Development of Azipod Propulsion for High Power Arctic Offshore Vessels

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Development of Azipod Propulsion for High Power Arctic Offshore Vessels

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Abstract

The traffic volumes in arctic waters are expected to grow rapidly in the near future. New fleets of oil and LNG carriers as well as ice classed drillships and offshore supply vessels and icebreakers with high ice-class are needed for the transportation and oil exploration. The recent growth in activities in the Arctic region has materialized in several projects, where Azipod propulsion system is playing an important role in making the projects technically possible and economically feasible. Azipod propulsion offers a very attractive and efficient propulsion solution for most of these vessels. However, there is an evident need for azimuthing propulsion units with power in excess of 15 MW with highest ice classes, such as the "new" IACS PC1. In response to the market demand ABB Marine has recently developed an Azipod propulsion concept with high power to meet the requirements of the high arctic ice classes.

This paper will outline some important design considerations during the development work, such as:

-different ice class rule requirements
-need for overload / overtorque capacity of the electric propulsion motor in ice
-utilisation of measurements from full-scale ice trials with podded propulsion

High power Azipod propulsion systems help the shipowners to access opportunities in the Arctic areas by providing safe and reliable operation in the region. With ABB electric propulsion and Azipod units, the shipowner gets equipment designed to meet the demanding Arctic requirements and which is proven to be reliable in ensuring safe navigation in the sensitive Arctic seas.

Azipod propulsion in icebreakers

The Azipod propulsion system enables the vessel to break ice using the revolutionary Double Acting (DA) principle, Heideman et al (1996). The DA principle means that the vessel can be designed with the stern optimized for icebreaking and the bow optimized for another condition, such as a bulbous bow for open water or a heavily ice-strengthened bow for multiyear icebreaking by repeated ramming. It is well known that when going astern the ice resistance of a ship will decrease as a result of the propeller flow around the aft part of the hull, which, among other factors, reduces friction. However, ships equipped with conventional rudders are difficult to steer when going astern. This problem does not affect ships equipped with an Azipod system, as the propeller thrust can be steered to any direction.

This DA principle has already been applied to several ships and ship types. Good examples include the Neste Oil tankers Tempera and Mastera, Juurmaa et al (2002), Norilsk Nickel's six icebreaking cargo vessels (Figure 2), Tyukavin (2010) and icebreaking PSV's in Sakhalin all equipped with Azipod propulsion.

A ship traveling through ice makes a channel. When many ships travel in the same channel, broken pieces of ice gradually accumulate on the sides of the channel, forming thick layers of ice. This thick layer tends to keep ships within the channel. One of the biggest problems with channel operation is how to get the icebreakers and particularly the assisted vessels out of the ice channel in order to avoid collisions between ships The Azipod system greatly improves the maneuvrability of ice going vessels. The turning unit allowes the propeller thrust to be directed so that breaking out of an ice channel becomes relatively easy.

Today the ice-strengthened Azipod vessels are sailing practically all over the world. The main operation areas are as follow, see Figure 1:

- Baltic Sea
- Russian Arctic areas
  - Barents Sea
  - Kara Sea
  - Sakhalin Island
- Caspian Sea
- Great Lakes

At the moment the cumulative operation hours of the high ice class Azipod units is over 1 Million hours.

Figure 1.Icebreaking vessels equipped with pod propulsion.

Figure 2.Norilsk Nickel icebreaking container carriers have sailed independently through the northern sea route.

Operational Experience with pod propulsion

During the past twenty years a great number of vessels intended for operation in ice covered waters have entered service equipped with ABB Azipod propulsion units. Azipod system has proven itself in the harshest marine environments. In the beginning of year 2012 the track record of vessels with Azipod units was:

Operation hours	>7 000 000 hrs
Azipod units delivered	close to 250
Ice class Azipod units (>1A Super)	close to 50
Icebreaking vessels with Azipod	close to 30
Vessels	>110

Azipod propulsion has been selected also for many other types of ships, such as cruise ships, ferries, megayachts, offshore supply vessels, research vessels and drilling rigs. For all the vessel types the common benefits of Azipod propulsion are improved fuel economy and excellent maneuvrability. More than thirty different shipyards have applied Azipod propulsion for their newbuildings and a great number of shipowners have gained extensive experience of its operation, maintenance and crew training.

Based on the operational experience gained it is possible to derive at some conclusions of the feasibility and reliability of the Azipod concept. Below is discussed at the experiences and lessons learned from vessel operations, focusing on system availability and reliability, and on the technical developments and improvements done over time.

