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DYPIC – A Multi-National R&D Project on DP Technology in Ice

by

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Introduction

The desire for exploration of oil and gas in arctic regions increases the demand of station keeping under ice drift conditions of arctic drill ships, icebreakers and offshore supply vessels. Physical model tests, such as oblique tests, are historically used to determine the necessary design parameters for ice going vessels. HSVA (Hamburg Ship model Basin) has long experience in ice model testing and initiated the DYPIC project [1] to improve its testing capabilities of DP vessel.

The objectives of the R&D project:

- Development and fabrication of a DP System for ice model testing
- Prediction of station keeping capabilities of vessels under ice loads by means of model tests
- Definition of model test procedures to determine necessary DP parameters
- Evaluation of the feasibility of DP in various ice conditions

During the project it became evident that a numeric dynamic ice load model should be developed in order to further develop and evaluate different DP control schemes and as a first tool for evaluating DP vessel concepts [2].

The project commenced early 2010 and will be completed within 2012. It is a part of the EU's ERA NET MARTEC program [3] with financial contribution from the national research agencies in Germany, France and Norway. The participating partners are HSVA (Hamburg Ship Model Basin) who manages the overall project, Statoil, DNV, NTNU (Norwegian University of Science and Technology), DCNS Research/Sirehna and Kongsberg Maritime.

Other research projects in this field with significant industry involvement which all addresses ice modelling and DP control are:

- "Arctic DP - Safe and Green Dynamic Positioning Operations of Offshore Vessels in an Arctic Environment" run at NTNU, the Norwegian University of Science and Technology (2010-2014) [4]
- "SAMCOT - Sustainable Arctic Marine and Coastal Technology" an eight year research program started 2011 also run at NTNU [5]
- "Dynamic Positioning in Ice Environment" a Canadian project at the Memorial University of Newfoundland commencing 2012 [6]

Challenges in ice conditions

Gürtner et al [7] have given an outline and discussions on challenges and learning both from early field operations with further lines to experiences gained in the DYPIC project. First of all the DP experiences are scarce. Some of the well known ones are the Sakhalin diving operation in spring 1999 [8], the Arctic Coring Expedition (ACEX) in the Polar Pack in August 2004 [9] and the coring operation North East Greenland 2008 [10]. Even though the numbers are very limited, they share important commonalities. [7] sums up the following factors:

Operation planning These were truly pioneering operations, far from routine jobs. Ice management specialists were a vital part of the planning. A drawback (just as relevant today) was the lack of numerical tool to quantify the DP capability of a vessel given a certain ice condition. To mitigate this, 'safe-learning-philosophy' was employed in which the real situation was tested but without exposing risk elements such as drilling. Due to this the experienced operability exceeded what could be expected given the ice condition in the planning phase.

Operational philosophy	The operations included systematic ice management such as a) detection, tracking and forecasting of sea ice, ridges and ice bergs; b) threat evaluation; c) physical ice breaking; and d) procedures for disconnection. [11]. Integration of ice management into the operational philosophy means a "design concept" in which vessel capability, DP capability and ice management are integrated components. Hence it is the total system performance which is of relevance. Here the ice management appears to be the major success factor as it was purpose designed for the respective operations, while vessel design and DP systems were not particularly optimized for the conditions.
General learning	The success of the projects was coupled to the well selected preferred time of year in which they were carried out and their temporary nature. The challenges with ice were limited with respect to severity. Therefore, it is difficult to generalize to other ice conditions and other seasons of the year.

It is apparently a need for developing the DP technology for arctic operations. The DYPIC project is one such initiative. This is also clearly stated by Jenssen et al [12]. Especially the DP control system's ability to track the quickly changing external loads imposed by the ice is a fundamental property which should be improved. Just increasing controller restoring and damping effects have minor impact.

Based on this learning Kongsberg has developed an enhancement to its DP control system with better tracking capability which has shown to improve the station keeping [13]. This has also been an important input for the design of the Model-DP.

The HSVA test facilities

As described in [14], feasibility studies of DP in ice require test set-up with a free running model vessel, Figure 1:

- The DP-system on the model must work in close-loop, requiring a real-time measurement of ship position in ice tank and real-time control of thrusters
- The scale effects impose faster ship dynamics than full scale and a hence reduced sampling time of control
- Adaptation of DP control algorithms to ice loads characteristics. This implies higher expectations of robustness towards external forces amplitude and variability compared to open-water.
- System must provide adaptation for several model types, meaning that DP control laws shall be as generic as possible

The HSVA ice tank is 72m long, 10m wide, and has a depth of 2.5m. A carriage run along the basin supplying power and commands to the model and feedback of its relative position with the help of an optical motion capture system (Qualisys). For the testing in August and September 2012, the model has run completely free inside the basin using WiFi interface for controlling the thrusters while batteries insured electrical supply. Concentration and composition of ice sheets are controlled during the fabrication process in order to recreate the desired characteristics of polar ice at model scale.

