

Study on design method and vibration reduction characteristic of floating raft with periodic structure

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Abstract. The noise level is getting higher with the development of high-power marine power plant. Mechanical noise is one of the most obvious noise sources which not only affect equipment reliability, riding comfort and working environment, but also enlarge underwater noise. The periodic truss type device which is commonly applied in fields of aerospace and architectural is introduced to floating raft construction in ship. Four different raft frame structure are designed in the paper. The vibration transmissibility is taken as an evaluation index to measure vibration isolation effect. A design scheme with the best vibration isolation effect is found by numerical method. Plate type and the optimized periodic truss type raft frame structure are processed to experimental verify vibration isolation effect of the structure of the periodic raft. The experimental results demonstrate that the same quality of the periodic truss floating raft has better isolation effect than that of the plate type floating raft.

1. Introduction

Mechanical vibration isolation technology is one of the main means to reduce the vibration and noise transmission of mechanical equipment. Floating raft structure has been extensively used to achieve the purpose of a quiet ship which has many advantages including reducing acoustic short circuit, the better vibration isolation effect, compact structure, saving space, less additional mass and so on. Mechanical radiation noise of submarine can be decreased by 20 ~ 40dB under usual conditions [1-3]. To achieve good vibration isolation effect, the selection of upper and lower vibration isolator, high impedance and transmission loss characteristics of the raft structure design is the key of floating raft vibration isolation.

Flotow[4] and Yong[5] studied the transfer of vibration in the truss structure used by the method of wave propagation. Gaowei [6-7] researched the vibration control method of arbitrary truss structure excited by random signal. The structure stability is studied by Xua[8] and xuBin[9] using the method of topology optimization and transfer. Bondaryk recommended a kind of truss structure Cabin raft which can effectively reduce the mechanical equipment vibration transmission in high frequency to the shell. Keane[10] changed the geometric dimensions of the element to promote the passive vibration isolation performance of the whole truss structure by means of transfer matrix and structure optimization.



Kuang[11] compared the vibration characteristics of periodic truss raft with traditional floating raft by use of frequency response function synthesis method.

Taking two sets of machinery equipment as the research objects based on previous study of the plate type raft vibration reduction of marine machinery, a set of floating raft isolation scheme and four different types of periodic truss type raft frame structures are designed in the paper. Vibration transfer characteristic of floating raft system with different structural type raft is researched. Then the paper further analyzes the influence on the effect of vibration isolation by several main parameters of raft including structural type of truss section, cross section and size of periodic truss. In the end, vibration reduction characteristics of periodic truss type raft are verified by experiments.

2. Evaluation method of vibration transfer characteristics

According to the vibration mode theory, the ship structure is a complex vibration system with multiple degrees of freedom. The mechanical admittance between the P point and the L point is shown as

$$H_{lp}(\omega) = \frac{X_l(\omega)}{F_p(\omega)} = \sum_{i=1}^n \left[\frac{\psi_{pi} \cdot \psi_{li}}{a_i(j\omega - \lambda_i)} + \frac{\psi_{pi}^* \cdot \psi_{li}^*}{a_i^*(j\omega - \lambda_i^*)} \right] \quad (1)$$

We get the vibration transmissibility through dividing transfer admittance by origin admittance, which is the ratio of distant structure point response and the ratio of excitation point response.

$$\frac{H_{lp}(\omega)}{H_{pp}(\omega)} = \frac{X_l(\omega) / F_p(\omega)}{X_p(\omega) / F_p(\omega)} = \frac{X_l(\omega)}{X_p(\omega)} \quad (2)$$

Divide up and down fraction by $F_p(\omega)$, we have

$$\frac{H_{lp}(\omega)}{H_{pp}(\omega)} = \left(\sum_{i=1}^n \frac{\varphi_{li} \cdot \varphi_{pi}}{K_i [1 - (\frac{\omega}{\lambda_i})^2 + j2\zeta_i \frac{\omega}{\lambda_i}] } \right) \cdot \left(\sum_{i=1}^n \frac{\varphi_{pi} \cdot \varphi_{pi}}{K_i [1 - (\frac{\omega}{\lambda_i})^2 + j2\zeta_i \frac{\omega}{\lambda_i}] } \right)^{-1} \quad (3)$$

