

The Evolution of a Newly Developed FCV-Loaded Electric Boat

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Abstract

A new boat driving system is developed by loading an FCV or an EV onto an electric-propulsion boat. The electric-propulsion boat can be driven by means of batteries. This new method resulted in dramatically increasing the amount of loaded electric energy; with prior and existing batteries the amount of electric energy had been inadequate. It has made it possible, for instance, to produce excellent new performance and convenience in cruising distance and sail-speed. A boat is built for substantial experiments during this research. The research was conducted with the prototype boat in order to accomplish such goals as the reduction of CO₂ emission and oil consumption. A Toyota “Mirai” fuel cell commercial vehicle, FCV, on board the hybrid boat is used to prove the usefulness of an FC system and a hydrogen tank as an electric generator. It is expected that the effective spread of a hydrogen system for marine transportation in the early 21st century might be provided by such a simplified way of an FCV as a hydrogen generator. We are hoping to provide the shipping circle with a new means of navigation for vessels in this century and to contribute to the country’s prosperity.

Keywords

FCV, hydrogen energy, hybrid boat, electric-propulsion boat

1. INTRODUCTION

Electric-driven vehicles are being popularized because of small oil consumption, and they are expected to contribute to global environmental conservation. Low exhaust gas and noise are the most important factors for electrification. Small electric boats often have no roof, and so the electrification of such boats is very effective to solve such an uncomfortable situation. However, the weight density stored in battery energy is extremely small in comparison with the petroleum fuel.

The total energy stored in the boat determines the cruising distance and speed. In addition, batteries are required to be recharged frequently at a battery charging station at piers. These factors have prevented electric boats from spreading widely at a global level. Compared with other countries, Japan in particular, though a technologically developed country, is not active about the practical usage of small electric boats.

To take the advantages above, we have demonstrated the capabilities of electric boats for many years [Mi-

nami and Yamachika, 2003; Minami, 2003]. We have also been engaged in the long-term development of a highly-feasible plug-in hybrid-boat, as a way of supplementing battery-performance [Minami and Yamachika, 2004, Minami et al., 2010; 2013; 2015; 2017].

The application of hydrogen energy has become important as a social mission in respect to the attainment of a clean energy-contained society and CO₂ reduction. Over the past several years, Japan has been leading the way in actualizing mass-produced FCVs and popularity has begun to grow. Meanwhile, research into FCV-loaded electric boats, which are loaded with hydrogen and fuel cells, has just begun by our research. The biggest developmental hurdle of a hydrogen boat is not efficiency, life, and other aspects of the performance of fuel cells, but rather it is how to fuel hydrogen on boats. It is relatively easy to charge electricity on boats, however, it is very dangerous to load hydrogen cylinders onto boats. There is the possibility of setting up a costly hydrogen refueling station on a pier, for example. However, it is very hard to supply hydrogen from a pier with hydrogen-supply pipes of no less than 70 MPa each due to sea waves making relative movements against the pier. This causes a danger of a hydrogen leak from the supply tube between them.

Given the danger of dropping the cylinders into the sea, it is also not commercially practical to load hydrogen cylinder bundles onto boats from a pier.

As a breakthrough to the problems of safety and practicability with respect to the loading hydrogen gas, we have invented a method of simple loading of an FCV or an EV as a “generator” on a boat. Using this method, it is possible for the FCV to be refueled at a hydrogen-refueling-station. The EV is also rechargeable at a charging-station on land. The boat is equipped with a highly-efficient electric-boat system which can resolve the shortcomings of existing electric boats. Those shortcomings have been an inconvenience and also the amount of energy storage. They can be resolved by using an FCV or an EV as a generator on the boat. Such an electric boat, loaded with an FCV or an EV, is therefore built to demonstrate the performance assessment and to encourage the prevalence of the system.

