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Use of Tunnel- and Azimuthing Thrusters for Roll Damping of Ships

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Abstract: This paper presents a novel technique of active roll damping in marine vessels by sole use of conventional thrusters. Many marine operations, such as crane operation and helicopter landing, should be carried out in small and steady roll motions. However, active roll damping devices such as fins and rudders lose their efficiency in low-speed conditions. This paper, by use of already installed thrusters, provides a new methodology for roll reduction by adjusting the shaft speed and pitch of the propellers. The numerical simulations, presented in the paper, shows promising results with significant roll damping.

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1 Introduction

In numerous marine operations, roll-damping at zero speed is of extreme importance. Typical active roll reduction systems such as Rudder-Roll Damping (RRD) and Anti-Roll Fins, are not effective at zero speed. Anti-roll tanks work well at low and zero speed. However, not all the vessels are equipped with such devices and in certain vessels and operations, they cannot provide sufficient roll reduction. The use of thrusters for active roll reduction has already been proven feasible for cycloidal propellers Jürgens and Palm (2009). However, to the best of our knowledge, there is no report on the use of conventional propulsion systems, such as tunnel thrusters and azimuthing thrusters, for the purpose of roll reduction in marine vessels.

Reduction of roll motion is essential during many operations. Roll reduction can also be necessary to secure life at sea by reducing the hazard of capsizing, as well as lowering the risk of damaging cargo. Additionally, certain operations are constrained to have sufficient small roll amplitudes, e.g. helicopter landings and crane operations. In Norway the criteria for landing helicopters on small vessels requests for 2° or 3° in roll and pitch depending on the helicopter type, Helideck Certification Agency (2016). Furthermore, a workability analysis by van den Boom (2010) shows that the downtime for helicopter operations in the wintertime with good visibility varied between 70% and 90%. This implies that roll damping techniques could lead to a significant economic benefit for operators since helicopters could be utilized year round, and the vessel will not have to transit to shore mid-operation.

According to Weinblum and St.Denis (1950), Perez (2005), roll damping modifications of ships come in three different varieties of technology that uses three different ways of achieving roll damping: a) increase the damping, b) increase the inertia and c) reducing the exciting moment.

The primary focus and contribution of this paper is on the reduction of the net exciting moment and increase the damping using the propulsion system. The work presented in this paper is in an elementary stage and far from being complete; however the simulation results show promising effectiveness in roll reduction. The concept of reducing the exciting roll moment with a propulsion system was first proven to be efficient by Jürgens and Palm (2009). The major challenge in the reduction of the roll motion using the conventional thrusters compared to cycloidal propulsion units, is due to their limited ability to change the direction of thrust. Voith Schneider's cycloidal propellers can change their direction of thrust nearly instantly, while the thruster dynamics of more conventional propellers is a function of the change of the shaft speed, pitching of the propeller blades, and the rate of change of azimuth angle.

The main drawback of actively changing the shaft speed and, propeller pitch and azimuth angle for roll reduction are the considerable wear and tear on the propulsion system. However, *"Roll Reduction Mode"* might be executed only during particular critical operations that are constrained to low roll motions. Thus the operation time of this control system can be of a minimal nature.

The structure of the paper is as follows. Thruster dynamics are covered in Section 2. Section 3, briefly summarizes the controller structure and the parameter tuning adopted in

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the paper. Numerical simulations are reported in Section 4. Conclusions and future works are summarized in Section 5.

In order to make the case realistic, an existing vessel has been used. The main particulars for the case vessel are listed in Table 1.

Table 1. Main particulars for case vessel

Ship			
Length overall	L_{OA}	[m]	99
Breadth moulded	B	[m]	21
Design draught	D	[m]	6
Natural roll period	T_{N4}	[s]	12

2 Thruster Modeling

The case vessel is equipped with two thruster pairs; two Azipull thrusters in the stern and two bow thrusters in the bow. The main parameters for the thrusters are summarized in Table 2.

Table 2. Main parameters for the propulsion system.

