The First Hybrid CRP-POD Driven Fast ROPAX Ferry in the World

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A fast ferry equipped with the world's first hybrid CRP-POD propulsion system having the same effects as contra-rotating propellers (CRP) has been developed by combining an electric pod propulsion unit and conventional diesel propulsion system. With this system, energy is saved by more than 13% as compared with the conventional twin shafts and propellers system, contributing to a reduction of operation costs and of CO_2 emission. Two ferries, named HAMANASU and AKASHIA, adopting this system were delivered to Shin Nihonkai Ferry Co., Ltd. at the end of June 2004. Excellent propulsion performance of the hybrid CRP-POD system was confirmed not only by the trial Maximum speed of 32.04 knots (59.3 km/h) but also by the vessels' operational record. They have been in commercial operation between Maizuru and Otaru since July 2004, and the previous one-way cruising time of 29 hours has been shortened to 20 hours. They are two of the fastest ro-pax ferries in the world.

1. Introduction

More than 20 fast ferries of the 30 knot class are operating in the world at present. Those fast ferries consume a greater amount of fuel and have very high operation costs, while cruising economy, CO_2 emissions and other environmental effects are also serious problems in need of solution.

The world's first hybrid CRP-POD driven system (**Fig. 1**) installed in the HAMANASU and AKASHIA is a 21st century-oriented propulsion plant featuring energy saving of more than 13% of the conventional level, enhanced cruising economy, and low environmental impact. This paper reports an outline of the new ferry, mainly with reference to the novel propulsion system

Fig. 1 CRP POD propulsion system

2. Outline of the Principal Particulars

The principal particulars of the ship are shown in **Table 1**.

To enhance the propulsion performance, the overall length is 224.82 m, surpassing the 200 m mark for the first time in Japan. It is the longest ferry in the world.

The main engine for propulsion and the main generator engines for supplying power to the pod are two units each of 12V46C manufactured by Wartsila, and the pod propulsion unit is Azipod(R) of ABB, adopted in view of its past record and reliability.

Table 1 Main specifications

Length overall (m)	224.82	Main engine	Wartsila 12V46C × 2 units
Breadth (m)	26.00	Maximum output	12 600 kW × 500 min^{-1}
Depth (m)	20.4	Main generator engine	Wartsila 12 V 46 C × 2
Draft (m)	7.40	Maximum output	12 600 kW × 514 min^{-1}
Gross tonnage (t) International Japanese	 34181 16 810	Auxiliary generator engine	Daihatsu 8DK32C × 1unit
Trial maximum speed (kn)	32.04	Maximum output	2 910 kW × 720 min^{-1}
Passenger capacity (persons)	820	Pod propulsion unit	AZIPOD Type 21
Vehicle capacity	158 vehicles of 12 m length; 65 passenger cars	Normal output (kW)	17 600

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3. History of development

The pod propulsion unit is an azimuth type one driving a propeller directly coupled with a motor by incorporating the motor in a pod unit. This propulsion unit is at the stern of the hull, and also the unit has a function of rudder due to rotation. Thanks to its 360-degree free rotation, excellent steering performance is realized in harbor and pier operations, together with powerful propulsion.

This compact system incorporating a propulsion motor in the pod was jointly developed by European electric manufacturer and shipyard in the early 1980s for ice breakers.

The pod propulsion unit, a revolutionary system in those days, has been employed in more than 70 vessels, but since it is an expensive system, it has been used mainly in cruise passenger ships so as to make the best of its features, including excellent steering performance, vibration and noise suppressing effect, and high flexibility of inboard layout.

MHI initially promoted investigation into applications of pod propulsion unit aiming at large cruise ships and LNG carriers. From around 2000, efforts have been concentrated on development of a novel propulsion plant using the pod unit as part of campaign to reinforce the competitive power of ferries and ro-ro ships which belong to the main strategic category for MHI.

As a result, it has been found that the "CRP-POD propulsion system," combining the conventional propeller propulsion system with pod propulsion, is sufficiently economical and competitive in general merchant ships.

In Europe, too, intensive studies have been made to apply the hybrid system in ferries as an application of the pod propulsion unit. In April 2002, MHI started joint research with ABB, an active manufacturer which is enthusiastically developing this concept.