The Azipod product family

The Azipod product family consists of two basic product series. They are based on different technologies and solutions although their basic system principle is the same. The Azipod C series is for the lower power range up to 4500 kW. Azipod C comes in two versions; an open propeller version for ship applications and a nozzle version for high thrust applications, such as for drilling rigs or drilling vessels. The Azipod V series is for higher power of up to 20 MW and above. The Azipod V series has versions both for open water and ice conditions. Whereas Azipod V is based on the product developed in the early 1990's, Azipod C was introduced in the beginning of this millennium. The newest generation, Azipod X, or Azipod XO which has now replaced Azipod V in open water applications, was launched for sales just recently.

Operator experience

What regards fuel savings and ship maneuvrability, the expectations set by ship operators have typically been fulfilled or exceeded. Particularly the ship captains have been enthusiastic about the ease of operation and the good maneuvrability of their vessels. Concerning energy efficiency, some operators have claimed fuel savings of more than 20 % compared to their vessels provided with conventional propulsion. The Azipod concept has been recognized as an unbeatable concept for icegoing ships. It has also proven to suit perfectly for DP operations. Dedicated ship operation simulation facilities have been set up to provide training in how to operate ships with Azipod propulsion.

Seven million operating hours with Azipod propulsion over a time span of almost two decades has resulted in a vast experience on how the system shall be used and maintained for trouble-free reliable operation, Figure 4.

We have identified the components and systems that are critical for undisturbed ship operation. These need some special attention when designing and selecting the solutions as well as in their operation and maintenance. Technical issues have been approached through systematic analysis and root causes for unwanted behavior have been identified. New solutions have been developed, over the years, when necessary.

The maintainability of the propulsion unit has proven to be an essential factor in providing reliable uninterruptable operation of the critical components of the system, which are the shaft seals, shaftline bearings, steering system, slewing seals, slewing bearings and the propulsion motor itself. These components and their subsystems are discussed below, see Figure 3.

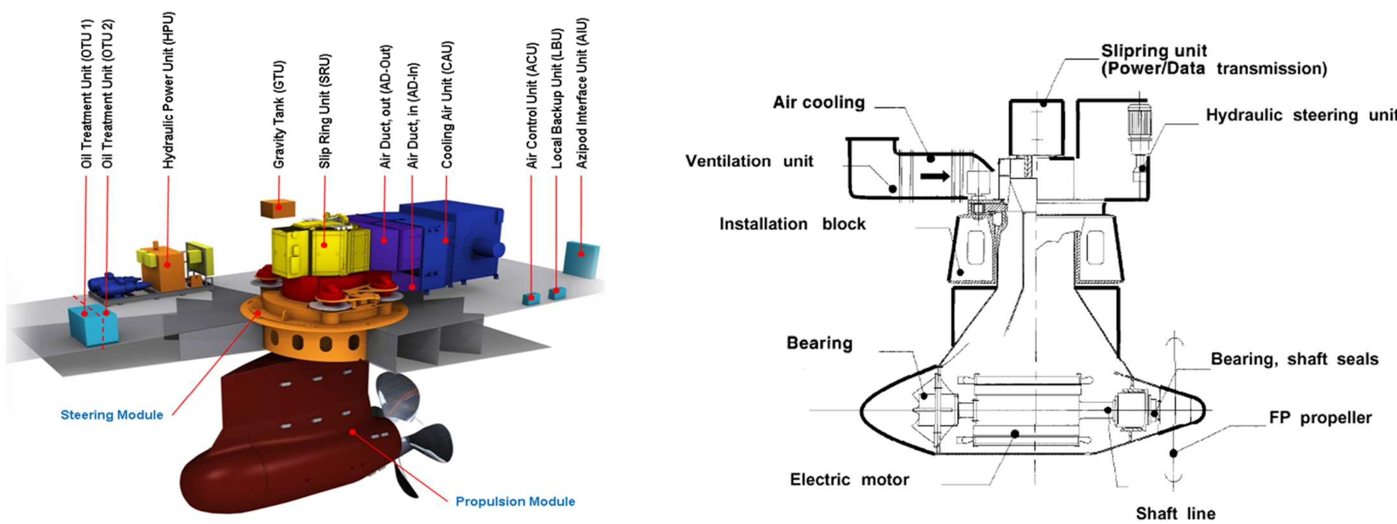


Figure 3. Layout of Azipod propulsion unit.

Shaft seals

In Azipod C the propeller shaft seal assembly combines a water lubricated face type seal and two grease lubricated lip-type seals running on a steel liner. The set air pressure inside the motor prevents sea water from entering into the propulsion module. The solution has proven to be reliable.

