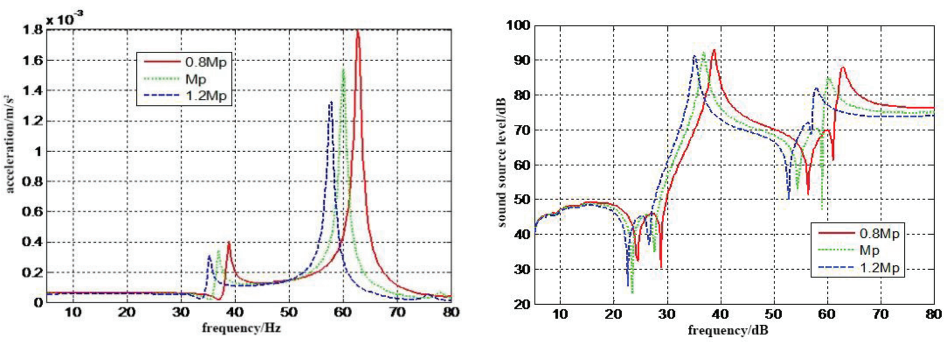
Figure.6 Longitudinal vibration transfer function of shafting under different simplified methods of propeller

The frequency spectrum of longitudinal vibration acceleration transfer function of shafting under different propeller simplified modes is shown in Figure. 6. It should be pointed out that, because the shaft itself has less contact with water and the effect of the attached ripple water on the shaft is small, the effect of the attached ripple water on the propeller is mainly considered, so the effect of the attached ripple water is not considered when the centralized mass and homogeneous disk simplification are adopted.

Compared with the pure shafting without propeller, the peak value of the longitudinal vibration transfer function of the shafting moves to the low frequency when the simplified method of lumped mass points and equal mass homogeneous disk is adopted, and the mass effect of the propeller has a greater impact on the longitudinal vibration of the shafting; when the precise three-dimensional elastic propeller is used, there are two peaks in the longitudinal vibration transfer function. The first peak corresponds to the first-order longitudinal vibration of the shaft and the second peak corresponds to the first-order bending vibration of the propeller blade in the same direction. It can be seen that the influence of actual propeller on the shafting vibration not only include mass, but also include the elasticity of the propeller blade. The mass effect and blade elasticity effect must be taken into account simultaneously in research of the influence of propeller on shafting vibration.

3.2 Influence of Propeller Mass on Longitudinal Vibration of Shafting

In order to study the influence of propeller mass on the longitudinal vibration of shafting independently, only the propeller material density is changed. For the exact three-dimensional elastic propeller-shaft system, the vibration acceleration and sound radiation transfer functions of shafting at the thrust bearing position under unit longitudinal excitation of propeller and different propeller mass are shown in Figure. 7.



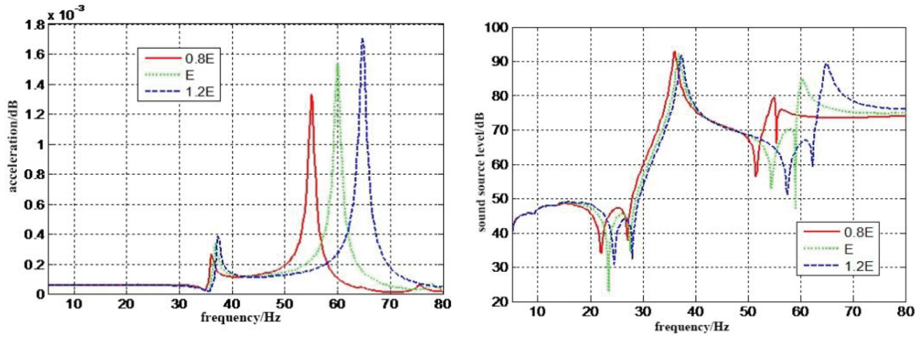
(a) acceleration transfer function (b) acoustic radiation transfer function

Figure.7 Influence of propeller mass on acceleration and acoustic radiation transfer function of shafting

In Figure 7, the first peak corresponds to the first-order longitudinal vibration of the shaft and the second peak corresponds to the first-order bending vibration of the blade in the same direction. It can be seen from the figure that with the increase of propeller mass, the peak value frequency of the transfer function of the shafting at the first-order longitudinal vibration of the shaft and the first-order bending vibration of the propeller blade in the same direction moves to the low frequency, and the amplitude decreases. The influence of propeller mass on the peak value of the first-order bending vibration of the propeller blade in the same direction is greater, and the maximum difference of the sound radiation transfer function at the second peak is 5.82 dB. It can be seen that without changing the elasticity of propeller blade, properly increasing the mass of propeller is beneficial to reduce the vibration and sound radiation of shafting.

3.3 Influence of Propeller Blade Elasticity on Shafting Longitudinal Vibration

In order to study the influence of propeller blade elasticity on the longitudinal vibration of shafting independently, only the elastic modulus of propeller material is changed. For an exact three-dimensional elastic propeller-shaft system, the vibration acceleration and sound radiation transfer functions of the shafting at the thrust bearing position under the unit longitudinal excitation of propeller and different propeller blade elasticity are shown in Figure. 8.



(a) acceleration transfer function (b) acoustic radiation transfer function

Figure.8 Influence of blade elasticity on acceleration and acoustic radiation transfer function of shafting

It can be seen from the figure that with the increase of propeller blade elasticity (the elastic modulus E of the propeller material decreases), the peak value frequency of the transfer function of shafting at the first-order longitudinal vibration of the shaft and the first-order bending vibration of the propeller blade in the same direction moves to the low frequency, and the amplitude decreases. The elasticity of the propeller blade has little effect on the peak value and frequency shift of the first order longitudinal vibration of the shaft. The elasticity of the propeller blade mainly affects the peak value of the first bending vibration frequency of the blade in the same direction. The maximum difference of the amplitude of the sound radiation transfer function at the second peak value is 9.12 dB. It can be seen that the longitudinal vibration of shafting can be effectively reduced by increasing propeller blade elasticity without changing propeller mass.

4. Conclusions

In this paper, the influence of propeller dynamic characteristics on acoustic and vibration characteristics of shafting is studied, and the following conclusions are drawn:

(1) The influence of propeller on shafting vibration is not only reflected in its mass effect, but also in its elastic effect. The blade elasticity is evidently reflected in the longitudinal vibration of shafting. It is inaccurate to simplify the propeller into a lumped mass or homogeneous disk in the study of shafting longitudinal vibration. The influence of the blade elasticity must be considered.

(2) From the point of view of shafting vibration control, increasing propeller mass and blade elasticity are beneficial to shafting vibration control.

5 References

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