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Technology and Industry Development of Marine Transportation Equipment

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Abstract: Marine transportation equipment is fundamental to building a strong marine economy. To promote the marine, manufacturing, and transportation sectors, China needs to accelerate its technological innovation and high-quality industrial development of marine transportation equipment. This study was aimed at identifying ways to achieve the technological and industrial development of China's marine transportation equipment. First, the demands of marine transportation equipment for future markets, scientific marine research, marine resource development, and green intelligent technology were determined. The technology and industry status of the global marine transportation equipment were then analyzed from the perspectives of higher education, scientific research, general design and assembly, information and communication equipment, and power and electromechanical equipment. Furthermore, the international advanced technologies for marine transportation equipment were briefly described. Then, the technological capabilities and industrial status of China's marine transportation equipment were investigated and the main problems were analyzed. Based on the findings, suggestions were made on five key technical aspects, namely, polar navigation ship technology, intelligent manufacturing technology, ship optimization, and energy-saving technology. Approaches to setting up major projects were proposed, including intelligent ship engineering, ships with eco-environment protection, and projects for ship lifecycle operation and maintenance. Finally, countermeasures and suggestions for developing China's marine transportation equipment were proposed in terms of top-level design, policy guidance, capital investment, collaborative innovation, talent construction, and international cooperation. The results of this study can be referred to in future technical research on China's shipbuilding authorities and relevant institutions.
Keywords: marine transportation equipment; ship and ocean engineering; green and intelligent ship; polar ship; marine equipment industry

1 Introduction

The ocean has a plethora of strategic resources for sustainable human development. The struggle for international maritime rights and interests, characterized by competition for marine resources, marine spaces, and marine science and technology, has become increasingly fierce [1]. Marine transportation equipment is very vital to safeguarding maritime security and sovereignty, maintaining the stable development of the marine economy, and promoting innovative research in marine science. To promote its marine, manufacturing, and transportation sectors, China needs to accelerate the technological innovation and high-quality industrial development of its marine transportation equipment. The technical aspect of marine transportation equipment includes the overall technology of various ships and marine transportation platforms, including design, manufacturing, and operation, the power technology and support technology of marine transportation equipment, the navigation technology of ocean transportation

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equipment [2], and an education and scientific research system dedicated to marine transportation equipment technology and industrial patterns.

Currently, marine transportation equipment technology and industrial development is mainly discussed from the perspective of general technology and assembly. The analysis and development of key support system equipment are under-researched and have not been systematically approached [3–9]. Therefore, in this study, based on investigation, expert discussion, project research, higher education, and scientific research, the general design and assembly, information and communication equipment, and power and electromechanical equipment were examined as pathways to research the development needs and technological and industrial patterns of the global marine transportation equipment, with specific focus on the development status, problems, and future directions of China's marine transportation equipment.

2 Demands of the world's marine transportation equipment

2.1 Market demand

Against the backdrop of uncertain global economic growth, the growth rate of the global import and export trade volume is exhibiting a downward trend and it is difficult for the global seaborne trade volume to increase significantly (Fig. 1). Currently, the global energy consumption is dominated by traditional energy sources such as oil and natural gas. However, the growth rate of demand for these energy sources will gradually decline [10]. Without extreme conditions, it will be difficult for the demand for marine transportation equipment to return to the peak witnessed in 2008. From the perspective of supply, the production capacity of marine transportation equipment has been in an adjustment stage of contraction owing to the influence of the market environment since it peaked in 2012. According to Clarksons database, the global active capacity fell to approximately 3.5×10^7 compensated gross tonnage (cgt) in 2019 [11]. In the future, it will be more difficult for major shipbuilding countries to further reduce their production capacity. In this context, market competition between major shipbuilding countries has become more intense.

