Review on vibration isolation technology

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Abstract: Submarine acoustic stealth technology is very important for national defense constructions. Vibration isolation technology is the key technology to realize submarine acoustic stealth. In this paper, the development of vibration isolation technologies in recent years is reviewed. The characteristics of several important active and passive vibration isolation technologies and vibration isolators are analyzed in detail. Besides, the latest research directions are discussed. Afterwards, the deficiencies of current intelligent vibration isolation technology and personal views on the development of intelligent vibration isolation technology are presented.

1. Introduction
The acoustic stealth capability of submarine is very important to the improvement of naval combat ability. With the development of sonar technology, its detection ability and positioning accuracy have been greatly improved, which makes the submarine concealment problems become a great challenge. Submarine noise mainly comes from mechanical noise, propeller noise and hydrodynamic noise[1], in which the low-frequency and medium-frequency mechanical noise generated by the operation of mechanical equipment has the greatest impact on the concealment of submarine in low-speed sailing conditions. The main energy of mechanical noise is transferred to the boat body through the supporting base. The vibration isolation technologies can effectively reduce the vibration transmission to the base. Therefore, the vibration isolation technologies have become the key technology of submarine shock absorption and noise reduction.

The basic principle of vibration isolation technologies is to reduce or weaken the transmission of vibration and suppress vibration by installing a vibration isolator between the vibration source and the controlled object. According to the different acting modes of vibration isolation devices, naval vibration isolation technologies mainly include passive vibration isolation, active vibration isolation and active and passive mixed vibration isolation. This paper will analyze and summarize the three vibration isolation methods and vibration isolators, discuss some current research directions and analyze their shortcomings, and put forward their own ideas for the development of vibration isolation technologies in the future.

2. Research contents

2.1 Passive vibration isolation technology
Passive vibration isolation technologies do not need external energy supply, it has simple structure, reliable performance, and easy implementation, passive vibration isolation technologies are relatively mature, in the high frequency suppression effect is significant. The development of passive vibration isolation technologies mainly includes single-layer vibration isolation system, double-layer vibration isolation system to floating raft vibration isolation system, as well as the research of various new vibration isolation devices.

The single-layer vibration isolation system is the most basic form of vibration isolation. A layer of vibration isolator is usually added between the equipment and the ship. The vibration level drop is generally between 20dB and 25dB[2], but the vibration isolation effect is still insufficient in the high frequency area. The two-layer vibration isolation system refers to adding a layer of intermediate mass between the equipment and the hull. The intermediate mass is connected to the hull through the vibration isolator and the equipment respectively. The vibration level drop of the two-layer vibration isolation system is generally between 40dB and 45dB[2], and the vibration isolation effect of the two-layer vibration isolation system for high frequency noise is better than the single-layer vibration isolation system. However, the two-layer vibration isolation system requires a relatively large intermediate mass, which is a big limitation for the wide application of the two-layer vibration isolation system [3]. The floating raft vibration isolation system is based on double-layer vibration isolation technology, which connects multiple devices to an intermediate mass at the same time, the vibration isolation effect in the low frequency vibration level gap is greater than 35 dB, can in the high frequency area more than 50 dB[4], the floating raft isolation system is currently widely used in submarine main and auxiliary engine vibration isolation due to its better vibration isolation effect and better shock resistance.

2.2 Active vibration isolation technology
The development of passive vibration isolation technologies is the most mature now, but it can not be targeted to the low frequency line spectrum efficient isolation. The low frequency line spectral noise will reveal the information of propeller, main and auxiliary engine type, speed and so on, which is a major bottleneck restricting the improvement of acoustic stealth performance of submarine. Active vibration isolation technologies have become an important research direction because of its good control effect for low frequency linear spectrum vibration (0-100Hz), and with fast response and high efficiency. Pure active vibration isolation is a vibration isolation component used as an actuator to replace passive vibration isolation device, which dynamically adjusts the supporting characteristic parameters of the system according to the set control law to solve the problem of vibration and noise reduction near the low frequency and resonant frequency[5].Active vibration isolation control algorithm mainly includes optimal control, adaptive control, PID control, robust control, fuzzy control, artificial neural network control and so on. Literature [6] proposed an active vibration isolation technology, in which a voice coil motor and a piezoelectric brake are in series as active brakes and controlled by robust control theory. Literature [7] presents a research method of active vibration isolation system based on hydraulic servo
actuator, taking a two-degree-of-freedom system as the research object. The U.S. navy submarine launched the advanced technology in the 1990s[8] (AST) research plan, using non-contact magnetic levitation actuator bearing the weight of large raft and equipment, at the same time actively controlled magnetic levitation actuator isolate low-frequency vibration, However, the project was finally abandoned due to technical bottlenecks such as excessive actuator power demand and difficulty in ensuring system stability and reliability.

