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Vibration characteristic analysis and control of hospital ship

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Abstract. Aiming at the problem of high requirement of hospital ship for hull vibration, this paper takes a hospital ship as an example to analyse its vibration characteristic. The three-dimensional finite element model of hospital ship is established. Take the pulsating force of propeller as the exciting force, the vibration response of the whole ship is calculated by acoustic-structure coupling method. Refer to related standard of ISO6954-2000(E), the numerical result shows that the vibration of some region of stern is over standard. An optimization scheme is proposed for the area whose vibration over standard, the result suggests that the whole ship vibration meets the standard after optimization design. This research provides a reference for design and construction of hospital ship.

1. Introduction

In recent years, as ships become larger and faster, the vibration of ships has attracted more and more attention. For the problem of large ship vibration, Yanhui Mao et al.[1] taking non-self-propelled cutter dredger as research object, the difference of ship vibration characteristics under different working conditions is discussed; the influence of different calculation methods of attached water quality on the inherent characteristics of ship total vibration is analyzed. Yu Song et al.[2] in view of the strong vibration of superstructure of a dump sand carrier during its voyage, the response values of forced vibration of ship hull under different working conditions are obtained by frequency response analysis method, and the improvement method of strengthening structure is put forward. Li Yu et al. [3] have carried out research on the vibration performance of a large multi-purpose ship, The calculation results show that the ship has good vibration performance and meets the vibration standard requirements.

In previous studies of ship vibration characteristics, Most of them focus on the vibration of conventional ships, but few on the vibration of hospital ships. Aiming at the problem of vibration characteristics of hospital ship, this paper takes a hospital ship as the research object. Take the fluctuating pressure of propeller as the exciting force, the vibration response of the whole ship is calculated by acoustic-structure coupling method. Referring to ISO6954-2000 (E) [4] related standards, the optimum design scheme is put forward for the vibration over standard area, which has reference significance for the design and construction of hospital ships.

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2. Dynamics Equation of Acoustic- structure Coupling

The vibration system of hull structure is simplified as a multi-degree-of-freedom vibration system, and the differential equation of forced vibration with damping is given as:

$$M\ddot{X} + C\dot{X} + KX = F \tag{1}$$

Where M is the mass matrix; C is damping matrix; K is stiffness matrix; F is exciting load; X is displacement response.

Assuming that the fluid is ideal acoustic medium, the acoustic wave equation can be expressed as:

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \tag{2}$$

Where p is instantaneous acoustic pressure, c is sound velocity.

For the acoustic-structure coupling problem, the finite element method is used to calculate the structural vibration and sound field in the same coupling environment. The dynamic equation of the acoustic-structure coupling is given as:

$$\begin{bmatrix} K_s + j\omega C_s - \omega^2 M & \bar{Q} \\ \rho_a \omega^2 \bar{Q}^T & K_a + j\omega C_a - \omega^2 M_a \end{bmatrix} \begin{bmatrix} u \\ p \end{bmatrix} = \begin{bmatrix} F_s \\ F_a \end{bmatrix} \tag{3}$$

Where $\bar{Q}$ is acoustic-structure coupling matrix; M_s and M_a are the mass matrix of structural and acoustic medium; C_s and C_a are the damping matrix of structural and acoustic medium; K_s and K_a the stiffness matrix of structural and acoustic medium; u is displacement vectors of structural nodes; p is sound pressure vector; F_s is structural load vector; F_a is sound field excitation load vector.

3. Numerical simulation

3.1. Numerical simulation model

3.1.1. Basic parameters. The light ship weight of the hospital ship about 14,000 tons. The vessel is propelled by four main engines and two propellers. The maximum power of main engine is 3000Kw. Propeller is a 4-bladed propeller, its rated speed is 160rpm.

3.1.2. Finite element model. According to the drawings of hospital ships, establishing a finite element model of the vessel. Simulation of hull plate structure by shell element, using beam elements to simulate stiffeners such as longitudinal frames, beams, and pillars. There are more than 40 kinds of plate thickness and section sizes in the model, for ensure that the structural parameters of the model are the same as those of the design. In order to simulate the effect of entrained water on ship structure vibration, the acoustic-structure coupling finite element method is used in this paper, that is to establish a semi-infinite flow field coupled with the hull. The radius of the flow field is two times breadth, the outer surface of the flow field is defined as a non-reflective boundary condition. The schematic diagram of the acoustic-structure coupling model is shown in Figure 1.

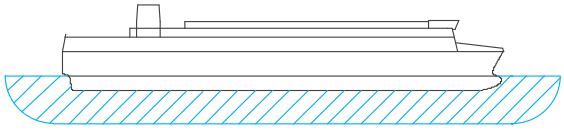


Figure 1. The schematic diagram of the acoustic- structure coupling model.

