Power requirements for PHERB powertrain

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Abstract. Boats are considered as favourite maritime transportation designed for recreation activities, fishing and surveillance purposes. However, in tropical developed countries, boats are employed for different applications such as passenger and goods transportation. In this paper, the power requirements for a proposed plug-in hybrid electric recreational boat (PHRB) powertrain is determined using a steady state velocity and the Kuala Terengganu river driving cycle according to the boat parameters, specifications and performance requirements. The boat power requirements can be used to size the main components for PHERB powertrain. The results obtained from this analysis are within reasonable range and satisfactory.

1. Introduction

There are several energy resources which are used widely in transportation, such as petroleum, coal, and natural gases. Currently, fuel from the petroleum sources is the major power and almost drained due to transportation consumptions [1]. The strain pertaining fuel availability and the increasing need of power in vehicle due to modern lifestyles, is resulting in a need for social and technological revolution that is capable of bringing a new, stable and durable balance between consumption and environmental concerns [2]. Boat propulsion is significantly responsible for environmental problems such as the greenhouse effect, acid rain and air pollution related to the emission issues [3-5].

The purpose of this paper is to introduce the plug-in hybrid electric recreational boat (PHRB) in order to reduce the fuel consumption and emissions for marine transportation by Figure 1 shows a schematic illustration of the series-parallel PHERB powertrain. The PHERB powertrain has only one electric machine (EM) to function as either electric generator or motor in different time intervals specified by a special developed energy management strategy that control the power flow according to desired operating mode. In order to improve the drive performance and energy efficiency, the PHERB uses a hybrid energy storage system (ESS) combining batteries and ultracapacitors, which can work together effectively. The size of the internal combustion engine (ICE) can be reduced since it is operated during certain operation mode only.

In this paper, a theoretical research of power requirement for PHERB powertrain was studied using a steady state velocity and a Kuala Terengganu (KT) river driving cycle. The calculation of power requirements for PHERB powertrain are based on the boat parameters, specifications and performance requirements.
2. Theoretical equations
To calculate the propulsion power for PHERB powertrain, the resistance and the total propulsive efficiency have to be determined with the highest possible accuracy. As empirical methods are normally used for these calculations, it is worthwhile to at least to know the accuracy of the different elements in the calculation procedures such that the propulsive power can be predicted in combination with an estimate of the uncertainty of the result.

2.1. Resistance
The resistance of a boat at a given speed is the force required to tow the boat at that speed in smooth water for the boat velocity, \( v \), and power propulsion, \( P \), in the low velocity range. When cruising, a boat encounter frictional resistance, \( C_F \), incremental resistance, \( C_A \), air resistance, \( C_{AA} \), and residual resistance, \( C_R \). At low velocity, frictional resistance, \( C_F \) is dominant. The total resistance coefficient, \( C_T \) of boat can be defined by

\[
C_T = C_F + C_A + C_{AA} + C_R = \frac{R_f}{0.5 \rho v^2 S}
\]  

(1)

where \( R_f \) is the boat resistance, \( \rho \) the density of water, \( S \) the wetted surface and \( v \) the speed.

The wetted surface, \( S \) is normally calculated by hydrostatic programs. However for a quick and fairly accurate estimation of the wetted surface many different methods and formulas exist based on only boat main dimensions.

\[
S = 1.025 \times L_{pp} \left( C_B B + 1.7T \right)
\]  

(2)

where \( L_{pp} \) is the length between perpendicular, \( C_B \) the block coefficient, \( B \) the breadth and \( T \) the draught.

The frictional resistance coefficient is defined by

\[
C_F = \frac{0.075}{(\log R_n - 2)^2} = \frac{R_f}{0.5 \rho v^2 S}
\]  

(3)

where the frictional resistance, is sum of tangential stresses along the wetted surface in the direction of the motion. \( R_n \) is the Reynolds number.
\[ R_n = \frac{v \times L_{\text{wt}}}{\nu} \]  

(4)

where \( \nu \) is the kinematic viscosity of water, \( L_{\text{wt}} \) the length hull in waterline and \( v \) the boat speed.

The total resistance, \( R_T \) is defined as,

\[ R_T = 0.5 \rho C_T V^2 S \]  

(5)

where \( \rho \) is the density of water, \( S \) the wetted surface, \( v \) the speed and \( C_T \) total resistance coefficient

2.2. Propulsive efficiency

Total propulsive efficiency can be defined as

\[ \eta_T = \eta_H + \eta_o + \eta_R + \eta_S \]  

(6)

where \( \eta_H \) is the hull efficiency, \( \eta_o \) the propeller in open water condition, \( \eta_R \) the relative rotative efficiency and \( \eta_S \) the transmission efficiency. In order to determined th propulsion power, the effective power can calculated using equation (7)

\[ P_E = R_T \times V \]  

(7)

where \( R_T \) is the total resistance and \( v \) the boat speed.

Power requirement for propulsion can be estimated , \( P_P \) using equation (8)

\[ P_P = P_E \times \eta_T \]  

(8)

where \( P_E \) is the effective power and \( \eta_T \) the total propulsive efficiency.

3. Results and discussions

Based on the parameters, specifications and performance requirements of PHERB powertrain in table 1, the power requirement of the boat can be determined. Figure 2 shows the selected route for KT river driving cycle. As in figure 3, the KT drive cycle lasts for 2414 s covering a distance of 12.09 km with an average speed of 18.02 km/h and maximum speed of 22 km/h.

Table 1. The parameters, specifications and performance requirements of PHERB powertrain

| Parameters and Specifications | Variables |
|-------------------------------|-----------|
| | Description | Dimension |
| \( L \) | Lenght overall | 12.4 m |
| \( L_{WT} \) | Lenght at waterline | 11.0 m |
| \( B \) | Breath | 1.8 m |
| \( T \) | Draught | 0.64 m |
| \( L_{PP} \) | Length between perpendicular | 10.67 m |
| \( \rho \) | Density of water | 1000 kg/m³ |
| \( W \) | Displacement | 395 kg |

| Performance Requirements |
|---------------------------|
| Maximum speed | 30 km/h |
| EV range | 10 km |
The relationship between speed and power requirement of the PHERB powertrain are shown in figures 4 and 5. The drivetrain power required for PHERB is determined using equation (8). During the steady state velocity, when speed is higher, the power requirement is higher too. The maximum speed of 40 km/h needed 17 kW of power requirement and for the minimum speed of 5 km/h, only 0.4 kW power is required. The drivetrain power requirements are different during different speed for KT river driving cycle. The size and capacity of the main components, which are EM, ESS and ICE can be selected based on the drivetrain power requirement.
4. Conclusions
Based on the results of this study, it can be concluded that the proposed method is possible to generate a recommended KT driving cycle that can be used for UMT PHEV powertrain, in order to measure fuel economy and emissions.

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