DP In Ice Conditions - Challenges and Opportunities

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Abstract
Dynamic positioning has never been used in station keeping in difficult ice operation. Manual control of thrusters has been used to keep station during limited duration during scientific drilling expeditions, which have used riserless drilling for soil cores. Such operations have much less stringent station keeping requirements compared to drilling for hydrocarbons exploration in terms of allowable offsets, reliability, etc. DP would give, when possible, clear advantage in start up of the operation, disconnection and reconnection as it would be possible to get rid of an anchored system, which would again require quite heavy anchor handling operation.

The problems that will be challenging for DP operations in ice are:

- Forces acting on the vessel
- Forces caused by ice dynamics
- Turning Yaw moment
- Changes in ice movement direction
- Predictability of ice load behaviour
- New type of thruster control allocation
- Forbidden or required sectors for ice flow management
- Specific methods to lower ice loads
- Ice management and operational risk control

This paper discusses the problematic involved in these challenges based on the experience gained in ice operation in general and on various ice model tests in the subject during the recent years.

Background
Keeping the vessel at location for different purposes has become an industry standard in ice free operations. The advantages have been quite obvious, no big anchor operation is needed and for instance disconnection and immobilization can be done quite easily. Dynamic Positioning has been adopted mostly in water depths over 100-200m. In the Arctic region most of the explored areas are shallower than this. However, there is an interest as the exploration activity goes more north, the waters are getting deeper and ice conditions tougher to use dynamic positioning.

Dynamically positioned vessel in the high Arctic conditions would need an efficient Ice Management, IM system. In the industry there is today a push towards developing a DP system and an IM system to work together to allow longer drilling seasons as today hardly one well can be drilled during available operation window.

Operational aspects
Ice operation has always had challenges. Traditionally icebreakers have assisted cargo ships through ice selecting routes based on overall information on ice conditions and some local reconnaissance. In hyrdrocarbon drilling operation, the drilling unit needs to stay at the location during the whole period of operation. However, the operation may be divided into four major events:

- Transit to location
- Drilling at location
- Transit to next location
- Supply activity
The whole operation scenario need to be planned. This would set requirements to the whole fleet:

- Transit performance, alone/assisted
- Ice management operations, what kind of icebreakers are needed.
- Supply philosophy, will the drilling vessel be resupplied by separate fleet or go itself off the operation area to be resupplied

**Ice forces/dynamics**

In open water operation the expected forces acting on the vessel can be pretty well estimated as the wave and current action is known. In ice operation the forces induced by ice are related to the following main categories:

- Quality of ice; level ice, ridges, multi-year ice,
- Thickness of ice
- Ice concentration
- Size of ice floes
- Speed of ice; impact speed

The affect of these is quite difficult to predict. The change in the acting force level can be very rapid and the response time needs to be set accordingly.

In DP mode, and assuming the vessel is aligned with the ice drift direction, the thrust created by the propulsion of the vessel has to resist all the forces caused by the ice drift, which include not only the mean and oscillating force in the longitudinal x-direction, but also an oscillating force in the transverse y-direction and an oscillating yaw moment.

The forces are presented in Figure 1.

The force level in the y-direction can sometimes be almost as high as the force in the x-direction. As an example, if the maximum force in the x-direction is 8 MN, it is not unusual for the force in the y-direction to be oscillating between ± 4 MN. The turning moments can also be very high, especially in floe ice, where the moment arms can extend to the length of several ice floes.

The illustration of typical ice force behaviour in the x-direction (under the assumption that the vessel is aligned with the ice drift direction) has a large mean value with superimposed low and high frequency oscillations, as shown in Figure 2.
The propeller thrust has tried to adjust itself to correspond the ice force acting on the vessel. In the last part of the graph, the thrust is almost the same as the measured average force but the oscillating force is still higher than the total available thrust of the vessel propulsion. This makes it difficult to counteract with the thrusters which have limitations in their frequency response. The oscillating forces are difficult to predict and will make the design of the DP-system very challenging. To be able to maintain station with sufficient accuracy, the system may require acceleration sensors in addition to on-line position and velocity measurements. Figure 3 presents a time history where a ship was in ice flow direction. The ice was managed to , about 100 - 200 m size floes.

**Figure 2, Principle behaviour force time history in ice.**

The graph in Figure 3 clearly shows that the turning moment of the vessel at first was oscillating around the zero level and could be handled by the thrust of the propulsion. In the last part of the graph one ice floe hits the side of the vessel and the turning moment is increasing heavily. In this case the vessel has to correct the turning moment and some of the available thrust lost is to this operation.

