

應用隔振系統降低船舶振動之研究

On the vibration reduction of ships using vibration isolation systems

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一、中文摘要

本計畫主要研究隔振系統在降低激振源對船舶結構產生振動之作用，隔振系統已廣泛應用在船舶之減振設計上，本研究首先分析激振源、隔振系統與結構之間之振動能傳遞情況，建立三者間振動能之交制模式，然後以一典型均質串接 Kelvin 阻尼為例，利用已建立之交制模式，探討其對振動傳輸率之影響。

關鍵詞：隔振系統、船舶振動

1. Abstract

Study of the effect of isolators for reducing the vibration transmissibility from engine to ship structure is presented. The interaction of the vibration among the excitation source, isolator, and foundation is studied. Finally, an isolator modeled on a series connection of a MDOF mechanical system and an SDOF model of a flexible foundation are examined to illustrate the advantage of this method in practical.

Keywords: Isolator, Ship vibration

2. Introduction

The vibration isolator is usually installed between a dynamic system and an excitation source to protect the system from undesired vibration. One purpose of using the isolators is to reduce the acting force

transmitted from the excitation force generated by an unbalanced revolution of the machine, called a force isolation system. The design objective is to obtain a lower force transmissibility for the former system and a velocity (or displacement acceleration) transmissibility for the latter system. Since a dynamic coupling among the machine, isolator and foundation exists, all of the components in the total system are considered to be simultaneous in the analysis, which may work well when the configuration of the isolator is very simply [1]. However, certain commonly used isolators, such as natural rubber or rubberlike material, are rationally modeled in practice as a series connected multi-degree-of-freedom (MDOF) dynamic system [2]. For these isolators, the computation is quite complex[3-5]. In fact, the isolator generally designed under the given condition of the machine and the foundation is fixed. If the interaction between the machine and isolator as well as the isolator and foundation can be known, the isolation system would be analyzed and designed more efficiently.

In this article, a closed form solution of the force and velocity transmissibility of the isolation systems is calculated. Finally, an isolator with a uniform multiple layered structure and a single-degree-of-freedom (SDOF) flexible foundation are examined.

3. Results

When an isolator is used to support a rotary machine with a periodical unbalanced

force on the foundation as shown in Fig. 1, this system can be modeled as a connection of three parts - a mass for the machine, a dynamic system for the isolator and a foundation. Assuming a periodical excitation force with frequency ω , the steady state response of the force $f(t)$ and velocity $v_m(t)$ and $v(t)$ should be also periodical and with the same frequency, but having different phase angles. Let the excitation be given as the real part of $f_{ext}(t) = F_{ext}e^{j\omega t}$, where F_{ext} is the complex amplitude with units of force containing information about the phase angle. j is defined by $j^2 = (-1)^{1/2}$. Based on Newton's law, the relationships of $f(t)$, $v_m(t)$ and $v(t)$ may also be expressed as

$$F_t = F_{ext} - j\omega m_m V_t, \quad V_m = V_t \quad (1, 2)$$

where F_m , V_m and V_t are the complex amplitude of $f(t)$, $v_m(t)$ and $v(t)$. These F_{ext} , V_b , F_t and V_m are defined as the power flow variables with respect to the dynamic system of the machine model. If F_{ext} and V_b are selected as the input variables, F_t and V_m should be a function of the input variables defined as the output variables.

Assume the isolator is modeled as a linear dynamic system. The steady state response of the velocity and force at the top and bottom of the system are also periodical with the same frequency as an excitation. If the complex amplitude of the acting force on the top F_t and the velocity of the bottom of the isolator V_b are selected as the input variables, the complex amplitude of the acting force on the bottom F_b and the velocity of the top of the isolator V_t can be expressed as

$$F_b = TR_{f,t,b} F_t + Z_b V_b, \quad (3)$$

$$V_t = Y_t F_t + TR_{v,b,t} V_b \quad (4)$$

where $TR_{f,t,b}$ is the complex force transmissibility of the isolator from the top to the bottom and $TR_{v,b,t}$ is the complex velocity transmissibility of the isolator from the bottom to the top of the isolator defined as

$$TR_{f,t,b} = \left. \frac{F_b}{F_t} \right|_{V_b=0}, \quad TR_{v,b,t} = \left. \frac{V_t}{V_b} \right|_{F_t=0} \quad (5,6)$$

Z_b and Y_t are the impedance and the mobility of the isolator at the bottom and the top defined as

$$Z_b = \left. \frac{F_b}{V_b} \right|_{F_t=0}, \quad Y_t = \left. \frac{V_t}{F_t} \right|_{V_b=0} \quad (7, 8)$$

For the first case, Case I, a system with a rigid foundation is considered. Thus, zero displacement and velocity response should be maintained. The boundary conditions are given by

$$F_d = F_b, \quad V_b = V_d = 0 \quad (9,10)$$

where F_d and V_d are the complex amplitude of the reaction force and velocity of the foundation. The force transmissibility from F_{ext} to F_b , $TR_{1,m,b}$, leads to

$$TR_{1,m,b} = \left| \frac{TR_{f,t,b}}{1 + j\omega m_m Y_t} \right| \quad (11)$$

If the foundation is flexible with mobility Y_d , called Case II, the boundary condition in Eq. (14) is changed to

$$V_b = Y_d F_b \quad (12)$$

According to Eqs. (3), (4), (9) and (12), the force transmissibility $TR_{2,m,b}$ can be calculated as [6]

$$TR_{2,m,b} = \left| \frac{TR_{f,t,b}}{(1 + j\omega m_m (Y_t + Y_d TR_{f,t,b} TR_{v,b,t} - Y_t Z_b Y_d) - Z_b Y_d)} \right| \quad (13)$$

Thus, the force transmissibility from F_{ext} to F_d should be equal to Eq. (11). The transmissibility from F_{ext} to V_b is $|Y_d| TR_{2,m,b}$.