Ice movement is simulated by moving the carriage with the Qualisys system while keeping the ship model in a fixed position relative to the carriage frame. Similarly ice drift angle is simulated by changing the heading of the model.

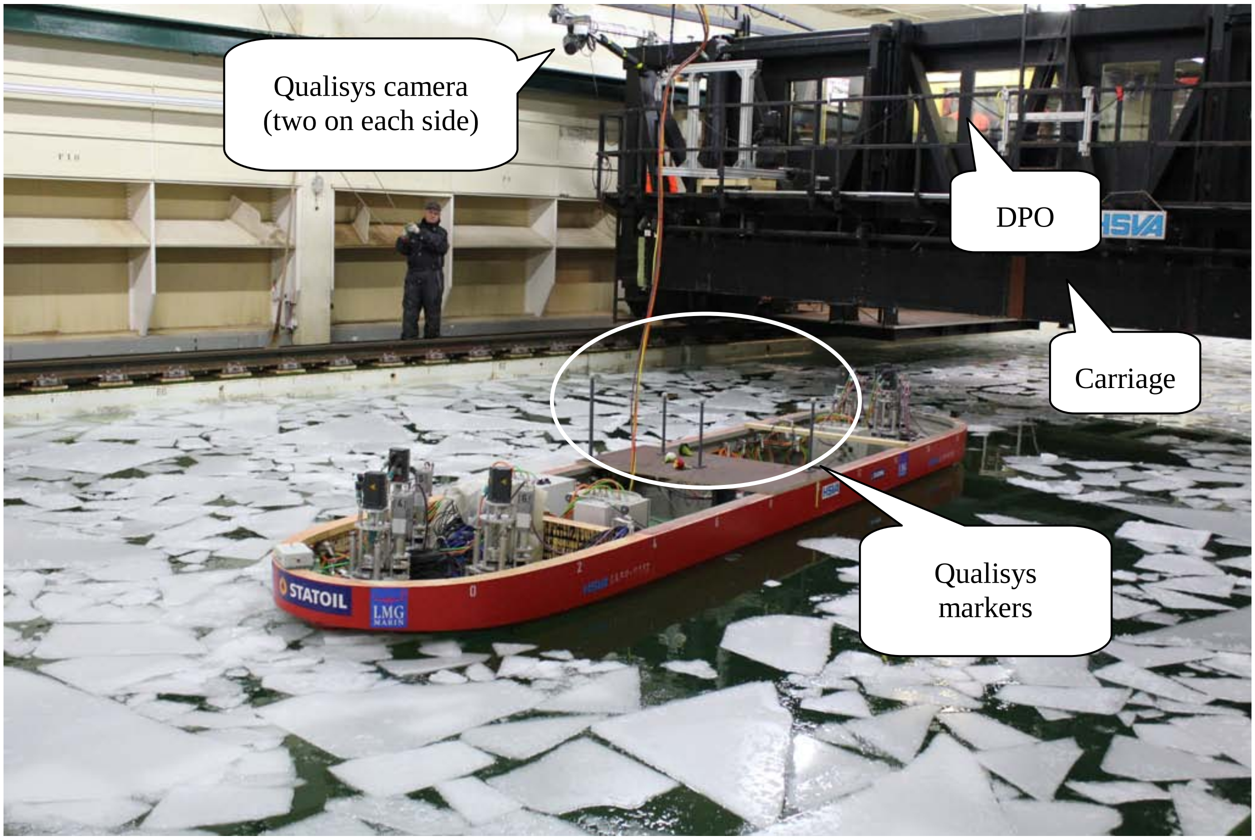


Figure 1: Test setup

Models of about 5m length can be investigated with almost no boundary effects caused by the basin side walls. In the scope of the DYPIC project, two types of vessels engaged in polar operations have been tested: a polar research vessel and an arctic drill ship representing a scale factor range of 1:18.6 up to 1:30.

The models were free to move in the basin in all six degrees of freedom with the objective to keep their position constant with respect to a carriage reference frame by controlling the thrusters. The research vessel has one bow- and two stern-azimuth pods while the drill ship has three bow and stern azimuth thrusters.

The propeller rotational speed and the orientation of each thruster are controlled independently by the DP system.