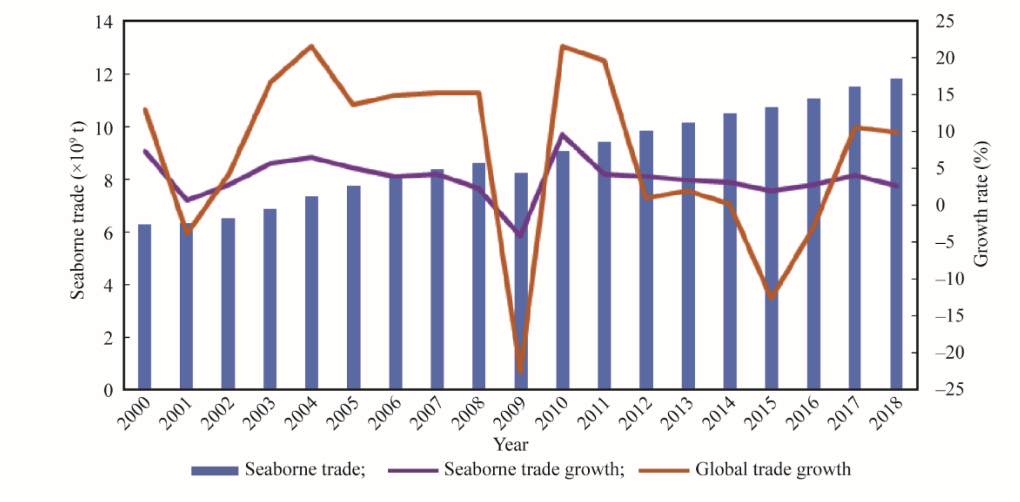

Fig. 1. Changes in global seaborne trade volumes.

2.2 Demand for marine scientific research and resource development

The deep sea has a plethora of scientific possibilities and resources that human beings have yet to fully understand. Global sustainable social and economic development depends on scientific research and resource exploitation of the ocean. The understanding and development of the deep sea, which is more than 1000-m deep and accounts for 90% of the ocean area, is still in its initial stages [12]. For the development of the deep sea oil, gas, and mineral resources and research and development (R&D) in terms of deep sea biological resources, the frontier technologies of deep sea transportation equipment, which will significantly impact the marine environment, science, economy, and security, as well as their breakthrough and development, have become important points of demand [13].

2.3 Demand for green intelligent technology

In the future design, construction, operation, and demolition of marine transportation equipment, through the

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application of advanced technology, it will be necessary to reduce the use of resources and energy consumption and reduce or eliminate environmental pollution while optimizing function and performance [14]. Similarly, with the rapid integration of the new generation of information technology and traditional industries, the intellectualization of marine transportation equipment will become a development hotspot. Intelligent ships possess the ability of perception, evaluation and analysis, decision-making, and learning and growth [15], and in the future, they will integrate various technologies, such as sensors, big data analysis, communication technology, and advanced materials, whereby the fully intelligent control of ship functions will be achieved. In addition, along other aspects, the information interconnection of ships, including navigation control at sea, on land, and in air and space, will be integrated, including energy and power system management, auxiliary equipment operation monitoring, ship safety monitoring, energy conservation and environmental protection monitoring, vibration and noise monitoring, and cargo management.

3 Technology and industrial pattern of the global marine transportation equipment

3.1 Industry status of the global marine transportation equipment

3.1.1 Higher education in shipping and offshore engineering

As the focus of the shipping and offshore engineering manufacturing industry gradually shifts to Asia, the scale of higher education in the fields of shipping and offshore engineering in Europe, the United States, and other countries and regions has reduced significantly, compared with the 1980s. Some popular universities have even cut their departments of shipping and offshore engineering, as well as other related majors. Nevertheless, higher education in Europe, the United States, and other countries and regions is still an important pioneering force in the research on new technologies in the fields of shipping and offshore engineering. With the rapid advances in teaching and scientific research and close cooperation with international academic institutions and organizations dealing with technical standards, the higher education community is active and influential in the international arena and marketplace. However, China still suffers from a gap in this respect and improvements are required.

3.1.2 Research on shipping and offshore engineering

The global marine equipment technology mainly relies on technology accumulation and an intellectual property foundation, high social benefits, flexible research mechanisms, traditional market development and service capabilities, and the advantages of technical personnel in the shipbuilding field. Over the past 20 years, although the scale of the shipbuilding industry in Europe, the United States, and other countries and regions, as well as the number of studies on the overall equipment technology, has decreased significantly, the research results still have an important impact on the development of global marine transportation equipment technology. Regions such as Europe and the United States have developed the vast majority of the world’s ship design, evaluation, and digital manufacturing software. They have also developed the core technology of high-end ships and support equipment and are playing a leading role in the manufacturing of marine equipment and marine transportation by international organizations such as the International Maritime Organization, International Association of Classification Societies, and International Organization for Standardization. It is worth noting that in some subdivisions of equipment development fields, Europe, the United States, and other countries and regions have many small- and medium-sized enterprises with more than a 100-year history. Furthermore, some of these countries have global technological monopoly and their scientific research strength cannot be underestimated.