2. OPERATIONAL PERFORMANCE OF THE BOAT

2.1 Outline of operational methods

The operation of this boat can be performed under the following seven modes:

- In which an FCV or an EV (loaded onto the boat) is driven in a generator-mode and the boat is driven as an electric-propulsion system. (Mode A)
- In which an FCV or an EV (loaded onto the boat) is driven in a generator-mode and a LiB (Lithium-ion battery) is recharged. (Mode B)

- In which an FCV or an EV is loaded onto the boat and an electric-propulsion system is operated by using only a LiB loaded on the boat. (Mode C)
- In which neither an FCV nor an EV are loaded on the boat and an electric-propulsion system is operated by using a LiB loaded on the boat. (Mode D)
- In which an FCV or an EV is loaded on the boat, but the electric-propulsion system is not operated. The boat is driven by an outboard fuel-motor. (Mode E)
- In which the boat is not moving with an FCV or an EV loaded on. This situation includes the use of a shore power-supplying system. (Mode F)
- In which the boat is not moving without an FCV or an EV loaded on, but the boat is storing the system described above. This situation includes the use of a shore power-supplying system connected with a grid. (Mode G)

2.2 The drive-system of the boat

2.2.1 The outline and main purposes of the boat

The boat built with on board FCV or EV for this research succeeded in dramatically increasing the amount of loaded electric energy. Also, the boat has made it possible to improve cruising distance, navigation speed, and handling convenience. The amount of energy is not adequate with prior and existing batteries. In this research, the boat is built to examine demonstration performance. The boat is expected to play a role in the social application of hydrogen energy and to serve the new practical spread and development of shipbuilding and the shipping industry in the future.

