SAYARINGO STaGE
– Next Generation MOSS-type LNG Carrier with hybrid propulsion plant –

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Mitsubishi Heavy Industries, Ltd. (MHI) developed a liquefied natural gas (LNG) carrier named "Sayaringo STaGE" for shipping shale gas from North America to Japan. The Sayaringo STaGE has a continuous cover over the tanks, a feature inherited from its predecessor the Sayaendo, and while keeping this merit, incorporates apple-shaped MOSS-type tanks and a twin-shaft hybrid propulsion system "STaGE" plant, enhancing economic efficiency, environment friendliness, and versatility. This report outlines the Sayaringo STaGE, which was developed based on MHI's cutting-edge technology.

1. Introduction

The Sayaringo STaGE (**Figure 1**) was developed by enhancing the highly regarded Sayaendo LNG carrier, which was also developed and built by MHI. The Sayaendo was named after *sayaendo* (podded peas) because its *mame* (legume)-like spherical tanks are covered with a continuous *saya* (pea)-like cover. On the other hand, the Sayaringo STaGE also has a continuous cover over the tanks. The reason for the naming is the upper semi-sphere of the tanks is larger than the lower semi-sphere, and the swelling shape of the tank seems like a *ringo* (apple) in the *saya* (pea)-like cover.

Other inherited advantages are the lightweight hull, low-wind resistance, and good maintainability. By combining the inherited features with the newly adopted propulsion system concept "STaGE," the Sayaringo STaGE dramatically enhances its fuel efficiency. The Sayaringo STaGE aims to ship LNG from North American shale gas deposits, which have recently been in the news regarding expansion of LNG resources. MHI has already received several orders. The following are the details of the Sayaringo STaGE.

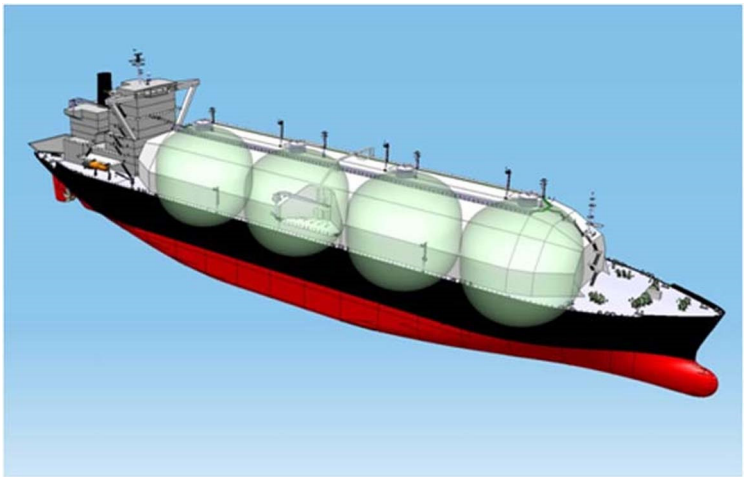

Figure 1 The Sayaringo STaGE

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2. Development background

2.1 Needs from shale gas projects

Historically, Japan has imported LNG mainly from the Middle East, Southeast Asia, and Australia. In terms of energy security and stable energy prices, it is desirable to expand energy resources. Recently, shale gas production has surged thanks to technological innovation, launching many projects to import LNG from North America to Japan to add shale gas as a new energy resource. The Sayaringo STaGE was developed to meet such demands. The proposed shipping routes have the following difficulties that are different from conventional routes.

(1) Long-distance routes

The LNG export terminals are located along the U.S. Gulf Coast and East Coast. The LNG carriers have to sail about 10,000 nautical miles (18,500 km) one-way from these terminals to Japan passing through the Gulf of Mexico, Panama Canal, and the North Pacific Ocean.

(2) Severe marine conditions

Severe marine conditions such as hurricanes in the Gulf of Mexico and on the east coast, as well as harsh weather in the North Pacific Ocean in the winter, are common on the routes.