In Azipod V the seal is formed of inner and outer lip-type seal rings. Between the seals there is the propeller bearing oil sump, which is partly filled with oil. There have not been any major issues of leakages due to the shaft seals. However, the Azipod V seals have been continuously improved to meet the increasing environmental requirements. Thus the Azipod XO has a new shaft seal design where the bearing oil seal is totally separated from the water seal. The new design brings with it better maintainability, increased life time and the possibility to use biodegradable lubrication.

Propeller bearing

In Azipod C the propeller bearing is a grease lubricated cylindrical roller bearing directly cooled by sea water. There have not been any major issues with the propeller bearing and the same design is used as in the original design.

In Azipod V the propeller bearing is a splash lubricated cylindrical roller bearing. The cruise ship ms Paradise, which has a Azipod V propulsion system, experienced a bearing failure in year 2000. After a deep root cause analysis a complete bearing system re-design was done. All the ships delivered with the same bearing system were modified according to the new design in their following scheduled dry-docking. The new design has functioned flawlessly and that design is used also in the new Azipod X product.

Thrust bearing

In Azipod C the thrust bearing is an oil sump lubricated spherical roller bearing directly cooled by sea water. There have not been any major issues with the thrust bearings and the same design is used as originally selected.

In Azipod V the propeller bearing is a splash lubricated spherical roller bearing. The Azipod V thrust bearings have faced some limitations regarding wear, mainly in the bigger power range. Two new thrust bearing designs have been developed and are being heavy-duty tested for better reliability and maintainability, one for Azipod V and one new hybrid bearing for the new generation Azipod X. The hybrid bearing design includes a radial roller bearing and a slide thrust bearing. The results so far have proven to be good and they satisfy all the requirements set.

Steering system

The Azipod C steering system is fully electric whereas Azipod V has a hydraulic steering system. Both systems have proven to be reliable and fulfill their technical requirements. Thanks to the good experience from Azipod C with improved efficiency, reduced noise and vibration and simpler yard installation, also the Azipod X generation received an electrical steering system.

Slewing bearings

In Azipod C there have not been any issues with the slewing bearing. Only some failures have been recorded on Azipod V. Root cause analysis pointed at failures in connection with heavy operation in open water condition. A new steering module design with better maintainability was designed for the Azipod XO. Now the slewing bearings can be replaced from below, with minimised work and time consumed.

Propulsion motor

The propulsion motor of the Azipod C is a permanent magnet synchronous motor directly cooled by sea water. The majority of the Azipod V motors are brushless synchronous motors. There are some lower power deliveries with an induction motor. These motors are air cooled with an air-water heat exchanger placed in the ship. The motor type selections have proven to be justified both from efficiency and performance points of view as well as when looking at reliability.

Service aspects

In order to avoid system failures of Azipod propulsion much effort has been directed at improving maintainability as well as on developing condition monitoring features. This has also helped clients in providing reliable operation of their existing Azipod systems. As an example the new Azipod X design (except the smallest unit) allows the change of shaft seals and thrust pads from inside the pod unit without the need to dry dock the vessel. A condition monitoring system for the critical elements like bearings, seals and lubrication oil etc has been developed. This system can be used locally and also remotely.

Based on our experience from systematically gathered data the component wear and failure phenomenon is now understood in detail. Combined with continuous condition monitoring it is possible to forecast the component lifetime well in advance so that ship owners can plan the overhaul schedules in good time before there is any risk for failure.

Extensive cooperation with ship operators and shipyards on a wide range of different Azipod applications for various demanding operating environments have complemented our understanding of the Azipod concept. Mostly the Azipod propulsion systems exceed expectations resulting in customers selecting Azipod also for their consecutive newbuildings.

We have identified the components and systems which are critical for undisturbed ship operation. These need somewhat more attention what regards their design, selection, operation and maintenance.

The technical challenges have been approached by systematic analysis and the root causes for some unwanted behavior have been identified and new solutions have been developed where necessary. These improvements have proven to be correct and successful.

The Azipod units installed on icegoing vessels operating in the high Arctic have not encountered any failures due to heavy ice loads.

Our conclusion is that a correct operation of the vessel combined with maintenance routines according to defined instructions are essential to guarantee faultless operation of the systems. Good maintainability and condition monitoring have proven to be efficient in optimizing ship owners' operations and maintenance work. As per today

