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Installing single-propeller twin-rudder system with less asymmetric maneuvering motions

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ABSTRACT

The inflow characteristics to each one of the rudders of single-propeller twin-rudder system are investigated. It is shown that this inflow is not parallel to ship's centerline. This may result in asymmetric maneuvering characteristic of the ship thereby reducing ship's maneuvering performance. For this purpose, a method of installing single-propeller twin-rudder system is proposed. This method is called "virtual zero rudder angle" arrangement. Here, each one of the twin-rudder is set at an angle corresponding to the inflow to the rudder. The improvement in ship's maneuvering characteristics with "virtual zero rudder angle" arrangement is investigated using experiments and numerical simulations for different ship types. It is shown that this arrangement may also improve ship's propulsion performance.

1. Introduction

In recent years, commercial ships such as very large crude carriers (VLCC) and container ships have become larger, however their maneuvering ability is not sufficient. This could cause accidents in restricted harbor area for such large ships. Lot of efforts are being made for improving the maneuverability of such large ships. One of the ways of improving ship's maneuverability is by utilizing control system. New types of control systems have been adopted in ships and they have the confidence of ship's master. Gierusz et al. (2007) proposed method for controlling harbor maneuvering while Kim and Goo (2004) proposed control techniques for maneuvering under external forces such as wind. However, the control systems may not improve ship's inherent maneuverability. If a ship has insufficient maneuverability, the control system may either not work properly or in some cases cannot even be adopted into the ship.

The maneuverability of ship, with typical single-propeller single-rudder arrangement, which have optimized hull form for propulsion, has reached the limits of its improvement. Therefore, recently special propulsion systems are being investigated for improving the maneuverability of these ships, e.g. cycloidal propulsion (Agdrup et al., 2006) and Azimuthing propulsion (Turan et al., 2008). These systems have been employed on ships that need superior maneuverability such as tugs, research ships, cruise ships, etc. Recently, several application of Azimuth propulsion system to large commercial ships has been reported.

On the other hand, improving ship's maneuverability using special rudder system is also being investigated. Flap rudder, Schilling rudder, etc. which have relatively higher rudder lift force as compared to mariner rudder, have been applied on single-propeller single-rudder ship. Kose et al. (1992) made experimental study of different rudders that have the same area and aspect ratio to investigate the variation of rudder characteristic due to rudder type. Nagarajan et al. (2008) investigated improvement of ship's propulsion performance under winds using schilling rudder. Lee and Fujino (2003) developed a mathematical model of twin-propeller twin-rudder system using experiment results and assessed its maneuvering performance. Hamamoto and Enomoto (1997) developed the mathematical model of single-propeller twin-rudder system. Hasegawa et al. (2006) investigated suitability of single-propeller twin-rudder system for large ships. Kang et al. (2008) developed a mathematical model of a single-propeller twin-rudder system for large ship. They also concluded that the geometrical layout of single-propeller twin-rudder system need to be further investigated. Nagarajan et al. (2009) proposed a method for predicting full-scale propulsion performance of ships fitted with single-propeller twin-rudder system. The previous investigations have shown that single-propeller twin-rudder system is also suitable for large ships from the aspect of maneuvering and

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Nomenclature

$A_{R\left\{\substack{S\\P}\right\}}$	area of starboard and port rudder
BHP	brake horsepower
B	ship breadth
C_B	block coefficient
a_H	interaction force coefficient induced on ship hull by rudder normal force
d_A, d_F	ship draft (aft, forward)
D_P	propeller diameter
$F_{N\left\{\substack{S\\P}\right\}}$	normal force for starboard and port rudder
$F_{RX\left\{\substack{S\\P}\right\}}$	axial force for starboard and port rudder
I_{ZZ}	yaw moment of inertia
J_{ZZ}	added yaw moment of inertia
K'	Nomoto's steering index relating to turning ability
L	ship length between perpendiculars
m	ship's mass
m_x	ship's added mass in surge
m_y	ship's added mass in sway
N_H	hydrodynamic moment acting on the ship about Z-axis
N_R	hydrodynamic moment due to rudder acting on the ship about Z-axis
n	propeller revolution
P	propeller pitch
r	yaw rate at ship's center of gravity
$\dot{r}$	yaw acceleration at ship's center of gravity
r'_m	non-dimensional yaw rate during zigzag experiment (Nomoto et al., 1957)
S	propeller slip ratio
T'	Nomoto's steering index relating to steering response and course stability
t_R	coefficient for additional drag of rudder
u	ship velocity in surge direction
$\dot{u}$	ship acceleration in surge direction
U	ship velocity
u_P	inflow velocity to the propeller in surge direction
v	ship velocity in sway direction
$\dot{v}$	ship acceleration in sway direction
x_G	location of center of gravity of ship in longitudinal direction
X_H	hydrodynamic hull force acting on the ship in surge direction
x_H	location of acting point of interaction force induced on ship hull by rudder normal force
X_P	hydrodynamic force due to propeller acting on the ship in surge direction
X_R	hydrodynamic force due to rudder acting on the ship in surge direction
x_t	location of center of gravity of ship's added mass in x-axis direction
Y_H	hydrodynamic hull force acting on the ship in sway direction
Y_P	hydrodynamic force due to propeller acting on the ship in sway direction
Y_R	hydrodynamic force due to rudder acting on the ship in sway direction
β	drift angle of ship
$\delta_{\left\{\substack{S\\P}\right\}}$	angles of starboard and port rudders
$\delta_{\left\{\substack{S\\P}\right\}0}$	hydrodynamic neutral rudder angles of starboard and port rudders

