

Energy Saving Technology of the Diesel-Electric Propulsion System for Japanese Coastal Vessels

YAMADA Hideki : Manager, Ecology Engineering Group, Engineering Division, IHI Marine United Inc.

MIYABE Hiroaki : Manager, Ecology Engineering Group, Engineering Division, IHI Marine United Inc.

SAEKI Aiichiro : General Manager, Ecology Engineering Group, Engineering Division, IHI Marine United Inc.

IHI Marine United Inc. (IHIMU) has developed an energy-saving, environmentally-friendly diesel-electric propulsion system with a Contra-Rotating Propeller (CRP) for Japanese coastal vessels. The system is called "IHIMU-CEPS" (the IHIMU-CRP Electric Propulsion System). The energy-saving technology of IHIMU-CEPS has achieved dramatic improvements in the area of vessels' propulsion efficiency due to their highly-advanced, optimally formed hull and the CRP. Starting with "Shin-ei Maru" completed in February 2007, twelve vessels with IHIMU-CEPS, such as chemical tankers, clean product oil tankers and cement carriers, have already been put in service by August 2010. Compared with conventional vessels with direct-drive diesel engine propulsion systems, vessels with IHIMU-CEPS are more fuel efficient and emit less CO₂, NO_x and SO_x. This paper explains the outline of IHIMU-CEPS and the features found by vessels' performance, including advantage of diesel-electric propulsion system and fuel efficiency improvement.

1. Introduction

Marine transportation is suited for long-distance mass transportation and is expected to lead the modal shift that the Ministry of Land, Infrastructure, Transport and Tourism of Japan is promoting, which is aimed at reducing environmental load and improving the efficiency of logistics. Domestic maritime transportation accounts for 40% of domestic transportation, and is an important lifeline that supports the economy and our everyday lives. Playing this major role, it is more important than ever that business is developed in this area with an energy-saving and environmentally conscious approach.

Against this background, IHI Marine United Inc. (IHIMU) has developed an electric propulsion system as an energy-saving and environmentally-friendly technology for domestic maritime transportation. The system is equipped with a Contra-Rotating Propeller (hereinafter called CRP) which has already been employed in large ocean-going vessels, and giving the system its name of the CRP Electric Propulsion System, or IHIMU-CEPS for short. The first vessel, the "Shin-ei Maru," was put into service in 2007 and since then, 12 domestic coastal vessels equipped with the IHIMU-CEPS have been put into service. Compared to conventional vessels equipped with a diesel main engine, fuel economy in these ships has been greatly improved and emissions of environmentally harmful materials have been reduced. At the same time, engine maintenance workload has been reduced and the work environment and living environment has been improved.

This paper presents an outline of IHIMU-CEPS by

describing its performance in actual use and its features, including the advantages of electric propulsion and improvement in fuel economy.

2. Development of the IHIMU-CEPS

2.1 Background of domestic coastal vessels using electric propulsion system

With conventional domestic coastal vessels, when using cargo handling equipment such as cargo handling pumps on a chemical tanker or pneumatic conveyor compressors on a cement carrier, the driving force of the main propulsion engine is changed over by a clutch or similar mechanism for efficient use of the limited space on the ship. Therefore, there have to be many clutches, gears, and other mechanical devices, and a large amount of labor and cost are involved in their maintenance.

Domestic coastal vessels enter and leave ports frequently, and the crew have to both operate the ship safely on a voyage and do cargo handling work at the ports. Therefore, the challenge has been to reduce workload in cargo handling, to improve the work environment, and to ensure a good living environment that enables the crew to rest when the ship is operating between ports.

One possible way to tackle this challenge is to implement electric motor-driven cargo handling equipment. However, a large power generator is required to supply the necessary electric power. Therefore, if electric propulsion system is used, the power source supplies electricity mainly for propulsion while the ship sails, and while the ship is berthed during cargo handling, electricity can be diverted to the cargo handling equipment. The practical

implementation of such a system had been anticipated for some time.

2.2 Development of IHIMU-CEPS

Electric propulsion vessels are generally known to be superior in terms of noise reduction and maneuverability at low speeds, so they have so far been used for special purposes, such as passenger vessels, research vessels, and icebreaker vessels, which can take advantage of these features. In an electric propulsion vessel, however, propulsion is only possible using multiple processes. As shown in Fig. 1, the power generating diesel engine generates rotational energy, which is converted by the power generator into electrical energy, which in turn is reconverted by the propulsion motor into rotational energy after passing through several electric devices. This is the reason for the electric propulsion system being less fuel efficient than the diesel engine direct-driven propulsion system.

