The Performance of a Newly Developed Plug-in Hybrid Cruising Boat

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Abstract

Power consumption is proportional to the cubic of the velocity. The lower the velocity, the smaller the energy consumption can be achieved for propulsion. To minimize the possible range for one charge is one of the most important issues for the electric boat because of the limited battery stored energy. A slow speed cruising boat is one of the best choices for the electrification of boats. The robust performance of a conventional internal combustion engine is also an important factor for the boat. In this paper, the performance of a newly developed plug-in hybrid electric cruising boat, based on such a kind of design concept, is described. A newly designed boat, with a riding capacity of 30 passengers and the length overall of 9.66 m, is driven by two 10 kW electric motors with 2 propeller shafts, and by a diesel outboard engine of 40 hp. These two power sources can be selected manually. A diesel engine of 11 kW (200 V AC) is used to charge the battery of 9.6 kWh. The cruising boat was demonstrated in public for one month in September 2015 travelling on a river near a Japanese old castle in Wakayama prefecture successfully with more than 200 passengers a day as a plug-in hybrid mode. The high power output of the on-board electric generator has also proved the usefulness of electricity in a case of disaster.

Keywords

electric boat, plug-in hybrid electric cruising boat, CO_2 reduction, river cruising, diesel outboard engine

1. INTRODUCTION

In this research, different kinds of plug-in hybrid boats were constructed. One is a prototype model of a plug-in hybrid boat, called PHEB-1® with the length overall (LOA) of 6.7 m. This boat has a 85 hp diesel engine and a 20 hp electric motor. It shows an effective performance of low noise, locally no polluted gas emission, low vibration by electric mode, and reliability because of the hybrid mode with a Diesel engine. The other is a plug-in fishing boat named PHEB-2 (LOA of 12 m). The PHEB-2 is constructed by modifying a normal diesel engine fishing boat. It was found that the boat shows an outstanding CO2 reduction performance of more than 80 % compared with simple diesel engine operation when the boat works as a fixed point fishing pattern including the outward and return journeys from the port to the point [Minami, 2003; 2013; Minami et al., 2014; 2015]. The evaluation was based on the use of electricity from the commercial grid. This research has been conducted at the fishing area around a detached fishing island in Japan. Actually, the CO_2 reduction could be more effective, because renewable energy of solar power and wind power were used during the campaign in 2014-2016.

Based on the actual fuel consumption patterns of fishing by the fishermen, the quantitative analysis of daily fuel consumption was performed [Minami et al., 2014; 2015]. The remarkable reduction of oil consumption is due to the high efficiency of the electric motor and the idling stop function during fixed fishing operation. The PHEB-2 system by modifying a normal diesel engine fishing boat would have a high potential to spread because of easier and lower cost for production. By using the PHEB-2 and renewable energy charging stations, the S2G system is experimentally conducted. The S2G stands for Ship to Grid. It was attempted to demonstrate the performance of the S2G (ship to grid). The PHEB-2 has a generator of 10 kW, so that it is possible to send electricity to the island when a natural disaster happens. This has been described by Minami et al. [2010; 2015].

The newly developed cursing boat, PHEB-3 also has a generator of 11 kW to supply not only the on-board charging of batteries but also the electricity supply in the case of electricity black-out by natural disaster.

2. CONSTRUCTION OF PHEB-3

The PHEB-3 is designed to be used for cruising of 30 passengers with the velocity of up to 10 km/h in rivers or lakes. The boat selected is the LOA of 9.66 m and the beam of 3.10 m. In Japan, there are still very few places for charging near boat terminals. It is actually necessary to generate on-board to charge the battery for the use of a battery boat.

The required power vs. the velocity of PHEB was experimentally tested before setting the motor and the battery. One outboard electric motor was temporally installed, as shown in Figure 1. The result, as shown in Figure 2, indicates that the input electric power of 20 hp (15 kW) is necessary to obtain the velocity of 10 km/h. An internal combustion engine for the main thrust is located at the centre axis of the boat. It is necessary to set two electric motors with 2 propeller shafts which have to be installed beside the main engine, as shown in Figure 3.

