

Effects and Analysis of Floating Raft Vibration Isolator Parameters on the Performance of Vibration Isolation

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Abstract—Floating raft vibration isolator (FRVI) is widely used in ship system. This study investigated effects of FRVI parameters on the overall performance of vibration isolation. Mechanical model of FRVI was established. Using the theory of admittance transmission power flow was deduced. The influence of FRVI transmission power flow by the weight of the raft frame, the thickness of the base and the bearing stiffness of the system was analyzed. The transmitted power flow curve was simulated by computer. In analysis found that the bigger the quality of the middle raft, the better for the performance of the system under actual conditions permit. In the condition of not affecting the stability of the system, the smaller the support rigidity of the system, the better for the system. The thickness of the infrastructure, the bigger, the better. A theoretical basis was provided for the design of intermediate weight, the foundation and the bearing stiffness of the system of FRVI.

Keywords—Floating raft vibration isolator (FRVI); intermediate weight; foundation; power flow; admittance transmission

I. INTRODUCTION

Vibration is widely found in nature in people's daily life and in process of production. With a variety of mechanical equipment developing toward to the high-speed, light, heavy, and they are more intense vibration and noise. For engineering equipment, aircraft, ships and other transportation machinery, the intense vibration and noise can cause fatigue damage to machinery and equipment, environmental pollution and adverse health impacts to human [1]. For an aircraft, the excessive vibration has a great influence on the electronic equipment of the aircraft and the comfort of personnel. Especially for rocket and missile systems, the sonic caused by the internal thrust and normal vibrations of the structure of rocket during flight produce severe vibration to the rocket and missile systems, the dangers of rocket systems and structures of very large, and have hazardous to the astronauts' operation in the cabin [2]. Secondly for torpedoes, submarines and other underwater vehicle,

Excessive vibration and noise will not only affect self-guided and guided of the underwater vehicle, and is likely to expose themselves to be the enemy, impact on their ability of the acoustic stealth and the attack capability [3], but also have impacts to the crews' working and living environment, and led to a reduction in the efficiency of communication contact, indirectly affect combat capability. So reducing air radiated noise in cabin and underwater, and improve its quietness are guarantee to improve its concealment and combat capability [4]. Vibration and noise reduction has become a very important issue in the engineering design. Early in the design of mechanical predict to vibration and noise may be generated is necessary and important. Design a good performance isolator is a very urgent and far-reaching work.

II. FRVI'S MECHANICAL MODEL

Fig .1 is a dynamic model of FRVI. FRVI consists of the object what need isolation, upper shock absorber, middle raft, lower shock absorber and infrastructure.

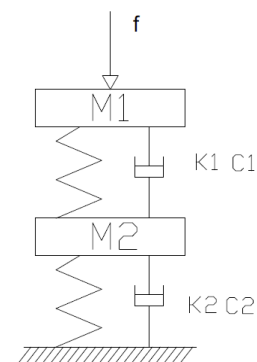


Figure 1

As the isolator are mainly used in reducing the vertical vibration, and because of the symmetry of space. Only analyze the vertical vibration in this paper. As shown in Fig .1, The quality of the object is M_1 , The quality of the middle raft is M_2 , exciting force $f = P \sin(\omega \cdot t)$, Damper what elastic is K_1 and Damping is C_1 connects

object and middle raft, Damper what elastic is K2 and Damping is C2 connects middle raft and infrastructure.

III. CALCULATE ADMITTANCE FOR EACH SUBSYSTEM

A. Objects' admittance

The object is regarded as a rigid body in this paper [5], so its admittance is:

$$H_m = \frac{1}{i\omega M_1}. \quad (1)$$

B. Middle raft's admittance

The middle raft is regarded as an elastic beam, As shown in Fig. 2, The ends of the beam are freedom, the length is L, Excitation force F is applied at L/2.

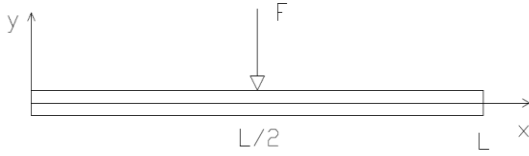


Figure 2

Assuming excitation force is:

$$F = a \sin(\omega t). \quad (2)$$

Excitation force is concentrated load, Concentrated load in the actual project needs expressed by the pulse function, pulse function is [6]:

$$F(x, t) = a \delta(x - L/2) \sin(\omega t). \quad (3)$$

The natural frequency of the beam:

$$\omega_j = \sqrt{\frac{EI}{\rho A}} (\beta_j)^2; \quad j = 1, 2, 3, \dots, n. \quad (4)$$

