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Dynamic Modelling, Investigation of Manoeuvring Capability and Navigation Control of a Cargo Ship by using Matlab Simulation

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Abstract: In this paper a simplified dynamic analysis of a cargo ship using simulation and modelling are presented. Provided with mathematical equations dynamics of ship motion characteristics with several maneuvering capabilities are demonstrated with MATLAB & SIMULINK as simulation tool. The equations extended with acting thrust, resistance, steering and ruder forces are demonstrated for several maneuvers like on straight track coasting from full ahead to stop, turning actions A numerical application of fast time simulations on a freighter ship is given with graphical representations. Furthermore a simplified model for rolling motion of ship is introduced and some examples are simulated to explain the general effects of stability and wave parameters. The relation of these results to the more practical use for decision making to avoid resonance effects of ship in waves by loading operations or speed/course changes is demonstrated by means of simulation tool.

Keywords: Navigation, Cascade Control, Ship, Modeling, Steering, Route

1.INTRODUCTION

Ship motion dynamic and ship manoeuvring is an important topic in ship Handling and Automatic navigation Control. Dynamic motion and analysis of a ship is associated with the knowledge of the couplings between surge, roll, yaw, and sway and this is an important task to improve the manoeuvring ability and modelling.

Generally for description of ship motion four degrees of freedom models are well known, as given by Abkowitz and Chislett and Stom-Tejsen, but models describing the interaction between surge, roll sway and yaw have only been scarcely studied.

Son and Nomoto presented a model obtained by combining planar motion mechanism (PMM) test data for lateral motion, using different values of static heel for the model under test, with independent roll motion tests. Källström and Otterson [10] obtained a model by combining a lateral PMM model with theoretical estimates of roll coefficients, using free sailing model tests to calibrate the roll parameters. Perez - Blanke presented models based on experimental results in the unique 4-DOF roll planar motion mechanism (RPMM) facility at the Danish Maritime Institute that allow model testing with full dynamic interaction between motions in roll, sway, yaw and surge.

Although different model publications are presented in the literature it is still difficult to find a fully-parameterized models. The main contribution of this paper is to provide a simplified approach for the equations of ships motion and manoeuvring.

Fully-parameterized non-linear and linear models can be utilized as a basis for analysis and design of ship motion control strategies. The results of a Matlab – Simulink model for cascaded navigation simulation are shown for different actions

In addition, to demonstrate the results of the obtained linearized model, a built up real like ship navigation model with cascade control is implemented successfully.

2.MOTION MODEL WITH ACTING FORCES AND MOMENTS

The equations describing ship dynamics are well known. They are obtained from Newton's laws expressing conservation of linear and angular momentum.The main difficulty when deriving the equations is to describe the hydrodynamic forces acting on the hull. The forces are in general complicated functions of the ship's motion, i.e. the time history of the velocity, angular velocity and the rudder motion. They also depend on trim and draught. In shallow water and close to shore the forces will also depend on the topography.

If a ship is considered as a rigid body it has 6 degrees of freedom corresponding to translations in 3 directions and rotation around 3 axes. The equations of motion are conveniently expressed using a co-ordinate system fixed to the ship. The hydrodynamic forces are easy to describe in such a co-ordinate system because the symmetry of the hull can be exploited. Neglecting sensor and actuator dynamics, the ship can thus be modelled as a 12-order system. Additional dynamics are also introduced by the rudder servo. In many cases it has, however, been shown that the model can be simplified. It is customary at least for tankers and similar ships to neglect the coupling between the yaw motion and the

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pitch and roll motions.Since the yaw motion is often sufficient to discuss steering and autopilot design, the following treatment will be limited to this motion only.

Motion model of a ship or vessel with acting forces and moments is shown in Figure 1.

A seagoing vessel is subjected to forces from wind, waves and current as well as from forces generated by the propulsion system.

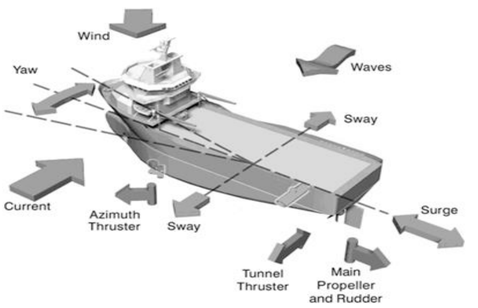

Fig. 1: Motion model of a see going ship with acting forces and moments

The vessel's response to these forces, i.e. its changes in position, heading and speed, is measured by the position-reference systems, the gyrocompass and the vertical reference sensors. Reference systems readings are corrected for roll and pitch using readings from the vertical reference sensors. Wind speed and direction are measured by the wind sensors.

