



# Building of Advanced Large Sized Membrane Type LNG Carrier

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*In the global demand for the environment friendly energy, LNG based trade has been increasing steadily, and demand for LNG carriers by customers has become more diversified. Under these circumstances, Mitsubishi Heavy Industries, Ltd. (MHI) has established the building record of Moss type LNG carriers, and also has been carrying out the technical developments, repair, and maintenance work of membrane LNG carriers first started in the 1970s. Thanks to the customer's evaluation for those activities, MHI was awarded the contract for six large membrane ships in 1999, which were the first large sized ships to be built in Japan. These ships were built and delivered by 2004 by MHI. Advanced design and building methods with new technologies were incorporated in the building of these ships which were endorsed by spherical tank technique as well. Accordingly, the most advanced and distinguished, largest class membrane type LNG carriers in the world were completed. Now MHI is continuing work on the development of the next generation LNG carriers to meet the further needs of customers.*

## 1. Introduction

The commercial marine transportation of liquefied natural gas (LNG), which first began in 1964, is increasing year by year. In 2003, it reached approximately 123 million tons in the world. About 150 LNG carriers were engaged in the sea-borne trade of LNG in 2003. MHI has delivered 26 LNG carriers (including 3 membrane type ships) since 1983, and is now building 10 LNG carriers. MHI has established a track record as the world's largest supplier of LNG carriers.

With the construction of those membrane type ships, MHI has become the first yard in the world to build both Moss and membrane type Large LNG carriers to meet the needs of customers.

After reviewing the features of each cargo containment system and MHI's activities, this paper will summarize the features, development, design, and construction record of Japan's first large membrane type LNG carrier. Future trends in LNG carriers are also mentioned briefly here.

## 2. Cargo containment system of LNG carrier and features of membrane type ships

LNG has several unique properties including temperature that reaches as low as approximately  $-160^{\circ}\text{C}$  and a low specific gravity of 0.43 to 0.50 at atmospheric pressure. Various types of cargo containment systems suitable to accommodate these properties have been put into practical use.

At present, independent spherical tank systems and membrane tank systems have become the mainstream type systems due to their economic efficiency and reliability. LNG carriers are uniquely different from other types of cargo transport ships in the sense that the cargo containment systems are not unified into one system but rather multiple systems are used instead.

### 2.1 Features and comparison of Moss and membrane tank systems

The features of each cargo containment system are briefly described below. As for detail, refer to reference<sup>(1)</sup>.

#### (1) Independent spherical tank system (Moss system)

An independent spherical tank system is formed in such a way that a self-supporting spherical tank is fixed to the hull by a cylindrical support structure (skirt). The liquid loaded in the tank acts on the self-supporting tank. MHI has thus far built and delivered 23 LNG carriers using this system, while improving this system.

Recently, the design of Suez Canal tonnage reduction to reduce Suez Canal fees and so-called stretch tank formed by inserting a cylindrical part into the tank's equatorial part to increase volume efficiency have been realized.

#### (2) Membrane tank system

A membrane system is formed by installing thermal insulating material into the hull of the ship and covering the surface with a metallic membrane. The purpose of the membrane is to maintain liquid-tightness so as to prevent any leakage of the cargo liquid. The load of the cargo liquid acts directly from the thermal insulating material to the hull. This system includes Gaz Transport System, Technigaz System and a system called the CS-1 (Combined System-One), which will be described later.

The membrane system makes the deck flat and the smaller size of the ship compared with a Moss system. In recent years, there has been increasing demand for the relaxation of filling limits of cargo liquid levels and relaxation of limits on tank length of membrane system. In order to improve the estimation accuracy of sloshing loads acting on the tank, GTT (Gaz Transport and Technigaz), Classification Societies, and shipyards have investigated the subject to be of practical use.

