Diesel engines are the principle source of power in the vast majority of the world's ships. From an environmental point of view, however, these engines are not the friendliest. The good news though is that pollution levels are not equal across the working range. In the optimum operating range, fuel efficiency is considerably higher and pollution lower than at low speeds. Therefore, the solution is to keep engines operating in this optimum range in all situations.

With traditional mechanical transmission this is not possible, as engine speed is rigidly coupled to propeller speed. Using electric transmission (generators and motors connected by cables), this is no longer the case. Additionally, power reserves can be shared with the vessel's on-board service supply, decreasing the total power installed while raising reliability. Furthermore, cables are more flexible than shafts and permit greater freedom in the location of the engines. This can increase the vessel's payload or permit more efficient loading and unloading. All these advantages translate into greater productivity and savings for the owner.

Another contribution to fuel efficiency is provided by Counter-Rotating Propellers (CRP). These improve the hydrodynamic properties of the propulsion system, further reducing fuel consumption.

Green shipping

Meeting tighter environmental regulations while improving fuel efficiency

Matti Turtiainen

Global warming and the mechanism known as the Greenhouse Effect are debated in the media almost every day. The causes and effects of this phenomenon are affected by people in many ways. Decisions that influence energy consumption and environmental issues are made on a daily basis, such as how much fuel a specific car needs or the heating arrangement selected for a new house.

The marine industry is aware of public sensitivity towards green issues and is facing environmental regulations that directly influence its business. The majority of marine propulsion systems use diesel engines as prime movers. There has been much research towards developing low-emission diesel engines, using alternative fuels such as gas, and developing methods to clean exhaust gases to meet tighter regulations.

Emissions in the marine industry

Nitrogen monoxide (NO) and nitrogen dioxide (NO_2) emissions cause acid rain. This leads to the over-fertilization of lakes as well as to smog formation. Combustion temperatures in engines have a significant influence on NO_x emissions.

Sulfur dioxide (SO_2) and sulfur trioxide (SO_3) are collectively called sulfur oxides (SO_X). These gases also contribute to acid rain and have detrimental effects on vegetation, human health and buildings. SO_X emissions are proportional to the sulfur content of the fuel and to fuel consumption.

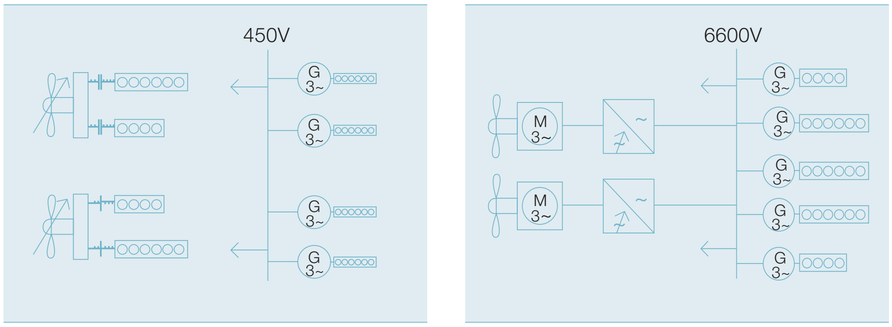
Carbon dioxide (CO_2) is the principle greenhouse gas contributing to global warming of the atmosphere. The predicted average global temperature rise for the 21st century is estimated at between 0.5–4.0 °C. Even a 0.5 °C increase would impact the global climate, lead to a rise in the sea level and possibly even trigger changes in the ocean current system. CO_2 emissions from diesel engines are proportional to their fuel consumption see textbox.

Diesel electric propulsion has been used in marine applications for decades. The capability of an electric motor to deliver high torque at low speed is a powerful argument in favor of electric propulsion, particularly in ice-breakers. This so called "power plant" concept permits diesel engines to run at optimal load, independently of the propeller speed. A further step towards greater fuel efficiency is made by the latest Counter Rotating Propeller (CRP) propulsion technology.

1 Power plant concept decreasing the total need for installed power.

a) Conventional ship power supply.

b) Diesel-electric "power plant" principle.