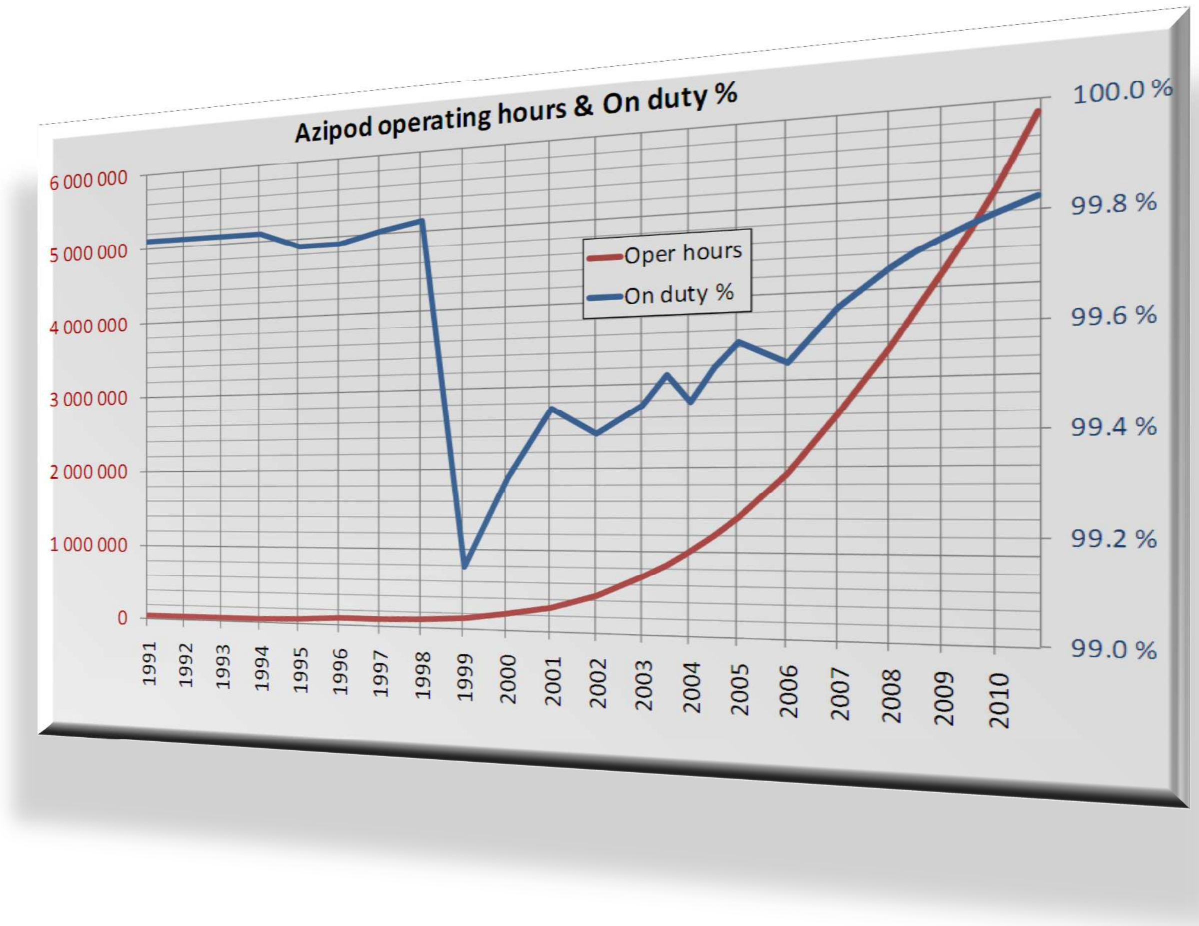


Figure 4. Azipod operating hours and on-duty %.

The Azipod propulsion and thruster units are designed for five years drydocking and maintenance intervals. For some applications a longer maintenance interval of even up to ten years has proven justified. This conclusion is based on results of a well-documented operational and maintenance history.

Development of high power ice class Azipod

The traffic volumes in arctic waters are expected to grow rapidly in the near future. New fleets of oil and LNG carriers as well as ice classed drillships and offshore supply vessels and icebreakers with high ice-class are needed for the transportation and oil exploration. The recent growth in activities in the Arctic region has materialized in several projects, where Azipod propulsion system is playing an important role in making the projects technically possible and economically feasible. Azipod propulsion offers a very attractive and efficient propulsion solution for most of these vessels. However, there is an evident need for azimuthing propulsion units with power in excess of 15 MW with highest ice classes, such as the "new" IACS PC1. In response to the market demand ABB Marine has recently developed an Azipod propulsion concept with high power to meet the requirements of the high arctic ice classes.

Ice classes

Very often laymen but also shipping people in general have a misconception that a certain ice class also guarantees the performance of the ship in ice, e.g. icebreaking capability. Fundamentally, the ice rules of different classification societies or authorities aim at safe and reliable operation in the intended operation area with suitable propulsion system and sufficient machinery power to match the increased resistance of the ship. The ice class can be considered as a generalized characteristic of a vessel's ability to operate in ice.

