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Prediction of manoeuvring abilities of 10000 DWT pod-driven coastal tanker

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ABSTRACT

This paper aims to present a new approach in the prediction of manoeuvring abilities of pod-driven ships. A new mathematical model of motions based on MMG methodology was developed and a new type of description of forces acting on azimuth drives is presented. Captive model tests of medium-size coastal tanker and pod open water tests were carried out in CTO S.A. (Ship Design and Research Centre S.A.) to obtain hull hydrodynamic derivatives and pod propulsor hydrodynamic coefficients. Fast-time simulations were carried out and results were compared with free running model tests. Validation shows acceptable agreement between numerical and experimental results, i.e. confirms the usability of developed mathematical model to identify the trends in performance also for course unstable ship.

1. Introduction

One of the main advantages comparing pod-driven ships with conventional propeller-rudder ships is very good manoeuvrability of ships equipped with pods (Toxopeus and Loeff, 2002). Significantly better turning abilities and freedom during port manoeuvres are observed. Nevertheless some problems regarding course keeping during sea voyages are observed (van Terwisga et al., 2001). The reason for that is different from conventional ships, shape of hull stern part, i.e. often pram stern with not much lateral resistance and thus small stabilising surface.

Between 1999 and 2007 four large-scale European Commission funded research projects (OPTIPOD; Pods-in-Service; FASTPOD; AZIPILOT) studied deeply the design of pod-driven ships, with special attention on resistance, propulsion, seakeeping and manoeuvrability. Some of initial findings from these research projects and from industry experience have been presented at two international conferences dedicated to the podded propulsors topic (T-POD, 2004, 2006). Also the International Towing Tank Conference formed, in response to a specific need, a Specialist Committee on Azimuthing Podded Propulsion. ITTC (2005) presents, inter alia, analysis of the applicability of the IMO criteria to pod-driven ships with a conclusion that they provide adequate benchmark for all ships regardless of propulsion type. ITTC (2008a) focuses on procedures for podded propulsors tests and extrapolation, hydrodynamics of pod propulsion for special applications and cavitation behaviour of podded propulsors.

Although there is enormous knowledge about podded propulsion gathered during last two decades and some efforts have been done to systematize the knowledge (Woodward and Atlar, 2005), the designers seem to miss wide-known efficient methodology for design of ships with pod propulsors to ensure both good propulsive performance and sufficient manoeuvring abilities. Usually case-to-case approach is taken to improve course keeping abilities of particular newly designed or already sailing ship in a situation when a problem with track keeping occurs.

As ships equipped with pod propulsors are still relatively new idea, there is a continuous development in this topic, including new hull shapes and new pod propulsor solutions. This progress needs constant research both on hydrodynamic and mechanical problems. Very useful in this action are the sea trial data, which give a valuable input to validation of prediction and simulation methods. Kurimo (1998) presented the results of sea trials with the cruise ship “Elation” which were carried out in the Gulf of Finland in December 1997. Although data for speed measurements, cavitation observations, pressure pulse measurements and manoeuvring tests are shown, the paper deal mostly with general issues and concentrate on the powering optimisation of the ship. Kurimo and Byström (2003) presented the results of sea trials of M/S Costa Atlantica, which was the first ship designed from the start to have azimuthing pods as the main propulsors. Results of these tests confirmed the ship to have excellent manoeuvring characteristics. The ship fulfilled the criteria in the Interim Standards for Ship Manoeuvrability of the IMO by a substantial margin. Trägårdh et al.

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(2004) presented sea trial results carried out with first Double Acting Tanker equipped with single ABB's Azipod propulsor. The tests with the Azipod equipped with a fin on the bottom showed fulfilment of IMO standards. Without this fin however the ship showed rather poor course stability. Nevertheless, taking into account that the global database of manoeuvring abilities of pod-driven ships is still an open box, every attempt to this question is appreciated.

Another issue in design of pod-driven ships is, that there are not many well-validated methods for prediction of manoeuvring abilities of such ships in early design stage. Although efforts have been put to elaborate reliable methods for prediction of IMO manoeuvres (OPTIPOD, FASTPOD, Woodward, 2005; Kano et al., 2006; Yang et al., 2009) and application of IMO criteria to pod-driven ships (Woodward et al., 2009), the number of attempts to this questions seems to be not sufficient to constitute wide-known fundamentals and still need exertions.

During the predictions two most popular methods are the Abkowitz method and the modular method presented for conventional ships with propeller-rudder systems by Japanese Mathematical Modelling Group, so called MMG method. Taking into account hull shapes of pod-driven ships other than the classic hull shapes and the possibility to generate thrust in any direction, ships propelled with azimuth thrusters do not fit directly into the MMG methodology. However, the development of appropriate hull-pod propulsors interaction coefficients used in MMG method allows to consider this method as rational also for pod-driven ships.

