

5.11 Azipod® propulsion

Azipod® technology, introduced in 1990, provided ship designers with greater freedom to optimize the ship's general arrangement which ultimately lead to further developments.

Improved efficiency and other benefits boosted the development of the Azipod product family to what it is today. Azipod propulsion brings reliability in the operations in the harsh arctic environment with ice-going vessels; it creates customer comfort in operations in the warm Caribbean sea with large cruise vessels; and it provides luxury of silence for private yachting around the world.

After being installed to many icegoing ships, the first cruise vessel installation on the Fantasy-class vessel Elation (Carnival Cruise Lines) in 1998 showed remarkably positive results with high efficiency and excellent manoeuvrability, also for cruise ships. The new technology provided ship designers with greater freedom to optimize the ship's general arrangement. These benefits encouraged to further develop the product which lead to the current world-class solution.

Processing further knowledge from experience and getting a better understanding of the sys-

tem's behavior in operation, a complete product family has been developed covering power range from 1 MW up to 22 MW in open-water applications and 2 MW up to 17 MW for ice operation.

We are constantly studying the shipping industry to better understand the needs of the market; our R&D group creates new Azipod models, as well as makes improvements on the current models in order to meet the needs of our customers today and in the future.

ICE OPERATIONS WITH AZIPOD PROPULSION

Advantages of Azipod propulsion in ice operation

The development history of Azipod propulsion systems started with icebreakers and derives from icebreaker operating challenges. Electric motors have been preferred for icebreaker applications instead of diesel engines since the very beginning because high propeller torque at low speeds of rotation is an important feature in ice operations.

One of the greatest challenges was how to get an icebreaker out of a so-called ice channel. Ships traveling along the same route on ice-coated sea make a channel in the ice. Broken pieces of ice gradually accumulate to become thick layers at the edges of the channel that tend to keep ships within the channel.

The Azipod system was created for the particular

purpose of getting out of ice channels. A steerable unit allowed the propeller thrust to be directed so that getting out of an ice channel became relatively easy. The first patent applications for this were filed in 1987.

The propulsion devices of ice-going vessels, particularly icebreakers, are under considerably higher stress than those of open-water vessels. As the Azipod system was being developed particularly for special vessels whose ability to navigate icy waters is decisive for their performance, the main principle of its design was the simplicity and reliability of the mechanical power transmission.

Ice-going vessels are divided into two main categories: ice-strengthened vessels and vessels designed for actual operation in ice. The former are primarily designed for open-water use and are equipped for ice operation by adding the ice reinforcements required by a classification society.

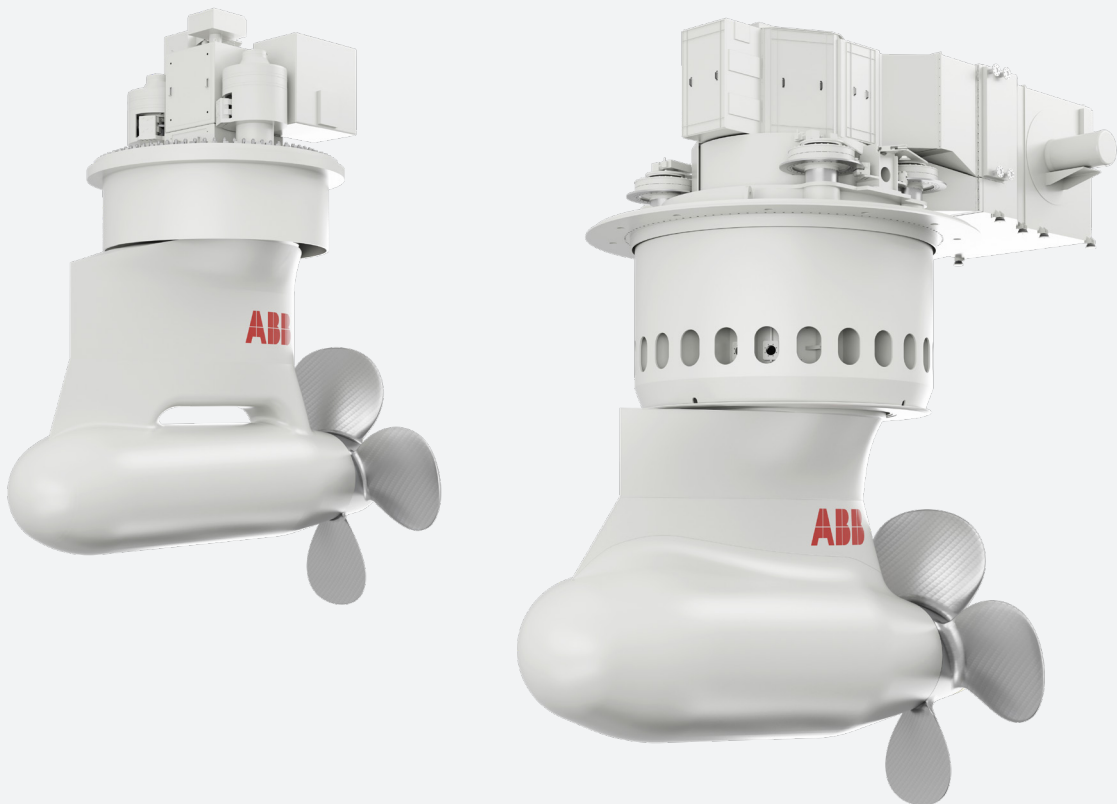
The ability to operate in ice is not an actual criteria for the vessel. Such vessels include almost all car ferries, dry bulk carriers and RO-RO vessels operating in the Baltic Sea.

