Performance of a Newly Developed Plug-in Hybrid Boat

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Abstract
We have produced a new-type of plug-in hybrid boat (named PHEB-2). This boat has excellent environment characteristics of running by electricity, while having the ability of long-distance cruising and long distance reliability because of the capability of a diesel engine. The excellent performance of this new plug-in hybrid boat system are described and compared with our previously made plug-in hybrid boat (PHEB-1).

Keywords
electric boat, plug-in hybrid, PHEB, lithium ion battery, induction motor

1. INTRODUCTION
We previously made a plug-in hybrid boat (length of 22 ft.) driven by an electric motor and a diesel engine [Minami et al., 2010]. This proto-type boat was named as "Plug-in Hybrid Electric Boat-1" or PHEB-1. The PHEB-1 system was produced based on past feasibility studies and experimental research [Minami, 2003; Minami and Yamachika, 2003; 2004]. This system shows good performance of silence, little vibration and no pollution characteristics as well as the reliability of a diesel engine. A block diagram of this boat (PHEB-1) is shown in Figure 1. A photograph of the PHEB-1 driving system is shown in Figure 2. This hybrid boat has electric motor power using the stored lithium ion battery of 10 kWh and can utilize external electric energy from a power line grid. The motor can also be used as a generator to charge the battery. One single propeller is driven by either the electric motor (10 kW) or the diesel engine (65 kW).

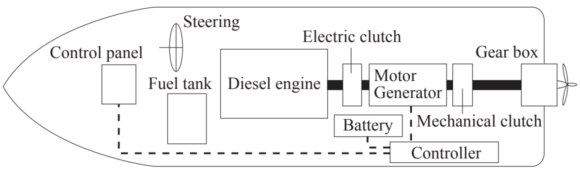

Fig. 1 A block diagram of PHEB-1

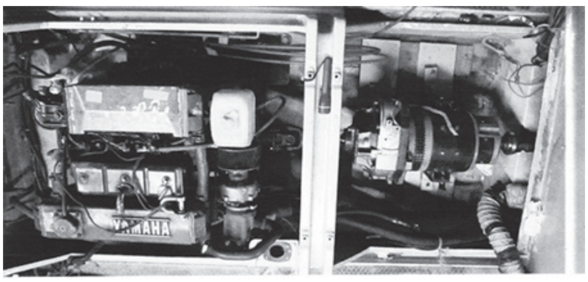

Fig. 2 A Photograph of PHEB-1

In principle, to spread this type of electric or hybrid boat like PHEB-1, it is important to modify used boats instead of making a new one, because the quantity is important to contribute to the total energy saving and to clean the environment. The way to utilize used boats results in better cost merit than a new boat. Recently in Japan, only about 2,000 new boats are released per year in the market. Japan has about 200,000 small boats to be modified as type of PHEB.
This prototype PHEB-1 was superior because a trial manufacturers boat has enough room to install an engine and the electric motor. It is not easy to modify most small diesel boats as a PHEB, because the propeller axis distance between the engine and the stern drive, where an electric motor is installed, is too short (such as 20 cm). To modify a boat to the PHEB-1 type system, a distance of almost 1 m is required.

2. NEW TYPE OF PHEB
To solve this issue, a new type of PHEB system has been developed. As shown in Figure 3, an electric propulsion system is installed independently from the previously installed diesel engine propulsion system. This system can be applied to different boat propulsion systems. To demonstrate the performance of