The mode functions of the beam:

$$\Phi_j(x) = \cos(\beta_j x) + \cosh(\beta_j x) + \frac{\sin(\beta_j l) + \sinh(\beta_j l)}{\cos(\beta_j l) - \cosh(\beta_j l)} (\sin(\beta_j x) + \sinh(\beta_j x)). \quad (5)$$

Among it:

$$\cos(\beta_j l) * \cosh(\beta_j l) = 1 \quad (6)$$

The equation (6) into equation (4) and equations (5) we can calculate ω_j and $\Phi_j(x)$, $j = 1, 2, 3, \dots, n$;

Generalized force:

$$F_j(t) = \int_0^L F(x, t) * \Phi_j(x) dx \quad (7)$$

Modal mass:

$$M_{pj} = \int_0^L \rho A \Phi_j^2(x) dx \quad (8)$$

The equation (5) into equation (8) and we can calculate modal mass.

Generalized coordinates displacement:

$$q_j(t) = \frac{1}{\omega_j M_{pj}} \int_0^t F_j(t_1) * \sin \omega_j(t - t_1) dt_1 \quad (9)$$

The equation (4), (5) and (6) into equation (9) we can calculate generalized coordinates displacement.

The vibration equation of the beam:

$$w(x, t) = \sum_{j=0}^{\infty} \frac{P A \sin(\omega t)}{M_{jp}(\omega_j^2 - \omega^2)} \Phi_j(x) - \sum_{j=0}^{\infty} \frac{P A \omega \sin(\omega_j t)}{M_{jp}(\omega_j^2 - \omega^2)} \Phi_j(x) \quad (10)$$

The first term of the right-hand side has the same frequency as the excitation force. So it is the steady-state response of the beam; the frequency of the second term of the right side is natural frequency of the beam. So it is ad joint vibration caused by the excitation force. Due to the damping is in the actual structure of the floating raft isolation. Free vibration item will gradually decays to negligible, therefore, the steady-state response is:

$$w(x, t) = \sum_{j=0}^{\infty} \frac{P A \sin(\omega t)}{M_{jp}(\omega_j^2 - \omega^2)} \Phi_j(x) \quad (11)$$

According to the steady-state response equations and the admittance formulas, we can obtain admittance at $x = L/2$:

$$H_r = - \sum_{j=0}^{\infty} \frac{A}{M_{jp}(\omega_j^2 - \omega^2)} \Phi_j\left(\frac{L}{2}\right) \omega i \quad (12)$$

C. Spring and damping admittance

Only consider the damping and elasticity, ignore the quality of the shock absorbers. Shock absorbers' admittance is:

$$H_k = \frac{i\omega}{k(1 + i\eta\omega)} \quad (13)$$

Among it: K Shock absorber' stiffness

η Damping ratio

D. Infrastructure admittance

In the actual situation, Isolator is usually installed in large size infrastructure, This article assumes that the infrastructure is an infinite elastic plate.

admittance at Incentive point is:

$$M_b = \frac{\omega}{8Bk^2} = \frac{1}{8\sqrt{B\rho h}} \quad (14)$$

Among it: h Thickness of the plate

ρ Density

B Bending stiffness, $B = Eh^3/12(1 - \mu^2)$, E is the elasticity modulus of the plate, μ is the Poisson's ratio of the plate.

IV. ISOLATOR RESULTANT ADMITTANCE AND POWER FLOW

Assuming excitation force is F1 and the speed is V1 at the input point. Input force is F5 and the speed is V5 at the connection point on the infrastructure. As shown in Fig. 3.

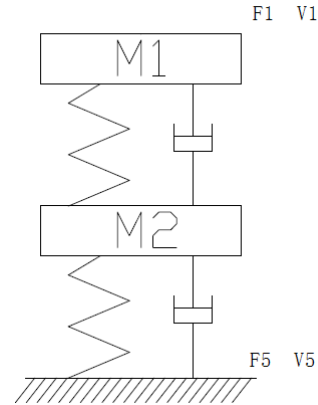


Figure 3

The formula for the resultant admittance [7]:

$$\begin{bmatrix} F1 \\ V1 \end{bmatrix} = \begin{bmatrix} 1 & \frac{1}{H_m} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ H_{1k} & 1 \end{bmatrix} \begin{bmatrix} 1 & \frac{1}{H_r} \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ H_{2k} & 1 \end{bmatrix} \begin{bmatrix} F5 \\ V5 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} F5 \\ V5 \end{bmatrix} \quad (15)$$

H_{1k} , H_{2k} is upper shock absorber restrained admittance an lower shock absorber restrained admittance, respectively.

