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SUPER ENGINEERING

Danping LOU, Yan LI

Large-scale liquefied natural gas ships

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Design Unit and Construction Shipyard: Hudong–Zhonghua Shipbuilding (Group) Co., Ltd.
Ship Classification Society: China Classification Society, Lloyd's Register of Shipping, American Bureau of Shipping, etc.

1 Overview of liquefied natural gas (LNG) ships

Compared with other fossil fuels, such as coal and oil, natural gas emits less carbon dioxide and no sulfide and dust; therefore, it is considered cleaner and an important direction for China's implementation of its energy strategy adjustment. Natural gas accounts for over 20% of primary energy worldwide. By the end of the 13th Five-Year Plan, China's natural gas will account for approximately 8%–10% of its primary energy. When pure natural gas is cooled to a liquid state under normal pressure, its volume is reduced to approximately 1/600, and in liquid state transportation efficiency can be considerably improved. The development and utilization processes of natural gas involve an inseparable supply chain, as shown in Fig. 1.

LNG ships are an indispensable part of the entire supply chain. A large-scale LNG ship has been hailed as the "Pearl of the Crown" by the world's shipbuilding industry because of its high technology, reliability, and added value. Such ship is the primary equipment for the water transportation of natural gas. An LNG ship must guarantee that LNG with a temperature of –163°C is safely transported under normal temperature and pressure. It should also ensure the ability of the liquid cargo control system to bear and deal with considerable temperature changes, along with the reusability of the naturally volatilizing component of LNG in the main engine through special pipelines. Thus, the special liquid cargo handling system, the special main propulsion system, the long-life requirements of the hull structure, and the large-scale use of low-temperature steel in the hull structure constitute the four major technical features of LNG ships.

Before China began building LNG ships, only a few LNG ships were being built in South Korea, Japan, and Europe. Japanese and South Korean companies monopolized the LNG ship market and imposed strict technical blockade on Chinese companies. Hudong–Zhonghua is the backbone shipyard of China State Shipbuilding Corporation Limited located in Shanghai. To fill the gap in materials and technology, Hudong–Zhonghua, in cooperation with the French Atlantic Shipyard, introduced a patented technology, called GTT film, to design the first steam propulsion 147000 m^3 LNG ship (Fig. 2). Through assimilation and immersion, Hudong–Zhonghua has embarked on a road to industrialization from the joint development by means of imported technologies and independent research and development (R&D) regarding design and construction.

Following the successful establishment of China's first generation 147000 m^3 LNG shipbuilding, Hudong–Zhonghua independently developed the second-generation double-stern propulsion LNG ships with zero cargo deduction in 2008. These 172000 m^3 low-speed engine propulsion LNG ships have been successfully produced and exported overseas. The aforementioned development filled the gap in the independent design and export of LNG ships in China. The third-generation 174000 m^3 medium-speed dual-fuel (DF) electric propulsion LNG ships were independently developed by Hudong–Zhonghua. These ships adopted for the first time the latest electric propulsion design, the first high-efficiency dual-axis extroverted arrangement, the full-gas fuel operation mode, and a series of new design concepts based on operational traits. The fourth-generation 174000 m^3 LNG ships directly driven by a DF low-speed engine were independently developed by Hudong–Zhonghua, realizing the full application of such

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Danping LOU (✉), Yan LI
Hudong–Zhonghua Shipbuilding (Group) Co., Ltd., Shanghai 200129, China
E-mail: loudp@139.com

Fig. 1 LNG supply chain.

Fig. 2 First China-built LNG ship "Dapeng Hao".

engine. The cargo boil-off rate is considerably reduced, and operational flexibility is excellent. To date, Hudong–Zhonghua has successfully delivered 21 LNG ships and has built an industrial manufacturing capability with an annual delivery capacity of 5 ships. In addition, Hudong–Zhonghua has conducted R&D on ship properties based on LNG ships. It has successively undertaken an order of two LNG floating storage and regasification units (FSRUs) and two 186000 m^3 LNG bunkering ships. Subsequently, Hudong–Zhonghua took over a project that involved converting conventionally powered super large container ships into LNG-fuelled ones, achieving significant social benefits.

