Research Trends and Prospect of the Catenary-Powered Ship

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Abstract. Combining the development of catenary-powered ship at home and abroad, the theoretical development and technological research dynamics of catenary power ship is reviewed and summarized mainly from the aspects of the design of power receiving devices and the prevention of ship offset technology. Responding to the background of promoting low-carbon transportation and energy conservation and environmental protection in China, the prospects for the further development and promotion of catenary power ship are expected to provide a certain reference for the research and development of the catenary-powered ship.

1. Introduction

The catenary-powered ship is a vessel that uses shore-based electricity as a power source [¹]. Through the construction of an overhead catenary at the shore, the electrical equipment is subjected to electrical power transmission to the ship. The ship distributes the power to the propulsion motor and other electrical equipment to drive the ship [²]. The catenary-powered ship is suitable for use in canals, lakes, scenic spots and other narrow watercourses with relatively stable hydrological conditions.

Currently, shore-based electricity has been successfully applied in high-speed rail, trolleybus and subway. The safety of its applications and the economic benefits it generates have been recognized by the community [³]. The application of shore-based power in ships mainly includes two forms of shore power and shore-based energy ships. The former mainly provides power for ships docked at ports, shipyards and ship repair yards; and the latter mainly uses shore power to provide the required drive power for navigation of ships, including battery-type ships, super-capacitive ships and catenary-powered ships [⁵]. This article mainly introduces the catenary-powered ships.

The key points in the design of a catenary-powered ship mainly include the design of shore-based catenary, the design of electric receivers, the prevention of galvanic corrosion of vessels and the prevention of ship displacement. The following chapters will combine domestic and international research trends to introduce the design of power receiving devices and technology to prevent ship offset. Shore-based power supply methods and prevention of hull electrochemical corrosion technology will be introduced together with the design of power receiving devices.
2 Basic structural characteristics and development

2.1 Basic Principles of Catenary Power Supply Ship
The catenary-powered ship is mainly composed of three systems: (1) catenary power supply system; (2) power connection system; (3) ship power system. Power is provided by the shore-based energy to the ship, and the power connected system will deliver the electricity to the ship. The power system of the entire ship will distribute electricity properly so that the ship can operate safely and steadily. The overall design of the system is shown in figure 1.

![Figure 1. The overall system design](image)

2.2 Features of Catenary-Powered Ship
Compared with the traditional diesel propulsion ship, the catenary-powered ship has many advantages in terms of energy saving and emission reduction, shipping cost, operation and maintenance, which are summarized as follows.

2.2.1 Reduce Ship Pollutant Emissions. The pollutants of ship are usually related to the type of ship and the amount of water discharge. According to investigations of Sichuan Yangtze River Water Transport Company, Nanjing Yangtze Oil Transportation Company, Minsheng Company, Chongqing Changjiang Steamship Company, and Changhang Wuhan Automobile Logistics in 2011. The companies have a total of 708 vessels (average DWT 3,118 tons) surveyed for energy consumption. The fuel consumption per kilo ton is 7.26 kg. In this paper, the Jianghan Canal was calculated as the object. In 2016, the cargo volume and freight turnover of the Jianghan Canal were 2,740,500 tons and 183,135,500 tons respectively. In 2016, the total fuel consumption of the vessels transported by the Jianghan Canal was 1,333.03 t. The specific emission reductions are shown in table 1.

| Diesel emissions | Specific fuel emission rate (kg/t) | Emission reduction (t) |
|------------------|-----------------------------------|------------------------|
| CO₂              | 3152.6                            | 4202.51                |
| SO₂              | 5.0                               | 6.67                   |
| C₅H₈             | 2.4                               | 3.20                   |
| CO               | 7.4                               | 9.86                   |
| N₂O₅             | 87.0                              | 115.97                 |
| PM               | 1.2                               | 1.60                   |
2.2.2. *Reduce Shipping Costs.* According to the analysis of the 2011 survey data, the current fuel consumption of the main engine of the canal is approximately 200 g per kWh, the price is approximately 1.4 yuan, and the electric energy at 1 kW/h is 0.52 to 0.62 yuan. The main power of the Jianghan Canal 1000 t class bulk carrier is 514.5 kW. When the generator power is 10 kW during normal navigation, a 1,000 t class bulk carrier can save about 3174 yuan by running at 60% load for 12 hours.

2.3. *Research Status of catenary-powered ship*  
At present, many research institutes are engaged in the research of catenary-powered ship and have achieved some results. The Steffi on Straussee (figure 2a) has a propulsion system with a power of 7.5 kW supplied by a single transmission line over the lake\(^4\). The power is transmitted to the ferry using a collector line and a collector ring power connection. The Canby (figure 2b) adopts a three-wire transmission system\(^5\). The power is transmitted through the tripod structure to connect the transmission line, and the iron chain connected to the two banks is added at the bottom of the ship to prevent the ferry from Route deviation occurs. The Mauvages tunnel in France supplies 600 V DC to the electric tugboat through the catenary (figure 2c). The motor is used to drive the immersed cable to push the ship forward.