The latter main category includes vessels for which the ability to operate in ice is a decisive performance factor. Performance in certain known, usually very severe, ice conditions is defined in the technical criteria for the ship. These vessels usually have the shipbuilder's guarantee for performance in ice, and the performance figures can be verified in corresponding ice conditions. Such vessels include icebreakers, multi-function icebreakers, freighters intended particularly for ice-covered seas and some research vessels.

Robustness suitable for ice classes

Azipod propulsion products are also available with range of ice classes from mild Baltic class to high polar ice classes suitable for every need. In-

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Azipod® propulsion units for ice operations range from 2 MW up to 17 MW.



side the Azipod propulsion, the electric motor is installed directly on the propeller shaft, making the drivetrain extremely simple and robust against any ice loads hitting the propeller. In contrast to mechanical Z- or L-drive azimuthing thrusters, there are no mechanical gears, so the Azipod shaftline can withstand both bending and high torque peaks under heavy ice loading.

Double Acting Ship (DAS™) concept

The Azipod concept provides completely new possibilities for the design of the general arrangements and functions of a ship. This resulted in the birth of a new vessel concept. This was the so-called Double Acting Tanker (DAT) developed at the arctic technology center of Aker Arctic Technologies, with the subsequent development of the more general DAS principle for all types of vessels.

The design of a vessel with good properties for both open-water use and ice operation is impossible in principle. A good ability to break even ice requires a relatively even, 'flat' bow shape. The drag of such ice decreases with reduced angle. An extreme example is a landing bow, where the angle of incidence between the bow and ice is no more than 15 to 20 degrees. However, such an ice-breaking bow is relatively poor in open water,

both in terms of open-water drag and navigation properties.

It has been known for a long time that when going aft first the ice drag of a ship will decrease as a result of the propeller flow, which, among other factors, reduces friction. However, ships equipped with conventional rudders are difficult to steer when going aft first. This challenge does not affect ships equipped with an Azipod propulsion system, as the propeller thrust can be steered to any direction.

The bow of a Double Acting Ship is designed on the basis of normal open-water criteria, while the aft shape is optimized for ice. This principle has already been applied to several ships and ship types. The DAS concept enables the optimization of the power plant, decreasing the need of installed power compared to a single-acting vessel with an ice bow.

Because ships employing the DAS principle can operate in fairly severe ice conditions without ice-breaker assistance, discussion has arisen on whether the ice dues for such ships should be reduced. Furthermore, the need for icebreaker assistance will generally decrease as ships with a weaker ability to break ice can travel in the chan-

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Azipod® propulsion units for open water operations with power range from 1 MW to 22 MW



nel opened by a Double Acting Ship.

ADVANCED PERFORMANCE OF AZIPOD PROPULSION

Resilience to weather

Extreme weather conditions can pose challenges during docking or approaches in tight channels. The ability to use full thrust from the main propellers in any direction improves control of the ship in extreme wind conditions, as well as the grabbing capability of the vessel.

Better resilience to weather improves on-time performance and allows the schedule buffer to be reduced. Time saved can be further used to decrease the maximum ship speed in transit or to increase number of sailings per time period. Decreasing maximum ship speed reduces fuel costs (OPEX) and enables a lower installed power requirement and cost for newbuilds (CAPEX).