The actual performance of the vessel can be determined by theoretical calculations or model tests in ice model basins. Understanding the requirements of different ice class rules is fundamental when designing ice going vessels. For propulsion systems there are requirements not only for power, but for propeller, shafting, rudder/pod hull scantlings, steering mechanics, sealing systems, overtorque etc.

All the major classification societies have their own ice rules, with ice classes for various ice conditions. With a few exceptions, the classification societies are using the Finnish-Swedish Ice Class Rules (FSICR) for sub-arctic ice conditions. Generally, the notations differ between the classification societies, but they actually refer to the same FSICR rule. For Polar or Arctic ice classes these societies have their own ice rules and interpretations. These rules differ from each other since they are based on different scenarios and philosophies resulting in quite different requirements for a vessel intended for a certain area of operation depending on which society you choose.

The comparison of different ice classes is difficult, as different rules emphasize different technical aspects. Several comparison tables have been created e.g.Appolonov et al (2005), but one has to remember that comparison tables are always an approximation of the equivalence. On a detailed level the differences can be significant. For instance, an equivalence table based on hull strengthening looks different from a table based on machinery.

To overcome the confusion that the variety of design rules creates, development work for common ice rules —the "Polar Code"— has been going on since 1995 within the International Association of Classification Societies (IACS). Even though ship owners, shipyards and equipment suppliers would welcome one uniform set of ice rules, achieving such a uniform set is not so straightforward. Different technical philosophies of the IACS members tend to lead to very conservative ice rules as all the members have to agree on the new rules. Too much conservatism could hinder the development of ice-strengthened vessels. The first version of IACS Unified Rules, generally referred to as Polar Class (PC) rules has been published and it is now adopted by all IACS member societies. Most societies publish the PC rules as a separate appendix along with their own Polar or Arctic rules.

For propulsion manufacturers the new PC rules present a challenge. The rules are descriptive by nature and nothing specific is said about the dimensioning of appendices to the hull, such as rudders, struts or podded propulsors. As a consequence of this most major classification societies have published or started to work on their own rules for podded propulsors. For this reason it is important for propulsion equipment manufacturers to cooperate with the classification societies in an early phase of a project with a PC class notation to develop a common understanding of the ice loads on the propulsion unit. Over the years ABB has made several full-scale measurement campaigns onboard Azipod vessels to gain information about the actual ice loads acting on the Azipod units and to understand the best operational practices with Azipod vessels.

The first attempts to design and build ships according to the PC rules have revealed shortcomings in the PC rules and amendments to the rules are expected in the near future.

Overtorque

Electric propulsion is common on vessels intended for operation in ice and in particular on icebreaking vessels, The electric power plant and electric drive system are integral parts of the Azipod concept. The electric propulsion offers excellent torque capability over the whole rpm range. This means that full power is available from bollard pull to trial speed in open water. Propulsion motor high torque at the propeller shaft is essential when the propeller is surrounded by ice. Unlike diesel engines, electric motors can be designed with a torque characteristic that gives maximum torque at low propeller speed, even when the propeller is stopped, Hänninen et al (2008).

Icebreaking vessels of higher ice classes generally are designed to generate more torque than required in bollard pull. This is called overtorque and is it is used to enable the electric propulsion plant to run at constant power when the propeller rpm decreases below bollard pull rpm under the influence of ice loads.

The overtorque is explained in the Figure 5. When the propeller encounters ice loads the rpm starts to drop along the constant power line. When the rpm drops below bollard pull rpm the machinery starts to utilize the overtorque capacity. Sometimes the ice load is so big that the rpm continues to drop until the maximum motor torque is reached. If the ice load continues and the rpm still drops the power will be start to decrease because the control system follows the horizontal constant torque line. This means that the prime movers will have to reduce power output. When the ice load eases the rpm starts to increase and the power control system asks the prime movers for more power. The power increase rate is depending on the power ramp of the prime movers. If the propeller encounters more ice loads before the power is restored there is a possibility that the power drops so low that the vessel stops. If this happens too often it might become an operational issue for the ship.

The dynamic behavior of the prime movers actually plays an important role in the design of the propulsion system. The power ramps of modern diesels are generally much slower than before due to exhaust emission considerations. Furthermore, the move to gas fuelled diesel makes the power ramps even slower and several measures to mitigate the effects have been brought forward.In order to avoid prime mover power drops the excessive energy generated by the prime movers needs to dumped or stored somewhere during intensive ice loads. There are load banks, either water or air cooled, that can be used to dump energy or supercapacitors or condensators that can store energy and release it when required, Hänninen et al (2012). The dynamic behavior of the power plant should be simulated in order to determine the actual need for these measures.