In addition to the ship position and attitude angles (pitch, roll and heading) provided by the Qualisys system, additional attitude angles and corresponding rotational speeds are measured by an inertial unit installed in the model. Model motion and time derivatives are then obtained by two independent devices whose outputs can be merged in order to provide measurements of improved quality.

Thrust forces (horizontal plane) and moment around vertical axis are measured with dynamometric devices mounted between the hull and the azimuth thrusters. This enables back-calculation of the ice loads acting on the ship hull by removing inertia and hydrodynamic forces from the measured system thrust.

Special designed Model-DP system

A special designed generic Model-DP control system has been developed for HSVA model testing by DCNS Research/Sirehna. The system based on DCNS Research/Sirehna previous experiences in open water - the EasyDP system - has been specifically designed for ships of reduced scale and interfaced with HSVA facility equipment. The control module and the display (with touch screen) for the DP-operator have been installed in a cabin on the carriage. Data exchange between facility equipment and model is done via wireless Ethernet.

The Model-DP system will be used in the ice tank facility with several types of ship. Contrary to usual DP systems installed on a single vessel, the entire system must be configurable according to the ship model and some key parameters like scale, mass, hull shape or thruster arrangement and characteristics. Feedback gains in control laws must then be a function of geometric and hydrodynamic parameters. This generic tuning enables easy tests set-up for research activities with a large number of models but it may cause under-optimized station-keeping performance. Since on-line tuning in model ice conditions are very costly, a compromise has to be made between model interchange ability and the optimization of its closed-loop behaviour.

Figure 2 shows the DPO in action during a test.

Figure 2: DP desk of Model-DP system

Model testing

The model testing formed the back bone of the project and was facilitated by HSVA. The first test phase, which was executed from May to July 2011, involved two different model ships; a Statoil/LMG designed Arctic Drill Ship (ADS) and a Polar Research Vessel (PRV). The objective of this first phase was to determine the parameters that influence a DP system in ice conditions. Both models were tested in free floating mode (where the model sailed solely by its own propulsion system) and fixed mode (where the model was oblique towed connected to a carriage).

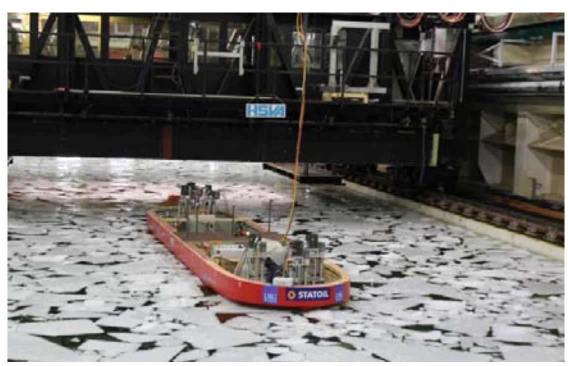


Figure 3: Free floating model test

An overview of the model tests can be found in [15] and [16].

One objective of the Phase II was to test and benchmark the Model-DP system developed within the DYPIC project. These tests took place in May, August and September 2012, but are not covered in detail in this paper.

In the free floating test mode the model travelled in front of the main carriage where it sailed solely by its own propulsion system. All azimuth thrusters were controlled by the DP system. Figure 4shows ADS in a free floating test. As the carriage moved forward, the model followed through the ice. The distance between main carriage and model was measured constantly. Heading, surge and sway of the vessel are to be kept constant relative the carriage.

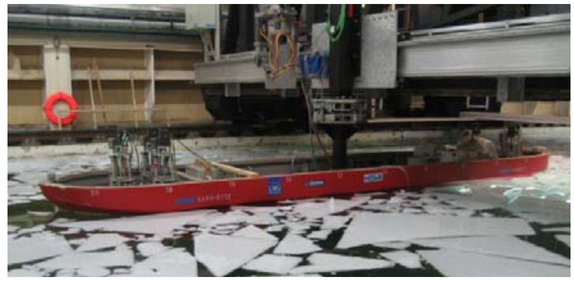


Figure 4: Oblique towing

In the so called fixed mode tests or oblique towing, the model was attached to the main carriage by a rigid post. The model was blocked in five degrees of freedom while it was free in heave. Figure 5 shows the ADS model tested in fixed mode.

Important factors regarding ice loads are the ice thickness, the ice concentration, the size of the ice floes, the floe size distribution and the drift velocity [12]. Next to these the drift direction is a crucial factor. When deciding on the ice conditions to be tested, it was chosen to test managed ice of one thickness only while the other factors and the drift angle were chosen to be varied as shown below.

Four different managed ice fields with systematically varied ice concentration and ice floe size were prepared in the ice tank. The intention was not to have more than one parameter varied at a time. Both the oblique towing and the free floating tests were executed for several velocities and headings in each of the four ice fields. The table below shows the relevant ice parameters of the tested ice fields. Note full scale values.