![Power line](image1.png)

(a) Steffi Ferry, Germany

![Power line](image2.png)

(b) Canby Ferry, United States

![Power line](image3.png)

(c) Mauvages Canal Ship

Figure 2. Foreign shore-based energy ships

Professor Yan Xinping from China proposed a canal ship system based on shore-based energy\(^6\) (figure 3). The system takes the Beijing-Hangzhou Grand Canal ship as the research object, applies the catenary technology of the electric train to the canal boat, adds a collector pole like the trolley power supply system to the canal vessel, sets up the catenary over the canal, and get electricity through the canal. The rod takes power from the catenary and transmits it to the ship, thus providing the canal vessel with propulsion power to replace the traditional diesel power system.

![Power line](image4.png)

Figure 3. Catenary powered ship model
3 Key technical issues

3.1. Design of Power Receiver
The power-receiving device gets electrical energy from the grid for the ship, which is mainly composed of a current-collecting device and a power transmission device.

Foreign countries mainly use catenary-powered ship for ferries. Germany applies the Steffi ferry on the Straussee lake, using a single-wire power supply method, through a bare wire erected between the pillars to provide electricity for the ferry, as shown in Figure 4. This kind of power supply forms a closed circuit due to the hull and water, which causes galvanic corrosion of the hull and reduces the service life of the ship. The Canby ferry operating on the Willamette River in the United States adopts a three-wire power supply system. This kind of power supply can avoid the formation of loops, reduce the corrosion of the hull, and increase the service life of the ferry; however, the power receiving device of Canby can only take power between the two shore-based pillars, cannot meet the requirement for long-distance operation of the ship.

![Figure 4. Steffi Ferry](image1)

![Figure 5. Canby Ferry](image2)

Only WHUT has conducted some studies for catenary-powered ship propulsion technology in China. In order to solve the problems of the catenary-powered ships are used in foreign countries, Yan Xiping proposed a two-wire system for power supply. The electrical device is shown in Figure 6. The way for the ship to get electrical energy is as follows: By establishing pillars on the shore base and placing an overhead catenary consisting of a fire line and a neutral line over the river, the ship obtains drive power from the L line and the N line through two collector poles. The advantage is that it avoids the galvanic corrosion of the hull and prolongs the service life of the ship; the collector pole type power receiving device can span the catenary hanging device on the pillar and can satisfy the long-distance navigation. However, in practical applications, this type of power receiving device may be affected greatly by fluctuations in water flow, changes in the water level, and deviations from the ship. Therefore, the technology needs to be tested and further studied.

![Figure 6. Three-dimensional schematic diagram of catenary-powered ship](image3)

3.2. Prevention of Ship Offset Technology
The function is to prevent the catenary-powered ship from deviating from the original fairway under the influence of water flow, wind and other factors, preventing the power receiving device from tripping off. This technology helps to improve the safety and stability of the ships.
At present, Foreign researchers mainly increase the iron chains at the bottom of the ship. The chain is connected to both sides of the ship to prevent the ship from shifting. The Canby ferry is the most representative, as shown in Figure 7. Wan Jianglong proposed a different way to prevent ship migration by establishing a virtual navigation system, using GPS and AIS to record ship routes on virtual channels. When the ship deviates from the original channel, the system will correct the heading of the ship and send a sound to the driver, as shown in Figure 8. This technology can improve the ship's ability to avoid collision. However, the positioning accuracy of the GPS in the civil domain is about 10 m. When the ship uses this accuracy level to navigate during navigation, there may be a large deviation of the ship due to inaccurate positioning, and this may cause electric shock. The device off-line causes the ship to lose power.

![Figure 7. Canby Ferry](image1)

![Figure 8. Virtual Channel System Diagram](image2)

4. Outlook and Suggestions for Development of catenary-powered ship

In the National 13th Five-Year Plan and the State Council's "Guidelines for Relying on the Golden Waterway to Promote the Development of the Yangtze River Economic Belt" issued by the State Council and the "Special Action Plan for Ship and Port Pollution Prevention and Control (2015-2020)" issued by the Ministry of Transport It is proposed to promote the requirements of low-carbon development in the transportation industry. In response to the national energy conservation and environmental protection, the promotion of the use of catenary-powered ship is a good solution. In order to promote the catenary-powered ship, after numerous investigations and exchanges with a number of experts and scholars, Establish the test boat, get government’s support and establish standards are the main suggestions for the catenary-powered ship.

5. Conclusion

All the above describes the main technologies for the application of catenary-powered ship, including the design of power-receiving devices and the technology for preventing ship offsets. It also makes recommendations based on national policies and the current status of catenary-powered ship in the country. The development and promotion of contact network-powered ship application technology is conducive to accelerating the progress of inland river green shipping, and it also responds to the energy-saving and emission reduction. However, this technology is still in the theoretical research stage in China, and the maturity of its related application technology has not yet been verified. Therefore, relevant research personnel are still required to continue research.

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