3.1.3 General design and assembly

According to the Clarksons database (Table 1), from 2014 to 2019, among the ships with design information, 30%–35% were designed by ship design institutes in China, 20%–25% in Japan, 10%–20% in South Korea, and 10%–15% in Europe [11]. In terms of ship design, institutions in China and Japan have focused on bulk carrier design, whereas South Korea is more involved in the liquefied natural gas (LNG) carrier design and Europe focuses on cruise ship design. From the perspective of technical connotation, European countries occupy a dominant or monopolistic position in the design of high-end ships (such as large cruise ships, ice ships, deep sea mining ships, LNG carriers, nuclear-powered surface ships, and offshore fishing and processing ships) and a leading position in the design and development of green and intelligent ships. Japan has advantages in the optimization and weight reduction design of the three main ship types and is preoccupied with the development of new concepts and green and intelligent ship design technology.

The global shipbuilding market presents a tripartite pattern for China, South Korea, and Japan. Since the global financial crisis of 2008, China and South Korea have competed fiercely for the main market share of global shipbuilding. Japan has adopted a cautious industrial development strategy and its share of the global shipbuilding market has gradually fallen behind that of China and South Korea. Japan and South Korea are at advanced levels in terms of general assembly and construction technology, adopting the information system of design–evaluation–manufacturing integration and gradually improving the level of process intelligence. The average production efficiency of Japanese and Korean shipbuilding is more than twice that of Chinese shipyards.

Table 1. Statistics of top-20 ship design companies in the world from 2014 to 2019 [11].

No.	Company name	Country/Region	Number of ships	The proportion of the number of newly designed ships in the world with statistical information	Newly designed ship cgt	The proportion of cgt of newly designed ships in the world with statistical information
1	Shanghai Merchant Ship Design and Research Institute	China	842	5.48%	16 628 050	7.09%
2	Marine Design & Research Institute of China	China	139	0.90%	5 081 416	2.17%
3	Shanghai Waigaoqiao Shipbuilding and Offshore Engineering Co., Ltd	China	99	0.64%	3 334 707	1.42%
4	Seaspan Corporation	Hong Kong, China	45	0.29%	2 476 441	1.06%
5	Nantong COSCO KHI Ship Engineering Co., Ltd	China	105	0.68%	2 048 884	0.87%
6	China Ship Design and Research Center Co., Ltd	China	64	0.42%	1 684 515	0.72%
7	Imabari Shipbuilding Co., Ltd	Japan	403	2.62%	7 687 110	3.28%
8	Tsuneishi Shipbuilding Co., Ltd	Japan	266	1.73%	4 884 411	2.08%
9	Japan Marine United	Japan	118	0.77%	3 949 511	1.68%
10	Oshima Shipbuilding Co., Ltd	Japan	215	1.40%	3 743 157	1.60%
11	Namura Shipbuilding Co., Ltd	Japan	115	0.75%	2 130 751	0.91%
12	Shin Kurushima Dockyard Co., Ltd	Japan	132	0.86%	2 011 327	0.86%
13	Hyundai Heavy Industries, Ulsan	South Korea	73	0.47%	3 346 483	1.43%
14	CSMARINE TECH	South Korea	101	0.66%	2 117 958	0.90%
15	Daewoo Shipbuilding & Marine Engineering Co., Ltd	South Korea	37	0.24%	2 016 803	0.86%
16	Samsung Heavy Industries	South Korea	39	0.25%	1 903 928	0.81%
17	Hyundai Heavy Industries, Mipo	South Korea	86	0.56%	1 733 720	0.74%
18	Dertamarin Ship Design	Finland	133	0.87%	3 117 182	1.33%
19	Maersk Line	Denmark	38	0.25%	2 784 906	1.19%
20	Royal Caribbean Group	the United States	12	0.08%	1 836 492	0.78%

3.1.4 Information and communication equipment

Europe, the United States, and Japan are the main competitors of the global ship communication and navigation equipment manufacturing and mainstream ocean transport ships are equipped with integrated systems from Europe and the United States. These shipping communication and navigation equipment manufacturers have a complete global service network and monopolize global communication and navigation product markets. Meanwhile, foreign enterprises have attached significant importance to the integration, standardization, and intelligentization of data resources for information and communication navigation equipment and its upstream and downstream products.