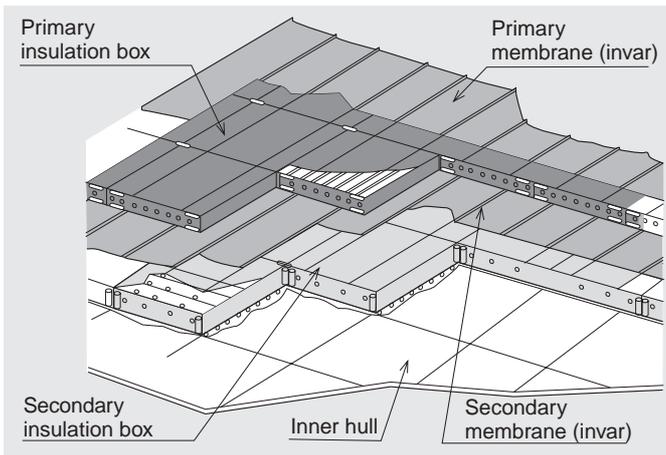


Fig. 1 Structural drawing of Gaz Transport NO96 insulation system

The large membrane ships designed and built by MHI adopt the Gaz Transport system. As shown in Fig. 1, this system consists of a double construction of invar (36% nickel alloy steel) with 0.7 mm thickness as primary and secondary membranes. The insulation box is also consists of a double layer structure. The total thickness of the insulation system is approximately 530 mm to ensure a BOR (Boil-Off Rate) of 0.15% per day.

### 3. MHI's activities for membrane type LNG carriers

Whilst, MHI has been recognized as a leading Moss shipyard. MHI's activities for membrane type LNG carriers started earlier than Moss system. MHI introduced the technologies of the Technigaz system in 1969 and the Gaz Transport system in 1973, and has continuously developed various technical improvements on these systems ever since.

In the Iranian Kalingas project in the latter half of the 1970s and the Northwest Shelf project in the former half of the 1980s, though they were not realized, MHI worked on development of the membrane system at the practical level. Since 1973, MHI has also concluded long-term maintenance contracts in the field of ship repair and has continuously performed repair work on membrane ships of both the Gaz Transport and Technigaz systems.

### 4. Building of large membrane type LNG carriers

In 1999, MHI was awarded the contract as a leading shipyard for six large membrane type LNG carriers for the PETRONAS Tiga project in Malaysia. Despite no building record of large membrane ships at the time, MHI's long-term activities on membrane ships and the design and construction technologies were evaluated for the receipt of the order. MHI R & D center, a design department, and a shipbuilding department devoted all their power and energy to the development, design, and construction of the first large membrane LNG carriers to be built in Japan.

Posterior to challenging to the new products, three of the world's largest class advanced membrane LNG carriers could be built and delivered with a high level of completeness. A brief outline of these LNG carriers is presented below.

#### 4.1 Basic concept

Basic concepts in the development and design of the ships are as follows:

- The volumetric efficiency and propulsion performance (fuel consumption) shall be to the world's highest level, and economy in operation shall be excellent.
- The quality of the cargo containment system shall be well assured.
- Operability and maintainability after delivery shall be excellent. Specifically, the specifications and arrangement are so designed that operation and maintenance could be performed safely, securely, and easily.

#### 4.2 Features of design (initial design, performance, structure, and outfittings)

##### (1) Initial design

Figure 2 shows the general arrangement of one of these ships, "Puteri Intan Satu", while Table 1 shows the principal particulars of the ship.

The major dimensions were determined to achieve excellent propulsion performance with best use of compactness of the membrane ship. The shape of the cargo tanks was improved so that the number of non-standard insulation boxes could be minimized. The cross sections of the Nos. 2, 3, and 4 tanks were the same by which the cargo containment work efficiently runs.

