DYNAMIC POSITIONING CONFERENCE
October 13-14, 2015

SOFTWARE DESIGN & CONTROL SESSION

Past, Present and Future of Hydrodynamic Research for DP Applications

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Abstract

MARIN has been involved in model testing for DP vessels for almost 4 decades. In 1976 a first project was carried out in which the main propeller of an offloading tanker was controlled based on the measured bow hawser tension. This basic idea was further developed into a complete DP system for use in model tests. Research topics included thruster-interaction effects, Kalman filtering and wave feed forward. The first DP projects for external clients were carried out in the early 1990s. Initially, it concerned mostly offloading tankers. Later, projects for DP assisted mooring, DP drill ships and semi-submersibles followed. Today, full DP model tests at MARIN are as common as mooring and seakeeping tests.

The first simulation models for DP vessels, developed in the 1980s, only included low frequency loads and motions in the horizontal plane. Present day simulation models include all 6 degrees of freedom, as well as combined low and wave frequency motions. The simulated DP system includes all components found in real DP systems (e.g. filter, controller and allocation). At this moment, developments are ongoing to integrate the different applications of DP systems at MARIN. Modern software architecture allows the use of the same DP system in model tests, time-domain simulations and bridge simulator training. This improves efficiency of projects, but also bridges the gap between engineering studies and operational analysis.

The focus of this conference paper is on future research. Some hydrodynamic research topics in the area of dynamic positioning that are foreseen for the near future are described below :

- ***Advanced Allocation Algorithms***
  The distribution of the total required force over the available actuators can be a complex task. Efficient and reliable methods are available, but several alternative methods with specific advantages exist, which require further research before they could be applied in DP systems.

- ***DP with Large External Loads***
  Large, irregular and intermittent loads acting on a vessel (e.g. by crane operations, dredging equipment, or ice) may disturb the performance of the DP system, sometimes even causing instabilities. Possible solutions may be found in modifications of the Kalman filter and controller.

- ***Multi-body DP***
  Stationkeeping relative to another moving body is fundamentally different from DP at a fixed location. An approach to use the relative motion signal as input for the DP system has to be chosen. Possible solutions include periodic up-dates of the reference position, filtering of the earth-fixed motions of both vessels prior to calculation of the relative motions, or a single Kalman filter for multiple bodies.

- ***Motion Compensation***
  In some cases, the thrusters used for stationkeeping could also be applied for reducing the vessel motions, e.g. by applying roll and pitch damping. Combining stationkeeping and motion control may require the use of a 6 DoF control system, instead of the current 3DoF (surge, sway, yaw) DP systems. This is an interesting area of research.

- ***Wave Feed Forward***
  Wind feed forward is successfully applied to improve stationkeeping accuracy. The thrusters on the vessel respond directly to the (varying) wind loads, which are estimated based on wind velocity measurements. The application of wave feed forward could potentially lead to

increased stationkeeping accuracy and fuel savings. However, further research is required on methods to accurately estimate the instantaneous wave drift forces. Present estimation methods are not yet sufficiently accurate, practical or reliable to allow application of wave feed forward in dynamic positioning.

The above topics will require significant research effort. It is unlikely that one single party, whether academic or from the industry, could investigate all these areas extensively. MARIN, as an independent not-for-profit research institute, is always open to cooperation with partners from the industry and academia. One of the initiatives we are taking to enable and stimulate cooperative research in the area of dynamic positioning is our initiative for the openDP joint industry project. In the openDP JIP we want to encourage innovation by providing a software frame work for joint development of new technology for dynamic positioning applications, dynamic tracking and motion control.

Introduction

This paper aims at giving an overview of interesting topics for future research in the area of dynamic position. The presented overview has a clear focus on hydrodynamic topics and is therefore not complete. The intention is to identify research topics that could lead to improved DP performance, either in terms of efficiency, or in terms of stationkeeping accuracy. MARIN would like to challenge parties from the industry and academia to define research projects in the identified areas and to develop new technologies that will help improve the performance of DP systems.

The main chapters in this paper describe the "past, the present and future" of hydrodynamic research for DP applications. The first part briefly describes the developments of DP model tests and time-domain simulations in the past 4 decades. The overview mostly describes developments that took place at MARIN, but it should be acknowledged that many others outside MARIN also worked on these topics. The second part of the paper describes the current situation. Recent developments focus on the integration of software applications, as used in time-domain simulations, simulator training and model tests. Furthermore, state-of-the-art tools such as PIV measurements and CFD calculations now enable investigation of the thruster wake flow in more detail than ever before.

The bulk of this paper is dedicated to the description of 5 research areas, which offer opportunities to further improve the performance of DP systems. These areas of research include improvements to DP system components, as well as developments for specific applications. We hope our overview will encourage discussion and motivate others to further investigate these topics.

