Approaches of the Energy-Saving ROPAX Ferry for the Next Generation

TETSUYA MORI*1
TOHRU KITAMURA*1
AKIRA YAMAMOTO*1
KATSUSHI OHNISHI*1
NAOKI UEDA*2
AKIRA DOI*2

Mitsubishi Heavy Industries, Ltd. (MHI) has built many ROPAX ferries with twin-screw, two-engine propulsion plants. The propulsion plant consists of a pair of propulsion systems, each with a propeller directly connected to a main diesel engine. Global warming and abnormally sharp climbs in the prices of fuel oil in recent years redouble the need for reduced fuel consumption and reduced environmental loads. An urgent task for MHI in addressing these issues is to develop energy-saving ROPAX ferries driven by propulsion plants based on new concepts. This paper describes the approach of MHI for the development of energy-saving ROPAX ferries with new propulsion plants designed for reduced fuel consumption.

1. Introduction

International efforts to conserve the global environment have steadily accelerated since the 3rd Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change in 1977. The public, private, and academic sectors in Japan have actively promoted the Modal Shift Policy targeting more efficient commodity distribution and reduced environmental loads, the Super-Eco-Ship Project(1) established by the Ministry of Land, Infrastructure and Transport, and the Project to Support Rationalized-Energy-Use Business(2) established by the New Energy and Industrial Technology Development Organization (NEDO). The recent jumps in the prices of fuel oil, however, are posing grave problems for the running of shipping firms by cutting into commercial profits from the operation of vessels. MHI, meanwhile, has committed itself to the development of low-fuel-consumption ROPAX ferries as one way to help harmonize the business activities of shipping firms with the global environment. The first parts of this paper explain the performances required of the ROPAX ferry and describe the features of the propulsion plant of the conventional ROPAX ferries now in operation. The latter sections of this paper describe the issues to be solved during the development of the energy-saving ROPAX ferry for the next generation, and introduce the concept of a new propulsion plant now being considered by MHI for the future.

2. Performance required of the ROPAX ferry

Japan is composed of the four main islands of Hokkaido, Honshu, Shikoku, and Kyushu, and the hundreds of smaller islands around them. The islands have always been connected by boats and ferries loaded with passengers and commodities. In recent decades, the long-distance ROPAX ferries (ROPAX ferries sailing sea routes of 300 km or longer, one way) have contributed to domestic commodity distribution as maritime trucks. **Figure 1** shows the increasing service speeds of the ROPAX ferries built year by year. The number of ROPAX ferries capable of traveling at service speeds in excess of 20 kt has gradually increased from around 1985. The important target for ferry shipping firms is to narrow the gap in transit time between their ferries and land transportation vehicles such as trucks and trains. The demand for faster ferries remains strong even now.

Faster speed, however, is just one of several concerns of ferry shipping firms. More important is the rapidly growing demand for better fuel economy to ease the burdens on the global environment and ease the financial strains from the rapidly escalating price of oil. Thus, the pursuit of the conflicting targets of higher speed and better fuel economy is of unprecedented importance in the design and engineering for the ROPAX ferries of the next generation.

During the 3rd Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change held in 1997, participating nations agreed to reduce their emissions of greenhouse effect gases to target

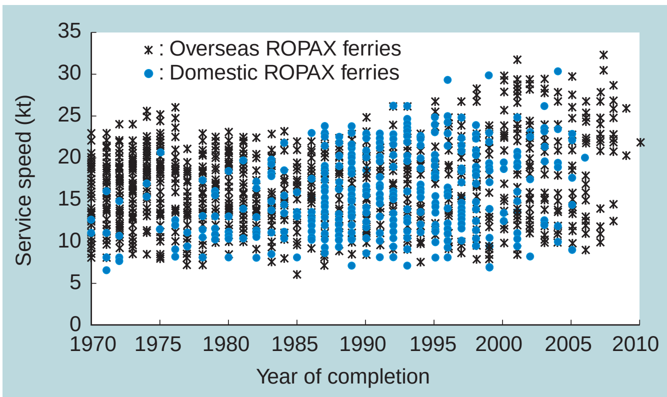


Fig. 1 Service speed of ROPAX ferries
Shows the transition of service speed from 1970 onwards.