Table 1 Principal particulars of the "PUTERI INTAN SATU"

Principal dimensions		
Length, overall	(m)	276.0
Breadth, moulded	(m)	43.40
Depth, moulded	(m)	25.50
Summer draught, moulded	(m)	12.01
Dead-weight and tonnage		
Dead-weight at		
designed draught	(t)	76 110
Gross tonnage (International)		93 038
Net tonnage (International)		27 911
Cargo tank capacity	(100%, -163°C)	137 489 m <sup>3</sup>
Main engine:		Mitsubishi Steam Turbine X 1 set
Max. output:		26 800 kW X 89.0 rpm
Normal output:		24 120 kW X 85.9 rpm
Main boiler:		Mitsubishi Water Tube Boiler X 2 sets
Max. evaporation:		60 000 kg/h per set
Generator:		
Turbo generators:		2 900 kW X 2 sets
Diesel generator:		2 900 kW X 1 set
Speed and endurance		
Service speed:	(kt)	Abt. 19.5
Endurance:	(s.mile)	Abt. 15 000

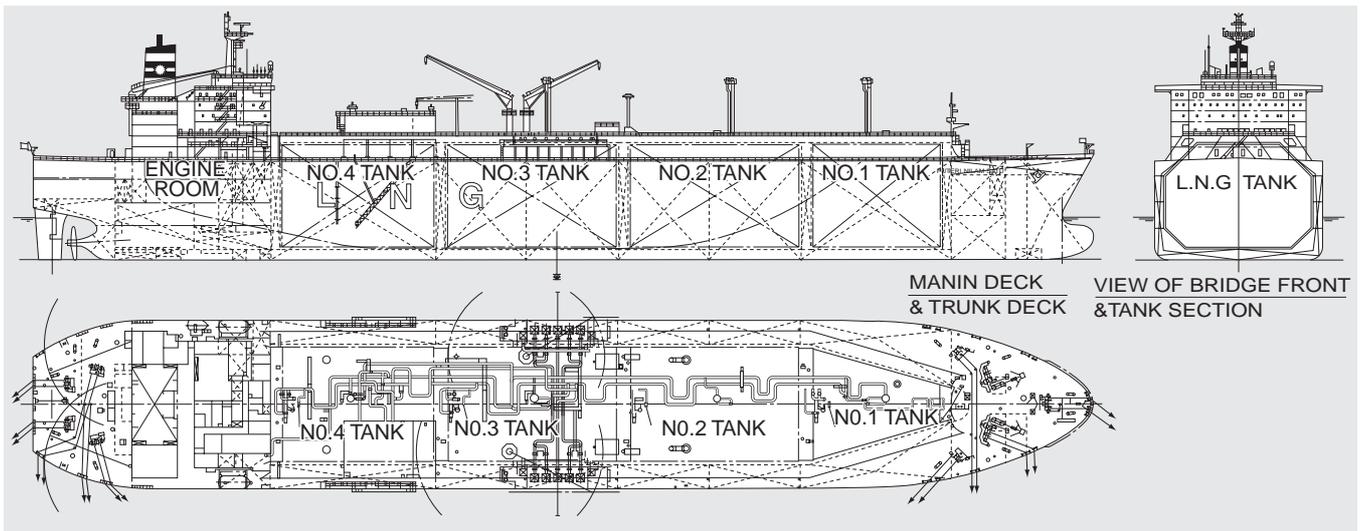


Fig. 2 General arrangement of "PUTERI INTAN SATU"

(2) Propulsion performance and fuel consumption

The optimum shape of a hull differs depending on the type of cargo containment system inside. MHI developed the optimum for membrane tanks by full use of computational fluid dynamics (CFD), in addition to model tests in a model basin. **Figure 3** shows an improved hull form obtained by CFD.

Parallely, MHI developed the optimum design of the propeller so as to be of high efficiency and vibration free. For the turbine plant, a simple two-stage feed water system was adopted by customer's preference in consideration of maintenance, and less fuel consumption was achieved by the improved heat efficient technologies.

