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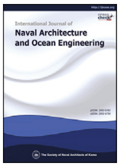

Hydrodynamic analysis of the surface-piercing propeller in unsteady open water condition using boundary element method

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Abstract

This article investigates numerical modeling of surface piercing propeller (SPP) in unsteady open water condition using boundary element method. The home code based on BEM has been developed for the prediction of propeller performance, unsteady ventilation pattern and cross flow effect on partially submerged propellers. To achieve accurate results and correct behavior extraction of the ventilation zone, finely mesh has generated around the propeller and especially in the situation intersection of propeller with the free surface. Hydrodynamic coefficients and ventilation pattern on key blade of SPP are calculated in the different advance coefficients. The values obtained from this numerical simulation are plotted and the results are compared with experiments data and ventilation observations. The predicted ventilated open water performances of the SPP as well as ventilation pattern are in good agreement with experimental data. Finally, the results of the BEM code/experiment comparisons are discussed.

Keywords: SPP; BEM; Hydrodynamic coefficients; Ventilation

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1. Introduction

A surface piercing propeller is a special type of super-cavitating propeller, which operates at partially submerged conditions. A defect of using SPP is that a complete performance prediction method is still under development and even though SPP are used largely in the boat racing community, the design of SPP is often performed in a trial-and-error basis. The first research activity has been recorded on SPPs was conducted by Shiba (1953). In this research, 2D section of surface propeller with different profiles and the various parameters affecting the ventilation phenomenon were investigated experimentally. During 1970s to 1990s, several experimental tests were conducted on ventilation parameters and their effects on average loss of thrust and efficiency such as Wang (1977), Olofsson (1996), Rose and Kruppa (1991), Kruppa (1992) and Rose et al. (1993). The first application of boundary element method was made for the partially cavitating flow in a two-dimensional foil by Uhlman (1987). A boundary element method based on velocity was used together with a termination wall model, and the cavity surface was iterated until the dynamic and kinematic boundary conditions were satisfied. Shortly after that, BEM based potential was applied for two dimensional cases by Kinnas and Fine (1990) and by Lee et al. (1992).

Pellone and Rowe (1981) calculated the super-cavitating flow on a three-dimensional hydrofoil using a BEM based on velocity and Pellone and Pellat (1995) extended the same method for partial cavities. Propeller wetted flow calculation using BEM based on velocity is performed due to Hess and Valarezo (1985) and with a potential based BEM by Lee (1987). The work done at MIT in the 90s on BEMs considerably advanced the application of the BEM to propeller flows: the work of Hsin (1990) for the unsteady wetted propeller flow and the work of Fine (1992) for the unsteady cavitating flow

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on propellers. Similar work has been carried out by Kim et al. (1994) and Kim and Lee (1996). The innovative work of Fine was then followed by Kinnas and Fine (1992) and a series of extensions and enhancements on the application of the BEMs to cavitating-ventilating flow on propellers was done by Kinnas and his group: surface piercing propellers by Young and Kinnas (2002), mid-chord cavitation by Mueller (1998), ducted propellers by Kinnas et al. (2003), rudder and propeller cavitation interaction by Lee et al. (2003), hydro-elastic analysis of cavitating propellers by Young (2003), and tip vortex cavitation modeling by Lee and Kinnas (2002).

The first modeling of surface piercing propeller was carried out by Oberembt (1968). He used a lifting line method to calculate the characteristics of SPPs. Oberembt (1968) assumed that the propeller is lightly loaded such that no natural ventilation of the propeller and its vortex wake occur. A lifting-line approach which includes the effect of propeller ventilation was developed by Furuya (1985). He used linearized boundary conditions to account for free surface effects. The blades were reduced to a series of lifting lines, and method was combined with a 2-D water entry-and-exit theory developed by Wang (1979), Wang et al. (1990, 1992) to determine thrust and torque coefficients. Furuya compared the predicted mean thrust and torque coefficients with experimental measurements obtained by Hadler and Hecker (1968). In general, the predicted thrust coefficients were within acceptable range compared to measured values. However, there were significant discrepancies with torque coefficients. Furuya attributed the discrepancies to the effects of nonlinearity, absence of the blade and cavity thickness representation in the induced velocity calculation, and uncertainties in interpreting the experimental data.