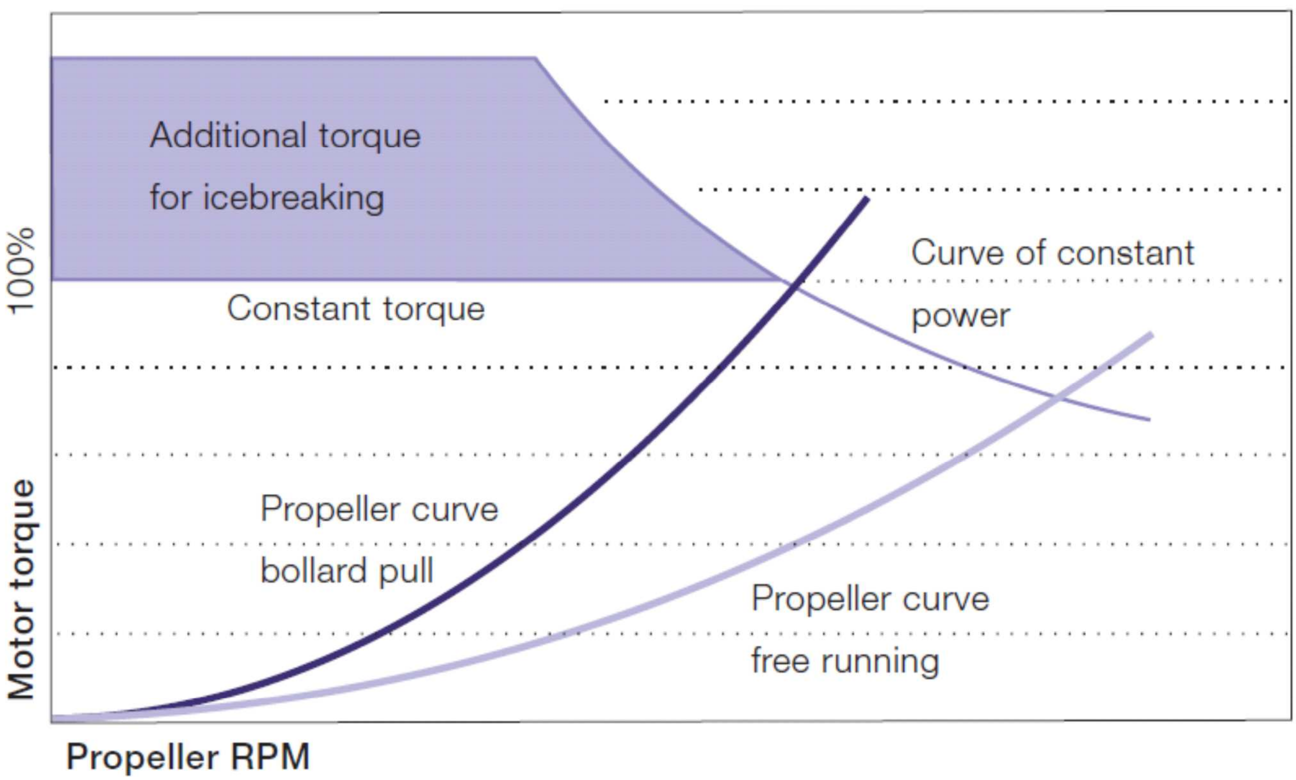
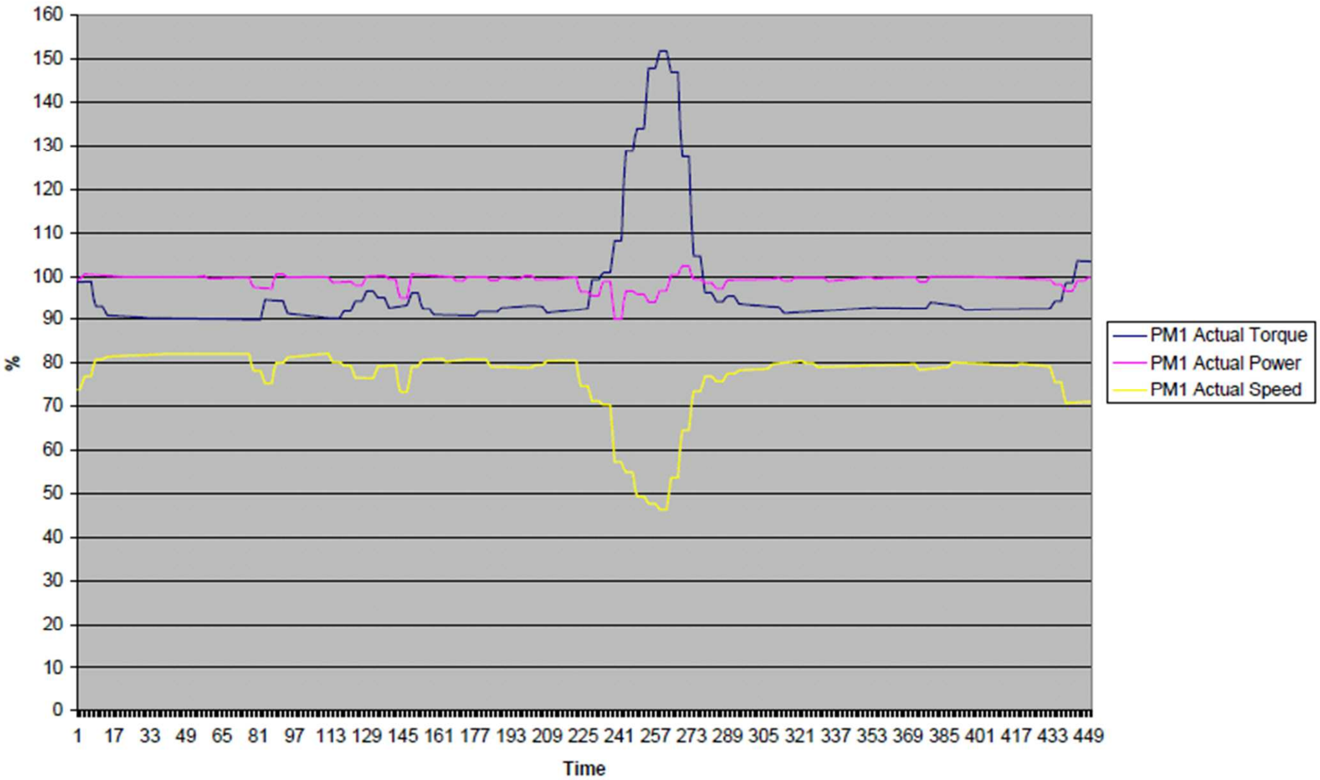


