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Effect analysis of geometric parameters of floating raft on isolation performance

LI Shangda^{1,2}, LIU Yan¹

1 China Ship Development and Design Center, Wuhan 430064, Hubei, China

2 Science and Technology on Ship Vibration and Noise Key Laboratory, Wuhan 430064, Hubei, China

Abstract: [Objectives] This paper focuses on the effects of the geometric parameters of a floating raft on isolation performance. [Methods] Based on the idea that the weight of a floating raft remains constant, a parametric finite element model is established using geometric parameters, and the effects of the geometric parameters when isolation performance is measured by vibration level difference are discussed. [Results] The effects of the geometric parameters of a floating raft on isolation performance are mainly reflected in the middle and high frequency areas. The most important geometric parameters which have an impact on isolation performance are the raft's height, length to width ratio and number of ribs. Adjusting the geometric parameters of the raft is one effective way to avoid the vibration frequency of mechanical equipment. [Conclusions] This paper has some practical value for the engineering design of floating raft isolation systems.

Key words: floating raft; geometric parameters; isolation performance; natural frequency

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0 Introduction

Mechanical vibration, which is inevitably generated by the operation of main, auxiliary engines and shaft systems within a ship, transmits through the base and excites the hull, causing the hull to vibrate and radiate noise into the surrounding water^[1]. The phenomenon is not conducive to the quietness of ship and will also worsen crew's working and living environment, so it must be controlled to reach a lower level of mechanical vibration. At present, isolation performance of a floating raft is the main means of centralized control (isolation) of mechanical vibration^[2-3].

After decades of development, theories and techniques for isolation performance of floating raft have been developed. In practical engineering applications, the ways to improve the isolation effect of floating raft mainly include selecting appropriate dynamic parameters, designing rafts and bases rationally and optimizing the arrangement of vibration isolators.

In terms of suitable dynamic parameters, Yan et al.^[4] studied the effects of main structures and dynamic parameters of the system on vibration isolation and noise reduction by taking a floating raft isolation system with two diesel generators as the object research. Zhang et al.^[5] studied the influence of raft mass, stiffness and damping on the isolation performance of the whole system from the perspective of vibration isolation transmissibility by establishing a reduced-order finite element model for the vibration system of floating raft. In the aspect of rational design of raft and base, Su et al.^[6] studied the effect of rotational inertia and rigidity of raft as well as base impedance on vibration performance by taking the floating raft vibration isolation mounting of some diesel generator and its base as the research project. In regard of optimizing the arrangement of vibration isolator, Du et al.^[7] deduced the transmission power flow of double-layer vibration isolator in aligned and non-aligned installation schemes based on the admit-

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Author(s): LI Shangda, male, born in 1989, master candidate. Research interest: vibration and noise control. E-mail: flexion@126.com

LIU Yan (Corresponding author), male, born in 1979, Ph.D., senior engineer. Research interest: Control of vibration and noise for ship. E-mail: liuyanhit@gmail.com

tance method and found when the structural transfer admittance is less than the input admittance, non-aligned installation is more conducive to reduce the transmission of wide-frequency vibration.

The above studies on vibration isolation system of a floating raft show that selecting reasonable parameters is an effective way to improve the isolation performance of the system. However, these studies mainly focus on the choice and effect of dynamic parameters, while the effect of geometric parameters of a raft on the isolation performance and the distribution of natural frequency for a floating raft are little studied.

In order to solve the above problems, this paper proposes to establish a parametric model of the floating raft, using the finite element method to analyze the effect of geometric parameters of the raft on the isolation performance of the system and the distribution of natural frequency of the raft under the premise of constant total mass of the elastic raft, so as to obtain some useful conclusions.

1 Establishment of parametric models for the raft

The prerequisite of parametric analysis is to establish a parametric model, which is built and analyzed using parameters (variables) rather than numbers, and a new model can be built and analyzed by simply changing parameter values in the model. The parametric model has two levels: parametric geometric model and parametric finite element model. Parametric geometric model is often the base of parametric finite element model, which is usually an extension of parameter action range in geometric models. Moreover, the geometric model cannot be directly used for analysis and calculation, which needs to be transformed into finite element model for the utilization of analysis and optimization programs^[8].