One of the numerical studies related to this topic was the prediction of the flow around surface piercing hydrofoil by time marching boundary element method that was carried out by Savineau and Kinnas (1995), Savineau (1996). In this research the non-linear cavity geometry is determined iteratively by applying the kinematic boundary condition on the exact cavity surface at each time step. According to the obtained results, the developed two-dimensional method is very efficient at predicting the cavity geometry and pressure distributions during the entry phase and thus can be used as a basis to design SPP blades.

Young and Kinnas (2003) extended a 3D boundary element method which was developed in the past for the prediction of unsteady sheet cavitation on conventional fully submerged propellers to predict the performance of super-cavitating and SPP. Then, Koushan (2004) presented his research about total dynamic loadings of ventilated propellers, and showed that fluctuations during one ventilation cycle can range from 0 to 100% of the average force of a non-ventilated propeller. Ghassemi (2009) used a practical numerical method to predict the hydrodynamic characteristics of the SPP. The critical advance velocity ratio is derived using the Weber number and pitch ratio in the transition mode, then the potential based boundary element method (BEM) was used on the engaged surfaces.

Following Koushan' research, numerical simulation was performed for different types of propeller ventilation by Califano and Steen (2009). This research aimed at analyzing the ventilation mechanism. The commercial RANS code was used to solve the viscous, incompressible, two-phase flow. In terms of both thrust forces and air content, the present analysis shows a satisfactory agreement with the filtered experimental data during the first half revolution. Classification of different types of propeller ventilation and ventilation inception mechanism based on analysis of a series of experiments were investigated by Kozlowska et al. (2009). Three different types of ventilation inception mechanisms were observed based on experimental results. Vinayan and Kinnas (2008, 2009) solved the flow field around a ventilated two-dimensional surface piercing hydrofoil and propellers using a robust nonlinear boundary element method. Results are presented for the fully wetted and ventilated cases with and without the effects of gravity, simulating the effect of changes in the Froude number. A series of four-bladed propellers of the surface piercing type was developed to design a SPP for a given operating condition by Misra et al. (2012). According to the Misra results, the best performance at all immersions was obtained from the propeller using wedge shaped sections with the trailing edge inclined at 60° to the horizontal axis. Only a propeller series with four blades has been developed in this work. Numerical analysis of surface piercing propeller using RANS method was extracted by Himei (2013). In this study analysis program using potential flow theory for supercavitating propeller was diverted for surface piercing propeller. Based on numerical results, RANS simulations have good agreement with experimental results.

The main target of this study is development of home code based on boundary element method for the prediction of propeller performance, unsteady ventilation pattern and cross flow effect on partially submerged propellers. In order to validation the numerical data, analysis of 841-B surface piercing propeller that experimental measurements are available has been done in unsteady open water condition under the free surface condition. All calculations were done at zero shaft yaw and inclination angle. The amounts of force/moment components of key blade in a revolution of the SPP calculated and have been compared with experimental data. Finally the results of pressure coefficients and ventilation pattern on the propeller and key blade have been discussed.

1.1. SPP-841B propeller

In this paper, numerical simulation of SPP-841B propeller model has been investigated that the test data of it, is available. All calculations have been done at $I = 0.33$ and zero shaft yaw and inclination angle. The immersion ratio ($I = h/D$) affects the values of K_T and K_Q since the thrust and torque depend on how much of the propeller blade is in water during each revolution, and this depends upon the immersion of the propeller. The immersion ratio is defined as the ratio of the blade tip immersion to the propeller diameter. Where h is the blade tip immersion and D is the propeller diameter. The actual geometry and modeling is similar to Fig. 1. Geometrical characteristics of the propeller are shown in Table 1.