Thus, the ratio between the response of the measuring point L on the lower base plate and the response of the measuring point P on the device installation location can be written as

$$\frac{X_l(\omega)}{X_p(\omega)} = \left(\sum_{i=1}^n \frac{\varphi_{li} \cdot \varphi_{pi}}{K_i [1 - (\frac{\omega}{\lambda_i})^2 + j2\zeta_i \frac{\omega}{\lambda_i}] } \right) \cdot \left(\sum_{i=1}^n \frac{\varphi_{pi} \cdot \varphi_{pi}}{K_i [1 - (\frac{\omega}{\lambda_i})^2 + j2\zeta_i \frac{\omega}{\lambda_i}] } \right)^{-1} \quad (4)$$

Vibration transmissibility under complex modes is as follows:

$$H(\omega) = \left(\frac{\varphi_{l1} \Lambda_1}{s^2 + 2\zeta_1 \omega_1 s + \omega_1^2} + \dots + \frac{\varphi_{lm} \Lambda_m}{s^2 + 2\zeta_m \omega_m s + \omega_m^2} \right) \cdot \left(\frac{\varphi_{p1} \Lambda_1}{s^2 + 2\zeta_1 \omega_1 s + \omega_1^2} + \dots + \frac{\varphi_{pm} \Lambda_m}{s^2 + 2\zeta_m \omega_m s + \omega_m^2} \right)^{-1} \quad (5)$$

This is the basic expression of the transmission rate of the vibration isolation system. Where 1, 2, m are the modal order with greater impact on the vibration of base, 1, 2, K are modal order with greater impact on the dynamic property of isolation system.

Vibration transmissibility based on the mechanical admittance is defined as the ratio of the transfer admittance to the origin admittance, and the physical meaning is the ratio of the vibration response far away from the excitation point and the relevant excitation point. Through the meaning of vibration transfer rate, we can see that its magnitude directly reflects the level of structure vibration transfer characteristics. The paper presents a new effective algorithm to express vibration transfer characteristic based on mechanical admittance which avoids difficulty of vibration load estimation in theory, and the measurement of the equipment excitation.

3. Design and optimization of periodic truss floating raft model

The vibration isolation device is a fan-motor system, and the double-stage raft type isolation system is designed. Following fundamental principle about the floating raft system design, four BE-10 type vibration isolators are selected under the fan, and four BE-15 type isolators are selected under the motor, and six BE-25 type rubber vibration isolators are selected under the raft. The mass ratio of raft to fan-motor is 0.75. We designed four kinds type of structure periodic truss floating raft based on existing plate type raft, and their effects of on the vibration transmissibility is calculated through numerical simulation analysis. Four kinds of periodic truss type raft structure are shown in Figure 1.

Table 1. Parameters of floating raft vibration isolation equipment.

Device name	Weight (kg)	Size(m×m)	Speed (rpm)	Excitation frequency(Hz)
Motor	44.6	0.28×0.42	2900	48.3
Fan	30	0.42×0.42	1400	23.3