IHIMU has taken hull form development technology and CRP technology developed in the building of large

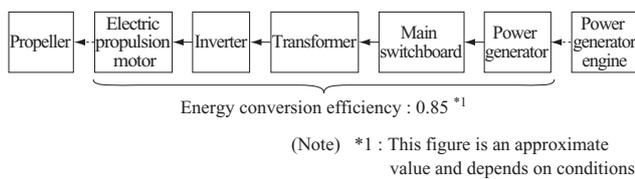


Fig. 1 Energy conversion efficiency of diesel-electric propulsion system

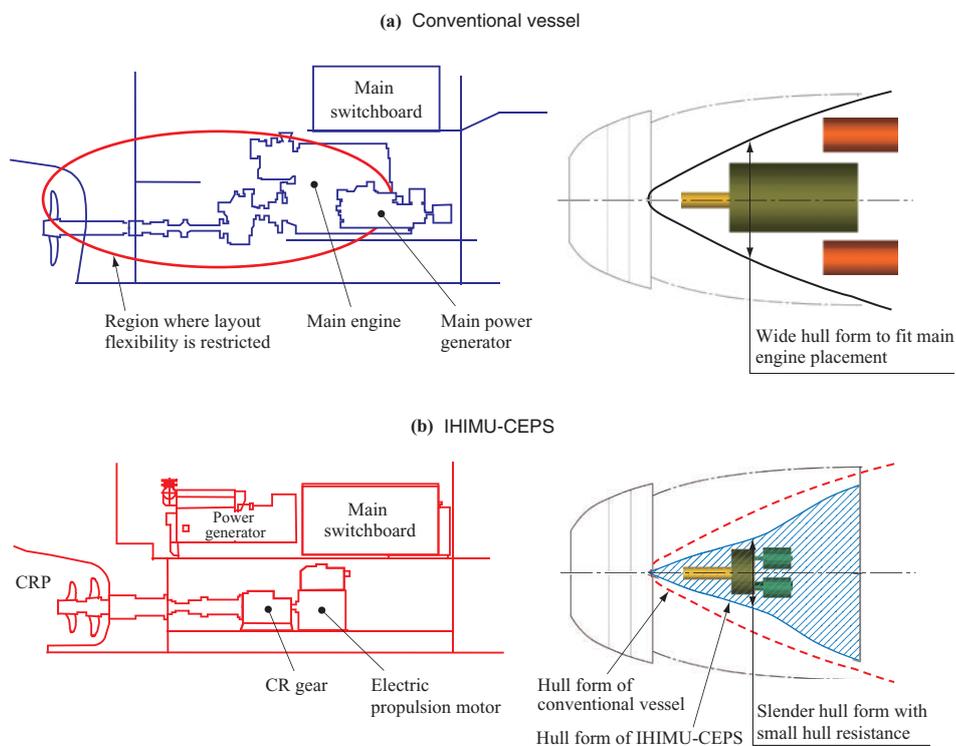
ocean-going vessels, and applied them to small- and medium-sized domestic coastal vessels. Overall propulsion efficiency was improved and a great improvement was achieved in energy saving performance, which more than compensates for the energy conversion loss due to the use of electric propulsion system. Therefore, using IHIMU-CEPS has enabled a balance between the operating economy required of domestic coastal merchant vessels and improvements in workability and onboard environment.

2.2.1 Hull form development

In the electric propulsion vessel, there is no need to connect a large main engine directly to the propeller shaft. Instead, two electric propulsion motors much smaller than the main engine are connected to the propeller shaft through a CR gear. Since the other electric propulsion devices are connected by electric wires, the arrangement in the engine room is more flexible than in conventional vessels. Therefore, the hull form from midship to stern, which is important to reducing fluid resistance, is greatly improved compared to conventional vessels (Fig. 2).

In addition, a special hull form called a stern bulb is employed. This hull form has a smooth bulbous form just in front of the working surface of the propeller. This improves propeller efficiency by making the water flow around the stern effectively converge onto the working surface of the propeller.

On some electric propulsion vessels, an energy-saving device called an LV-Fin⁽¹⁾ (Fig. 3) is employed. This is a pair of triangular fins attached on both sides near the stern



(Note) The highly flexible engine room arrangement makes it possible to improve the hull form.

Fig. 2 Flexible engine room arrangement and development of hull form



Fig. 3 LV-Fin and CRP

bulb in front of the propeller to smooth the water flow around the stern effectively. Straightening the water flow at the stern reduces the viscous pressure resistance and improves efficiency.