4. Outline of hybrid CRP-pod-driven propulsion

Generally speaking, large ferries have twin shafts and propellers arranged symmetrically to the center line because propeller diameter are limited due to limitation of draft, and because plural independent propulsion plants are needed to assure the safety of passengers in case of trouble. For a ship adopting the twin shafts and propellers, the propeller shaft is generally exposed from the streamlined hull, and is supported by bossing and brackets as shown in **Fig. 2**. This is known as the "shaft bracket system," and the additional resistance may occupy 10 percent of the total resistance.

As shown in **Fig. 3**, in this ship, the pod propulsion unit is located immediately behind the coaxial line of the main propeller of one shaft, and two propellers are arranged like one set of contra-rotating propellers. The main propeller is a controllable pitch propeller, and is driven directly by two sets of medium speed diesel main engines by way of reduction gears with clutch and intermediate shaft. The pod propeller positioned behind is an electric propulsion unit driven by an electric motor in the pod, using electric power from the power generation plant.

As a result, two sets of propellers can be installed without any appendages such as shaft bracket, and the resistance performance is significantly improved as compared with the conventional twin shafts ship. In addition, rotating the adjacent propellers in opposite directions could realize high propulsion efficiency by reducing tangential water flow. (It is called contra-rotating propellers, CRP, effect.)

This pod propulsion unit has a larger loss of energy conversion due to electric propulsion as compared with mechanical driving. This demerit is compensated by lowering the distribution rate of electric propulsion. Thus, by combining the pod propulsion with conventional mechanical drive propulsion plant, the concept of CRP is realized, and is accordingly called as hybrid CRP-POD driven propulsion.

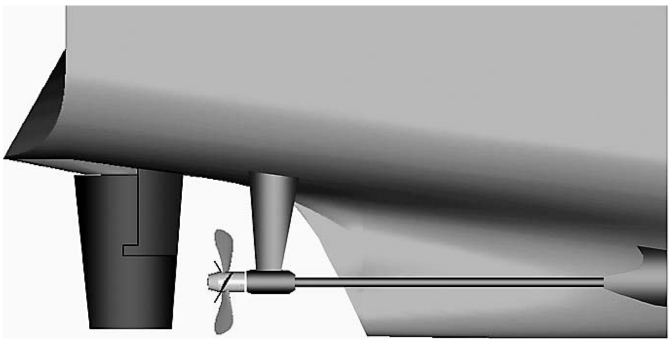

Fig. 2 Conventional twin shafts ship (shaft bracket system)