Figure 5. Icebreaking vessel propulsion motor torque –rpm curve.

Use of Full-Scale Measured Data

Over the years ABB has made several full-scale measurement campaigns onboard Azipod vessels to gain information about the best operation practices with Azipod vessels and to understand the actual ice loads acting on the Azipod unit.

The figure 6 shows how rpm, power and torque behave when the machinery control system works the way it is supposed to do. When the propeller encounters iceloads the rpm (yellow) drops and the torque (blue) increases so that the power (red) remains more or less stable.



Note: Actual Speed recovers just below 50%, and no significant drop in Actual Power.

Figure 6. Electric propulsion motor behaviour under heavy ice load.

For a vessel project the overtorque capacity can be simulated and optimized in case the propulsion maker has measurement data from corresponding vessels in operation. The simulation is to be done by solving the equation:

$Q_{Motor} = Q_{Propeller} + Q_{Inertia} + Q_{Ice}$ for every time step.

where:

Q_{Motor} is motor torque.
$Q_{Propeller}$ is hydrodynamic propellertorque that depends on propeller design, rpm and vessel speed.
$Q_{Inertia}$ is inertial torque of the rotating components and it depends on the moments of inertia of the components and the changes of rotational speed of the shaftline.
Q_{Ice} is iceload calculated from existing measurements/vessel

Since Q stands for torque power is reached by multiplying by the rate of revolution. Generally simulation is one tool to optimize the overall vessel ice performance and cost for designed ice condition and operation profile.

Design of a high power Azipod with high iceclass

The basis for the design is the well proven Azipod VI2300. To date 16 Azipod VI2300 units have been delivered to Russian owners and they have operated for several years without any major problems. ABB instrumented the first vessel, the “Norilskiy Nickel” for four years and measured ice loads on the hull and propeller of the pod. These measurements form a valuable database for the design of a pod with higher iceclass and more power.

The goal was set high, we decided to see if we are able to design the pod to PC1 ice class. As pointed out before in this paper the PC rules themselves say nothing about the design of podded propulsors. To be able to go ahead ABB and DNV jointly worked out a way of assigning ice loads to the hull of the Azipod for different PC classes, Norhamo (2010). The PC rules present a method to design the propeller. The loads and load scenarios jointly developed with DNV were applied to the hull of the pod and the structure of the pod was modified to carry these loads.

The structural response of the pod was investigated both locally and globally, Figure 7. Suppliers of critical components, such as bearings, were approached with the upgraded loads and revised dimensions were obtained from them. PC1 loads on the propeller led to increased blade scantlings and stronger blades. The single blade break scenario in the most unfavorable position is a typical and well founded scenario for icebreaking ships and in this case it led to considerable strengthening of the propeller shaft elements.

