Efforts toward Development of Energy-Saving Large-Size ROPAX Ferry

MASANORI ONZUKA[*1] YOKI UEMURA[*2]
KUNIAKI YAMATO[*3] AKIRA DOI[*4]
TESTUYA MORI[*4]

Mitsubishi Heavy Industries, Ltd. (MHI) has built numerous ROPAX ferries. With the socioeconomic background around ROPAX ferry operators, such as fluctuating fuel oil prices and domestic cargo logistics, the need for energy-saving ROPAX ferries with a high capability of attracting customers and freight is increasing more than ever before. This paper describes MHI's efforts on the development of energy-saving ROPAX ferries equipped with new propulsion plants, highlighting the perspective of a reduction in fuel consumption.

1. Introduction

Rising price of fuel oil that started in fiscal 2005 seemed to come to an end in the second half of fiscal 2008 immediately after the failure of Lehman Brothers. In fiscal 2009, however, fuel oil prices began to rise again and resulted in nearly 10 years of concern for ROPAX ferry operators until the middle of fiscal 2014 (**Figure 1**). Taking the existing fleet of very old ships that waste fuel in conjunction with this increase in fuel oil prices into consideration, a reduction in fuel consumption is undoubtedly an urgent issue facing ROPAX ferry operators.

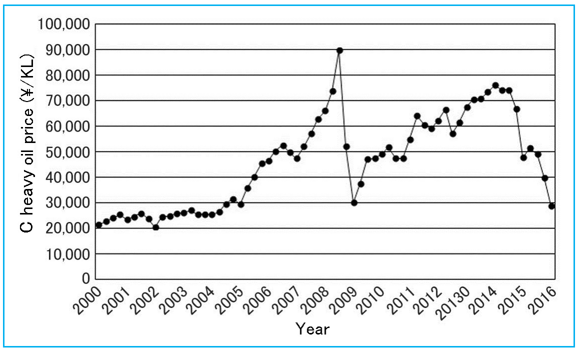


Figure 1 Transition of C heavy oil price

In order to survive, long-distance ROPAX ferries essentially need to improve their capability of attracting customers and freight, so that they can win the battle for acquiring passengers against Shinkansen high-speed trains, LCC (low cost carrier) airlines, express bus lines, and expressways, and promote a modal shift policy as a solution to the chronic shortage of long-distance truck drivers caused by the changing social structure, the decreasing birthrate and the aging population.

Against such a backdrop, MHI has been working on the development of a next-generation ROPAX ferry in order to achieve the conflicting purposes of an increase in size and the enhancement of energy efficiency. This paper first presents the concept of the propulsion plants for the next-generation ROPAX ferry that we have developed, and then the most advanced large-size ROPAX ferries introduced successively to lines between Shinmoji and Izumiotsu and between Osaka and Shinmoji in 2015 as examples of actual introduction. Finally, we summarize our future approach.

*1 Shimonoseki Ship & Ocean Engineering Department, Shipbuilding & Ocean Development Division, Commercial Aviation & Transportation Systems
*2 Deputy Director, Shimonoseki Ship & Ocean Engineering Department, Shipbuilding & Ocean Development Division, Commercial Aviation & Transportation Systems
*3 Manager, Shimonoseki Ship & Ocean Engineering Department, Shipbuilding & Ocean Development Division, Commercial Aviation & Transportation Systems
*4 Chief Staff Manager, Shimonoseki Ship & Ocean Engineering Department, Shipbuilding & Ocean Development Division, Commercial Aviation & Transportation Systems

2. Next-generation propulsion plants

Typically, ROPAX ferries, which have higher propulsive power and navigate at higher speeds in comparison with general merchant ships, are subject to draft limits by the wharves being used and therefore their propellers are limited in diameter. For this reason, it is difficult for a single propeller to handle the required propulsive power, and a twin-screw, two-engine diesel propulsion system with two sets of independent propulsion systems located bisymmetrically is normally used. A twin-shaft propulsion system can suppress vibration and noise due to the reduction in propeller vibratory force resulting from the separation of the required propulsion power into two. Such a system has redundancy, where even if one propulsion system or steering equipment fails, navigation can be continued using the other, providing excellent reliability and safety. There is, however, a problem with this system where the supporting structure of the shaft system, which includes shaft brackets and bossings, must be installed below the waterline and therefore the resistance caused by the additional objects becomes larger in comparison with a vessel using a single-shaft system.

