

Demonstration Experiment of Electric Outboard Motor for Small Boat

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ABSTRACT

The authors conducted a demonstration experiment of a small electric outboard motor system that utilizes an electric scooter power unit and swappable batteries. As the use case, the experiment took place on the “Horikawa Meguri” sightseeing tour in Matsue City, Shimane Prefecture, in which a small boat is used to tour a moat.

The braking distance when berthing was reduced by 30% by using a switch that changes propeller rotation direction and a speed adjustment function that enables control even at very low speeds. In terms of operability, the authors verified how operators used the equipment and tuned the relationship between the throttle position and tour boat speed for an electric outboard motor. Furthermore, the use of swappable batteries enabled quick battery replacement on board. As a result, the performance and feeling of the outboard motor were better than those of internal combustion engine outboard motors.

1. Introduction

Some regions of the United States and Europe are starting to consider zero emissions regulations for small outboard motors of 19 kW or less⁽¹⁾. Torqeedo GmbH is one company expanding its business worldwide, especially in Europe, as an electric water mobility manufacturer⁽²⁾. In Japan, Yamaha Motor Co., Ltd. began demonstration operations of HARMO, a new boat- maneuvering technique integrated with an electric propulsion unit and steering control system on cruise boats in August 2020⁽³⁾.

In November 2021, Honda announced the concept model of the small electric outboard motor shown in Fig. 1 as a proposal for a next-generation clean outboard motor in a quest to achieve carbon neutrality by 2050⁽⁴⁾.

In response to this announcement, the Matsue City Tourism Promotion Public Corporation in Shimane Prefecture inquired about using Honda’s small electric outboard motor on a tour boat.

Matsue City has announced a long-term goal of achieving net zero CO₂ emissions to become carbon neutral by 2050. As one effort to achieve this goal, the tourism promotion corporation wanted to reduce CO₂ emissions by replacing Honda internal combustion engine (ICE) outboard motors on tour boats operating in the city with electric outboard motors⁽⁵⁾.

Honda is also working to develop electric outboard motors for mass production, and while it is a challenge to achieve the same long-hour, high-load operation as ICE outboard motors, given battery energy density and cooling performance, Honda also hoped to hear actual customer feedback and clarify the value provided by electric outboard motors, appropriate sales prices, requirements, and



Fig. 1 Concept model of electric outboard motor for small boat

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operating methods.

This situation led to the start of a business demonstration project making maximum use of existing resources to build a pilot small electric outboard motor in a short period of time and operate it in Matsue.

Customers on the “Horikawa Meguri” sightseeing tour take a leisurely ride on a small boat through the moat in the Matsue castle town, where they can enjoy the scenery. As shown in Fig. 2, the ride is about 3.7 km long and takes about 50 minutes. During the busy season, more than 20 boats may be on the course at the same time, and at these times a single boat may travel the course up to eight times a day. Boats are about 23 ft long (about 7 m) and have a capacity of up to 13 people. Boats normally operate even in the rain and are in use year-round.

In some places along the course, there are rows of private homes. These are defined as “quiet zones,” where boats are required to travel with the ICE outboard motors running at a low speed of rotation⁽⁶⁾.

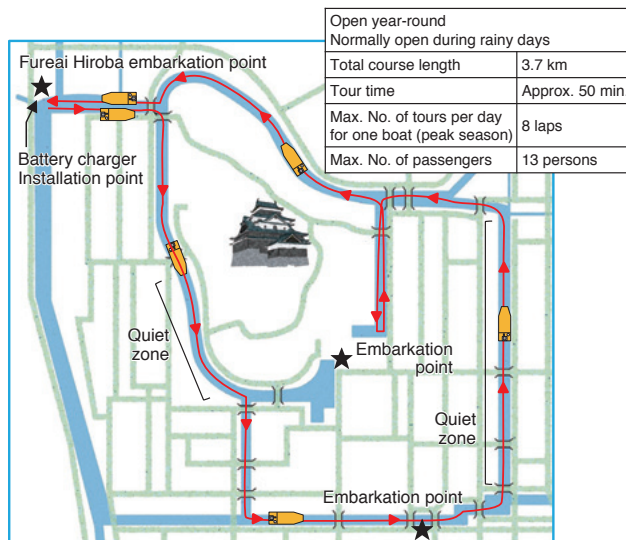


Fig. 2 Tour course overview

2. Specification Review and Target Performance

2.1. Power Performance Requirements

During the tour, boats operate at a speed of about 4 to 6 km/h. To determine the performance requirements of the outboard motors on the boats, the researchers checked the load that they were under during one lap of the course.