Past

MARIN has been involved in model testing and computer simulations for DP vessels for almost 4 decades. Dynamic positioning involves many different aspects. As a result, research over the years included many different topics, including the control system itself (controller, filter and allocation), thruster performance (thruster interaction effects) and the environmental loads (wind and current loads, wave drift forces, vessel motions). The aim has always been to be as complete as possible, to ensure that the performance of the DP systems in model tests and time-domain simulations closely matched the behavior of real life DP systems. In the following sections some background information about the developments in the past 40 years is presented.

DP Model Tests

In 1976 a first project was carried out in which the main propeller of an offloading tanker was controlled based on the measured tension in the bow hawser. In the 1980s this basic idea was further developed into a complete DP system for use in model tests (Nienhuis and Pinkster, 1986). During this period research topics included thruster-interaction effects, Kalman filtering and wave feed forward.

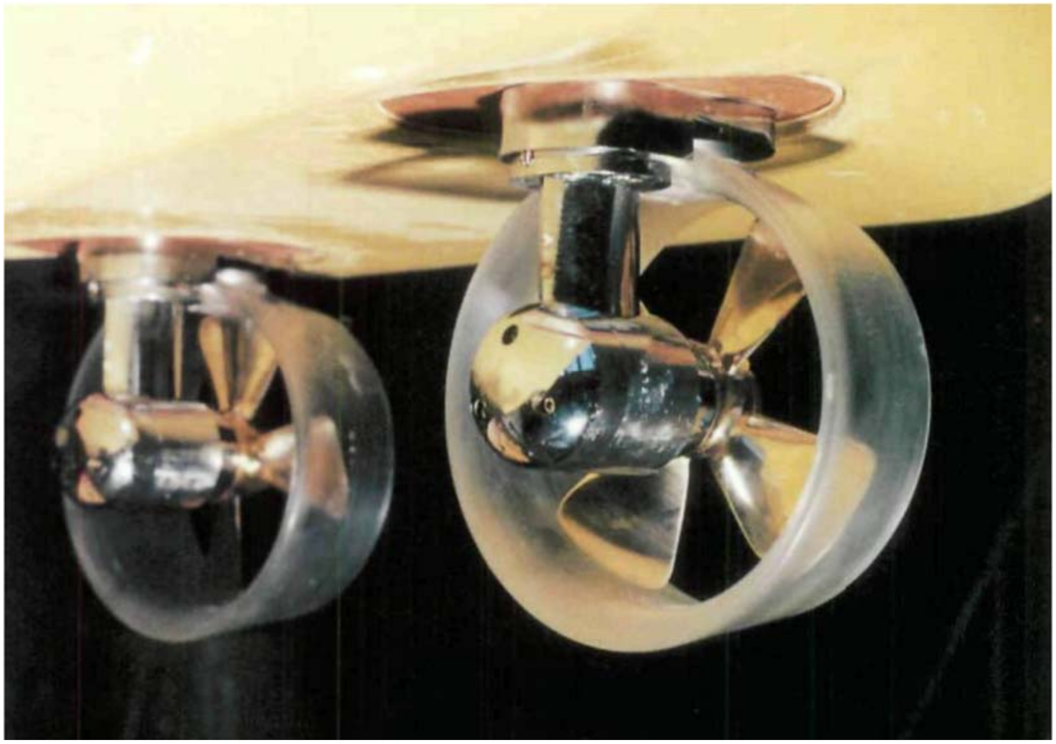

Figure 1 - First Generation Model Azimuthing Thrusters for DP - MARIN Photo No. F854763 (1985)

By the late 1980s time-domain simulation models had been developed, to complement the model tests. The first DP projects for external clients were carried out in the early 1990s. Initially, it concerned mostly offloading tankers. Later, projects for DP assisted mooring (Aalbers and Merchant, 1995), DP drill ships (Wichers et al., 1996) and semi-submersibles followed (Cozijn et al. 1999), as well as DP semi-submersible crane vessels (van Dijk et al, 2005). Today, full DP model tests at MARIN are as common as mooring and seakeeping tests (Serraris 2009, de Wilde et al. 2014).

Thruster-interaction Research

The effective force generated by the thrusters on a DP vessel can be significantly smaller than the nominal thrust values. Thruster-hull, thruster-current and thruster-thruster interaction effects may cause a reduction of the effective thrust during DP operation. These interaction effects are the result of pressure and friction forces on the vessel hull, combined with a change of thruster inflow velocity, caused by current and the wake flow from neighboring thrusters. Thruster-interaction effects were first studied by Lehn (1985) and Nienhuis (1992). Both carried out large numbers of model tests, systematically varying thruster positions and orientations. The wake behind azimuthing thrusters was studied and mathematical models describing the thruster-interaction effects were developed. Thanks to the systematic parameter variations in their research, the results of both Lehn and Nienhuis are still considered as bench marks, even today.