2 Introduction to ship properties

The length of current LNG ships is less than 300 m, the draught is 11.5 m, and the width ranges from 45 to 46.95 m. The cabin capacity is 147000 m^3 in the first generation, 172000 m^3 in the second generation, and 174000 m^3 in the third and fourth generations. All ships are equipped with four cargo tanks, and some ships are equipped with reliquefaction systems and twin skeg propulsion systems. After years of technical research, Hudong–Zhonghua has successively launched its second- to fourth-generation of independent R&D on LNG ship design. The fourth-generation LNG ship is a world-class ship that adopts the latest design concept and equipment technology in the world. It has low boil-off rate, low energy consumption, high reliability, green design, and strong versatility, with forward-looking and economic prospects. Comprehensive indicators have reached advanced international levels, and the first ship has been delivered at the end of 2019.

(1) This ship type is the first in the world to adopt the GTT L03+ cargo containment system. The cargo tank's full-load boil-off rate is lower than 0.10% per day. Compared with the traditional No. 96 system, insulation performance is improved by over 30%. In gas mode, the evaporative gas balance speed is lower than 18 knots, which is cost-effective. The ship adopts the latest multi-point optimal design of the hull line to achieve full optimization for a wide speed range of 12–19.5 knots. Flexible route matching can fully satisfy the diverse needs of shipowners for both long-term fixed routes and non-fixed trade routes in the international market.

(2) Two X-DF low-speed main engines are designed for direct driving, with high system efficiency, low fuel consumption, and good shipping economy. In addition, both the main engine and the generator are equipped with selective catalytic reduction (SCR) system, thus their fuel and gas modes can satisfy the most stringent NO_x Tier III emission requirements in the world.

(3) This ship type is the most popular in the world. The design can meet the berth compatibility requirements of more than 100 major LNG shore stations worldwide (Fig. 3). Simultaneously, the compatibility of ship-to-ship

Fig. 3 Artist's impression of an LNG ship and a shore station (Qingdao terminal).

transfer with the LNG FSRU, which is universal, is fully considered.

(4) The design of the ship considers the current standard requirements (as of 2025) officially issued by the International Maritime Organization. The energy efficiency design indicator already meets the third stage requirements and is 50% lower than the reference line. The ship is forward-looking and exhibits strong market adaptability.

(5) The design of the power-saving cargo-handling system minimizes the displacement of the boil-off gas compressor, considerably reducing the energy consumption of the gas compressor during operation, decreasing comprehensive energy consumption, and improving environmental protection and economy efficiency.

3 Technical difficulties and innovations of LNG ships

3.1 Construction technology of the film-type cargo containment system

The film-type cargo containment system is a cargo tank insulation storage system with a designed temperature of –163°C. The system is in the form of GTT No. 96. It consists of an insulating box filled with perlite and two layers of Invar stainless steel with a thickness of 0.7 mm (Fig. 4).

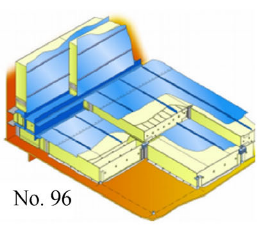
The construction process of the film-type LNG ship cargo containment system includes the following major steps (Fig. 5):

a. Installation of the insulation box. The insulation box must be installed in such a way that ensures sufficient flatness and the flatness of the film installed on it.

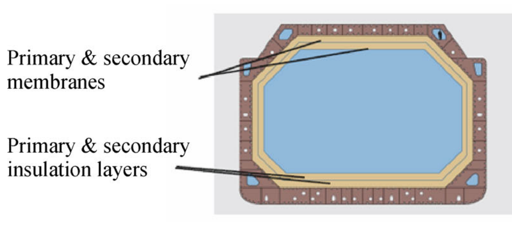
b. Welding of the film. The film weld of the 147000 m^3 LNG ship is 130 km long. Film installation and welding must be conducted to ensure no leakage.

c. Tightness test. The tightness test includes the load and helium tests to verify and confirm that the cargo tank film has no leakage and can withstand the weight of the LNG cargo.

d. Disassembly and assembly techniques for the special working platform of the cargo tank. The disassembly of the special working platform of the cargo tank is performed after the work of the cargo tank is completed. Dismantling must follow detailed procedures and instructions, and the film must not be touched. In general, one month is required to disassemble a tank. Therefore, a detailed disassembly procedure, skilled disassembly and assembly workers, and complete disassembly and assembly tools are the keys to ensure rapid, orderly, and safe assembly and disassembly of the special working platform of the cargo tank.