The power plant principle

Conventionally, ship propulsion and electric power generation are supplied by two separate and unconnected plants 1a. The location of engine compartments is dictated by propulsion shafting and engine exhaust arrangements.

In the diesel-electric power plant principle there is no direct mechanical connection between engine and propeller 1b, allowing greater flexibility when arranging and locating machinery. Machinery can be re-arranged to provide more room for cabins or cargo. The flexibility and productivity of the vessel is increased which benefits the competitiveness of the operator.

The total installed engine power also decreases: the two power plant systems can share reserves and there is always sufficient power available to start big energy consumers such as thruster motors without subjecting the electric network to excessive voltage fluctuations.

The number of diesel engines needed also decreases as individual units can be made larger. A greater modularization is achieved, reducing spare part inventory and lowering maintenance costs.

Reliability and safety

The number of main engines used can be varied according to load condition permitting these engines to operate in their optimum load area. Fuel consumption, emissions, and wear and tear are reduced.

The power plant principle enables the ship to maintain a specified speed and consumer load even when some of its main engines are out of use. A large power plant is also well suited to cope with sudden changes in the electrical network, such as current peaks on the starting of a large thruster or air conditioning compressor.

Fuel economy and environmental issues

When diesel engines are operating at constant and optimum service speed, fuel consumption is lower than running the same engines at variable speed. In addition, in a "geared" propulsion system, which involves the slowing down and changing from two-engine mode to single engine mode, the propeller speed and pitch has to be controlled to avoid overloading the diesel engines. This lowers the efficiency of the propeller which must be compensated by additional installed power.

In a diesel-electric power plant, the propulsion motor is capable of providing the required torque at all times,

Contribution of shipping to air pollution:

- Five percent of total world oil consumption – about 140 million tonnes.
- Five percent of the oil based CO_2 production globally – 450 million tonnes of CO_2 annually.
- Two to three percent of total world consumption of fossil fuels.
- Thirteen percent of the global fuel based NO_x production.
- Two to five percent of the global SO_x emissions.

(Source: A. A. Wright, MEP Series, Volume 3, Part 20: "Exhaust Emissions from Combustion Machinery", Published by The Institute of Marine Engineers, 2000.)

over the entire speed range, even through zero speed and into reverse. It is therefore ideally suited for driving a fixed pitch propeller. This contributes to system efficiency: when the vessel speed is low, a controllable pitch propeller consumes energy just to maintain its rotation.

In vessels that operate in dynamic positioning mode, the propulsion power is very low most of the time. Electric propulsion systems with a fixed propeller pitch can, when required, rapidly deliver high thrust while keeping standstill power consumption to a minimum.

> The conventional ship concept requires over 20 percent more fuel to perform the same service as ships with CRP Azipod® propulsion.

A mechanical propulsion train can be optimized for a given operating point. 2 shows that a very high efficiency is attained at this optimum. The flexibility of electric propulsion allows the power demand in the electric plant to be matched with various prime mover combinations maintaining the optimum loading condition for the engines over almost the full power range of the plant. For ships that operate at variable speeds or in dynamic positioning mode, an electric power plant and propulsion system is, in many cases, the best choice.

Besides fuel consumption, emissions from ships have become a major issue, especially in environmentally vulnerable areas such as Alaska and the Baltic Sea. NO_x emissions from a diesel engine increase dramatically when the engine cannot operate at its optimum speed and power range 3. In this respect, the advantages of an electric propulsion system over a direct drive are clear.

CRP Azipod® propulsion concept

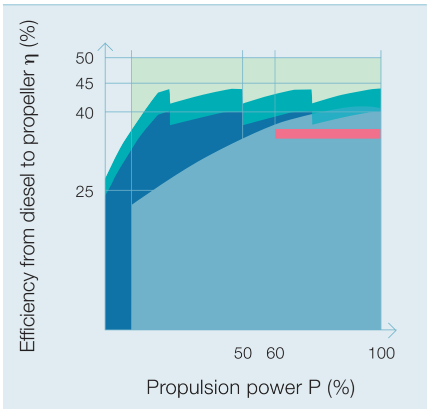
The CRP concept 4 features a novel combination of conventional propulsion and Azipod®[1)] propulsion. The propulsion systems are arranged coaxially, but not directly connected. This arrangement allows the recovery of the main propeller's forward rotational velocity component.