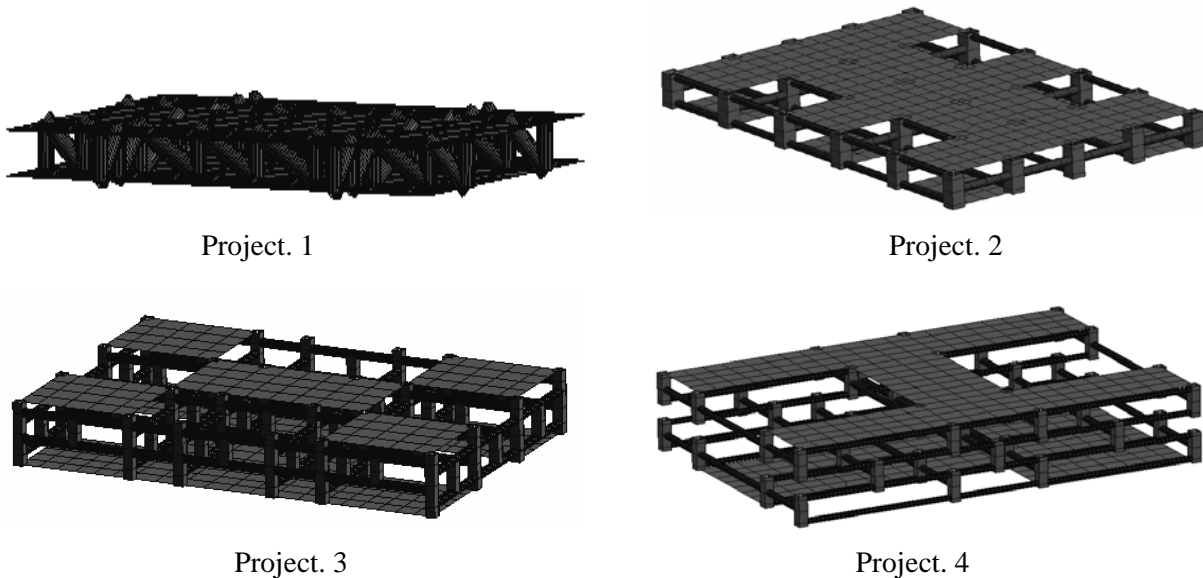


Figure 1. Finite element models of four periodic truss types raft.

The dynamic calculation of four different types of raft vibration isolation system is carried out. The overall structural modal analysis of different design project indicates the first-order natural frequency of the periodic raft type intermediate mass is much smaller than the excitation frequency, and all of them accord with the requirements of the vibration isolation design. Then the frequency response analysis is done, and the results are shown in figure 2.

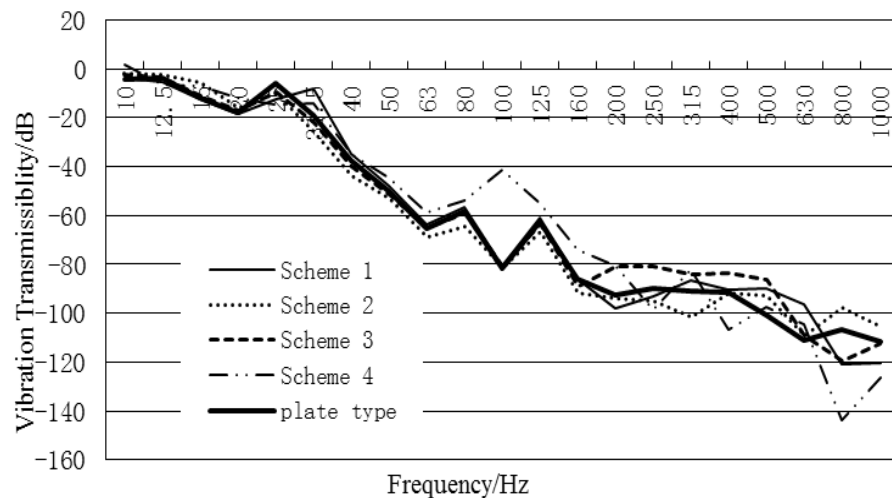


Figure 2. Vibration isolation effect of different designed scheme.