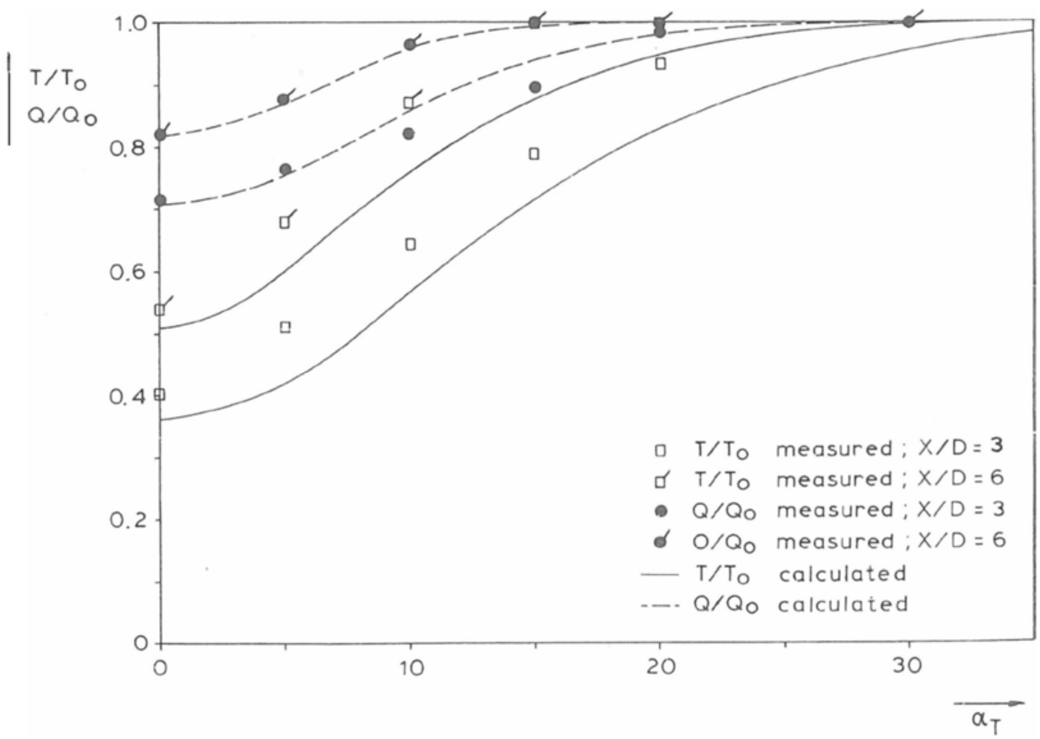

Figure 2 - Interaction as a Function of Azimuth Angle for a Pair of Thrusters - Nienhuis (1992)

Time-domain Simulations

The first simulation models for DP vessels only included low frequency loads and motions in the horizontal plane. Therefore, a Kalman filter to separate the low and wave frequency content in the vessel motions was not yet included. These early simulation models are described in van den Boom and Nienhuis (1983) and Nienhuis (1986). Later, Aalbers et al. (1995) extended the models to simulation of combined low and wave frequency motions. Today, the simulated DP system includes all components found in real DP systems (filter, controller and allocation). Thruster models are included describing the thrust and torque, as well as thruster-interaction losses. A description is given by Serraris (2009).

Present

Recent research and development at MARIN has focused on the integration of software applications, used in time-domain simulations, simulator training and model tests. Furthermore, state-of-the-art tools such as PIV measurements and CFD calculations have enabled the investigation of the thruster wake flow in more detail than ever before.

Software Developments

In the early 2000s the need existed to integrate multiple functionalities into a single time-domain simulation application for floating bodies in environments of combined current, swell, wind seas and wind. The required functionalities included mooring analysis, lifting analysis, terminal moorings, dynamic positioning and side-by-side mooring. The multi-body tool aNySIM was developed for the simulation and analysis of a wide range of offshore operations. The combined low frequency and wave frequency motions of multiple bodies in 6 degrees of freedom are calculated. And complete DP systems can be modeled, including a Kalman filter, PID controller and thrust allocation algorithm.

In 2009 the next step was made to integrate all time-domain simulations for typical offshore and ships applications in a single software frame work. Furthermore, it was the ambition to share the same code for fast-time and real-time applications. This improves the maintainability of the code and offers the possibility to share functionality between the different user groups of the frame work. And this can link the field of engineering studies (fast-time without visuals) to the areas of operational analysis and training (real-time with visuals). At this stage the eXtensible Modeling Framework (XMF) was initiated. The software frame work XMF is programmed in C++, while all previous codes were implemented in Fortran. The functionality within the frame work is implemented using results and feedback from several sources, including e.g. the aNySIM user group and the OBELICS JIP. The OBELICS JIP focused on the operability of ballasting and lift operations. More background information is given by De Vries and Frickel (2012) and by Bovens et al. (2013). Currently, all software developments for time-domain simulations at MARIN focus on the further development of the XMF software frame work. This frame work serves as a basis for all time-domain simulation software, whether for offshore applications, for seakeeping or for manoeuvring, in fast-time or in real-time.

