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Application of a movable active vibration control system on a floating raft

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ABSTRACT

This paper presents a theoretical study of an inertial actuator connected to an accelerometer by a local feedback loop for active vibration control on a floating raft. On the criterion of the minimum power transmission from the vibratory machines to the flexible foundation in the floating raft, the best mounting positions for the inertial actuator on the intermediate mass of the floating raft are investigated. Simulation results indicate that the best mounting positions for the inertial actuator vary with frequency. To control time-varying excitations of vibratory machines on a floating raft effectively, an automatic control system based on real-time measurement of a cost function and automatically searching the best mounting position of the inertial actuator is proposed. To the best of our knowledge, it is the first time that an automatic control system is proposed to move an actuator automatically for controlling a time-varying excitation.

1. Introduction

Noise and vibration is a principal issue for warships and submarines. Any techniques and applications that decrease noise and vibration levels of warships and submarines by even a few decibels are worth pursuing. Floating rafts and floating floors are such applications which can reduce noise and vibration in ship cabins effectively [1]. They have been widely applied to ships [2,3], submarines [4], and buildings [1,5–8] to control noise and vibration transmission and therefore enhance human comfort and well-being [9].

Floating rafts and floating floors are passive control systems. Floating rafts are a kind of two stage vibration isolation system. Floating floors are a kind of vibration control system combined vibration isolation and structural damping. Vibration isolation and structural damping are the most widely used passive vibration control methods [10]. Passive vibration control methods can be successfully utilized to reduce vibration transmission in the middle and high audio frequency ranges [11]. Passive vibration control methods are effective and efficient at high frequencies but expensive and bulky at low frequencies [12]. Moreover, passive vibration control methods are sensitive to variations of excitation sources. In contrast to passive vibration control methods, active vibration control systems can be cheaper, for the same level of performance [13]. Active vibration control systems can also be smaller and lighter than passive ones. In addition, active vibration control systems have the advantage of being able to control vibration across wider bands of operating frequencies, which implies robustness to changes in operating frequencies [14]. Moreover, active vibration control systems can be integrated with adaptive algorithms, which ensure the active vibration control systems follow up the changes of time-varying systems. Passive vibration control

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systems are simple, while active vibration control systems contain a lot of components: sensors, actuators, power amplifier and a digital control system. Active vibration control systems are therefore much more complex than passive vibration control systems like periodic structures, which employ dispersion bands of structure-borne sound wave to control vibration transmission [15]. Another disadvantage of active vibration control systems is that external energy is consumed [16].

In practice, a passive floating raft cannot perform outstanding isolation performance in low frequencies and for time-varying excitations [17]. To improve vibration isolation performance in low frequencies, semi-active and active control technologies have been applied to floating rafts [2,17,18]. Niu et al. [2] proposed an active floating raft isolation system, in which active actuators were inserted between machines and the intermediate mass as well as the intermediate mass and the foundation. Daley et al. [19] developed a hybrid active-passive smart "spring machinery" mounting system that controls the rigid modes of the machinery it supports. To control time-varying excitations of machines on a floating raft effectively, Sun et al. [17] proposed to utilize adaptive dynamic vibration absorbers (DVAs). They compared the performance of the adaptive DVAs for three cases of which the adaptive DVAs were mounted on three distinct positions. Their simulation results have shown that differences existed among vibration reduction performances of adaptive DVAs mounted on distinct positions. Similarly, Hui et al. [9] pointed out that mounting positions of isolators had a considerable influence on the vibration isolation performance of floating floors. This phenomenon can be explained by that floor mobility can affect vibration isolation performance of isolators efficiently [20]. To improve performance of active vibration control system, the problem of determining the optimum mounting positions of actuators is of considerable interest in engineering [21]. A lot of works have been devoted into this field and can be classified according to the cost functions been utilized. Cost functions for determining the optimum mounting positions include maximization of controllability/observability index [22–25], maximization of control forces transmitted by actuators to the structure [26], minimization of the H_2 norm of the control system [27], minimization of the required control energy [28,29] et al. Most of these works are focused on piezoelectric actuators [30].

The adaptive dynamic vibration absorbers utilized by Sun et al. [17] were mounted on the intermediate mass directly, do not need to react off a base structure as actuators utilized by Niu et al. [2] did, can be applied to more circumstances. Similarly, inertial actuators are free from the requirement of react off a base structure and thus present a much more appealing solution [31,32]. Inertial actuators have been utilized to improve performances of vibration isolation systems in low frequencies [31–35] and turned out to be effective. But, vibration isolation systems in these literature are one-stage isolation systems. In this paper, an inertial actuator is being proposed to utilize in a kind of two-stage vibration isolation system – floating rafts. Besides, to the best knowledge of the authors, there are no published works about the best mounting positions of inertial actuators utilized in vibration isolation systems. The best mounting positions of an inertial actuator on the intermediate mass of a floating raft is investigated firstly in this paper. Similar to DVAs and isolators, inertial actuators mounted at different positions on a flexible structure can show different performances. Therefore, for a time-varying excitation, it is possible to improve performance of an inertial actuator by utilizing a control system which can move the inertial actuator automatically. In this paper, a novel movable active vibration control system is firstly proposed to improve the vibration isolation performance of a floating raft. The theoretical study of the floating raft system is based on a generalized mobility/impedance-power flow mathematical model developed by Xiong et al. [36]. The criterion for selecting the best mounting positions is the minimum power transmission.

2. Methods

The model of the floating raft system with the natural coordinate system attached is shown in Fig. 1, where "*s-s*" denotes the boundary condition of simply supported. The floating raft system is consisted of five substructures: two identical rotatory machines (substructure 1), eight identical upper isolators (substructure 2), a rectangular flexible intermediate mass (substructure 3), four identical lower isolators (substructure 4), and a rectangular flexible foundation with all edges simply supported (substructure 5).

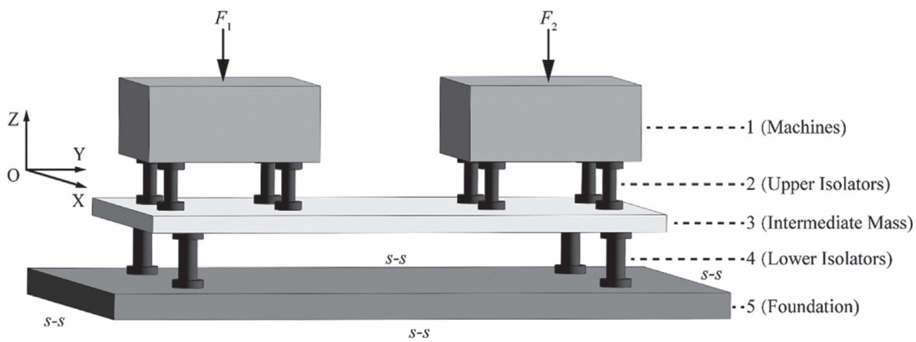

Fig. 1. A schematic diagram of the floating raft system.