(3) Ship size limits

To pass through the New Panama Canal, the LNG carrier has to meet the New Panamax limits on ship dimensions (**Table 1**), which also maintain compatibility with the LNG export/import terminals in the U.S. and Japan.

Table 1 New Panamax (Source: The Panama Canal Authority website)

	Length	Width	Draft
Lock gate* dimension	427m	55m	18.3m
Maximum ship size	366m	49m	15.2m

* A gate to raise or lower ships from one water level to another on rivers or canals

(4) Environmental concerns

The sea area off the Pacific Coast of the U.S. and Canada is designated as an Emission Control Area (ECA). Ships passing through ECAs have to minimize the environmental impact of propulsion plant exhaust -gas.

2.2 Development concept and solutions

The development concept includes securing LNG supply, reducing shipping costs, and meeting the requirements described in Section 2.1 and below.

- Building an LNG carrier with high reliability and safety that matches the characteristics of the shipping routes.
- Pursuing economic benefits by reducing the life cycle cost.

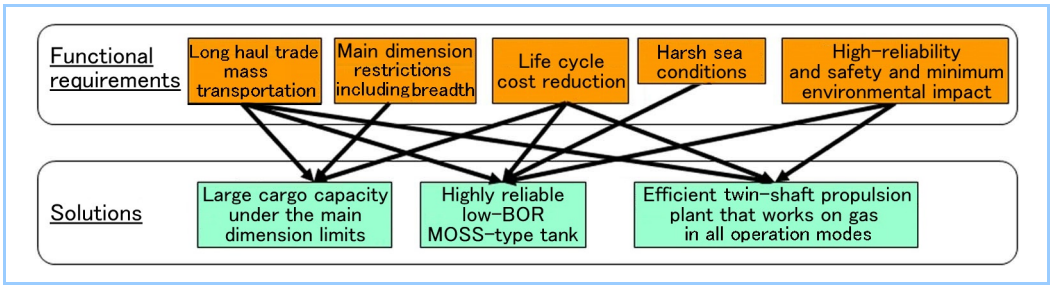

Figure 2 Functional requirements and solutions

Figure 2 shows the functional requirements of the development concept and the linkage between the solutions. The Sayaringo STaGE is developed based on the already-built model, the Sayaendo, to meet the following requirements:

(1) Highly versatile ship size that meets the New Panamax limits and matches existing LNG terminals, while securing the maximum cargo capacity.

(2) Low boil off rate (BOR, an index of volume of gas generated by heat penetration) and high-reliability by using MOSS-type cargo tanks.

(3) New concept of efficient propulsion system that enables gas burning in all operation modes including in harbors.
The details are described in Chapter 3.

3. Features of the Sayaringo STaGE

3.1 Principal dimensions and layout

Table 2 is the comparison of the principal dimensions between the Sayaendo and the Sayaringo STaGE. The Sayaringo STaGE uses the same continuous tank cover as the Sayaendo, inheriting the lightweight hull and low-wind resistance. Combining the inherited benefits with further improvements, the Sayaringo STaGE becomes a state-of-the-art LNG carrier. The highly versatile dimensions of less than 300 m in length overall and less than 49 m in breadth matches the New Panamax limits and with over 100 LNG terminals worldwide without sacrificing the maximum cargo capacity. A twin-skeg hull (**Figure 3**) and a hybrid propulsion plant "STaGE" using an efficient twin-shaft steam turbine are newly adopted.