According to the formula (15):

$$F5 = \frac{F1}{a_{11} + a_{12} * M_b} \quad (16)$$

$$a_{11} = \left(1 + \frac{H_{1k}}{H_m}\right) \left(1 + \frac{H_{2k}}{H_r}\right) + \frac{H_{2k}}{H_m} \quad (17)$$

$$a_{12} = \frac{1}{H_r} \left(1 + \frac{H_{1k}}{H_r}\right) + \frac{1}{H_m} \quad (18)$$

$$a_{21} = H_{1k} \left(1 + \frac{H_{2k}}{H_r}\right) + H_{2k} \quad (19)$$

$$a_{22} = 1 + \frac{H_{1k}}{H_r} \quad (20)$$

According to the definition of power flow, the power delivered to the infrastructure is:

$$P_{out} = \frac{1}{2} |F_5|^2 \text{Re} (M_b) \quad (21)$$

The equation (16) into equation (21) we can get that:

$$P_{out} = \frac{1}{2} |F_1|^2 \left| \frac{1}{a_{11} + a_{12} M_b} \right|^2 2 \text{Re} (M_b) \quad (22)$$

Floating Isolator Raft System resultant admittance is:

$$H = \frac{\frac{V_1}{F_1}}{H_m (H_{1k} H_r + H_{1k} H_{2k} + H_r H_{2k} + H_{1k} M_b + M_b H_r + H_m H_r + H_{2k} H_m + H_m M_b)} = \frac{a_{21} F_5 + a_{22} V_5}{a_{11} F_5 + a_{12} V_5}$$

Floating Isolator Raft System Input power flow [8]:

$$P_{in} = \frac{1}{2} |F_1|^2 \text{Re} (H) \quad (23)$$

The standard formula for the power flow output is:

$$P = 20 \lg (P_{out}) - 20 \lg (P_{out}(0)) \quad (24)$$

Among it: $P_{out}(0)$ is P_{out} when ω is 0.

V. ANALYZE THE IMPACT OF ISOLATOR VARIOUS PARAMETERS ON THE PERFORMANCE OF THE ISOLATION

Assuming the parameters of the system: $M=211\text{kg}$, $K_1=500\text{N/mm}$, $\eta_1=0.03$, $K_2=1800\text{ N/mm}$, $\eta_2=0.03$, the quality of the middle raft is 180kg , The thickness of the infrastructure is $h_2=0.01\text{m}$, elasticity modulus $E=2.1 \times 10^{11}\text{Pa}$, Poisson's ratio $\mu=0.25$, Density $\rho=7900\text{kg/m}^3$

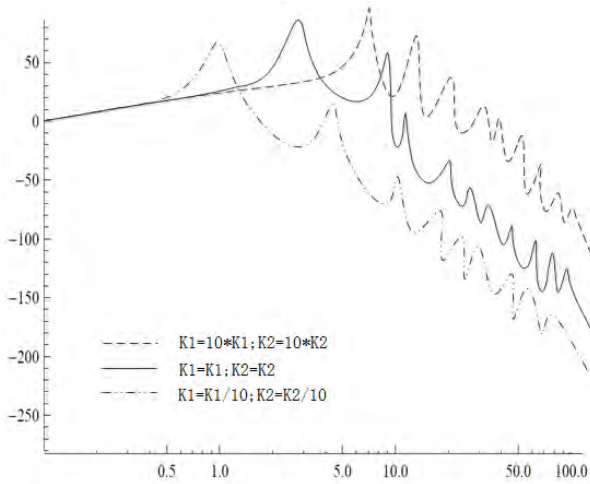


Figure 4

Fig .4 shows how the power flow what is transmitted to the infrastructure changes when changing the system's bearing stiffness. From the figure we can get that: the power flow what is transmitted to the infrastructure is increased when raise the system's bearing stiffness. And the effects of the isolator become bad. Conversely become better. In the range of low frequency, the natural frequency of the system is decreased when reduce the system's bearing stiffness. Conversely is increased. Therefore, in the design of vibration isolation system, If the excitation frequency is low frequency, We can make the system's

natural frequency by changing the support stiffness shifted excitation frequency. Avoid system resonance issue. However, when the excitation frequency is the high frequency, in the premise of not affecting the stability of the system, we can reduce the support stiffness to reduce the power flow.