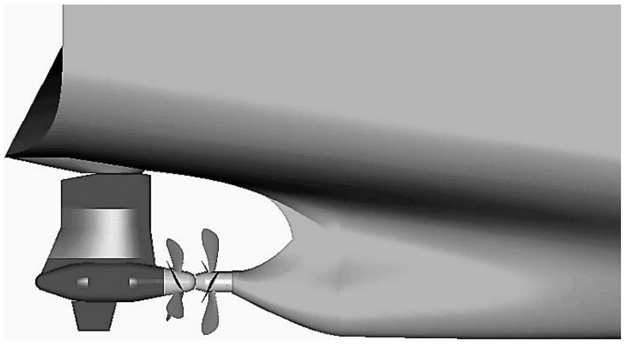

Fig. 3 CRP POD propulsion system

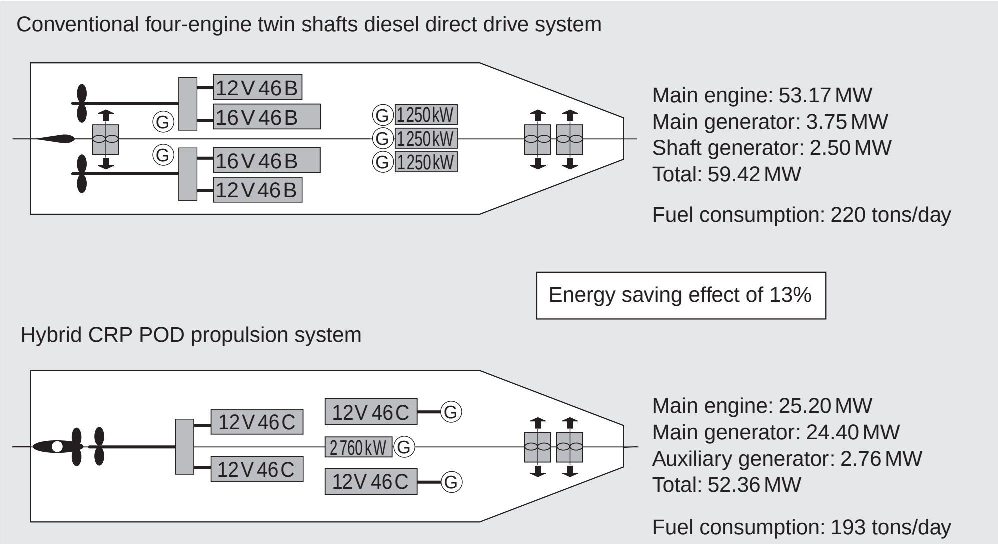

Fig. 4 Plant comparison

Fig. 4 compares the conventional mechanical drive twin-shafts system and the hybrid system, and shows that the energy saving effect is as high as 13%.

This plant has the same redundancy as a twin-shafts ship because the two driving systems are completely independent.

5. Technical subjects in development

5.1 Propulsion performance

At the beginning of the development, using the experimental tank at MHI's Nagasaki Research & Development Center and the depressurized towing tank of MARIN in the Netherlands, which is noted for its achievements in pod-driven ships, the resistance and propulsion performance, and propeller fluctuation pressure were investigated.

On the basis of the findings obtained, a hull model for minimizing the resistance at design speed was developed by utilizing computational fluid dynamics (CFD), and this was verified at the Nagasaki R&D Center experimental tank. **Fig. 5** shows an example of hull side waveform by CFD.

As a result, along with the effect of optimization of length, residual resistance decrease of 22% is realized as compared with the 30-knot ro-ro ship developed by MHI in 1998, as shown in **Fig. 6**.

Since the main propeller operates in the wake of the hull, it is important to incorporate a design that reduces generation of cavitation and propeller fluctuation pressure. The essential design points for the pod propeller are avoidance of tip vortex generated from the main propeller, and strength on the fluid force in pod steering condition. The pod propeller was designed jointly with ABB, and perfect verification was achieved.

In the design of both propellers to harmonize with each other as the CRP, numerical calculation by CFD and model verification were executed repeatedly. In numerical calculation, the Navier-Stokes equation was solved in the propeller running state, the flow to the propulsion unit was calculated, the propeller fluid force designed by UQCM (unsteady quasi-continuous method), a numerical propeller calculation method used for years at MHI, was put back to a CFD model by the multiblock lattice structure theory, and a theoretical calculation of high precision was performed.

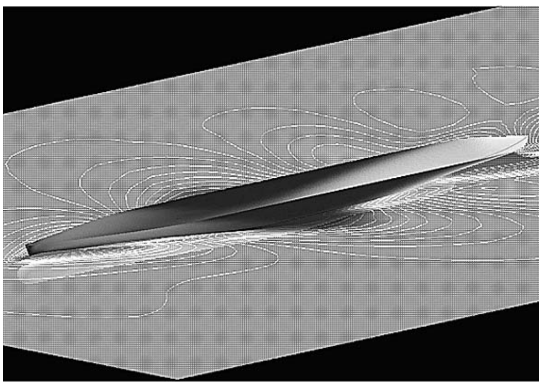

Fig. 5 Waveform calculation by CFD

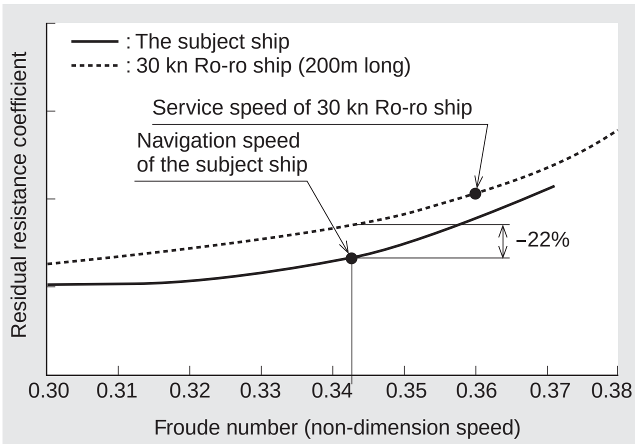

Fig. 6 Comparison of residual resistance (main hull only)

