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Improved hybrid isolator with maglev actuator integrated in air spring for active-passive isolation of ship machinery vibration

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ABSTRACT

A hybrid isolator consisting of maglev actuator and air spring is proposed and developed for application in active-passive vibration isolation system of ship machinery. The dynamic characteristics of this hybrid isolator are analyzed and tested. The stability and adaptability of this hybrid isolator to shock and swing in the marine environment are improved by a compliant gap protection technique and a disengageable suspended structure. The functions of these new engineering designs are proved by analytical verification and experimental validation of the designed stiffness of such a hybrid isolator, and also by shock adaptability testing of the hybrid isolator. Finally, such hybrid isolators are installed in an engineering mounting loaded with a 200-kW ship diesel generator, and the broadband and low-frequency sinusoidal isolation performance is tested.

1. Introduction

Isolation of the low-frequency sinusoidal vibration excited by ship machinery is important in the development of ship-vibration isolation technology. Passive isolation devices can suppress the level of broadband vibration, but can hardly eliminate the low-frequency sinusoids. Instead, active control technology [1–3] is considered to be an effective means of attenuating low-frequency sinusoids.

The types of actuator used in active vibration control include electromagnetic inertial-mass actuator, maglev actuator, servo-hydraulic actuator, pneumatic actuator, and smart-material actuators such as piezoelectric actuator and magnetostrictive actuator.

Piezoelectric actuators and magnetostrictive actuators are currently used in active vibration isolation for precision equipment [4] and in the control of structural noise radiated from ship hull structures [5]. However, these two types of actuator are contact actuators with stiffness almost as large as metal, hence they are rarely used in ship machinery with large weight, severe vibration, and large relative displacement.

Hydraulic actuators have been used in the vibration isolation of power machinery [6], precision equipment, and active suspension of vehicles. However, they require auxiliary equipment with large size such as hydraulic pressure source and oil pipeline, so this type of actuator does not suit ship application with narrow space.

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Electromagnetic inertial-mass actuators have been used in power machinery vibration isolation [7], ship structural noise control [8,9], and aircraft cabin structural noise control, but they also have drawbacks. The acceleration of the inertial mass is required to be several times of the acceleration of gravity (g) [7,10], so a heavy mover is usually required to obtain large enough low-frequency force. In addition, the phase-frequency characteristic of the output force has a step near the resonance frequency. These factors may lead to reduced reliability, installation inconvenience and poor controllability.

A properly designed maglev actuator is another type of electromagnetic actuator [11,12] that requires no inertial mover and has compact structure, large output force, fast response and flat frequency response from quasi-static to several hundred Hertz. Its nonlinearity can be minimized by nonlinear compensation algorithms [11,13] and nonlinear control algorithms. Hence this type of actuator has good reliability and controllability, and it has been used in the vibration isolation of power machinery, precision vibration isolation platform, etc.

However, some limitations still hinder its application in ship machinery vibration isolation [11,12] and [14]:

(1) Vibration isolation for ship machinery still needs an active-passive hybrid isolator with compact size, large loading capacity and high-level broadband isolation.
(2) The actuator usually should have a large enough air gap [11] to avoid collision between the iron core and the armature at different ship operation conditions (such as shock, swing, and tilt), but such an air gap also has to increase the power consumption. This problem has not been well solved yet.
(3) The stability (i.e. positive total stiffness) of the hybrid isolator is quite difficult to ensure, because the negative stiffness of actuator will become significantly larger with the narrowing down of the air gap. Thus, under some conditions, ship motion (such as shock and swing) may destabilize an active-passive mounting system mounted with such hybrid isolators.

In this short communication, an active-passive hybrid isolator is proposed, with compact structure and largely improved shock and swing adaptability. It consists of a non-contact maglev actuator and an air spring with good loading capacity, positive stiffness and low natural frequency. The actuator is integrated into the air spring to form a compact structure.

New engineering designs are also proposed and implemented in such a hybrid isolator, including compliant protection for the actuator, stiffness matching of the active and passive isolators, and a disengageable suspended structure for isolator protection under large relative displacement. Next, the dynamic characteristics of this hybrid isolator are analyzed and the stiffness of the hybrid isolator is tested for different vibration displacements in Section 4.2, the dynamic characteristics of actuator force with/without the suspended structure are tested in Section 4.1, and the shock adaptability of the hybrid isolator is tested in Section 4.3. Finally, in Section 4.4, six of such hybrid isolators are installed in an active-passive isolation mounting loaded with a 200-kW ship diesel generator, and the vibration-isolation performance of this system is tested. The stability of this hybrid isolation mounting is also tested under simulated ship tilting.

2. Theoretical analysis of the hybrid isolator

2.1. Linearized dynamic equation of the hybrid isolator

The actuator used in the hybrid isolator is a maglev actuator with permanent magnet bias, and the basic structure of such an actuator is shown in Fig. 1. The iron core is of the "E" type, with the inner magnetic pole intertwined with coil, and the permanent magnet is placed on the top of the outer magnetic poles and inner magnetic pole, and the armature is of the "horizontal line" type. An air gap is set between the armature and the permanent magnet on top of the iron core, so the maglev actuator is non-contact.

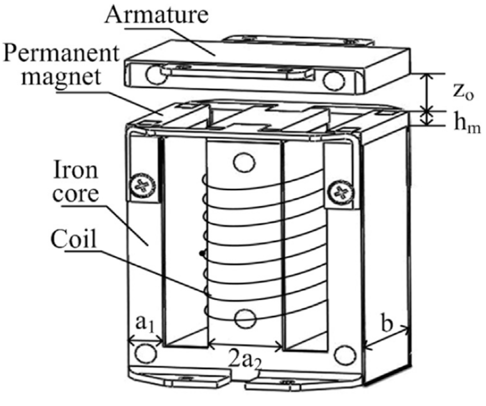

Fig. 1. Schematic structure of the maglev actuator with permanent magnet bias.