At present, when parametric analysis or optimization for the vibration isolation system of a floating raft is carried out, the complicated structure of a raft is often simplified for the established parametric model. For example, geometrical parameters of raft structure are usually not involved when the raft is simplified into a steel plate with a certain thickness or a rigid body with a certain mass, which is not conducive to the checking computation of vibro-acoustic transfer properties and acoustic design of the raft structure.

1.1 Parametric geometric model of a raft

The floating raft with horizontal grillage is most

widely used at present. Based on the geometric voxel characteristics of such floating raft structure, it can be decomposed into three parts: upper and lower panels and an intermediate orthogonal rib with waist with middle holes, as shown in Fig. 1.

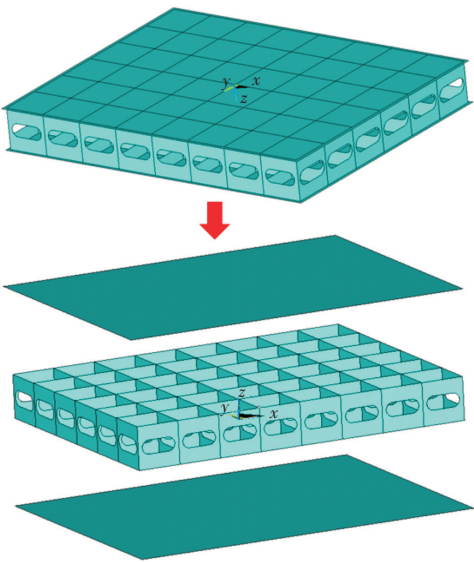


Fig.1 Floating raft with horizontal grillage

According to the shape analysis, the upper and lower panels of floating raft can be determined by the total length, total width of the raft, as well as total height and thickness of upper and lower panels of the floating raft; the ribs can be determined by the distance and thickness of the rib as well as the length and width of middle holes on the rib (Fig. 2).

Among them, the rib distance is controlled by the number of ribs, so the location dimension——rib distance can be expressed by the number of ribs. Therefore, all geometric parameters of the raft are shown in Table 1. The purpose of modifying the size and shape of the raft can be achieved by modifying the

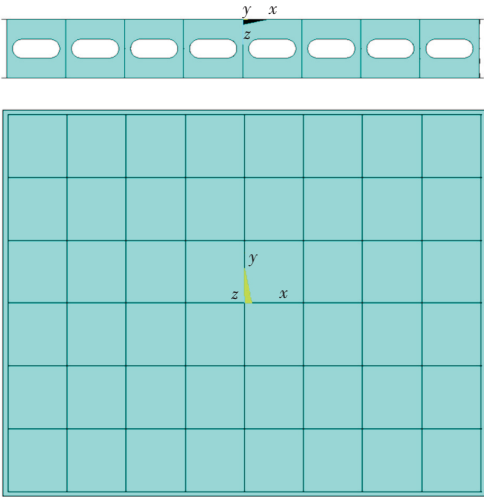


Fig.2 Geometric parameters of floating raft

value of geometric parameters.

Table 1 Geometric parameters of floating raft

No.	Parameter	Meaning
x_1	<i>FRH</i>	Total height
x_2	<i>FRL</i>	Total length
x_3	<i>FRW</i>	Total width
x_4	<i>TLTK</i>	Thickness of upper panel
x_5	<i>NOLLB</i>	The number of ribs in the length direction
x_6	<i>NOWLB</i>	The number of ribs in the width direction
x_7	<i>BLTK</i>	Thickness of lower panel
x_8	<i>LEL</i>	Middle hole length of ribs in the length direction
x_9	<i>LEW</i>	Middle hole width of ribs in the length direction
x_{10}	<i>WEL</i>	Middle hole length of ribs in the width direction
x_{11}	<i>WEW</i>	Middle hole width of ribs in the width direction
x_{12}	<i>LBTK</i>	Rib thickness

1.2 Parametric finite element model of a floating raft

ANSYS Parametric Design Language (APDL) is a scripting language that can automatically perform finite element analysis or set up analytical models by means of parameterized variables, and its parameters include geometric dimensions, material properties, mesh size, load boundary conditions, etc.^[9]. The material of a raft used on ships is generally steel. Therefore, the influence of material parameters is not considered in this paper, while the effect of geometric parameters on isolation performance and its natural frequency distribution is emphasized.