CRP System Hydrodynamical Study

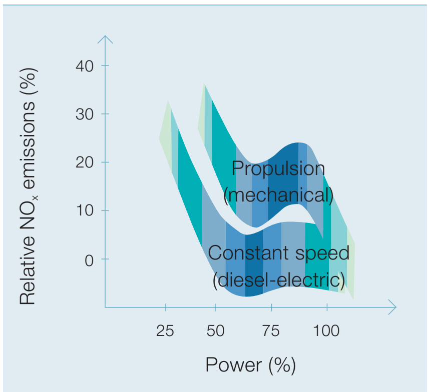
ABB has studied and performed several model test series for the CRP concept on different ship types. The efficiency gain from this new propulsion system depends on factors such as ship type, ship speed, power level, loading, RPM and machinery. In general, an efficiency improvement of 5 to 15 percent is achieved with a CRP system. 5 shows test results for a high speed Ropax[2)].

2 Propulsion efficiency comparsion.

Optimal operation area/Electric drive
Optimal operation area/mechanical drive
Azipod propulsion/four prime movers/optimized hull form
Diesel-electric propulsion/four prime movers
Mechanical propulsion/one prime mover



3 NO_x emissions are lowest at high engine load (Source: Wärtsilä Diesel)



4 Contra-rotating propellors improve the vessel's hydrodynamic performance.

ENVIROPAX was a joint R&D project – partly funded by the Finnish government – involving ABB and two Finnish shipbuilding companies, Kvaerner Masa-Yards and Wärtsilä. The success of the project can be attributed to the combined know-how and experience of these individual companies – ABB is a leading player in the diesel-electric and pod propulsion sector, Kvaerner Masa-Yards in shipbuilding and Wärtsilä in marine power units.

Two fast displacement Ropax concepts with CRP Azipod® propulsion were studied in the ENVIROPAX project. The project focused on the hydrodynamic aspects of CRP propulsion systems. The following aspects were studied:

- Effect of power distribution on propulsion efficiency.
- Propulsion performance of two different pod sizes.
- Cavitation performance of the propellers in different conditions.
- Pressure pulse levels on the hull.

Hydrodynamic aspects of propulsion systems were tested and analyzed using exactly the same ship hull to clearly determine the effects of different propellers and pod units.

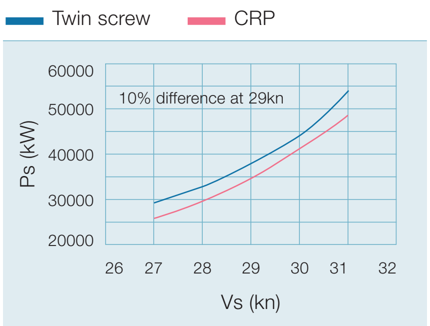
Power division between propellers

The effect of power division between propellers on overall efficiency is important because this has a considerable effect on the cost of the propulsion system. It is important to understand how a power division can be selected that does not impose too high a penalty on propulsion efficiency.

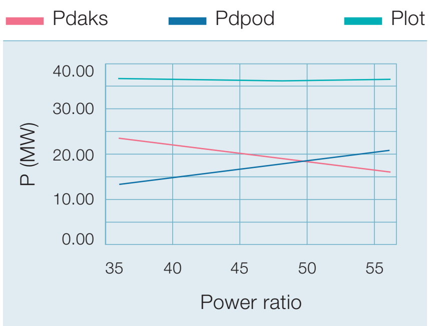
Several calculations for different power distributions were made. These show that from an economical point of view, the smaller the installed pod-power the better, but from a hydrodynamic point of view, a larger and more powerful pod has advantages. From the shipbuilders' point of view, the cost of the vessel is most important, whereas from the owner's point of view the operating cost is also vital.

