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Reduction of vibration and noise radiation of an underwater vehicle due to propeller forces using periodically layered isolators

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ABSTRACT

Using periodic structure theory, the suppression of vibration and noise radiation from an underwater vehicle due to excitation from propeller forces is investigated. The underwater vehicle is modelled in two parts (the hull and the propeller/shafting system). A model of the propeller/shafting system is constructed using a modular approach and considers the propeller, shaft, thrust bearing, isolation structure and foundation. Different forms of isolator are considered – a simple spring-damper system, a continuous rod and a periodically layered structure. The dynamic properties of the underwater vehicle and the isolation performances of various isolators are compared and analysed. The stop band properties of the periodic isolator are used to enhance the passive control performance. Furthermore, an integrated isolation device is proposed that consists of the periodic isolator and a dynamic absorber, and its isolation performance is investigated. The effects of the absorber parameters on the performance of the integrated device are also analysed. Finally, the radiated sound pressure is calculated to verify the attenuation. The numerical results show that the vibration and noise radiation are greatly attenuated in the stop bands. By optimising the design of the periodic isolators and its integrated structures, the suppression of the vibration and noise radiation can be improved effectively.

1. Introduction

Suppression of vibration and noise radiation of an underwater vehicle (UV) is a topic of great concern [1–15] because vibration and noise radiation not only affect passenger comfort and the properties of precision instrumentation but also increase the likelihood of detection by passive sonar over large distances. The significant amount of noise that radiates from the UV is generated by on-board machinery, the propulsion system and hydrodynamic noise. Excitations from the propeller are mainly caused by operation in a spatially non-uniform wake [3,4]. At low frequencies, the excitation of the hull, which is transmitted from the propeller through the shaft and the fluid [1,2], is a major source of radiated noise. In addition, there are other propeller noises such as the noise radiated directly by the propeller and the noise generated from cavitation. Hence, the overall noise signature is a combination of broadband noise and tonal noise. Among all of the contributions to the

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radiated noise produced by the propeller, the structure-borne noise of the hull excited by the force transmitted through the propeller/shafting system is principal especially when the UV operates at large depths and at low speeds.

To understand and reduce the hull's vibro-acoustic response, many studies have been carried out, and some effective approaches have been generated [5–11]. Pan et al. [3] investigated propeller-induced structural vibration through the thrust bearing using a scaled experimental model. Castellini and Santolini [12] developed a measurement system to detect the vibration of a naval propeller rotating in water in which the vibration signal is sampled by a tracking laser scanning vibrometer. Lewis and Allaire [13] introduced a negative spring stiffness using magnetic actuators to reduce a ship's propeller-induced structural vibrations. Zhang and Cao [14,15] investigated the effect of the longitudinal vibration of the shaft on sound radiation from the stern of the UV, and they studied the influence of the stiffness of the thrust bearing, the propagation path of the forces and the application of isolators. Li et al. [16] and Cao and Zhang [17] studied the attenuation of propeller/shaft-mediated vibration and noise radiation using dynamic absorbers.

Moreover, a systematic investigation was conducted by scholars in Australia using a resonance changer (RC) to minimise the vibration transmission and the noise radiation from a submerged hull [1,2,5,9,18–20]. The approach of using an RC to reduce vibration transmission through the propeller-shafting system was adapted from Goodwin [21]. Overall, these publications provide useful guidance for the suppression of vibration and noise caused by propeller forces. On the other hand, improvements in isolation of the propeller/shafting system need to be made, and research into new methods to reduce the vibration and noise should still be advanced further.

Periodic structures exhibit transmissibility “stop bands” within which the propagation of elastic/acoustic waves can be attenuated effectively. Clearly, this property is of great interest in the field of vibration and noise control. Thus, the dynamic properties of periodic structures have attracted much attention [22–32]. For example, Szefi et al. [26,27,33] performed a series of studies of high-frequency periodically layered isolators to reduce helicopter gearbox noise. They designed and analysed the layered isolators and enhanced their performance by introducing embedded inertial amplifiers and active control. Dynamic properties of a shell that has been periodically stiffened by ribs have also been studied extensively [34,35]. All of these studies provide good evidence for the use of periodic structures to reduce vibration and noise radiation. However, the problem remains that periodic structures cannot always be designed to meet target frequencies due to physical constraints including the mass, stiffness and size of the periodic structure, especially when the target frequencies are in the low frequency range. Some researchers have explored how to improve isolation performance at low frequencies and widen the stop bands [33,36–42].

In this paper, a periodic isolator is employed to reduce the vibration and noise radiation of a UV caused by propeller forces. A simplified physical model of a UV is developed first. The isolation performance of the periodic isolator is investigated and compared with the traditional homogenous isolator. Next, an integrated isolation device is proposed, and its performance is studied. Finally, the suppression effect of the periodic isolator and its integrated structures is verified by measuring the radiated sound pressure of the UV.

2. Theoretical model

2.1. Physical model of the UV and various isolation structures

A simplified physical model of a UV is shown in Fig. 1. The model consists of the UV hull and the propeller/shafting system. The UV hull is modelled as a thin-walled cylinder with evenly spaced ring-stiffeners and bulkheads. The stern of the UV is simplified as a cone, and the bow is modelled as a hemisphere. The foundation of the propeller/shafting system is modelled as a circular plate that is connected to the UV hull around the whole boundary of the plate. The on-board machinery and other internal structures are reduced to a distributed mass attached to the UV hull. The density of the hull is adjusted to maintain neutral buoyancy.

The propeller/shafting system is composed of the propeller, shaft, thrusting bearing, isolation structure and foundation. The machine is connected to the shaft via an adapter. As shown in Fig. 1, the main transmission paths for the longitudinal

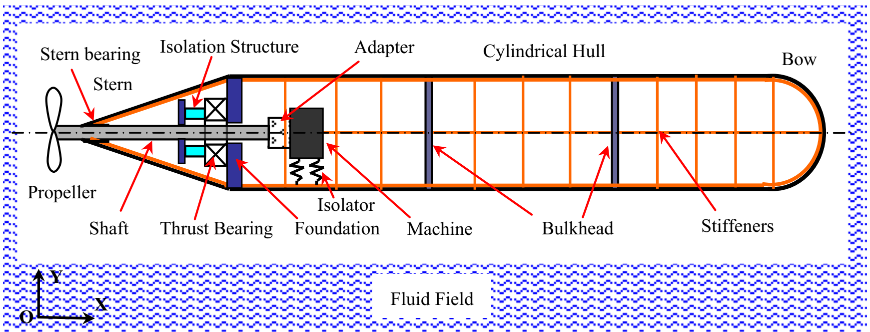

Fig. 1. Simplified physical model of a UV.