*1 Shimonoseki Shipyard & Machinery Works
*2 Shipbuilding & Ocean Development Headquarters

values, or to lower emissions from 2008 to 2012 (the target value for Japan is the reduction of 6%). According to an investigation[3] by the Ministry of Land, Infrastructure and Transport, CO_2 emissions from domestic transport in Japan in fiscal 1990 were 217 million tons of CO_2. Of that amount, the emissions from vessels were 6.3% (13.7 million tons of CO_2). By fiscal 2005, the emissions had increased to 257 million tons of CO_2, of which 5.0% (12.9 million tons of CO_2) was discharged by vessels. Though CO_2 emissions for the whole of the transportation field are apt to increase, the ratio of emissions from vessels relative to the whole has fallen. Following the enforcement of the Kyoto Protocol in February 2005, the Japanese Cabinet set targets for CO_2 reduction by industry to satisfy the protocol, in a meeting of April 2005. Railways and aircrafts, whose CO_2 emissions had increased, are thus expected to reduce CO_2 emissions by improving the energy efficiency of single units. Though concrete target values for vessels have yet to be stipulated, the expectations are high. To realize higher efficiency in commodity distribution mainly in accordance with the Modal Shift Policy to promote the conversion from truck transportation to railway and marine transportation, a rather high target for CO_2 reduction has been set (relative to the various other measures taken in the field of transport overall). Vessels suitable for the long-distance transport of large quantities of cargo are apparently expected to play an important role in the overall effort to reduce environmental loads.

Figure 2 shows the fluctuation[4] of the C-oil price (per kL) since 1995. The recent C-oil price has steeply risen to double the levels in and before 2000. Assuming a unit price of C-oil of 47,000 yen/kL, the fuel cost of a large ROPAX ferry with a service speed of 23 kt and gross tonnage of a little less than about 30,000 GT can be provisionally estimated to account for more than 30% of the vessel cost overall. The steep rise of the fuel cost clearly imposes a heavy burden on the running of the ferry shipping firms.

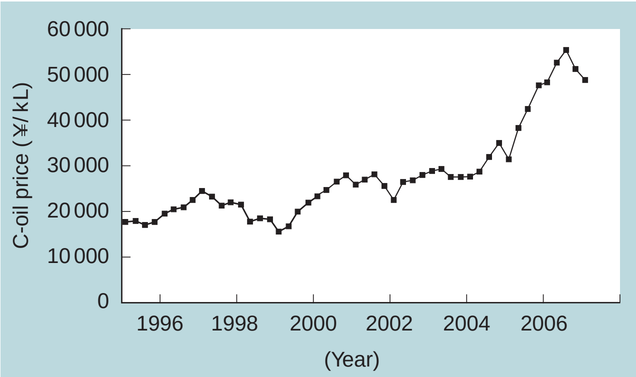


Fig. 2 C-oil price
Shows the price fluctuation from 1995 onwards.

3. Propulsion plant of a conventional type ROPAX ferry

A ROPAX ferry is generally faster than a normal merchant vessel and uses more propulsion power. The diameter of the ferry propeller, however, is limited by the draught determined from the water depth of the quay. Since it is difficult for only one propeller to generate the required propulsion power, the conventional ROPAX ferry has adopted a twin-screw system driven by two independent propulsion systems symmetrically allocated. The twin-screw system generally adopts a shaft bracket system (**Figure 3**) to support the shaft and propeller with bossing and a bracket, as the propeller shaft is exposed from the hull.