According to Figure 2, under the same structure parameters, the comparative analysis of the vibration transmissibility of different design schemes shows that all the periodic truss type raft schemes except scheme 4 have improved vibration isolation effect to some extent, and the scheme 4 has good performance of vibration isolation in high frequency band. The effect of scheme 2 is slightly better than the other schemes in the whole frequency band. Then the scheme 2 is used for parameter optimization. The influence of periodic truss structure on vibration transmission is considered. The results are shown in Figure 3. The increase of panel thickness is advantageous to the transmission of isolated vibration. Taking the quality of the model and vibration isolation effect into account, the thickness of upper and lower panels is selected for 5mm. The size of the square tube in the final processing is 16*16mm, and the thickness is 2mm.

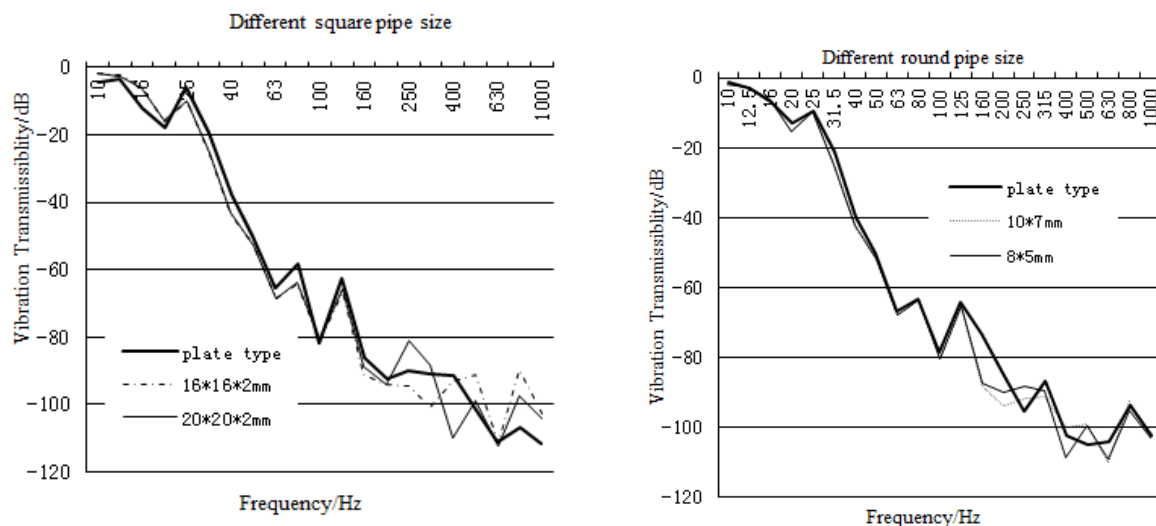


Figure 3. Transmissibility of periodic type raft device with pipe of diverse shapes.

4. Structural vibration transfer characteristics experiment and analysis

Two intermediate massed of different raft type system are illustrated in Figure 4 including plate type (Figure a) and periodic truss type (Figure b). The acceleration sensors are arranged at the feet of the

power equipment including fan and motor, as well as these points which connect lower isolators to base. Those relevant measuring points are selected to analyze in periodic truss type floating raft isolation system. The vibration transmissibility was given between measured machine points and measured lower isolator connecting points.