3.1.5 Power and electromechanical equipment

The global high-end diesel engine market is mostly monopolized by developed countries. According to the statistics of the brand share in the Clarksons database, the MAN Group of Germany has more than an 80% market share of low-speed diesel engines in the world. Wärtsilä of Finland, Caterpillar of the United States, Hyundai Group of South Korea, and Daihatsu Industry Co., Ltd. and Yanmar Co., Ltd. of Japan account for more than 90% of the market share of medium-speed diesel engines in the world [11]. In the field of marine nuclear power, the United States and Russia are typical representatives of advanced R&D and industrial systems, constituting a complete spectrum of marine nuclear power equipment. In terms of special propulsion equipment for ships, foreign countries have also conceived high-power, standardized, and serialized products to meet the market demand of all types of

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ships. Meanwhile, foreign enterprises also occupy a leading position in the fields of deck, cabin, and other ship auxiliary machinery industry.

3.2 Advanced frontier technology of global marine transportation equipment

3.2.1 Current advanced technology

(1) Application of LNG fuel technologies to offshore ships

In the future, LNG will be the main alternative fuel for ships. The natural gas reserves are large. With the continuous construction of infrastructure, natural gas is becoming increasingly available [16]. Ferries and offshore ships account for the majority of existing LNG-powered ships and the proportion of container ships, oil tankers, and chemical tankers is increasing. For example, the international development and design of 20 000 TEU LNG-powered container ships have progressed remarkably.

(2) Application of solar and wind energy technologies to large ships

The shipping industry is exploring the application of renewable energy and related technologies have entered the trial and testing stages. For example, the world's first ultra-large crude carrier, weighing 3.08×10^5 DWT, with a sail installation built by Dalian Shipbuilding Industry Group for China Merchants Energy Shipping Co., Ltd. has been put into operation and has completed several voyages. The most potential future application is to reduce fuel consumption.

(3) Polar ship technology

With continuous improvements in the strategic positions in the Arctic region, maritime transportation in the region has attracted extensive attention. The reduction of ice owing to global warming has also made Arctic navigation more feasible. In addition, the continuous development of tourism and fisheries in polar regions has also given rise to new demands for polar ships. The hull structure design, monitoring system, emergency response system, and equipment reliability in the changeable environments of polar ships are the focus of follow-up R&D.

(4) Noise-control technology for ships

Ship noise may affect the health of marine life, crews, and passengers. The *Rules for Noise Levels on Ships* issued by the International Maritime Organization is a reference standard for the prevention of potentially dangerous noise levels on board ships to an environmentally acceptable level [17]. In addition, the International Organization for Standardization has promoted the development of international standards for ship noise. Research on the mechanism, prediction, and control methods of ship noise remains an important topic.

(5) Advanced material technology

Materials are the basis of marine transportation equipment. Newly developed advanced materials boost the performance of marine transportation equipment. Advanced materials in the field of marine transportation equipment include thick high-strength crack-arresting steel plates for super large container ships, low-temperature steel and polar low-temperature marine materials, structural acoustic composite marine materials, drag-reductive, anti-corrosive and anti-fouling coatings, composite materials, and low-temperature materials.

3.2.2 Frontier technology in research

The research frontier technology of marine transportation equipment is mainly related to the intelligentization of marine transportation equipment aimed at accelerating the intelligentization of equipment and the safe and efficient development of the shipping industry.

(1) Intelligent ship technology

The key aspects of intelligent ship technology include intelligent navigation and control technology, energy and intelligent power system management technology, auxiliary intelligent safety equipment operation monitoring technology, whole ship safety intelligent monitoring technology, energy-saving and environmental protection intelligent monitoring technology, vibration and noise intelligent monitoring technology, intelligent cargo energy management technology, and integrated intelligent ship information system technology.