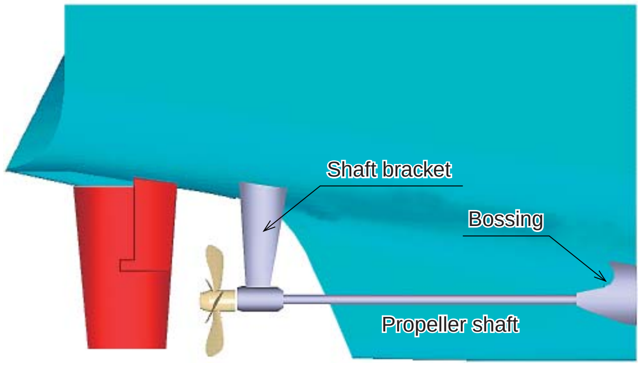
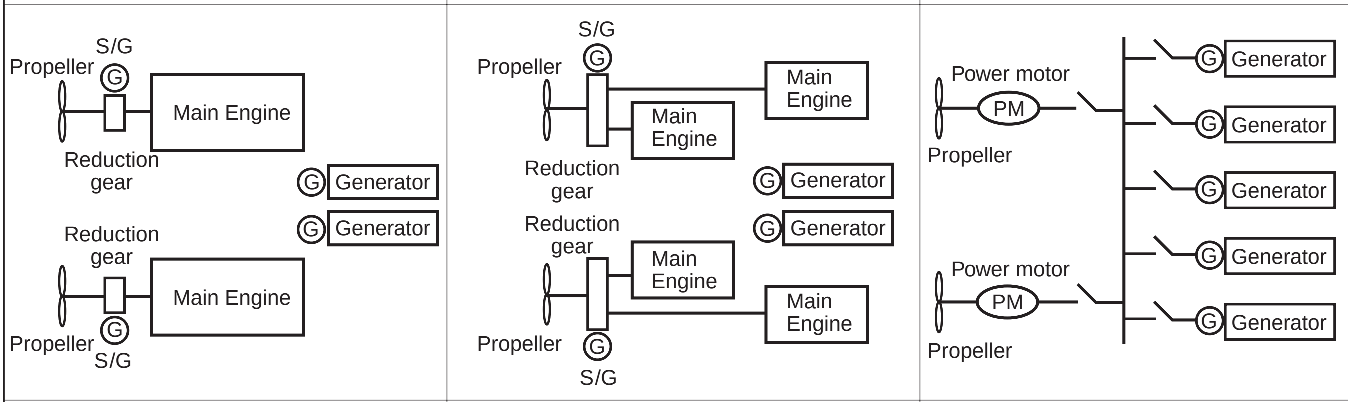


Fig. 3 Twin-screw prupulsion system (shaft bracket system)
Many conventional ROPAX ferries adopt this system.

The twin-screw system effectively reduces the propeller vibratory force and suppresses vibration and noise, as the required propulsion power is divided into two parts. Even if trouble occurs in one propulsion system, navigation can be continued with the other propulsion system. The system provides excellent redundancy and safety for a passenger ship. Another advantage of dual propulsion plants is the use of dual rudders for steering. This improves the accuracy of maneuvering in harbors and narrow, heavily trafficked seas. Many conventional ROPAX ferries have adopted the twin-screw system to gain these benefits.

Figure 4 compares the propulsion plants of conventional twin-screw ROPAX ferries. The propulsion systems are roughly divided into a diesel directly coupled system and an electric propulsion system. The diesel directly coupled system adopts either a twin-screw, two-engine-driven system or a twin-screw, four-engine-driven system. Japanese ROPAX ferries generally use the twin-screw and two-engine-driven system, whereas many ROPAX ferries in Europe have recently been built with twin-screw and four-engine-driven systems. The twin-screw, four-engine-driven system has excellent redundancy for coping with troubles of the main engines, as well as the flexibility to enable adjustment of the number of main engines operated in accordance with the sea speed. Fuel oil consumption and CO_2 emission can both be reduced by reducing the number of main engines operated while cruising at low speed. The electric propulsion system, meanwhile, operates with considerably less noise and vibration than the diesel directly coupled system. This benefit has persuaded many shipbuilders to adopt it for large cruise ships.

Twin-screw, two-engine directly coupled diesel propulsion system	Twin-screw, four-engine directly coupled diesel propulsion system	Twin-screw, electric propulsion system



(Features)	(Features)	(Features)
■ System to directly couple the main engine and propeller on a one-to-one basis via a reduction gear. ■ Almost all domestic ROPAX ferries adopt this system. ■ In some cases, side thruster electric power during harbor operation is supplied by the diesel generator without adopting a shaft generator (S/G).	■ System to directly couple the main engines and propeller on a two-to-one basis via reduction gears. ■ Propulsion system has excellent redundancy. ■ Engine cutoff operation is possible with twin-screw propulsion maintained in a low speed range (no check helm required). ■ Many of these systems have recently been adopted for ROPAX ferries in Europe.	■ System to drive propellers with electric motors (ample experience in passenger ships). ■ Outperforms the diesel directly coupled systems shown in the left columns, from the viewpoint of vibration and noise.