(3) Structural design

Strength of hull structure has been verified by the whole ship FEM model shown in **Fig. 4**, and it has been confirmed enough strength in stress and buckling requirements. Analysis using fine mesh FEM models was also performed to confirm fatigue strength mainly for the knuckle points of the inner hull, which were the most critical points because of the boundary

between the insulation and the ballast tank. Based on the above analyses, SDA (Structural Design Assessment for stress and buckling) and FDA (Fatigue Design Assessment for fatigue) notations, which are the latest notations of Lloyd's Register of Shipping (LR), were obtained.

Separately, an analysis using DISAM (DIScrete Analysis Method), which is a MHI's in house special analysis method, was carried out to confirm fatigue strength with wave data in the ship's specific sea route.

(4) Design & arrangement of outfitings and automation

The design for the arrangement of the passages on the upper and under deck and the engine room was carried out in consideration of traffic and maintenance onboard. The arrangement of electrical cables and pipes shall be so designed not to expose, as far as practicable, in consideration of future maintenance. And the selection of materials and determination of coating specifications were also carefully done considering long-term use. In the design of the cargo piping arrangement, stress calculations of piping was performed to assure sufficient reliability.

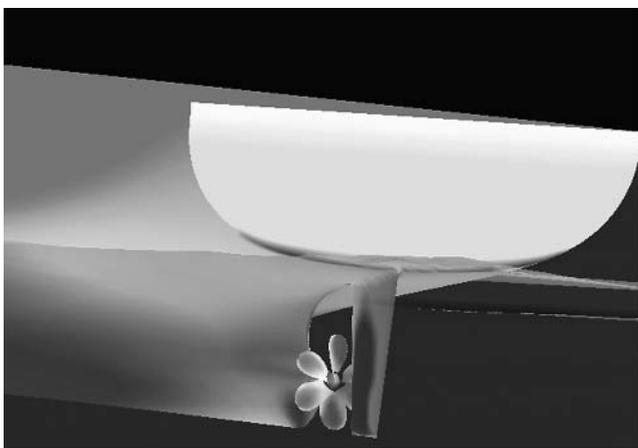


Fig. 3 Development of ship model by CFD (Estimation of self propulsion factors)

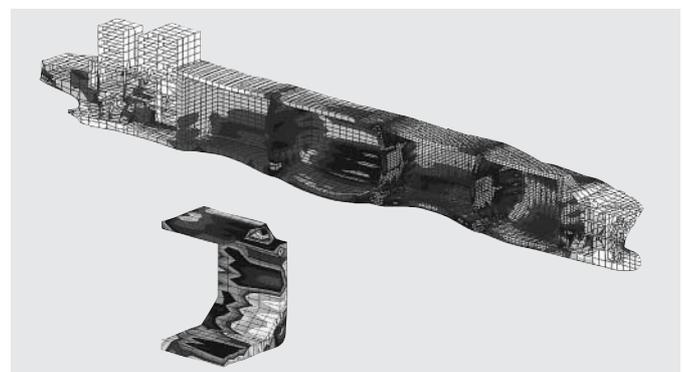


Fig. 4 Strength and fatigue analysis by an FEM model of the whole ship (amount of deformation is exaggerated for clarity)

**Figure 5** shows the arrangement of the piping system on the deck of the ship.

With regard to the tripod mast of the internal structure in the cargo tanks specific to membrane ships, MHI independently verified that excessive stress did not occur under all conditions of operation.

As for the automation system, the factors of the membrane system were incorporated into the system based on the know-how cultivated from the Moss system in order to simplify various operations such as cargo operations and to increase safety. In addition, the ship is also furnished with an automated system for exchanging ballast water to protect the marine environment.

### 4.3 Securing of design quality

The cargo containment system of the ship is an extremely large consisting of some 700000 structural components. In addition, since the inner hull structure is directly adjacent to the cargo containment system, sufficient quality must be secured for the inner hull and the surrounding ballast tanks in order to avoid water leakage into the cargo containment system.

For this purpose, a joint project team formed of the design department and the construction department was organized and design issues and building method were examined about two years before the start of actual design work. During the course of this examination, objects that needed to be carefully verified were narrowed through the analysis by FMEA (Failure Mode and Effects Analysis).

