DYNAMIC POSITIONING CONFERENCE
November 15-16, 2005

Thrusters

Ice-Breaking with Steerable Thrusters

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Ice breaking with steerable thrusters

Introduction

Since several years the requirements for offshore support, supply and constructions vessels are increasing, due to a constantly growing offshore market and oil exploration in varying environmental conditions. In the beginning of the offshore market, for sure high temperatures in Brazil, the Gulf of Mexico or the Persian Gulf was the biggest challenge for the equipment on those vessels. With the beginning exploration in the northern and Baltic sea the equipment has to face an opposite challenge, very cold temperatures and combined with that, ice.
An area which today really shows a growing demand for ice breaking supply vessels is the Caspian Sea, where, since the fall of the communist regime in the former USSR, a growing oil exploration takes place. In addition to ice breaking requirements those vessels have to face very shallow waters and for sure the requirements of DP classified vessels, which brings us to steerable thruster in ice or better ice braking with steerable thrusters. I like to give you a little overview about this application, which becomes more and more common, not only for mechanical thrusters but also for podded drives. Based on our companies experience my article is more related to the "smaller" ice classes which are more common for supply vessels which operate not particular as an icebreaker. Nevertheless I like to mention that already pure icebreakers are already fitted with steerable thrusters, mechanical or podded drives.

Operating in ice in general

Different ice classes

The table, you can find below, shows an overview about the general ice classes up to 1A super where "the real" ice braking starts. The given ice classes are all related to the Finish/Swedish Ice class which makes a comparison between the different Classification societies more easy. From the description of the ice classes you can see that it starts with a so called soft ice class which more or less has no significant impact to the thruster design. With higher ice classes the impact to the thruster design increases, i.e. strengthening of the housing and torque restrictions will be necessary, but that will be described later on. What I think may be of interest while looking at those descriptions, is the fact, that a certain ice class requires a minimum installed power, i.e. without having the particular power you can not get an ice class certificate, except for ice class II. The minimum required power also shows the significant step you take if you go from Ice class 1A to 1A super, which is a difference of about 1800 kW.
But what is the influence of the ice to the propulsion equipment?

Different ICE Classes:

Finish/ Swedish	GL	DNV	LRoS	BV	ABS	MRoS		CCS	RINA
						alt	neu		
IA super	E4	ICE 1A*	1AS	1A SUPER	1AA	ULA	LU 5	B1*	1A SUPER
1A	E3	ICE 1A	1A	1A	1A	L1/UL	LU 4	B1	1A
1B	E2	ICE 1B	1B	1B	1B	L 2	LU 3	B2	1B
1C	E1	ICE 1C	1C	1C	1C	L 3	LU 2	B3	1C
II	E	ICE-C	1D	1D		L4	LU 1	B	1D

Ice Influences

First of all by operating in ice you increase the drag resistance of a ship, which very simple leads to a higher power requirement to achieve the same speed as in open waters, which on the other hand means the engine or e-motor, should have a certain torque reserve.
Since you are in ice, you cannot avoid that broken ice will hit the propeller and increase the dynamical load at the gear set, shaft and propeller, in this situation the propeller blade acts like a lever which when hitting the ice delivers a certain moment to the gear.
But not only the propeller will be hit by ice but also the housing which on the other hand means the whole structure has to bear an increased dynamical load, further more you have to face a higher wear of the paint and the housing itself.
What about the cold environmental conditions in general, even those have an impact to your thruster, you get viscous lub oil which makes the lubrication of the bearings and the gear set worse. You also have to face an increased risk of condensation and a brittling of the material either the propeller or the housing.
Those are more or less the major direct influences of the ice. How can we consider those influences when using a mechanical thrusters or electrical pod?

Mechanical thrusters

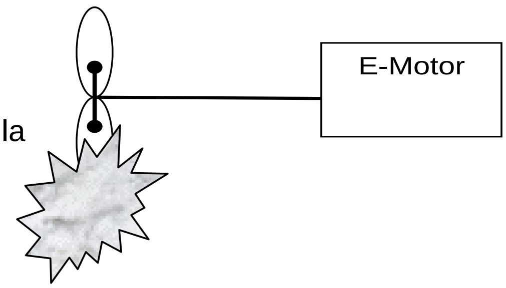
Ice class formula for gear sets

Before I come to podded propulsion I like to describe the mechanical thruster, as due to the gear set some more subjects have to be considered than for a podded drive even that some of the things I'm going to describe have to be taken into account for both systems.
Let's start with the ice class formula which considers a lot of the points discussed in the last chapter; the formula gives you the total torque you have to consider with a certain ice class for the design of your gear.

$$T_{ges} = T_N + \frac{m \bullet D^2 \bullet \frac{J_M^*}{J_M^* + J_P}}{1}$$

The formula considers the nominal torque as a basis and adds a safety margin for the ice class, which considers an ice class factor m, given by the class rules, the moment of inertia of the drive chain, the moment of inertia of the propeller and the propeller diameter.