According to the initial values of geometric parameters of the raft, APDL is used to establish the finite element model expressed by the above parameters, as shown in Fig. 3. Rafts are simulated by Shell 181 shell element, which can well simulate the bending and shearing deformation.

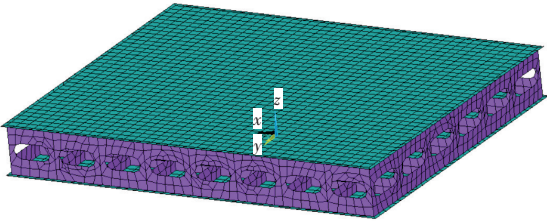


Fig.3 Parametric finite element model of floating raft

2 Effect of geometric parameters

After taking the vibration isolation system of a floating raft as the research object, the finite element model is established based on the parametric model of a raft structure, and the harmonic response analysis is performed. The power equipment is connected

with the raft through an upper isolator, while the raft is connected with the base through a lower isolator. The following methods are used at modeling time: Mass 21 unit is used to obtain the equivalent mass, rotational inertia and inertia moment of power equipment; the connection between power equipment and isolator is established by coupling degree of freedom (DOF). Three Combine 14 elastic damping elements are used in all vibration isolators to simulate the stiffness and damping in three directions. The accuracy of this finite element simulation method has been verified in Reference [10]. The finite element model of the floating raft isolation system is shown in Fig. 4.

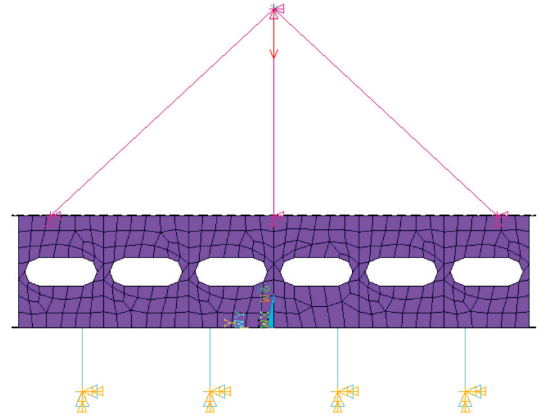


Fig.4 Finite element model of floating raft isolation system

The isolation performance is evaluated by the vibration level difference, and the vibration displacement level difference L_D is selected as follows:

$$L_D = L_U - L_B = 10 \lg \left(\frac{\sum_{i=1}^m \frac{S_{U-i}^2}{m}}{\sum_{j=1}^n \frac{S_{B-j}^2}{n}} \right) \quad (1)$$

where L_U is the vibration displacement level at the engine mount of device; L_B is the vibration displacement level at each joint on the interface between the lower isolator and the raft; S_{U-i} is the displacement response at the i^{th} joint node on the interface between the device and the upper isolator; S_{B-j} is the displacement response at the j^{th} joint node on the interface between the lower isolator and the raft; m is the number of upper isolator; n is the number of lower isolator.

Due to the parameterization of raft, the vibration displacement level difference can be expressed as the function (h) of 12 geometric parameters and frequency f i.e.,

$$L_D = h(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, f) \quad (2)$$

The total raft volume v can be expressed as a function (g) of 12 geometric parameters, so the following equation can be obtained on the premise that

the total raft mass is constant:

$$m = \rho v = \rho g(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12})$$

(3)

where m is the total raft mass; ρ is the material density of raft; v is the total raft volume.

As can be seen from Eq. (3), at least the values of two geometric parameters should be changed to keep the total mass of elastic raft unchanged. For example, the raft model increases the thickness of upper panel by 0.01 mm while reduces the thickness of lower panel by 0.01 mm. The total raft mass can remain unchanged if other geometric parameters are kept the same. When modal analysis is performed on the raft, the finite element model of the raft in the floating raft isolation system can be taken out to calculate the inherent characteristics of the raft under free boundary conditions and analyze the influence of geometric parameters on the natural frequency distribution of the raft.

Due to a large number of different combinations of geometric parameters, and space limitations, only several parameter parametric combination with significant impacts are analyzed in the paper with the consideration of practical engineering application.