The maximum power of the electric motor is 10 kW continuous. The permanent magnet DC brushless motor for 96 V nominal battery voltage was selected to obtain high efficiency and safety. The battery of 10 kWh was used for 1 hour continuous cruising. At any time, it is possible to charge the battery by the on-board generator. The generator of 11 kW, single phase

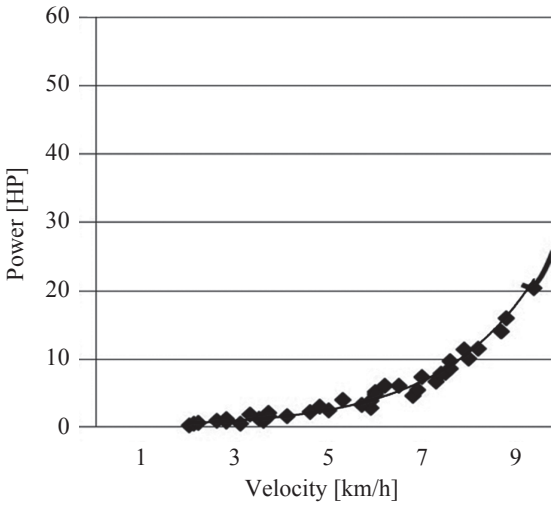

Fig. 2 The relation between the required input electric power vs. the velocity of the boat

Fig. 1 A photograph of the tested boat and the temporally installed electric outboard motor

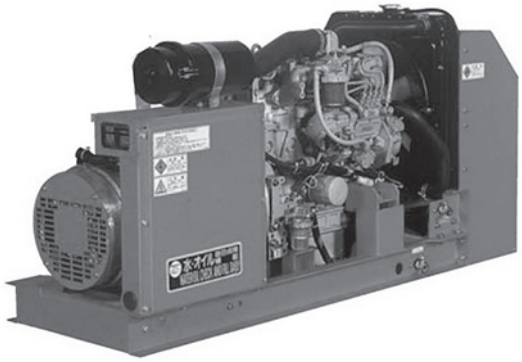

Fig. 4 A photograph of an 11 kW diesel electric generator

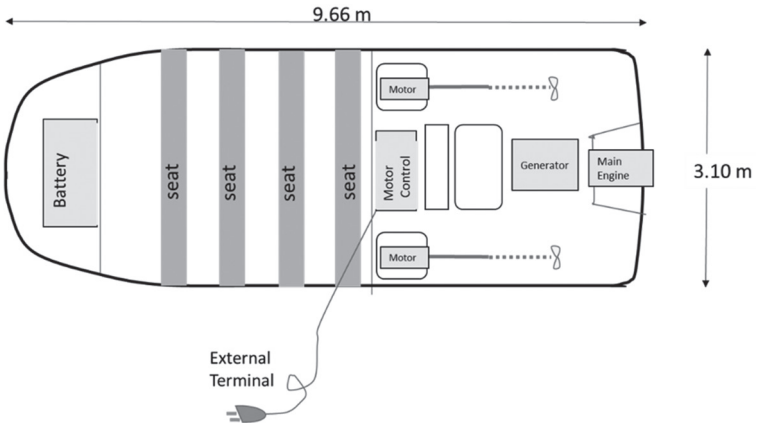

Fig. 3 The layout of the power train and the location of the equipment of PHEB-3

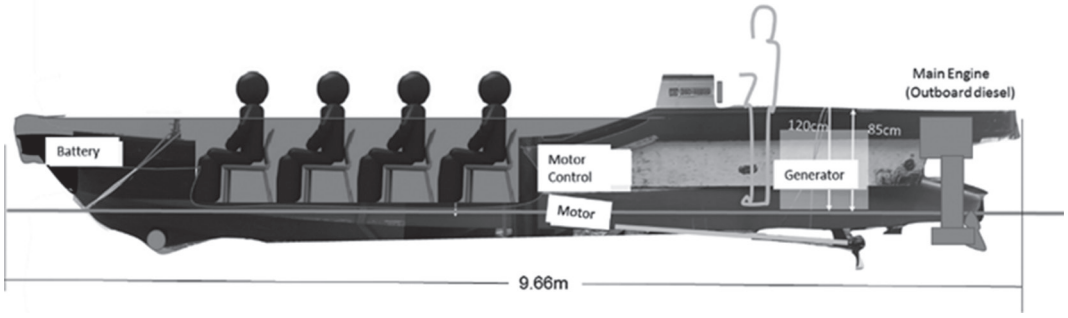

Fig. 5 The arrangement of the equipments of the PHEB-3

Fig. 6 A photograph of the unique diesel outboard motor

200 V, was used as shown in Figure 4.
For the capacity of 30 passengers, 4 wooden bench seats were used. Japanese law requests an area of 45 cm x 45 cm for each passenger. The arrangement and the location of the drive train and the equipment are shown in Figure 5. For chemical safety, reliability and good fuel efficiency, a diesel engine was selected for the main thrust power. Figure 6 shows a unique outboard diesel engine, model S403X (maximum power of 40 hp), made by Yanmar Co., Ltd.

