Design of Power and Energy System for a Small Garbage Cleaning Ship

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Abstract. Port garbage and dirty oil will cause pollution to the marine environment, and the sea area of port is narrow and not easy to clean, which limits the use of conventional cleaning ships. There is a need for an environmentally friendly and flexible small garbage cleaning ship. This study introduces the composition and principle of the ship propulsion system, analyzes and calculates the characteristics of the motor and the power of the ship shaft, determines the type of the motor and the composition of the energy system, and further analyzes and calculates the solar power generation system. The results show that the mode of using lithium battery as main energy and solar energy as auxiliary energy can meet the power needs of the small cleaning ship and meet the relevant environmental protection requirements.

Keywords: Power and energy system; Garbage cleaning ship; Lithium-ion battery; Solar photovoltaic power generation.

1. Introduction
With the increasing of human activities on the sea, port garbage has caused pollution to the marine environment and affected the daily work of the port. The pollution problem caused by port garbage needs to be solved urgently. In order to deal with the floating garbage in the port and not cause secondary pollution to the sea, a small garbage cleaning ship with battery as the main energy is designed to meet the cleaning needs of the port, and by adding a group of solar photovoltaic power generation system as the auxiliary energy of the ship, the battery charging times are reduced, the battery life is prolonged, and the energy is saved. Battery electric propulsion is different from traditional mechanical propulsion in that it has more flexible configuration, less noise, better turning performance in shallow sea, no fuel, and can be charged by solar energy or shore power. It can be used as a new direction for the development of power propulsion system of small garbage cleaning ships in the future[1].

2. General Introduction of Ship

2.1. Ship Parameters
The small garbage cleaning ship is a catamaran structure with a conveyor belt in the middle, and its design is shown in figure 1.
Figure 1. Design of small garbage cleaning ship.

The ship’s data are as follows: ship length is $L = 1.8m$; ship width is $W = 0.90m$; ship form depth $h = 0.43m$; floating body width is $B = 0.30m$; floating body spacing is $K = 0.60m$; underwater depth is $d = 0.17m$; working speed is $V = 0.514m/s$; running time at working speed is $t_1 = 4h$; maximum speed is $V_\text{m} = 1.029m/s$; running time at maximum speed is $t_2 = 1h$; Froude number is $F_n = 0.263$; Block coefficient is $C_b = 0.64$; the total resistance of the ship in the water obtained from the experiment is $R = 26.378N$; sea water density is $\rho = 1020kg/m^3$; the ship is equipped with two shaft-driven propellers as propellers, rated speed of the propeller is $n = 1100r/min$; the diameter of propeller is $D = 0.140m$; the pitch ratio is 0.5.

2.2. Composition of Ship Energy and Propulsion System

The marine electric propulsion system is mainly composed of power supply, power distribution system, solar photovoltaic power generation system, control system, propulsion motor, and thruster[2]. The schematic diagram of the energy and propulsion system is shown in Figure 2.

Figure 2. Figure of energy and propulsion system.
This system is provided by the power supply to the main power of the ship, relying on the power distribution system to use the power of the solar photovoltaic power generation system as an auxiliary for the use of the ship to improve the endurance. According to the motor load, the above two kinds of power are converted into power that meets the conditions of frequency, voltage, current, etc., through the control system to make the ship work normally within the safe parameter range, and then drive the motor to drive the propeller to rotate and adjust it according to the working conditions. The speed of the motor is adjusted to realize various work requirements of the ship[3].

3. Ship Power Analysis and Calculation

3.1. Calculation of Ship Shaft Power

According to the ship performance parameters, the total resistance $R$ and the maximum speed $V_s$ of the ship in the water can be obtained. On the other hand, the effective thrust of the ship is numerically equal to the navigation resistance of the ship, so we can get the effective propulsion power of the hull when the ship is sailing in the water, as shown in equation (1).

$$P_{Te} = R \cdot V_s = 27.14W$$

The hull produces motion through the thrust of the propeller, and the hull influence coefficient between the hull and the propeller is $\eta = 0.983$, so the propulsion power $P_T$ emitted by the hull propeller can be obtained by equation (2).

$$P_T = \frac{P_{Te}}{\eta} = 27.61W$$

The propeller will receive the work rate $P_D$ from the front end of the propeller. The relative rotation efficiency of the ship is $\eta_r = 1.0$ here, then the receiving power $P_D$ of the propeller can be obtained through equation (3).

$$P_D = \frac{P_T}{\eta_r} = 27.61W$$

The propeller is connected with power plant through the shafting, and the shaft power transmitted is $P_s$, where the total transmission efficiency of the ship's shafting is $\eta_s = 0.98$, so the shaft power $P_s$ can be obtained directly through equation (4).