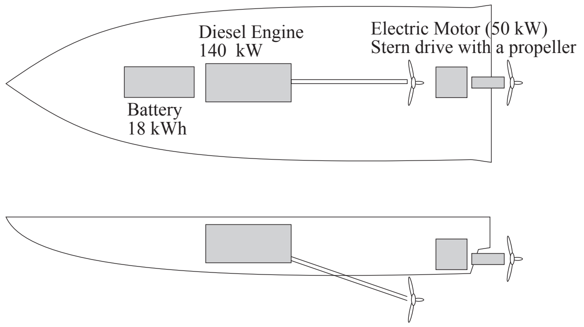

Fig. 3 A block diagram of the PHEB-2

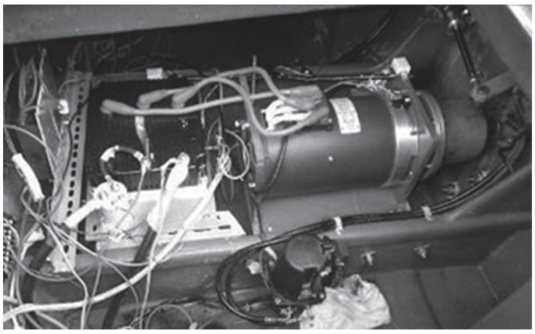

Fig. 5 A photograph of the electric motor

Table 1 Specifications of PHEB-1 and PHEB-2

	PHEB-1	PHEB-2
System of PHEB	Motor and engine are connected together	Motor and engine run independently
Length of waterline	22 ft	38 ft
Engine power	65 kW	150 kW
Motor Power	10 kW	50 kW
Type of Motor	Shunt DC	Induction
Battery type/Voltage	Li-ion/96 V	Li-ion/96 V
Battery Energy	10 kWh	20 kWh
Charging	Plug-in/on board motor/Generator 10 kW	Plug-in/on board independent generator 10 kW

Fig. 6 A photograph of PHEB-2

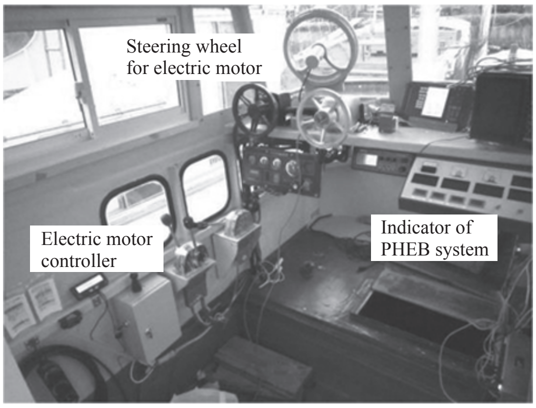

Fig. 7 A photograph of the control room of PHEB-2

PHEB-2, a 4 ton, was 38 ft diesel (140 kW at maximum output power) inboard propeller fishing boat was used. The specifications of the PHEB-1 and PHEB-2 are shown in Table 1. An electric motor driving system with a stern drive, a propeller, and helm station are installed. By such a method, the electric motor system (an induction motor of 50 kW at maximum and an inverter) does not influence the performance of the diesel engine system installed previously. A photograph of the stern electric propulsion system is shown in Figure 4. A Photograph of the installed electric motor (induction motor) is shown in Figure 5. A photograph of PHEB-2 is shown in Figure 6. A photograph of the control room of PHEB-2 is shown in Figure 7.

Fig. 4 A photograph of the stern electric drive of PHEB-2

3. PERFORMANCE OF PHEB-2

A performance test was conducted to investigate the power consumption during one fixed point fishing operation. It was found that the power consumption of the PHEB-2 under the wind velocity of 5 m/s is 0.35 kW on average, as shown in Figure 8.