In the development of XMF a strong emphasis has been placed on a sophisticated and versatile architecture. Therefore, a clear separation is being made between the numerical model of the DP vessel and the DP system, denoted as "XDP". Data exchange between the vessel model and the DP system can be facilitated in different ways. One method is the use of the industry accepted standard of NMEA messages. The main advantage of this approach is that MARIN's generic DP system can easily be exchanged with a DP system of an external DP systems supplier. This offers DP suppliers the possibility to carry out time-domain simulations for DP vessels, using MARIN's hydrodynamic models, so that they can focus on the functionality and performance of the DP system. Background information about this coupling and its application can be found in Voogt et al. (2014) and Voogt and Hallmann (2015).

The next step is to exchange the numerical model of the vessel with a scaled physical model of the DP vessel in a model basin. In this manner identical DP algorithms are applied for both numerical time-domain simulations and for physical model testing. As a proof of concept, this exchange has recently been carried out successfully in MARIN's Offshore Basin.

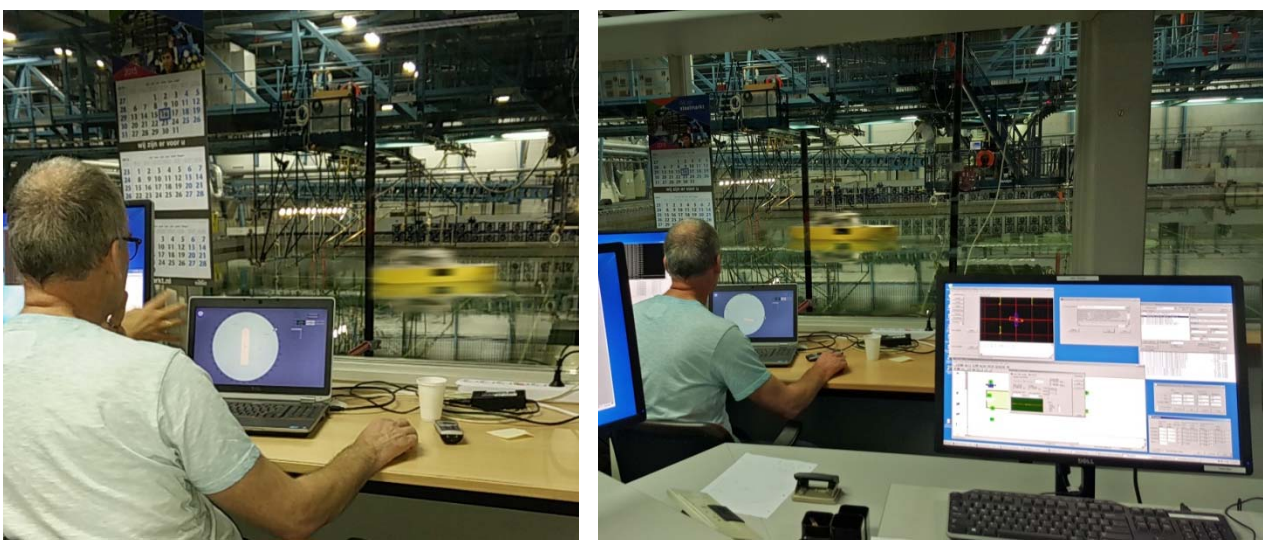

Figure 3 - Ship Model in MARIN's Offshore Basin, Controlled by XDP (2015)

The main benefits of these developments in the software frame work can be summarized as follows :

- Efficient software development and maintenance
- Better comparison between time-domain simulations, model tests and simulator training
- Easier exchange of MARIN's generic DP system with external commercial DP systems

At this moment, developments are ongoing to complete the integration of DP systems at MARIN. The modern software architecture will allow the use of the same DP system in model tests, time-domain simulations and bridge simulator training. This improves efficiency of projects, but also bridges the gap between engineering studies, operational analysis and training.

Thruster-interaction Research

Today, state-of-the-art tools, such as PIV measurements and CFD calculations offer new possibilities to investigate the thruster wake flow in more detail than ever before. Detailed velocity measurements and visualization of the flow patterns may help to understand the physics of the thruster-interaction effects. Furthermore, these measurement results can be used as validation material for CFD calculations. PIV measurements and CFD calculations complement existing tools, such as force measurements in model tests, but they also offer new possibilities, such as the investigation of scale effects.