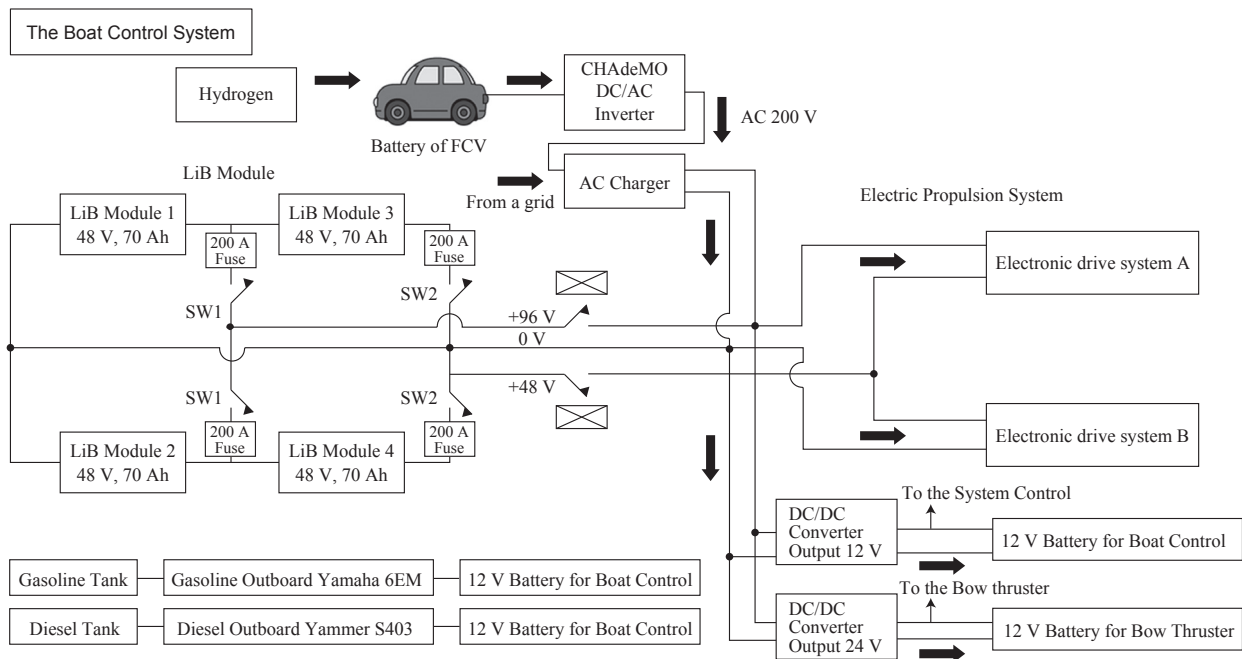


Fig. 1 An example of operational methods in Mode A

Although this boat can also run on fossil fuel, it can run with a LiB loaded on, and it runs as an optimal robust solution of a plug-in hybrid-boat across a wider range of navigation scenes. It will offer a flexible, highly-efficient, and low-emission driving system configuration. The main features of the boat are: the possibility of mass marketing on a scale of several hundred thousand in Japan; the advantage of loading an FCV of which safety is proved for its safe running onshore, and; the advantage of an FCV-loaded electric boat powered by the FCV for a long distance with a low emission of gas. With these great features of the FCV-loaded electric-boat, it is expected to solve the difficult problems related to the loading of hydrogen fuel onto boats as well as the safe control of the hydrogen system.

Boats with only an insufficient amount of batteries loaded on them have a problem. However, FCV-loaded electric-boats can carry much more electric-power energy at any time, and thus, they can be highly convenient as electric boats. These features will pave the way for the dissemination of electric boats across a number of uses in the future. The purpose of this research is to demonstrate and prove the usefulness of this boat system.

The overall layout of the boat “PHEB-3” is shown

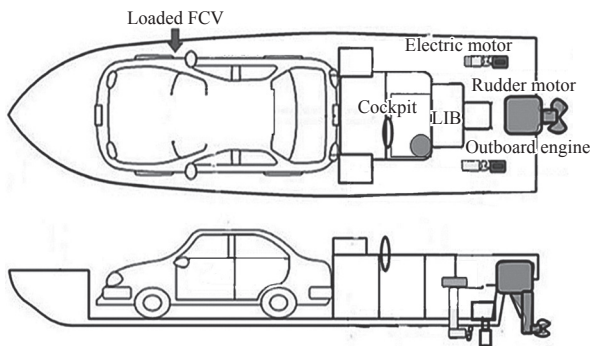


Fig. 2 General arrangement when an FCV or an EV is loaded on the boat

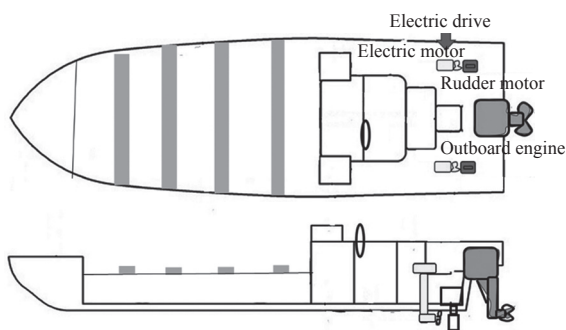


Fig. 3 General arrangement of the plug-in hybrid-boat when an FCV or EV is not loaded on the boat

below. Figure 2 is the general arrangement of the boat when propulsive electric-power is obtained from a loaded FCV or EV. Figure 3 shows an arrangement in which the boat runs only by means of a loaded LiB and gasoline/diesel, without having an FCV or an EV loaded.

Table 1 Specifications of the FCV-loaded electric boat

Length overall	9.50 m
Length	8.67 m
Beam	3.20 m
Depth	1.73 m
Draft	0.50 m
Maximum passengers	<ul style="list-style-type: none"> • 28 passengers, 1 captain, 1 other (Without an FCV, a total of 30) • Crew: 3, others: 7 (With an FCV, a total of 10)
Gross tonnage	2.6 t
Main engine	Yammer S403 (28 kW@4500 min ⁻¹) or Yamaha 6EM (95.60 kW@6300 min ⁻¹)
Auxiliary electric propulsion	NAVY6 × 2 (6 kW × 2@1550 min ⁻¹)
Speed (80 % Max power)	<ul style="list-style-type: none"> • 8 kt (Yammer S403) • 15 kt (Yamaha6EM) • 6 kt (NAVY6)
Fuel tank	Gasoline (0.2 m ³), Diesel fuel (0.1 m ³)
Battery	24 kWh (LiB) (96 V), 2.4 kWh (24 V), 1.2 kWh (12 V)
Electricity source	FCV, EV, Grid electricity



