Modelling and control of thruster assisted position mooring system

Analysis and model testing

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Abstract

Lately there have been reported a number of cases where excessive roll and pitch motions have caused operational difficulties for semi-sumbersibles. Using control methods to improve the dynamics of the semi-submersible is one way of creating a safer environment. Several control methods are studied. Among them, a method where the cross-coupled dynamics of the vessel are exploited by implementing a roll and pitch damping control law. Results are obtained by simulations and model tests.

Introduction

In recent years, thruster assisted position mooring systems have become more commercially available, especially in the oil industries, according to [2]. Both turret moored systems and spread moored systems are widely used. For semi-submersibles, it is common to use spread moored system.

Lately there have been reported a number of cases where excessive roll or pitch motions have caused operational difficulties for semi-sumbersibles. Because of the semi-submersible's shape, with small-waterplane-area columns and relatively small pontoons, the inertia, damping, and restoring forces in roll and pitch are small in comparison with other kinds of constructions with equal mass.

The excessive roll and pitch motions are found to be results of both linear and nonlinear effects, that is, wave-frequency and low-frequency effects. Counteracting the wave-frequency roll and pitch motions is quite a waste of energy. It is the low-frequency motions that must be damped, which means that good low-pass filtered roll and pitch angular velocities must be obtained. This places great demands on the performance of the observer.

Main Objectives

The main objective of this Master Thesis is to study the interaction between a thruster assisted position mooring system (TAMS) and its passive mooring system. The main goal is increased stationkeeping in surge and sway for harsh weather. Some of the other objectives that can be achieved through a successfull merge between mooring and thruster assistance, are:

- Reduced fuel consumption compared to regular dynamic positioning systems (no mooring)
- Increased positioning accuracy compared to passive mooring only
- Decreasing the possibility of mooring line breakage
- Ensuring mooring line integrity
- Larger operational window in harsh seas
- Increased dynamic stability

An algorithm that manages to combine the dynamics of both the mooring system and the thruster system in a good manner, is the key to a stable and robust thruster assisted postion mooring system.

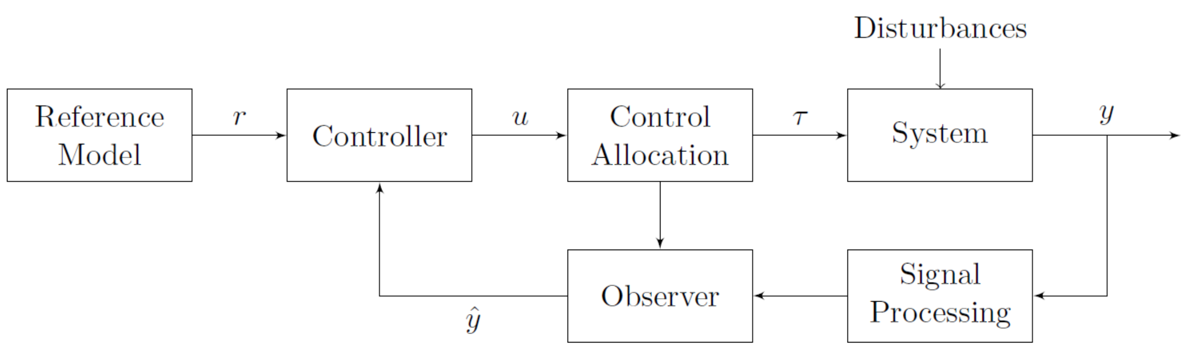

Figure 1: Outline of the control system.

Materials and Methods

A Matlab Simulink model including the dynamics of the semi-submersible, the mooring system and the control system is developed and used in the analysis of position mooring (PM) algorithms. An outline of the simulation system can be seen in Figure 1, the disturbances and thruster forces are depicted in Figure 3. Model tests were carried out using the 1:100 scale model semi-submersible Cyberrig I, designed and built by Tyssø and Aga in 2006, [4], as seen in Figure 2.

Figure 2: The model Cyberrig I.

Mathematical Section

The nonlinear 6 DOF low-frequency process plant model can according to [1] be stated

$$\dot{\boldsymbol{\eta}} = \mathbf{J}^T(\boldsymbol{\Theta})\boldsymbol{\nu}, \tag{1a}$$

$$\mathbf{M}_{\mathrm{RB}}\dot{\boldsymbol{\nu}} + \mathbf{M}_{\mathrm{A}}\dot{\boldsymbol{\nu}}_r + \mathbf{C}_{\mathrm{RB}}(\boldsymbol{\nu})\boldsymbol{\nu} + \mathbf{C}_{\mathrm{A}}(\boldsymbol{\nu}_r)\boldsymbol{\nu}_r + \mathbf{D}_{\mathrm{L}}\boldsymbol{\nu}_r + \mathbf{D}_{\mathrm{NL}}(\boldsymbol{\nu}_r)\boldsymbol{\nu}_r + \mathbf{G}\boldsymbol{\eta} = \boldsymbol{\tau}_{\mathrm{wind}} + \boldsymbol{\tau}_{\mathrm{wave2}} + \boldsymbol{\tau}_{\mathrm{thr}} + \boldsymbol{\tau}_{\mathrm{moor}}. \tag{1b}$$

