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Measurements of the rudder inflow affecting the rudder cavitation

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ABSTRACT

The main objective of present study is to examine the characteristics of the complex rudder inflow(propeller slipstream) against the rudder cavitation using visualization technique. The rotating propeller of 6 blades and the semi-spade rudder are set in a medium-size cavitaion tunnel with a uniform flow condition. The rudder distorts the angle-of-attack (AoA) or incident angle to the leading edge of the rudder blade. Several methods such as uniform stream line, time-averaged velocity field and locally sampled area are proposed to analyze the AoA and show similar AoA values of 5–7° at the region of no rudder and no propeller trailing vorticity effects. However, it increases to 20° by those effects as the inflow comes to the rudder. From the AoA analysis the cavitation durability is found to be about 7° in terms of the rudder angle. Cautious access is additionally necessary to introduce a reasonable safety against those cavitation phenomena that would significantly influence the durability of the movable part.

1. Introduction

Modern marine ships are becoming larger and their power consumption is also increasing. High axial momentum behind a ship propeller may induce strong cavitation on the surface or discontinuities in the ship rudder. The propeller wake intrinsically has the contracted slipstream tube in the condition of uniform flow; however, it has specific angles of attack to the left (port) and right (starboard) sides of the rudder blade, which is located behind a propeller as exhibited in Fig. 1. The different incident flows toward the rudder have affected its lift forces and ships' maneuverability. To obtain sufficient lift forces in the rudder, an excessive rudder angle may be required in the actual operation of ship. On the other hand, an increased rudder angle induces a large amount of violent rudder cavitation, and may cause cavitation erosion of its surface. Securing sufficient lift has often conflicted with the trials of reducing rudder cavitation in both full-spade and semi-spade rudders. Unsteady cavitation on a rudder surface can cause erosion. In addition to the erosion on the rudder surface, rudder cavitation can have a negative effect on ships from hydrodynamic and structural viewpoints. If strong cavitation on the rudder results in serious damage, considerable time and cost would be necessary to maintain or repair a rudder eroded by cavitation. Therefore, it is very important to inspect flow behaviors around the rudder when the propeller is ahead of the rudder.

Kracht (1992) measured the lift and drag forces of a rudder in the towing tank and the cavitation tunnel, and studied the interaction of rudders and propellers. Shen et al. (1997) reported that the cavitation inception and erosion problems associated with the existing fleet rudders could be avoided or reduced by using the concept of a twisted rudder.

Recently, Felli et al. (2006) and Kinnas et al. (2006) conducted experimental and theoretical studies on the flow behaviors around full-spade rudders. Felli et al. observed effects similar to the potential bumping at the leading edge of the full-spade rudder using a high-speed camera, and visualized the transverse flow fields in front of and behind it by LDV (laser Doppler velocimetry). Kinnas et al. numerically tried to solve the complex dynamic behaviors of the propeller vortex filaments around a rudder. Unlike the full-spade rudder, the flows over a gap entrance of the semi-spade rudder were examined by Paik et al. (2008). They used qualitative and quantitative visualization techniques, under the propeller rotation ahead of the rudder, to investigate cavitation performances with scaling of the gap clearance. They considered the propeller in their experiments; however, the authors did not discover how the propeller action affects the flow behaviors ahead of the rudder in detail.

As the rudder is positioned at the center of the propeller slipstream, the interaction between the propeller and rudder has attracted much attention from many ship researchers. Molland and Turnock (1992) investigated the interaction between the propeller and the rudder in a wind tunnel. Kracht (1992) also studied this interaction by measuring the flow velocity with LDV. Li (1994) developed a linear method to calculate the interaction and compared it with experimental results.

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In the present study, experiments were conducted to investigate the characteristics of the propeller wake (slipstream) ahead of a rudder without a hull wake. The PIV (Particle Image Velocimetry) technique for the velocity field measurements was employed in a high Reynolds number over 10^6 to investigate the flow structure between the propeller and rudder. In particular, the information on the angle-of-attack of the oncoming flow against the rudder leading edge was obtained at the rudder angle of 0° and ±6° because it is highly related to the rudder performance and cavitation. The basic data about the interaction between the rudder and the propeller can be obtained from the results of the angle-of-attack measurements. In addition, the velocity field data would be useful for updating the propeller wake modeling.

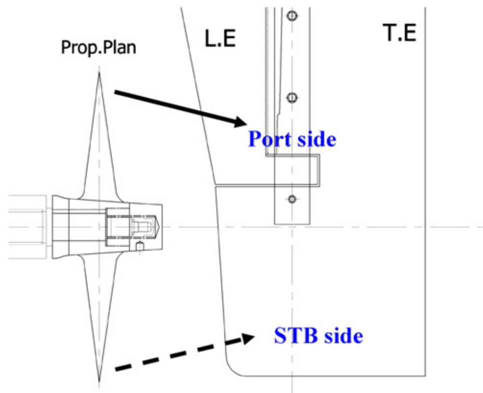


Fig. 1. Variation of rudder incident flow caused by propeller wake (port side view).