Another questions during manoeuvring predictions are regarding proper description of forces acting on azimuth propulsors. Both experimental (Szantyr, 2001; Stettler et al., 2004; Islam et al., 2006, 2007; Reichel, 2007) and numerical methods with the use of RANSE solver (Xingrong et al., 2009; Funeno, 2009) or panel methods (Lijun and Yanying, 2006; Ma et al., 2006) have been used. Nevertheless all the methods have pros and cons and cannot be used without further development.

In this paper the MMG approach for manoeuvring abilities prediction has been developed to cover ships with pod propulsors. Captive model tests with the use of Planar Motion Mechanism (PMM) have been carried out to complement equations of motion with hull hydrodynamic derivatives and hull-pod propulsors interaction coefficients.

Open water model tests of pod propulsors in a wide range of advance coefficients and deflection angles have been carried out. On this basis a method for describing hydrodynamic forces on pod propulsors has been developed and a multi-variables regression has been used to approximate the model test data.

Using the hydrodynamic coefficients obtained from model tests and approximation, simulations of standard IMO manoeuvres have been done. Finally the simulation results have been compared with free running model tests and conclusions on the prediction method have been presented.

Investigations presented in this paper were a part of a large research programme on manoeuvring abilities of pod-driven ships, which was carried out at Ship Design and Research Centre in Gdańsk, Poland. Results of wider analysis of manoeuvring abilities of ships with different stern shapes and pod propulsion versions will follow.

2. Mathematical model

The motion of a manoeuvring ship, taking into account wave and wind disturbances, should generally be analysed in six degrees of freedom. However, for the purposes of fast simulation of manoeuvring abilities a widely accepted practice is to consider motions only in the horizontal plane. Therefore, the mathematical model can be described by Eqs. (1)–(3), corresponding to surge, sway and yaw motions, respectively, when using the coordinate system in Fig. 1.

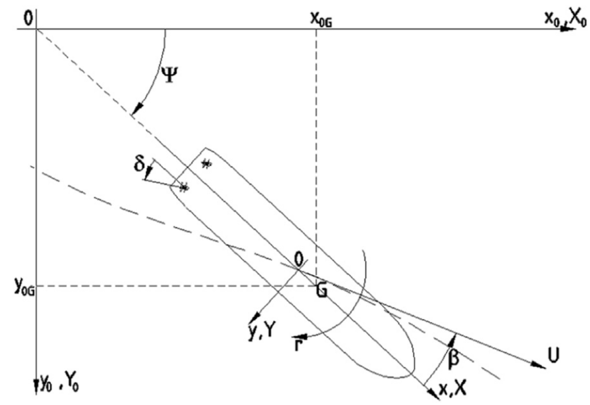

Fig. 1. Coordinate system.

$$m(\dot{u} - vr - x_G r^2) = X \quad (1)$$

$$m(\dot{v} + vr - x_G \dot{r}) = Y \quad (2)$$

$$I_z \dot{r} + m x_G(\dot{v} + ur) = N \quad (3)$$

where

m is the mass of the ship,
I_{zz} is the moment of inertia with respect to the z-axis,
u, v, and r are the surge, sway, and yaw velocities,
$\dot{u}$, $\dot{v}$, and $\dot{r}$ are the surge, sway, and yaw accelerations.
X and Y represent the forces acting in the longitudinal and lateral directions
N is the moment with respect to the z-axis.

One of the ways of describing forces acting on hull and steering-propulsion system was presented by MMG methodology (Ogawa and Kasai, 1978; Kose, 1981; Inoue et al., 1981). Taking into account differences between conventional and pod-driven ships, this methodology has been developed and a special attention has been put on hull-propulsors interactions.

The forces and moment according to the MMG method, including replacement of the propeller and rudder terms, can be described by separating them into the components responsible for hull and propulsors forces, as in Eqs. (4)–(6).

$$X = X_H + X_{POD} \quad (4)$$

$$Y = Y_H + Y_{POD} \quad (5)$$

$$N = N_H + N_{POD} \quad (6)$$

where the subscripts H and POD refer to hull and pod propulsors respectively.

2.1. Forces and moment acting on the hull

The forces and moments acting on the hull were approximated in similar way as for hull in conventional propeller-rudder propulsion-steering system. Following polynomials were used for the forces description (7)–(9).

$$X_H = X_{\dot{u}}\dot{u} + X_{vv}v^2 + X_{vvvv}v^4 + (X_{vr} - Y_{\dot{v}})vr + X_{rr}r^2 + X_{uu}u^2 \quad (7)$$

$$Y_H = Y_{\dot{v}}\dot{v} + Y_{\dot{r}}\dot{r} + (Y_r + X_{\dot{u}}u)r + Y_v v + Y_{vvv}v^3 + Y_{vvr}v^2 r + Y_{vrr}vr^2 + Y_{rrr}r^3 \quad (8)$$

$$N_H = N_{\dot{v}}\dot{v} + N_{\dot{r}}\dot{r} + N_v v + N_r r + N_{vvv}v^3 + N_{vvr}v^2 r + N_{vrr}vr^2 + N_{rrr}r^3 \quad (9)$$

2.2. Forces and moment acting on pod propulsors and hull-propulsors interactions

Azimuth propulsors have quite complicated hydrodynamic char-