**Figure 3, Principle time history for a vessel in direction of ice flow.**
Role of Ice Management in DP operations in ice
The station keeping capability of the DP vessel can be increased/made possible by Ice Management (IM) operation. As illustrated in the Figure 4, the purpose of the IM operation is to decrease the severity of ice conditions to so low level that it is operable by the DP vessel.
In practice this means that the approaching ice is broken into small floes before they reach the hull of the DP vessel and arranging space for the broken ice floes to pass the vessel (see Figure 5).

Figure 4, Purpose of Ice Management (IM).
The intensity of Ice Management needs to be so high, that it decreases the severity of ice conditions to the level, which is operable by the vessel in DP mode.

Figure 5, IM in practice. The IM vessels (IMVs) break ice to smaller floes from the sufficient area providing space for the ice floes to drift beside the DP vessel. The “effective width of IM track” \( (W_{\text{IM,eff}}) \) can be calculated by reducing the beam of the vessel from the IM track. Arrow indicates the ice drift direction.
The maximum size of the managed ice floes as well as the effective width of IM (W_{IM,eff}; see Figure 5) have great effect on the station keeping capability of the vessel. This is due to the ice floes should be so small that they are able to drift by the DP vessel without breaking and wedging against it or accumulating in front of it. In general, when the managed ice floes are small and there is plenty of space for the managed ice floes to pass the vessel (W_{IM,eff} is large), also the ice loads acting on the DP vessels are low. These two key parameters (managed floe sizes and effective width of IM) assign the basic requirements for the IM system, which is designed to protect the specific DP vessel.

From the point of station keeping capability of the DP vessel, the above mentioned two key parameters are however associated to each other because. To float easily around the DP vessel, the smaller ice floes don’t require as much space around the vessel as the larger floes. Sometimes also the ice thickness of managed may have significant effect on the DP capability on the vessel. Therefore, the requirements for the specific IM system can be indicated so that all of allowable combinations of these three key parameters are indicated. Example of how the requirement for the specific IM system supporting the DP vessel could be given is presented in the Table 1.

<table>
<thead>
<tr>
<th>Ice thickness</th>
<th>Maximum diameter of the managed ice floe</th>
<th>Minimum width of IM track</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 m</td>
<td>50 m</td>
<td>400 m</td>
</tr>
<tr>
<td>0.2 m</td>
<td>20 m</td>
<td>200 m</td>
</tr>
<tr>
<td>0.4 m</td>
<td>30 m</td>
<td>300 m</td>
</tr>
<tr>
<td>0.4 m</td>
<td>10 m</td>
<td>150 m</td>
</tr>
</tbody>
</table>

The numbers presented in Table 1 are very case specific and difficult to define in practice. Today real-life experience has started and limited experiments exist. DP capability is a sum of many parameters, which makes analytical estimation very rough. Model testing is a good tool that gives sufficiently accurate values for the design purposes.

As the station keeping capability of the DP vessel in ice is very limited, the role of IM is critical. To provide sufficient IM intensity and redundancy, typically more than one IMV are required. The principle procedure is that the first set of IMVs operates further from the DP vessel (so called primary IMVs) and second set operates closer to the vessel (so called Secondary IMV). The primary IMV(s) breaks the ice cover into larger floes and the secondary IMV breaks them smaller and the ice loads and especially their dynamical behaviour against the DP vessel is decreased.

Figure 6 illustrates how the IM operation could function. The secondary IMV may also “blow” the pre-managed ice floes sideways by utilising her propeller generated flow. This clears the ice from the track of the DP vessel and represents the most efficient IM operation. This operation requires relatively easy ice conditions/well pre-managed and/or intensive performance of the primary IMV(s) to work properly. This is why it is typically considered with open water DP vessel designs when extending operational window or during short term offshore operations like loading operations.

To work properly, the use of propeller wake requires effective flow direction control. This is best achieved when the Secondary IMV is equipped with Azimuthing thrusters. This allows efficient and quick directing of the water flow to the desired directions. The thrusters can also be directed towards divergent directions so that one thruster (two thrusters) is used in flushing ice while the other thruster provides balancing force to keep the IMV at position during the operation. Different alternatives regarding typical procedures performed with azimuthing thrusters are illustrated in the Figure 7.
Figure 6. IM performed by two IMVs. IMV operating further from the DP vessel breaks the ice to a smaller floes and the second IMV, which operates closer, blows the managed ice floes sideways so that the ice interaction with the DP vessel is minimized.

Figure 7. Typical "blowing" procedure alternatives performed with azimuthing thrusters. Left and middle: The IMV stays in position in front of the supported DP vessel. In the middle the ice drift speed is lower than in the left, which allows IMV to direct it's thrust more sideways without losing the position of the IMV. Right: blowing with three thrusters. Side thrusters are blowing and one is providing supporting thrust to keep the IMV's position.