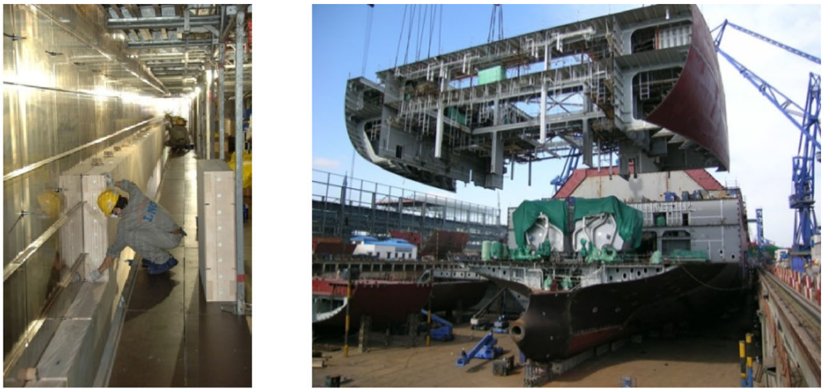


(a) The No. 96 ststem



(b) The insulating box

Fig. 4 GTT LNG cargo containment system.



(a) Installation of the insulation box (b) Lifting of the engine room block

Fig. 5 Construction of the LNG cargo containment system.

3.2 Design and construction technology of the cryogenic liquid cargo control system

The cryogenic liquid cargo control system involves the volatilization of gases during loading, unloading, and shipping, with the presence of cryogenic liquids and gases in the cargo tanks and pipelines. Controlling pressure changes in the cargo tank and eliminating the effects of liquid–gas mixing on loading and unloading is difficult in system design.

a. Design of the cryogenic liquid cargo control system. LNG cargo is loaded and unloaded at the dock and transported across the sea at $-163°C$. Thus, substantial amounts of volatile gases are present during the process, which affects loading and unloading efficiency. Moreover, volatile gases in the cargo tank will increase cargo tank pressure, causing safety problems. The cryogenic liquid cargo control system is designed to solve these problems.

b. Reliquefaction system design (Fig. 6). A system that liquefies volatile gases is necessary when the ship is sailing at low speeds.

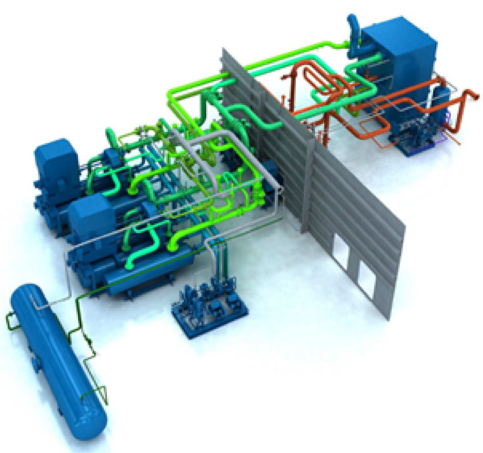


Fig. 6 Reliquefaction system.

c. Welding technology for cryogenic piping. A butt welding technology for large-diameter stainless steel pipe system requires skilled stainless steel welders and reliable welding techniques.

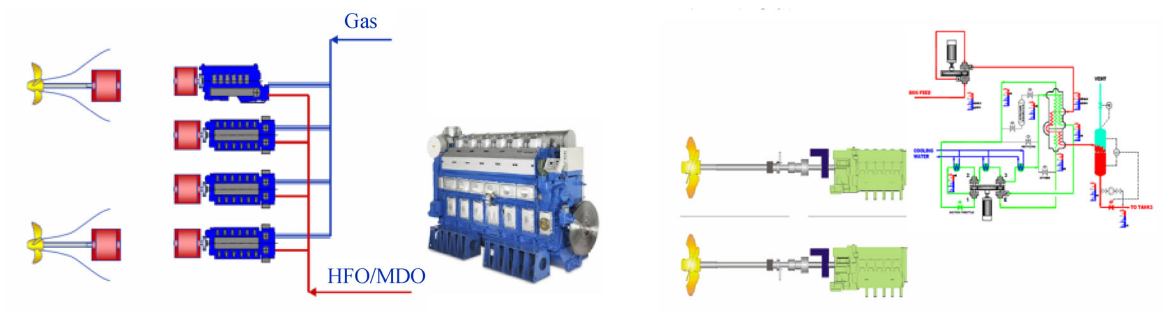
d. Insulation-laying technology for low-temperature pipelines. Pipes that can withstand alternating temperatures at normal and low temperatures require reliable insulation, either foamed in situ insulation or wrapped insulation. Meeting this requirement is a challenge.