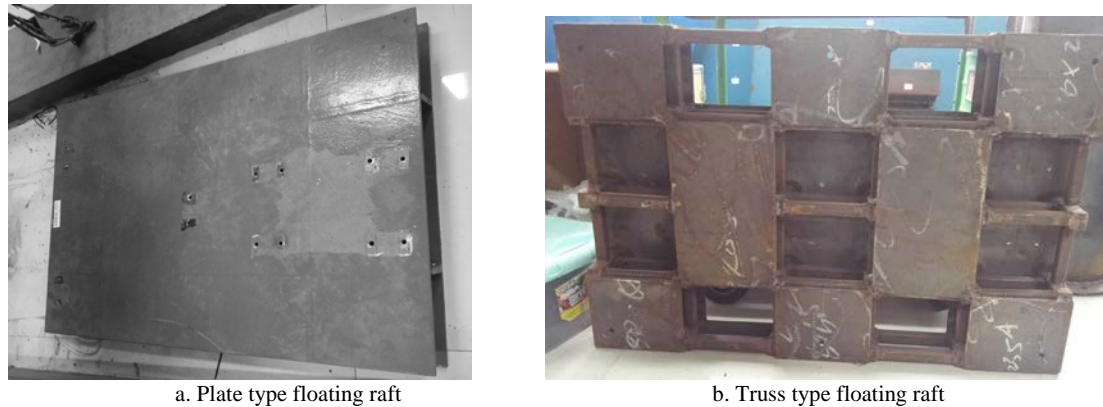
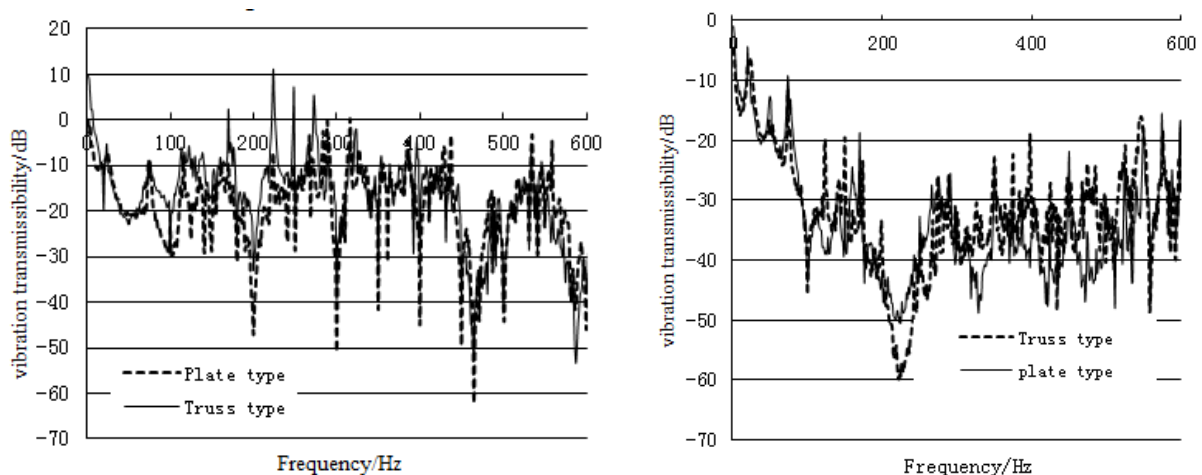


Figure 4. Different type of floating raft model.



a. Measuring points under the motor

b. Measuring points under the fan

Figure 5. Vibration transmissibility of different measuring points.

The vibration transmissibility experiment results of two type raft type vibration reduction system are illustrated in Figure5. Respectively, transmissibility at measuring points under the motor and the fan are given. Transmissibility of two type floating raft isolation system results agree well in low frequency. There is much difference in the frequency beyond 100Hz. Vibration transmissibility of periodic truss type floating raft under the motor is less than plate type in the whole frequency, which indicates the design of truss type floating raft is very well. Vibration transmissibility of truss type floating raft under the fan has a lot of fluctuations, but its efficiency is better than plate type in the frequency with greater excitation force. Therefore, isolation effect of truss type floating raft has reached the expected result.

5 Conclusions

Vibration transmissibility is proposed as a new evaluation method of vibration transfer characteristics in the paper. Based on finite element theory, FE models of four periodic truss type raft system are

established. Their dynamic characteristics are calculated and analyzed. An optimal raft frame is processed and used to contrast with plate raft by experiments. Some conclusions are obtained.

Detailed conclusions are as follows.

1. The periodic truss design of each scheme reflects the good vibration isolation effect.
2. The final design of the periodic truss parameters optimization shows that the size and quality of the periodic truss support is conducive to the enhancement of vibration isolation effect.
3. Experimental study showed that design of truss type floating raft is very well. The vibration suppressed effect in low and middle frequency bands has reached the expectation.

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