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Arctic

DP In Ice Conditions

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Abstract

The paper discusses the topic of DP operations in arctic ice conditions. Different from open water DP, qualification of DP control in such environments is difficult since there are no well established methods for doing so. The paper shows that there is a need to make a DP control system more reactive to cope with the highly varying ice loads acting on a DP vessel. Assuming such a measure is taken DP operations should be feasible. However, it will require well planned and executed ice management.

Introduction

Ice conditions in the Artic regions are a new challenge to oil field development.
There is very little operational experience regarding DP in ice. Some full scale tests with ice breaking DP vessels have been carried out such as the IODP 302[1] core drilling expedition (2004) involving several ice breakers, one with a DP control system installed. In the expedition joystick control was applied. The vessel configuration did not allow ordinary DP control. The crew managed to keep the vessel within the required watch circle for the activity.
It is understood that DP operations with ice breakers in the Sakhalin region are taking place. The ice conditions in this area are, however, quite different from the ice in e.g. the Beaufort Sea and the Chukchi Sea, mainly due to ice consistency. The Sakhalin area has only 1st year ice where as the other areas where exploration activities are being considered have the potential for multi year ice inclusion. Multi year ice inclusions are much harder to deal with.

The IOP 302 expedition is not actually representative for the ice condition in potential petroleum exploration areas. Station keeping criteria for core drilling is significantly different from exploratory drilling with Blow Out Preventors. Ice conditions during Expedition 302 were severe with more than 90% ice coverage, much of it composed of hard, multiyear ice. The figure below shows ice condition in the Beaufort Sea summer 2008.

Figure 1 Beaufort Sea summer 2008

On the nature of ice loads

Ice thickness, concentration, size distribution of ice floes and drift velocity are known to be important factors regarding ice loads. In addition the motions of the vessel itself will affect the forces. Ice forces are quite different from open water environmental forces, and the separation principle (forces of each source can be added as vectors) can not be applied when analysing vessel behaviour in an ice field. The ice field has its own dynamics which are coupled with the vessel dynamics.

From ice model resistance tests of the Frontier Drilling's Bully class of vessels we learn that the ice load may be very high in average and showing very rapid high peaks of considerable duration.

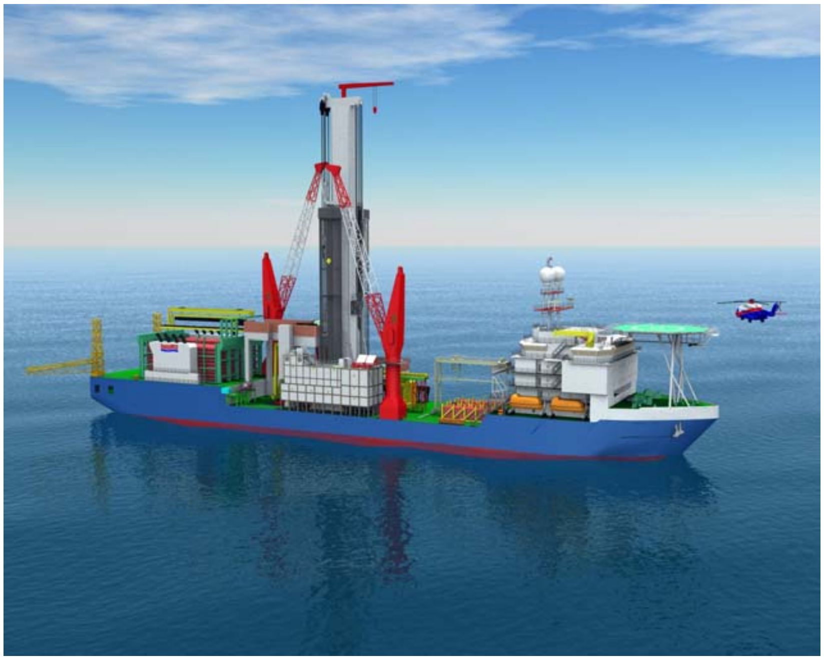

Figure 2. The Bully

The 'Bully' rig design represents a flexible, smaller and highly capable, vessel suited for worldwide deepwater and configurable for arctic drilling, while reducing the construction and operational costs.
The Bully hull design features the bow of an icebreaker capable of breaking ice floes as well as avoiding ice floes coming under the hull. It is constructed from an ultra-flexible grade of steel to protect the hull from shattering in extreme cold. Special heating systems are installed along piping and to protect the ballast tanks. Engine vents are widened and warmed to keep ice from building up. The 'Bully' rig design has been developed by Frontier in cooperation with Shell's deepwater experts.