Precise manoeuvring with 150 percent more side thrust

Generally, a conventional rudder can produce only about 40 percent side thrust compared to maximum ahead bollard pull thrust. The figure for flap rudders is up to 60 percent. The 360-degree rotating Azipod propulsion system delivers 150 per-

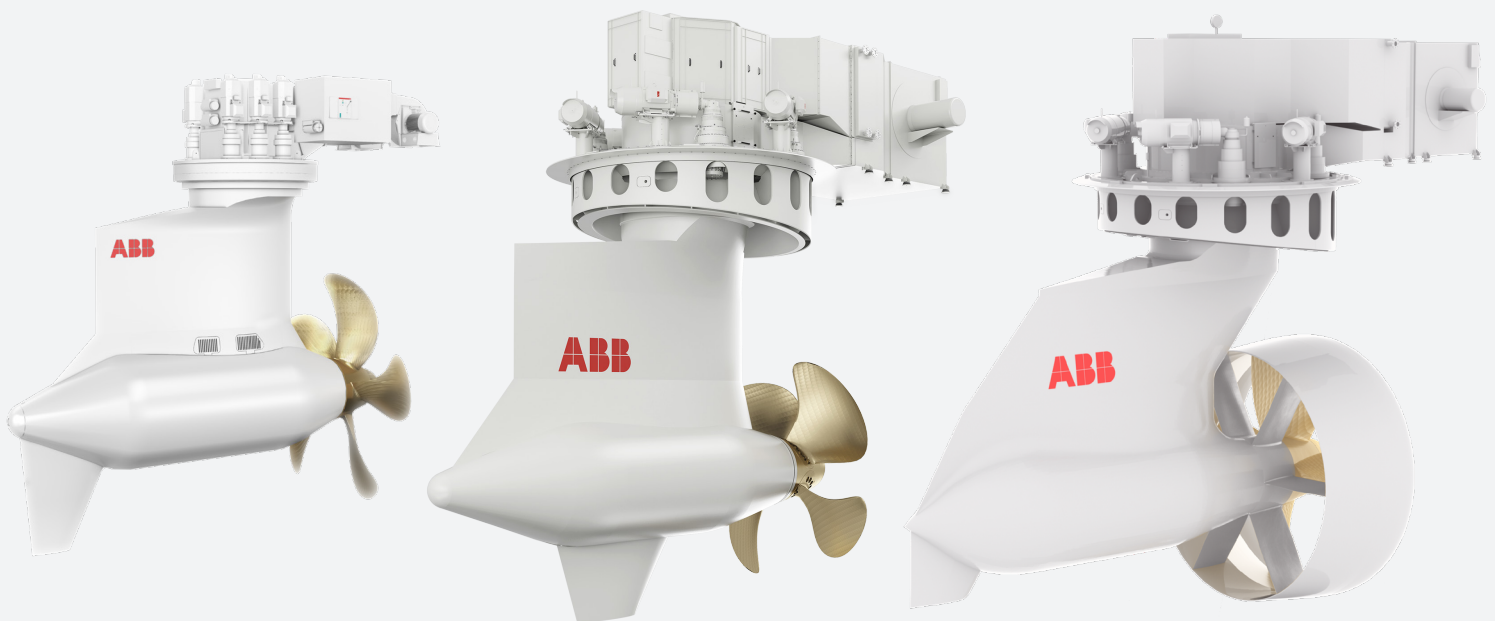
cent more side thrust than a conventional rudder. Full thrust in any direction is a significant benefit when manoeuvring ships in tight and busy channels.

57 percent better grabbing capability

One of the best-known Ferry and RoPax designers, Deltamarin Ltd., has performed a detailed case study of an Azipod equipped RoPax ship compared to conventional shaftline-rudder design, including grabbing performance. According to the study, Azipod propulsion improves the grabbing capability of a 225 m long RoPax by as much as 57 percent. Tailwind conditions are especially challenging for conventional shaftline propulsion, whereas Azipod propulsion excel in tail winds.

Superior safety with 38 percent smaller turning circle

In collision avoidance manoeuvres, a vessel equipped with Azipod propulsion is more likely to avoid collision than a vessel with conventional shaftline-rudder arrangement. This is because conventional rudders typically require stern tunnel thrusters to assist in manoeuvring. However, tunnel thrusters do not work effectively at higher ship speeds, whereas the superior steering capability of Azipod propulsion units is effective



throughout the ship's speed range.