In the little sketch below you can see what basically the source of that formula is; the propeller hits the ice and is blocked for a second, and causes a sudden high load in the gear which is reflected by the given formula. In the next chapter I'll like to discuss what the this formula can be used for.



Ice class formula for gear sets

If you divide the whole formula by T_N you get the ice application factor which is $k_{a\ ice}$ which is the basis for your gear design, the higher $T_{ges}/T_{N,}$ or better the ice application factor, the stronger the gear have be, e.g. for a standard thrusters this application factor is about 1.25. For an ice classed thruster in general it is bigger than 2, which in most cases means the thrusters or gear set you select has to be one model bigger than it would be under standard conditions.

$$\frac{T_{ges}}{T_N} = \frac{T_N}{T_N} + \frac{m \bullet D^2 \bullet \frac{J_M^*}{J_M^* + J_P}}{T_N}$$

But what can you do to improve the situation, with knowing this formula we can play with the particular factors, to adjust our thrusters as good as possible.
The easiest thing is to increase the allowable torque of the thruster by using a larger model which on the other hand most probably has the highest cost impact of all measures.
An other simple measure would be, instead of using an open propeller, to use a ducted propeller which decreases the ice class factor m, but on the other hand bears the risk that ice could block your nozzle, whereas with a steerable thrusters you may have the option to use one thruster to blow against the other one to remove the blockage.
The propeller diameter, as you can easily see, has a strong influence since it is used by square in the formula, if we decrease the propeller diameter we decrease the result of the formula which may lead to a smaller gear set, but we for sure have to consider the propeller housing relation and the propeller load as a limit. What else can be done, the propeller can be made heavier to decrease the upper left part of the formula through the increased moment of inertia, or you can try to decrease the moment of inertia of the drive chain.
The formula we discussed now is only of interest for mechanical thrusters, since it is related to gears, the next one has also to be considered for podded drives.

Ice class formula for propeller shafts

The basic philosophy of this formula is that the propeller blade shall break before the propeller shaft and gear set is overloaded. The diameter of the propeller shaft is basically determined by the material hardness of the blades and the shaft and of course by the resisting force of the blade.
The question is, what can be done to decrease the propeller shaft diameter, to

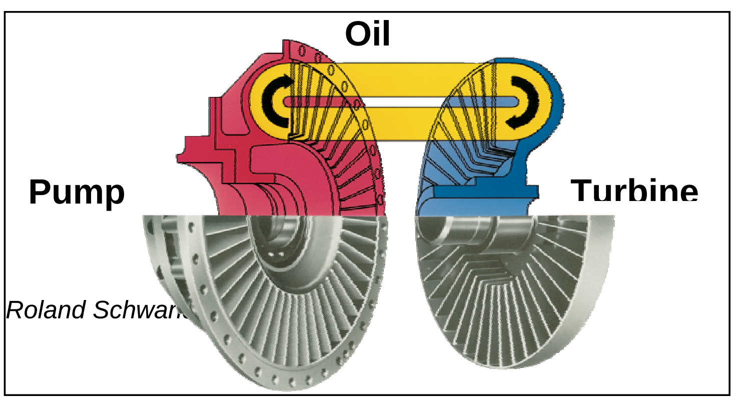
$$d_W = 11.5 \bullet \sqrt[3]{\frac{\sigma_b \bullet ct^2}{\sigma_y}}$$

make sure that it still fulfils the given requirements, but also doesn't force us to choose a bigger thrusters model, we can either increase the number of propeller blades or use a hardness increased propeller shaft material. A higher number of blades lead to weaker blades, which results in a smaller resisting force, a better propeller shaft material increase sigma y which on the other hand decreases the result of the formula.