$$P_s = \frac{P_D}{\eta_s} = 28.17W$$

3.2. Selection and Analysis of Ship Motor

As the core and power source of the ship's electric propulsion system, the propulsion motor will drive the propeller to rotate through the transmission, thereby generating thrust as the driving force to overcome the resistance of the ship to move the ship. The choice of motor type is directly related to the performance of the power system and even the entire ship. The basic parameters and requirements of the ship, such as structural size, weight, and distribution of various equipment, should be fully considered when selecting the model. The following kinds of typical marine propulsion motors are selected and compared in terms of technical indicators. As is shown in Table 1.
Table 1. Characteristic tables of four typical motors.

| Motor type          | BDC Motor | Brushless Motor | Switched Reluctance Motor | Asynchronous Motor |
|---------------------|-----------|-----------------|---------------------------|--------------------|
| Structural reliability | Low       | High            | High                      | High               |
| Efficiency          | Higher    | High            | Higher                    | Lower              |
| Speed regulation performance | High      | High            | High                      | Higher             |
| Power cost          | Lower     | High            | Higher                    | Low                |
| Controller cost     | Low       | Higher          | Lower                     | Higher             |

DC motors have better adjustability than AC motors, when using a DC motor, its speed control system is relatively simple, which is more suitable for miniaturized hulls. Because the unmanned ship uses the power battery as the energy source of the propulsion system, the inverter module which converts direct current into alternating current is omitted, which makes the structure of the ship’s electric propulsion system simpler and smaller. It makes the installation and maintenance of dismantling ships more simple and convenient[4]. In addition, the brushless motor not only maintains high efficiency and high power density, but also has smaller volume and mass, which further enhances the flexibility of layout. Considering all aspects, brushless motor not only has the advantages of high energy conversion efficiency, large working torque and good speed regulation of ordinary DC motor, but also has the characteristics of simple structure, convenient maintenance, long service life and high reliability of AC motor[5]. Therefore, this study will choose the brushless motor as propulsion motor of the small unmanned ship electric propulsion system.

Because the shafting of the ship is connected with the motor, the mechanical efficiency between motor and mechanical shaft is $\eta_m = 0.51$, so the total power $P_M$ of the motor is shown in equation (5).

$$P_M = \frac{P_s}{\eta_m} = 55.24W$$

(5)

Because equation (5) calculates the total power of two motors, the power of a single motor is $P_{M1} = 27.62W$. The selected thruster is a shaft-driven fixed-pitch propeller, at this time, the attached resistance coefficient is 0.1, and the reserve power is 30%, so the final single machine power is $P_m = 38.67W$, and the motor with single machine power of 40W or above should be selected. It is necessary to comprehensively consider the speed, size and power of the motor when selecting the motor. Therefore, 60WS02 is selected as the propulsion motor of this small garbage cleaning and floating ship. The basic parameters of the motor are shown in Table 2.

Table 2. Motor basic parameters table.

| Model    | Rated power (W) | Rated voltage (V) | Rated speed (N) | Length (mm) |
|----------|-----------------|-------------------|-----------------|-------------|
| 60WS02   | 60              | 12                | 3000            | 82          |

4. Analysis and Calculation of Ship Energy

Due to the narrow sea area and low sea depth of the port, it is difficult for ordinary large garbage cleaning ships to operate normally, so small ships are needed to carry out accurate garbage cleaning. Marine diesel engine is not suitable to be used as power source for small garbage cleaning ships due to its large volume, high vibration and noise and poor stability at low speed. The electric propulsion system which uses storage battery as the main energy and solar photovoltaic power generation as auxiliary energy can reduce the size, put it on the small hull, has good maneuverability, and has almost no pollution to the environment. It is suitable to be used as the power source of small garbage cleaning ships[6].
4.1. Analysis and Calculation of Power Supply Selection

The batteries commonly used in engineering include lead-acid batteries, fuel cells, zinc-manganese batteries, lithium-ion batteries and so on. Lithium-ion battery has excellent performance, such as high working voltage, high energy density, long cycle life, low self-discharge rate, low pollution and no memory effect, so it is more suitable to be equipped in this small garbage cleaning ship to provide electricity for electric propulsion system. Lithium-ion battery is a kind of concentration difference battery, and both positive and negative active materials can undergo lithium ion intercalation and deintercalation reactions[7].

During charging, the lithium-ion is removed from the positive active material and migrated to the negative electrode through the electrolyte driven by the external voltage, at the same time, the lithium-ion is embedded in the negative active material, and the charge balance requires the same amount of electrons in the external circuit to flow from the positive electrode to the negative electrode. On the contrary, the lithium-ion is detached from the negative electrode and migrates to the positive electrode through the electrolyte. At the same time, the positive lithium-ion is embedded in the lattice of the active material, and the electrons in the external circuit flow to form an electric current to realize the conversion from chemical energy to electric energy[8]. Therefore, according to the reaction principle of lithium-ion battery, the charge-discharge reaction of lithium-ion battery is an ideal reversible reaction, which is suitable for the power source of small ships. Lithium intercalation compounds, such as $\text{LiCoO}_2, \text{LiNiO}_2, \text{LiMn}_2\text{O}_4, \text{LiFePO}_4$, etc, are generally used as cathode materials for lithium-ion batteries. The comparison table of common cathode materials and their properties is shown in Table 3.

