Comparison of Time Domain Simulation and Steady State Capability Analysis of Dynamic Positioning

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ABSTRACT

Many newly built ships and floating platforms are fitted with dynamic position (DP) systems. DP systems maintain floating structures in fixed position or pre-determined track by means of active thrusters. In the designing and analysis progress of DP systems ship motion responses and DP capability are calculated to estimate the DP performance. Both steady state DP capability analysis and time domain dynamic DP simulation are conducted. In this paper the difference between them is studied on a pipelay crane vessel.

KEY WORDS: dynamic positioning; capability analysis; dynamic simulation; thrust allocation; control system.

INTRODUCTION

Steady state DP capability analysis provides thruster utilization rate under certain environment condition or the maximum environment loads that the vessel can withstand and time domain dynamic DP simulation are conducted to obtain displacement and force data. A basic rule is that thrusters should not use more than 80% of the maximum thrust in design working condition. The thrust margin of 20% is kept for dynamic variations. However this margin is often conservative. To get full knowledge of the working thrusters, time domain dynamic simulations is necessary, where the thrust allocation, forbidden azimuth angles and the whole control loop is taken into consideration. In the traditional simulations the effect of power limit is often neglected, which may be the most limiting factor in failure conditions. The scope of this paper is to study the difference between static analysis and dynamic simulation with a pipelay crane vessel chosen as the platform of the system.

Generally there are more control signals than commanded forces and moments, so the system is over-actuated. Most existing marine vessel control allocation solutions rely on a linear model that describes the relationship between the control signals and the generalized forces. A thrust-allocation scheme is presented by Sørdalen(1997) which significantly reduces the fuel consumption for DP vessels using azimuth thrusters. An energy optimal solution combining a static and a dynamic non-recursive algorithm is proposed by Berge and Fossen with azimuth angles. In the work of Tjønnas and Johansen(2007) a dynamic approach is considered by constructing actuator reference update-laws that represent an asymptotically optimal allocation search. By using Lyapunov analysis, uniform global/local asymptotic stability is guaranteed.

In this paper the low frequency (LF) mathematical models are formulated with only surge, sway and yaw (3DOF) considered based on the work of Fossen(2002) and Sørensen(2011). The wind and current loads are calculated referring API rules. The mean second-order wave loads are determined by means of quadratic transfer functions and slowly varying wave loads are calculated with the approximation by Newman. What’s more, the wave frequency (WF) model is acquired by a second-order linear model driven by white noise describing the first-order WF-induced motion as a mass-damper-spring system. For the DP control system PID control with Kalman filter is utilized.

VESSEL MODEL

It is common to separate the vessel model into a LF model and WF model. The nonlinear LF equations of motion contain 2nd-order mean and slowly-varying wave, wind, current and thruster forces. The WF motion of the vessel is due to 1st-order wave-induce loads. To accomplish the controller design and analysis, it is detailed enough to simplify and derive a nonlinear LF model in DOF of surge, sway and yaw at low speed. The equations are as blow:

\[
M \dot{\mathbf{v}} + D \mathbf{v} = \tau + \omega \\
\dot{\mathbf{\eta}} = J(\psi) \mathbf{v}
\]

where \( \mathbf{v} = [u, v, r]^T \), \( \mathbf{\eta} = [x, y, \psi]^T \) are the position vectors in parallel coordinate and Earth-fixed coordinate. The rotation matrix

\[
J(\psi) = \begin{bmatrix}
\cos \psi & -\sin \psi & 0 \\
\sin \psi & \cos \psi & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

For the low-speed condition,