As Fig. 3 shows, the power unit used during the tour requires an output of about 1.0 kW for cruising and temporarily up to 3.5 kW when decelerating, such as when berthing at the embarkation points and when stopping. The resulting energy consumption is 1.2 kWh per lap.

2.2. Study of Electric Outboard Motor Power Unit and Motive Power Supply

For the study of a power unit capable of producing this motive power, the researchers looked at the BENLY e:, the business-use electric scooters shown in Fig. 4, which was being sold to corporate customers at the time. BENLY e: is an electric scooter based on the 110 cc class BENLY and powered by the Mobile Power Pack e: (MPP), the swappable battery shown in Fig. 5.

The maximum output of the ICE outboard motor BF9.9 currently used on the tour boats is 7.3 kW. This motor was chosen so boats can run quietly at low rpm. As Fig. 6 shows, the BENLY e: power unit is capable of the range of outputs used during the tour. It was therefore decided to make the tour a use case that could take advantage of the output characteristics of the electric motor, which can generate high torque from the low-rpm range.

2.3. Setting the Target Performance as an Electric Outboard Motor

Based on the use case, the researchers set the following performance targets in terms of motive power and marketability. The purpose was to provide ease of use equal

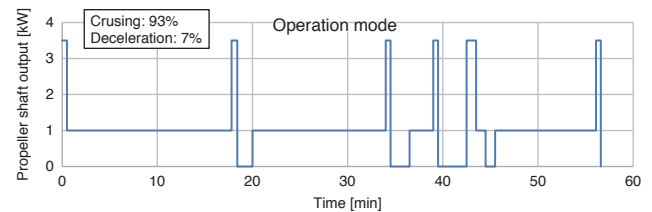


Fig. 3 Mode of used power during one tour lap



Fig. 4 BENLY e:



Fig. 5 Mobile Power Pack e: (MPP)

to or greater than that of ICE outboard motors along with the new value associated with electric motors.

- (1) Needs to have braking performance and control system layout capable of berthing a boat
- (2) Throttle grip with speed adjustment function needs to allow natural adjustment from very low speed to maximum speed without having to release and re-grip
- (3) Needs to be possible to swap batteries while the boat is in operation during rain

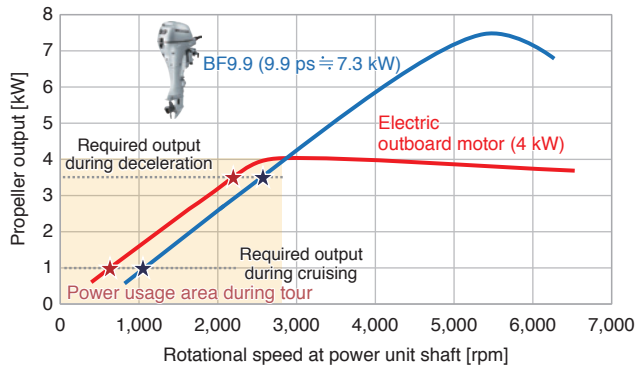


Fig. 6 Comparison of output characteristics between ICE outboard motor and electric motor

3. Electric Outboard Motor System Specification Configuration

3.1. Overview

As Fig. 7 shows, the electric outboard motor system built for this research consists of three components: the outboard motor itself, a battery box, and an electric device box that contains various wiring connectors and devices and fuses for using two MPPs in series. As shown in Fig. 8, the battery box was moved on board for ease of use, and the electric device box was mounted in the space where the fuel tank had been housed to make effective use of the space it had occupied^{(8), (9)}.