2.3 Active and passive vibration isolation technology
Pure active vibration isolation technologies have high requirements for the static load capacity of actuators, its structure is complex and energy consumption is large. If the contact actuators with large stiffness such as piezoelectric actuators are used, the wide frequency isolation effect will be affected. but the active and passive hybrid vibration isolation system is based on passive vibration isolation system plus active vibration isolation system, the active components do not need to carry the weight of the equipment, which make the system have both the advantage of passive vibration isolation system for high frequency vibration isolation, and active vibration isolation system for low frequency vibration, combine the strengths of both, become a kind of low energy consumption, with low system complexity of vibration isolation system. In addition, the reliability of the active and passive vibration isolation system is higher. When the active vibration isolation system fails, the passive vibration isolation part still maintains the effect of passive vibration isolation in its effective vibration isolation frequency band, thus improving the safety and stability of the vibration isolation system. Especially for equipment or precision instruments in harsh environment, active and passive hybrid vibration isolation can provide wide band vibration isolation, and can achieve the best vibration isolation effect. This makes the passive vibration isolation technologies more and more become the focus of research. Literature[9]proposes a research method of active vibration control based on passive vibration isolation platform. Literature [9]proposed a kind of active and passive mixed vibration isolation technologies, which combined the centralized pump arrangement and the floating raft isolation with the active isolation. Literature[10] proposed a semi-active periodic vibration isolation technology for power machinery based on magnetorheological damper. A semi-active optimal impact resistance technology based on fuzzy synovial membrane control was proposed in Literature[11].Literature[12] proposed a research method that applied air bag vibration isolator and electromagnetic actuator to the floating raft vibration isolation system to form a magnetic-gas hybrid active and passive floating raft vibration isolation system. there are also the active and passive isolation technologies, which combines the magnetic levitation actuator with the airbag vibration isolator by the Naval University of Engineering, which have also achieved remarkable results.

2.4 Research status of vibration isolator
Vibration isolators are very important for ships and mechanical equipment. The technical development of vibration isolators is also becoming mature. Traditional vibration isolators, such as rubber vibration isolators and steel wire rope vibration isolators, are difficult to solve the contradiction between low frequency and high efficiency vibration isolation and displacement stability of the device. New type of air vibration isolator, the use of internal capsule reaction of compressed air as the elastic restoring force,
can very good to solve this problem, the inherent frequency of airbag vibration isolator is low (less than 5 Hz), the carrying capacity is strong, with high standing wave frequency, there is no creep, the high frequency vibration isolation performance is good, with small size of structure, easy to install, more representative is our independent research and development of intelligent airbag vibration isolator technologies[13], and the ship propulsion system airbag [14], vibration isolation system using airbags vibration isolator has obtained the good effect of vibration isolation, and ensure the stability of equipment displacement profile. The working pressure of JYQN series air bag vibration isolators independently developed in China can reach 2.5MPa, and the bearing capacity range is 1-50 tons. The VAA series airbag vibration isolator developed in Japan can carry a capacity of 40 tons, work pressure up to 1MPa, and its vibration isolation effect is about 15-20dB. The high pressure and large load airbag vibration isolator developed by Russia has a rated working pressure of 2.8-3MPa and a carrying capacity of more than 100 tons.

3. Summary and Prospect
With the progress of society, whether it is ships or mechanical equipment, the requirements for vibration isolation technologies are increasingly high. Passive vibration isolation technologies are relatively mature, but its development is limited. For the active control technologies and active and passive control technologies we do not have a mature grasp. As for the control method, we can not well meet the requirements of different environments, and the intelligent vibration isolation is still just taking shape, which requires us to do more research and experiments. The research on vibration isolators also requires us to develop more suitable types of vibration isolators for different conditions. In the development process of vibration isolation technologies of the future, we should be more towards the direction of intelligent vibration isolation, combing modern intelligent control technologies with vibration isolation technologies, through condition monitoring and intelligent control, making the intelligent vibration isolation device capable of long-term autonomous operation without external interference and in the whole life cycle to keep good performance of vibration isolation. The development of our intelligent vibration isolation system should have perfect autonomous learning ability and good adaptability to the complex external influence. I believe that intelligent vibration isolation technologies will bring a bright future to the development of our vibration isolation technologies.

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