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Investigation of the Effect of Managed Ice Field Parameters on Global Forces of a Dynamically Positioned Drillship

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An approach for evaluating the performance of dynamically positioned vessels in managed ice is proposed. The approach is based on implementing two Design of Experiments techniques to determine the influence of the pertinent ice field parameters on the vessel's time-averaged thruster forces. A set of ice basin experiments was used to illustrate the manner of determining the relationship between ice forces and ice field parameters and to examine the effects of the interactions between those parameters. The results determined relationships between ice forces and ice concentration, thickness, floe size, and velocity. Future research requires examining broader sets of experimental data to increase the confidence and accuracy of thruster force predictions.

INTRODUCTION

The present work emphasizes an approach for employing Design of Experiments (DOE)-based regression models to examine a vessel's interaction with managed ice. The models aim to determine the time-averaged thruster force on the vessel and the influence of the pertinent ice cover parameters. The present work concerns cases with ice encroachment angles in the range of ±5° and examines the time-averaged total thruster force on the drillship along the surge direction (hereafter referred to as global surge force). Ice basin tests (Islam et al., 2018) are used to develop relationships between the global surge force and the following ice cover parameters: ice concentration, thickness, floe size, and velocity. A brief survey of available literature concerning ice basin tests and empirical methods to investigate the parameter effects on the forces on a station-keeping vessel is provided below.

Early ice basin tests dealt with ice action on moored vessels. Subsequent research examined various aspects of station keeping in ice for dynamically positioned (DP) vessels as well. The DYPIC project was carried out at the Hamburg Ship Model Basin. That project addressed ice interaction with drillships and issues of concern to station keeping (see, e.g., Jochmann and Evers, 2014; Kerkeni et al., 2014). Another test program was conducted at the National Research Council of Canada (NRC) ice basin in St. John's, Newfoundland (Millan and Wang, 2011; Gash and Millan, 2012). That work addressed aspects of DP station keeping in managed ice conditions. Other ice tests were also carried out at Aker's ice model basin on both moored and DP systems (Jenssen et al., 2009).

Early studies of empirical modelling of ice forces include those of Wright (1999a, 1999b), who derived formulas from full-scale measurements of the global ice forces on the Kulluk platform. More recently, Croasdale et al. (2009) and Palmer and Croasdale (2013) developed similar empirical expressions using the Kulluk platform data. Spencer and Molyneux (2009), Woolgar and Colbourne (2010), and Wang et al. (2010) developed different empirical methods based on regression analyses of basin tests performed in pack ice conditions. Woolgar and Colbourne (2010) developed a stepwise regression process to reduce the pack ice forces to a simple analytical expression to evaluate the ice parameters' effect on the global surge force of the moored vessel. Allan et al. (2009) developed and presented several DOE technique-based and multiregression-based empirical models for estimating pack ice forces using basin test data on pack ice acting on a moored drillship. Also, Wang et al. (2010) compared various empirical and numerical methods to investigate the effects of drift speed, concentration, thickness, and drift angle. None of the work mentioned above discusses the interaction effects of various parameters.

ICE BASIN TESTS

In the present analysis, the tests were conducted in the ice basin of the NRC in St. John's, Newfoundland. A drillship model at a 1:40 scale was tested in managed ice conditions. At this scale, the model represents a full-scale vessel that is 206 m length overall, 45 m beam, and 12 m draft and is able to displace 100,000 MT. Test variables included ice thickness, ice strength, ice concentration, ice floe size, drift speed, and ice encroachment direction.

The model vessel was equipped with a dynamic positioning system with six active podded propulsor units, three at the bow and three at the stern, as shown in Fig. 1. The propeller centre of each unit was at least two times its diameter below the hull bottom, thus minimizing any propeller-hull interactions. The thrust on each unit was estimated by using the established correlation between thrust and propeller shaft speed with the assumption that the propeller-hull, propeller-propeller, and propeller-current interactions would be minimal as a result of low-speed DP operations. Regarding the DP control logic and thruster allocations, the control design choices included the following:

- Simple, decoupled proportional-integral-differential (PID) control loops were used on each vessel axis (surge, sway, and yaw).
- The global set-point error was rotated into the vessel's body reference frame, and those rotated errors were fed into an error-state Kalman filter, which removed sensor noise and provided velocity estimates.

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KEY WORDS: Design of Experiments (DOE), factorial design, response surface method, physical model testing, managed ice parameters, dynamic positioning in ice.