3.1.3. Exciting force. This paper studies the forced vibration characteristics of hospital ship under the propulsive force of propeller pulsating pressure, due to propeller is one of the main exciting sources of hull vibration and noise. The pulsating pressure of propeller is mainly driven by blade frequency. The formula for calculating blade frequency is given as:

$$f = \frac{n}{60} \times Z \tag{4}$$

Where f is exciting frequency; n is shaft speed; Z is number of blades.

Propeller pulsation pressure is generally estimated using approximate method. The maximum pulsating pressure P_{max} of the propeller when there is no air bubble can be given as [5]:

$$P_{max} = 4.77 K_{P_0} \frac{SHP}{nD^3} \tag{5}$$

Where SHP is power of propeller shaft; n is shaft speed; D is diameter of a propeller; K_{P_0} is dimensionless factor.

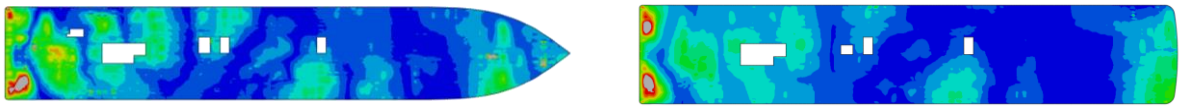
3.2. Vibration analysis and control of hospital ship

3.2.1. Vibration standard. This paper refers to ISO69540-2000(E) standard. It proposed a proposal for the suitability of different areas of the ship for the vibration speed as shown in Table 1.

Table 1. Suitability of different areas of the ship for the vibration speed (mms^{-1}).

	Areas classification		
	Passenger cabins	Crew accommodation areas	Working areas
Values above which adverse comments are probable	4	6	8
Values below which adverse comments are not probable	2	3	4

3.2.2. Forced vibration response of hospital ship. Based on acoustic-structure coupling model of hospital ship, taking pulsating pressure of propeller as exciting force, calculated the vibration response of the whole ship. The calculated frequency band is 1Hz~80Hz. Figure 2 shows the distribution of vibration velocity response of typical decks at the propeller blade frequency. It can be seen that the vibration response of the stern of hospital ship structure is larger than anywhere else, and the vibration response from stern to bow shows a decreasing trend.



(a) (b)

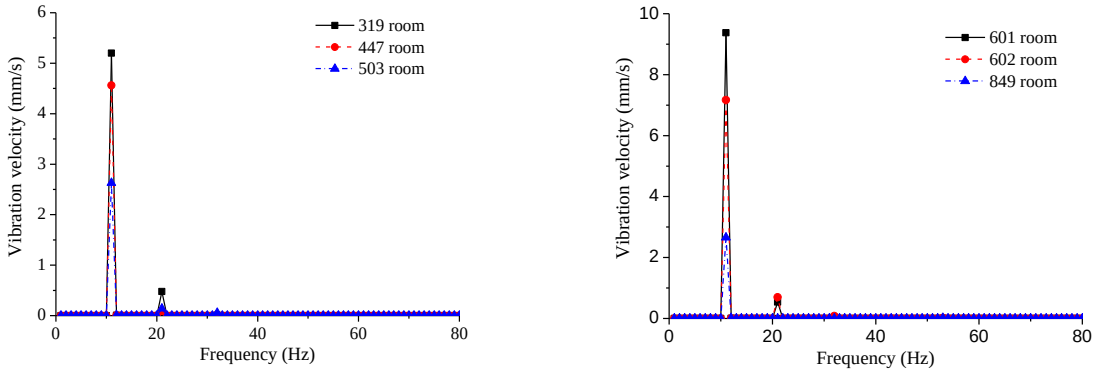
Figure 2. The distribution of vibration velocity response of typical decks (a) deck 3, (b) deck 5.

According to ISO6954-2000 (E) standard, the overall frequency-weighted r.m.s. velocity of local area are calculated and compared with the standard. Limited to space requirements, only partial results are given, as shown in Table 2. The vibration response curves of deck in typical cabin is shown in Figure 3. The results show that the vibration response of most areas of the hospital ship meets the standard, some areas have potential over-standard risk, vibration response in some areas is over standard, the over-standard area are mainly located in the stern.

Table 2. Evaluation of local vibration response.