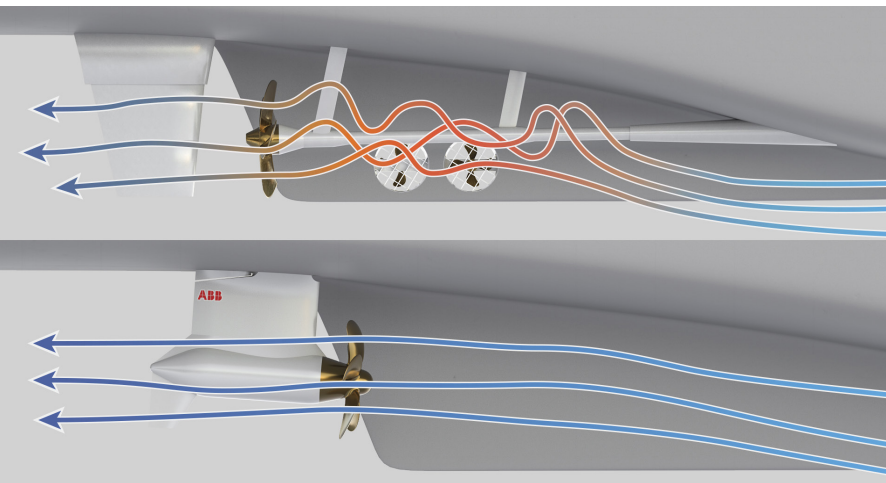
The more effective and safer turning capabilities of Azipod propulsion have been verified by full-scale and full-speed turning circle tests on sister ships MS Fantasy with conventional propulsion, and MS Elation with Azipod propulsion. A 38 percent reduction in tactical diameter was recorded.

Shorter crash-stop distance with full heading control

With traditional rudder steering, an emergency crash-stop is accomplished by reversing the propeller pitch or rpm from positive to negative. Especially changing rpm from positive to negative direction is time-consuming, as the ship's power machinery must go from full to zero power and then ramp up again to full power in the opposite direction. In practice, any vessel operating with a rudder will also lose control of heading during the crash-stop, as the rudder does not work efficiently unless the propeller is producing thrust, and negative propeller pitch or rpm generates very little thrust for the rudder. This means that ship heading and direction during the crash-stop are effectively at the mercy of current, wind and waves, a condition exacerbated in heavy seas.

In ships with Azipod propulsion, crash-stop can be accomplished by steering the Azipod propulsion units 180° and keeping positive propeller rpm during the entire procedure. This shortens crash-stop distance considerably – typically by about 50 percent. Moreover, during the crash-

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Comparison between
Azipod propulsion and
a shaftline on a Ro-Pax
vessel



stop, Azipod propulsion units can generate enormous side force in any desired direction irrespective of the vessel's speed. This gives the captain full control over the heading and direction of the vessel during the entire crash-stop, even in heavy weather conditions. The combination of short crash-stop distance and full heading control is an extreme advantage in onboard safety when considering worst-case scenarios.

More payload, more room for alternative energy sources

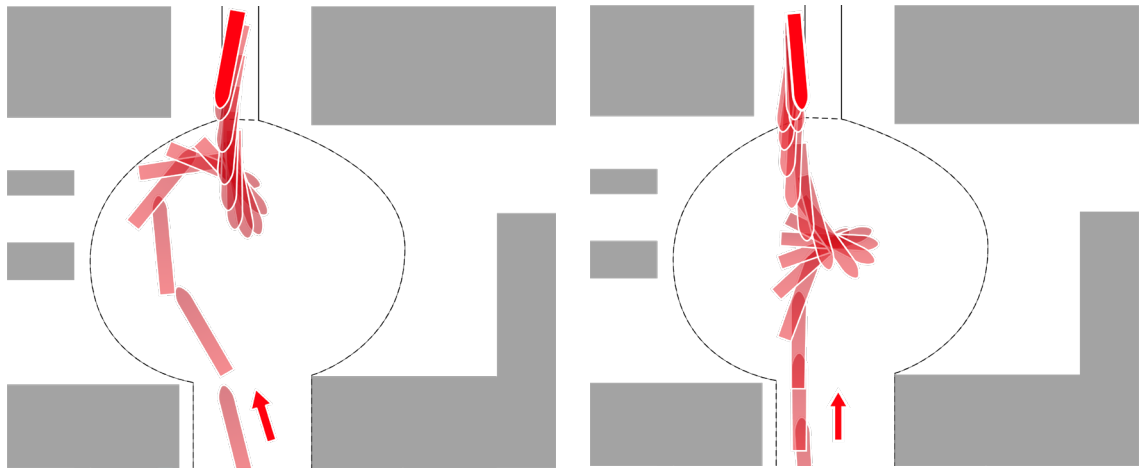
Azipod propulsion enables a flexible machinery arrangement that is easy to design for the vessel's specific requirements and priorities. In the case study, Azipod propulsion motors installed outside the vessel hull, without long shaftlines, saved 255 m² of machinery footprint compared to conventional diesel-mechanical shaftline propulsion of a 225m long RoPax vessel. Lack of fixed shaftlines gives more freedom for locating propulsion and power plant machinery, enabling rearrangement for higher payload, and clearing additional space needed for alternative energy sources such as LNG tanks, batteries or fuel cells.

