Current Status and Future Development of Fuel Cell Ships in China

Zhipeng Zhan¹,*

¹ School of Naval Architecture, Ocean and Energy Power Engineering, Wuhan University of Technology, 430063, Wuhan, Hubei, China
*Corresponding author email: zhanzhipeng@whut.edu.cn

Abstract. The high quality development of fuel cell ship industry is of great significance for China to achieve carbon dioxide peaking and carbon neutrality. The research of fuel cell ships in China is still in its early stage and faces many challenges to achieve industrialization. In this paper, the types and characteristics of fuel cells are introduced, and the fuel cell types suitable for marine applications are identified. Then, the research status of fuel cell ship projects in China and abroad is introduced. By comparing fuel cell ship projects, the gap between domestic and foreign fuel cell ship projects is discussed. Finally, in view of the existing problems of fuel cell ships in China, some suggestions for the development of marine hydrogen fuel cells in China are put forward, and the future development of marine hydrogen fuel cell technology in China is prospected.

1. Introduction

As a major part of the globalized economy, International shipping transports more than 80% of global trade [1]. The shipping industry has not only made a great contribution to the international economy and trade, but has also led to serious emission problems with regard to pollutants and greenhouse gases. According to some statistics, shipping contribute to approximately 3-5% of global CO₂ emissions, while emissions of NOₓ and SOₓ represent roughly 15% and 13% of the global total, respectively [2-4]. In April 2018, the International Maritime Organization (IMO) adopted mandatory energy efficiency measures to reduce pollutant emissions from international shipping. The total emission of global greenhouse gases in the maritime sector should be reduced by at least 50% by 2050 compared to 2008 [1, 4].

In addition to IMO rules, several countries impose additional rules to reduce these emissions further, and take an additional step in the maritime green shift. Norway has made the decision to implement regulations to cut emissions from shipping by 2030, which imposes the requirements for low- and zero-emission shipping as soon as technically possible and, for tourist boats and ferries operating in World Heritage fjords, no later than 2026 [1]. The Chinese government has also raised the requirements for controlling the emission of air pollutants from ships by issuing emission standards for ships and expanding emission control zones. In August 2016, a national standard for marine engine emission control, Limits and Measurement Methods for Exhaust Pollutants from Marine Engines (CHINA I, II) (GB15097-2016), has been issued, which significantly reduce the emission limits and move closer to the stricter emission standards in Europe and the United States [5]. In November 2018, the Ministry of Transport of the People's Republic of China has issued Implementation Scheme of the Domestic Emission Control Areas for Atmospheric Pollution from Vessels, which expands the domestic emission control area from the Yangtze River Delta, Pearl River Delta and Bohai Rim to the national coastal waters (extending 12 nautical miles from the baseline of territorial sea), and set the
main lines of the Yangtze River and Xijiang River as the inland river emission control area [3,5]. Therefore, it is increasingly urgent to reduce pollutants emissions from ships and achieve green shipping.

With the increasing impact of environmental protection and emission reduction on ships, clean and high efficient alternatives for internal combustion engines are highly desired. Among possible alternatives, fuel cell is considered to be one of the most promising candidates. Due to green energy, high energy efficiency and outstanding reliability and high tolerance to environmental factors, fuel cells are attracting extensive attentions to shipping industries gradually [1-5]. The fuel cell is considered one of the most promising future clean energy technologies.

Developed countries and international organization such as the United States, the European Union and Japan have taken marine fuel cell technology as a key direction of government support, and have issued a series of plans and standards in succession to guide and support the development of fuel cell shipbuilding industry [6]. In Made in China 2025, the development plan of hydrogen fuel cells is clearly proposed, and the development and application of hydrogen fuel cells are promoted to a strategic height. The China Classification Society has also issued Guidelines for Ships Using Alternative Fuels, which provide technical standards for the application of hydrogen fuel cell power units and systems on ship [5].

Therefore, fuel cells have great application potential in ships and are an important direction of green shipping in the future. In particular, hydrogen fuel cell ships are receiving special attention in China. In this paper, the development of fuel cell ships is introduced, and the projects of fuel cell ships in China are compared with that of other countries in the world. Some suggestions are given for the development of fuel cell ships in China.