e. Debugging technology for the low-temperature control system. The low-temperature control system includes the pump tower system, emergency shutoff system, cryogenic liquid cargo-metering system, ship–shore connection and compatibility system, water detection system, compartment heating system, and the cargo machinery room. Debugging technology is critical for constructing a low-temperature control system.

f. Gas test technique. The gas test assesses the loading, transport, and unloading processes of a real ship. It is the final inspection of the liquid cargo system.

3.3 Design and construction technology of the main propulsion system

The propulsion power system of an LNG ship (Fig. 7) has achieved the key technologies of steam turbine ship propulsion power system, DF medium-speed machine electric propulsion, and DF low-speed machine direct driving power system. Hudong–Zhonghua has successfully built LNG vessels with the three aforementioned power systems; thus, it is keeping up with the global trends in LNG ship technology development and pursuing goals, such as energy conservation, emission reduction, low carbon production, and environmental protection. The steam turbine system uses a high-temperature and high-pressure boiler and turbine system at the temperature of 515°C and under the pressure of 65 bar (kg). The design, installation, and debugging of an LNG ship's cabin system



(a) DF electric propulsion (b) DF low-speed direct thrust engine

Fig. 7 Power systems of LNG ships.

are dangerous and challenging. The key technologies include:

a. System design and layout, high-temperature piping design

b. High-temperature piping system installation

c. High-temperature pipe steam flushing

d. Boiler commissioning (the number of alarm points is more than 1000)

e. Turbo host debugging

f. Turbine generator debugging

g. Integrated automation system (IAS) debugging

h. Power management system (PMS) debugging

The DF electric propulsion system and the DF low-speed direct-driving system use different technical routes compared with the steam system. The DF electric propulsion system consists of a DF medium-speed unit, a power generation unit, variable-frequency transformer equipment, propulsion motors, and gearboxes. It exhibits features such as redundancy, flexibility, and high safety. The DF low-speed direct-driving machine exhibits higher energy efficiency. After considerable research, Hudong–Zhonghua has achieved power system integration and mastered key technologies related to design, construction, installation, and commissioning.

3.4 Promotion of local materials

The technological innovation in the design and construction of large-scale LNG ships has not only provided shipbuilding output value to China but also driven the rapid development of domestic supporting industries. Building an LNG ship involves comprehensive and cross-industry system engineering. An LNG ship's numerous supporting materials and equipment cover a wide range of fields, including machinery, chemistry, metallurgy, and instrumentation. While developing the first-generation of LNG ships, Hudong–Zhonghua actively promoted the use of local materials and equipment and cooperated with domestic suppliers to develop a large number of special materials and equipment.

The LNG ship project has considerably promoted the rapid development of related supporting industries. The major materials related to the liquid cargo containment system, including Invar steel materials, Invar prefabricated parts, glass wool, perlite, pump towers, low-temperature stainless steel pipes, insulation boxes, mounting accessories, and cryogenic valves, have already been produced locally. With the use of local equipment, including DF main engines, DF generators, cryogenic valves, and cryogenic pumps, the localization ratio of LNG ships will increase from the current 45% to over 60%.

4 Conclusions

The LNG ships designed and constructed by Hudong–Zhonghua solved a series of technical problems caused by low-temperature and dangerous materials used in the loading, unloading, and transportation of low-temperature cargo. In terms of risk assessment, safety design, construction quality control, operation procedure control, and evaporation gas treatment technology, Hudong–Zhonghua has developed its own technologies, processes, and technical standards to guarantee the performance and quality of LNG ships.

The successful development of large-scale LNG ships indicates that Hudong–Zhonghua has mastered the design and construction methods for such ships and has developed the capabilities of independent design, construction, and industrialization that are in line with international standards, which provides reliable transportation under the security of China's energy strategy.