3.2. Braking Performance and Control System Layout Specification Configuration

Figure 9 shows a conventional ICE outboard motor. Here, the drive shaft directly connected to the engine can only rotate in a constant direction. To change the propeller rotation direction, it is necessary to operate the clutch and change the engagement of the forward and reverse gears. As shown in Fig. 10, to perform the switching operation, one hand operates the throttle grip while the other is used to move the clutch by physically operating the lever. The electric outboard motor shown in Fig. 11, the use of a motor makes it possible to switch the drive shaft's direction of rotation by operating a control switch. This eliminates the need for a clutch, reverse gear, and a shift lever to operate

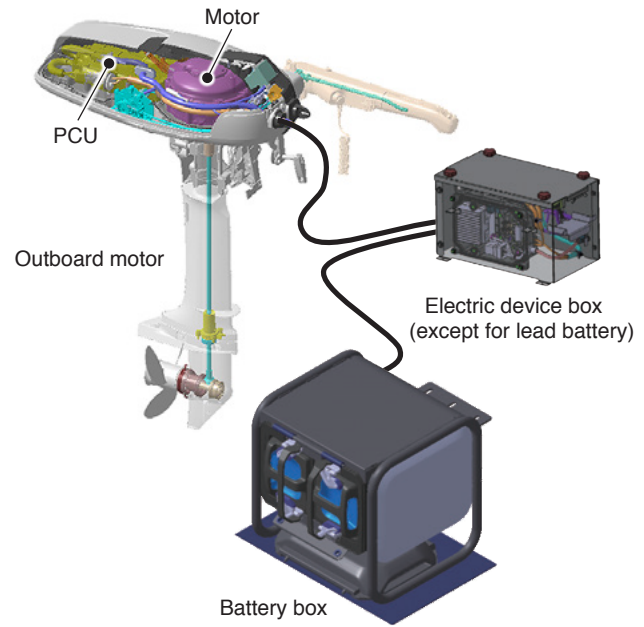


Fig. 7 Configuration of electric outboard motor system

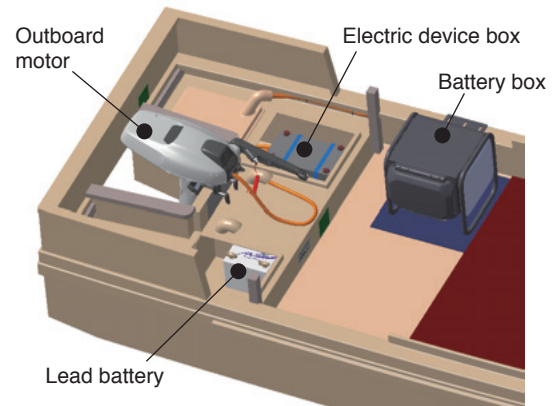


Fig. 8 Image of electric outboard motor system mounted on boat

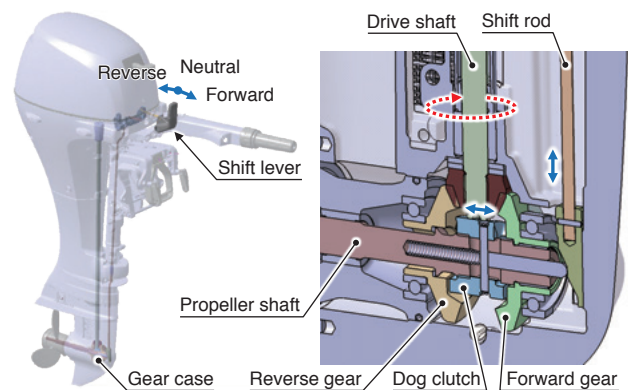


Fig. 9 Internal structure of gear case of ICE outboard motor (BF9.9)

them. The reverse gear and clutch were eliminated based on an existing ICE outboard motor gear case. However, it was necessary to reconsider adjustments for tooth contact among other factors since the gear, which had previously rotated in a fixed direction, would now rotate in forward and reverse. TOHATSU CORPORATION developed the electric outboard motor gear case shown in Fig. 12.

To electrify the control switch, an alternating switch was installed at the end of the throttle grip, as shown in Fig. 11. The switch is positioned to be close to the thumb while the operator is holding the throttle grip. This allows easy one-handed operation, in contrast to the two-handed operation



Fig. 10 Conventional method of shift switching



Fig. 11 New method of shifting by alternating switch

required with ICE outboard motors. During berthing, when the switch is pressed with the throttle open, the power control unit (PCU) outputs an instructional value equal to the output torque multiplied by a negative value. This allows the motor to quickly decelerate, stop, and switch smoothly and quickly to reverse.

This control system simplifies the stopping operation and reduces the distance it takes to brake from a speed of 5 km/h by 30% compared to an ICE outboard motor, enabling the operator to easily berth the boat⁽¹⁰⁾.