2. Promising Fuel Cell Types for Ship Application
Fuel cells are usually classified according to their operating temperature or electrolyte properties. According to different operating temperatures, fuel cells can be divided into the low temperature fuel cell and high temperature fuel cell. According to the different electrolytes, fuel cells can be divided into low temperature polymer electrolyte membrane fuel cells (PEMFC and HT-PEMFC), solid oxide fuel cell (SOFC), melt carbonate fuel cell (MCFC), phosphoric acid fuel cell (PAFC), alkaline fuel cell (AFC) and direct methanol fuel cell (DMFC). Some important characteristics of fuel cells are summarised in Table 1[1,7-9].

It is difficult to choose the most promising fuel cell for marine applications. Considering energy efficiency, power capacity and sensitivity to fuel impurities, Xing et al. [10] believed that the PEMFC, MCFC and SOFC are the promising marine fuel cells. The European Maritime Safety Authority (EMSA) provided a report - Fuel Cell Applications in Shipping. In the report, Tronstad et al. [7] evaluated the possibility of application of existing fuel cells in ships by selecting 11 most relevant parameters from five aspects of technology, cost, safety, environment and ship application. The importance of the 11 parameters was weighted to obtain an overall score for each fuel cell. A higher total score indicates greater attractiveness. The results are also shown in Table 1.

The PEMFC and HT-PEMFC scored the top two technologies with 75 and 73 in the ranking, respectively. While there are many similarities between the two fuel cells, there are also major differences, with one working at low temperature and the other at high temperature. The third on the list is the solid oxide fuel cell (SOFC), a high-temperature fuel cell. These three fuel cells are considered the most promising for use in ships in the report.

The MCFC and PAFC are not suitable for marine applications due to their large size. The drawback of AFC is its high sensitivity to impurities and the need for high purity hydrogen and oxygen, which increases the complexity of commercial marine use as well as the cost. The DMFC is still in the early stage of research and is not mature in many aspects. Neither type of fuel cells is an option for marine applications. In the following, the three most promising fuel cells for use in ships are further discussed.
Table 1. Characteristics of different types of fuel cells.

| FC type     | Electrical efficiency | Cost | Fuel                  | Size | Maturity | Emissions | Lifetime | Operating Temperature (°C) | Total Score |
|-------------|-----------------------|------|-----------------------|------|----------|-----------|----------|-----------------------------|-------------|
| PEMFC       | 50-60%                | L    | Hydrogen, LNG, Diesel | Small| H        | No        | Good     | 50-100                      | 75          |
| HT-PEMFC    | 50-60%                | M    | Hydrogen, LNG, Diesel | Small| L        | CO₂, NOₓ  | Good     | 140-200                     | 73          |
| SOFC        | 60%                   | H    | Hydrogen, LNG, Diesel | Medium| M      | CO₂, NOₓ  | Low      | 800-1000                    | 69          |
| MCFC        | 50%                   | H    | Hydrogen, LNG, Diesel | Large| H       | CO₂, NOₓ  | Low      | 600-700                     | 67          |
| AFC         | 50-60%                | L    | Hydrogen, LNG, Diesel | Small| H       | No        | Good     | 80-120                      | 66          |
| PAFC        | 40%                   | M    | Hydrogen, LNG, Diesel | Large| H       | CO₂, NOₓ  | Moderat e| 150-200                     | 64          |
| DMFC        | 20%                   | M    | Hydrogen, LNG, Diesel | Small| L       | CO₂       | Moderat e| 50-120                      | 61          |

2.1. Proton Exchange Membrane Fuel Cell (PEMFC)
The PEMFC is a mature technology that has been successfully used in submarines and other applications. The maturity of the technology is the main reason it has become one of the most promising fuel cell technology for marine application, which has also resulted in relatively low cost. The PEMFC normally operates in the low temperature range of 50–85 °C, which allows for safer operation. The PEMFC has high power density and can quickly respond to changes in power demand and compete with the diesel engine when it comes to startup and shutdown times. Using hydrogen as fuel, the only emission is water and low-quality heat. Mostly, the physical size of a PEMFC is small, which also makes it a good candidate for small ship.

The major drawbacks of the PEMFC are sensitivity to impurities in the hydrogen as sulphur and CO, and a complex water management system. The PEMFC efficiency is moderate at 50-60%, and heat recovery is not feasible due to the low operating temperature.