| Types                     | $\text{LiCoO}_2$ | $\text{LiNiO}_2$ | $\text{LiMn}_2\text{O}_4$ | $\text{LiFePO}_4$ |
|---------------------------|------------------|------------------|---------------------------|------------------|
| Working voltage (V)       | 3.6              | 3.6              | 3.6                       | 3.4              |
| Theoretical capacity (mA·h/g) | 274             | 274              | 148                       | 170              |
| Actual capacity (mA·h/g)  | 130-150          | 150-220          | 110-130                   | 140-160          |
| Cycle life                | >500             | >500             | >500                      | >500             |
| Thermal stability         | Lower            | Low              | Medium                    | Higher           |
| Cost                      | High             | Higher           | Low                       | Lower            |
| Pollution degree          | High             | Higher           | None                      | None             |

$\text{LiFePO}_4$ battery has high capacity, good thermal stability, low cost and no pollution, so it is suitable to be used as the power source of this small garbage cleaning and bleaching ship.

The load of the power battery is shown in equation (6).

$$W = \frac{P}{\eta}$$  \hspace{1cm} (6)

$W$ is the load power of the machine, $\eta$ is the efficiency of the motor, where the efficiency is 85%. $P$ is the rated power of the motor. So the load power of the battery is 141.18W.

The power battery follows equation (7) in the actual selection process[9].

$$AH = \left(\frac{W \times t}{\rho \times f}\right)$$  \hspace{1cm} (7)

$AH$ is the power capacity, $W$ is the load power, $\rho$ is the battery energy conversion efficiency, $f$ is the battery discharge rate, where the lithium battery charge and discharge efficiency is 99%. Finally, the total capacity of the battery is 12V47AH. When selecting the battery, we should select the battery type which is larger than this capacity and provided by the manufacturer, and finally select the lithium-ion battery of 12V60AH as the energy of the ship power system.
4.2. Analysis and Calculation of Solar Power Generation System

The ship is designed to be used in the offshore area of the port, through remote control operation by shore personnel to control the ship's move, turning, garbage collection and other actions. The working time for garbage collection is 4 hours. After the work is completed, we will return to the shore for garbage collection and replenish electricity through shore power. Due to the small size of the ship, the space in the battery compartment is limited, it is unable to carry a large number of batteries, and the endurance is slightly lower. In order to increase some voyage, solar panels are installed on the outside of the ship to absorb energy, and then the absorbed energy is stored in the battery to provide energy to the ship's electric propulsion system, so as to achieve the purpose of improving voyage. Solar panels can not only store energy when the ship is working, but also store energy when the ship is on standby, which can not only increase the life of the ship, but also reduce the use and consumption of shore power and save energy.

The solar radiation perpendicular to the solar photovoltaic panel is about $21000 \text{mW}$, If the solar radiation angle deviates from the photovoltaic panel at an angle, the solar radiation on the photovoltaic panel is $1000 \cos \alpha \text{mW}$, so the output power of the solar photovoltaic panel is shown in equation (8):

$$P_q = 1000 \cos \alpha \cdot S \cdot \eta_q$$

(8)

Where $S$ is the surface area of solar panels and $\eta_q$ is the conversion efficiency of solar energy into electric energy. When the ship is running, it will encounter the change of the angle of the sun and the change of the weather, so it is impossible for the sun to radiate vertically to the panel perfectly, so the conversion efficiency of solar energy into electric energy here is 10%[10].

The ship uses three solar panels, one rectangular panel and two trapezoidal panels. The dimensions of the three panels are shown in figure 3.

![Figure 3. Solar panel size diagram.](image)

According to the design requirements, two pieces of trapezoidal panels and horizontal Angle cosine value of 0.6, rectangular panels are parallel to the horizontal plane, the area of the trapezoid panels is $0.325 \text{m}^2$, the area of the rectangular panel is $0.15 \text{m}^2$, so you can find out three pieces of the output power of the panels for $P_q = 54 \text{W}$. This power can be provided to ship propulsion system to improve ship endurance.

5. Conclusion

Through the research on the battery electric propulsion system of small ships, this paper obtains the feasibility of the application of electric propulsion system with lithium-ion battery as main energy and solar photovoltaic as auxiliary energy in small garbage cleaning and drifting ships. It provides the basis for the optimization of the ship in the future. At the same time, electric-propelled ships bring convenience to the work of cleaning up floating pollutants in the port. Compared with other kinds of
ship propulsion systems, this kind of battery electric propulsion system is more suitable for the use of small or micro ships, and has significant advantages in cost and environmental protection. With the development of ship automation and intelligence, the ship can be improved into the ability to completely liberate manpower and clean port waters automatically. It has a broad development space and market prospects in the 21st century when there is a strong call to protect the environment.

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