	Unit	Ice field #1	Ice field #2	Ice field #3	Ice field #4
Concentration	1/10th	7	9	9	7
Size of floes	m	15/30/45	15/30/45	7.5/15/22.5	7.5/15/22.5
Ice thickness	m	0.75	0.75	0.75	0.75

Ice floe distribution:

Area of ice made up with floes this size	*Floe size* in field #1 and #2	*Floe size* in field #3 and #4
45%	15m	7.5m
40%	30m	15m
15%	45m	22.5m

One generally known problem with managed ice model tests is the wall effect. During a test run the model may accumulate ice towards the side walls and especially towards the end of the basin. Figure 5 shows pictures of the area in the end of the basin before a test run and at about half way of a run. The stars in the figure mark some selected ice floes. It can be seen that floes are visibly compacted in the end of the basin even before the model has reached final location. This is an unavoidable effect in limited size basin model testing.

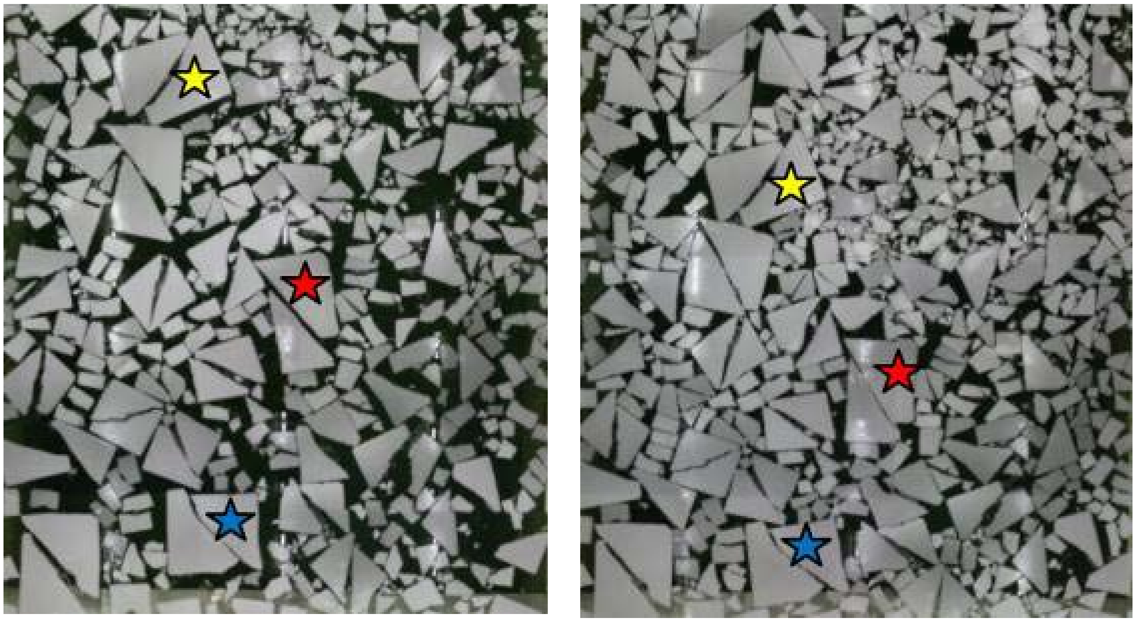


Figure 5: Run with target ice concentration of 9/10: Area in the end of the basin before (left) and at about half way through the basin (right)

For the purpose of knowing exactly what the actual tested ice conditions were, a camera was mounted on a crane underneath the ceiling of the basin. Several pictures were taken along the tank covering the entire tested area of the basin. In average this resulted in 28 pictures taken; 14 on port and 14 on starboard side of the basin. After testing, the pictures were "stitched together" resulting in one high resolution picture of the ice condition. An example of a final picture is shown in Figure 6.