3.3. Controllability of Speed Adjustment Function

Speed is adjusted by opening and closing the throttle grip. As Fig. 13 shows, the operator operates the throttle by rotating the throttle grip, which turns the accelerator position sensor (APS) through a cable, as in the BENLY e:. The fully open throttle grip angle was set to 100 degrees, the same as that of an ICE outboard motor. To use the BENLY e: power unit for this purpose, the map of power output against throttle position must be tuned specifically to the boat, because the resistance and propulsive force mechanisms at work will differ for a scooter and boat. In addition, while the ICE outboard motor could not turn the propeller below idle speed, the electric motor can turn it at extremely low rotation speeds and generate high torque even at low rotation speeds, making it possible to operate

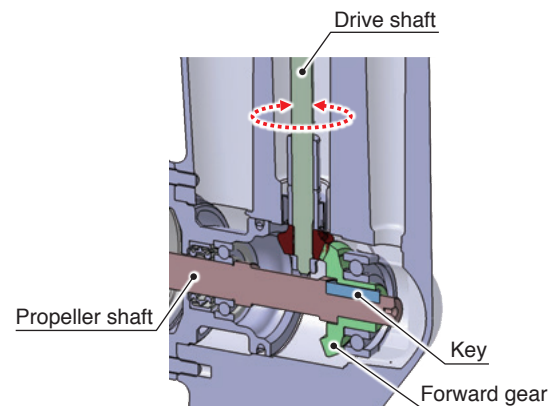


Fig. 12 Internal structure of gear case of electric outboard motor



Fig. 13 APS position in electric outboard motor

the boat even at extremely low speeds. Figure 14 shows the relationship between tour boat speed and the tuned throttle position. When establishing operability, the researchers verified how actual operators used the equipment and took the following into consideration.

- (A) Considering the burden on the wrist during grip operations, it needs to be possible to control the boat speed range in practical use without exceeding a 40° throttle position.
- (B) It needs to be possible to make adjustments in the cruising speed range (4 to 6 km/h) without much twisting of the wrist.
- (C) It needs to be possible to operate the throttle over a wide range of angles when cruising at the extremely low speeds required for subtle maneuvering.

3.4. Adaptation of Swappable Battery to Tour Boat

The battery, the energy source for the motor, is an MPP that can easily be installed and removed, replaced, and transported.

There are many examples of electric outboard motors in the same or greater power range from other manufacturers that have large-capacity batteries mounted inside the vessel. Under that operating approach, a large-capacity battery capable of meeting the needs of the use case for one day is installed, and the battery is recharged over a period of several hours during the night when not in use. The battery is charged from a power source on land, for example, at the pier, installed especially for this purpose⁽⁷⁾. This study used MPPs because they do not require major modifications of existing boats and do not require a land-based power supply, which is expensive to install.

In the case of a boat, MPPs need to be swapped outdoors where there may be precipitation. This is a major difference from the case of an electric scooter, whose MPPs are likely to be swapped indoors or under the eaves of a building. As mentioned previously, these boats run as many as eight times per day, making it necessary to swap MPPs four times. Swapping time is limited to a few minutes while

passengers are embarking and disembarking. Another need in the case of tour boats is that the shape and installation layout should not obstruct the view from the operator's or passengers' seats.

There are many points to consider in this use case, such as a box shape for easy replacement and installation layout on board, and water resistance during operation and swapping.

Specific approaches to address these issues include a shape that allows the MPP to be inserted and removed horizontally, as shown in Fig. 15, to help prevent water exposure. Additionally, the battery height is set to be at least 120 mm, which helps prevent water from entering the MPP box in the event of rain accumulation in the boat and makes it easier to work with. The box is located on the deck in front of the steering seat, making it easy for the operator to swap batteries and maneuver the boat.

By doing these operations, the researchers were able to construct a battery system compatible with the existing tour boat navigation use case and hull.

When using the MPP, batteries need to be swapped after every two laps of the tour. To facilitate this operation, a battery charger was installed in a maintenance shed at the "Fureai Hiroba embarkation point" in Fig. 2. Batteries were swapped while passengers were embarking and disembarking.