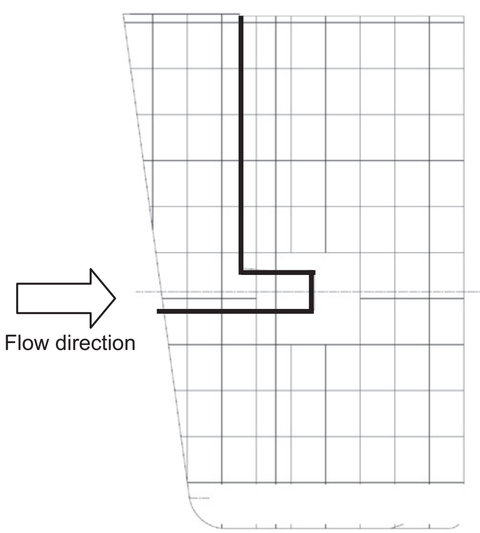
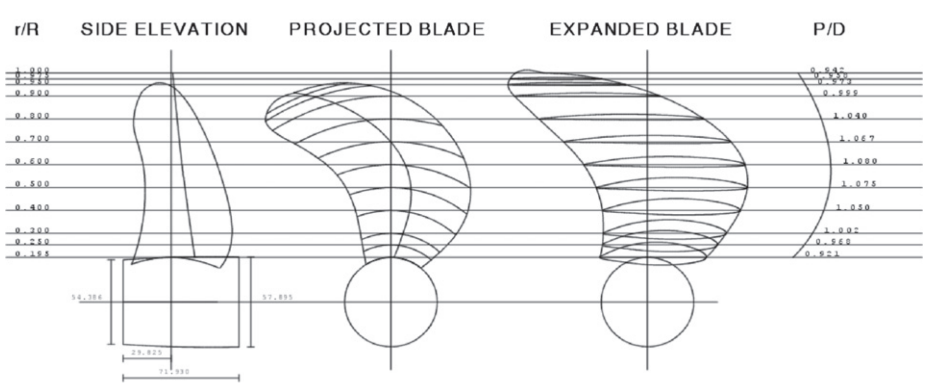


Fig. 2. Sketch of the semi-spade rudder (thick solid line: gap).

2. Experimental apparatus and method

Measurements of the flow fields between the propeller hub and the rudder leading edge were carried out in the cavitation tunnel of the Korea Ocean Research and Development Institute (KORDI) Daeduk branch. The dimensions of the rectangular test section were $0.6 \times 0.6 \times 2.6\ m^3$. The maximum flow speed was 12 m/s, and the pressure varied from 10.1 kPa to 202 kPa. The flow uniformity and the turbulence intensity in the tunnel test section were less than 1% and 2%, respectively. The selected rudder to be installed in a large container ship consisted of the horn and the movable part, which was manufactured to rotate up to ±10°. Fig. 2 shows the sketch of the rudder and the gaps of its pintles. The rudder model had a chord length of 262.5 mm and a height of 403.3 mm at the center of the lower pintle. Both the horn and the movable part used the NACA section. Here, the terminology t_0/C, which indicated the ratio of the section thickness to the chord length, was introduced to explain the distribution of the rudder section. The rudder had section distribution in which the t_0/C at the top and bottom of the movable and horn parts was 21%. The rudder model was manufactured according to the scale of 1 over 28.5. The rudder angle θ of 0° was defined as the chord line on top of the rudder parallel to the centerline of the tunnel, and the positive angle was defined when the trailing edge of the movable part was going away from the centerline of the tunnel in the port(left side when looking from downstream) direction.

The propeller model was also prepared on the same scale, which is the largest in the given size of the test section. The principal particulars of the propeller are shown in Fig. 3. The diameter (D) of the propeller was 294.7 mm, and it had 6 blades. The propeller model had a design advance coefficient (=inflow speed/(propeller rps × propeller diameter)) of 0.75 and a mean pitch ratio of 1.0320. The camber/chord ranged from 0 to 0.0338 and had a value of 0.013 at r/R=0.7(R is the radius of the propeller). The thickness/diameter ranged from 0.0077 to 0.1078



PROPELLER PRINCIPAL PARTICULARS	
DIAMETER (mm) : 294.7	SCALE RATIO : 28.50
(P/D) mean : 1.0320	PORP. TYPE : FPP
HUB RATIO : 0.195	SECTION : NACA66
NO. OF BLADES : 6	

Fig. 3. The geometry of propeller model.