And verification in particular of the quality of the part components in the cargo containment system, the containment system itself (membrane, insulation box, other fastening devices), inner hull structures, coating of the ballast tanks, and the arrangement of the parts in the ballast tanks were surely studied.

Once the design began, abt. 100 items to be followed were taken up from the objective items determined during the preliminary verification, after which a follow-up system was organized, and efforts were made to secure the quality of the actual design, accordingly.

### 4.4 Manufacture and procurement of materials for cargo containment system

The key of the building of a Gaz Transport system LNG carrier is the procurement of insulation boxes amounting in quantity to 52000 per ship.

#### (1) Malaysian content and insulation materials

Upon request of the customer, MHI attempted production of insulation boxes using local plywood in Malaysia in order to promote industry and cultivate manufacturing technologies there.

Some kinds of wood were selected from the wood produced in Malaysia, and the plywood of the some candidate wood types were manufactured and tested. Finally, a Keruing plywood was approved by GTT. The insulation box was formed by Malaysian plywood and only top plate by Finnish plywood which facilitates handling by vacuum machine.

In order to adopt the plywood, productivity tests and the strength tests of box were carried out in addition to the strength tests of the plywood itself.

**Figure 6** shows a strength test of the insulation box.

#### (2) Organization for manufacture of insulation boxes

In the Malaysia plant, approximately 2/3 of the total number of insulation boxes were produced. Most of them were the standard type. For this purpose, local insulation box manufacturing company of joint venture were established under the lead of MHI.

**Figure 7** shows a view of the insulation boxes being produced at the Malaysia plant. The remaining 1/3 of the boxes, mainly of non-standard boxes, were manufactured at a plant in Japan.



Fig. 5 Arrangement of piping on deck

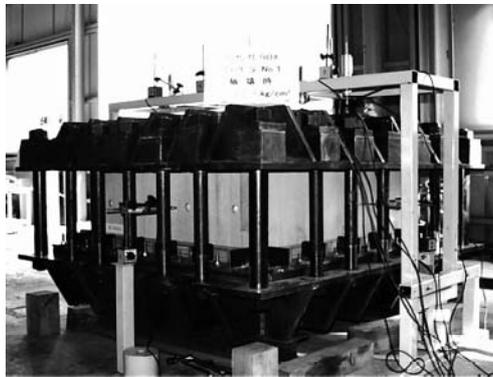


Fig. 6 Strength test of insulation box

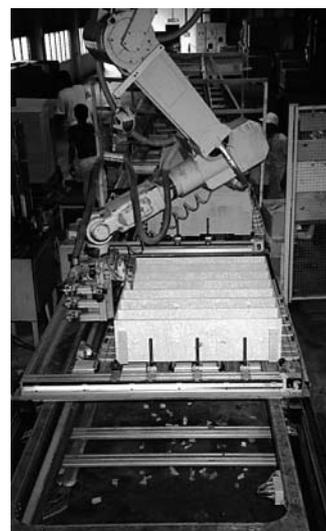


Fig. 7 View of side plate stapling robot in insulation box manufacturing factory

### (3) Procurement of invar materials

Invar materials for LNG carrier used to be exclusively handled by Imphy of France. Hence, MHI adopted the invar materials produced by Imphy in the 1st and 2nd ship of the project based on the track record of that company. At the same time, however, MHI also partly adopted the invar products of two companies in Japan, and endeavored to improve the workability and weldability of the materials. As a result, in the 3rd and later ship, MHI has adopted the products of the Japanese manufacturers, which have greater delivery flexibility.

As the result of efforts to satisfy the needs of the customers, MHI could develop and procure materials for the cargo containment system from new manufacturers while still placing emphasis on past track records. These materials form the main part of the membrane ship and successfully met the specified requirements for quality and performance.