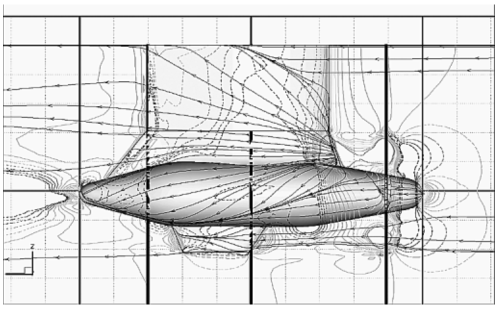

Fig. 7 Pressure and streamline vector calculation of pod surface

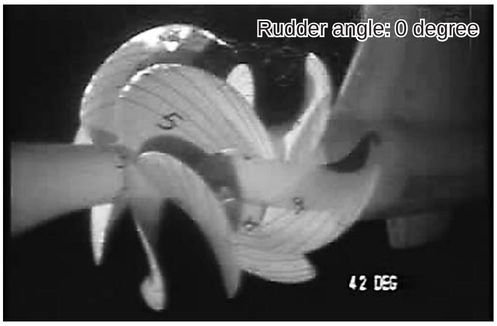

Fig. 8 Example of cavitation observation in depressurized towing tank

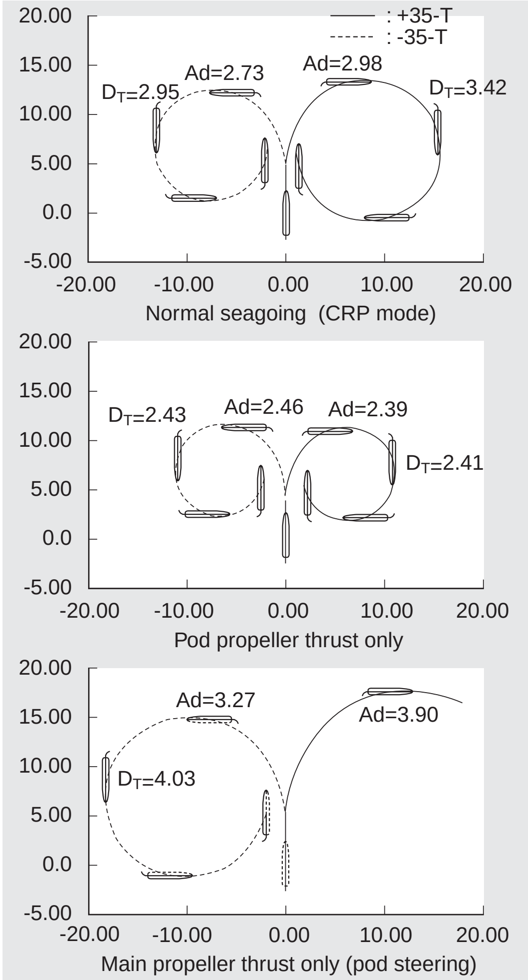

Fig. 9 Turning performance (model test)

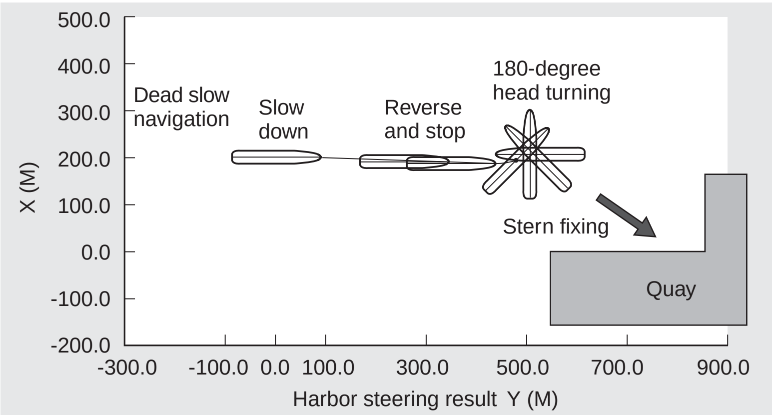

Fig. 10 Simulation of harbor operation (model test)

Fig. 7 shows an example of calculation of pressure distribution and speed vector on the pod surface in the propeller running state.