2.1 Effects of different combinations of total floating raft length (FRL) or total floating raft width (FRW) and total floating raft height (FRH) on the vibration isolation

Generally, the effects of changes of FRL or FRW tend to be consistent on the vibration isolation system. Without loss of generality, this paper takes the case of changing FRW and FRH while keeping other geometric parameters unchanged as an example to analyze the effect of different combinations of these two on the vibration isolation performance, and the case of changing FRL and FRH will not be repeated. Fig. 5 and Table 2 respectively show the curves of vibration level difference and the modal frequency of raft under free state with three combinations of FRW and FRH.

As can be seen from Fig. 5, curves of vibration level difference basically overlap at the low frequency, but there is a large difference at the middle and high frequencies, which shows that the isolation performance of FRW and FRH is mainly reflected at high frequency. In the middle and high frequencies of 100–1 000 Hz, the vibration level increases with the rise of the raft height, and the fluctuation amplitude of vibration level difference decreases, which im-

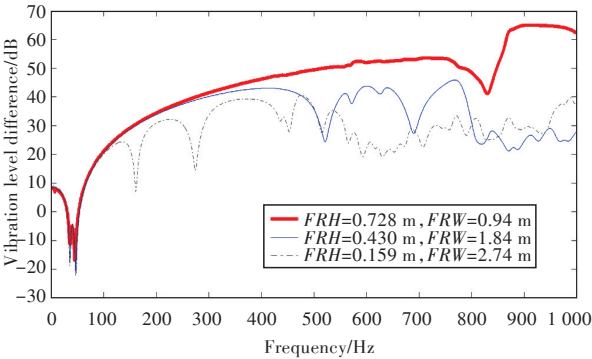


Fig.5 Curves of vibration level difference with FRW and FRH as variables

Table 2 The natural frequencies of floating raft with FRW and FRH as variables

Order	Modal frequency/Hz		
	FRH=0.728 m	FRH=0.430 m	FRH=0.159 m
	FRW=0.94 m	FRW=1.84 m	FRW=2.74 m
1	447.56	331.06	123.11
2	456.77	357.40	157.29
3	462.74	357.53	221.31
4	471.66	368.31	254.76
5	492.77	368.49	280.86
6	502.85	369.70	359.14

proves the isolation performance of the system. From Table 2, it can be seen that with the increase of FRH and the decrease of FRW, natural frequencies of the first six-order elastic vibrations move toward high frequency, which means that the increase of raft height can increase its stiffness, reduce the modal vibration density, and improve the vibration isolation performance. It can be seen that FRH is one of the most important geometric parameters that affect the isolation performance of the system. Therefore, in practical engineering applications, if the conditions permit, properly increasing FRH will improve the vibration isolation performance.

2.2 Effect of the length-width ratio of raft (RATIO) on vibration isolation performance

With other parameters remaining unchanged, only the RATIO ($RATIO = FRL/FRW$) is changed, that is, only the combinations of FRL and FRW of raft are changed. Curves of vibration level difference and the modal frequency of raft under the free state with RATIO as a variable of three different floating rafts are shown in Fig. 6 and Table 3.

Fig. 6 shows that curves of vibration level difference basically overlap at low frequency and RATIO almost has no effect on isolation performance. Curves of vibration level difference fluctuate with

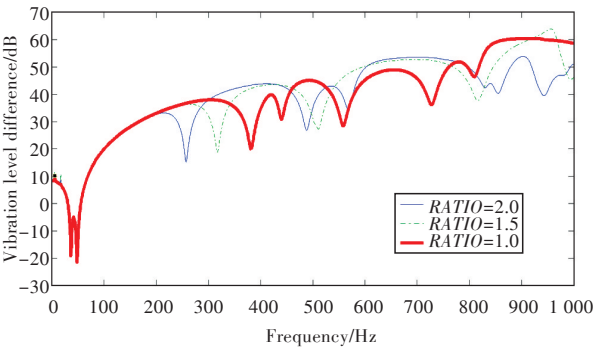


Fig.6 Curves of vibration level difference with *RATIO* as a variable

Table 3 The natural frequency of floating raft with *RATIO* as a variable

Order	Modal frequency/Hz		
	<i>RATIO</i> =1	<i>RATIO</i> =1.5	<i>RATIO</i> =2
1	252.74	254.24	252.12
2	379.47	315.59	258.04
3	438.00	501.20	481.77
4	541.42	509.52	541.67
5	556.22	601.65	577.22
6	727.42	689.63	585.36

the decrease of *RATIO* at the middle and high frequencies. After combining with Table 3, it can be seen that natural frequencies of elastic vibration in the first few orders do not move in the direction of high or low frequency as the *RATIO* increases or decreases. For example, when *RATIO* = 1, natural frequencies of elastic vibration in the first and second order are the highest, which are the lowest in the third order. Therefore, the distribution of natural frequencies of elastic vibration can be changed by adjusting *RATIO*, which is an effective means to stagger the vibration frequency of mechanical equipment.