Fig. 4 Propulsion plant for the twin-screw ROPAX ferry

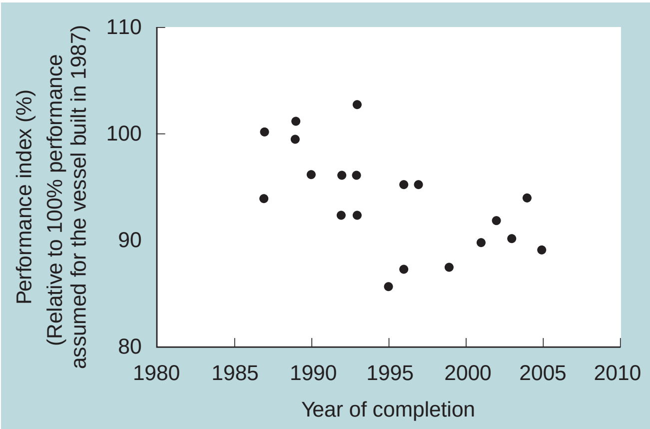


Fig. 5 Propulsive performance of the large twin-screw ROPAX ferries built by MHI
Performance has been improved by about 10% over the last 20 years or so since 1987.

Figure 5 shows the propulsive performances of large twin-screw ROPAX ferries with lengths of 150 m or more between perpendiculars, built by MHI over the decades. The performance indexes plotted on the vertical axis are relative to an assumed propulsive performance of 100% for the vessel built in 1987. New hull designs developed with the aid of computational fluid dynamics (CFD) help to limit increases in the main engine horsepower while improving the speed capabilities of the ROPAX ferries. A performance improvement of about 10% has been achieved over the 20 years or so from 1987 to the present.

4. Issues in the development of ROPAX ferry for the next generation

Reduced hull resistance will be a crucial design target in future efforts to compatibly pursue the dual aims of faster service speeds and improved fuel economy. The single-screw hull (**Figure 6**), the type adopted to most commercial vessels in common-sense terms, generally has less hull resistance than the twin-screw hull because of the simplified shaft system support structure under the water line (there is no shaft bracket, and only one bossing is installed). The adoption of the single screw hull can thus be expected to improve the propulsive performance by about 10 to 15%. Encouraged by this prospect, MHI has decided to focus its efforts on the development of a ROPAX ferry with a new propulsion plant adopting a single-screw system.

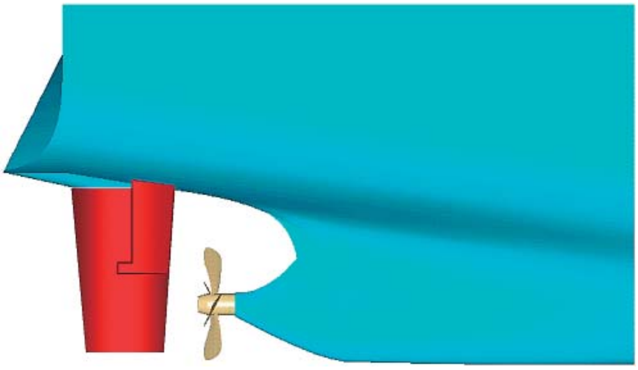


Fig. 6 Single-screw propulsion system
The support structure for the shaft system can be located in the hull, owing to the single shaft.

The designs for the ROPAX ferry with a single-screw system must meet the same standards of safety, reliability and habitability as a passenger ship while conforming to requirements of a vessel for cargo transport (such as trucks, etc.). The twin-screw vessel has two separate propulsion systems. The adoption of the single-screw, two-engine system for a single-screw vessel will ensure redundancy for coping with main engine troubles, but not the same degree of redundancy ensured by the twin-screw vessel. This makes it all the more important to ensure the reliability of the shaft system equipment. From the point of view of less noise and high propeller efficiency, the design target should be to adopt a large-diameter propeller while maintaining sufficient clearance between the propeller and the aft bottom of the hull to reduce the propeller vibratory force. It will be important to carefully balance of all of these design elements, however, as the propeller diameter is limited by the draught determined from the water depth of the used quay.

5. Propulsion plant of ROPAX ferry for the next generation

Figure 7 shows the concept of the propulsion plant during the development of the ROPAX ferry for the next generation. The single-screw, two-engine system makes use of the excellent propulsive performance of the single-screw hull, but the reliability of the shaft system must be assured, as mentioned earlier in Section 4. The electric propulsion system (twin pod propulsion system) and hybrid propulsion system seem feasible as options for coping with this requirement.

If opting for an electric propulsion system, the twin electric driven pod propulsion units can be adopted in place of the propeller. This system increases the freedom of the layout design, as the adoption of twin pod propulsion units permits the omission of the main engine and shaft systems. Electric propulsion also generates far less vibration and noise than propulsion plants based on conventional systems (mechanically driven systems).