2.2.2 Contra-rotating propeller (CRP)

The CRP^{(2), (3)} (Fig. 3) consists of a set of contra-rotating propellers positioned in tandem. The energy loss caused by the rotating flow occurring behind the fore propeller is recovered by the aft propeller and converted to propulsive force. Because the two propellers share the propulsive force, the load one propeller must bear is reduced and therefore the rotation speed may be reduced. With this propulsion system, a higher propelling efficiency can

be obtained compared to a single propeller of the same diameter.

2.2.3 Electric propulsion system⁽⁴⁾

A standard equipment configuration of this electric propulsion system is shown in Fig. 4.

The number of power generators to be installed was determined to be between 2 and 4, based on the layout space of the engine room and the electric power requirements. These diesel power generators with the same rated output generate electric power for onboard use and for electric propulsion. The generated power passes through two sets of transformers and pulse width modulation (PWM) inverters and drives two electric propulsion motors. The driving force is transferred through a contra-rotating reduction gear to a line shaft CRP set, which produces propulsive force.

This is a system with high redundancy. Two or more power trains are provided from the power generators and electric propulsion motors to the propeller. Therefore, should a failure occur in some part, it is possible to continue operation of the vessel using the remaining intact system.

The PWM inverter controls the output power, torque, and rotation speed of the electric propulsion motor with high accuracy. The transformer is installed to reduce harmonic noise, which would otherwise cause abnormal overheating of the motor in the onboard equipment. The braking resistors are installed to absorb regenerative electric power. The propulsion motors act as induction generators when the ship is navigated to decelerate.