#### 4.5 Logistic control and quality control in construction

The cargo containment work on the inner surface of the tank of the membrane type LNG carrier is performed on the scaffolds that are installed in the tank after the hull structure has been constructed (Fig. 8).

Unlike Moss ships which use aluminum alloy of approximately 40 to 150 mm in thickness, membrane ships are not only confronted with a number of technical problems, such as the need to master techniques for welding 0.7 mm

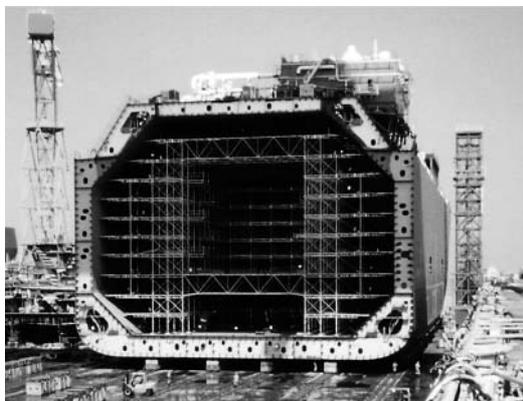


Fig. 8 Section of cargo tank under construction  
Scaffolds for construction of insulation installed in the tank.

thick sheets, but also need to pay close attention to several points such as establishing effective logistical and quality controls. These may include such controls as:

- Logistic control of a large volume of thermal insulation materials exceeding 700 000 items,
- Advanced precise control of the mounting of insulation boxes and membranes, and
- Confirmation of the integrity of welded points for membrane that may be as long as approximately 108 km.

#### (1) Logistic and quality control system

The cargo containment system consists of a variety of parts such as insulation boxes, invar materials, resin rope (resin material used to make sure the flatness of the insulation boxes), and couplers (insulation box mounting fittings). The total number of such items exceeds 700 000 items. Given this large number of items, effective logistical control of all parts becomes a key to the secure and proper building of the ship.

For effective logistics and quality control of the parts, MHI has developed the system so-called LOGIQ (LOGistics and Quality control system). The logistics system is requested to deliver parts to a proper place at a proper time. Parts are always collated with the latest building schedule, and adjusted and controlled, accordingly. The most important thing in the quality control system is to hold and evaluate the records of the inspection results ranging from production to final installation.

For example, although the secondary insulation boxes are mounted on the inner hull through a resin rope, the applicable portions of the rope and related parts must be re-worked if the resin is not suitably cured. In this task, traceability is essential to be able to specify a defective part.

For these purposes, data and inspection results are stored by the LOGIQ so that they can be monitored for traceability. The recognition of each part is performed using bar-codes, and the state of the inspection is confirmed by a separate monitor.

Using this system makes it possible for MHI to perform the logistical and quality control functions of the large number of parts much more efficiently and effectively (Fig. 9).

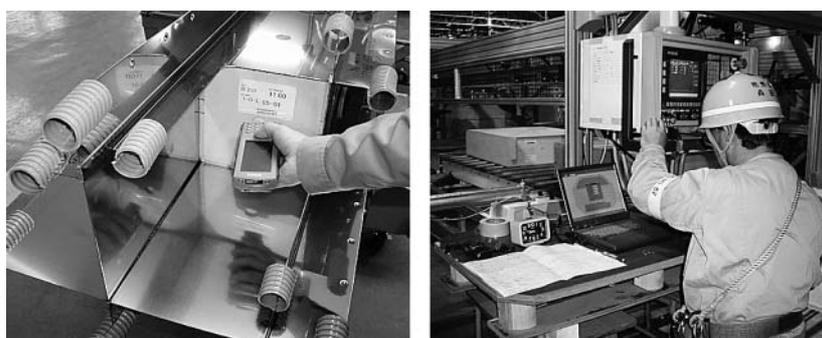


Fig. 9 Logistics and quality control system: LOGIQ for components of cargo containment system (Reading of bar codes on parts and control of resin ropes)