Some examples of ice load tests at Aker Arctic's ice model basin (Helsinki, Finland) are shown in the figures below.

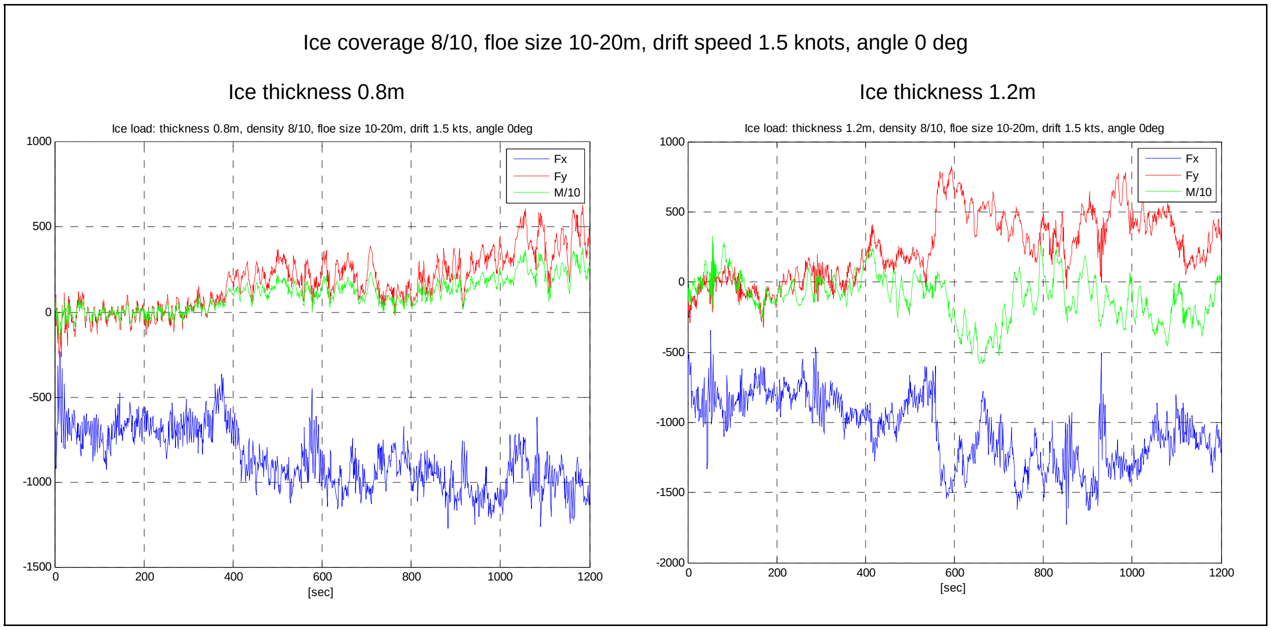

Figure 3 Ice loads at 80% concentration

Legend: Fx - longitudinal ice load
Fy - Lateral ice load
M - Turning moment (divided by 10)

There are some significant similarities between the two graphs which are worth pinpointing.

- 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 different resulting in a significant lateral force as well.
- Similarly we observe that a turning moment builds up. The point of attack for the lateral ice force will move and will not necessarily remain on the same side of the horizontal centre of gravity (close to mid ship). Hence the turning moment from ice may be either stabilising or destabilising the vessel heading and this can change over time.
- The increasing values of the forces are the result of ice building up around the hull.