The hybrid propulsion system combines a mechanical driven propeller with an electrically driven pod propulsion unit or azimuth propulsion unit. Electrically driven systems such as pod propulsion units, azimuth propulsion units, etc. have much greater energy conversion loss than mechanically driven systems. This demerit can be attenuated, however, by decreasing the share of the electrically driven system through the combination with the mechanically driven propeller. These hybrid propulsion systems have completely independent configurations to ensure a redundancy equivalent to that of the twin-screw propul-

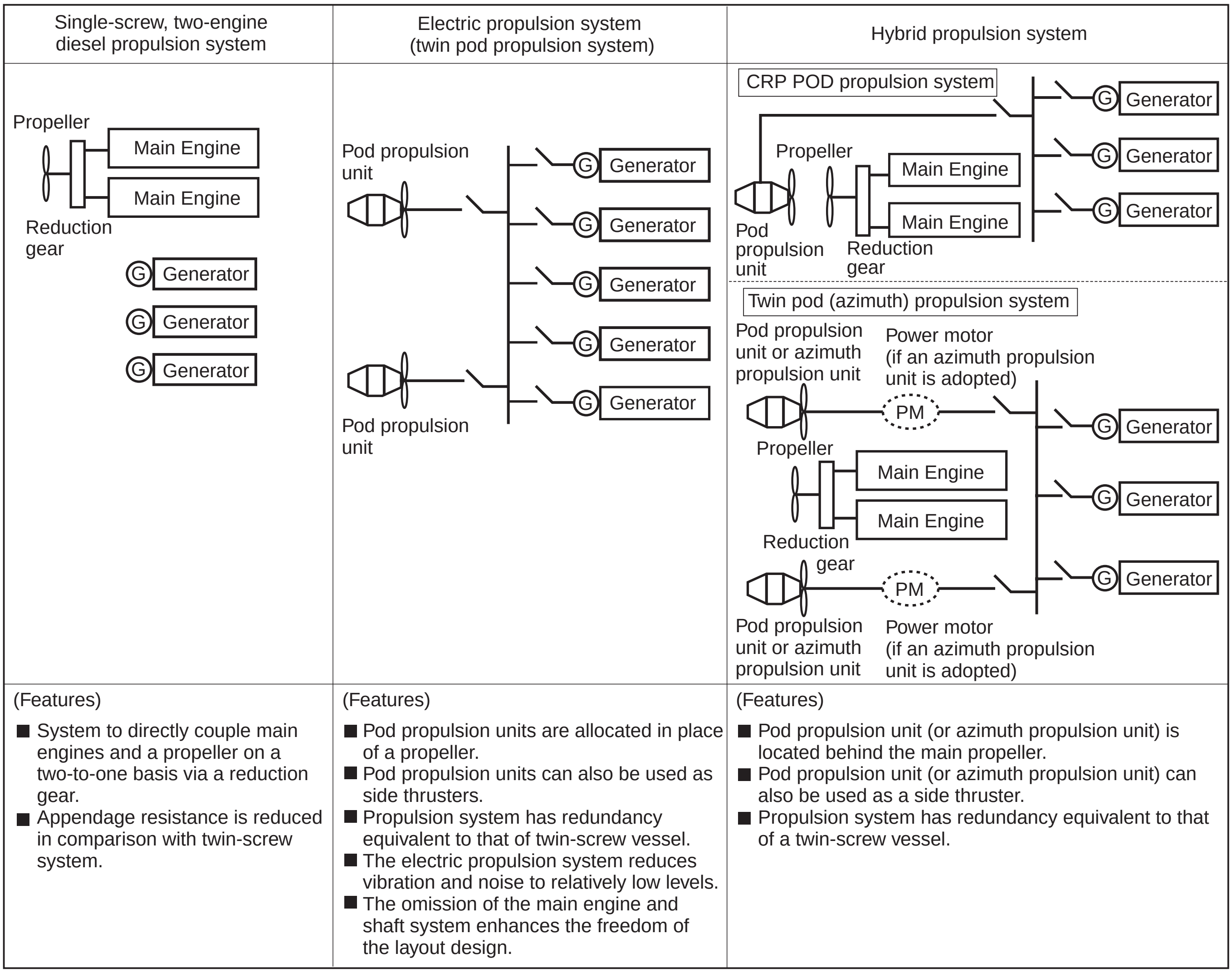


Fig. 7 Propulsion plant for the ROPAX ferry for the next generation

sion system. Though Figure 7 shows a single-screw, two-engine system as the mechanically driven system, the backup of the electrically driven system would permit the adoption of a single-screw, one-engine system as well.

