Study of Acoustic Stealth and Vibration Performance of Solid-core Composite Rudder Installed on Underwater Vehicle

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ABSTRACT

The acoustic stealth and vibration performance of solid-core composite rudder with damping materials has been studied and discussed in this paper. The simulating models of composite rudder and steel rudder for calculating the target strength ($TS$) are built and the $TS$ distribution versus direction and frequency is obtained. The simulating data of both the two rudder models are mainly matched with the test result. Compared with steel rudder, the average $TS$ of composite rudder is lower in almost directions. The composite rudder has a definite superiority in directions of abeam and aft and the difference could be 5.3 ~ 8.9dB. As the frequency is higher than 4 kHz, the $TS$ of composite rudder is 4 ~10dB lower than steel rudder. The result of the vibration test of two rudder partial models indicates that the vibration acceleration of composite rudder is significantly lower in the frequency range of 100Hz~10 kHz. The total acceleration level is 7dB lower approximately. All these features are related to the solid-core structure and damping composite. The solid-core composite rudder shows great superiorities in acoustic stealth of underwater vehicle.

KEY WORDS: rudder; composite materials; solid-core, target strength; vibration; acoustic stealth

INTRODUCTION

As a hull appendage, rudder protrudes from the underwater vehicle and is with a strong reflection of sound waves, making a vital component of acoustic target. Additionally, rudder vibrates and produces amounts of radiations for helming and flowing. That makes rudder a significant role in acoustic stealth of underwater vehicle. The usual measure of stealthy is covering anechoic coating on rudder surface, which could not eliminate noise radiation and reflection completely. As a kind of modern advanced materials, composite material has been widely applied in naval equipment and aerospace. It is light-weight, corrosion-resistant, fatigue damage-resistant, damping and its thermal expansion coefficient is low. Weight saving of 25 to 50% is attainable if traditional steel material is replaced by composite material. Composite material is gaining popularity in naval equipment for its large specific strength, stiffness and easy processing. The rudder fabricated with composite material has been installed on a DDG-51 and DDG-1000 class destroyer (Bi, 2009; Luo, 2009). Sun (2010) designed a kind of composite rudder, which was filled with rigid composite inside. The effectiveness of the filling material’s density on rudder’s mechanical properties and natural vibration characteristic has been investigated. And the optimum parameter of density and thickness to achieve a better acoustical performance is calculated by transfer matrix theory. Chen (2013) fabricated a rudder blade surface with high strength carbon fiber composite instead of steel. Mei (2016) and Zhao (2017) manufactured a solid light-weight composite rudder by adding buoyant material into the blade cavity and damping material around rudderpost, which makes the whole rudder blade as a sealing unit. This method resolves the weakness of the erosion of the steel rudder and contributes to decreasing the vibration and noise.

That the damping composite material with great advantage on acoustic radiation of vibrating component has been proposed (Lin, 2004; Zhu, 2007; Zhu, 2008; Luo, 2009). Liu (2009) and Wang (2017) have studied composite rudder’s vibrating behavior with steel rudder as a control and revealed hydrodynamic pressure distribution of composite rudder, stress and deformation of shaft end. Li (2015) and Song (2017) have computed the target strength of composite rudder based on acoustic finite element theory and automatic matching boundary layer technique. It has shown that composite rudder has lower target strength in high frequency range while closing in low frequency range. Liu (2009) and Liu (2017) have analyzed the vibration characteristic of composite rudder. The composite rudder’s skeleton has been optimized which improves its vibrating performance by changing first order natural frequency (Wu, 2018; Wu, 2018).

This paper has researched the acoustic stealth performance and vibration of solid composite rudder with damping material by simulation and test. The computing data are mostly matched with the test result. With steel rudder as a control, the $TS$ of composite rudder is 4dB~10dB lower in the direction of abeam and backward. The picking points’ vibration acceleration on skeleton is about 8dB lower than steel rudder and the total vibration acceleration degrades normally 7dB. The composite rudder shows a clear preponderance in depressing acoustic target strength and vibration.

RESEARCH OF TARGET STRENGTH OF SOLID COMPOSITE RUDDER

Target strength simulation of rudder

Target strength ($TS$) is defined as sound intensity level at 1m distance to object center, which is a critical parameter in detecting target. It represents the ability of scattering wave of target in acoustic field. The rudder’s $TS$ is simulated on acoustic finite element theory and computed with software of Acoustic Harmonic FEM in LMS Virtual. Lab (a commercial software for computing the target strength). In acoustics, fluid pressure ($p$), particle velocity ($V$), mass density ($\rho$) are used to describing the characteristic of acoustic field. Based on the law of