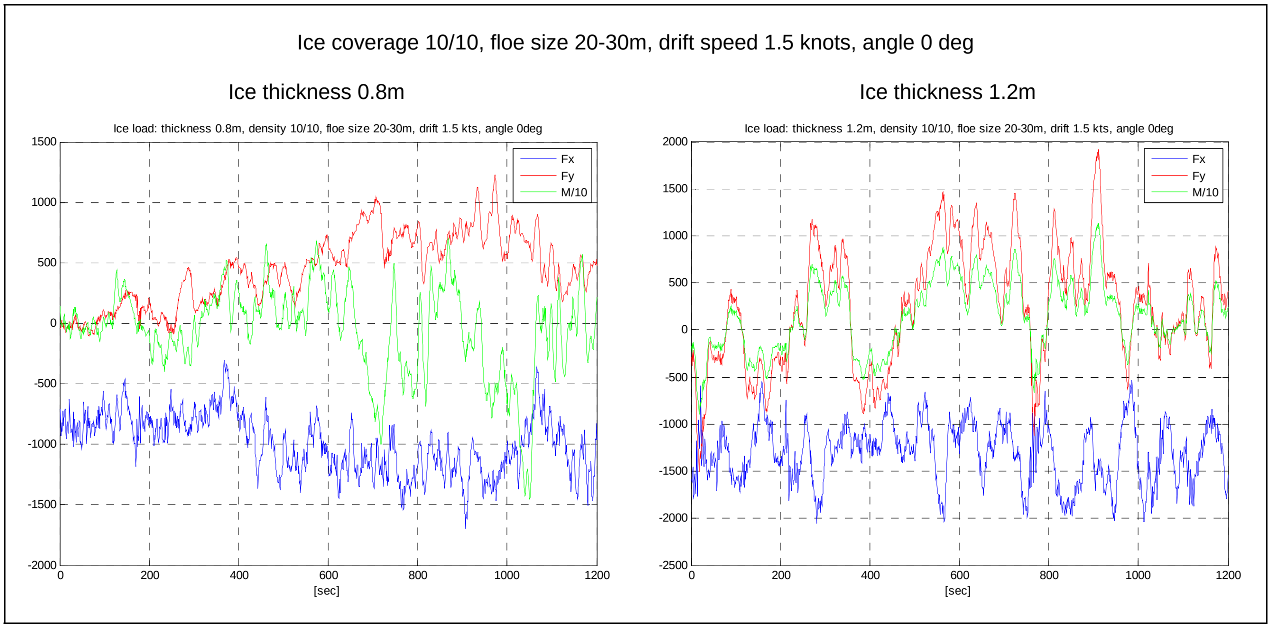

Figure 4 Ice loads at 100% concentration

Another observation comparing Figure 3 and Figure 4 is that by increasing the ice concentration and floe sizes both the average level of the ice forces increase as well as the dynamic (stochastic) components.

Ice management (the use of ice breakers to reduce the ice loads and potential impacts on the station keeping abilities of the vessel being supported - typically achieved by breaking the ice floes into smaller floes and/or deflecting the floes) will be of utmost importance to facilitate DP operations.

The ice drift direction changes with time. In the polar area the drift direction will change each 12^{th} hour similar to the tide. (Even though there is no tide at the North Pole). The changing of drift direction is one of the most challenging aspects of DP operations in ice conditions; the drill rig has to head up towards the drift all of the time. As the ice drift will continue rotate in the same directions special ice management means must be implemented to enable the vessel to rotate back to “neutral” now and then to avoid wind up of umbilicals and kill/choke line hoses.

Ice under the hull is another challenge. High speed ice floes propelled by the thrusters may do great harm to hull mounted equipment like hydro acoustic transducers as well as the riser. A good hull design with “built-in ice management characteristics” and correct draught setting are therefore essential. The figures below show the ice condition under the hull of “Bully” model before and after modification of the bow of the ship.

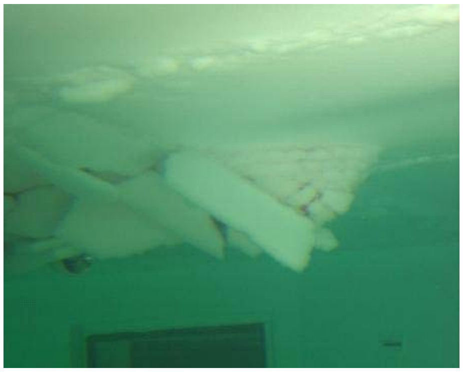

Figure 5 Before "built-in ice management"

Figure 6 After "built-in ice management"

Design basis of DP system for ice conditions

It is not a straight forward task to design a DP system for arctic operations. There are no established theoretical models for developing a DP capability plot to assess performance in different ice conditions. In short; there is no practically applicable theory from which we can make assessments on the ice drift load – our tool box is empty.

Much work has been done regarding mathematical modelling of ice in training simulators, but the focus point in this area is ice breaking to facilitate ice navigation (i.e. to facilitate transit of vessels). Modelling the ice field resulting from ice management to facilitate station keeping is still in nascent stages. However, many modelling studies and efforts to derive a practical usable time domain simulator have been carried out in the academic world and by some research institutes, e.g. SSPA in Sweden. No qualification of DP system against such a simulator has been carried out yet. Such simulators simulate a huge set of individual ice floes, each floe constitute a dynamic element with mass, added mass due to water as well as wind and current load characteristics. There will be friction between the floes as they collide and hit the ship hull. Breaking up of ice floes as they hit each other and the hull may also be modelled. This becomes really complex and requires large computer processing capacity.