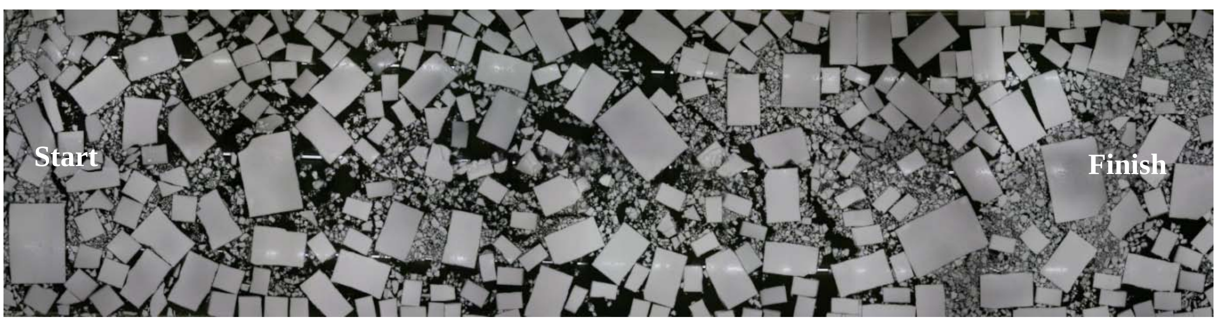


Figure 6: The complete ice field

Ice concentration, floe size and floe size distribution was derived from the pictures. Image analysis software detects each individual floe (minimum floe size to be considered can be adjusted). Each floe is given a number and its size is derived by the known relation of pixels and distance. The ice concentration is derived by summing up the area of all floes. The floe size distribution is derived by defining groups of floe sizes and calculates the percentage of the total area covered by each group.

Phase I model test results

Due to earlier experiences [13] with the Kongsberg K-Pos system in the model tank, it was decided to use this DP system in the first testing phase performed in May and June 2011. The DP system adapted to ice conditions and scaled to model parameters was configured specifically for operations in managed ice in order to cope with the large variations in ice drift forces. The need for dedicated DP control strategies due to the large and rapidly varying ice drift forces are outlined in [11] and [17].

The test matrix consisted of tests with varying:

- ice drift angle (from 0 to 10°)
- ice drift velocity (from 0.25 to 1.0 knot full scale)
- ice concentrations (7/10 or 9/10)
- ice floe size distribution

The distribution of different floe sizes was varied between the tests. Twelve test series were collected for each vessel during the test period.

Results and analysis

Example results from two of the tests are presented. The first test run is with the ADS operating at 0, 5 and 10° ice drift angle and ice drift speed 0.25 knots with concentration 9/10th.

Two snapshots from the DP screen are included in Figure 7 (zero ice drift angle) and Figure 8 (10° ice drift angle). The thruster forces during the entire test run are presented in Figure 10. The 5° drift angle is introduced at time 80 and the 10° angle at time 140. The 50% and 67% thrust utilization is included to illustrate the force level where a two-split or three split power configuration would have given alarms relative to a DP class 2 or 3 operation.

From Figure 7 it can be observed that even though the vessel is moving directly towards the ice, the build-up of ice on the port and starboard sides of the vessel is resulting in a significant lateral force. This force is varying during the test run. The green position time trace includes the initial repositioning of the vessel at the start of the test run. In the rest of the 0° run, the position is within +/- 3 meter from the wanted position.

Figure 8 shows the situation with ice drift angle 10°, the vessel is losing the position due to continuously saturated bow thrusters as shown towards the end of the time series in Figure 10.