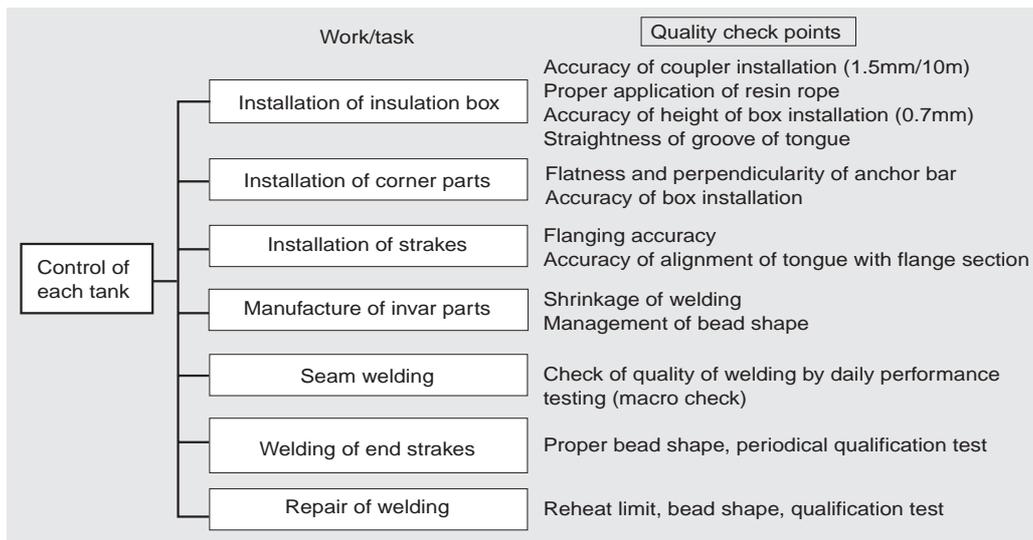


Fig. 10 Items of quality control in insulation work

## (2) Accurate quality control

The base of the membrane must be adjusted as flat as possible for carrying out the welding of the membrane with a high degree of accuracy to prevent any problems related to strength from occurring in the membrane part, which forms the inner wall of cargo tank.

The range of the quality checks for this work is wide and deep, including checking the flatness of the inner hull, the mounting accuracy of the coupler, the height accuracy of each insulation box, the mounting accuracy of the membrane, and welding accuracy, etc. An example of quality control items generally covered is shown in Fig. 10.

## (3) Leak test

Welding length of membrane extends to approximately 108 km in total. The welded points must be checked visually and also shall be confirmed the no possibility of leak. For this purpose, after the membrane installation work is completed, a helium leak test (identification of leaking parts) and a global tightness test (confirmation of the tightness of the overall tank system) shall be performed to confirm the integrity of the welded points.

In the helium leak test, shown in Fig. 11, helium with a concentration of 20% is filled into the insulation layer and pressurized. An helium leak detector runs along all weld points of the membrane to check for any leakage of helium. In the global tightness test, the insulation layer is brought to a vacuum (-800 mbG) state, and its pressure is measured for 24 hours to check that any variations in pressure fall within allowable values. These tests are performed for each of the tanks and insulation layers. Apart from the GTT's instruction, MHI has developed its own eddy current based defect detector which is utilized beforehand prior to leak inspections to check the integrity of the welded seam, which comprise about 83% of the all welded points. Figure 12 shows the inner surface of a completed cargo tank.

