Improvements in Azipod® design

Efficiency and availability

JUKKA VARIS - Technical developments and improvements have been achieved over the years to improve energy efficiency and availability of Azipod propulsion based on experiences gained from vessel operations.

Azipod technology was introduced in 1990 on a pilot installation for a Finnish fairway maintenance vessel and later installed in some ice-going vessels and ice breakers. It took seven more years to make a breakthrough in wider markets. The first cruise vessel installation on the Fantasy-class vessel *Elation* in 1998 showed remarkably positive results with high efficiency and excellent maneuverability.

The technology also provided ship designers with greater freedom to optimize the ship's general arrangement. After gaining initial operational experience it was noted that further development of some critical components was needed.

Improvements were initially focused on components and systems like bearings, seals and lube oil systems. After processing further knowledge from experience and getting a better understanding of the system's behavior in operation, the scope of development was widened to cover larger systems and then, finally, by combining customer feedback and all knowledge gathered, complete redesigns and the development of completely new products were undertaken.

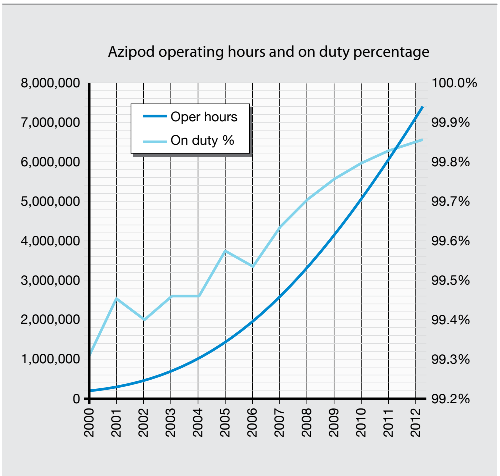
Design improvements

The load conditions on an operating Azipod unit are continuously changing. The propeller generates dynamic forces and torques, which are dependent on propulsion power, vessel speed, steering angle and vessel motions that depend on the weather conditions. There may be rapid changes in the load direction to all three directions and there will also be additional impacts loads when operating in ice.

At first the improvements were mainly concentrated on shaft bearings and seals. While the basic mechanical design remained the same, the focus was to provide improved lubrication conditions to maintain proper oil films between rolling surfaces in different conditions and to improve seals to prevent any leakages into the lube oil or into the sea.

System reliability and availability was improved by promoting both internal changes in the bearing housing and external changes in the lube oil system, with more redundant seal designs that had improved lip materials also introduced. Lube oil monitoring and vibration monitoring systems were brought in to provide better knowledge of system status and

1 Azipod operating hours and on duty percentage



The target was to improve the control of the whole process from development and component supply to unit transportation, installation, commissioning, and finally operation and maintenance.

to perform necessary maintenance actions in time. These improvements were performed in a very close cooperation with customers and follow-up was done together to share experience and validate the design changes.

After collecting several years of operational experience with wider knowledge and deeper understanding of system behavior, improvements were broadened to include processes like better control of manufacturing, delivery and operational processes, and general quality control. All of this was improved further through the adoption of strict manufacturing procedures and general requirement specification updates. The target was to improve the control of the whole process from development and component supply to unit transportation, installation, commissioning, and finally operation and maintenance.