2.2. High Temperature PEMFC (HT-PEMFC)
Compared with the PEMFC, The HT-PEMFC can operate at temperatures up to 200 °C by using a mineral acid electrolyte instead of a water based one. Because of high operating temperature, the HT-PEMFC is less sensitive to poisoning by sulphur and CO, and the water management system can be simplified in the HT-PEMFC system, since H₂O is present in the gaseous phase. It is also possible to harness the excess heat from the fuel cell system. The HT-PEMFC has a lower power density, and it is not possible to cold start it. The electrical efficiency of the HT-PEMFC is similar to that of the PEMFCs (50-60%), but there is a potential to harvest more excess heat to improve the total efficiency of the cells. The HT-PEMFC is a technology that is less mature than conventional low temperature PEMFC, but the problems of catalyst poisoning and complex water management system in low temperature PEMFC are solved. By excess heat recovery, the total efficiency of fuel cell can be further improved. Therefore, the HT-PEMFCs have a good application prospect in the future.
2.3. Solid Oxide Fuel Cell (SOFC)
The SOFC operates at a temperature between 500–1000 °C. The electrolyte is a porous ceramic material such as yttrium stabilized zirconia. The SOFC is highly efficient, moderately sized fuel cell. Mostly, SOFC has been used in a large-scale power production system of up to 10 MW [7]. As a high-temperature fuel cell, the efficiency is high accounting for 45–60%. If the heat recovery system applied, higher efficiencies of up to 85% can be reached. The SOFC is flexible towards fuels, and the reforming from hydrocarbons to hydrogen takes place internally in the cell.

The high temperature raises a safety concern, and when using hydrocarbon fuel there will be emissions of CO$_2$ and NO$_X$. The SOFC has a long startup time and high cost. These disadvantages limit the use of solid oxide fuel cell in small vessels such as inland rivers and offshore. The SOFC is better suited for larger vessels.

3. Fuel Cell Projects in Shipping

Due to technology and cost constraints, fuel cells are currently only used for special purposes, such as space exploration and submarines, and have yet to be widely used for general purposes. However, with the focus on reducing emissions, fuel cells are increasingly being considered for other applications. Compared with diesel engine emissions, fuel cell can effectively eliminate NO$_X$, SO$_X$ and particulate matter (PM) emissions and reduce CO$_2$ emissions. Fuel cells powered by low-carbon fuels such as natural gas will benefit the emission control areas because of the reduction in emissions and noise. In the long term, hydrogen fuel generated from renewable energy sources can enable ships to achieve zero carbon emissions to meet current environmental regulations and contribute to a more sustainable shipping industry. Therefore, many countries have carried out fuel cell application projects in ships. The applications of fuel cells in ships will be introduced in the following paragraphs.

| Project          | Ship type                  | FC type | Fuel                  | Capacity            | Year          |
|------------------|----------------------------|---------|-----------------------|---------------------|---------------|
| US SSFC          | Naval platforms and systems| PEM, MCFC | Diesel                | 500 kW (PEM) 625 kW (MCFC) | 2000-2011    |
| Class 212A/214 Submarines | Submarines | PEM        | Hydrogen              | 306 kW,           | 2003-present |
| FellowSHIP       | Offshore Supply Vessel     | PEM, MCFC | LNG                   | 320 kW             | 2003-2011    |
| FELICITAS– subproject 2 | Mobile hybrid marine version | SOFC, HTPEM | LNG, other fuel also evaluated | 250 kW | 2005-2008
| RiverCell        | River cruise vessel        | PEM      | Methanol              | 250 kW             | 2015-2022    |
| MC-WAP           | large vessels for auxiliary power | MCFC  | Diesel                | 150 kW             | 2005-2010    |
| SF-BREEZE        | passenger ferry            | PEM      | Hydrogen              | 2.5 MW             | 2015-present |
| Water-Go-Round   | passenger ferry            | PEM      | Hydrogen              | 360 kW             | 2019-present |

3.1. Fuel Cell Projects for Ship Outside China

Since 2000, the installed FC power in marine applications has grown rapidly and steadily, from 9 MW in 2000 to 520 MW in 2018 [1]. Tronstad et al. [7] summarized major maritime fuel cell projects and identified a total of 23 typical fuel cell projects related to maritime applications. The projects vary from assessments of potential for fuel cell use, rule development and feasibility studies and concept design to testing of fuel cells in various vessels. In these projects, the PEMFCs were used 11 times, and the HT-PEMFCs, MCFCs and SOFCs were used 4 times each. Among the fuels, Hydrogen was
used for 11 times, methanol for 3 times, diesel and LNG for twice each, and hydrocarbon for 1 time. These projects give a broad picture of fuel cell ship projects around the world.