For this reason, MHI has been working on the development of next-generation propulsion plants that can attain favorable fuel efficiency while maintaining the redundancy of the propulsion plant. **Figure 2** shows the concept of next-generation propulsion plants.[1]

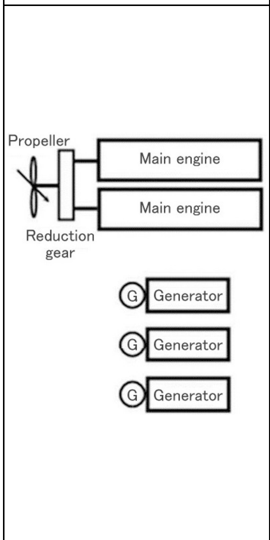
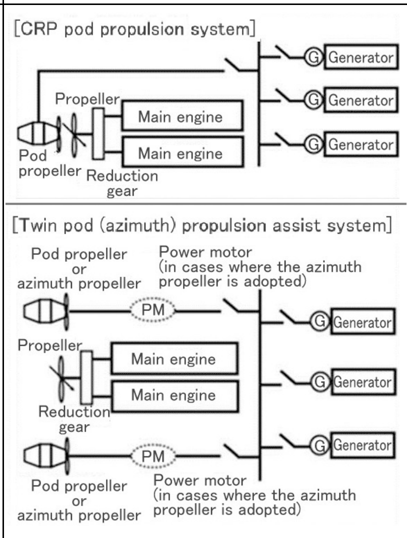
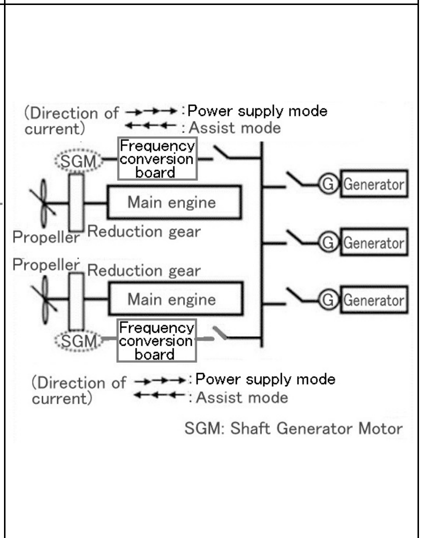
Single-screw, two-engine diesel propulsion system	Hybrid propulsion system	Dual hybrid propulsion system
		
(Features) - A system where the two main engines are directly connected to the one propeller through a reduction gear - Resistance caused by additional objects becomes smaller than that of the twin-shaft system.	(Features) - The pod propeller (or azimuth propeller) is arranged behind the main propeller. - The pod propeller (or azimuth propeller) can be used as a thruster. - The propulsion system has a redundancy similar to that of a twin-screw vessel.	(Features) - A system established by adding to the conventional twin-screw, two-engine diesel propulsion system a shaft generator motor equipped with a frequency conversion board - The shaft generator can be driven by a wide range of main engine speeds to supply electricity to the ship. - The shaft generator can be used as a motor for propulsion assist using electric power from the main generator.

Figure 2 Next-generation propulsion plants

A twin-engine, single-screw diesel propulsion system adopts a single-screw vessel type to eliminate the shaft brackets and reduce the number of bossings in order to provide higher propulsion performance than that of a twin-screw vessel. While the twin-main engine construction secures redundancy against the failure of a main engine, the single-shaft structure has less redundancy in terms of the shaft system and the steering equipment in comparison with a twin-shaft structure. Therefore, it is important to secure reliability when the twin-engine, single-shaft diesel propulsion system is adopted. In addition, when the propeller diameter is increased in order to improve the propeller efficiency, a proper clearance between the propeller and the vessel bottom outer panel under the waterline must be secured in order to reduce the effects of propeller vibratory force.