propulsion. However, their optimum maneuvering performance is mostly realized by experienced shipmasters. Further investigation is required for their operation and installation on specific ship types. In this paper, the layout of single-propeller twin-rudder system on ship's maneuvering performance is investigated and some guideline for its installation on ship is proposed based on the investigation.

2. Coordinate system and ship model

The coordinate system and the definition of various parameters are shown in Fig. 1. The mathematical model of ship's maneuvering motion is described based on three degrees of freedom, surge, sway and yaw motion. The ship maneuvering motions are written as per Mathematical Modeling Group (MMG) model and shown in Eq. (1).

$$(m+m_x)\dot{u}-m(vr+x_Gr^2)=X_H+X_P+X_R$$
$$(m+m_y)\dot{v}+(mx_G+m_yx_t)\dot{r}+mur=Y_H+Y_R$$
$$(I_{zz}+mx_G^2+J_{zz}+m_yx_t^2)\dot{r}+(mx_G+m_yx_t)\dot{v}+mx_Gur=N_H+N_R \quad (1)$$

In the right hand side of Eq. (1), subscripts H, P and R refer to hydrodynamic hull forces, propeller force and rudder force, respectively. The propeller and rudder forces were calculated from Kang et al. (2008) model and the hydrodynamic hull coefficients were referred from the Kang and Hasegawa (2007) regression model.

In this study, three different model ships were studied. The particulars of the model ships are shown in Table 1. The model ship I is used for the investigation with experiments, while the model ship II is used for that with numerical simulation. The model ship III was only used for the investigation for propulsion performance. The model ship I has a full-scale equivalent (L=99.20 m) installed with single-propeller twin-rudder system (hereinafter, twin-rudder system). The model ship II scales up to an oil tanker of size, L=315 m, while the model ship III scales up to an oil tanker of size, L=219 m. The model ships II and III were built for evaluating the adaptability of twin-rudder system to large ships. The rudder arrangement for model ship I is shown in Fig. 2. The detailed descriptions of model ship II and model ship III is given in Kang et al. (2008) and Nagarajan et al. (2009), respectively. The ratios of rudder

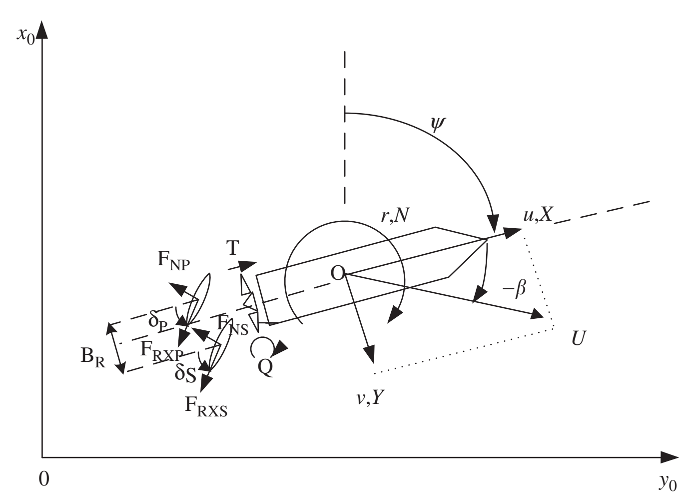

Fig. 1. Coordinate system.