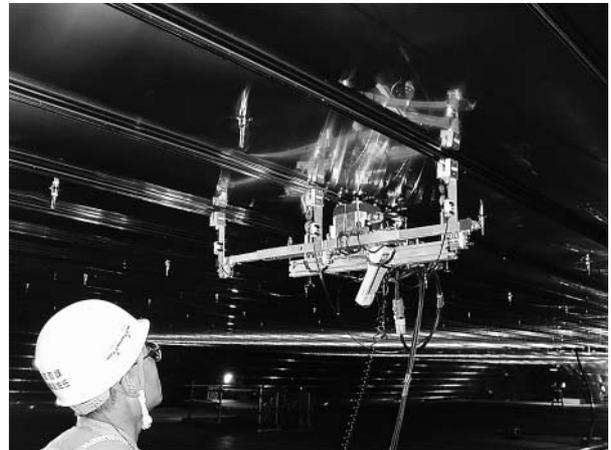


Fig. 11 Detector for helium leak test



Fig. 12 View of interior of completed cargo tank

## 5. Future trends of membrane LNG carriers

Various future trends of LNG carriers can be considered. A brief description is given here of an enlargement in size and a new cargo containment system.

### 5.1 Enlargement in the size of cargo tank

The merit of enlarging the size of LNG carriers is to raise the economic efficiency due to a reduction in unit transportation cost. The tank size of the LNG carriers now under construction are gradually increasing from 135 000 m<sup>3</sup> to 145 000 m<sup>3</sup> class, with further expansion to 150 000 m<sup>3</sup> class. Further, work is already now under way on the design of 200 000 m<sup>3</sup> class. Compared with the Moss type of the same tank capacity, the membrane type can be designed with more compact form, and it is considered to be comparatively suitable for enlargement of cargo tank size.

One of the points to be considered in enlargement of size is the ship-shore compatibility with existing LNG terminals. Based on the restriction of LNG terminals, the 150 000 m<sup>3</sup> class LNG carriers have best compatibility with existing LNG terminals, which thus have the maximum flexibility, in general. Although the number of terminals is limited, 160 000 m<sup>3</sup> class LNG carriers are the maximum size that have the compatibility with existing terminals. Carrier sizes beyond this class shall be considered for the newly planned large terminals.

Another points to be considered in enlargement of size with membrane ship is the counter-measures for sloshing. At present, four tanks design can be done in the range of 150 000 to 160 000 m<sup>3</sup> class, and five tanks design is said to be sure in the 200 000 m<sup>3</sup> class from the view point of sloshing. To reduce the number of tanks, it is necessary to continue to investigate and evaluate the sloshing in large-sized ships in the future.

### 5.2 New CS-1 cargo containment system

In recent years, a new CS-1 cargo containment system has been developed by GTT in which the advantages of both Gaz Transport and Technigaz systems have been combined together into one system. The basic structure of the system uses invar (Gaz Transport system) for a membrane, reinforced plastic foam (Technigaz system) for insulation, and triplex (material formed by aluminum sheet reinforced with glass cloth: Technigaz system) for secondary barriers.

At present, MHI have been performing a technical verification of the CS-1 in association with GTT and Classification Societies mainly with respect to those items that have been changed from the Gaz Transport system (structure of invar tube corners, corrugated strips, invar/triplex adhesion) and has been verifying the installation of the system using a mock-up model. Through these works, we have reached to the level to offer this system in actual business according to the request of customers, paying attention to the actual ship application in France.

## 6. Conclusion

After introducing the basic technologies of Moss type and membrane type LNG carriers in the period from 1969 to 1973, MHI has developed various technologies for safety and economic efficiency, and has applied these to actual ships. Based on the long-term accumulation of the technologies and expertise, MHI has now built and delivered the first large membrane ship of its type to be built in Japan. Now, MHI could supply both Moss and membrane systems according to the needs of customers.

In the ever increasing demand for LNG expected in the future, the circumstances surrounding LNG is changing and the needs for LNG carriers by customers are also becoming more diversified. By making full use of the experience in building of membrane ships, MHI would like to make challenge of supplying customers with attractive LNG carriers. Especially, MHI will actively endeavor to achieve enlargement in size, environmentally friendly plants and CS-1 from the viewpoint of a CS (Customer Satisfaction) improving transportation economy.

Now, MHI has received an order for five large membrane LNG carriers (152 300 m<sup>3</sup>) on August, 2004.

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