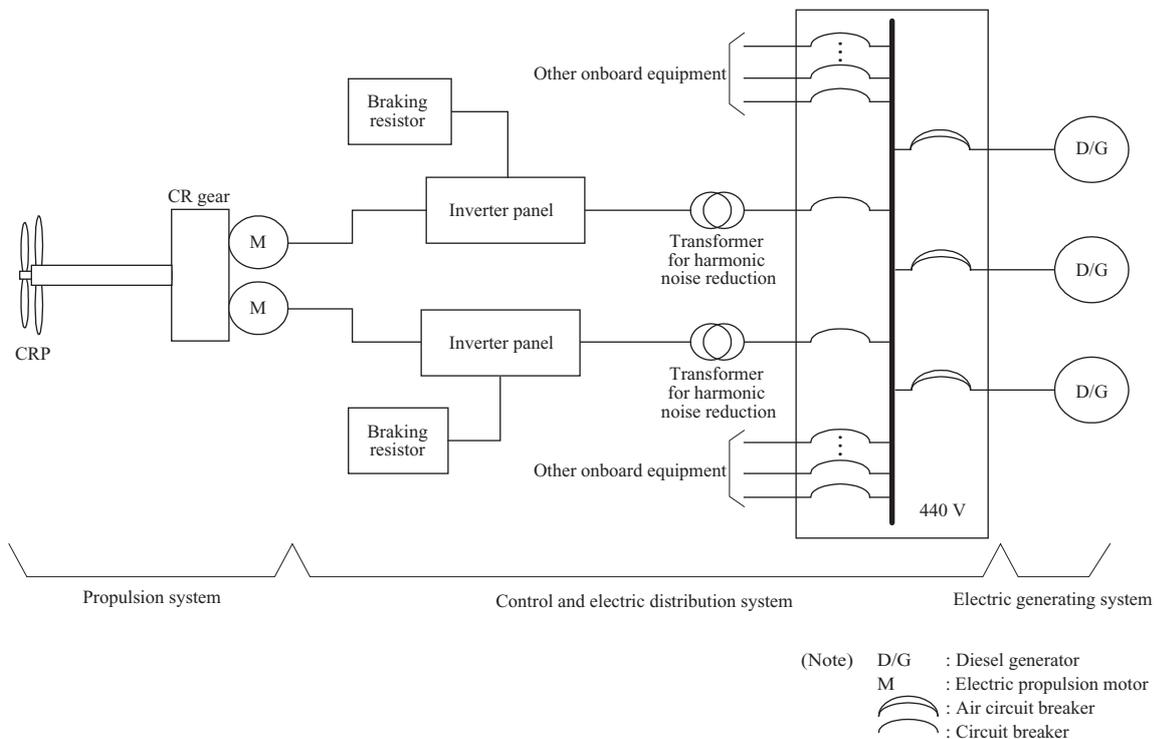


Fig. 4 System configuration of IHIMU-CEPS

3. Construction result of vessels with IHIMU-CEPS and their features

3.1 Construction result of vessels with IHIMU-CEPS

As of August 2010, the following 12 domestic coastal electric propulsion vessels equipped with IHIMU-CEPS are in service: one 655 DWT general cargo and tanker; five 1 230 m³ type chemical tankers; one 1 230 m³ type paraffin wax tanker; two 2 200 m³ type purified oil tankers; two 1 350 DWT cement carriers; and one 2 500 m³ type chemical tanker. A total of three vessels, that is, one 1 550 m³ type liquefied petroleum gas (LPG) tanker and two 7 900 DWT cement carriers are now being built. **Table 1** gives their main details.

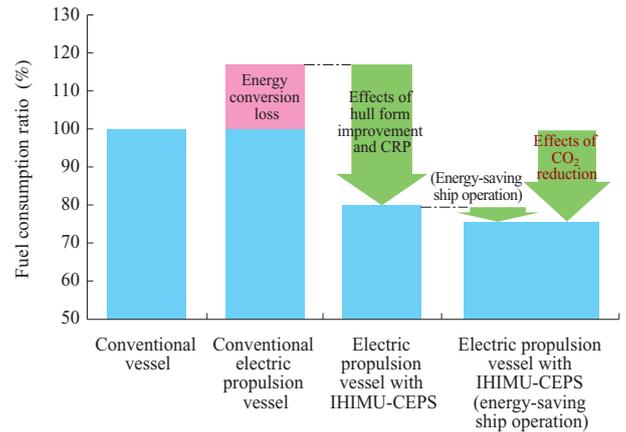
3.2 Features of vessels with IHIMU-CEPS

3.2.1 Energy saving and environmental load reduction

When the developed hull form and CRP described earlier are employed in them, electric propulsion vessels have a greatly improved overall propulsion efficiency compared to conventional vessels and achieve a large reduction in fuel consumption, which compensates for the reduction in efficiency due to the use of electric propulsion system. Using the 1 230 m³ type chemical tanker as an example, electric propulsion vessels have an improved fuel economy of about 20% according to measurements taken during trial operations at sea (**Fig. 5**), though this figure depends on the ship type and the choice of conventional vessel with which it is compared.

This reduction in fuel consumption is accompanied by reductions in CO₂ and SO_x emissions of about 20%.

In addition to lower fuel consumption, emission of NO_x has been reduced by about 40% as a result of adopting



(Note) The effects of hull form improvement depends on the comparison vessel.

Fig. 5 Comparison of fuel consumption between conventional vessel and electric propulsion vessel with IHIMU-CEPS (1 230 m³ type chemical tanker used as an example)

medium-speed diesel generator engines in comparison with low-speed main diesel engines for conventional vessels.

3.2.2 Improvements in onboard work environment

The chemical tanker is equipped with an electric deepwell cargo pumps in each cargo tank, which eliminates main engine-driven cargo pumps and a pump room to install them, with which conventional vessels are equipped. This achieved an improvement in transportation quality by preventing the contamination of cargos of different kinds and an improvement in the safety of cargo handling work. The cement carrier is equipped with a large air compressor

Table 1 Principal particulars of electric propulsion vessels with IHIMU-CEPS

Ship's name	Use (cargo)	Date completed (Year/Month)	Cargo tank volume (m ³)	Length by breadth by depth (L _{pp} × B × D) (m)	Main generator (kW) × (Number of units)	Electric propulsion motor (kW) × (Number of units)
Shin-ei Maru	General cargo and tanker	2007/2	655*1	55.0 × 9.8 × 3.5	400 × 3	500 × 2
Nikko Maru No. 5	Chemical tanker	2007/5	1 230	61.8 × 10.0 × 4.5	350 × 3	370 × 2
Nadeshiko Maru	Purified oil tanker	2007/11	2 200	69.95 × 11.5 × 5.25	410 × 4	600 × 2
Kokuho Maru	Chemical tanker	2008/6	2 500	76.9 × 12.2 × 5.8	700 × 3	745 × 2
Nojigiku	Chemical tanker	2009/1	1 230	61.8 × 10.0 × 4.5	350 × 3	370 × 2
Hourin No. 3	Chemical tanker	2009/4	1 230	61.8 × 10.0 × 4.5	350 × 3	370 × 2
Houwa Maru	Chemical tanker	2009/9	1 230	61.8 × 10.0 × 4.5	400 × 2	260 × 2
Rokkou	Chemical tanker	2009/12	1 230	61.8 × 10.0 × 4.5	350 × 3	370 × 2
Kaiko Maru	Cement carrier	2010/3	1 350*1	72.0 × 14.6 × 7.6	800 × 3	900 × 2
Toa Maru	Purified oil tanker	2010/4	2 200	69.95 × 11.5 × 5.25	450 × 3	500 × 2
Hohko Maru No. 5	Paraffin wax tanker	2010/6	1 230	61.8 × 10.0 × 4.5	350 × 3	370 × 2
Kakuyo Maru	Cement carrier	2010/7	1 350*1	72.0 × 14.6 × 7.6	800 × 3	900 × 2
To be determined	Liquefied petroleum gas carrier	Under construction (1 vessel)	Approx. 1 550	65.0 × 11.6 × 4.9	480 × 3	550 × 2
To be determined	Cement carrier	Under construction (2 vessels)	Approx. 7 900*1	109.0 × 18.2 × 9.4	1 500 × 3	1 400 × 2