There are more than 30 fuel cell ship projects reported in the literatures [1,7-11]. In this paper, some typical high-capacity fuel cell ship projects are selected (as shown in Table 2). In Table 2, only a few characteristics of corresponding fuel cells are listed, for details, please refer to the literatures [1,7-11]. These projects involve not only high capacity power, but also fuel cells, fuels and ship types. Although we selected 7 projects, the engineering development of fuel cell ships abroad can be reflected from them. Developed countries and regions such as EU, Germany, US and Norway are in a leading position in the field of marine fuel cell technology. Demonstration projects of marine fuel cell ships have been carried out. The fuel cell ships are beginning to be used in these countries.

3.2. Fuel Cell Projects for Ship in China

Under the guidance of sustainable and stable planning, Chinese enterprises are actively involved in hydrogen production, storage, transportation and hydrogen utilization. The hydrogen energy industry chain has been improved, and hydrogen energy technology has been strengthened. China is the largest hydrogen producer in the world, with an annual hydrogen output of about 25 million tons, mainly produced from coal and mainly from industrial by-products. By the end of 2020, the number of hydrogen fuel cell vehicles in China had reached 7352, and more than 140 hydrogen fuel cell stations had been built or under construction [12]. Fuel cell ship research in China did not begin until the end of the 20th century. At present, there are few successful cases of fuel cells applied to ships in China, and specific application examples are shown in Table 3.

| Project               | Ship type      | FC type | Fuel  | Capacity | Year |
|-----------------------|----------------|---------|-------|----------|------|
| FUYUAN-1              | Yacht          | PEM     | Methanol | 0.4 kW  | 2002 |
| TIANXIANG-1           | Test vessel    | PEM     | Hydrogen | 2 kW    | 2005 |
| Marine FC Propulsion System | Yacht        | PEM     | Hydrogen | 3.5 kW  | 2016 |
| Bulk Cargo-2000       | Cargo vessel   | PEM     | Hydrogen | 540 kW  | 2019-present |

In 2002, Beijing Fuyuan Fuel Cell Company developed the proton exchange membrane fuel cell yacht - FUYUAN-1, which successfully launched its maiden voyage in Beijing Economic and Technological Development Zone in September 2002. FUYUAN-1 is the first fuel cell yacht developed in China, with rated power of 400 W, voltage of 24 V and sailing speed of 7 km/h [13].

In 2005, the Fuel Cell Electric Propulsion Laboratory of Shanghai Maritime University successfully developed the experimental ship - TIANXIANG 1, which was officially exhibited at the first Shanghai International Industry Exposition in July 2005. Its main data are 4.7 m long, 1.7 m wide, 0.25 m deep draft, 700 kg displacement, and 2 kW fuel cell. The ship can sail continuously for about 3 hours with a 50 L hydrogen cylinder. The design speed is about 7 km/h, and the actual speed is about 7 knots/our [13].

In 2016, according to the typical operation conditions of conventional sightseeing ships, Jimei University developed a marine fuel cell-lithium battery hybrid electric propulsion system with PEMFC as the main power of electric propulsion and lithium battery as the energy buffer unit. The fuel cell-lithium battery hybrid electric propulsion system suitable for typical working conditions of sightseeing ship was developed, and the energy management control strategy and the structural design of the cruise ship were optimized by combining platform test and sea trial [14].

In 2018, China Classification Society (CCS) cooperated with China State Shipbuilding Corporation (CSSC) to develop an inland waterway 2000-ton bulk carrier as a hydrogen fuel cell powered demonstration vessel. At the Shanghai Maritime Exhibition in December 2019, CCS awarded the corporation (CSSC) AIP certification for the design of China's first hydrogen-fuelling ship. The ship is
a 2100-ton fixed route inland river self-unloading vessel, using 4x135 kW proton exchange membrane hydrogen fuel cells as the main power source, supplemented by 4x250 kWh lithium battery packs for peak adjustment compensation. The ship has a continuous sailing distance of about 140 km. At present, the overall technical design of the ship and the design of the principle of hydrogen fuel power system have been completed. CSSC 605 Institute is cooperating with CSSC 712 and 718 Institute to carry out the research and development of the ship. It is planned to complete the construction and demonstration operation of the vessel by the end of 2021 [15].