An isolator modeled as an n series connection of identical mechanical subsystems as illustrated in Fig. 2 is considered in the example. For each layer,

the subsystem includes one mass series to a parallel connection of a spring and a damper. If the force and velocity of each component in the i th subsystem from the base are defined as Fig. 2, the dynamic equations expressed by the complex amplitude of these force and velocity variables are given by

$$F_{i-1} = F_i - j\omega m V_i, \quad (14)$$

$$V_i = V_{i-1} + F_{i-1} / (c - kj / \omega) \quad (15)$$

According to Eqs. (14) and (15), the force complex transmissibility of the isolator leads to [6]

$$TR_{f,t,b} = \left(\sum_{i=0}^n C(n+i, 2i) L^i \right)^{-1} \quad (16)$$

Where $L = -\omega^2 m / (j\omega c + k)$. The velocity complex transmissibility $TR_{v,b,t}$ is equal to the force complex transmissibility $TR_{f,t,b}$. The driving mobility at the top and the driving impedance at the bottom of the isolator lead to [6]

$$Y_t = \frac{\sum_{i=0}^{n-1} C(n+i, 2i+1) L^i}{(c - kj / \omega) \left(\sum_{i=0}^n C(n+i, 2i) L^i \right)} \quad (17)$$

$$Z_b = \frac{-j\omega m \sum_{i=0}^{n-1} C(n+i, 2i+1) L^i}{\sum_{i=0}^n C(n+i, 2i) L^i} \quad (18)$$

If the flexible foundation of Case II is modeled as an SDOF mass-spring-dashpot component as illustrated in Fig. 3, the mobility of the foundation leads to

$$Y_d = \frac{\omega}{c_d \omega + j(\omega^2 m_d - k_d)} \quad (19)$$

4. Conclusions

In this study, the interaction between the machine and isolator as well as the isolator and foundation were illustrated. Moreover, the solutions of the force and

velocity transmissibility were calculated. The analytical solution of the three cases of the isolation systems, including the force isolation systems with rigid and flexible foundations subject to a periodical excitation from the machine and the velocity isolation system subject to foundation vibrations, have been investigated. Finally, an MDOF series mechanical model of the isolator and an SDOF mechanical model of the foundation were examined.

5. References

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6. Figures

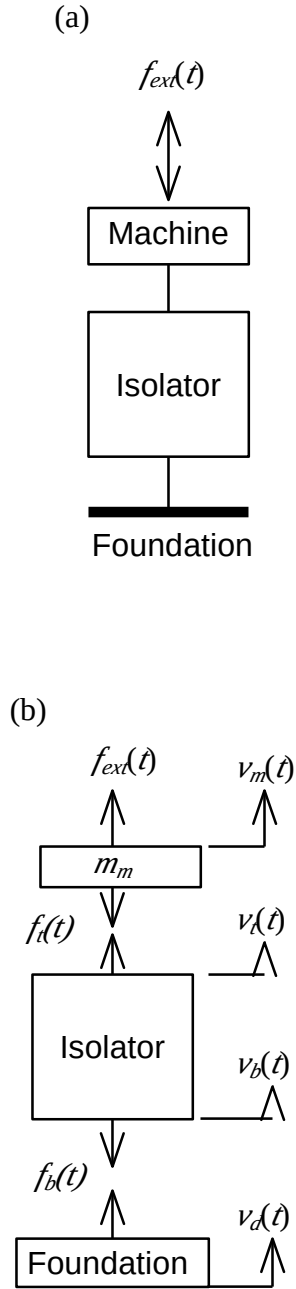


Fig. 1 (a) physical model and (b) variables definition of an isolation system

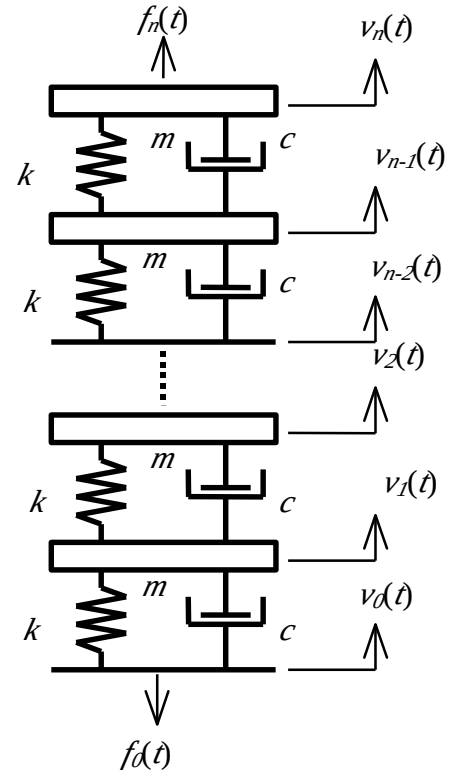


Fig. 2 Mechanical model of the MDOF isolator

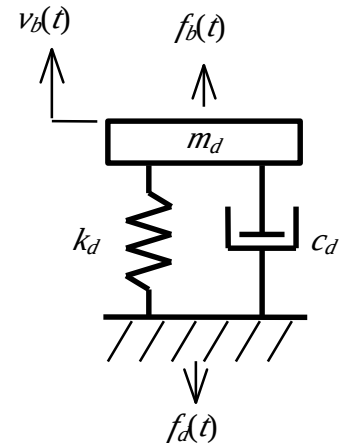


Fig. 3 (a) mechanical model, and (b) power-flow model of the SDOF foundation

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