Table 2 Comparison of principal dimensions

	The Sayaendo	The Sayaringo STaGE
LNG tank type	4 spherical tanks (stretch type)	4 spherical tanks (apple-shaped)
Cargo capacity (m^3) (100% full at -163°C and, atmospheric pressure; excluding dome)	abt. 155,300	abt. 180,000 *1
Loa (m)	abt. 288.0	abt. 297.5 *2
B (mld.) (m)	48.94	48.94
D (mld.) (m)	26.0	27.0
Service speed (kt)	19.5	19.5
Propulsion plant	Single-shaft single-rudder UST (ultra-steam turbine)	Twin-shaft twin-rudder STaGE (steam turbine and gas engine)

*1: Changeable from 165,000 m^3 to 180,000 m^3
*2: Depends on cargo capacity

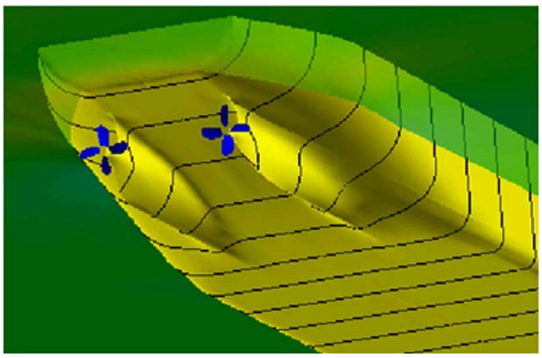

Figure 3 Twin-skeg hull

Owing to the continuous tank cover, the layout around the cargo compartments is similar to the Sayaendo. The cargo manifolds, which are to connect with onshore LNG terminals during cargo loading/unloading, are placed between No. 2 Tank and No. 3 Tank, and the cargo machinery room is arranged inside the tank cover between the No. 3 Tank and No. 4 Tank. The complex structures that support pipes, wires, and passageway placed over the cover are simpler than those of conventional tankers with semi-sphere tank covers, significantly enhancing maintainability.

3.2 Apple-shaped LNG tanks[(3)]

The apple-shaped LNG tanks are based on a highly reliable MOSS-type tank with extensive track records. MHI improved the MOSS-type tank into an apple-like shape to increase the volumetric efficiency and maximize the cargo capacity along with meeting the New Panamax limits, and thus named it the "apple-shaped tank" because of its appearance.

Figure 4 compares the ordinary stretched MOSS-type tank used in the Sayaendo and the apple-shaped tank. The ordinary tank consists of semi-spheres and a cylinder, and the apple-shaped tank consists of a donut-shaped torus as well as semi-spheres and a cylinder. Because of the lower height, the center of gravity of the apple-shaped tank is at a lower position than the ordinary one despite the same volumetric capacity.