A hybrid propulsion system is a combination of the main propeller driven by the main engine and an electrically driven propeller such as a pod propeller or an azimuth propeller. A pod propeller is a pod-shaped casing incorporating a motor and an azimuth propeller is driven by the power motor installed in the ship. This system has mutually independent propulsion systems driven by the main engine and driven by electricity in order to secure redundancy similar to that of a twin-screw vessel, while taking advantage of the good propulsion performance of a single-screw vessel. A pod propeller and an azimuth propeller, which swivel 360 degrees, can be used as a steering device or a stern thruster and can be expected to improve ship maneuverability in navigation or controlling in a harbor. A CRP pod propulsion system, which is a hybrid propulsion system, coaxially arranges the pod propeller immediately at the rear of the main propeller driven by the main engine and on its shaft center line, and uses the main propeller and the pod propeller as a single set of contra-rotating propellers (CRP). The pod propeller recovers the rotating flow generated by the main propeller in order to improve the propeller efficiency. A twin pod (azimuth) propulsion assist system, which arranges electrically driven azimuth propellers on both sides of the main propeller driven by the main engine, attains excellent ship maneuverability and redundancy against accidental problems of the drive system or the shaft system.

A dual hybrid propulsion system, which is a system established by adding to a conventional twin-screw, two-engine system the idea of propulsion assist made by a shaft generator, is intended to reduce the main engine power while utilizing the advantages of a twin-screw, two-engine system. Typically, conventional twin-screw, two-engine diesel propulsion systems have a shaft generator that is driven by the main engine through a reduction gear in order to provide electric power for the side thruster used for ship control in a harbor. The electricity generated by this type of shaft generator cannot be used in the ship because the frequency of the generated electricity varies in response to changes in the main engine speed in combinator-controlled acceleration/deceleration or in stormy weather. A dual hybrid propulsion system can, however, supply energy from the high fuel efficiency main engine for use in the ship during normal navigation regardless of the main engine speed, using a frequency converting board that adjusts the frequency of the electricity generated by the shaft generator to a frequency suitable for supply in the ship. Furthermore, the shaft generator can be used as a propulsion assist motor when supplied from the main generator, and therefore a more flexible navigation mode is attained by using the functions of this shaft generator motor (SGM) properly depending on the required ship speed.

3. Recent examples of introduction

Among the next-generation propulsion plants described in chapter 2, the dual hybrid propulsion system was introduced to ROPAX ferries Izumi and Hibiki of Hankyu Ferry Co., Ltd., which were brought into service in 2015 for the line between Shinmoji and Izumiotsu. Furthermore, a hybrid twin azimuth propulsion assist system was introduced to ROPAX ferries Ferry Osaka II and Ferry Kitakyushu II co-owned by the Japan Railway Construction, Transport, and Technology Agency and Meimon Taiyo Ferry Co., Ltd., which were brought into service also in 2015 for the line between Osaka and Shinmoji. On the Setouchi Route where these ROPAX ferries travel, high ship maneuverability is required because there are many islands, the marine traffic is heavy, and overtaking is restricted in narrow water areas. For these ROPAX ferries, the optimum propulsion plants were selected in consideration of not only energy-saving capability, but also the circumstances of the route described above, redundancy against the failure of the propulsion system, usability for the crew and the lifecycle cost including the maintenance cost. In addition, energy-efficient vessels suitable for their propulsion plants were developed, and combined with the Mitsubishi Air Lubrication System (MALS),[2] MHI's proprietary energy-saving technology, in order to improve the fuel efficiency. The propulsion plants of these ROPAX ferries are summarized in the next section.

3.1 Dual hybrid propulsion system

The planning of the propulsion plant to be used for Izumi/Hibiki proceeded while also considering the possible adoption of the CRP pod propulsion system based on the required propulsion power. The dual hybrid propulsion system based on the medium-speed twin-screw, two-engine propulsion system was, however, ultimately selected because the system had past results and the crew members were familiar with the system. **Figure 3** shows the plant structure of Izumi/Hibiki. This plant is equipped with a thyristor shaft generation system consisting of a frequency conversion board, synchronous phase modifier and shaft generator. In the shaft generation power supply mode, AC power from the shaft generator is converted to DC power by the thyristor convertor in the frequency conversion board, then converted to AC power with a certain frequency by the synchronous phase modifier and the thyristor invertor and supplied to the main switchboard. The shaft generator can be operated in parallel with the main generator by automatic load sharing control of the main switchboard. In the propulsion assist mode, on the other hand, the shaft generator is supplied with excess electric power from the main generator and is used as a motor for propulsion assist, resulting in an increase in propulsion output with the main engine kept in a fuel-efficient output region. As described above, the dual hybrid propulsion system has features that enable the energy of the main engine and the generator to be used flexibly in response to the required propulsion power of the ship and its demand for electric power.