Fig. 8 is an example of cavitation observation using a depressurized towing tank. In the sea trial, the cavitation of actual ship was observed, and the results of estimation were verified.

5.2 Steering performance

The pod propulsion unit features high steering performance. In the hybrid system, steering variations combined with the conventional propulsion system may be considered. **Fig. 9** shows three modes of turning track chart: CRP mode, pod alone, and main propeller alone. In the main propeller alone mode, the pod propeller idles and the pod functions as a rudder.

Fig. 10 shows a track of turning-round motion by bow thruster and pod 90-degree steering from the dead slow ahead in the model test. The turning motion is completed in a state close to in-situ head turning motion, and safe and prompt steering is realized in narrow waters in harbor or at piers.

The ship has an automatic control system that maintains the output balance of pod and main propellers in the optimum state, and during normal navigation it is possible to operate in CRP mode to accelerate and decelerate the pod and main propellers at the same time by a single main engine telegraph lever. In harbor operation, by changing to the maneuvering mode, the pod and main propellers can be operated independently. The wing operation panel in the wheelhouse includes remote controllers for regulating the thrust of the main propeller, thrust and steering of the pod, and operation of the bow thruster. Although the sense of maneuvering is different from that of existing ships, it can be learned in a short time, and excellent maneuverability has been demonstrated in actual navigation.

5.3 Structural strength and vibration countermeasure

Greatest attention has been paid to the strength design of structures for supporting the weight of the pod installed at the end of the stern, generated thrust by pod propeller, and large turning force generated during turning motion. **Fig. 11** shows an FEM analysis model of the stern section including the pod support structure, in which the fitting portion of the support structure and hull is shown finely in the mesh size corresponding to the plate thickness.

To minimize noise as required in a passenger ship, vibration mode and local vibration were investigated by full ship FEM model. This ship has four main sources of vibration of different frequencies, namely the main engine, main generator engine, pod propeller, and main propeller. The dominant vibration source is the main propeller, for which vibration countermeasures have been carefully chosen and applied. The effect of vibration countermeasures has been confirmed that correspond exactly to prior estimations at the sea trial.

5.4 Layout of propulsion plant

The prime movers of the propulsion plant are two sets each of 12V46C of Wartsila in both the mechanical driving system and the electric propulsion system, with a view to common use of maintenance parts.

The power generation plant also has one auxiliary power generation engine to assure electric power in port. A total of three generators can supply power to the high voltage power distribution board at 6 600 V.

As measures to restore stability in damage case, these principal facilities are installed in three independent compartments: the generator room, the generator engine room, and the main engine room. The space behind the main engine room is effectively utilized as the passenger car deck.

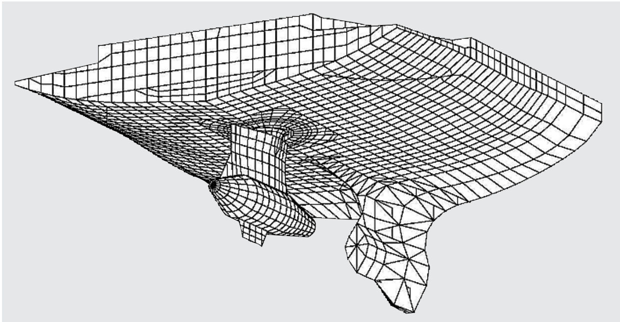

Fig. 11 FEM model of pod support structure

The pod room located immediately below the stern of the car deck accommodates the pod steering unit, its hydraulic unit, and cooling unit, while the stern of each deck has a sheer that accommodates the slip ring compactly without projecting to the car deck. In addition, the cooling unit and slip ring of the pod are of limited height as specially ordered.

6. Conclusion

The hybrid CRP-POD propulsion system allows the Hamanasu and Akashia to achieve excellent performance in terms of both propulsion efficiency and maneuverability. The performance was confirmed by the vessels' operational record since June 2004. This innovative propulsion system could be applied to other kinds of vessels e.g. large container carrier and/or LNG carriers.

The authors highly appreciate the pioneer spirit and the advices with operational experience of those vessels' owner, Shin Nihonkai Ferry Co., Ltd.

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