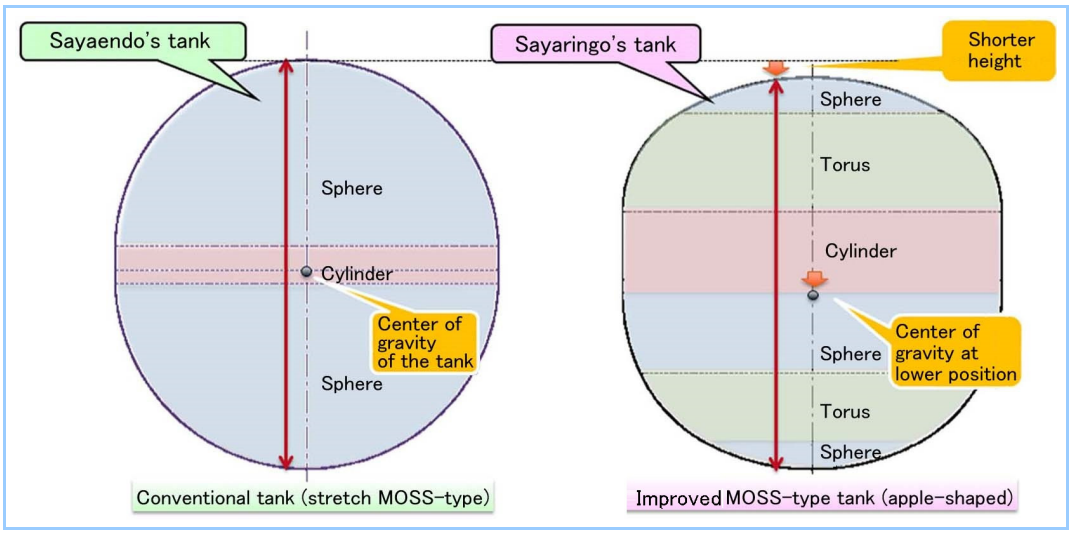

Figure 4 Comparison between conventional tank and apple-shaped tank

The total holding capacity of the tanks is changeable from 165 km^3 to 180 km^3 depending on the customer's shipping needs by adjusting the composition ratio of the semi-spheres, cylinder, and torus.

The outer surface of the aluminum tanks is covered with heat insulator. The heat insulator thickness is different in each place depending on the surrounding structures and conditions to keep the predetermined heat insulation for the whole tanks.

3.3 Propulsion plant STaGE

STaGE (**Figure 5**) is an abbreviation for Steam Turbine and Gas Engine, and is a hybrid propulsion plant that consists of an ultra-steam turbine (UST) plant on the port side and a combination of a dual-fuel diesel engine (DFE) and a propulsion electric motor (PEM), DFE-PEM plant, on the starboard side. The MHI UST plant is also used in the Sayaendo. The DFE can work on both gas and oil. The details of the features are described below.

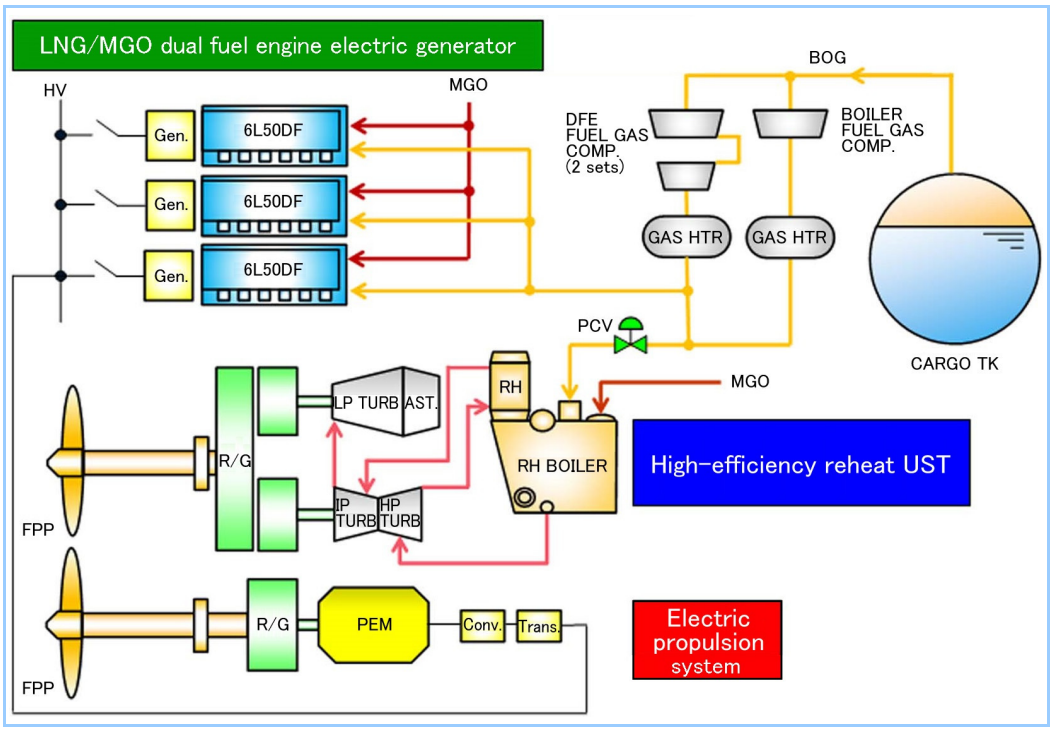

Figure 5 STaGE propulsion plant

(1) High-fuel efficiency

The exhaust-gas and jacket waste heat from the DFE are recovered to heat the feedwater going toward the UST plant, achieving significant improvement in fuel efficiency.