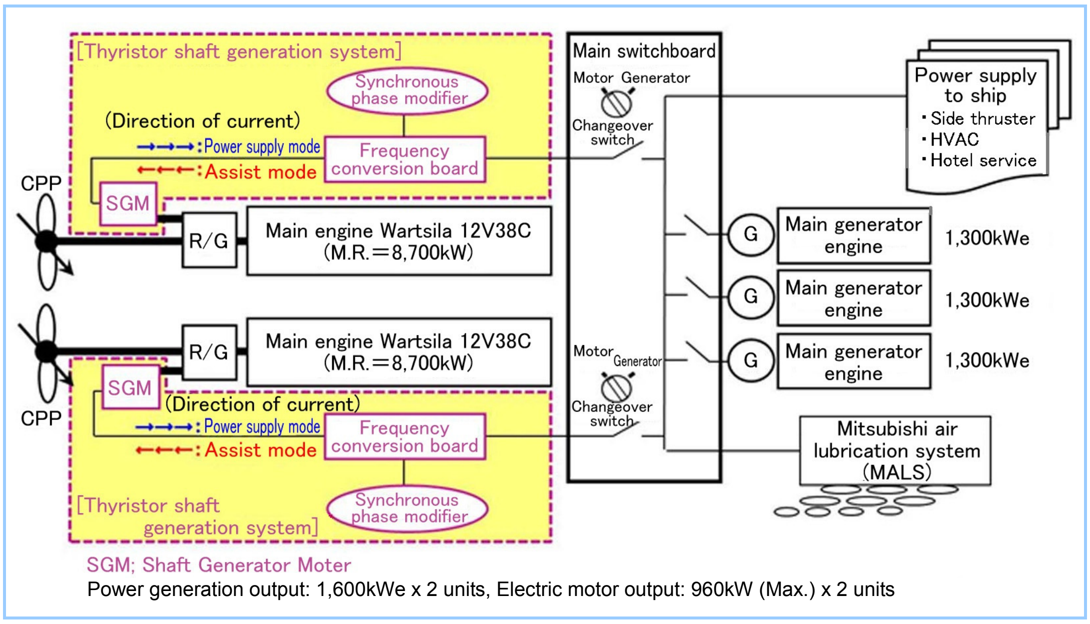


Figure 3 Dual hybrid propulsion system

Table 1 compares the specifications between Izumi/Hibiki and the ROPAX ferry that they replaced. Izumi/Hibiki improve fuel efficiency due to adoption of MHI's proprietary energy-saving technologies, while enhancing the cargo loading capacity by enlarging the vessel by increasing the number of lanes from eight to nine. They also attain a reduction in transportation fuel cost per truck of approximately 35% in comparison with the ROPAX ferry they replaced.

Table 1 Main specifications comparison table of Izumi/Hibiki

ROPAX ferry name		ROPAX ferry replaced	Izumi/Hibiki
Main dimensions	Length overall	189.0m	195.0m
	Breadth/Number of Lanes	27.0m/8 lanes	29.6m/9 lanes
	Gross tonnage (Domestic)	15,188	15,897
	Gross tonnage (International)	-	35,327
Cargo loading capacity	8.5-m trucks	219 vehicles	277 vehicles
	Passenger vehicles	77 vehicles	188 vehicles
Passenger capacity		810	643
Service speed		23kt	23.5kt
Propulsion and steering plant		Twin-screw, two-engine CPP	Twin-screw, two-engine CPP ＋Shaft generator motor
Main engine	Max output×units	11,915kW×2	8,700kW×2
Shaft generator motor	Max output×units	—	960kW×2
Propeller	Type×units	Controllable pitch propeller×2	Controllable pitch propeller (with HVFC) ×2
Other		—	MALS