Improvement measures

Let's now summarise and detail what can be done to adjust the thruster as good as possible to the ice class requirements.
The propeller diameter can be decreased down to a certain amount considering always, propeller load and propeller thruster housing relation, with a smaller propeller diameter the propeller speed can be increased, which on the other hand decreases the nominal torque.
A ducted propeller gives higher thrust at low speed during manoeuvring in the ice and on the other hand decreases the ice class factor which is considered in the gear set formula, always keeping in mind that there is a certain risk of blocking the propeller through ice by using a nozzle.
An increased tip clearance allows the ice a more or less free driftage above the propeller.
A relatively light electric motor or diesel engine with a small moment of inertia has also a positive influence to the ice torque, as well as a short, weight saving shaft arrangement.
A further instrument which has a positive influence to the ice torque is a fluid coupling which mechanically separates the motor from the thruster and can therefore decrease the moment of inertia of the drive chain drastically with the result that in some applications you can gain 10% more input torque, compared to an arrangement without a fluid coupling.
Since a thruster sticks out of the hull, during ice operation high bending moments can occur, which means a decreased propeller arm length, the distance between propeller shaft centre line and power input shaft centre line, should be as small as possible.
To improve the resistance of the underwater part of the thrusters against abrasion it is possible to use a special paint or Niresist cast which increases the housing life time drastically.
The last improvement I like to mention is a stainless steel propeller which has a higher wear resistance than the standard bronze propeller.
As the mentioned fluid coupling is a very specific instrument which may not be well known I like to give you a little introduction.

Fluid coupling



Prof. Dr. Ing. Föttingers ingenious idea was utilized for the first time in 1909, power transmission without mechanical linkage.
The fluid coupling consists in general of a pump, a turbine

and a fluid in between the pump is at the engine side and the turbine on the thrusters side as soon as the engine starts the pump drives the turbine and secures the power transmission, with for sure a certain slip. The advantage for ice applications is now that, through, the mechanical disengagement of the motor from the thruster a considerable amount of the drive chain moment of inertia is no longer considered in the gear set formula. This in some case avoids a step up to the next thruster model.
The fluid coupling further more has the advantage that it can be used to separate the motor from the thrusters during a heavy propeller blockage, just by blowing out the oil.

Electrical pods in ice

After we looked into these different aspects of mechanical thrusters in ice I now like to come to podded drives.

The picture shows the ARKONA a multipurpose ice braking vessel which operates in the Baltic Sea and is fitted with two 2000 kW electrical pods, she operates as a small sister ship of the "NEUWERK" which is fitted with ducted mechanical thrusters and operates in the Northern Sea. Those two vessels have the same ice class and similar operational areas which gave a good chance to make a comparison between both systems. Actually aside from the well known difference in normal operations between mechanical thrusters and podded drives we found not much difference which was caused by the ice operation.

Icebraking multipurpose vessel Arkona

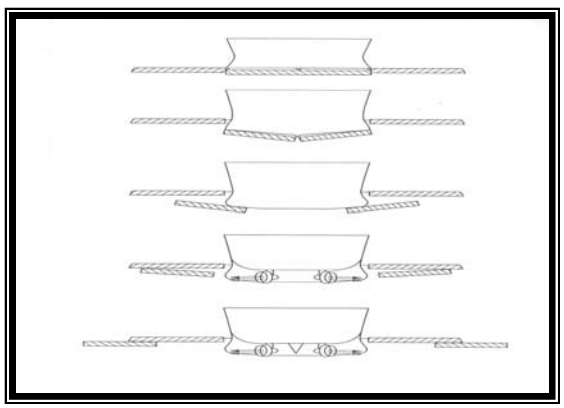
But where is the major difference between the mechanical thrusters and the podded drive in ice? It is for sure the gear set which at the mechanical thrusters has a major influence to the selection of the correct thruster model and restricts the input torque of the thruster.
With a podded drive the propeller is directly linked to the motor which means you have "only" to consider the moment of inertia of the electric motor which may be higher, compared to the motor of a mechanical thrusters, due to the slow speed of the motor, but you can neglect the drive chain in between since it is not existing anymore, i.e. on the other hand for a certain ice class the nominal torque for those podded drives can in general be higher than with a comparable mechanical thruster.

Schottel SEP2 in an ice braking vessel

Due to the fact that we have no gear set the critical point at the podded drive is the connection between rotor, propeller and shaft.
A further difference between the standard mechanical thruster and the podded drive which counts during ice operation is the design of the housing. Most mechanical thrusters have a more simple not necessarily hydro dynamically optimised housing as they are designed for speeds up to max 14 to 15 knots, most of the podded drives are designed for higher speeds and therefore have a slim hydrodynamic optimised housing. In ice operation the slim housing of the podded drive has the big disadvantage that it increases the bending moment the thrusters has to bear, that has to be considered during the design of the thruster to avoid problems with the steering gear or bearing.
Other than that there are no major difference between mechanical thrusters and podded drives which are caused just by the ice operation.
Where are now the advantages of the steerable thrusters in ice operations, either podded drives or mechanical thrusters?