Cozijn and Hallmann (2012, 2013, 2014, 2014) presented results of PIV measurements for different configurations. Their results included measurements for schematical cases, such as an azimuthing thruster in open water, a thruster under a plate and a thruster under a barge, as well as practical cases, such as a semi-submersible, a drill ship and a DP shuttle tanker. An example is shown in the figure below.

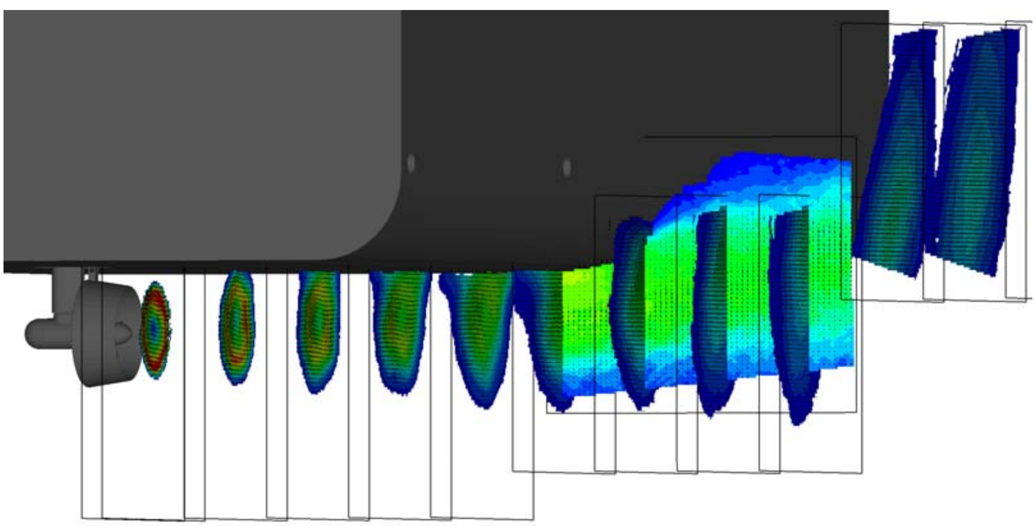

Figure 4 - PIV Measurements for a Thruster under a Barge - Cozijn and Hallmann (2014)

CFD calculations for thrusters on a DP vessel are not straight-forward, especially in bollard pull conditions (J = 0). Ottens et al. (2011, 2012) investigated thruster-hull interaction effects for a semi-submersible crane vessel, comparing CFD calculation results with model tests and full scale measurements. Maciel et al. (2013) investigated thruster-hull interaction effects for a number of schematical configurations, including an azimuthing thruster under a plate and under a barge. The results these studies show that CFD calculations can be successfully used to determine thruster-hull interaction effects. However, the computational effort is large, limiting the use of these methods as engineering tools.

CFD calculations to determine thruster-thruster interaction effects are significantly more complex than calculations to determine thruster-hull interactions. Especially the correct modeling of the thrust and torque of the down-stream thruster are challenging. Research in this area is still ongoing. The work of Bulten and Stoltenkamp (2013) contains some results of thruster-thruster interaction effects.

Scale effects in thruster-interaction can also be investigated by CFD. Results of full scale calculations were presented by Ottens and van Dijk (2012) and by Bulten and Stoltenkamp (2013). The first publication focuses on calculations and measurements for a semi-submersible crane vessel in transit conditions. The second publication shows a comparison between model scale and full-scale performance in open water, complimented with full scale thruster-hull and thruster-thruster interaction calculations. The results suggest that the performance of the thruster in open water is better at full scale than at model scale. However, further research is necessary before solid conclusions can be drawn on scale effects in the thruster-interaction effects.

Future

The objective of this conference paper is to identify areas of future research, with an emphasis on hydrodynamic aspects. Below, a number of topics is proposed, in which developments could be made to improve the performance of DP vessels.

- Advanced allocation algorithms
- DP with large external loads
- Multi-body DP
- Motion compensation
- Wave feed forward

A more detailed description of the proposed research topics is given in the next sections. Each of these topics will require significant research effort.

Advanced Allocation Algorithms

The distribution of the total required force over the available actuators can be a complex task. The basic optimization problem may be straightforward, but additional constraints, such as maximum thrust and forbidden zones, complicate its solution. Efficient and reliable methods are available, but more advanced methods may bring additional improvements in stationkeeping accuracy and energy consumption.

The power optimization problem can be solved using a Lagrange multiplier approach. By assuming a quadratic relation between power and thrust, this results in a linear system of equations to determine the thruster RPMs and azimuth angles. However, the obtained solution needs to be checked and corrected for maximum thrust and forbidden zones. The method is simple and robust, but an approximate power-thrust relation is used($P \sim T^2$ instead of $P \sim T^{3/2}$) and the handling of multiple corrections for forbidden zones and maximum thrust can be complicated. Furthermore, the obtained solutions may be outside the range of thruster RPMs and azimuth angles that can be physically achieved within the next time step.