The dynamic positioning control system calculates the forces that the thrusters must produce in order to control the vessel's motion in three degrees of freedom - surge, sway and yaw - in the horizontal plane.The system is designed to keep the vessel within specified position and heading limits, and to minimise fuel consumption on the propulsion equipment.

Dynamic motion and analysis of a ship is associated with the knowledge of the couplings between roll, yaw, and sway and this is an important task to improve the manoeuvring ability and modelling.

3.EQUATIONS OF MOTION

The basic dynamics of manoeuvring and course-keeping can be described and analysed using Newton's equations of motion. Basic equations in the horizontal plane can be considered first with reference to onset of axes fixed relative to the earth and a second set fixed relative to the ship.

Figure 2 shows typical fixed and moving axed for a surface ship. The path is usually defined as the trajectory of the ship's centre of gravity. Heading refers to the direction (ψ angle of yaw) of the ship's longitudinal axis with respect to one of the fixed axes. The difference between the heading and the actual course (or direction of the velocity vector at the centre of gravity) is the drift or leeway angle β.When the ship is moving along a curved path, the drift angle is thus the difference in direction between the heading and the tangent to the path of the centre of gravity.

There are significant factors that couple the speed of a ship and its path. For example, path changing (turning) and even path keeping (course-keeping) cause involuntary speed reductions. These effects arise from the fact that any misalignment between the x-axis of the ship as shows in Figure 3 and its velocity vector, V, increases the drag force acting on the ship.

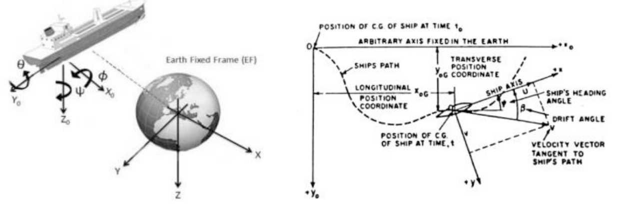

Fig. 2: Orientation of fixed and moving axes

The motion of a ship in six degrees of freedom is considered as a translation motion (position) in three directions: surge, sway, and heave; and as a rotation motion (orientation) about three axes: roll, pitch and yaw. To determine the equations of motion, two reference frames are considered: the inertial or fixed to earth frame O that may be taken to coincide with the ship-fixed coordinates in some initial condition and the body-fixed frame O0— see Figure 1. For surface ships, the most commonly adopted position for the body-fixed frame is such it gives hull symmetry about the x0z0-plane and approximate symmetry about the y0z0-plane, while the origin of the z0 axis is defined by the calm water surface The magnitudes describing the position and orientation of the ship are usually expressed in the inertial frame and the coordinates are noted: [x y z]t and [φ θ ψ]t respectively, whilst the forces [X Y Z]t, moments [K M N]t, linear velocities [u v w]t, and angular velocities [p q r]t are usually expressed in the body-fixed

$$J(\phi,\theta,\psi) = \begin{bmatrix} c(\psi)c(\theta) & -s(\psi)c(\phi)+c(\psi)s(\theta)s(\phi) & s(\psi)s(\phi)+c(\psi)c(\phi)s(\theta) \\ s(\psi)c(\emptyset) & c(\psi)c(\phi)+s(\phi)s(\theta)s(\phi) & -c(\psi)s(\phi)+s(\psi)c(\phi)s(\theta) \\ -s(\theta) & c(\theta)s(\phi) & c(\theta)c(\phi) \end{bmatrix}$$

$$\mathrm{M}_{\mathrm{RB}}\dot{\mathrm{v}} = \tau(\dot{\mathrm{v}},\mathrm{v},\eta) - \mathrm{C}_{\mathrm{RB}}(\mathrm{v})\mathrm{v} \qquad (5)$$

Where MRB is the matrix mass and inertia due to rigid body dynamics, the term CRB(ν)ν arise from the coriolis and centripetal forces and moments also due to rigid body dynamics, and J(η) is given in (3). The forces and moments vector τ is defined as

$$\tau = [\mathrm{X} \quad \mathrm{Y} \quad \mathrm{Z} \quad \mathrm{K} \quad \mathrm{M} \quad \mathrm{N}]^{\mathrm{T}} \qquad (6)$$

And these magnitudes are generated by different phenomena and can be separated into components according to their originating effects:

τ = τhyd + τcs + τprop + τext where

- hyd: These forces and moments arise from the movement of the hull in the water.