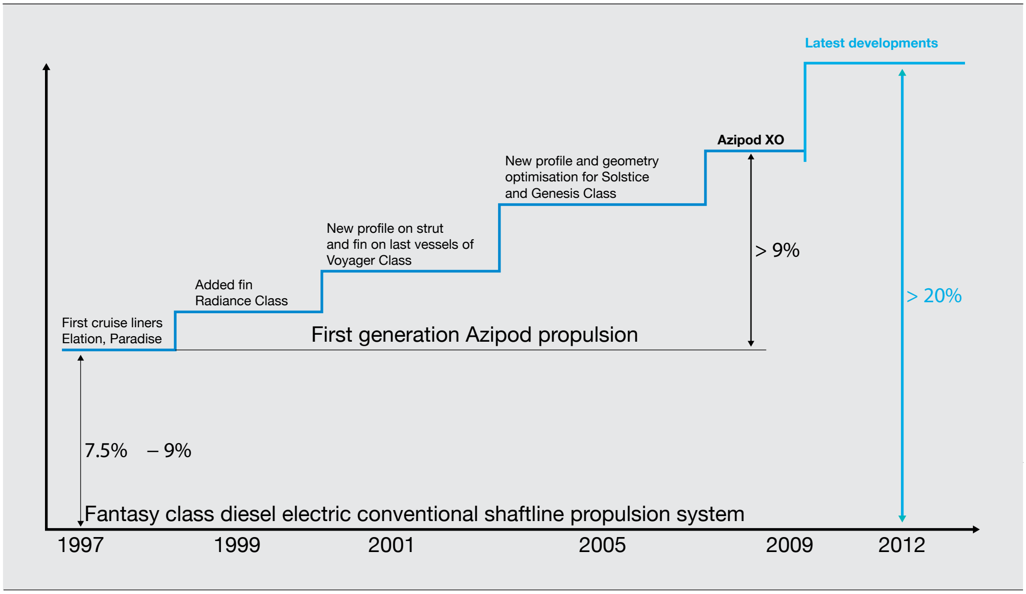
After several generations of updates from the original design, it was seen that a concurrent redesign would be necessary to be able to combine all identified improvement ideas. The first such development project addressed the larger open water unit series, which was subsequently given the identifying type code Azipod XO where X stands for “next generation Azipod” and O means that it is mainly made for vessels that will operate in open water conditions.

In this research and development project ABB Marine decided to utilize well-known, proven technologies for components and design, with the components either proven reliable in the previous Azipod units, or brought in from other marine operation applications where good references had been secured. As an example of the latter, sliding bearings were selected for thrust bearings.

This made it possible to maintain this aspect of operations without dry-docking the vessel. However, because Azipod propulsion generates totally different loads in the shaft system, a thorough full-scale testing was performed to guarantee suitability for the unit. According to tests, the bearing met the requirements and in many cases even exceeded them by a good margin.

The outer shaft seal was also completely redesigned to provide similar benefits: reliability and maintainability. The new seal design consists of four different lip seals against water and two against the bearing oil chamber to provide redundancy. The new seal arrangement separates the seal packages for water

2 Propulsion efficiency has been improved by several steps in design optimization



and bearing oil seals, meaning that there is only a theoretical possibility of water leaking into the bearing or into the sea.

The seal system enables advanced condition monitoring to a degree not seen elsewhere in the market. It controls the seal's operational environment, and the balance between pressure and heat, for example, is automatically optimized.

For larger models the seal can be changed from inside the pod through an ingenious design, arranged by using a temporary inflatable seal placed around the hub during the seal change operation. The seal is designed for a five-year lifetime and to be replaced during normal dry-dockings, but in case of an emergency situation this can also be done with the vessel afloat.

The fully electric steering gear was originally designed for smaller Azipod sizes, but it was the right time to introduce it for larger open water unit sizes to replace conventional electro-hydraulic steering gear. The main reasons for this step were that it reduced energy consumption and noise, as well as cutting the amount of oil in the installation, in order to make it more environmentally friendly. Electric steering gear is now installed on recent Azipod deliveries for open water conditions and first factory tests have been completed to verify its operation.

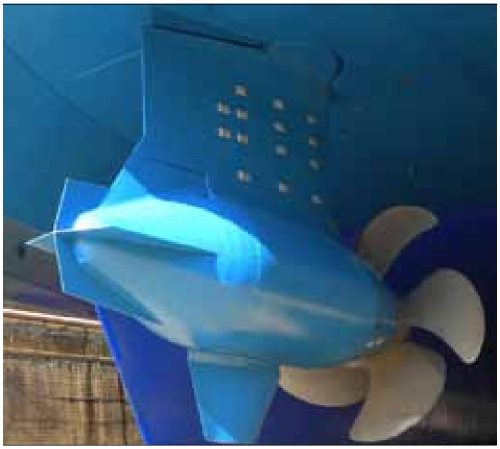
Testing

To reach the high reliability achieved today, ABB has added to its knowledge through undertaking more measurements, tests and research on podded propulsion and its critical components than anyone with comparable products. Very thorough data collection and analysis has been undertaken within various areas to increase the understanding of the design loads and conditions experienced, in order to offer systems that meet both ship design and operational requirements. This also includes long-term measurements from operating units in both open water and ice-going units.