Division of power is probably the most important issue when this kind of propulsion system is evaluated for a vessel. Several items have to be thoroughly considered. The size of

5 Comparison between CRP and Twin Screw Ropax.



6 Power distribution can be selected flexibly without decreasing the propulsion efficiency significantly.



the electric power plant is important, because it affects the propulsive efficiency of the whole system. The losses in the electric system between the generators and the Azipod® propeller are higher than on the mechanical side. This is why the size of the Azipod® unit is important. When an Azipod® type is selected, the efficiency of the whole system has to be considered from a mechanical, electrical and hydrodynamic point of view. After several different machinery setups were studied the following configurations were selected.

Case Number 1:

- 10 MW Azipod®.
- Lips CP propeller driven by two Wärtsilä medium speed diesel engines with combined installed power of 33.6 MW.
- Total propulsion power (Azipod® power + CP propeller): 43.6 MW.

Case Number 2:

- 19 MW Azipod®.
- Lips CP propeller driven by two Wärtsilä medium speed diesel engines with combined installed power of 23.2 MW.
- Total propulsion power (Azipod® power + CP propeller): 42.2 MW.

Propeller Design

Two CRP couples were designed to give the best possible efficiency, taking into account cavitation and pressure pulse levels. The task was very challenging because of the high loading of the propellers and the CRP with pod concept increasing the complexity of the analysis.

Many calculations were needed to support the choice of propeller diameter, shaft speed, distance between the two propellers and the power split between them.

Propulsion tests with propellers and Azipod® units were carried out to determine the effect of the power split between the main propeller and the pod propeller. There were two test series: two alternative main propeller/Azipod® unit pairs were used, and for each combination four different power splits were applied. The speed in all these tests was 29 knots.

The test results 6 clearly show that the power distribution can be selected flexibly without significantly decreasing propulsion efficiency.

Results of the hydro-dynamical study

The goal of the project was the investigation of the effect of the propulsor power split on the total propulsion efficiency and power demand of the ship. The hull shape was kept the same through all tests. This data is important because the power split between the electric pod and the mechanical propeller influences many aspects of the design and total performance of the ship, such as investment costs, transmission losses and machinery space demand. The study aimed at identifying effects on hydrodynamic efficiency and power demand.

The results show that propulsion efficiency remains almost unchanged over a wide power split range. This means that the pod power can be kept small, thus giving ship designers greater flexibility when selecting machinery for their vessel.

However, the pod should not be reduced too much. The limiting factor is not the power share, but rather how much power can be applied to the mechanical propeller. If the load of this propeller is too high, undesirable phenomena such as cavitation and pressure pulses can occur.

CRP Azipod® propulsion in operation

The CRP Azipod® propulsion concept has been applied to two fast ferries operating in Japan. The Shinni Honkai ferries Hamanasu and Akashia 7 have been in service since June 2004. The ships were built at the Mitsubishi Heavy Industries yard in Nagasaki. The operational concept is based on a high operating speed (30.5 knots). The ships have a 24.4 MW main CP propeller driven by medium speed diesels and a 17.6 MW Azipod®.

The fuel economy of this concept has been compared to conventional shaftline ships. The operator reports that the conventional ship concept requires over 20 percent more fuel to perform the same service as the ferries with the CRP Azipod® propulsion. Emissions are decreased by the same proportion.

Conclusion

The use of electric power transmission and CRP technology provides considerable savings for ship operators through lower fuel consumption, lower maintenance costs and greater flexibility in ship design. The reduction in pollution achieved is another important factor whose importance will grow as environmental legislation is tightened.

7 Akashia ropax ferry in operation in Japan.

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Footnotes

1) See also "Turning point: CRP Azipod® gives a boost to marine propulsion efficiency", Matti Turtiainen, ABB Review 1/2003.

2) A ropax vessel is a RoRo (roll-on roll-off) vessel that also offers comfortable passenger amenities.