Fig. 4 A photo of the boat “PHEB-3”

Figure 5 shows the device used when a car is loaded onto the boat by a crane. Figure 6 shows photos when an FCV Toyota “Mirai” is being loaded onto the boat by a crane. Figure 7 shows the specifications of the FCV, which is to be loaded onto the boat, and it also shows a structure drawing of the device used for loading by crane. Figure 8 is an example of the DC output

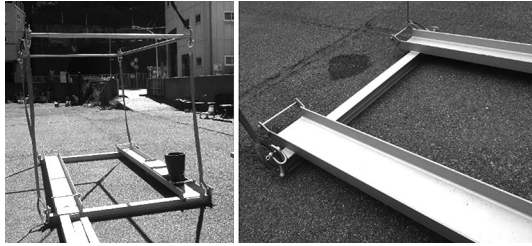


Fig. 5 Photos of a device used to load an electric vehicle as an electric source onto the boat by a crane

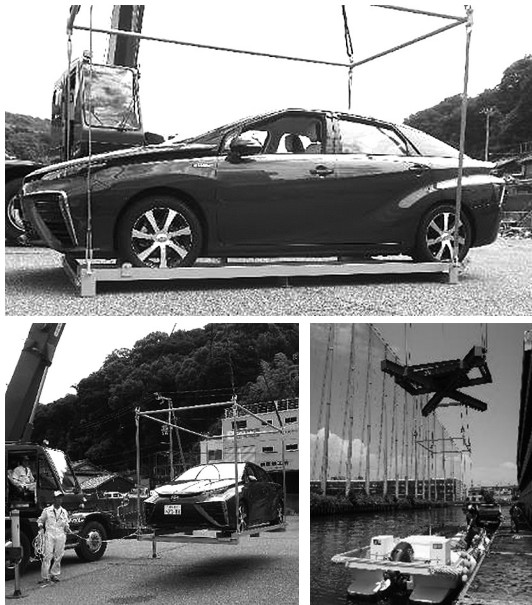


Fig. 6 Photos of loading an FCV “Mirai” by cranes

Specification of the FCV, Toyota Mirai
 Front weight: 1,000 kg
 Rear weight, 750 kg
 Wheelbase, 2,780 mm
 Front tread: 1,535 mm
 Rear tread: 1,545 mm
 Tire: 215-55R17
 Maximum stable inclination angle: 50 deg
 Height of gravity: 641 mm

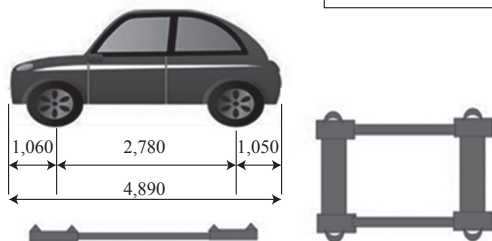
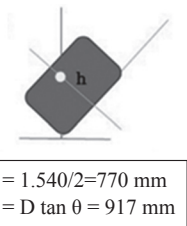


Fig. 7 Specifications of an FCV (Toyota “Mirai”) to be loaded, and a structure drawing of the device used for loading by crane

CHAdEMO terminal loaded (Toyota “Mirai”) on an FCV or an EV as a standard. Using this, an inverter is installed inside the vehicle on the boat and AC200



Fig. 8 An example of a CHAdEMO terminal loaded (Toyota “Mirai”) on a vehicle as a standard

V is outputted from the vehicle. A maximum-output of 6 kW is possible with a Nichikon inverter, and a maximum-output of 9 kW is possible with a Honda inverter. All of the FCVs and EVs sold in Japanese markets today generate AC200V. When an FCV or an EV is loaded with one of the inverters onto the boat, the electric power is used to drive the boat. At the same time, the electricity can charge the LiB on the boat.