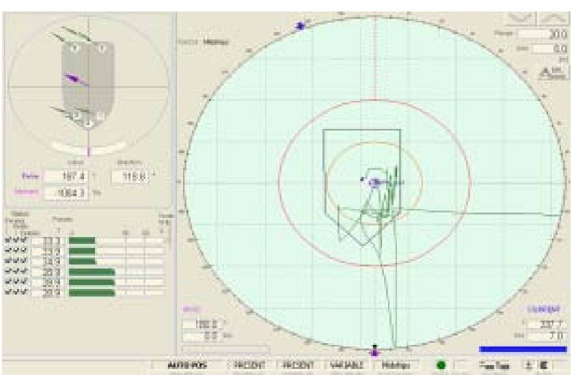


Figure 7: The ADS operating at 0° ice drift angle

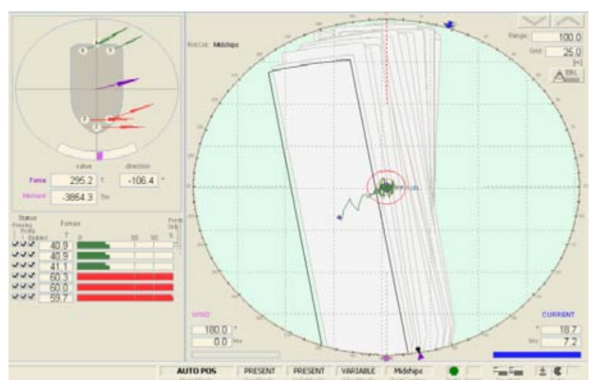
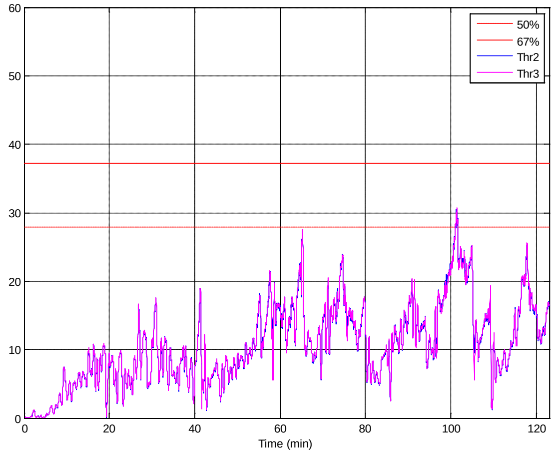
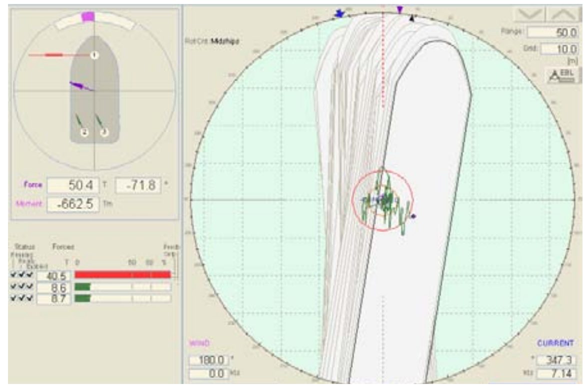


Figure 8: ADS operating at 10° ice drift angle

Similar results for the PRV are included in Figur 10 and





Figur 9: PRV operating at 5° ice drift angle

Figure 11. The PRV bow thruster was saturated already at 5° ice drift angle, whereby the vessel lost its position.

During the model tests the only forces acting on the vessel was the ice drift forces and the sea current in the exactly same direction and speed as the ice drift. In a real life operation the vessel must also be able to compensate for the wind load on the vessel.

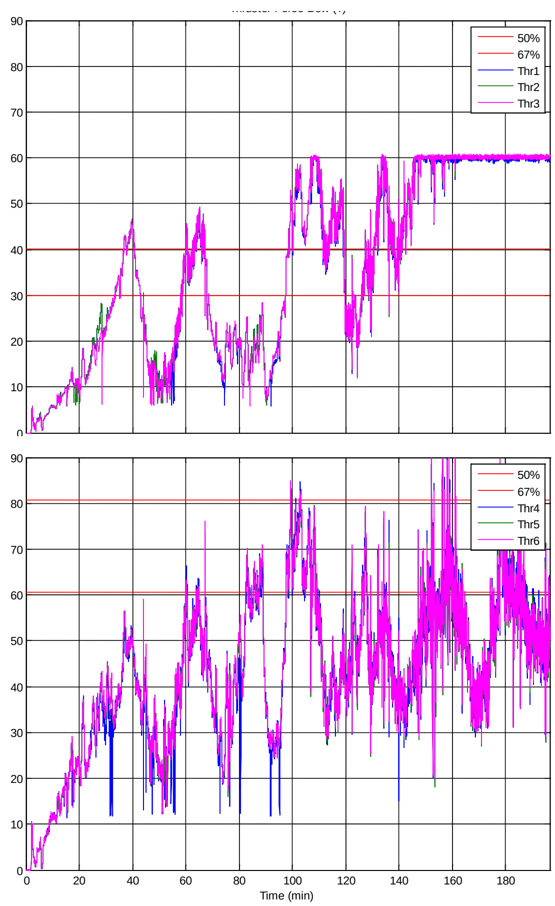


Figure 10: Thruster forces of ADS (ton force) bow (top) and stern (bottom) for the full test series