These installations have been fitted with strain-gauges at different locations in the propulsion unit frame to measure stresses and also with vibration sensors, and in some cases proximity sensors to follow-up shaft dynamics. ABB has also invested in a full-size bearing test setup to provide test capacity exceeding normal operational bearing loads and also to simulate extreme situations like major angular misalignment. The test setup has also been used to recreate undesirable operating conditions, such as when high metal particle content is found in oil to verify internal flow and particle removal process.

New systems are also tested during the ship delivery process and during operation to verify that they work according to design criteria. The first installations with

3 Azipod with X-tale



The propulsion motor technology in Azipod units is selected so that it will achieve high efficiency throughout the entire propeller speed range.

the new Azipod X will be thoroughly tested and monitored to confirm that their performance is consistent with laboratory tests. For example, the wear of thrust pads will be checked regularly to ensure that the slide type bearing is functioning as expected. Lessons learned to date suggest that caution is a prerequisite and ABB wants to ensure that the design works as promised in real operating conditions.

Availability

The Azipod's availability has been monitored throughout the years by collecting unplanned off-hire time data and comparing this with the total planned operational hours (Figure 1). Off-hire time that is due to Azipod units but not due to external reasons like ground contact etc.., is measured directly. This number gives indicative feedback on the level of success achieved by design improvements.

The figures show that availability has increased to over 99.8 percent. The increasing availability Figure is an indication of the design and process improvements, but is also a result of improvements in the way the propulsion is used and of the greater awareness of maintenance issues. The relation and cooperation between suppliers and operators is a key factor here.

Improved fuel efficiency

The propulsion efficiency of Azipod propulsion, when originally installed on cruise ship *Elation* back in 1997, improved by some 9 percent, when comparing full scale measurements to measurements from earlier identical sisterships with traditional shaftlines. Since then, the propulsion efficiency has been improved by several steps in design optimization (Figure 2).

One major hydrodynamic improvement was gained early by installing a fin under the Azipod to reduce rotational flow losses generated by the propeller. The lower fin was also an efficient means of reducing steering system loads by reducing the azimuthing counter torque. In the next steps, the Azipod strut design was modified by making it slimmer and more optimal for operation in the propulsion environment. Finally, with the Azipod XO, the propeller hub and motor module diameters were reduced and the unlt is entire hull was optimized with the help of CFD and model testing. All in all Azipod hydrodynamic improvements from the first units to Azipod XO have been improved by 9 percent when compared to the *Elation* results.

During 2011, ABB introduced an additional package to improve Azipod propulsion efficiency further. This package consists of an asymmetric lower fin and crossed plates (X-tail) that are integrated in the aft cone.

The asymmetric lower fin will improve efficiency up to 1 percent by reducing the losses from the propulsion system and the X-tail will further increase efficiency by up to 1.5 percent by reducing the rotational flow losses at the aft cone section. These changes can also be made as a retrofit installation on open water units. Due to different design and load conditions these modifications are not applicable to ice-going vessels.

The first retrofit work with asymmetric fin and X-tail was done in 2011 during the vessel's normal dry-docking. To verify the results, the same measurements were taken for two similar vessels before and after dry-docking. The first vessel did not feature the modifications and the second one did. Both vessels benefited from the same scope of hull cleaning and painting during dry-docking. Finally the numbers were verified and approved together with the customer and a third party. The results showed a 2.8 percent reduction in fuel consumption for the propulsion.

Also in 2011, ABB launched a method of optimizing the energy efficiency of Azipod installations on board vessels. This was based on the finding that further fuel consumption savings can be reached by optimizing the toe (steering) angle of the Azipod units dynamically, in addition to the angle optimization already undertaken at the vessel design stage. This package has the acronym ADO from the words "Azipod Dynamic Optimizer." Fuel consumption is estimated to be reduced further by up to 1.5 percent using ADO.