3. PERFORMANCE OF THE BOAT

The performance of the PHEB-3 hybrid boat with the FCV’s electric-propulsion system on the boat and the boat with the gasoline outboard engine are described in this section.

Figure 9 shows the relationship between the measured input-power and the boat-speed with the electric-propulsion system. When the boat runs at 8 km/h, it requires approximately 5 kW from a total of two electric outboard-engines together. Meanwhile, when the FCV-Mirai is loaded on the boat, the loaded amount of hydrogen is 50 m³ when full. Thermal energy of 165 kWh can be loaded. Even if fuel-cell efficiency is estimated as low as 50 %, it is possible to produce about 80 kWh of electric-energy when full. Besides 15 kWh of energy needed for running on land, approximately 65 kWh of energy is available for running the boat. This means that it is possible to run for about 13 hours

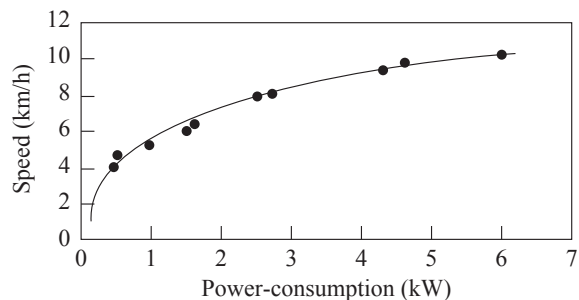


Fig. 9 Characteristics of speed and power-consumption using two electric outboard-engines loaded on the boat

at a speed of 8 km/h.

If the boat runs at the speed of 4 km/h, the electricity consumption is 0.7 kW. This means that it is possible to run for about 93 hours at that speed. The experiment was conducted on Dotonbori River in Osaka, Japan. The width of the river is narrow and the speed limit for cruising is about 4 km/h. The boat in this research can run for about one week on one filling.

Moreover, the boat has a gasoline or diesel outboard-engine independent from the electric navigation system. Figure 10 shows the characteristics of the actual measurement speed vs. the engine RPM of the loaded gasoline outboard-engine. The fuel-consumption at 8 km/h is about 10 L/h, and approximately 20 hours (160 km) of running is possible using the engine alone. Thus, it is an extremely robust boat.

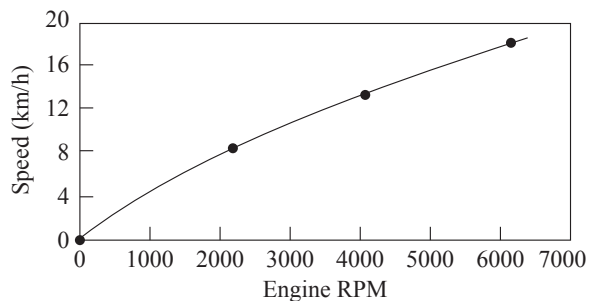


Fig. 10 The relation between the boat speed and the engine RPM of the gasoline outboard-engine loaded on the boat

Toyota's FCV-Mirai was used as a generator for the boat in this research. The specifications have already been shown in Table 1. The maximum amount of hydrogen which can be loaded is 50 m³ (5 kg), and approximately 65 kWh of electric-energy can be outputted.

The boat has been open to the public and has been utilized as a verification project with the goal of popularizing boats which use only hydrogen, based on the system described so far. Figure 11 shows photos of the boat at a press-preview.

4. CONCLUSION

We have developed a new drive-method for a boat loaded with hydrogen fuel using an FCV or an EV as a generator, and we conducted demonstration experiments. As was expected, the boat can run electrically for a long period of time, and by means of hydrogen it can also have safe and convenient propulsion. The application of this system to boats will make it possible for such boats to be in widespread business use in the future.



Fig. 11 Photos during a demonstration experiment with an FCV-loaded electric boat

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