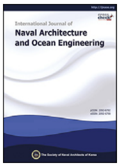

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# Numerical prediction analysis of propeller bearing force for full-scale hull—propeller—rudder system

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## Abstract

The hybrid grid was adopted and numerical prediction analysis of propeller unsteady bearing force considering free surface was performed for mode and full-scale KCS hull—propeller—rudder system by employing RANS method and VOF model. In order to obtain the propeller velocity under self-propulsion point, firstly, the numerical simulation for self-propulsion test of full-scale ship is carried out. The results show that the scale effect of velocity at self-propulsion point and wake fraction is obvious. Then, the transient two-phase flow calculations are performed for model and full-scale KCS hull—propeller—rudder systems. According to the monitoring data, it is found that the propeller unsteady bearing force is fluctuating periodically over time and full-scale propeller's time-average value is smaller than model-scale's. The frequency spectrum curves are also provided after fast Fourier transform. By analyzing the frequency spectrum data, it is easy to summarize that each component of the propeller bearing force have the same fluctuation frequency and the peak in BFP is maximum. What's more, each component of full-scale bearing force's fluctuation value is bigger than model-scale's except the bending moment coefficient about the Y-axis.

*Keywords:* Full-scale; Propeller; Free surface; Bearing force; Scale effect

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## 1. Introduction

Propellers produce periodically varying exciting forces in the three-way non-uniform wake field at the stern, which are transferred to the hull by the shaft system and fluids, significantly increasing the underwater noise and vibration of the hull. The pressure transferred to hull surface by fluids is called fluctuating pressure, on which extensive researches and calculations have been made by scholars all around the world (Huse, 1972; Duttweiler and Brennen, 2002; Huiping, 2009; Boswell and Miller, 1968) and which has been demonstrated to be heavily subject to propeller cavitation. The force transferred to the hull by the shaft system is called bearing force, which includes six fluctuation components termed as thrust, vertical force, horizontal force of fluctuation, and torque, vertical bending moment and horizontal bending moment of fluctuation. Torque and bending moment are great contributors to blade intensity while axial and side forces can cause intense vibration and noise to the hull (Merz et al., 2009). Nevertheless, the complex coupling between the propeller and rudder working at the stern as well as the limited magnitude of propeller-induced unsteady bearing force has challenged both theoretical calculation and test measurement. As such, predicting and analyzing propeller unsteady bearing force at the stern using numerical processes is nonetheless an effective method.

In most cases, research of propeller unsteady bearing force are targeted at submarines (Wei and Wang, 2013; Jingming et al., 2003), while few intensive studies have been reported on propeller unsteady bearing force of surface vessels. People like Yanshou and Wei (2006); Xiong et al. (2002) calculated the bearing forces of conventional and unconventional propellers using theoretical and empirical processes and discovered that quasi-steady method can be widely applied to the bearing force calculation of conventional propellers, while theoretical methods like lifting surface or panel method are more suitable for highly-

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Table 1
Main parameters of KCS ship and KP505 propeller.

| KCS container ship | | KP505 propeller | |
|---|---|---|---|
| LPP (m) | 230.0 | Diameter (m) | 7.9 |
| Draught (m) | 10.8 | No. of blades | 5 |
| Wetted surface ($m^2$) | 9424 | Boss ratio | 0.167 |
| Reynolds no. | $2.39 \times 10^9$ | Area ratio | 0.7 |

Table 2
Working conditions introduction.

| No. | Description | Velocity (m/s) | Reynolds no. | Propeller velocity (rpm) | No. of grids | Calculation method | No. of CPUs in parallel |
|---|---|---|---|---|---|---|---|
| 1 | Model-scale bare hull resistance calculation | 2.196 | $1.4 \times 10^7$ | — | 3.75 M & 5.32 M | Steady VOF | 96-core |
| 2 | Model-scale unsteady bearing force calculation | | | 570 | | Transient VOF | |
| 3 | Full-scale bare hull resistance calculation | 12.346 | $2.39 \times 10^9$ | — | 15.63 M & 22.40 M | Steady VOF | 192-core |
| 4 | Full-scale self-propulsion test simulation | | | 89, 95, 101,107 & 113 | | Steady VOF | |
| 5 | Full-scale unsteady bearing force calculation | | | 107.3 | | Transient VOF | |

skewed or other unconventional propellers. Ruxing et al. (2014) calculated propeller unsteady bearing force by using perturbation potential panel method and achieved satisfactory accuracy than the test results. Wang (2004) examined the propeller exciting force variation under axial wake flow and provided an analysis approach for numerically calculation of propeller exciting force. Overall, there are some shortfalls in the calculation and research of propeller unsteady bearing force so far: (a) Most of the studies are performed by simulating axial wake flow, ignoring radial and axial wake flows; (b) Most of the calculations do not include for the effect of free surface and the propeller—rudder disturbance and the calculation conditions are too ideal; (c) The study objects are all model-scale propeller without paying enough attention to the contribution of scale effect. Obviously, it is highly necessary and practically significant to perform full-scale numerical prediction studies on propeller bearing force for a full-scale “hull—propeller—rudder” system while considering the free surface.

In our study, a KCS ship and a KP505 propeller are used as the study objects. A numerical pool model is established on Fluent software. First, transient two-phase flow calculation is conducted on the model “hull—propeller—rudder” system under self-propulsion to obtain the model-scale propeller unsteady bearing force. Next, full-scale simulation is carried out under self-propulsion to determine the self-propulsion point of the ship. With the results, the full-scale propeller unsteady bearing force is calculated and compared with the calculation results of the model. The full-scale and model flow fields and wave patterns are identified. Systematic analysis is also performed on the time and frequency domains of bearing force and its scale effects.

## 2. Mathematic base

### 2.1. Control equation and turbulence model

Fluid flow is governed by physical conservation laws. Basic conservation laws include law of conservation of mass, law of conservation of momentum and law of conservation of energy. As the medium in our calculation, water, is an incompressible fluid whose heat exchange is little enough to ignore, only the mass conservation equation and the momentum conservation equation are solved. Detailed formulae are given in literature (Karim et al., 2014). The turbulence model for our calculation is an SST model frequently used in calculating propeller hydrodynamic performance. This model effectively integrates the merits of both k—ε and k—ω models and can well simulate complex flows in the presence of flow separation and strong adverse pressure gradients.

### 2.2. VOF model

The essential of Volume of Fluid (VOF) (Zhanzhi, 2014) method is to determine the free surface by investigating the fluid-grid volume fraction function in the grid cells and trace the variation of the fluid rather than the particle movement on the free surface. As long as the value of the function on each grid of the flow field is known, the movement interface can be traced.

The entire computational domain is defined as$\Omega$; the main-phase fluid domain is defined as$\Omega_1$; the secondary-phase fluid domain is defined as$\Omega_2$. VOF defines such a function:

$$\omega(\vec{x},t) = \begin{cases} 1, & \vec{x} \in \Omega_1 \\ 0, & \vec{x} \in \Omega_2 \end{cases} \tag{1}$$

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