Figure 6 shows the image of waste heat recovery in the STaGE plant. In the UST plant,

the heated feedwater flows to the boiler to generate steam to be used to drive the turbine. The electricity generated by the DFEs drives the PEM. Ordinarily, a huge amount of waste heat from DFEs is dumped into the exhaust-gas and jacket cooling water. But the STaGE plant uses the waste heat to heat the boiler feedwater, enhancing the plant's total efficiency.

The waste heat from the DFEs is also recycled to generate auxiliary steam as well as the drive steam for the main turbine, also enhancing total efficiency. Instead of a turbine generator used in conventional steam turbine plants, the power generator of the DFE plant supplies power to the ship, resulting in a simpler plant configuration and higher efficiency.

As such, the STaGE plant achieves significant efficiency enhancement by combining two different propulsion engines and by optimizing the waste heat energy.

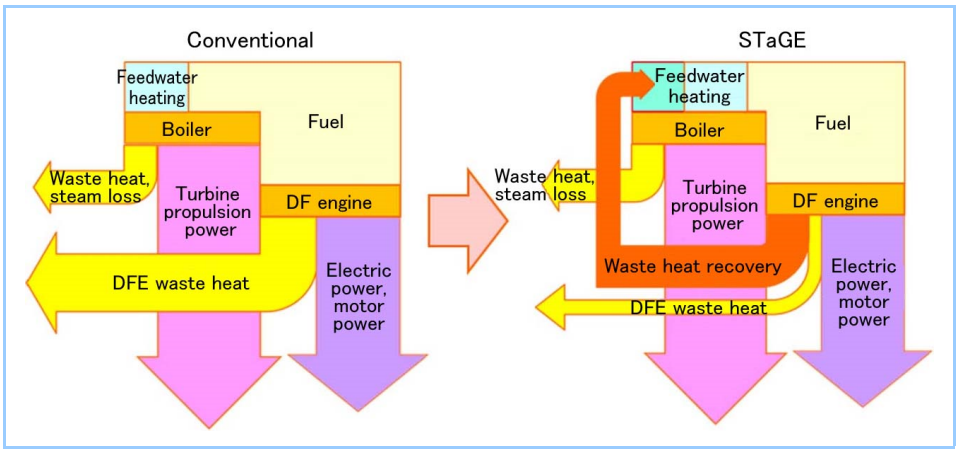

Figure 6 Image comparison of waste heat recovery

(2) Easy maintenance

The main engines are the maintenance-free UST plant and the DFE-PEM plant. There are about 20 cylinders, which are about half that for an only-DFE-PEM plant. This reduces the maintenance workload and DFE maintenance cost and also halves the usage of lubricant and pilot oil (MGO).

(3) Excellent environmental performance

The STaGE plant itself emits about 20% less CO_2 than conventional turbine plants. The Sayaringo as a whole emits about 40% less CO_2 per cargo unit than conventional LNG carriers with a 147 km^3 cargo capacity and conventional turbine plant, thanks to the STaGE plant and the various design improvements described above including remodeled enlarged light-weight twin-skeg hull-form and wind load reduction (**Figure 7**).

Gas burning is available in all operation modes, including in harbors, achieving high environmental performance that meets the emission regulations in the North American ECA.