The pod propulsion unit and azimuth propulsion unit are both installed on the lower part of the aft hull, and both can carry out the 360-degree rotation. Thus, the rudder and side thruster functions are provided simultaneously for improved steering performance during harbor and pier operations.

6. Case examples of adoption by MHI

Among the hybrid propulsion systems described earlier in Section 5, the hybrid CRP-POD propulsion system was adopted for the HAMANASU and the AKASHIA, two vessels commissioned for service by Shin Nihonkai Ferry Co., Ltd. in June 2004. The two vessels consume 13% less fuel than comparable vessels adopting the conventional twin-screw propulsion systems, and thereby help to reduce cruising costs and CO_2 emissions[5]. An outline of the propulsion plant for these vessels follows below.

The pod propulsion unit drives a propeller directly coupled with a motor incorporated in a pod-shaped unit.

As shown in **Figure 8**, the pod propulsion unit is located on the extension of the shaft centerline of the main propeller. The main propeller and pod propeller are closely arranged to enable them to operate like a single set of contra-rotating propellers (CRP). Adjacent propellers rotating in opposite directions can realize high propulsion efficiency by reducing the tangential water flow via the 'CRP effect.'

The main propeller is a controllable pitch propeller (CPP) driven directly by two medium-speed diesel main engines via a reduction gear with a clutch and intermediate shaft. The pod propeller positioned behind is an electric propulsion unit driven by an electric motor in the pod powered by electricity from the power-generation plant.

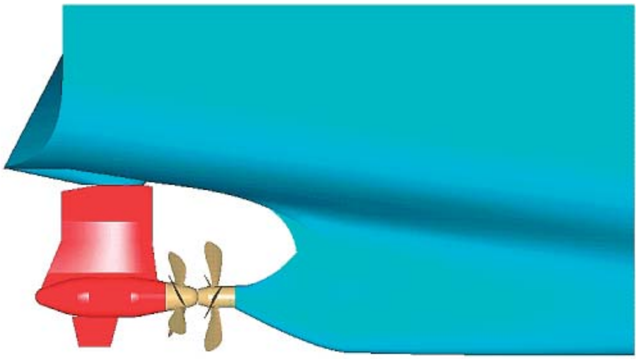


Fig. 8 Hybrid type CRP POD propulsion system
CRP POD propulsion unit is equipped behind main propeller.

7. Conclusion

The demand for crude oil is increasing in step with the growth of the global economy, and the rises in the price of fuel oil have been alarmingly steep. The need for environmental preservation, meanwhile, grows all the more urgent as the phenomenon of global warming caused by the use of fossil fuel changes the climate and ecosystems of the planet.

Amidst these global-scale changes, we make it our mission to help protect the environment by delivering ships with high efficiency and low fuel consumption.

In addition to the development of new propulsion plants, for the development of the ROPAX ferry for the next generation, we need to review our layout design by anticipating the international regulations which are to be incorporated into domestic regulations, in order to improve the safety of passenger ships and prevent marine pollution:

(1) New probabilistic damage stability evaluation (HARDER) due to revision of SOLAS (International Convention for the Safety of Life at Sea); and
(2) Realization of a double hull for the fuel oil tank in accordance with the revision of MARPOL (International Convention for the Prevention of Pollution from Ships).

We also intend to offer a high-value added ROPAX ferry to please passengers as well the shipping firms by enhancing special features for habitability, comfort, barrier-free systems, and so on.

References

(1) http://www.jrtt.go.jp/business/vessel.htm
(2) http://www.mlit.go.jp/kaiji/nedo/nedo.html
(3) http://www.mlit.go.jp/sogoseisaku/kankyou/ondanka1.htm
(4) http://www.geocities.jp/tetchan_99_99/oil/c-oil.html
(5) Ueda, N. et al., The First Hybrid CRP-POD Driven Fast ROPAX Ferry in the World, Mitsubishi Heavy Industries Technical Review Vol. 41 No. 6 (2004)


Tetsuya Mori


Tohru Kitamura


Akira Yamamoto


Katsushi Ohnishi


Naoki Ueda


Akira Doi