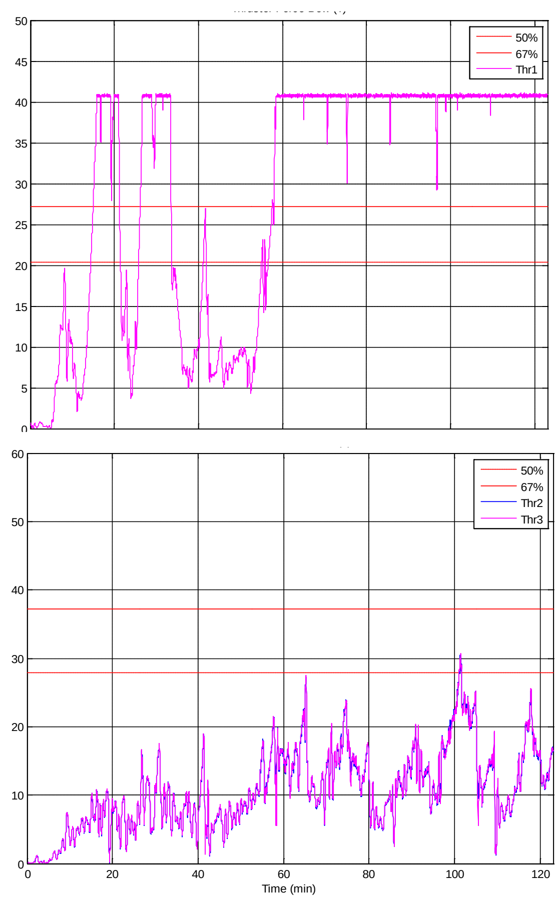


Figure 11: Thruster forces of PRV (ton force) bow (top) and stern (bottom) for the full test series

The analysis of the results also confirmed one of the earlier assumptions from analysis of oblique towing test data: When operating on DP the peak ice loads are slightly reduced compared to forced towing tests.

Simulations based on data from model tests

Recorded thruster forces are used to derive the ice forces acting on the vessel by subtracting inertia effects. These calculated ice load data can be used for new simulations. The derived ice load data was applied to a DP system without the specific ice adaptation. As expected the results show a significant degradation in station keeping performance during the start of the time series, where the actual model test gave results within +/- 3 meter compared to +25 to -35 meter using a normal DP tuned for open water operations, see Figure 13.The loss of position due to insufficient thrust towards the end of the series is not replicated in the simulation as ice loads are reduced when the vessel slowly drifts off position.

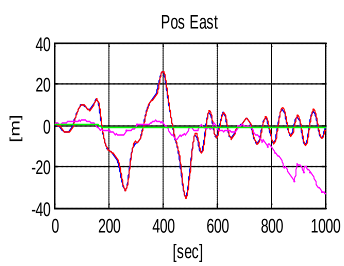


Figure 12: Transverse position using simulated “Open water DP” (red) compared to recorded data (magenta)

Highlights of results for Phase II model tests

The Phase II testing has several purposes; tuning and evaluation of the HSVA's Model-DP for tank test purpose, evaluation of the numerical ice model being developed, comparison of the Model-DP with the commercial system, and investigation of typical operation scenarios like realistic DP maneuvers, changes in ice drift, thruster failures etc.

The tests have been performed in May, August and September 2012. Concerning the test setups, one of the main differences between the two phases was that a quantity of brash ice has been added in Phase II in order to better represent realistic ice fields.

All the results deserve a thorough analysis which should be completed within mid-year 2013. However, one of the first outcome concerns brash ice which apparently smooth's ship motions and seems also to reduce ice loads. It is also noteworthy that several other new test setups have been tested within this phase (conclusive DP trials in level ice, realistic operational scenarios, etc.) which will be analyzed deeply in the time to come.

Results

The following shows two example results (Figure 13and Figure 14) similar to those presented before for both vessels.

The importance of the improved ice management is clear when comparing e.g. Figur 10 and Figure 14. On those tests and within the campaign, the Model-DP system has been really successful.

The thruster commands and feedbacks are shown in Figure 15 to Figure 17.

Note that the Model-DP system operates in model scale coordinates.