(2) Additive manufacturing technology

Additive manufacturing technology can not only improve the design of mechanical parts and their efficiency and lifetime but also allow the production of relevant spare parts in different ports around the world. This will improve the response ability of enterprises to market demand, shorten maintenance time, and improve the operational efficiency of ships. Additive manufacturing technology has been applied in the field of rapid prototyping manufacturing and is gradually being integrated into traditional manufacturing industries such as automobile and aircraft manufacturing. Currently, the United States Navy has begun to test various technology on ships to assess their potential spare part production capabilities.

(3) Advanced sensor technology

The next generation of sensors is miniaturized and capable of self-calibration. They can collect data independently, including characteristic data such as air/water surface/underwater/submarine wind, wave, load, motion, and intensity data of the ship's operating environment, working status of the electromechanical equipment, cabin environment, and loading details, which can be transmitted in real time. Future ships will have a complete network of sensors to monitor various aspects such as fault detection and identification of areas that require maintenance or repair.

(4) Advanced communication technology

The integrated application of fifth-generation mobile communications, wireless Internet access, next-generation satellites, and traditional radio communication networks will make the long-distance transmission of marine information more economical and convenient. Managers or users can access audio, high-definition video, and three-dimensional (3D) video on real-time onboard recording equipment to reduce the demand for actual onboard investigations.

3.2.3 Future disruptive technology

Hydrogen fuel power is a representative disruptive technology at the frontier of marine transportation equipment globally. Because hydrogen fuel can achieve zero emissions, the International Energy Agency avers that hydrogen energy will become the ideal fuel if the International Maritime Organization's 2050 carbon emission reduction target for the shipping industry will be achieved [18]. Development and widespread application of hydrogen fuel power technology is expected to reshape the industrial form of marine transportation equipment and profoundly impact the design, general assembly, support, and service of marine transportation equipment. In recent years, an increasing number of shipyards, energy companies, and power system suppliers have begun to increase their R&D of hydrogen fuel-powered ships and have made substantial progress. At present, there are many ship types powered with hydrogen fuel cell power and more large-scale projects are under development [19].

4 Status and problems in technological capabilities and industrial structures of marine transportation equipment

The scale of China's marine transportation equipment industry continues to grow after many years of development. In January to November 2019, China had 1052 shipbuilding enterprises above the designated size and the main business revenue was approximately 394.77 billion CNY [20]. China's marine transportation equipment industry chain is relatively complete, including R&D and design, final assembly construction, power and support, and the entire chain of services, and supports the development of the marine industry.

4.1 Higher education in shipping and offshore engineering

The higher education scale of China's shipbuilding and ocean engineering has continued to expand for nearly 40 years. There were only nine colleges and universities engaged in teaching shipbuilding in the 1970s. At the beginning of the 21st century, there were more than 40 colleges and universities. Globally, Chinese schools have the highest number of teachers and students. China has trained more than 50% of the global shipbuilding industry talent. Furthermore, these colleges and universities have built large-scale ship and ocean engineering test facilities at advanced international levels.

Problems of higher education in shipbuilding and ocean engineering include the prioritization of the teaching of ship and ocean engineering technology over corollary equipment, such as power equipment, auxiliary machinery, communication navigation equipment, comprehensive information equipment, and ocean exploration and perception basic device technology such as supporting equipment technology, intelligent technology, and new material technology. There are fewer internship opportunities for students and students tend to have weak grasp of engineering concepts.

4.2 Research in shipping and offshore engineering

A significant number of teams are engaged in research on shipping and offshore engineering, the core of research and design institutes, shipyards, colleges, and universities, which have formed a technology R&D system with a complete professional configuration, serving the design and manufacturing needs of the overall systems and their support for surface and underwater ships and marine engineering equipment [21]. Compared with the global scene, at the follow-up level, only a few studies are conducted in China. Majority of the studies are conducted at the parallel

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running level and local research is at the leading level.

The main problem in the field of ship and ocean engineering research is the insufficient basic technology for the research reserves. For example, there is a lack of basic technology research on the mechanism and optimization of basic key units, such as core components, special materials and processes, and testing methods. Research on equipment intelligence and common green technologies, such as the intelligent management of energy and power systems, energy saving, and environmental protection monitoring, is relatively lagging.

