The study about the impact of the free surface on the interaction between a submarine and its propeller

Jia-jie Sun1, 2, 3, Ya-dong Liu1, 2, 3, Zhe Chen1, 2, 3, Chao Chen4, Yaping He1, 2, 3, 5
1. State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai, China
2. School of Naval Architecture, Ocean & Civil Engineering, Shanghai Jiao Tong University, Shanghai, China
3. Institute of Marine Equipment, Shanghai Jiao Tong University, Shanghai, China
4. COSCO SHIPPING Energy Transportation Co., Ltd, Shanghai, China
5. Jiangsu Hai Xin Shipping Heavy Industries Co. Ltd, Nantong, China
* Corresponding Author

ABSTRACT

The interaction between the propeller and the submarine navigating under limited depths is obviously affected by the free surface due to the changes in the flow field characteristics around the submarine. And what is mentioned above will significantly influence the hydrodynamic performance of the submarine and threaten the security of navigation and operation. To figure out the effect of the free surface on the interaction between the submarine and the propeller, in this paper, the DES (Detached Eddy Simulation) equations coupled with SST k-ω turbulence model are used for the numerical simulation of the performance of the target self-propulsion model under different depths based on Star-CCM+ numerical calculation software. The influence of the free surface on the interaction between the submarine and the propeller is analyzed through the research of the self-propulsion model under multiple conditions. The results show that the existence of the free surface has a nonnegligible impact on the interaction between the propeller and the hull and the performance of the self-model and increases the rotational speed of the propeller at a specific navigating rate, which corresponds to the self-propulsion point. The effect of the free surface on the stern flow field is great by comparison with the bow flow, which gradually reduces to negligible as the depth increases and the speed decreases. Meanwhile, the axial velocity of the propeller disc's forward flow is decreased due to the changes in the flow field characteristics around the submarine. The study is of great benefit to improving the safety of submarine navigation and the hydrodynamic performance, including rapidity, of the submarine and is of particular value to provide a reference for the design of a submarine with a mating propeler.

KEY WORDS: submarine; propeller; free surface; interaction.

INTRODUCTION

With the rapid development of science and technology and the increasingly fierce competition in marine development, people have higher requirements for the overall performance of submarines. Reasonable rapidity means higher speed, higher propulsion efficiency and lower energy consumption, thus increasing its operating range and time, so it is one of the critical indicators to evaluate the hydrodynamic performance of a submarine (Cui and Ma, 2009). As the propeller of the submarine, the proper operation of the propeller and the reasonable matching between the propeller and the hull are essential to ensure the rapidity of the submarine. The process of the propeller and the interaction between the propeller and the submarine navigating under limited depths is affected obviously by the free surface due to the changes in the flow field characteristics around the submarine. And what is mentioned above will significantly influence the hydrodynamic performance of the submarine and threaten the security of navigation and operation.

Therefore, many scholars have studied the interaction between the submarine propeller and hull and the self-propulsion performance. Yang, Wang and Zhang (2012) solved the Reynolds averaged Navier-Stokes equations using the RNG k-ε turbulence model to numerically analyze the three-dimensional viscous flow field of a fully attached body model with a propeller Suboff. In the following year, Yang (2013) performed a CFD-based method to analyze the drag and self-propulsion performance of the submarine, comparing the drag performance and self-propulsion performance of the Suboff submarine (single propeller) with that of the Non-DOR submarine (twin propellors). Nathan and Pablo (2013) performed numerical simulations of the DARPA Suboff submarine and propeller E1619 using the fluid solver CFDSHIP-Iowa V4.5 to evaluate the effect of turbulence models on wake flow by comparing the results of RANS, DES, DDES and no-turbulence models. In the same year, Nathan, Thad and Pablo (2013) performed numerical simulations of a fully attached DARPA submarine self-model using both the slip-grid propeller and CFDSHIP-Iowa/PFU-14 methods.

Considering the effect of free surface on submarine navigation, Zhang, Zhang and Shen (2012) used RANS combined with RNG k-ε turbulence model and VOF free surface capture method to numerically simulate the rear thrust and torque of a submarine model with propeller under different immersion depth sailing conditions, analyzed the self-propulsion factor, and studied the boat/propeller interference characteristics. After that, Zhang and Zhang (2014) used the same