Research on Various New Technologies of Shuttle Tankers and Their Optimization of Offshore Platform-Based Oil Supply Chain

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Abstract: In December 2023, COSCO Shipping Heavy Industry Company's latest design project 'Methanol Dual-Fuel 154,000 DWT Shuttle Tanker' received the principle-based approval of multiple classification societies. As a special type of ship, the shuttle tankers are always equipped with the latest shipping and loading technology. This paper aims to analyse a series of shuttle tanker research projects undertaken by COSCO in recent years, studying the innovative new technologies related to these projects such as Dynamic Positioning System, which helps the ship stay steady in working position; Bow Loading System, which allow the ship to extract the oil from offshore platform much more efficiently; And Lithium-ion Battery, which enables the ship to reduce carbon emission. The paper will introduce the latest shuttle tankers of COSCO, then talk about the fundamental diagram of those new technologies. After that, the paper will assess their positive effects on offshore platform supply chains with data from its market performance, and propose constructive suggestions for shipbuilding enterprises.

1 INTRODUCTION

Nowadays, Oil and gas produced by modern offshore platforms are transported to terminal warehouses before entering the market in a general sense. Due to the lack of complete storage and docking systems on offshore platforms, this transfer process significantly relies on shuttle tankers which are technically demanding and equipped with numerous complex devices. These tankers, with their large carrying capacity, complex structure and additional technological systems such as cargo monitoring system and dynamic positioning system, are very costly. Therefore, maximizing the efficiency of limited shuttle tankers, akin to buses shuttling back and forth, in terms of vessel energy efficiency and oil and gas transfer efficiency has become a worthy operational research problem.

In recent years, China has applied various advanced equipment and designs to shuttle tankers, diversifying their application prospects. The question now is-whether these new technologies can bring considerable data benefits or even revolutionary progress to offshore platform oil and gas supply after thorough application.

This paper aims to introduce recent leading new technologies in domestic shuttle tankers, such as the latest dynamic positioning system and bow loading system. By collecting relevant literature online, learning about the operating principles of these technologies, and analysing the changes they have brought to the tanker market and offshore oil and gas supply chain, the paper will identify which new equipment and technological improvements have the most significant positive effects on offshore platform oil and gas supply. Based on this, the paper further considers and proposes future trends in shuttle tanker equipment development, providing inspiration for daily research on the offshore oil and gas market.

In recent years, there have been numerous documents studying technological innovations in shipbuilding. Liu from Zhoushan China Ocean Shipping Company Shipping Heavy Industrysummarized (COSCO) the tanker design and key technologies of his company several years ago (Liu, 2019). Scholar Zhao studied the supply chain of offshore platforms as a whole and obtained the

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optimization strategies through mathematical modelling (Zhao, 2015). Other scholars such as Xu etc studied the dynamic positioning system of COSCO shuttle tankers and proposed several optimization schemes for the highest-level DP-3 dynamic positioning system (Xu, 2023). Scholar Li introduced the composition of dynamic positioning system of 152,000-ton shuttle tanker (Li, 2021). Scholar Zhang etc studied a new oil loading and unloading mode: the bow loading system. By analysing the shortcomings of the systems on the market, they attempted to propose their own new horizontal bow loading system and presented various innovative design points (Zhang, 2024). Chen and other scholars focused on analysing the advantages of the bow loading mode in oil extraction work in 2018, when the bow loading method had not been widely introduced in China (Chen, 2018). Moreover, scholar Zhuang etc studied the detailed structure of bow loading system and listed its typical shortage (Zhuang, 2013). Zhang studied the design and installation of gas detection system for shuttle oil tankers (Zhang, 2024). Feng further studied the compound energy storage of shuttle tanker and discussed about their prospects, which includes the latest lithium battery system (Feng, 2023).

2 COSCO SHUTTLE TANKERS

In March 2015, COSCO Shipping Heavy Industry constructed the first 152,000-ton shuttle tanker of the world-the RAQUEL KNUTSEN, with a total length of 276.3 meters, a beam of 46 meters, a depth of 24.3 meters, a service speed of 14.5 knots, and a range of 22,000 nm. The ship is capable of operating in unlimited navigation areas and is equipped with adjustable pitch propellers for the main propulsion system. To ensure dynamic positioning requirements under different sea conditions, the ship is also equipped with five lateral thrusters and retractable full-rotatable thrusters in total at both bow and stern, respectively. Its manipulation, speed, and fuel consumption indicators are among the world's top levels in similar vessels. This series of 152,000-ton shuttle tankers, with high technological content and complete intellectual property rights owned by COSCO, can be considered the starting point for recent technological innovations in domestic shuttle tankers.