Although the propulsion efficiency of the Azipod has already reached a high value, one should never stop looking for opportunities to improve it. The propulsion efficiency for operating units can be further improved by applying optimized propeller geometry to meet current design criteria. For a retrofit installation, it is possible to reduce blade thicknesses to provide lower losses. By applying stainless steel materials that are common in ice-classed Azipod units, the thicknesses can be further reduced and efficiency further improved. The estimated reduction on fuel consumption on such vessels may reach up to 4 percent.

The overall improvement in propulsion efficiency has been above 10 percent over the course of the existence of the Azipod, with a more than 20 percent gain when compared to the shaftlines being used back in the mid 1990s. However, it is fair to acknowledge that there have also been improvements in shaftline propulsion during this time. Even so, a recent comparison test at Marin showed that Azipod propulsion compared to a fixed shaftline propulsion design still had a 6-8 percent lead what regards to propulsion efficiency. Furthermore, these tests were made before the introduction of asymmetric fin, X-tail and ADO, which can improve the efficiency of the Azipod system overall by up to four percent.

To support high propulsion efficiency and to provide best overall system efficiency, the propulsion motor technology in Azipod units is selected so that it will achieve high efficiency throughout the entire propeller speed range. As an example, on a typical dynamically positioned drill ship, the required thruster power will be below 15 percent for over 90 percent of the time. Azipod C, with its permanent magnet motor compared to a similar thruster unit provided with an induction motor, will have over 10 percent higher efficiency at low power loads, providing savings on fuel consumption and emissions. Similar effects will apply to larger units with synchronous motors that also have high efficiency with very low loads.

Operation experience

With regards to fuel savings and ship maneuverability, the expectations set by ship operators have typically been fulfilled or exceeded by the Azipod. Ship captains in particular have expressed satisfaction with the ease of operation and the maneuverability of their ships. Concerning energy efficiency, some operators have claimed fuel savings of more than 20 percent, compared with their vessels operating with conventional propulsion. The Azipod concept is established and recognized to be the preferred solution for ice going ships and icebreakers. The thrust and power efficiency makes it also very suitable for DP operations.

Dedicated ship operation simulation facilities have been set up to provide training in how to operate ships optimally with Azipod propulsion and take full advantage of its characteristics. It is greatly satisfying to see that the continuous efforts to meet customers' expectations have resulted in the major cruise ship operators choosing Azipod propulsion for their latest vessels ordered.

Seven million operating hours with Azipod propulsion over a time span of two decades have resulted in the largest pool of experience in how podded propulsion systems should be designed, used and maintained for trouble-free reliable operation.

During the Azipod's existence, components and systems that are critical for undisturbed ship operation have been identified. These have needed special attention during design and the selection of components, as well as for their operation and maintenance phases. 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.

ABB has established a unique position being the only company that has in-depth and in-house product and integration knowledge, with a responsibility covering the whole concept from hydrodynamics, mechanics, electronics, cooling to operating, maintenance and services, as well as the integration of the complete electrical and control system. The advantage of having data available from a large number of operating units, as well as a wide range of test results from models and full size units, has been essential for continuous development. Close cooperation with a large group of ship operators and shipyards on a variety of Azipod applications and ship designs for various demanding operating environments have complemented our understanding of the Azipod concept.

The maintainability of the propulsion unit has shown itself to be one of the more important factors in providing reliable 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.

Nowadays, Azipod propulsion and thruster units are designed for five years dry-docking and maintenance intervals. For some applications a longer maintenance interval of even up to 10 years has proven supportable. This conclusion is based on results drawn from a well-documented operational and maintenance history.

Today, there are some 100 vessels using Azipod propulsion. It has been selected for a wide range of ship types and operations; such as cruise ships, icebreakers and ice-going cargo vessels, ferries, megayachts, offshore supply vessels, research vessels, wind turbine installation vessels and drilling rigs.

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