Compared with foreign marine fuel cell projects, there is a big gap between China and foreign fuel cell application projects in ship. The marine fuel cell application in China is still in the trial stage. The scale and quality of the projects, the depth and breadth of the technology, and the types of fuel cells used are not up to foreign level. There is no long-term systematic research plan for development of fuel cell ships in China. The fuel cell ship projects in China were mostly independently carried out by various research institutions, which need in-depth cooperation to carry out systematic research on design, installation, safety and operation. In sharp contrast, systematic application projects for fuel cell ships have been carried out abroad, a rather large number of marine fuel cell projects have been run in Europe the last 10-15 years. For example, the Norwegian Maritime Administration has supported more than 10 marine fuel cell projects from 2002 to 2022. The fuel cell types used in the projects include the MCFC, SOFC, HTPEMFC and PEMFC, and the fuels cover LNG, Methanol, diesel and hydrogen [7]. However, only hydrogen PEMFCs were used in China's fuel cell ship projects.

4. Suggestions on the Development of Fuel Cell Ships in China

4.1. Improving Innovation Mechanisms and Systems

Fuel cell application projects have long research period, high cost, technical difficulty and require huge manpower and material resources, which are not the work that can be accomplished by a single institute. The projects require the collaboration of fuel cell and ship research institutes and companies. Government departments need to clarify the development ideas and technical routes of fuel cell ships, and formulate national strategies and objectives for the development of fuel cell ships. According to the strategic positioning and development objectives, the policy and general plan for the development of fuel cell ship technology shall be formulated, and the government administrative department should establish a national promotion mechanism. Science and technology departments should formulate action plans for scientific and technological support for marine fuel cell projects.

An action plan should be formulated to ensure that science and technology support and guide fuel cell ship projects. Major R&D and demonstration projects for key technologies related to the projects should be set up in national key R&D programs, making use of open competition mechanisms to select the best candidates to lead the projects, and intensifying core technology research for fuel cell ships. We should boost the principal role of enterprises in innovation, support their participation in major national projects, and encourage the sharing of facilities, data, and other resources. The testing, evaluation, and certification systems for them should be improved.

4.2. Enhancing Innovation Capability and Personnel Training

National laboratories and national technology innovation centers related to fuel cell ships should be set up, relevant major national science and technology infrastructure should be planned in advance, and enterprises, universities, and research institutes should be guided in a joint effort to build national green energy ship centers. We should develop new approaches in personnel training, encourage institutions of universities to accelerate discipline development and talent training in hydrogen production, storage, transportation hydrogen and hydrogen use. We should deepen industry-education integration, encourage school-enterprise cooperation to educate people for hydrogen energy ship industry and set up a number of national innovation platforms for industry-education integration on hydrogen energy technology.
4.3. Strengthening the Construction of Regulations and Standards for Fuel Cell Ships

Green energy industry has a long chain and high safety requirements. In the initial stage of industrialization, it is very important to establish a perfect standard system for realizing safe and steady development of scale. In 2017, China Classification Society issued Guidelines for Alternative Fuels used in Ships. In the second part of the fuel cell system, according to the main structure of fuel cell system and the application characteristics of each system in ships, the safety technical requirements of fuel cell ship layout, system design, fuel storage fuel, bunkering of fuel and auxiliary system are put forward. However, maritime fuel cell systems are more powerful and store more energy. Moreover, the ship environment has its particularity, which requires higher system matching, reliability and safety, environmental adaptability, monitoring and energy management technology. Standards, regulations and Guidelines in key areas such as hydrogen production, storage, transportation and use should be improved, and an evaluation and inspection system for the whole industrial chain should be established to provide strong support for the industrialized development of hydrogen energy.

4.4. Accelerating the Demonstrations Applications of Hydrogen Fuel Cell Ships

We should intensify innovation on technologies, particularly into the safe, stable operation and control of major complex hydrogen fuel cell systems, low-cost hydrogen production, high-efficiency reforming, high-capacity hydrogen storage, and accelerate R&D in basic materials such as catalyst, proton exchange membrane and hydrogen storage materials.

The application of mature PEMFCs in small ships should be carried out first, and demonstration application should be carried out for small ships such as sightseeing ships, ferries and law enforcement ships in waters with high environmental protection requirements. The Yangtze River, Pearl River, Beijing-Hangzhou Grand Canal and other inland rivers have a large shipping volume and flow through areas mainly concentrated in China's densely populated and economically developed areas, which have high requirements for environmental protection and local governments have the ability to provide more financial support. Hydrogen fuel cell ships are expected to be promoted first in these areas.