4.3 General design and assembly

China already has a full range of ship type R&D, design, and construction capabilities for mainstream types and has achieved serialized and mass production. China can design and construct large-scale LNG ships, ultra-large fully cooled LNG carriers, and automobile ro-ro ships. Since 2010, China's total shipbuilding capacity has been ranked first globally and its annual shipbuilding completion volume accounts for 35%–44% of the world's total shipbuilding volume (in terms of deadweight tonnage) [11]. Similarly, China has made rapid developments in research on green and intelligent ship technologies.

However, the main problems in ship design and manufacturing is that the design software is mostly imported and independent innovative design capabilities for new ship types and transportation platforms is lacking. The degree of automation, intelligence, and greenness of assembly construction is significantly lower than those of Japan and South Korea. The construction efficiency is significantly lower than the international advanced level. Likewise, the development of a smart ship design and manufacturing technology has been relatively lacking.

4.4 Information and communication equipment

In recent years, through independent R&D, domestic enterprises and scientific research institutions have been developing mid-to-high-end ship communication and navigation products such as electronic chart display and information systems, marine navigation radar, integrated ship bridge systems, and ship automatic identification systems. Some of these systems have been certified by the China Classification Society and are gradually being applied to official and small and medium offshore ships. As complete sets of communication and navigation equipment, most of these systems have solved the problems of independent brands and independent R&D.

The main problems of information and communication navigation are the relatively low application rates of communication and navigation equipment for ocean-going ships. Such equipment is heavily dependent on imports. The accuracy and reliability of the key components of domestic communication and navigation equipment lag behind those of foreign products. The basic electronic components of communication and navigation equipment are primarily obtained through imports; further, they lack a relatively complete integrated communication and data platform system that meets the requirements of the development of intelligent ship technology.

4.5 Power and electromechanical equipment

The scale of China's power and supporting electromechanical industry has expanded rapidly, exceeding the designated market-driven size by more than 500. The mechanical power and electrical equipment manufacturing and test verification facility systems have basically been completed, forming a relatively complete industrial chain. These products include power systems, deck and cabin machinery, automation, and outfitting, and have reached an advanced global level in terms of processing, manufacturing, and production capacity. They can support the three major types of mainstream ship power and electromechanical equipment.

However, some self-designed and manufactured power and electromechanical equipment lack reliability indicators. Moreover, serialization and standardization are yet to be achieved and the application rate remains low. The development of power-supporting equipment services is slow. Finally, a large gap with European companies exists in terms of the number of service outlets, service efficiency, and service coverage.

5 Key development directions of marine transportation equipment

The shortcomings in the industry chain and the implementation of key technologies in China's marine transportation equipment industry urgently need to be improved. The green and intelligent levels of marine transportation equipment must be continuously upgraded. The construction efficiency and quality also need to be improved. Core key systems and equipment with independent intellectual property rights need to be cultivated quickly to form a complete marine transportation equipment R&D design, final assembly construction, equipment supply, technical service industry system, and standardization [22].It is necessary to promote the development model of the marine transportation equipment industry through technological innovation.

5.1 Key breakthrough technologies

5.1.1 Polar sailing ship technology

In this regard, the overall design of polar sailing ships, ice pool tests, ice navigation stability/speed/maneuverability, polar environmental protection and emergency rescue, polar ice and cold protection, and pollution prevention were examined.

5.1.2 Ship intelligent manufacturing technology

The study was also aimed at examining technical research on the design integration and control of typical intermediate ship production lines, intelligent process design, intelligent manufacturing processes, intelligent control of the manufacturing process, and intelligent decision-making in key manufacturing links.

5.1.3 Ship optimizing and energy reduction technology

This study was also focused on integrated research into the main dimensions and linear design of a low-resistance hull, air resistance optimization of the hull superstructure, bottom air lubrication resistance reduction, ship thermal power generation system, and other technologies.

5.1.4 Design technology of ship propulsion equipment

In this area, the focus is on the reasonable integration of efficient propeller design optimization technology, /rudder integrated design technology, propellers/stern matching design optimization technology, and overlapping double-propeller contrary-turning propulsion technology.

5.1.5 Vibration and noise reduction, and comfort technology

Technical research has been conducted on equipment vibration isolation, high-performance marine acoustic materials, construction acoustic technology and outfitting management, structural acoustic design, active acoustic and vibration control, and comfort cabin design.