Van Daalen et al. (2011) proposed an improved Lagrange multiplier method. The exact power-thrust relation for bollard pull conditions ($P \sim T^{3/2}$) is used and the additional constraints (maximum thrust and forbidden zones) are directly included in the optimization process, by additional equations. The non-linear system of equations is solved iteratively. Arditti et al. (2014) further extended the approach by including additional physical limitations of the thrusters (rate of turn, rate of change of RPMs).

Most allocation algorithm determine the thruster RPM settings and azimuth angles, based on the open water bollard pull characteristics of the thrusters. However, the total effective force will be smaller, due to thruster-interaction effects. Arditti et al. (2012) included the thruster-hull interaction losses in the cost function. This results in an allocation algorithm that automatically avoids inefficient solutions (azimuth angles with strong interaction effects), thus eliminating the need to define forbidden zones. The study included model tests and computer simulations and the results show a reduction in consumed power, compared to an allocation algorithm with pre-defined forbidden zones. A similar approach, this time not only including thruster-hull interactions, but also thruster-thruster and thruster-current interactions, was applied by Arditti et al. (2014). The algorithm was tested, but not yet applied in a DP system.

Allocation methods that include the expected thruster-interaction losses in the power optimization have a number of promising advantages. Both the efficiency and the stationkeeping accuracy may improve. And forbidden zones are not pre-defined, but are avoided automatically. The next step is to investigate the performance and robustness in more detail, in simulation studies and model tests, before these methods can be applied in real life DP systems.

DP with Large External Loads

Most DP systems are designed for stationkeeping of a free floating vessel. Large, irregular and intermittent loads acting on the vessel may disturb the performance of the DP system. Such large external loads may be caused by lifting operations, dredging, nearby structures or stationkeeping in ice. Possible solutions may be found in modifications of the Kalman filter and controller.

Figure 5 - Heavy Lift Model Tests with DP Crane Vessel - Waals (2010)

Wouts (2002) discussed the restoring force, caused by the load in the lifting wires during set-down of a top-side by a DP crane vessel. Depending on the weight of the lifted load, the additional "mooring" stiffness can be significant. During offshore lift operations instabilities were observed, resulting in harmonic surge oscillations of the crane vessel. The same effect is also mentioned by Jenssen (2004). Solutions to prevent instable behavior were developed and tested using combined simulations of the crane vessel and the DP system.

Flint and Stephens (2008) describe a DP pontoon carrying a bridge section with a large mass. When the bridge section is lifted from the deck, an additional spring is created by the tensioned lifting wires. This results in a low relative damping and instabilities similar to those described above. Furthermore, the large external loads may disturb the position and velocity estimates of the Kalman filter. Solutions for manual, as well as automatic operation are discussed. The controller of the DP system is modified such, that additional damping can be applied if necessary. The damping of the DP controller can be gradually increased, so that no sudden changes occur in the properties of the DP system. The approach is tested in simulations and sea trials and might also be applicable for other heavy lift cases.

A different approach was investigated by Waals (2010). Instead of adding damping to the system, the tension in the lifting wire was measured and used to determine the additional horizontal forces on the vessel. The model test results showed that a feed forward signal can be successful in suppressing the instabilities in the DP system during the lifting of a top-side on to a jacket. However, several aspects need to be further investigated to improve the reliability of the method for use in offshore lifting operations.

Heavy lifting is an area where the external loads acting on the DP vessel may be estimated with some accuracy, based on measurements of vessel positions and tension in the lifting wire. This information can then be used by the DP system to avoid an undesired motion response. However, loads with an even more irregular and unpredictable character (e.g. due to ice, or interactions with fixed structures) may require a different approach. This is still a mostly unexplored area of research.

Multi-body DP

Some offshore operations require a vessel to maintain position and heading relative to another floater. Examples include accommodation vessels, offloading operations and heavy lift operations. Stationkeeping relative to another moving body is fundamentally different from dynamic positioning at a fixed location. Using the relative motion signal as input for the DP system, instead of an absolute motion signal, may not result in acceptable stationkeeping performance. Furthermore, the presence of a nearby floater may affect the environmental loads acting on the DP vessel. Shielding effects in wind, waves and current may be significant, depending on the size of the floaters, the vessel headings and their relative distance.