In addition the deflections of the propeller shaft at the single blade break load was investigated, Figure 8. Please note that the deflection is magnified in order to demonstrate the shape of the shaft during bending.

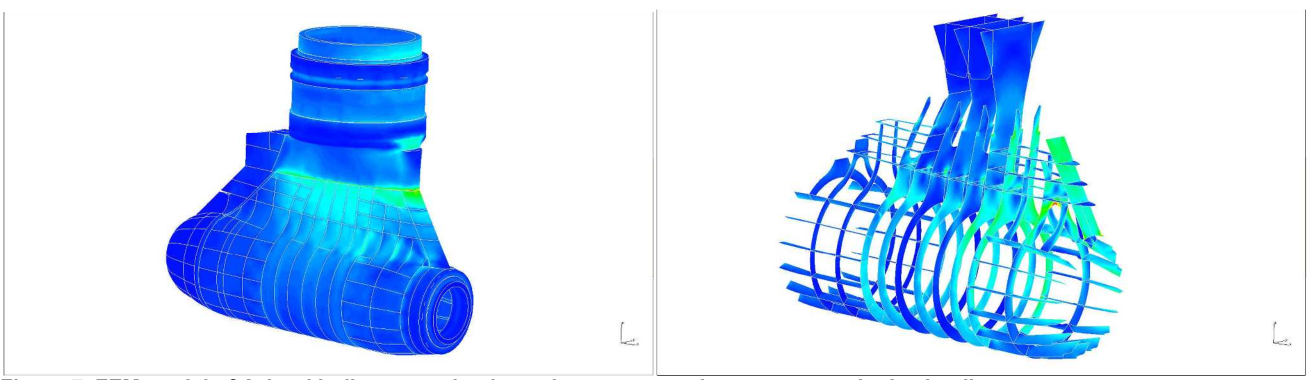


Figure 7. FEM model of Azipod hull was used to investigate structural responses under ice loading.

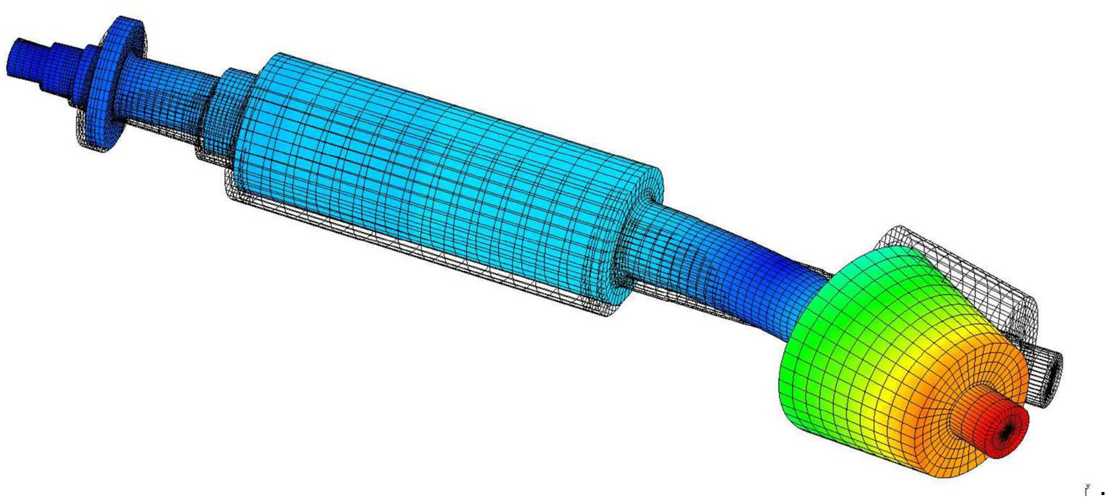


Figure 8. Deflections of the Azipod propeller shaft under blade break force (Note! Deflections are magnified to demonstrate the displacements).

Conculsions

Azipods have been in operation in icegoing ships since the late 1980's without any problems related to ice operation. This provides a firm basis for the development of Azipods with high power for high Arctic ice classes. The development so far carried out gives ABB full confidence to believe that it is feasible, both technically and economically, to build an Azipod with power in the range between 15 and 17 MW to the highest Arctic ice class, PC1. Component manufacturers can deliver components that can withstand the loads and the mechanical solutions do not become unmanageable.

Recent development in the Arctic, both in North America but also in Russia seems to open markets for this upgraded Azipod. Also in Europe there is interest, ABB has promised to try to develop Azipods for the "Aurora Borealis" project, the joint Europen Polar research icebreaker, Niini et al (2012).

ABB is ready for the challenge!

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