5.1.6 Key material technology of ship

The focus here is on technical research on above EH47 high-strength steel, titanium alloy materials, low-temperature materials (atmospheric temperature ≤−50 °C), lightweight composite materials, and new environmentally friendly materials for anti-pollution and drag reduction.

5.2 Major engineering and technology projects

5.2.1 Smart ship project

This project was aimed at improving the top-level design and planning of intelligent ships, consider typical ships as the object, realize intelligent management and control, and gradually achieve the ability to navigate autonomous ships based on intelligent collision avoidance. A comprehensive test environment that integrates the virtual reality of intelligent ships with test mechanisms and test conditions for ship–shore–sea linkage will be built. The construction of ship data and equipment security will be strengthened.

5.2.2 Special ship technology project of super ecological environmental protection

A number of internationally leading green brand ship types, standard ship types, and series of ship types have been developed and have greatly enhanced leading technological capabilities. Breakthroughs in the key technologies of green support equipment have been made and the technical level ranks among those of advanced nations in the world. New types of green ships powered by low/non-carbon fuels have been developed.

5.2.3 Special technology project for ship lifecycle operation and maintenance guarantee

A ship–shore integrated Internet of Things, big data, and Internet technical systems has been established, gradually realizing a ship–shore integrated operation and maintenance guarantee. Remote fault diagnosis, predictive maintenance, and remote control for key systems, such as electromechanical ship equipment, deck systems, cabin systems, and nuclear power systems, have been developed. The relevant equipment has self-sensing and self-adaptive capabilities, thereby enabling independent maintenance and self-protection.

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6 Suggestions

6.1 Strengthen top-level design and develop overall planning

Some scientific research institutions are not devoting sufficient attention to basic and cutting-edge technology R&D. It is recommended that the top-level design work, overall planning and guidance be further strengthened. Overall strategic planning should be formulated and basic research should be strengthened. Furthermore, redundant construction should be avoided and extreme competition should be further strengthened. It is advisable to maximize the overall strength of the country and industry, clarify the key directions of development, and guide relevant enterprises to unify and channel their technology R&D to a key consensus on the development of medium- and long-term ships and transportation technology.

6.2 Strengthen policy guidance and promote domestic applications

It is recommended that the education, industry, and other competent departments actively conduct policy guidance and gradually adjust the industrial structure, prioritizing “general assembly construction” over “internal organs and basic parts.” This will encourage the promotion and application of independently developed marine transportation equipment design, evaluation, and manufacturing and operation software. It is also necessary to formulate and implement incentive policies for the first-set application, independent brand promotion and application, and support service capacity building.

6.3 Increase investment in scientific research and expand funding channels

Relevant enterprises, scientific research institutes, and universities should be encouraged to strengthen independent R&D investment and maximize relevant national technology and financial support policies. In addition, direct financing should be conducted through multiple channels and private investors should be incentivized to participate in the construction of scientific and technological innovation projects. Furthermore, a diversified and sustainable investment mechanism should be constituted.

6.4 Promote multi-subject integration and coordinated development

The cooperation of internal R&D should be strengthened, and rights protection and achievement-sharing mechanisms should be clarified based on professional expertise, with major technological projects carried out jointly. At the same time, cooperation and exchange between R&D institutions in the industry and other domestic research institutions and universities should be strengthened to build a multi-level R&D system involving enterprises, universities, and research institutions.

6.5 Explore incentive mechanisms and promote talent development

Innovative talent training and incentive mechanisms should be developed to explore reasonable and effective medium- and long-term incentive and restraint systems and accelerate the training and construction of professional teams such as innovative R&D, senior marketing, project management, and senior skilled talent development [23]. The use of patent licenses, patent rights transfers, invention patent capital contributions, intellectual property pledges, and other forms should be encouraged to promote the transfer and industrialization of innovation results.

6.6 Focus on international cooperation and promotion of technological innovation

Global scientific and technological resources should be fully exploited, while deeply integrating a global scientific and technological innovation network, conducting technical exchange activities in the international ocean field, and strengthening research on international intellectual property rules. Furthermore, the governance capabilities of the marine transportation equipment industry should be continuously improved through scientific and technological cooperation. Finally, resources should be developed and utilized. China should also aim to participate in the formulation of international standards.

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