A good dynamic ice simulator could in addition to be used for evaluating the design of DP systems, also be used for deriving effective ice management strategies.

To design the DP system one has to rely on tests in an ice model basin. The question is, however, how to interpret and utilise the results from such trial. There are no model basin that can run a free positioned DP vessel model similar to open water model test which are quite regularly carried out.

Generally tests are carried out in the way that the model is moved on a straight line with fixed speed through the ice, Figure 7. A DP vessel in real life will not move that ideally relative to the encountering ice. It is therefore reasonable to believe that peak wise (the stochastic component) ice forces recorded in the model basins are above what could be expected at sea.

Figure 7 Model test with Bully at Aker Arctic

Even though not exactly correct, our option today is to use recorded time series of ice forces as extra inputs to an ordinary DP system simulator. Doing so and applying normal DP system settings for open waters we will experience disputable results.
An example is shown in Figure 8. The ice load is shown in Figure 3 (left part). There are several observations regarding the station keeping performance:

- The excursions are so large that the validity of the simulation is zero. In this case the real ice forces would be totally different.
- The figure shows both the measured (blue) and estimated (red) position and heading in the DP control system, and we observe that the Kalman filter does not keep up with the peaks and lags behind dramatically.

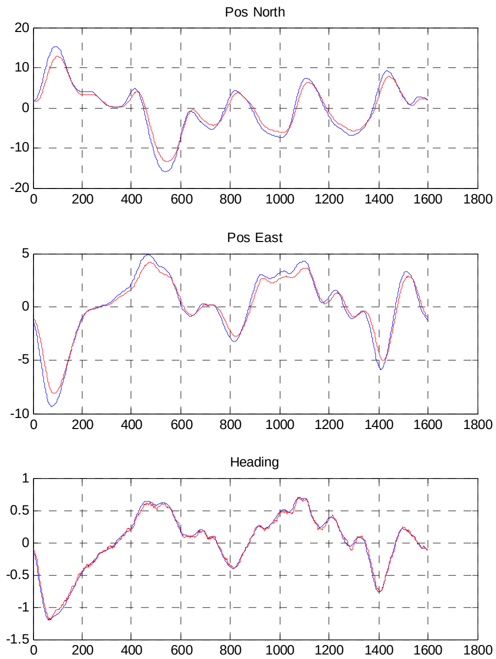

Figure 8 Simulated excursions (units: m, deg)

Conclusions from this simulation are that the DP control needs to be more responsive and improves its capability to track unknown external forces.
Reference systems and sensors are the sensing nerves of a DP system.

For GPS, the frontier areas are not that far North. The most northern relevant part is at about 72° latitude. At this latitude the GPS satellite coverage is fully adequate as shown in the figures below.