			Azipull	Bow
Power	P_D	[kW]	2200	970
Propeller diameter	D	[m]	3	2.2
Propeller speed	n	[RPM]	201	242
Pitching time	P_T	[s]	15	15

2.1 4-Quadrant Model

Even though the current paper's main attention is on the roll reduction at zero-speed, is it not sufficient to model the thrust by bollard pull condition due to the fact that the ship is rolling, and thereby the inflow velocity to the thrusters is varying. Furthermore, roll reduction using the thrusters is not a conventional operation where the propellers are working in only one direction, e.g. positive advance ratio. Because of the zero-speed case with roll motion, the motions will introduce oscillating advance speeds to the thrusters as they are pointing in the direction of the roll motion. Thus leading to both positive and negative advance ratios. Standard open water diagram can no longer address the problem sufficiently; for further discussions on this, see Smogeli (2006), Miniovich (1960), and van Lammeren et al. (1969). In this report, the Wageningen B-Series propellers are used to describe the 4-quadrants. The quadrants are separated by the angle of attack β, which is described by the ambient water velocity (V_a), the tangential water velocity (V_t), the propeller rotation rate (n) and the propeller diameter (D) (see Table 2) as

$$\beta = \arctan(\frac{V_a}{V_t}) = \arctan(\frac{V_a}{0.7\pi n D}), \tag{1}$$

The quadrants as defined by Carlton (1994) are described in Table 3.

Table 3. The 4-quadrants

1st quadrant	$0° \leq \beta \leq 90°$	$V_a > 0$	$n > 0$
2nd quadrant	$90° < \beta \leq 180°$	$V_a > 0$	$n < 0$
3rd quadrant	$180° < \beta \leq 270°$	$V_a < 0$	$n < 0$
4th quadrant	$270° < \beta \leq 360°$	$V_a < 0$	$n > 0$

During the proposed roll reduction operation in zero-speed, only the 1st and 4th quadrant are of concern since the shaft speed direction is positive. Thus, the relevant β values are in the interval $-90° \leq \beta \leq 90°$. The non-dimensional thrust coefficient for the 4-quadrant model is defined as

$$C_T = \frac{T_a}{\frac{\pi}{8}\rho(V_a^2 + (0.7\pi n D)^2)D^2}. \tag{2}$$

2.2 Model Representation

The open water characteristics are determined experimentally, and in order to use these results in simulations, a further modification must be introduced to avoid the non-continuous behavior of the experimental values.

The thrust- and torque coefficients for some propellers were described by van Lammeren et al. (1969) using a 20th order Fourier series using two coefficients for the thrust (A_T and B_T) and two for the torque (A_Q and B_Q). The thrust and torque representations can then be calculated using:

$$C_T(\beta) = \sum_{k=0}^{20}(A_T(k)\cos(\beta k) + B_T(k)\sin(\beta k)), \tag{3a}$$

$$C_Q(\beta) = \sum_{k=0}^{20}(A_Q(k)\cos(\beta k) + B_Q(k)\sin(\beta k)). \tag{3b}$$

Fig. 1 can depict this, where the 1st and 4th quadrants are plotted using equations (3). The coefficients used are found from the Wageningen B4-70 which is tabulated in van Lammeren et al. (1969, Table 7) and is discussed thoroughly in Smogeli (2006).

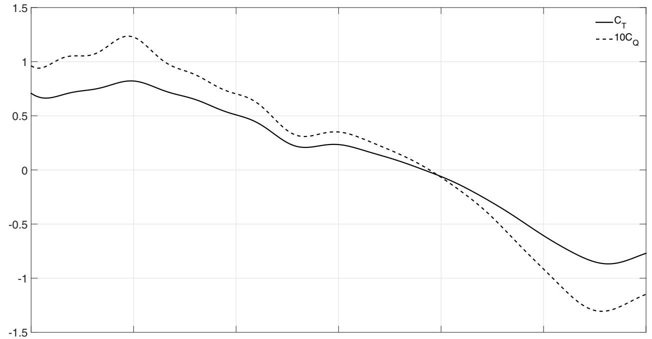

Fig. 1. C_T and C_Q 1st and 4th quadrant from the 20th Fourier series, van Lammeren et al. (1969).

For our case vessel, the open water characteristics of the propeller were not available and instead, the Wageningen B-series propellers were modified to match the bollard pull results. The 4-quadrant thrust coefficient for zero speed,

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