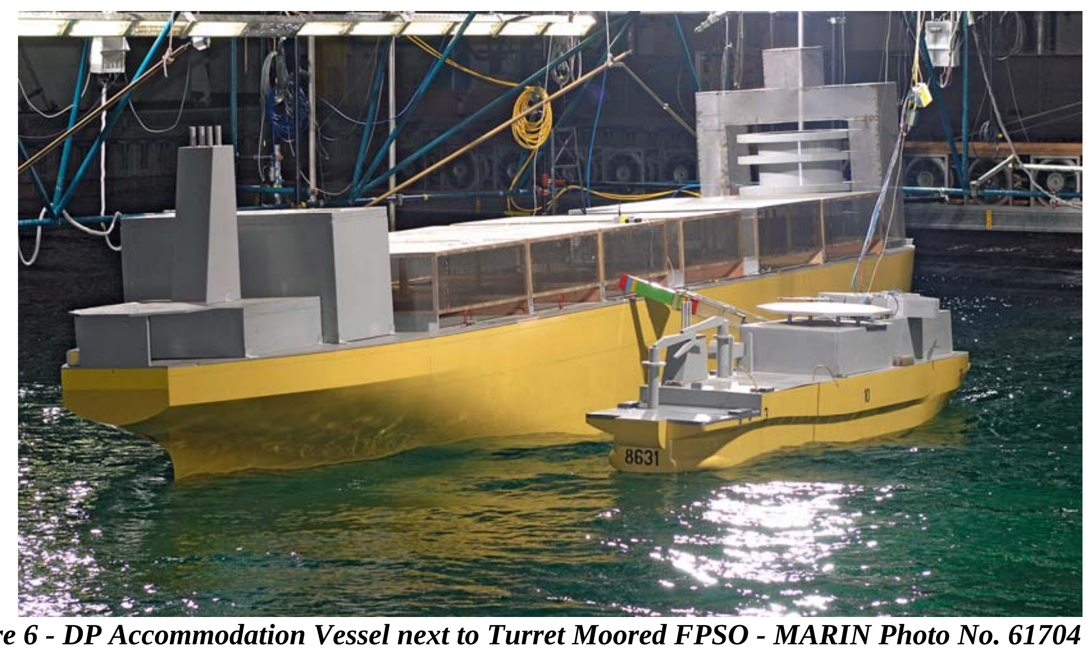

Figure 6 - DP Accommodation Vessel next to Turret Moored FPSO - MARIN Photo No. 61704 (2006)

Jenssen (2004) describes an approach in which an earth-fixed position set-point is used, which is periodically up-dated. A reaction circle is defined, and as soon as the target reaches the edge of the circle, the position of the set-point and the reaction circle are up-dated. De Wilde et al. (2010) successfully used the same approach for a tandem offloading operation with a dynamically positioned LNG-carrier. The results of model tests are discussed, comparing the performance of tandem offloading using DP and a conventional hawser mooring.

Quadvlieg et al. (2011) present the results of model tests and full scale measurements for two naval vessels in a transshipment operation. The considered vessels were large and they were both equipped with a DP system. Furthermore, the vessels worked in very close proximity and thus requirements for the (relative) stationkeeping accuracy were very strict. The complicated operations were investigated using MARIN's in-house model test DP system RUNSIM, as well as using a Kongsberg DP system. With both vessels using a DP system, one master vessel was defined (on earth-fixed DP) and one slave vessel (on relative DP). Several control strategies were investigated to achieve the required DP performance.

For stationkeeping with multiple vessels Queiroz Filho et al. (2013) suggest a cooperative control system, rather than individual DP systems for the different vessels. In the cooperative control, position information of both vessels is exchanged between their DP systems. The results of model tests and time-domain simulations are discussed and the cooperative control shows smaller positioning errors compared to the conventional approach.

It is clear that relative DP is more complex than stationkeeping at a fixed location. The use of a periodically up-dated position set-up is a practical and successful approach. However, the stationkeeping performance could be further improved by using information from both vessels as input for the control system. Cooperative control is one approach, but other strategies could also be further investigated. A Kalman filter for the earth-fixed position of both vessels, prior to calculation of the relative motions, could be an option. Or perhaps a single Kalman filter for multiple bodies could be defined, directly describing the relative motions between both vessels.

Motion Compensation

In some cases, the thrusters used for stationkeeping could also be applied for reducing the vessel motions. Large semi-submersibles may have roll and pitch natural periods that are sufficiently long for roll and pitch natural periods to allow the use of thrusters to generate additional damping. Jenssen (2010) discusses a DP semi-submersible in irregular seas that shows combined wave frequency and low frequency pitch (and roll) motions. Filtering of the pitch motions is required before any thruster response to these motions can be determined. Simulations with and without pitch rate control are compared. The pitch rate control is shown to reduce the low frequency pitch motions of the semi-submersible.

Jurgens et al. (2012) discuss some examples of offshore supply vessels equipped with Voith-Schneider Propellors (VSPs). The vessels are equipped with a DP system, combined with a roll stabilization control. The thrust direction and magnitude of the VSPs can be changed extremely fast, making it possible to respond to wave frequency roll motions of the vessel.