HVFC: Hub Vortex Free Cap

3.2 Twin azimuth propulsion assist system

The planning of the propulsion plant to be used for Ferry Osaka II/Ferry Kitakyushu II primarily proceeded considering improvement in fuel efficiency and also pursuing ship maneuverability, which is particularly required for the Setouchi Route. **Figure 4** shows the arrangement of the propellers of Ferry Osaka II/Ferry Kitakyushu II. The main propeller is a controllable pitch type and driven directly by the two medium-speed diesel main engines through a reduction gear with a clutch. In addition, the azimuth propellers located on both sides of the main propeller are controllable pitch type and driven by propulsion motors installed in the vessel immediately above the azimuth propellers using electric power from the main generator. Taking advantage of the twin-engine, single-screw diesel propulsion system, Ferry Osaka II and Ferry Kitakyushu II intentionally adopt small azimuth propellers and use the mechanically driven highly efficient large-diameter propeller as a main propeller in order to reduce fuel consumption. There are three control modes to make full use of the functions of the 360-degree swiveling azimuth propellers used as the stern thruster for berthing and deberthing, the rudder and the propeller for low-speed navigation and the propulsion assist unit for high-speed navigation. Despite the small size, the two azimuth propellers contribute to improvement in ship maneuverability in low-speed navigation zones such as the inside of a harbor or an area with islands, and can be said to be a propulsion plant suitable for the Setouchi Route.

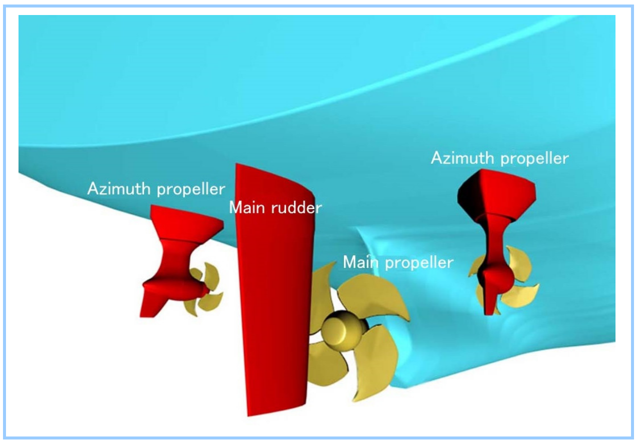


Figure 4 Propeller layout on Ferry Osaka II/Ferry Kitakyushu II

Table 2 compares the specifications between Ferry Osaka II/Ferry Kitakyushu II and the ROPAX ferry that they replaced. This table shows that although Ferry Osaka II and Ferry Kitakyushu II are approximately 1.5 times larger than the ROPAX ferry they replaced on a gross tonnage basis in order to provide an increase in the cargo loading capacity and the accommodation area, the overall power output of the propulsion plant is reduced significantly. The fuel cost reduction rate per a truck is approximately 30%, and this remarkably contributes to a reduction in the operating cost.

Table 2 Main specifications comparison table of Ferry Osaka II/Ferry Kitakyushu II

ROPAX ferry name		ROPAX ferry replaced	Ferry Osaka II/Ferry Kitakyushu II
Main dimensions	Length overall	160.0m	183.0m
	Breadth/Number of Lanes	25.0 m/7 lanes	27.0 m/8 lanes
	Gross tonnage (Domestic)	9,479	14,920
	Gross tonnage (International)	-	23,984
Cargo loading capacity	12-m trucks	110 vehicles	146 vehicles
	Passenger vehicles	100 vehicles	105 vehicles
Passenger capacity		713	713
Service speed		22.9kt	23.2kt
Propulsion and steering plant		Twin-screw, two-engine CPP	Twin-screw, single-engine CPP ＋Azimuth propulsion assist
Main engine	Max output × units	9,930kW × 2	7,000kW × 2
Shaft generator motor	Max output × units	—	1,000kW × 2
Main propeller	Type × units	Controllable pitch propeller × 2	Controllable pitch propeller × 1
Azimuth propeller	Type × units	—	Controllable pitch propeller × 2
Other		—	MALS

4. Conclusion

In a long slump in the domestic economy since the failure of Lehman Brothers, MHI has been developing energy-saving ROPAX ferries with excellent truck transportation efficiency in order to promote a modal shift policy to coastal shipping and business innovation of ROPAX ferry operators. Going forward, we will endeavor to meet the needs of ROPAX ferry operators by expanding the lineup of energy-saving propulsion plants in view of the development of next-generation plants including a propulsion plant powered by LNG, which is attracting attention as clean energy. In addition, MHI believes that it is our responsibility to offer added values that allow general ROPAX ferry users to fully enjoy sea voyages.

References

1. Mori, T., et al., Approaches of the Energy-Saving ROPAX Ferry for the Next Generation, Mitsubishi Heavy Industries Technical Review Vol. 44 No. 3 (2007)
2. Mizokami, S., et al., Implementation of Ship Energy-Saving Operations with Mitsubishi Air Lubrication System, Mitsubishi Heavy Industries Technical Review Vol. 50 No. 2 (2013)