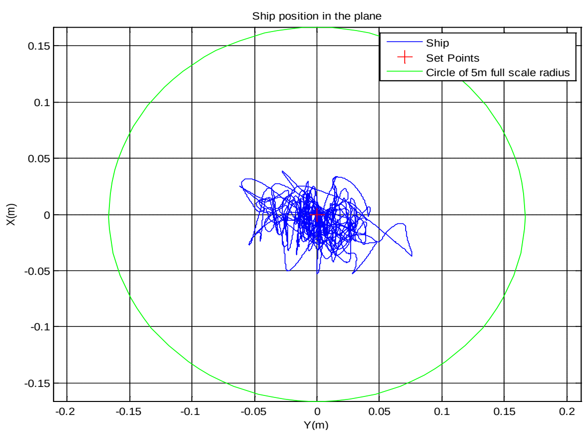


Figure 13: ADS test run

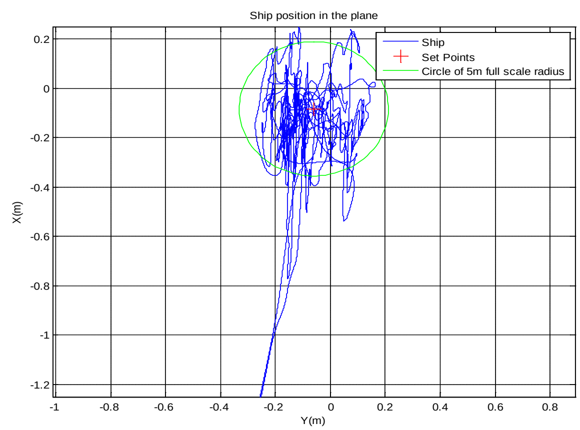
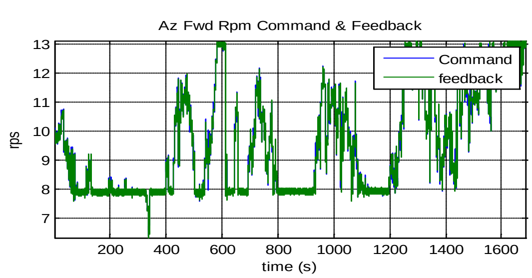


Figure 14: PRV test run



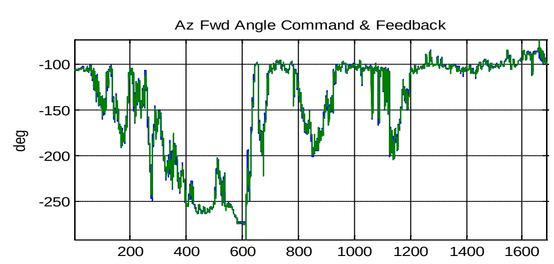


Figure 15: Bow thruster speed (rps) and azimuth (deg)

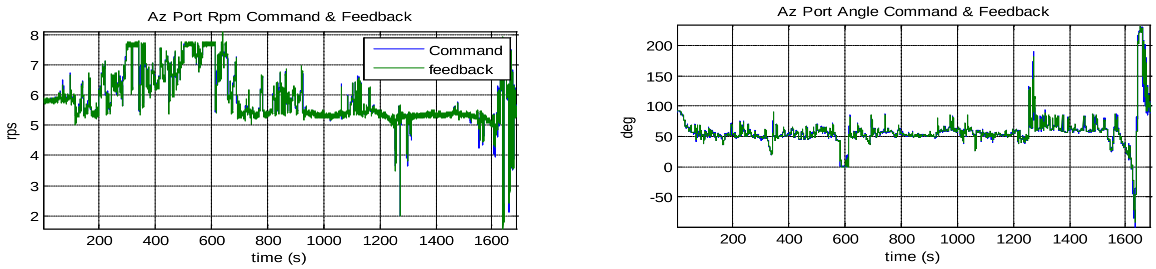


Figure 16: Port stern thruster speed (rps) and azimuth (deg)

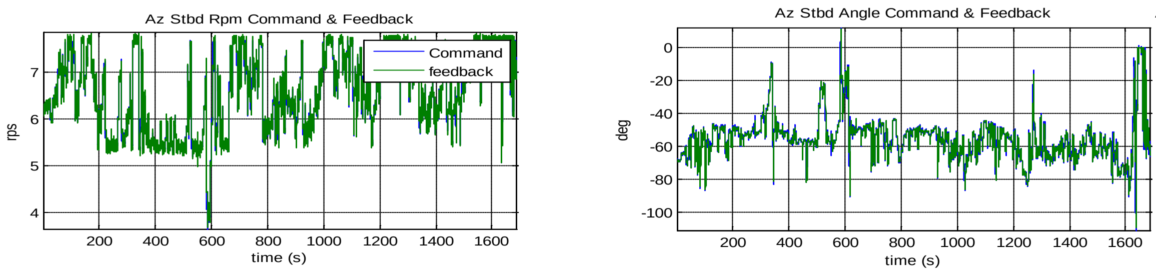


Figure 17: Starboard stern thruster speed (rps) and azimuth (deg)

Conclusion

Within DYPIC two phases of model testing were conducted. During the first phase mainly data for developing a DP system has been collected, while in the second phase the DP system was tested. The majority of tests were performed in managed ice as this is the most realistic scenario for DP operations in ice. But also few tests in level ice have been performed successfully.

Overall the project has resulted in significantly increased understanding of the impact of ice for dynamic positioning. From a prior knowledge on DP systems for open water operation and lessons learned by the large number of model test runs, analyses and simulations performed on the recorded data, new solutions have been implemented showing successful performance in ice environment.

The test facility at HSVA has been modernized with its own generic Model-DP system developed in cooperation with DCSN Research/Sirehna. Also the Kongsberg DP system has been adapted and thoroughly tested in the ice model tank. Next to the efforts made with DP equipment the procedure of managed ice field preparation and its analysis has been improved at HSVA.

Also a numeric model of ice loads to further qualify DP operations in ice conditions is under development at NTNU and will be used to optimize control strategies and for analyzing vessel capabilities.

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