This result shows that the energy used during the 6

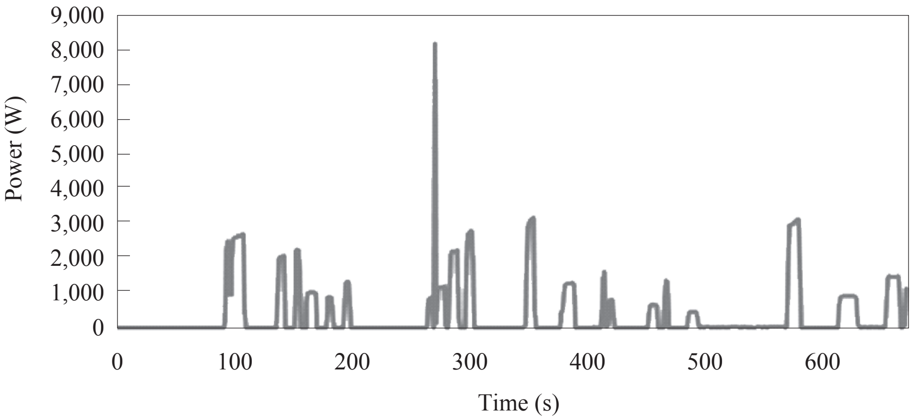

Fig. 8 An example of power consumption for fixed point fishing operation during wind velocity of 5 m/s

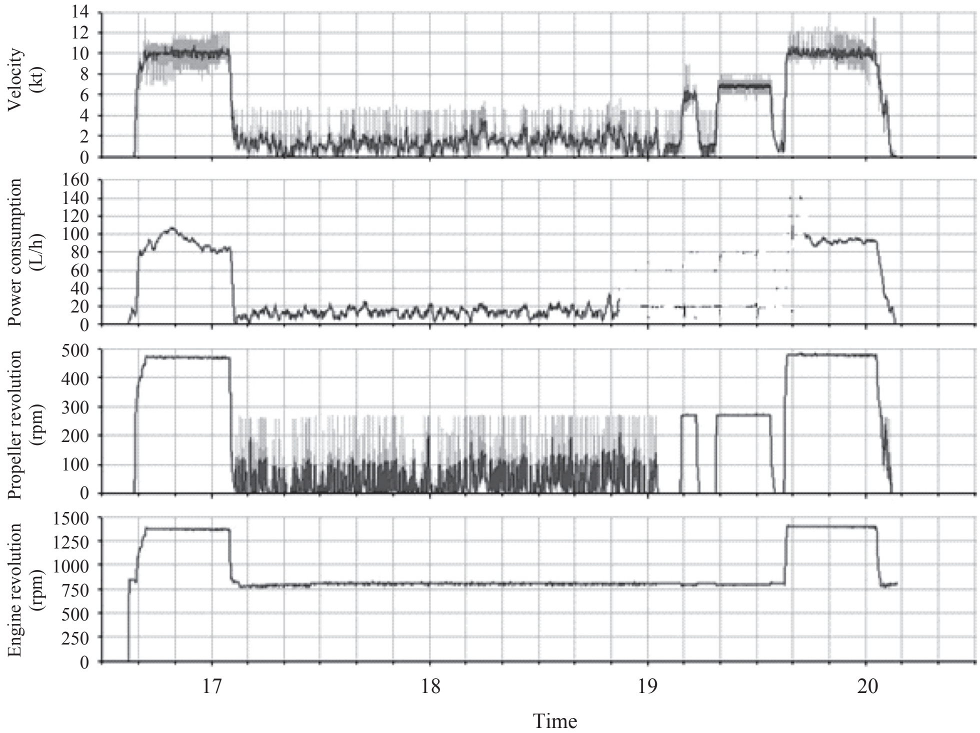

Fig. 9 An example of fuel consumption data during the fixing point fishing operation [Ministry of Agriculture, Forestry and Fisheries, 2011]

hours fixed point operation for professional fishing is only about 2 kWh. Such high performance can be performed because of the high efficiency of the electric motor system and the idling stop function.

Figure 9 shows a typical fixed point fishing operation by a diesel fishing boat [Ministry of Agriculture, Forestry and Fisheries, 2011]. In this case, 40 L of oil is used from the port to the fishing point. About 40 L is also used from the fishing point to the fish market. During the fixed point operation of 2.5 hours, the boat used about 50 L because the engine is continuously running during the fixed fishing operation. It means that the diesel fishing boat used 130 L totally.