(Notes) As of August 2010
*1 : DWT

for pneumatic cargo transportation. In the conventional mechanical driving method, the use of mechanical power from the main engine is changed over from the propeller shaft to the air compressor. The electric propulsion vessel employs inverters to control electric motors for propulsion to double for this purpose, and thus achieves a reduction in noise during operation and a reduction in machine maintenance work.

Engines are a source of vibration and noise, but because electric propulsion system enables a smaller engine to be used, a reduction in vibration and noise is achieved and the living environment onboard is greatly improved.

3.2.3 Unification of onboard power sources and selection of the number of power generators put into operation

Conventional vessels are separately equipped with a main engine for propulsion and a main power generator for onboard power supply, and these supply their respective onboard energy demands. On the other hand, electric propulsion vessels unify onboard power sources by supplying both electric power for propulsion and electric power for other equipment onboard from a common power generating system. This makes efficient use of power generating equipment possible.

The ship's electric power demands vary according to ① factors such as whether it is full load voyage or ballast voyage for the ship, ② the hydrographic conditions such as whether there is calm or heavy weather, and ③ the work type, such as sea going, navigating in a harbor (arrival/departure), or cargo handling. Using the electric propulsion vessel equipped with three power generators shown in Fig. 6 as an example, three generators are in operation during sea going and two are in operation when navigating in a harbor (arrival/departure). By selecting the number of power generators in operation in this way, the power generator engine can avoid low-load operation, and it can be operated at a load factor with a good fuel consumption rate. In calm sea conditions, operating two generators (engine cut-off operation) covers the power demands for propulsion and for other equipment onboard, because the necessary ship speed can be maintained with low motor output power.

This engine cut-off operation also contributes to reducing maintenance work, because the operating time of each power generator engine is reduced over the same operating time of the vessel.

3.2.4 Consideration of the ocean environment

The 2 200 m³ type purified oil tanker considers the conservation of the ocean environment, for example, by employing double hull construction to protect the cargo from a collision or other accidents. Moreover, this vessel succeeds in ensuring a cargo tank capacity of 2 000 kL, which is equal to the capacity of a conventional single-hull vessel, without increasing the gross tonnage. This is achieved by reducing the engine room length by taking

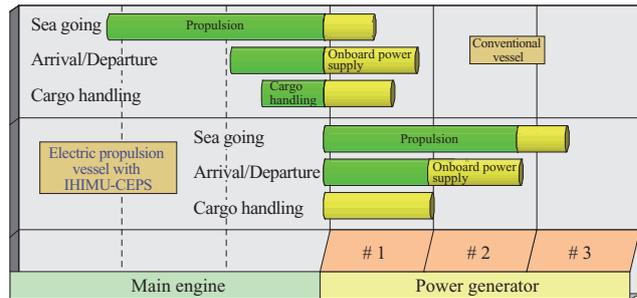


Fig. 6 Unification of onboard power sources and selection of the number of operating generators

advantage of the highly flexible engine room layout, which is a feature of the electric propulsion vessel, and by eliminating the pump room.

4. Conclusion

The 12 electric propulsion vessels equipped with IHIMU-CEPS in service have achieved good energy-saving performance and environmental load reduction, and have been highly evaluated by the ships' owners. The crew have also expressed satisfaction with the quiet living environment, which was something they had never experienced on conventional vessels.

IHIMU is making efforts to develop and spread environmentally-friendly energy-saving technology to be able to contribute to the development of the marine transportation industry and the conservation of the global environment and to achieve environmental performance and operational economy at a higher level than ever.

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