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Development of a safe operation capability chart as the design basis of a rudder area

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Abstract

Ship owners now demand a new design approach for the rudder that considers detailed design information such as maneuverability and environmental loads etc. on a quantified basis. In this paper, we developed the concept of a safe operation capability chart for the design of a rudder area. The chart can be used as the basis of design considering the maneuverability and environmental loads. To confirm the applicability of the safe operation capability chart for use as the basis of design, four different rudders are assumed in this work. First, it is determined whether or not it is appropriate to design a rudder by applying a conventional design approach based on IMO maneuvering tests. The proposed concept is reviewed for use as the basis of the design by investigating the effect of rudder area on capability charts that are plotted according to the rudder under various environmental conditions.

Keywords: Maneuverability; Environmental loads; Safe operation capability chart; Design; Rudder

1. Introduction

In shipbuilding companies in South Korea, large ships such as container ships, Liquefied Natural Gas Carriers (LNGCs), and Very Large Crude oil Carriers (VLCCs) have mostly been constructed. They are generally operated based on a simplified navigation plan that minimizes complicated maneuvering motions in terms of sailing safety. Accordingly, the hull, propeller, and rudder are designed by considering mandatory scenarios such as course changing, turning, and stopping, etc.

The designs are confirmed by conducting mandatory tests to evaluate the maneuverability of the ship based on the recommendation proposed by the International Maritime Organization (IMO) (IMO, 2002). These tests include an initial turning test, a 35° turning test, a 10°/10° zigzag test, a 20°/20° zigzag test, and a stopping test at design speed. The obtained values from each test are then compared with the criteria regulated in the regulation.

To evaluate the maneuverability of the ship, simulations, model tests, and sea trials for the mandatory tests have been used (Kim et al., 2006, 2009, 2001). Because model tests can be conducted after the initial design of a ship and sea trials can be performed after a ship has launched, simulations are frequently used to evaluate the maneuverability of a designed ship from an initial design stage. Hydrodynamic coefficients for a hull, which are needed to simulate the maneuvering behavior of a ship, have been obtained from empirical formulas (Kijima et al., 1990). Recently, a new approach has been presented to obtain the coefficients by conducting virtual captive model tests using Computational Fluid Dynamics (CFD) (Sung and Park, 2015).

A rudder is designed by using empirical formulas proposed by classifications such as the Germanischer Lloyd (GL) and the International Association of Classification Societies (IACS) to determine the rudder area and the capacity of the

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steering gear (Germanischer Lloyd (GL), 2013; IACS, 1990). Although this design approach has been used for several decades, when building new ships, ship owners demand that the rudder design considers detailed design information such as resistance, maneuverability, torque, and environmental loads, etc. on a quantified basis. However, a method for designing the rudder as requested is not yet available, and a new approach is needed to design a rudder by considering the prescribed factors to meet the needs of ship owners.

Similarly, a request has recently been made to design a rudder considering the environmental effect in the Suez Canal (You and Kim, 2016). Basic research was conducted to assess the appropriateness of the designed rudder. Before a design methodology of a rudder is determined, a quantifying method of sailing safety is needed that considers maneuverability and environmental loads such as wind and current. Such as the method was recently proposed (You et al., 2017).

The suggested approaches (You and Kim, 2016; You et al., 2017) overlap the latest research trends. Recently, discussions on applying the Energy Efficiency Design Index (EEDI) have been carried out by the IMO (Jung, 2011), and the regulations of the International Organization for Standardization (ISO) have been updated to consider the environmental effects, including wind, waves, current, water depth, etc., to predict the speed from a sea trial (International Organization for Standardization (ISO) 15016, 2015). Nowadays, EU funded research project called as the Energy Efficient Safe Ship Operation (SHOPERA) (Papanikolaou, Zaraphonitis, Bitner-Gregersen, Shigunov, Moctar, Soares, Reddy, Sprenger). To consider energy efficiency on ship design, the relation between environmental loads and operating performance including CO2 emission, minimum powering, and maneuvering has been studied (Prpic-Orsic et al., 2016; Papanikolaou and Shigunov, 2014; Sutulo and Soares, 2015, 2016).

In this paper, we developed the concept of a safe operation capability chart for the design of a rudder. The chart can be used as the basis of design by considering detailed design information such as maneuverability and environmental loads.

First, this research is carried out on a twin-screw container ship while considering recent market trends. To simulate the maneuvering behavior of a ship, the hydrodynamic coefficients for a hull and the lift coefficient of a rudder are mostly predicted from empirical formulas (Kijima et al., 1990; Fujii and Tsuda, 1961, 1962). Coefficients for resistance and thrust are obtained from model tests conducted by the Daewoo Shipbuilding and Marine Engineering Co., LTD. (DSME). Simulations are conducted by using a verified mathematical model (Kijima et al., 1990; You et al., 2017).

Environmental loads such as wind, wave and current are additionally considered. Wind load coefficients are obtained from empirical formulas and irregular wind speeds are generated from a wind spectrum (Fujiwara et al., 2001; Andersen and Løvseth, 1992). Wave loads are calculated by following the procedure process summarized in references (International Organization for Standardization (ISO) 15016, 2015; International Towing Tank Conference (ITTC), 2011). Wave drift forces and moment are calculated using the commercial software that called HYDROSTAR provided by Bureau Veritas (BV) classification. The relative speed of a ship under a given current is used to predict the hydrodynamic loads including the current loads (Hwang, 1980).

In the previous study, the concept of a safe operation judgment chart as a quantifying method of sailing safety was proposed, after maneuvering simulations were conducted under given operating conditions (You et al., 2017). The concept of the above mentioned chart was that sailing safety was quantified as a value from the calculated minimum relative distances between four edges of a ship and allowable safe boundaries by assuming a sailing ship with an autopilot system (Hasegawa and Kouzuki, 1987).

Here, the quantified concept of the safe operation judgment chart is developed as a safe operation capability chart. Fundamentally, the simulations are conducted identically. However, they are repeatedly conducted under different wind, wave, and current speeds at regular intervals. After the maximum wind speeds for safe operation are confirmed according to each wind direction, the searched values are marked on a polar plot. The envelope is called a safe operation capability chart.

This concept is similar to a Dynamic Positioning (DP) capability chart, where a radius axis indicates the tested wind speed and an angle axis indicates the tested wind direction (Hendzik, 2013). A DP capability chart has two purposes. First, a capability chart is used as the basis of design to determine the capacity of the equipped devices on a quantified basis. Second, an operating instruction can be guided for an operator to perform work safely. It is anticipated that the suggested safe operation capability chart can also be used to accomplish prescribed objectives. Like DP capability chart, polar capability charts are used to indicate the performance of a ship, as well (Prpic-Orsic et al., 2016; Papanikolaou and Shigunov, 2014).

To confirm the applicability of the safe operation capability chart for use as the basis of design, four different rudders are assumed. These rudders have different areas, although their aspect ratios are identical. It is determined whether or not it is appropriate to design a rudder by applying a conventional design approach based on IMO maneuvering tests. From the simulated results, determining the correct rudder area causes ambiguity, because all values meet the IMO maneuvering criteria related to the IMO maneuvering tests, and the differences between values are insignificant. In addition, effect of rudder area on capability charts which are plotted according to rudders under various environmental conditions is investigated to determine whether the proposed concept can be used as the basis of design. Finally, the applicability of the suggested concept for use as the basis of design is confirmed to determine the rudder area.

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