In general, there are many different IMV operations that may come into question when protecting a DP vessel in moving ice. Therefore every potential IMV procedure alternative needs to be studied.
and planned on the case-by-case-basis well in advance before the actual execution of the operation. Due to the fact that the capacity of DP with the current equipment is limited, the requirement for the output of IM is challenging.

**Model testing possibilities for DP in ice**

DP testing in open water is quite well in hands but moving into ice we are facing quite different challenges. As mentioned earlier the force changes are quite rapid and the magnitude of change can be considerable. To date there isn’t any application to model the DP in ice. In ice model testing we have presently a few alternative test arrangements to estimate the forces coming from ice.

- Model fixed to towing carriage, variable ice drift angle,
- Model fixed to towing carriage, variable ice drift angle, model free to heel, heave and pitch,
- Model anchored, model free to move to any direction,
- Model anchored, restoring force/offset to be measured

The above are done with or without propulsion

- Manual DP where the model is kept at location controlling manually the thrusters.

**Model fixed to towing carriage, variable ice drift angle,**

The model is fastened from above to the towing carriage through a six-component and acting forces $F_x$, $F_y$ and $F_z$ are measured. The acting $M_z$ moment and arm may the be defined. Figure 8 shows the arrangement. Before ice tests the system is calibrated with outside weights and the model will be run in ice free basin to define the hydrodynamic forces. As the model is fixed the affect of the dynamic response of the model is not measured.

**Model fixed to towing carriage, variable ice drift angle, model free to heel, heave and pitch,**

The model is fastened from above to the towing carriage through a six-component and a cardan shaft which allows the model to heel, heave and pitch. The acting forces $F_x$, $F_y$ and $F_z$ are measured as well as the movement of the model. Figure 9 shows the arrangement.

**Model anchored, model free to move to any direction,**

In this case the model is anchored either from above or underneath. The measured quantities are mooring force and model offset. Figures 10 show the mooring arrangements.
Manual DP where the model is kept at location controlling manually the thrusters.

Here the model is free, only connection to carriage are electric cables. For station keeping a pin is attached to the carriage and a circular ring on the model representing allowed offset. Figure 11 shows the DP arrangement.

In manual DP tests the problematics are how the thrusters are controlled. We may have six (6) individually operated thrusters. We need to have either a multihanded person or as done today one person controls the power and the other thruster angles. This can be achieved by training and good cooperation/communication. In each test case some of the thrusters may be in fixed position with fixed power.

In model tests the movements of the model is recorded with “Qualisys” position recording system.

Propulsion

Typically a DP drillship has six (6) thrusters. In ice we need to take care of both x-direction forces and forces oscillating trying to turn the vessel. Ice may pile up around the vessel and even go under the hull, which may then cause interaction with thrusters, see Figure 12. This may cause the loss of available thrust, which may make DP operation impossible. Ice flowing around and interacting with propellers causes significant reduction in thrust compared to open water operation. If the propeller of ducted type, ice may completely fill and clog the nozzle, causing a total loss of thrust.
Such interaction between ice and propellers is possible even in relatively light ice conditions, and can cause significant loss of thrust for the DP system at random times, resulting in large offsets without warning. Existing DP system control algorithms are developed for open water and cannot address such loss of thrust. To make DP systems to function effectively in ice, it will be necessary to develop control algorithms mitigating the loss of thrust due to propeller interaction with ice.

**Availability of equipment**

The algorithms for DP in ice, we believe, can be developed with reasonable effort. What is still uncertain how to get the machinery; drive motors and thrusters to react in due course to the power and thrust needed. In sudden change of force level we do not have tens of seconds to react, but corrective actions need to be done immediately. Here is needed some really creative thinking. The problems might be; the engine power adjustment time, turning time of the thrusters etc.. We need to find the most efficient way to operate. It might be that all the thrusters are running at full power and the control would be just turning them to proper direction. It would be ideal to have one huge power “battery” and by just opening a “valve” the power could be adjusted without any limit.

**Conclusion**

To keep the ice forces to a reasonable level the drillship should be aligned with the ice flow direction and small angles up to c. 15° in change on heading against the ice flow could be possible. The DP system will need to cope with ice forces also in the y-direction and resist ice yaw moments. Almost in every ice condition some ice management is necessary to keep the ice forces low. In severe conditions the most efficient approach might be to position one icebreaker in front of the drillship, just like in escort operations and have the other icebreaker perform the circular breaking work some miles away. The channel made by the standby IM icebreaker will reduce the forces in all directions and minimize the turning moments to reasonable level.