Underwater noise restrictions are a new challenge

Environmental concerns have led to restrictions with the maximum allowed underwater noise in an increasing amount of coastal areas. The most obvious way of decreasing the noise is to lower the speed of the vessel, however in many cases this may become impractical if a ship is in passenger or cargo traffic and leads to designing new ships to incorporate the low noise emissions to the vessel design. As an example, DNV-GL has introduced its' standardized noise emission level notations, which can be utilized by ship owners in order to prove local authorities their vessels noise level. The Azipod propulsion can also be designed to fulfil these requirements, and there are currently several large cruise vessels sailing with the DNV-GL Silent E-notation.

Whereas the underwater noise restrictions are meant to protect the environment from the broadband and high intensity noise of vessels, fulfilling these requirements may have an effect on the fuel consumption of the ship. In the case of

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Example of berthing tracks of RoPax dockings by professional captains in a bridge simulator. Right image with Azipod propulsion, left image with conventional shaftline.



Azipod propulsion, the noise levels can be limited by adjusting the propulsion drive (frequency converter) to a more silent but less energy efficient mode. As solution to limit excess energy consumption, the system can be set to a silent mode when needed and when operating in water with no noise restrictions, set to regular mode.

HYDRODYNAMIC IMPROVEMENTS AND EFFECT ON HYDRODYNAMIC EFFICIENCY

Hydrodynamic efficiency

The Azipod propulsion system is known for its high hydrodynamic efficiency. Ever since releasing Azipod propulsion to the market in 1990's, several improvements have been made to its hydrodynamics. Main features affecting on the hydrodynamics of the Azipod as well as latest improvements are described below:

1. Pulling propeller configuration: Pulling open propeller is the first component of the propulsor in the direction of ship's movement and thus seeing as homogenous field of water as possible. There are no disturbing nor resisting components in front of the propeller and the propeller is therefore loaded as equally as possible. Also the wake field behind the propeller is close to optimal.
2. Integration to ship hull: Simple and flexible structure of the Azipod propulsion units allows optimized positioning of the propeller according to ship's hull shape. Adjustable strut height of the underwater propulsion module makes possible to use the best possible propeller diameter without

a head box on ship's hull and large tilting angles of the Azipod propulsion units in both longitudinal and transversal direction. This enables locating the Azipod propulsion units to undisturbed wake field.

Flexibility of Azipod electric propulsion system gives more freedom to ship designers as the hull shape, especially the skeg, can be designed based on hydrodynamical evaluation without dimensional restrictions of a long, traditional shaft line. The propeller positioning and the hull form are always designed together with the shipyard or design offices. Additionally, fully 360 degrees directable thrust of the Azipod propulsion units eliminates the need of stern tunnel thrusters, leading to more optimized hull shape and less hydrodynamic drag.

3. Hydrodynamic appendages: Hydrodynamic efficiency of the Azipod propulsion can be further optimized by additional appendages on the Azipod propulsion hull to reduce rotational flow losses generated by the propeller. These features include both symmetrical and asymmetrical fin on the bottom of the hull as well as crossed plates (X-tail) integrated on the aft cone. The fin on the bottom of the Azipod propulsion hull also provides an efficient way to reduce the loads of the steering system, by decreasing the azimuthing counter torque, and thus minimize the power needed for steering of a ship.

