**Navigation Support System for Hybrid Electric Boat**

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**ABSTRACT**

The possible cruising distance of the battery powered boat is still short compared with that of similar-sized internal combustion engine boats. In order to solve this problem, the battery powered boat with a diesel generator to recharge the battery, i.e., the hybrid electric boat has been created in 2014. The previous Navigation Support System (NSS) for the electric boat is made a calculation only a suitable speed and an output power based on battery. Therefore, NSS which present the possible cruising distance was extended for considering the added electricity.

**KEY WORDS:** Electric boat; Navigation Support System; Series Hybrid System; Lithium-ion Battery; Generator; electric power generation; State of charge.

**INTRODUCTION**

The proportion of exhaust gas from boats is high at Tokyo Bay area. Boats are required to reduce exhaust gas like cars to conserve the environment. However, the adoption of environment-improving technologies in the field of sea transport is delayed compared to land transport and automobiles. In order to prevent air and water pollution from conventional boats, zero emission boats like battery powered boats are desired.

However, the general battery powered boat is required long time to recharge the battery. Moreover, since the battery capacity of the battery powered boat is limited because of restrictions on battery cost, weight, and charge time, a possible cruising distance of the battery powered boat is short compared with that of similar-sized internal combustion engine boats.

The quick charging battery powered boat named “RAICHO-I” have been constructed by Tokyo University Marine Science and Technology in May 2010 (Nishimura, 2012; Shimizu, 2011). “RAICHO-I” is the first battery powered boat adopted CHAdeMO standard which is the standard of the quick charging method for electric vehicles in Japan (CHAdeMO Association, 2014). This boat is possible to navigate about 45 min with 25 kW output. The charging time of this boat is about 30 min by the quick charger. The operational time of the battery powered boat is insufficient for many boat users.

In order to compensate this weak point of the battery powered boat, Tokyo University Marine Science and Technology has created a new type of the battery powered boat, i.e., a hybrid electric boat named “RAICHO-N” in March 2014. This hybrid electric boat equips not only the li-ion battery but also an emergency diesel power generator. The propulsion system of this boat is basically driven by the electric motor using the battery power. The power generator is only used to recharge the battery. The battery can be recharged during cruising. This kind of the hybrid system is called as the series hybrid system. The system is also adopted in the electric car operating an engine in the most suitable efficiency range in consideration of state of charge (SOC) (Metin, Seta, and Douglas, 2006). The advantage of the series hybrid system is that the boat can be operated as a pure battery powered boat when the stored battery power is enough for the desired operation and the generator is stopped. The hybrid system of the boat is designed to be able to replace the diesel generator to the fuel cell etc. in the future. Since the energy density of the diesel oil is higher than it of the li-ion battery, the possible cruising distance (PCD) of the hybrid boat is dramatically increased.

On the other hand, the Navigation Support System (NSS) which estimates PCD etc. has been developed by authors in the viewpoint of operational safety for battery powered boats. However, the previous system has not been considered and the effect of the recharging energy. Therefore, the NSS for the hybrid electric boat which takes the recharging energy from the diesel power generator into account and achieves the desired operation have been developed.

A function which can calculate the suitable speed to the destination with the present SOC and the required power generation amount to satisfy the desired navigation time and the speed is added for new NSS. In order to clarify a calculation algorithm, the relation between the speed and the output is required. The relations is obtained from navigated data at an actual water area. In order to elucidate the characteristic of the generator, the relation between the torque and the electric current is also required. Two estimate equations are derived from these two relations. For algorithm, desired values (a departure time, a remaining SOC at arrival time, a navigation time, and a distance to destination) are defined as given values from an operator. The