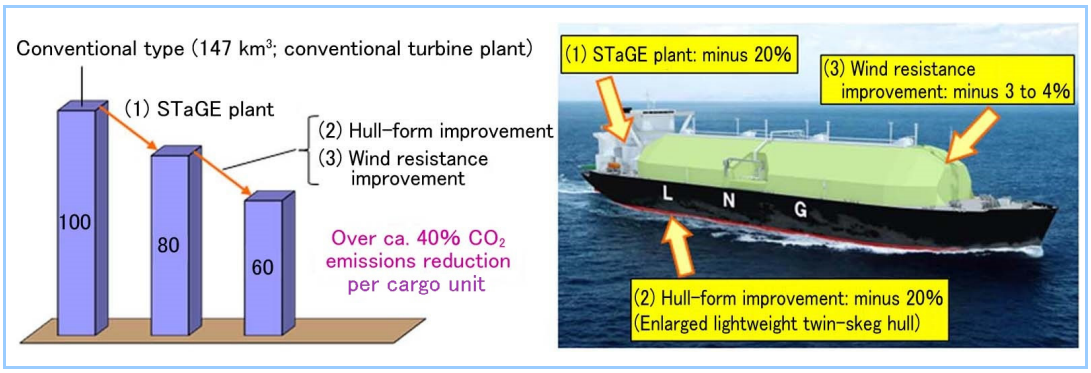

Figure 7 CO_2 reduction effects per cargo unit of Sayaringo

(4) High reliability

The STaGE plant gains high-reliability by combining the proven turbine plant and DFE-PEM plant and high-redundancy by using different propulsion systems on both port and starboard sides.

4. Other features of Sayaringo STaGE

4.1 Maneuverability

One of the important indexes showing LNG carrier performance is ship maneuverability during port arrival and departure. Due to the continuous tank cover and twin-skeg hull-form, the Sayaringo has different wind resistance and fluid properties from single-shaft LNG carriers with conventional tanks. **Figure 8** is the simulation results showing in-port maneuverability including straight-ahead, pinwheeling, and sideways sliding (docking) conducted by an independent third party, Japan Marine Science Inc. These results verify the Sayaringo has sufficient in-port maneuverability that equals or surpasses conventional single-shaft LNG carriers with conventional tank covers.