2.3 Effect of different combinations of *FRH* and thickness of ribs (*LBTK*) as variables on isolation on isolation performance

With other parameters remaining unchanged, only *FRH* and *LBTK* are changed. Curves of vibration level difference and modal frequencies of raft under the free state with three combinations are shown in Fig. 7 and Table 4.

As can be seen from Fig. 7, when *FRH* and *LBTK* change, curves of vibration level difference at low frequency are basically the same, which fluctuate at the middle and high frequencies with *FRH* and *LBTK* as variables. The curves corresponding to the maximum vibration level difference also vary in different frequency ranges. Therefore, according to spectrum fea-

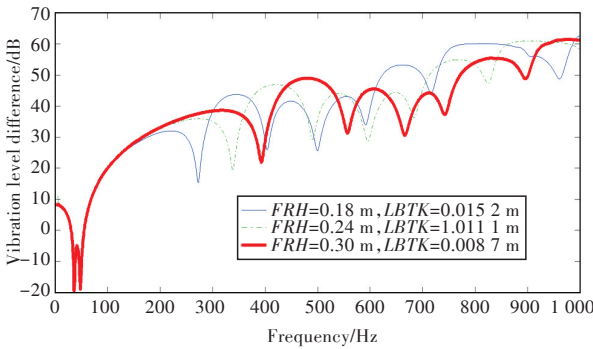


Fig.7 Curves of vibration level difference with *FRH* and *LBTK* as variables

Table 4 The natural frequencies of floating raft with *FRH* and *LBTK* as variables

Order	Modal frequency/Hz		
	<i>FRH</i> =0.18 m <i>LBTK</i> =0.015 2 m	<i>FRH</i> =0.24 m <i>LBTK</i> =0.011 1 m	<i>FRH</i> =0.30 m <i>LBTK</i> =0.008 7 m
1	198.12	249.08	291.45
2	269.18	336.41	391.08
3	400.68	488.61	556.13
4	428.97	518.27	582.22
5	495.90	594.27	665.28
6	590.70	684.61	741.89

tures of the power equipment, the isolation performance of the vibration isolation system in specific frequency band can be improved specifically by adjusting the *FRH* and *LBTK*.

In addition, from Table 4, it can be seen that with the increase of *FRH* and the reduction of *LBTK*, the natural frequency of elastic vibration in the first few orders moves to the direction of high frequency, which shows that *FRH* is one of the most significant geometric parameters that influences the stiffness and natural frequency of the raft. Therefore, the purpose of adjusting the distribution of natural frequency and improving the isolation performance can be achieved by adjusting *FRH* and *LBTK*.

2.4 Effect of the number of ribs in the length direction (*NOLLB*) and the thickness of the upper panel (*TLTK*) as variables on isolation performance

When other parameters remain unchanged, only *NOLLB* and *TLTK* of the raft are changed. Curves of vibration level difference and modal frequencies of raft under the free state of three different combinations are shown in Fig. 8 and Table 5.

Fig. 8 shows that the influence of *NOLLB* and *TLTK* as variables is mainly reflected at medium and high frequencies. After combining with Table 5, it can be seen that as *NOLLB* increases, *TLTK* decreases-

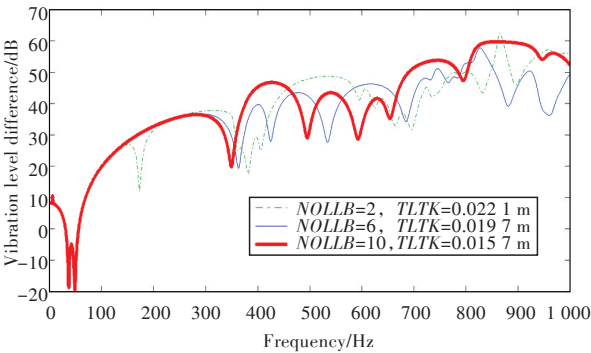


Fig.8 Curves of vibration level difference with *NOLLB* and *TLTK* as variables

Table 5 The natural frequencies of floating raft with *NOLLB* and *TLTK* as variables