Deck	Number of cabin	Name of cabin	vibration velocity（mm/s）	standard （mm/s）	Evaluation
3	314	Operating room	2.2	4	Acceptable
3	319	General office	4.5	4	Unacceptable
4	447	Treatment room	3.9	4	Potential dangerous area
5	503	Standard ward	2.3	4	Acceptable
5	508	Standard ward	2.5	4	Acceptable

5	552	Standard ward	3.9	4	Potential dangerous area
6	601	Waiter room	8.1	4	Unacceptable
6	602	Waiter room	6.2	4	Unacceptable
6	651	Doctor room	1.8	4	Acceptable
8	849	Wheelhouse	2.4	4	Acceptable



(a) (b)

Figure 3. Vibration response curves of deck in typical cabin.

3.2.3. Vibration control of hospital ship. For the problem that the propeller causes vibration over standard, main control measure is to attach high damping material to the bottom of the ship above and around the propeller. This paper aims at the over-standard areas and potential dangerous area, the proposed optimization measure is to lay constrained damper plates in the bottom area from 0# to 21#. The laying thickness is 12mm, in the simulation calculation, the loss factor is 0.05 when the restrained damper plate is laid. The schematic diagram of the constrained damper plate is shown in Figure 4.

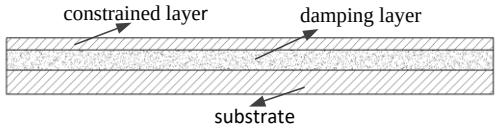
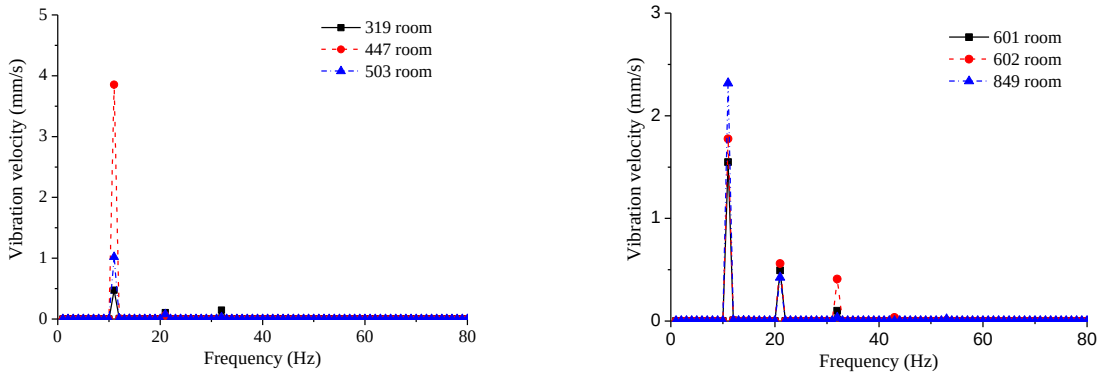


Figure 4. The schematic diagram of the constrained damper plate.

After laying damping material, Limited to space requirements, only partial results are given, as shown in Table 3. The results show that the optimized vibration response of the whole ship meet the standard. Optimized vibration response curves of deck in typical cabin is shown in Figure 5.

Table 3. Evaluation of local vibration response.

Deck	Number of cabin	Name of cabin	vibration velocity（mm/s）	standard （mm/s）	Evaluation
3	314	Operating room	1.8	4	Acceptable
3	319	General office	0.4	4	Acceptable
4	447	Treatment room	3.3	4	Acceptable
5	503	Standard ward	0.9	4	Acceptable
5	508	Standard ward	0.5	4	Acceptable
5	552	Standard ward	3.2	4	Acceptable
6	601	Waiter room	1.4	4	Acceptable
6	602	Waiter room	1.7	4	Acceptable
6	651	Doctor room	1.0	4	Acceptable
8	849	Wheelhouse	2.0	4	Acceptable



(a) (b)

Figure 5. Optimized vibration response curves of deck in typical cabin.

4. Conclusion

This paper take the fluctuating pressure of propeller as exciting force, the vibration response of the hospital ship is calculated by acoustic-structure coupling method. Referring to ISO6954-2000 (E) related standards, the optimum design scheme is put forward for the vibration over standard areas. Through the above research, we can draw the following main conclusions :

(1) Under the action of propeller fluctuating pressure, structural vibration of hospital ship mainly concentrates on the stern part. The vibration response shows a downward trend from stern to bow.

(2) Referring to ISO6954-2000 (E) standards, under the action of propeller fluctuating pressure, the vibration response of most areas of the hospital ship meets the standard, only some areas is over standard. These over-standard areas are mainly located in the stern.

(3) Aiming at the over-standard areas and potential dangerous area, the proposed optimization measure is to lay constrained damper plates in the bottom area from 0# to 21#. The laying thickness is 12mm. The optimized vibration response of the whole ship meet the standard.

Reference

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