5. Conclusions

Compared with other maritime powers, there is still a big gap in the research and application of fuel cell ships in China, which needs to strengthen and promote the development of fuel cell ships in China. In October 2021, The State Council issued Action Plan for Carbon Dioxide Peaking Before 2030. By 2030, the proportion of non-fossil energy consumption will reach about 25%, CO₂ emissions per unit of GDP decreased by over 65% compared with 2005, successfully achieving carbon dioxide peaking before 2030. We will expand the application of new and clean energy in transportation, such as electricity, hydrogen power, natural gas, and advanced liquid biofuels. We will work faster to upgrade old ships. We will further promote the use of shore power by ships while in port. We will make in-depth efforts to advance demonstration and utilization of green, smart ships along coastline and inland waterways according to local conditions. With the issuance of the action plan, China's shipping industry will step into a new development process of decarbonization transformation, which will also bring new opportunities for the scientific research and industrialization of fuel cell ships in China. China's fuel cell ship industry will get rapid development in the future.

6. References

[1] Shakeri N, Zadeh M and Nielsen JB 2020 IEEE Electrif. Mag. 6, 27-43 https://doi.org/10.1109/MELE.2020.2985484
[2] Biert L van, Godjevac M, Visser K and Aravind PV 2016 J. Power Sources 327 345-64 https://doi.org/10.1016/j.jpowsour.2016.07.007
[3] Yang F, Li S, Shen Q and Yang G 2020 Ship Engineering, 42 (4) 1-7 https://doi.org/10.13788/j.cnki.cbge.2020.04.01
[4] Hoecke L Van, Laffineur L, Campe R, Perreault P, Verbruggen SW and Lenaerts S, 2021 Energy Environ. Sci. 14 815-843 https://doi.org/10.1039/d0ee01545h
[5] Gao Q 2020, Diesel Engine, 42(5), 61-64
[6] Peng Y and Xu Z 2019 Strategic Study of CAE 21(6) 018-21
https://doi.org/10.15302/J-SSCAE-2019.06.003

[7] Tronstad T, Åstrand HH, Haugom GP and Langfeldt L 2017 Study on the use of fuel cells in shipping (Arnhem: The Netherlands/European Maritime Safety Agency, DNV GL) p 1-108
http://www.emsa.europa.eu/emsa-homepage/2-news-a-press-centre/news/2921-emsa-study-on-the-use-of-fuel-cells-in-shipping.html

[8] Roh G, Kim H, Jeon H and Yoon K 2019 J. Mar. Sci. Eng. 7, 230
https://doi.org/10.3390/jmse7070230

[9] Stambouli A, Boudghene and Traversa E 2002 Renew. Sust. Energ. Rev. 6 297-306
i. https://doi.org/10.1016/S1364-0321(01)00015-6

[10] Xing H, Stuart C, Spence S and Chen H 2021 Sustainability 13 1-14
https://doi.org/10.3390/su13031213

[11] Liu Y, Wang F, Wang J and Yuan J 2021 Ship Engineering 43(3) 18-26
https://doi.org/10.13788/j.cnki.cbgc.2021.03.04

[12] Ma G 2021 J. Sinopec Management Institute 23(2) 67-70
https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&dbname=CJFD20211&filename=20210627-113774209222213835585820000001&uniplatform=NZKPT&v=Ax/36Z8k6y4x7Q5DfS72v8Pw04khlyMk7CNmU1fJ2ZG291Ku3Cz2Hr

[13] Zhao W 2009 Research on simulation of marine electrical propulsion based on fuel cell (Wuhan: Wuhan University of Technology press) p 7
https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CMFD&dbname=CMFD20111&filename=2010036360.nh&uniplatform=NZKPT&v=OigHrVlFHZHV560gcFr0aaAa4j2TX3fviUQYMJeP7GVuQUOBVrBuuXYQ2xNq7d

[14] Pan Q, Zhu Z and Zheng Q 2016 Ship Engineering, 38(4) 35-38
https://doi.org/10.13788/j.cnki.cbgc.2016.04.035

[15] Wang S 2020 China Ship Survey 2 58-62
https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CJFD&dbname=CJFDLAST2020&filename=ZGCJ202002019&uniplatform=NZKPT&v=tg09ycGSbyzpEHTbYplHqAYQVuwZNlpGvmpywfyYlOJGhsE5gAjrABeNicXQeWDF_