4. High torque electric propulsion motors enable using larger propeller diameters, generally resulting in higher hydrodynamic efficiency. Improved

torque density can also be utilized to minimize the front surface area of the Azipod propulsion hull and to design a sleeker, more streamlined hull shape.

5. Optime: In addition to the static angle optimization already performed during the design stage of the vessels, further saving on fuel consumption can be achieved by dynamically optimizing the toe (steering) angle of the Azipod propulsion units. The OptimE -system continuously adjusts the toe angle towards the most optimum inflow depending on the ship's trim, ballast, speed and sea conditions.

6. Optimization of the hull shape and propeller characteristics by advanced CFD (Computational Fluid Dynamics) analysis: Development of computational tools theoretically allows limitless number of optimization rounds during the design phase. Propellers can be designed in the most optimal way based on different, typically conflicting requirements.

The Azipod propulsion projects are always evaluated case-by-case for the best final result. Overall improvement in propulsion efficiency has been

above 10 percent over the course of the existence of the Azipod propulsion, with a more than 20 percent gain compared to the shaftlines being used back in the mid-1990s.

Mechanical and electrical efficiency

The unique hydrodynamic efficiency is finalized with the top-performance technical solutions inside the vessel and Azipod propulsion unit. A diesel-electric propulsion power train combined with the simple and flexible structure of the Azipod propulsion not only gives substantial flexibility for designing of a ship, but offers a high total efficiency of the whole propulsion system.

Azipod propulsion is available with different propulsion motor alternatives: synchronous, with excitation machine or permanent magnets, as well as with asynchronous motor. Depending on the most valuable characteristics for the customer, optimal solution can always be offered.

• Synchronous machines

Electric motors in which the rotating part (rotor) revolves at the same speed as the magnetic field in the windings of the stationary part (stator), in a continuous steady state, are called synchronous

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Azipod® propulsion
units





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Azipod® propulsion
units

motors. In Azipod propulsion units, magnetization of the rotor is arranged by using permanent magnets in the rotor, or alternatively by using a separate excitation machine on the rotor shaft. Permanent magnet motors contain no components prone to failure and thus are used in inaccessible, smaller Azipod propulsion units. PM motors have the ultimate electrical efficiency up to 98%, but are more sensitive to high temperatures, limiting cyclic overloadability performance. Electrically excited motors are the most cost effective solution for high power units. Technically they have the highest torque and power densities, given adequate cooling, but includes maintainable components on the propulsion shaft line.

Electrically excited motors can therefore be used only in accessible propulsors. Electrically excited motors offer efficiency close to permanent magnet motors, give the best over torque performance, and are widely used in ice class applications.

- **Asynchronous machines**

The rotor of an asynchronous machine do not contain permanent magnets, nor is excitation machine used. Instead the rotor has so called cage winding, which consists of axial bars connected at both ends of the rotor by short circuit rings. Rotor follows the rotating magnetic field of the stator, but at a slower speed. The difference in speeds is called 'slip', and also leads to the solution being called 'asynchronous'.

Induction motors typically offers the most cost competitive solution in the lower end of the Azipod propulsion power range. Induction motors provide fast response to increased torque demand and good overloadability, making it a competitive solution for small and medium size ice-breaking vessels. Induction motors are simple and reliable, and contain no components that would require maintenance and thus they can be used in small, inaccessible propulsors. As a trade-off, efficiency level is below synchronous machines, reaching up to 96.5%.

Azipod propulsion system has only two bearings on the propeller shaft, reducing the mechanical losses to minimum of ~0.3%. Compared to mechanical shaft line or mechanical azimuthing propulsors having up to 10 bearings, 1-2 gear box(es) or bevel gear(s) and several thousands of liters of lubrication oil, significantly higher efficiency can be achieved. Taking into account mechanical losses (3.5 percent) of a shaft line propulsion system and electrical losses of an Azipod propulsion drive train (9 percent) including propulsion motor, transformer, frequency converter and generators, the savings in engine power with Azipod propulsion can be up to 7% percent. Even higher impact on the fuel oil consumption can be achieved on partial loads as the main engines can be loaded in more optimal manner in case of diesel-electric propulsion system.

CUSTOMER CASE: ICEBREAKER POLARIS

Polaris propulsion system is based on ABB's well proven Azipod® propulsion and it applies a three propulsion unit concept, where one 6 MW unit is at the bow and two 6,5 MW units at the stern. The Azipod® propulsion unit at the bow considerably enhances the ship's maneuverability and ice-breaking capability.