The problems considered in this Master's Thesis do only review aspects of stationkeeping, and $\boldsymbol{\nu}_r = \boldsymbol{\nu}$ can be assumed. Since the semi-submersible is assumed port/starboard and fore/aft symmetric, the system inertia matrix will have the following form:

$$\mathbf{M} = \mathbf{M}_{\mathrm{RB}} + \mathbf{M}_{\mathrm{A}} = \begin{bmatrix} m_{11} & 0 & 0 & 0 & m_{15} & 0 \\ 0 & m_{22} & 0 & m_{24} & 0 & 0 \\ 0 & 0 & m_{33} & 0 & 0 & 0 \\ 0 & m_{42} & 0 & m_{44} & 0 & 0 \\ m_{51} & 0 & 0 & 0 & m_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & m_{66} \end{bmatrix} \tag{2}$$

The form of the inertia matrix leads to the idea of *roll and pitch damping* (RPD) presented in [3]. The theory is based on damping the wave-induced surge and sway deviations of the vessel by exploiting the cross-couplings between the surge-pitch and sway-roll degrees of freedom. The control law in the horizontal plane can therefore be stated:

$$\boldsymbol{\tau}_{\mathrm{thr}} = \boldsymbol{\tau}_{\mathrm{rpd,3DOF}} = -\mathbf{G}_{\mathrm{rpd}}\boldsymbol{\nu} = -\begin{bmatrix} 0 & g_{xq} \\ g_{yp} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{3}$$

The roll and pitch damping control law will in theory contribute to increased damping in the overall system, as can be seen by studying the 3 DOF control plant model in Equation (4).

$$\mathbf{M}\dot{\boldsymbol{\nu}} + (\mathbf{D} + \mathbf{G}_{\mathrm{rpd}})\boldsymbol{\nu} + \mathbf{G}\boldsymbol{\eta} = \boldsymbol{\tau}_{\mathrm{env}} \tag{4}$$

In reality, however, the highly submerged thruster system will infact also produce moments in roll and pitch.

Results

The introduction of a roll and pitch damping control law is expected to increase the stationkeeping performance and at the same time damp the roll and pitch motions. The task of getting satisfactory low-frequency roll and pitch angular velocity estimates in model scale, has revealed itself as cumbersome. This is a result of the low scale ratio of the semi-submersible model.

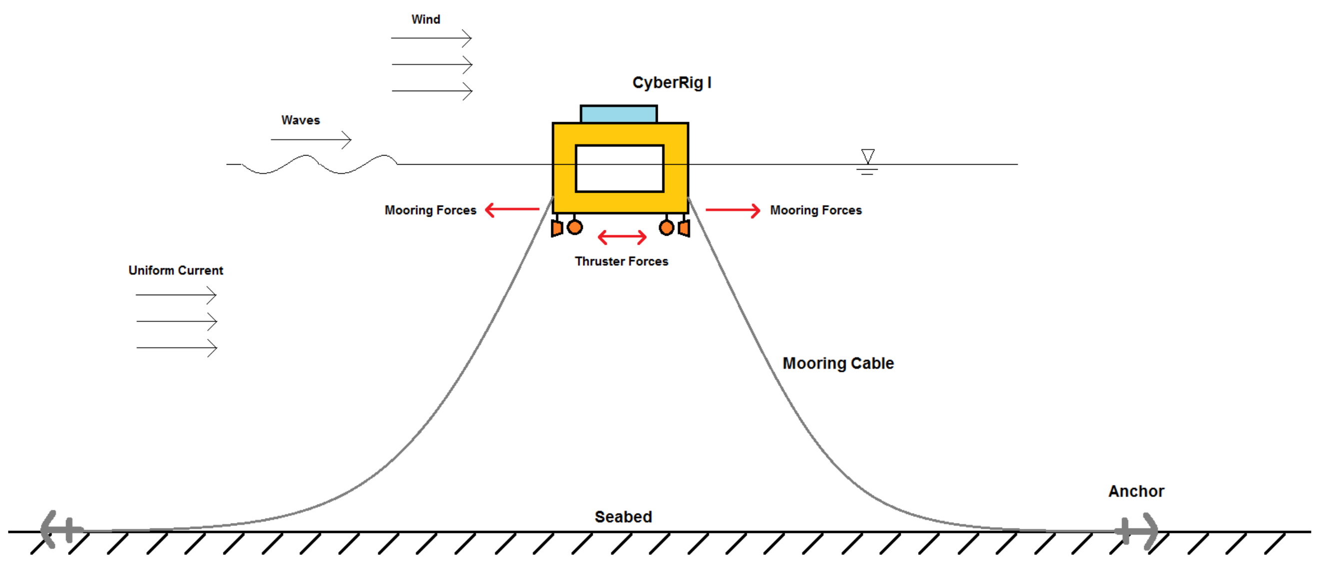

Figure 3: Spread moored rig under impact from disturbances and loads from the thruster system.

Conclusions

Several methods are available for improvement of thruster assisted position mooring systems, but only a few of them are widely used commercially. Model test results using a semi-submersible will comply to the research of [3], where simulation results using roll and pitch damping controller for a semi-submersible were submitted. The results in [3] show increased performance of the total system.

Forthcoming Research

Although spread moored semi-submersibles have proven to be quite stable systems, an advancement towards control systems based on a structural reliability criterion could increase the overall operational safety in harsh environments.

References

[1] FOSSEN, T. *Handbook of Marine Craft Hydrodynamics and Motion Control*. 2011.

[2] SØRENSEN, A. J. A survey of dynamic positioning control systems. *Annual Reviews in Control 35*, 1 (2011), 123 – 136.

[3] SØRENSEN, A. J., AND STRAND, J. P. Positioning of small-waterplane-area marine constructions with roll and pitch damping. *Control Engineering Practice 8*, 2 (2000), 205 – 213.

[4] TYSSØ, J., AND AGA, A. H. Dp control system design for cyberrig i. Master's thesis, NTNU, 2006.

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