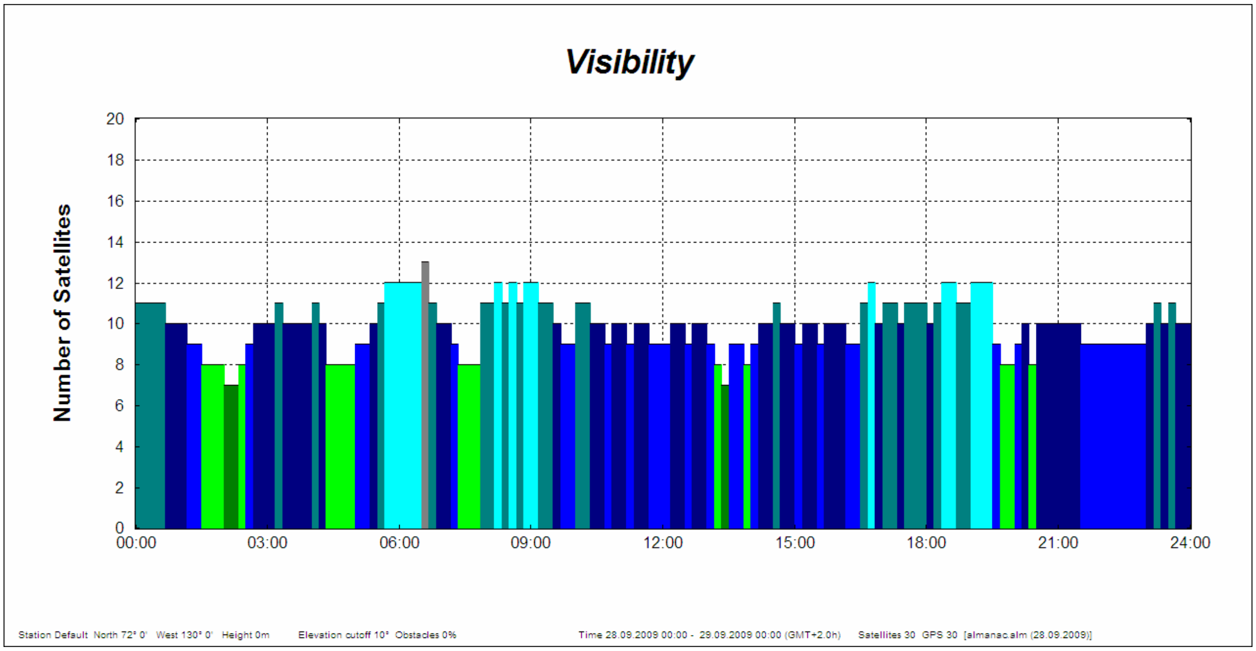

Figure 9 GPS satellites visible at 72°. From [2]

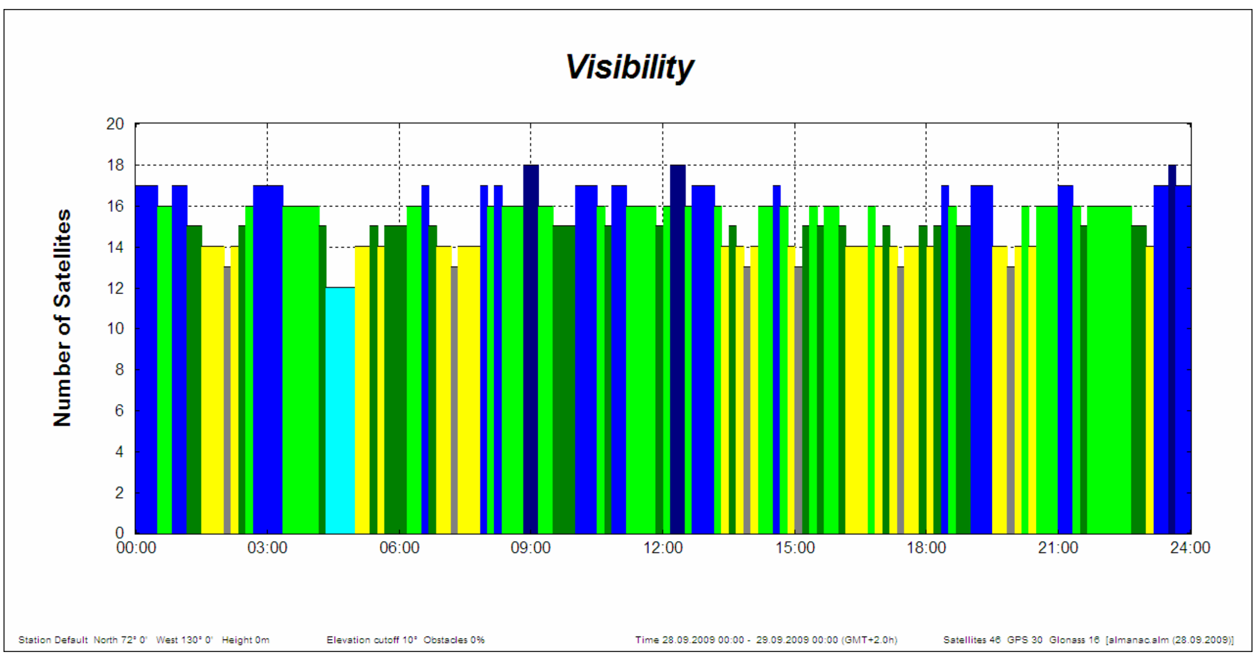

Figure 10 GPS and Glonass satellites visible at 72°. From [2]

For arctic DP operations acoustic positioning will be needed to comply with redundancy requirements. These will have to operate in the noisy ice environment with reflections from the ice.

Since water depth in these areas often are in the range of 35 – 700 meters new riser based reference systems may also become a reliable position reference system.

The gyro compass errors are a function of the latitude, proportional to 1/cos(Lat). Referring to the fields on the northern Norwegian continental shelf such Goliat (on similar latitude) no problems have been reported. At significant higher latitudes, GPS based compasses must be considered.
Wind sensors may become a problem if exposed to sea spraying; otherwise built-in heating should be adequate.