It is well known that the CO_2 emission from the electric motor is reduced by about 50 % to the diesel running during the same driving speed. The CO_2 emission from a diesel engine (assuming the efficiency of 20 %) is 1.3 kg-CO_2/kWh, while an electric motor (assuming the efficiency of 85 %) emits 0.65 kg-CO_2/kWh when the CO_2 emission to make electricity is 0.5 kg-CO_2/kWh. It is the reason why the CO_2 emission by an electric motor is roughly 50 % to the diesel engine operation.

When the PHEB system uses an electric motor, the operation has a resemblance to the idling stop driving of automobiles. During the fixed point operation, the motor uses electricity when it is necessary to maneuver the boat into the fishing point only. As shown in Figure 8, it is expected that energy consumption can be drastically small because of the idling stop operation by the electric motor. The equivalent fuel consumption expected would be only 4 L for the electric motor operation during the fishing when the PHEB-2 is used for 6 hours (2 kWh) (0.2 L oil equivalent per 6 hours) is taken into account. It means that the total oil consumption by a same length of PHEB is 84 L (considering the length ratio). It results in the CO_2 reduction of 35 %. Usually the working hours of fixed point fishing is 6 hours in average in Japan, so that more CO_2 reduction can be expected than this estimation.

Figure 10 shows the schematic drawing of the comparison of the CO_2 reduction performance of the PHEB system to a diesel engine boat applied to the fixed position fishing operation. The excellent performance of the CO_2 reduction is shown in comparison with the currently used diesel engine operation.

As shown in Figure 11, the PHEB-2 is now used to conduct a research program of "empirical study of the independence distribution energy system technology based on DC technology in a detached island and a fishing village" by the Ministry of Environment subsidy 2014-2016. We are trying to show the data to prove the high performance function of a PHWB-2 type fishing boat.

4. CONCLUSION

It was shown that the type of PHEB-2 makes it possible to travel for a long distance manoeuvring to the fishing point and return navigation by a powerful diesel engine and also fishermen enjoy the advantages of quietness, less vibration, and a lack of toxic gas during fishing by the electric motor operation. We know that pure battery electric boats are also a wonderful way to accept the above advantages brought by electric motor system.

If only a battery is used to run the boat for the higher velocity or the long distance cruising, however, a huge quantity of batteries will be needed requiring a high cost and increasing the weight. In contrast, the operation by the PHEB-2 system has flexibilities to select the running either by diesel engine or electric motor as required.

It is pointed out here that the CO_2 reduction of a PHEB by usual fixed point operation in Japan is expected to be more than 35 % to the diesel engine boat. During fishing, the electric motor of a fishing boat is almost an idling stop status except the small manoeuvring to keep to the fishing point. It is important to