Since March 27, 2015, COSCO Shipping Heavy Industry has continuously delivered four 152,000-ton shuttle tankers to KNUTSEN of Norway. In November 2021, COSCO Shipping Heavy Industry completed the first 154,000-ton shuttle tanker of the world-the N786 project, further strengthening its cooperation with KNUTSEN in shuttle tanker orders. Despite being built during the COVID-19 pandemic, the ship still achieved a high level of design completion, with successful trial operations of vessel manipulation, navigation systems, DP systems, and other functions. It also applied green ship technologies such as reduced main engine power, hull shape optimization, hull weight reduction design, and energy-saving device installation, receiving high praise from shipowners and ship inspections (Liu, 2019).

Although shuttle tanker orders from COSCO Shipping Heavy Industry are relatively scarce due to their high technological content, a series of technological accumulations have gradually borne fruit. As China's national tanker brands go global, China's offshore platforms will gradually begin to operate with domestically produced shuttle tankers.

3 INNOVATIVE TECHNOLOGIES

3.1 Dynamic Positioning System

The Dynamic Positioning System (DPS), also known as the DP system, refers to a system that utilizes the vessel's own power to overcome external interference forces, enabling the vessel to automatically maintain a certain position (fixed position or preset track). Due to the sharp increasing demand for modern offshore operations, the dynamic positioning technology which enables vessels to maintain a fixed berthing position in various complex sea conditions, was born in the 1970s. Its basic principle is to collect wind waves and sea current-related parameters through advanced sensors and input them into the computer to calculate the vessel's movement state which is affected by sea conditions. Then, it controls the thrust of propellers and the positions of rudders and propellers at various locations of the hull to offset the impact, achieving the purpose of maintaining vessel stability. Figure 1 shows the operation diagram of the dynamic positioning system. A dynamic positioning system installed on a vessel can be divided into three parts: measurement, control, and execution.

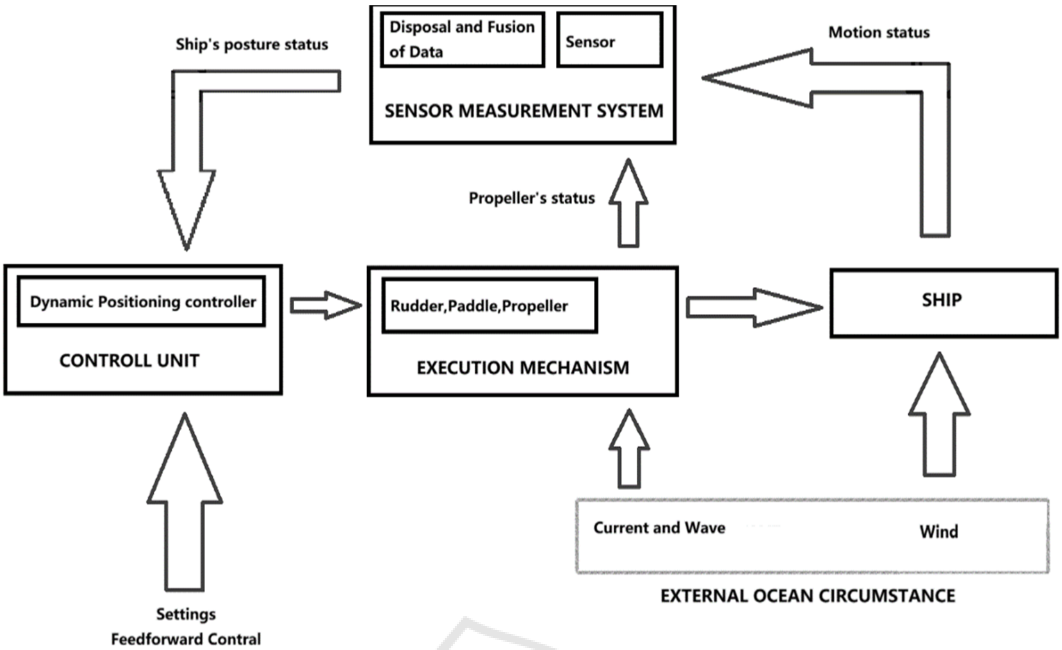

Figure 1: Basic operating principle diagram of dynamic positioning system (Li, 2021).

