Study of Self-Propulsion Performance of a Single-Screw Ship in Waves Based on Improved Propeller Body Force Model

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ABSTRACT

So far, self-propulsion simulation using fully discretized approach by modelling all moving components, especially for the rotating propellers, is very time consuming. It is very important to find a more efficient approach to evaluate the hydrodynamic performance with acceptable accuracy. In this paper, an improved blade element momentum theory (BEMT) propeller body force model is proposed to predict the propulsion performance considering hull-propeller-rudder interaction. The single-screw KRISO Container Ship (KCS) under head wave is simulated by in-house CFD solver naoe-FOAM-SJTU. Dynamic overset grid method is used to deal with the large ship motion in waves, while the improved body force model is utilized to calculate the propeller performance. Predicted results, i.e., ship motions, thrust and torque in waves, are compared with discretized propeller results and the experimental data. The results showed that the proposed propeller body force model is suitable and reliable in predicting the self-propulsion performance of ship sailing in waves.

KEY WORDS: Propeller body force model, self-propulsion, overset grid method, hull-rudder interaction in waves

INTRODUCTION

The performance of free running ship in waves is very complicated due to the complex hull-propeller-rudder interactions under large amplitude 6DoF motions. Therefore, the prediction of self-propelled ship in waves has been a widely concerned issue in the research field of ship hydrodynamics. Previous studies are mostly using the fully discretized approach based on dynamic overset grid method. This approach was firstly introduced to ship and ocean engineering for CFD simulations of self-propelled ships (Carrica et al., 2010; Castro et al., 2011). Wang et al., (2019a) employed the same approach to study the self-propulsion behaviors under different ship speeds. Wang et al., (2017) further applied the dynamic overset grid method to simulate the free running ship in different wave headings. With the help of dynamic overset grid technique and 6DoF motion solver with a hierarchy of bodies, simulations of ship self-propulsion become very convenient.

However, fully discretized approach by modelling all moving components, especially for the rotating propellers, is very time consuming. It is very important to find a more efficient approach to evaluate the hydrodynamic performance of self-propulsion with acceptable accuracy. Body force propeller model has long been used to predict the performance of open water test and self-propulsion test. Phillips et al. (2010) carried out rudder-propeller interaction simulation based on the Uniform Thrust (UT) distribution model, HO model (Hough and Ordway, 1965), and BEMT model (Benini, 2004). The results showed that BEMT model give relatively good predictions among three models. It was also noted (Yamazaki (1977), Tokgoz (2013)) that local velocity plays an important role in BEMT propeller model. The modified body force propeller model was further applied to the simulation of hull-propeller interaction (Li et al. (2019), Feng et al. (2020a, b) and Yu et al. (2021)).

Previous studies most focused on the clam water condition or quasi-steady condition when predicting the hull-propeller interaction with body force propeller model. However, ship self-propulsion in waves has very complex interactions and the propeller performance are highly nonlinear, which means a more accurate propeller body force model is needed to conduct the simulations. The motivation of this study is to find out whether it is reliable for the numerical computations of ship self-propulsion in waves based on body force model and to study the wave effects on the propulsion performance. In the present paper, an improved BEMT body-force model is proposed to predict the performance of ship self-propulsion in waves. The results are compared with fully discretized model to examine the accuracy of propeller body force model.

The outline of this paper goes as follows: the numerical approach including discretized model and body force model are presented in the second section; the simulation designs, including the geometry model,