Jin et al. (2014) show results of time-domain simulations of a DP semi-submersible. Besides the position control for the horizontal motions, also roll and pitch control is applied. The motion control contains angular velocity, as well as angular acceleration feedback. The use of roll and pitch control is shown to reduce the roll and pitch motions, but this does affect the stationkeeping accuracy of the platform.

The above cases all have an existing DP system to which roll or pitch control is added. An integrated approach, using a 6 DoF control system (instead of a 3DoF control system with added motion control) could improve the performance of the roll and pitch control, without affecting the stationkeeping accuracy. This integrated approach is an interesting area of research. Possibly, experience and ideas from the areas of AUV or airplane control may be useful here.

Wave Feed Forward

Wind feed forward is successfully applied in DP systems to improve stationkeeping accuracy. The instantaneous wind loads on the vessel are estimated using a measured wind velocity and dimensionless wind load coefficients. The thrusters on the vessel directly counteract the (varying) wind loads, instead of responding to the position off-set resulting from the wind loads. The basic principle is straight-forward, but errors or disturbances in the wind velocity measurements may result in an incorrect response of the DP system.

The application of wave feed forward could potentially lead to increased stationkeeping accuracy and fuel savings, especially because the wave drift loads on the vessel may show much larger variations than the wind loads. However, real-time estimation of the wave drift forces is no simple task. Pinkster (1978) proposed an approach for ship-shaped floaters. The method relies on the fact that the largest contribution in the low frequency wave drift forces is directly related to the relative motions around the ship. Aalbers et al. (1987, 2004), as well as Quadvlieg et al. (2011) further explored this approach. Aalbers et al. (2004) found improved operability for the offloading operations of a DP Shuttle Tanker, especially in sea states close to the operational limits. Quadvlieg et al. (2011) found improved stationkeeping accuracy (smaller watch circle) for a single vessel and side-by-side operations, at zero speed, as well as low forward speeds.

The use of wave feed forward is expected to improve the stationkeeping performance of DP vessels, but a practical realization is complex. First of all, the relative wave motions have to be measured at several locations around the ship. Reliability of these measurements is vital for the quality and accuracy of the drift force estimation. Second, estimating the low frequency wave drift forces requires low pass filtering of measured signals. Possible phase lag in the filtered signals will affect the accuracy of the estimated wave drift forces and thus reduce the benefits of the application of wave feed forward.

Naaijen and Huijsmans (2010) presented a different approach, using remote measurements of the (short-crested) wave field around the ship, instead of relying on relative wave measurements on board. Originally, the method was aimed at predicting the first order vessel motions. First, the wave field is measured at some distance from the ship, using X-band radar. Second, the propagation of the waves towards the ship is calculated. Third, the complete representation of the wave field around the ship is used to calculate the vessel motions. An extension of the method resulted in a prediction of the low frequency wave drift forces. Although promising, further research is required to improve the accuracy of the predicted wave drift forces.

The successful application of wave feed forward requires developments to further the accuracy of the estimated wave drift forces. The existing relative wave motion approach was developed for monohull vessels. However, the wave drift forces on semi-submersible platforms can not be linked directly to the relative wave motions alone and viscous effects may also play a role.

openDP JIP

MARIN wants to stimulate the development and use of innovative ideas in dynamic positioning applications. We believe that the maritime industry could benefit from open technical discussions, cooperative research efforts and sharing of new developments. For this reason we are taking the initiative for a new joint industry project called "openDP". In this JIP a software platform for the development and testing of dynamic positioning applications will be made available to all project participants. The tool box consists of a complete time-domain simulation model of a vessel in wind, waves and current, combined with a generic DP system and thrusters. Users can directly connect their own control algorithms, without the need to worry about the correct modeling of the vessel behavior. MARIN, as an independent not-for-profit research institute, is always open to cooperation with partners from the industry and academia. We hope our openDP JIP initiative will enable and stimulate cooperative research in the area of dynamic positioning, dynamic tracking and motion control.

Conclusions

The objective of this conference paper is to identify areas of future research on DP applications, with an emphasis on hydrodynamic aspects. Five research areas are described, which offer opportunities to further improve the performance of DP systems. The following research topics are discussed :

- Advanced allocation algorithms
- DP with large external loads
- Multi-body DP
- Motion compensation
- Wave feed forward

We hope that the presented overview will encourage discussion and motivate parties from the industry and academia to further investigate these areas. Developments on the above topics will require significant research effort. It is unlikely that any single party could investigate all areas extensively. MARIN, as an independent not-for-profit research institute, is always open to cooperation with external partners. One of the initiatives we are taking to enable and stimulate cooperative research in the area of dynamic positioning is our initiative for the openDP joint industry project. In this JIP we want to encourage innovation by providing a software frame work for joint development of new technology for dynamic positioning applications, dynamic tracking and motion control.

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