3. PHEB-3 SHOWN IN PUBLIC

The purpose of the construction of PHEB-3 was to demonstrate the usefulness of the plug-in hybrid boat to gain revitalization of marine industries in the future. Figure 7 and Figure 8 are photographs of PHEB-3. As shown in Figure 9, the PHEB-3 is used in public to show the excellent performance of such plug-in system; quietness and no polluted gas emission from the electric drive train. The easy operation of continuing cruising for almost all day long was demonstrated as an established fact in September 2016 at Wakayama river cruising in Japan. As shown in Figure 9, 30 people on board of almost each cruise reported an enjoyable trip throughout the campaign.

Fig. 7 A photograph of the side view of the PHEB-3

Fig. 8 A photograph of the stern view of the PHEB-3

Fig. 9 A photograph of the demonstration of the PHEB-3 in 2015

4. CONCLUSIONS

The PHEB system for cruising was examined by a newly developed 30 passenger river cruising plug-in hybrid boat. The result shows a successful performance of technological usefulness as well as the passenger's full satisfaction for river cruising. To improve such a PHEB system, it would be necessary to have an easier handling function and automated operation in the future. Low cost production is also an important factor for the spread of such systems. It is said in Japan that electric high speed boat with a simple pure battery will not succeed to spread. People who are just optimistic and do not have experience of the real world often expect such a difficult electric boat. There are very few places to change the battery near ports in Japan. The energy density of the battery is still very low for long range as well as high speed travelling. From the reliability point of view, such a pure battery boat cannot be the showcase for the future spread of boats. Actually, in Holland in 2015, many pure battery electric boats could be seen. The country has luckily many marinas to charge the battery.

Japan is really an underdeveloped country concerning river cruising pleasure boats compared to other countries in Europe and North America. It is hoped that Japanese people can find the beauty of a river itself from being on the water as a source of a peaceful mind. By the use of an electric boat, people can have a pleasant time because there are so many beautiful rivers and lakes in Japan.

There are several important practical usages of an electric boat, such as fixed point fishing, slow speed cruising, and working boats, which require quietness at a clean area. The newly developed cruising boat is designed to be used in such lakes or rivers with slow speed.

The system of the power train with a battery and an electric motor has higher weight rather than the system with foci fuel and an internal combustion engine. To utilize the great advantages of quietness and no polluted gas exhaust of electric motor systems, an electric boat is an extremely good choice rather than an electric vehicle. The internal combustion engine has been well advanced for automobiles. Small boats are usually not surrounded by a roof to prevent noise and pollution from the engine.

It is also important to use the boat as slowly as possible to minimize the use of battery energy. If a boat runs twice the velocity, the power of 8 times is necessary. Including the 50 % of run time, still the total energy of 4 times is required. This is the reason why the electrification is recommended for the cruising boat [Minami, 2003; 2004; Minami et al., 2003].

In this paper, such advantages of an electric boat with an internal combustion engine are described by showing the results of a newly constructed 30 PAX 9.66 m LOA plug-in hybrid cruising boat.

Acknowledgements

We would like to offer our special thanks to Mr. Ichiro Ban with Ban PR Inc., who conducted the safe and reliable steering of the PHEB-3 during the campaign. We are also deeply grateful to Mr. Tooru Ueda with The General Environmental Technos Co., Ltd., for providing the opportunity to perform the river cruising in Wakayama. The boat construction was performed by Daimatsu Shipyard in Wakayama, Yokota Iron Works, Co. in Wakayama, and Nanshin Shipyard in Osaka, Japan.Without people's hard work and their warmest passion to complete, it would have been impossible to reach the completion of the PHEB-3.

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(Received November 16, 2015; accepted December 1, 2015)