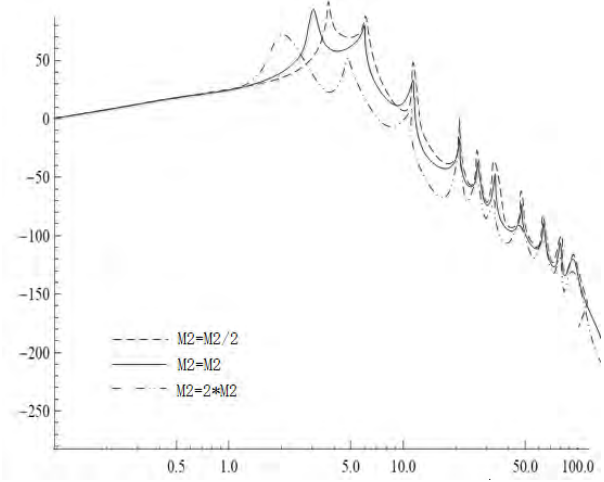


Figure 5

Fig .5 shows how the power flow what is transmitted to the infrastructure changes when changing the quality of the middle raft. From the figure we can get that: at the natural frequency of the system, because the vibration response of the system is strong, input power flow and output power flow become heavy. Therefore, in the design of vibration isolation system, the natural frequency of the system should avoid the excitation frequency to reduce the input power flow. Two natural frequencies in the range of low-frequency are the object's natural frequencies and the middle raft's natural frequencies. These two natural frequencies are related to the quality of object, the quality of middle raft and damper's damping and stiffness. The figure shows curves of power flow in three different qualities of middle raft situations. We can get that with the increasing middle quality, first-order natural frequency decreasing, and delivered to the base of the power flow also decreases. With increasing excitation frequency, transmission power flow decreases faster. Therefore, in theory, increase the quality of the middle raft can reduce transfer power flow. In project, the quality of the middle raft cannot be increased infinitely. Therefore, the quality of the middle raft should be selected according to the actual situation. The nature frequency in the range of high frequency are mostly of the natural frequency of the middle raft, so if you expect to reduce the input power flow in the rang of the high frequency must try to increase the stiffness of the raft in order to improve its natural frequency, so that the floating raft isolator can achieve better isolation effect in the wide band excitation frequency.

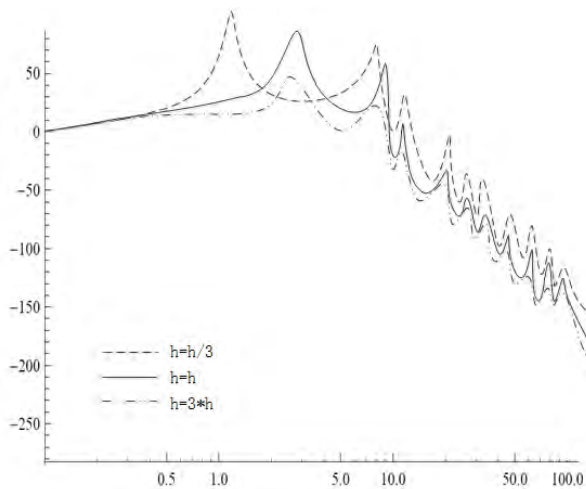


Figure 6

Fig. 6 shows how the power flow what is transmitted to the infrastructure changes when changing the thickness of the infrastructure. In this paper, thicknesses were taken $h/3$, h , $3h$. When the thickness of the infrastructure is $h/3$, the power transmitted to the foundation significantly larger. This is because the smaller thickness of the infrastructure, the lower stiffness of the infrastructure, and the greater admittance of the infrastructure. So the more power flow transmitted to the infrastructure. When the thickness of the infrastructure is h , the power flow what transmitted to the infrastructure became less. When the thickness of the infrastructure is $3h$, the power flow what transmitted to the infrastructure is the least. And in this case the infrastructure could be treated as rigidity foundation. From the above analysis, we can get the following conclusions. The power flow transmitted to infrastructure is closely linked with the elastic of infrastructure. The smaller admittance of the infrastructure, the less power flow transmitted to infrastructure. So If you want to reduce the power flow, you must reduce the admittance of the infrastructure, in engineering usually add ribs and other ways to improve admittance of the infrastructure.

VI. CONCLUSION

In this paper, selection of power flow theory as an evaluation index of the effects of the isolator. The mechanical model of the system has been established. The admittance matrix of the system and the mathematical expression of the power flow have been deduced. At last,

we cite an engineering example to carry integrated dissections, analysis of the system's bearing stiffness, the quality of the middle raft and the thickness of the infrastructure how to effect on the system.

In the premise of not affecting the stability of the system, we can reduce the support stiffness to reduce the power flow. And we can increase the quality of middle raft and the stiffness of the raft in order to reduce the power flow. But the quality of the middle raft cannot be increased infinitely. Therefore, the quality of the middle raft should be selected according to the actual situation. Within a certain range to increase the thickness of the infrastructure can effectively inhibit high-frequency peak and enable getting better performance of the vibration isolation system, but blindly increasing the base thickness is not obvious, and the actual situation is not allowed, so choose the thickness of the infrastructure based on the actual situation.

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