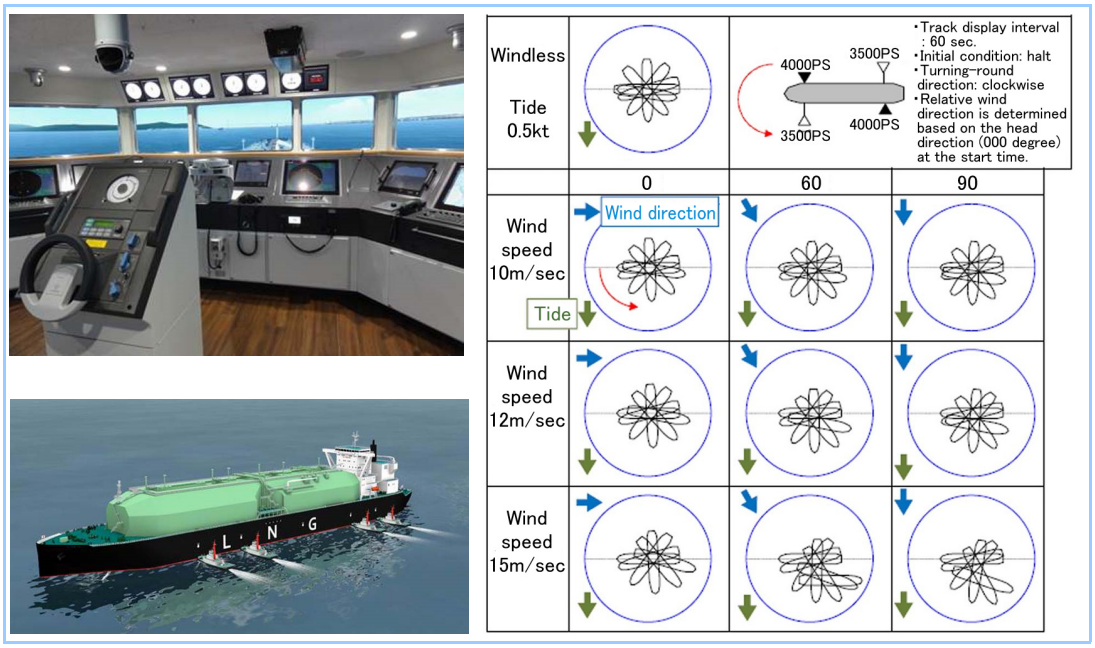

Figure 8 Maneuverability simulations

4.2 Flexible gas operation at low load of main engine (Liquid pressure and heat accumulation in cargo tank)

More flexible gas operation has been required amid diversified purposes of LNG carrier use and newly proposed shipping routes such as for shipping shale gas through the Panama Canal. While passing through the canal or stopping before it, the main engine load is particularly low because of the decreased gas consumption in the main engine. In this condition, some amount of gas fuel has to be disposed of by being wastefully combusted in the boiler or gas combustion unit (without being used for propulsion) to prevent the cargo tank pressure from surpassing the acceptable value. It is important to prevent or minimize such wasteful gas fuel disposal.

In fully loaded conditions, the LNG can store penetrated heat as sensible heat. If the liquid-phase surface under a vapor-liquid equilibrium is partially heated, however, the cargo tank pressure may sometimes increase before gaining sufficient heat store effect. To avoid it, the tank should be equipped with LNG spray nozzles to cool the liquid phase surface. Then, some of the nozzles are relocated to the upper position so that the liquid phase surface can be sufficiently sprayed and cooled in fully loaded conditions.

In ballast conditions, the amount of LNG is too small to turn the penetrated heat into sensible heat. The gas temperature is inevitably and significantly increased due to the penetration heat, resulting in a cargo tank pressure rise. One solution is to recognize the cargo tanks as accumulators and the excess gas as pressure. To avoid this, MHI recommended increasing the cargo tank pressure to 100 kPaG (for example), which is higher than the ordinary upper limit of 25 kPaG, only in ballast conditions. There is no need to additionally reinforce the tanks to maintain the high pressure because the liquid pressure in ballast conditions is low and allowable. The upper pressure limits of the tanks are different in ballast and fully loaded conditions, requiring different working pressure for safety valves. For a specific countermeasure, MHI recommended double-pilot safety

valves (**Figure 9**) for the cargo tanks.