Order	Modal frequency/Hz		
	<i>NOLLB</i> =2 <i>TLTK</i> =0.022 1 m	<i>NOLLB</i> =6 <i>TLTK</i> =0.019 7 m	<i>NOLLB</i> =10 <i>TLTK</i> =0.015 7 m
1	168.65	265.41	262.33
2	253.57	360.36	346.93
3	257.70	420.84	492.14
4	304.80	508.28	517.12
5	358.53	528.99	589.65
6	379.80	647.89	654.33

es, but the fluctuation of corresponding vibration level difference tends to weaken, which indicates that the stiffness of raft can be improved by appropriately increasing the number of ribs, and reducing the number of local vibration modes at the same frequency is beneficial to improve the overall isolation performance of floating raft in the whole frequency range. Besides, when the first-order natural frequency of floating raft is changed by adjusting the number of ribs and the panel thickness, the first-order natural frequency has the maximal value. After exceeding the maximal value, if the number of ribs continues to increase, the first-order natural frequency of floating raft will be reduced. Therefore, the number of ribs may not be increased at the expense of panel thickness in the acoustic design of raft structure. The values of the two should be weighed according to the spectrum features of mechanical equipment and the excitation frequency should be avoided to obtain excellent vibration performance.

2.5 Effect of *TLTK* and the thickness of the lower panel (*BLTK*) as variables on vibration performance

When other parameters remain unchanged, only the thickness of the upper and lower panels is changed. Curves of vibration level difference and modal frequencies of raft under the free state of three

different combinations are shown in Fig. 9 and Table 6.

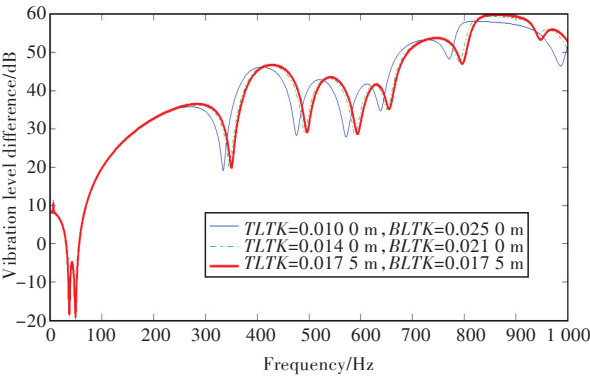


Fig.9 Curves of vibration level difference with *TLTK* and *BLTK* as variables

Table 6 The natural frequencies of floating raft with *TLTK* and *BLTK* as variables

Order	Modal frequency/Hz		
	<i>TLTK</i> =0.010 m <i>BLTK</i> =0.025 m	<i>TLTK</i> =0.014 m <i>BLTK</i> =0.021 m	<i>TLTK</i> =0.017 5 m <i>BLTK</i> =0.017 5 m
1	246.15	259.97	263.48
2	332.86	345.04	348.19
3	475.10	490.28	494.19
4	497.96	515.21	519.50
5	570.96	587.96	592.25
6	641.69	654.31	657.46

Fig. 9 shows that curves of vibration level difference basically overlap at low frequency, and have the consistent trend at high frequency, showing that the overall isolation performance cannot be significantly improved by changing *TLTK* and *BLTK*. It can be seen from Table 6 that a slight offset at the natural frequency of elastic vibration occurs by changing the combinations of *TLTK* and *BLTK*. For example, the offset of natural frequencies of the first few orders in Table 6 is about 15–22 Hz. When upper and lower panels have the same thickness, the natural frequency of the elastic vibration in the first few orders will reach a maximum value. Therefore, if there is little room for adjusting the overall size of raft in practical engineering applications, changing the combinations of *TLTK* and *BLTK* is a way to adjust the natural frequency of raft, avoid the vibration frequency of mechanical equipment, and improve isolation performance of the system.