With the development of ship control systems and automation technology, the stability of dynamic positioning systems has been continuously improved. Nowadays, dynamic positioning systems are classified into three levels named DP-1, DP-2, and DP-3 according to their performance (Jiang, 2018). In 2011, the "CNOOC 201", a deepwater pipelaying crane ship subject independently developed and constructed by Rong Sheng Heavy Industries with investment from China National Offshore Oil Corporation, was launched. This was the first deep-sea operation vessel with DP-3-level dynamic positioning capabilities of the world, marking China's leading position in the technical level of dynamic positioning systems. Several years later, the 152,000-ton shuttle tanker series produced by COSCO Shipping Heavy Industry was fully equipped with DP-3-level dynamic positioning. The ship is equipped with six power generation auxiliary engines to power the thrusters, along with a new single-point fault-tolerant design of dual-redundant controller units and high-precision error estimation using an extended Kalman filter. The dynamic positioning capability of this ship is such that, under conditions of a wave height of 5m, wave period of 8.6s, wind speed of 20.5m/s, and current speed of 1.1m/s, it can still maintain the angle between the ship and the wind and current within 20° in the worst-case scenario, even when one set of equipment or system fails. The detailed classification of dynamic positioning capability can be consulted in Table 1.

Table 1: The Classifications of DNV for DP system. (Jiang, 2018).

Classifications	Function standards
DYNPOS(AUTS)	No equipment redundancy. Automatically maintaining ship position
DP-1	Equipped with thrust remote-control backup and position reference backup. Automatically maintaining the ship's position.
DP-2	It has redundancy in technical design. Automatically maintains the position of the ship.
DP-3	It has redundancy in practical use. Automatically maintaining the ship's position.

3.2 Bow Loading System

As an oil tanker that travels between terminals and offshore platforms, its oil loading process also features advanced design. Shuttle tankers generally adopt external hoses for loading and unloading oil, with bow loading being the most advanced method. Unlike the traditional midship loading method commonly used in oil extraction in the South China Sea, the bow loading system transfers the towing hawser and the guide line of the oil hose to the shuttle tanker simultaneously during the process of reeling in the hawser to the shuttle tanker. After the friction chain of the mooring hawser is locked on the chain stopper, the guide line of the hose can be guided to the dedicated winch and the oil hose can be transferred immediately (Zhang, 2024), reducing the excessive frequent contact loss of the external long hose and reducing maintenance costs. At the same time, the special winch at the bow of the shuttle tanker can get rid of manual operations, and be remotely controlled through mechanical means. It also has a safety emergency release mechanism that midship loading lacks. Both safety and docking efficiency have been significantly improved (Chen, 2018).

Currently, the shuttle tankers produced by COSCO Shipping Heavy Industry have not fully applied bow loading in their loading system. After investigation, it is found that the standard bow loading system equipment costs about 30 million yuan, has a long order lead time, and is affected by the shipping cycle. The retrofit cycle is about half a year, making it difficult to retrofit old ships. The standard bow loading mode requires adding a new deck to the original deck, placing a series of mooring system equipment on the upper part of the new deck, and placing oil hose auxiliary equipment on the lower part of the new deck. This mode centrally lays out the oil pipeline, requiring high land occupation, suspending the oil hose, and making docking difficult. However, it is convenient for equipment inspection and maintenance. Nowadays, COSCO Shipping Heavy Industry's technology is gradually upgrading. The recently launched N787 project, the world's largest shuttle tanker "NS Pioneer", is equipped with multiple advanced technologies including the bow loading system. At the same time, in order to break the monopoly of foreign MacGregor companies in the manufacturing of bow loading systems, COSCO's independently developed new bow loading system project has also been put on the agenda.

3.3 Lithium Battery System

Lithium-ion battery (li-ion batteries for short) is a secondary battery that uses lithium-containing compounds as the positive electrode and achieves charging and discharging through the embedding and de-embedding of lithium ions between the positive and negative electrodes of the battery during the charging and discharging process. Compared with traditional batteries, lithium batteries have higher energy density, larger charge-discharge rate, simpler maintenance, and longer lifespan. Relying on lithium batteries, large-scale machinery such as ships can use electricity as a new energy source on a large scale. In ships, a li-ion battery energy storage system can effectively assist the ship's auxiliary generator. It can serve as a supplementary power source to replace the generator for energy supply in emission-restricted areas, and it can fully absorb excess electricity generated by the generator in non-emission-restricted areas. When there is a temporary high-power demand for the load, the li-ion battery can effectively alleviate the power pressure of the generator through discharging.