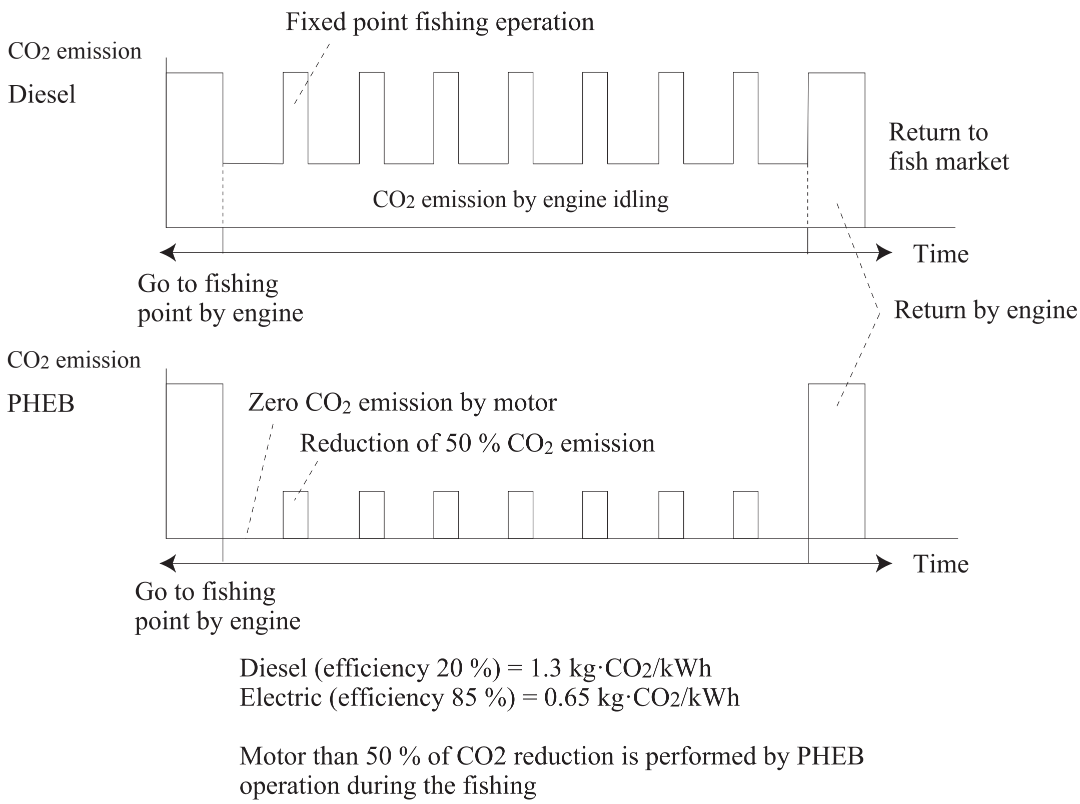

Fig. 10 The schematic drawing of the comparison the effective CO2 reduction performance of the PHEB system applied to the fixed position fishing operation

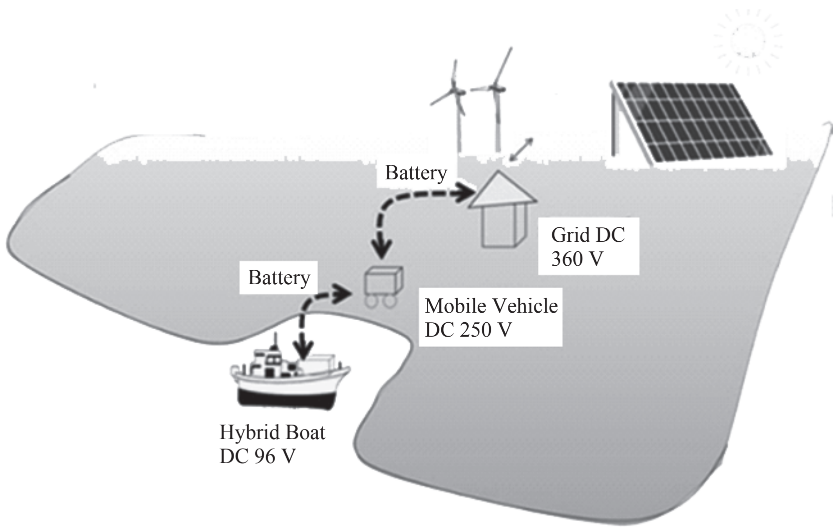

Fig. 11 This PHEB-2 is used to conduct the ship-to grid (S2G) research program by the Ministry of Environment subsidy 2014-2016

know that a pure battery electric boat also emits CO_2 gas of about 50 % to the diesel engine boat to produce electricity by electric power generator from oil. It can be obviously concluded that the PHEB system is more useful than a pure electric boat, if we consider about the above mentioned advantages, such as reliability, providing high speed performance ability and low building cost etc. The CO_2 emission by electric boat system has a small difference and it depends on the operation pattern.

The PHEB contributes not only to the quietness and energy (fuel) saving but also to provide the reliability and usefulness of the boat. When long-distance travel by PHEB is required, this is also possible. In addition to these merits, the newly developed PHEB-2 system has an electric motor and propeller independent to the previously installed diesel engine system with another propeller.

This new type of plug-in hybrid boat was produced and it was found that the performances is excellent and expected to spread widely because of easy modification from conventional diesel engine boats. This system is appropriate for river cruising boats as well as fishing boats.

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