Fig. 15 Battery box shape

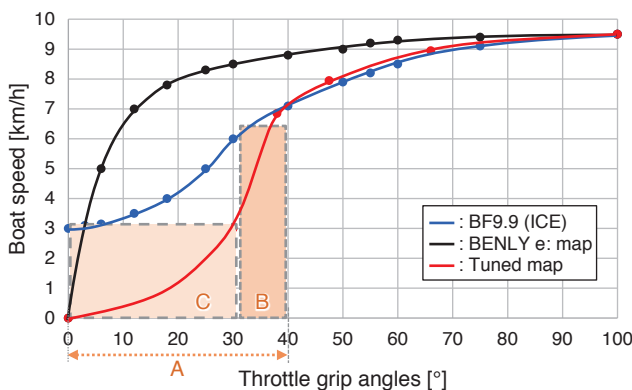


Fig. 14 Boat behavior at each throttle position

4. Demonstration Experiment Results

An electric outboard motor equipped with the new control system and power map described above was installed on a tour boat and the operator operated the boat to evaluate how it felt. As Fig. 16 shows, the output characteristics of the electric outboard motor provided better acceleration and responsiveness than the ICE outboard motor. Throttle controllability and ease of deceleration scored higher than those of the ICE outboard motor as a

result of the specification configuration.

The following are two new values to be gained by electrification.

From the point of view of the tour boat operator, it is easy to detect and remove foreign objects tangled in the propeller.

Algae blooms occur in the “Horikawa Meguri” route during the summer. Although the algae is regularly cut, it cannot all be cut away, which is why it becomes tangled in propellers, as shown in Fig. 17, lowering motive power performance and increasing energy consumption. With an electric outboard motor, there is less vibration to the operator’s hand and arm, so even slight changes in this vibration that may be caused by an unbalanced propeller tangled with algae can readily be perceived. As a result, the operator can sense algae entanglement and quickly and easily remove it from the blades by reversing the direction of propeller rotation.

Regarding sound, the research showed that there is even greater value when the viewpoint is expanded to include all the passengers on the tour boat.

Given that there are quiet zones on the tour course, the researchers believed that replacing engines with motors would reduce the impact of noise on the surrounding environment. During tours, some situations require two-

way communication, such as when the operator is talking to passengers as their guide and passengers ask questions of the operator. The noise from the ICE outboard engine sometimes made it a challenge for the operator to hear passengers’ questions, making it necessary to reduce the engine speed and to ask them to repeat their question.

With less noise, passengers can better hear the operator talk about the site, and communication with the passengers goes more smoothly. This enhances the value unique to a tour boat, since passengers enjoyed the ride even more.

5. Conclusion

The researchers constructed an outboard motor system, described below, that is easier to operate than an ICE outboard motor and is compatible with the existing tour boat navigation use case and hull.

- (1) The control system that makes it easy to switch the direction of propeller rotation facilitates stopping, resulting in a 30% reduction in the distance it takes to brake from a speed of 5 km/h compared with a conventional control system.
- (2) The tuning of the speed adjustment function was set to reflect the way the operator actually operates the boat, making it easy to operate at extremely low speeds and cruising speeds.
- (3) MPPs were used as the motive power source and the battery box shape was optimized for both quick replacement and rain exposure for tour boats, which operate frequently and need to be water-resistant. The result was performance that was satisfactory for this use case.

Afterword

Test rides have already been offered for general passengers on boats operated by “Horikawa Meguri” operators, and many have commented on the quietness of the boat. They note, for example, that the tour is more enjoyable because they can hear birds singing, the sound of water moving on the surface while cruising, and the sounds of birds and insects. The system has also been praised for enabling operators to perform all control with one hand.

As Honda engineers, the researchers were deeply impressed by the opportunity to hear comments from people onsite and be able to develop this project together with the people of Matsue City. They will continue to study the value of electrification over the long term and hope also to study value that can be provided to passengers other than those on this tour boat.

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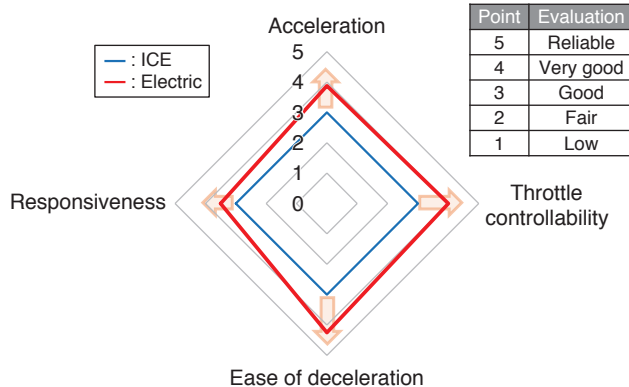


Fig. 16 Comparison of drivability between ICE onboard motor and electric motor



Fig. 17 Tangled algae around propeller

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