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Mathematical Model of Wave Forces for the Depth Control of a Submerged Body near the Free Surface

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ABSTRACT

A submerged body's dynamics model in vertical plane is proposed to simulate motions near free surface. First, a mathematical model is proposed to calculate the wave forces acting on a submerged body, which is based on the wave exciting forces and moments acting on a square pillar. Second, the free surface effect acting on a hull is considered. Finally, a mathematical model for control forces is suggested, which considers the free surface effect and wave orbital motions of fluid particles. Through this process, a control system was designed that can maintain a constant depth below the mean sea level and minimize the pitch angle.

KEY WORDS: Wave exciting force; Free surface; Depth control; Submerged body; Mathematical model;

INTRODUCTION

A submerged body, operating beneath a free surface, is subjected to the effects of free surface and incident waves. When wave exciting forces and moments are exerted on the submerged body, suction forces will increase to pull the body to the free surface. If the wave suction forces are greater than the control forces, the submerged body will broach the free surface. Therefore, for submerged bodies moving in the region near free surface, to keep the constant depth is very important for safe operation.

Richards and Stoten (1981) proposed a mathematical model of wave exciting forces and moments by sea waves which includes irregular wave loads and effect of the submerged depth. Furthermore, they investigated the control of a submerged body with low speeds in shallow water. Dumlu and Istefanopulos (1995) suggested a submarine's dynamics equation considering the effect of auxiliary tank, and designed a controller with stochastic theory. Sadko (1998) presents wave spectrum and mathematical model of wave with respect to submerged depth.

In previous studies, the wave forces and moments with respect to submerged depth were considered in dynamics equations. However, they did not consider the free surface effect on the hydrodynamic coefficient in the equations of motion.

In this paper, the mathematical formula for estimating the 1st and 2nd order wave exciting forces and moments are proposed. And in the dynamics model, the submerged depth effect on the hydrodynamic coefficients and also the effect of orbital motion on the inflow angle to control planes are considered. Finally, the control system is designed based on new dynamics model, and the simulation results show that the submerged body can maintain the constant depth and minimize the pitch angle at sea states 4 and 5.

Equation of motion including the free surface effect

The equation of motion which considers the free surface effect, can be derived by modifying the external force term of the equation for submerged body in deep water.

Coordinate system

The submerged body is assumed to be rigid, while the motions of the submerged body are presented in vertical plane only (x-z plane) so the heave & pitch motions are considered.

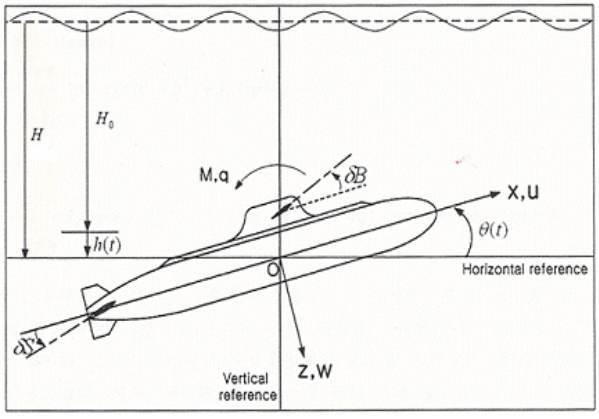

Fig. 1 Coordinate system