In recent years, the IMO's energy conservation and emission reduction targets have become increasingly stringent, which has also forced the shuttle tanker market to choose vessels with lower emissions. Therefore, COSCO Shipping Heavy Industry has been adopting the highest standards of green and environmentally friendly design to produce new ships, and li-ion battery energy storage systems have been widely used in the latest 154,000-ton series of shuttle tankers. Due to the special nature of shuttle tanker operations, their energy consumption during navigation accounts for a relatively small proportion, but their energy consumption during frequent port calls and berthing at sea accounts for a larger proportion. Therefore, the energy-saving benefits of auxiliary engines are greater than those of main engines. Li-ion battery energy storage systems can meet these needs and effectively improve the economy and environmental protection of engines. Assuming that the shuttle tanker operates 50 voyages annually on average, with 15 hours of dynamic positioning operation during each oil loading cycle, the configuration of three sets of 420 kW/h lithium battery packs can reduce the operation of one generator (capacity of about 4MW) for 750 hours per year. This can significantly save fuel consumption, extend the service life of diesel generators, and provide convenience for operation and maintenance. However, as part of the composite energy storage system of shuttle tankers, the li-ion battery system still has room for optimization in terms of discharge capacity, energy storage service life, and performance under different temperature environments (Feng, 2023).

4 MARKET PERFORMANCE

In the first cooperation with the shipowner of Norway's KNUTSEN-the world's second largest shuttle tanker operator and the earliest customer of old shuttle tankers, four 152,000-ton shuttle tankers and five 154,000-ton shuttle tankers have been delivered, and another six orders for 154,000-ton shuttle tankers are still in progress. It is estimated that the unit price of each tanker can reach about USD 100 million, which is approximately RMB 719 million. From January to September 2023, as one of the important shipbuilding clusters in China, the total profit of Zhejiang's above-scale shipbuilding enterprises reached RMB 2.55 billion, and the profitability of the industry hit a new high since 2009. Among them, the shuttle tankers, which represent the high-end shipbuilding industry, contributed 28% to the profit with only one 154,000-ton order. This series of oil tankers, which are completely independently developed, designed and built, are qualified to be classified by Det Norske Veritas (DNV), completely breaking the market monopoly of Europe, America and South Korea.

5 OPTIMIZATION OF SUPPLY CHAIN

The advancement in shuttle tanker manufacturing technology also provides inspiration for the offshore platform supply chain in the South China Sea. Offshore oil and gas fields are production lines for petroleum products manufacturing, which differ from conventional oil fields in terms of their heavy reliance on vessels for transportation and limited production space. Under such conditions, the manipulation, speed, and fuel consumption of China's oil tanker hulls are among the world's leading levels in their respective categories, thus playing a leading role in the construction of oil and gas supply chains. Dynamic positioning and float-over installation technology can be applied to offshore platform installation, and research has begun on new bow loading systems suitable for the operating environment in the South China Sea. However, the cutting-edge technology centres around li-ion batteries, which use lithium-containing compounds as the positive electrode and achieve charging and discharging through the embedding and de-embedding of li-ion between the positive and negative electrodes during the charging and discharging process. Compared with traditional batteries, Li-ion batteries have higher energy density, higher charge and discharge rates, simpler maintenance, and longer life. Relying on Li-ion batteries, large-scale machinery such as ships can use electricity as a new energy source on a large scale. In ships, a li-ion battery energy storage system can effectively assist the ship's auxiliary generator, serving as a supplementary power source to replace the generator in emission-restricted areas, while fully absorbing excess power generated by the generator in non-restricted areas. When there is a temporary high-power demand from the load, the Li-ion battery can effectively alleviate the power pressure on the generator through discharging, which can significantly reduce the voyage cost of the shuttle tanker.

6 CONCLUSION

According to the paper, shuttle tanker construction is becoming more and more complicated nowadays to involve the latest technologies mentioned above while the proceeding trend of optimizing oil supply chain is also getting bloom. In the view of shipping market where the shuttle tanker remains unexpected part of offshore platform-based oil supply chain, technologies applied in shipbuilding have their potentials. Besides, the author can also learn that there is still room for improvement in adaptability. For example, the 152,000-ton series equipped with a bow loading system suffers from a bow-down phenomenon, which necessitates reducing the cargo capacity by adding ballast water to the stern. Therefore, innovative design in ship types can be explored to address the weight distribution issue. However, when designing new ship types, it is necessary to solve the problem of excessive fuel consumption and reconfigure the dynamic positioning system. As a high-end vessel type, it is evident that efficiently integrating innovative technologies on shuttle tankers remains a challenging task for Chinese shipbuilding enterprises.

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