3 Conclusions

In this paper, parametric modeling technology is used to establish a parametric finite element model for the floating raft. Under the premise of keeping the total mass of the elastic raft unchanged, the effect of geometric parameters of raft on the isolation

performance of system and distribution of natural frequencies of raft are discussed. The conclusions are as follows:

1) In low frequency range, the geometric parameters have little effect on the isolation performance of the vibration isolation system of floating raft, and the raft can be simplified as a rigid body for analysis and calculation. The effect of the raft elasticity on the isolation performance of the vibration isolation system can be ignored; in the middle and high frequency ranges, the geometric parameters of floating raft have a great influence on the isolation performance of the vibration isolation system of floating raft, which is mainly reflected in the fluctuation of vibration level difference curves and frequency shift.

2) The natural frequency of the first-order elastic vibration of raft can be improved by increasing the total height of raft, the number of ribs and making the total length equal to the total width under permitting conditions, which is beneficial to improve the isolation performance of vibration isolation system of floating raft.

3) According to spectrum features of the power equipment, the vibration isolation performance can be improved by adjusting the geometric parameters of floating raft to avoid the excitation frequency of the mechanical equipment.

References

- [1] SHAO K W, MA Y Y. Introduction to Technology and Design of Ship[M]. 2nd ed. Beijing: National Defense Industry Press, 2014: 719-745 (in Chinese).
- [2] YOU C X, ZHANG G D, HE X S, et al. The calculation method of the isolation system based on the improved FBS theory[J]. Chinese Journal of Ship Research, 2015, 10(1): 109-113 (in Chinese).

- [3] PENG W C, LIU Y, YUAN C H. FRF-based substructure technique for modeling machinery isolation system[J]. Chinese Journal of Ship Research, 2012, 7(1): 65-70 (in Chinese).
- [4] YAN J K, SHEN M Q, SHANG G Q. Selection of structural dynamic parameters of floating raft equipment[J]. Noise and Vibration Control, 1995(1): 2-9 (in Chinese).
- [5] ZHANG H L, FU Z F, QU Z Q. The effects of parameters of floating raft isolation system on its isolation characteristics[J]. Journal of Vibration and Shock, 2000, 19(2): 5-8, 4 (in Chinese).
- [6] SU C W, ZHU H C, MAO R F. Influences on isolation effectiveness of a generator set and raft vibration isolation system[J]. Ship Science and Technology, 2014, 36(12): 36-42, 61 (in Chinese).
- [7] DU K, WU X J, CHENG G L, et al. Research of best isolation-fixing scheme of floating raft system[J]. Journal of Naval University of Engineering, 2005, 17(2): 92-94, 99 (in Chinese).
- [8] GUAN Z Q, DU X Y, ZHANG H W, et al. Parameterization technique for elastic-plastic analysis and shape optimization design of mechanical structures[J]. Journal of Mechanical Strength, 2003, 25(4): 420-425 (in Chinese).
- [9] GONG S G, XIE G L, HUANG Y Q. ANSYS parameterized programming and command manual[M]. Beijing: Machinery Industry Press, 2009 (in Chinese).
- [10] XIE Z Q. Numerical calculation of underwater noise radiation from diesel generator set by FEM and BEM method[J]. Technical Acoustics, 2015, 34(2): 438-440 (in Chinese).

筏架几何参数对隔振系统性能的影响分析

黎上达^{1,2}, 刘彦¹

1 中国舰船研究设计中心, 湖北 武汉 430064

2 船舶振动噪声重点实验室, 湖北 武汉 430064

摘要: [目的] 为了研究几何参数对浮筏隔振系统性能的影响, [方法] 运用参数化建模技术建立筏架的参数化有限元模型, 以振级落差作为隔振效果的评价参数。在弹性筏架总质量不变的前提下, 分析筏架几何参数对系统隔振性能和筏架固有频率分布的影响。[结果] 结果表明: 筏架的几何参数对浮筏隔振系统隔振效果的影响主要体现在中、高频段; 筏架高度、长宽比、肋板数目是影响浮筏隔振系统隔振性能和筏架固有频率分布最重要的几何参数; 调整筏架几何参数是避开机械设备激振频率的有效途径之一。[结论] 所得结论对浮筏隔振系统设计具有一定的工程实用价值。

关键词: 浮筏隔振技术; 几何参数; 隔振效果; 固有频率