Adaptation of DP control system to ice conditions

The most important modification needed is to improve the Kalman filter's tracking capability. The present case does not improve significantly by just increasing controller (restoring and damping) gains. The effect of the tracking improvement is illustrated in Figure 11 with exactly the same inputs as used before.
The plots show very good performance with position and heading excursions of about 0.5m and 0.1 deg respectively. Referring to Figure 8 where the simulation results show large excursions and hence not in compliance with the conditions of the model test, the new case is in good match with "station keeping" conditions of the recorded ice load. Therefore the simulations of the latter case should be valid and give a representative picture of the thruster utilisation to cope with these forces. If it is necessary to increase the tracking capability as much as done in this case may be questioned. It is assumed that the ice loads are less rapidly changing when the vessels has the freedom to move slightly with the ice field. To conclude on this we need to make simulations with a dynamic representation of the ice loads interconnecting vessel motions with the ice dynamics or conduct full scale or model scale DP tests.

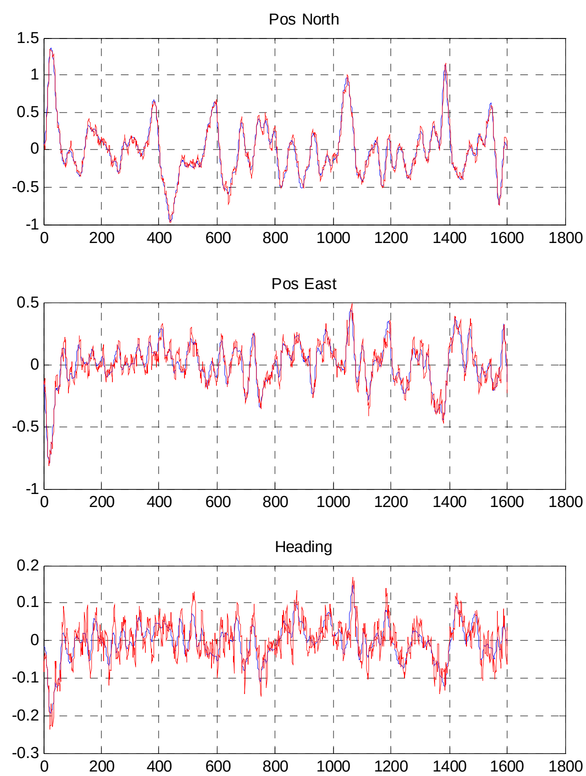

Figure 11 *Simulated excursions (units: m, deg)*

The tracking capability comes at the cost of less position/heading filtering. In practical terms this requires that position reference systems must be of very good quality (sub meter accuracy). With high quality DGPS system and acoustics such requirements can be fulfilled.

The improved tracking and responsiveness of the DP control will result in somewhat more aggressive thruster utilisation which also is required to be able to respond to the rapidly changing ice forces. An example of thruster command (red) and feedback (blue) plot for the same case is shown in Figure 12.

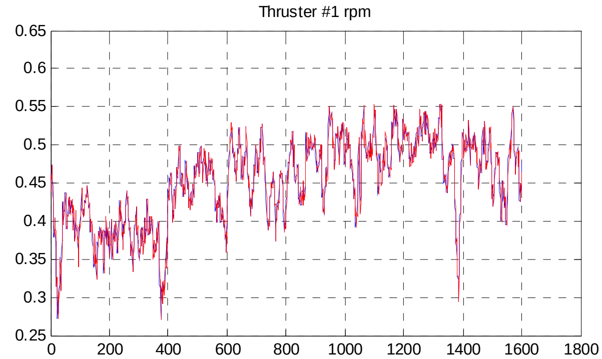

Figure 12 Thruster utilisation (fraction of full rpm)

Conclusions

Presently there is no experience in arctic DP operations in heavy ice conditions. Unfortunately we do not have sufficient tools (qualified by full scale validation) for readily designing a DP control system in terms of thruster sizing according to ice field condition specification. At present we need to rely on ice model basin tests. To carry out DP operation in the Arctic in a safe and effective manner, robust ice management is a crucial enabler. Provided efficient and effective ice management is available, DP operations should be feasible with a DP control system that is designed and capable of compensating for the quickly changing ice forces. This will however be at the expense of increased thruster utilization and additional wear and maintenance. Given that drilling activity in the Arctic, in ice conditions is a limited seasonal activity (not estimated to be more than three months) this could be a manageable issue.

References

[1] http://publications.iodp.org/proceedings/302/
[2] http://www.trimble.com/planningsoftware_ts.asp