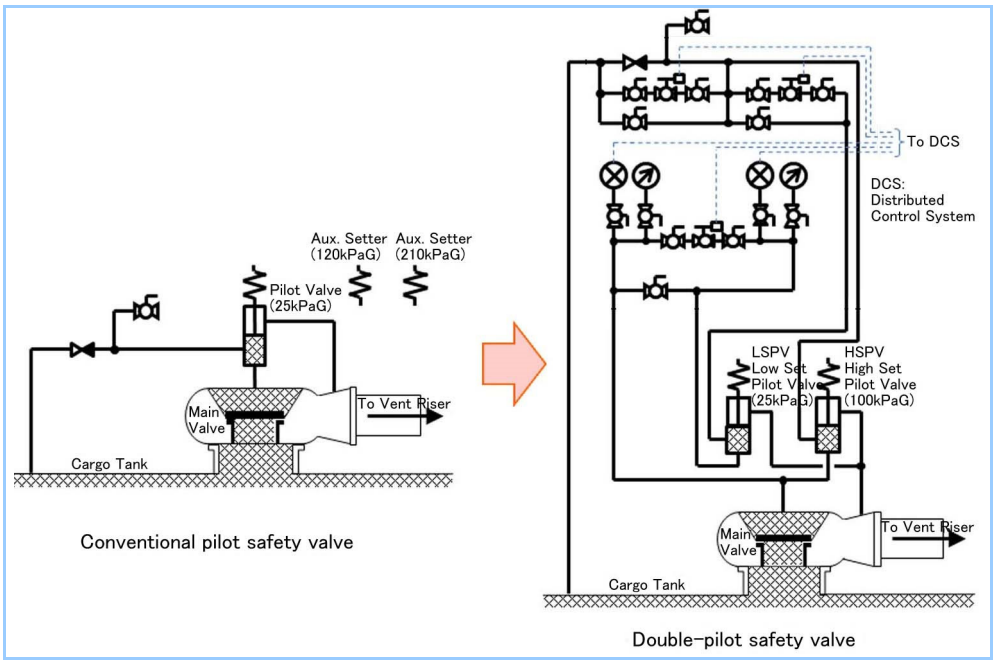

Figure 9 Double-pilot safety valve

4.3 Optimum load sharing (OLS) of the main engine

The DFE-PEM plant changes the number of working DFEs depending on the required output. Changing the number of working DFEs also significantly changes the DFE load and fuel consumption in a step-by-step manner at the required output. For example, if the number of working DFEs has to be increased to meet the required propulsion speed, the DFE load significantly drops, resulting in low-efficient operation.

On the other hand, the STaGE plant has different propulsion plants on the port side and starboard side. It enables OLS by sharing the increased load with the turbine under conditions where other DFEs are supposed to work to provide the required ship speed (**Figure 10**).

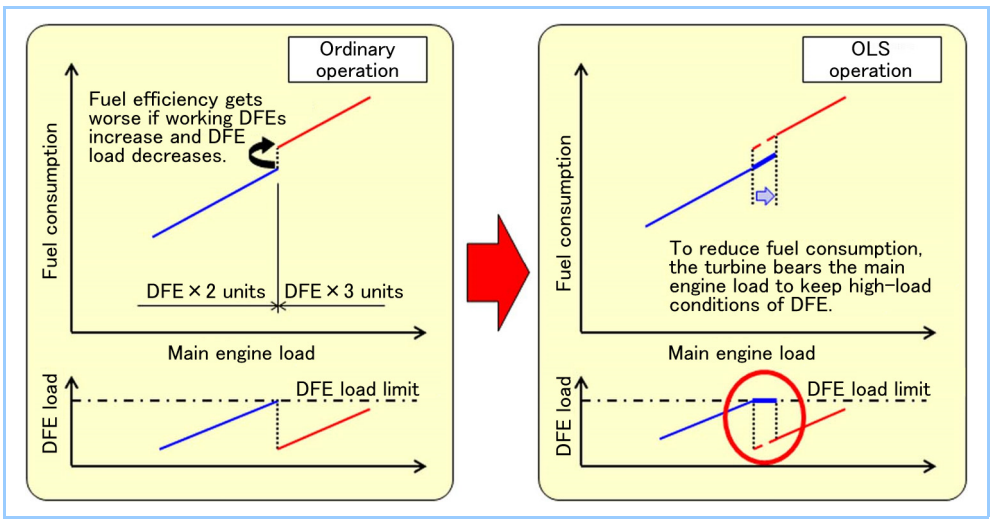

Figure 10 Optimum load sharing (OLS) of main engine

5. Conclusion

The demand for LNG as a power generation fuel has recently surged worldwide. MHI developed the Sayaringo STaGE for shipping North American shale gas.

This cutting-edge LNG carrier, which inherits the benefits of the Sayaendo, is based on MHI's own technologies such as apple-shaped tanks and STaGE propulsion system and ensures high ship-shore compatibility for LNG terminals across the globe, achieving excellent shipping efficiency, fuel efficiency, and environmental performance. The various assessments on the

economy and technology verified the excellent benefits of the Sayaringo STaGE even in the early development stage. Gaining a good reputation, MHI has already received several orders and begun construction. The Sayaringo STaGE has joined in MHI's specialty LNG carrier lineup as one of the flagship products. MHI intends to continue making efforts to strongly support the global LNG supply chain by developing LNG carriers that meet diversifying LNG shipping methods and customer needs.

References

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