Advantages of steerable propulsion in ice operation

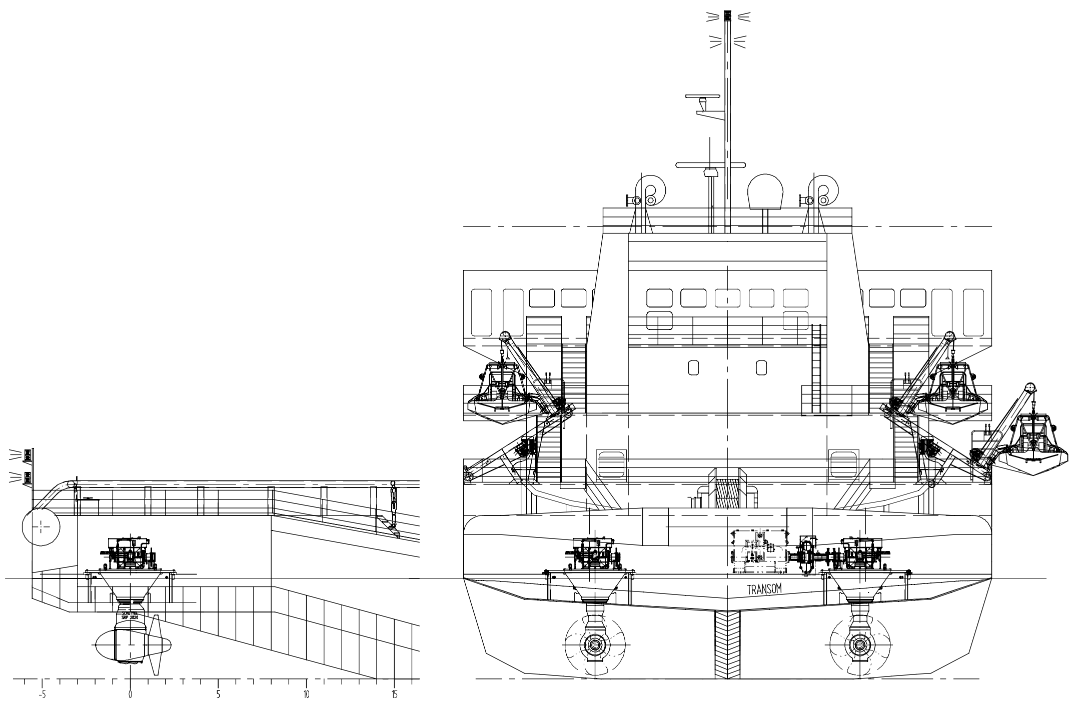
As always the big plus is the high manoeuvrability a vessel gets with a steerable thrusters, a standard manoeuvre which is done by ice braking vessels is the 3 step turning manoeuvre which we measured during the ice test of the "Neuwerk" which took about 3 min, whereas turning on the spot, which is only possible with steerable thrusters and took about half the time.
For sure those manoeuvres depend also on the ice conditions, but it clearly shows that a steerable thruster also in ice gives an advantage in manoeuvrability.
An other key advantage of steerable thrusters we found during different ice tests is that the thrusters can be used to push the broken ice below the remaining ice field which ensures that an ice free channel can be created and maintained sufficiently broad for a certain time. This method is also know under the title ice management



Ice management

The so called ice milling is a further advantage we see, a vessel which is fitted with a pull propeller can go backwards into the ice and use the propeller to mill the broken ice. You have to have a pull propeller arrangement for this operation to make sure that propeller goes first into the ice and protect with that also the structure of the thrusters being hit by large ice piece, which works also during operation ahead since the propeller in that mode also looks ahead.
A further advantage of this installation is the fact that the thrusters in some way lubricate the area of contact by forcing a stream of water between the ice and the hull, and in this regards works like the well known water spray system

The picture on the rigth shows an ice class 1A super classified shallow water supply vessel during ice milling operation in the Caspian Sea.
The drawing of the propulsion unit of this vessel shows how small the propeller is in comparison to the housing of the thrusters, it also shows that the thrusters stick out of the hull only to its minimum to avoid high bending moments. On the right side you can see the electric motor linked to the thrusters via a fluid coupling, which on this vessel avoided a step up in the thruster model



Summary

Even that ice braking is not a very common application in offshore business you can see that it becomes more and more important with the growing exploration also in remote and environmental critical regions like the Caspian Sea. I hope this gave you article gives a feeling how specific ice braking is for a steerable thruster and what requirements occur with this task. It now should be clear that a steerable thruster is able to fulfil this task and can provide certain advantages but for sure has to be adjusted in the right way.