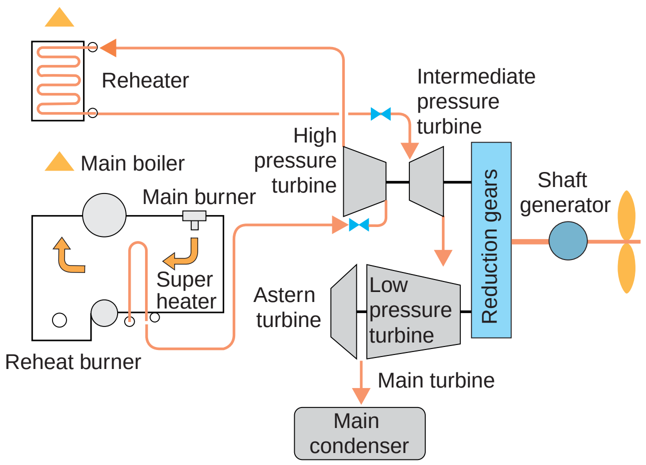

Development of High Efficiency Marine Propulsion Plant (Ultra Steam Turbine)

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One environmental change for LNG carriers in recent years is the very rapid increase in propulsion plant energy saving, which is attributed to the increase in the price of crude oil. In an effort to cope with this, in addition to conventional steam turbine ships, the DFE (dual fuel engine) ship with an electric propulsion motor, with higher plant efficiency and the DRL (diesel engine with re-liquefaction plant) ship fitted with a 2 cycle, low speed engine, for propulsion have been introduced. The first DFE ship was built in a French shipyard and is already in service, and a number of the LNG carriers with DFE and DRL plants are now being constructed in Korea. Although existing steam turbine plants have good operational reliability, maintainability, and operability proven by past performance, they are far behind the new plants in plant efficiency, which is an urgent issue. To address this issue, Mitsubishi Heavy Industries, Ltd. (MHI) has developed the UST (ultra steam turbine) with 15% higher efficiency than a conventional steam turbine plant, while retaining the high reliability, maintenance workability, and operability of a conventional plant. This paper introduces this new UST plant.

1. Introduction

Until a few years ago, steam turbines were used for almost all LNG carriers for the propulsion plant because of their operation profitability, reliability, operability, maintainability and initial investment. Another reason is that the steam turbine plant could safely treat boil-off gas (BOG) generated from the cargo tank and could also use heavy oil as fuel.

However, due to the following factors, new DFE and DRL plants using diesel engines began to attract attention and the use of alternative propulsion plants accelerated rapidly. These factors include: (1) the introduction of gas-burning diesel engines, (2) energy-saving trends as a result of the rising price of crude oil in recent years, and (3) a shortage of crew for steam turbine ships due to the LNG carrier construction boom caused by the rapid increase in worldwide demand for natural gas. In the current LNG carrier market, it is no exaggeration to say that DFE and DRL ships are becoming the mainstream.

However, as the new DFE and DRL plants use new technology, it is naturally presumed that the crew will also need a level of technical knowledge as with turbine ships. In other words, in selecting a propulsion plant for an LNG carrier today, plant efficiency is the most important issue. In these circumstances, MHI has developed the UST (ultra steam turbine) plant whose efficiency is equal to the new diesel plants while retaining the merits of conventional turbine plants.

2. UST plant

2.1 Plant configuration

The UST plant is a 2-stage feed water heating system based on the reheat cycle, ensuring a simple configuration considering improved efficiency, operability, and maintainability. A comparison with the conventional plant is shown in **Table 1**.

Table 1 Comparison of conventional steam turbine plant and UST plant

	CST (conventional plant)	UST
Boiler steam conditions	6 MPa X 515°C	HP: 10 MPa X 560°C
Steam flow	BLR→HP→LP	BLR→ HP → REHTR → IP → LP
Flange standard	ANSI 900 LB	ANSI 2500 LB

BLR: boiler, HP: high pressure turbine, LP: low pressure turbine
REHTR: reheater, IP: intermediate pressure turbine

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The steam conditions of the UST plant were determined considering the actual performance and cost-effectiveness of land use natural circulation boilers as well as the scope of the ANSI2500LB flange. On the reheat cycle plant, steam flows through the reheater (REHTR) as shown in **Fig. 1**.

2.2 UST plant layout

An outline of the arrangement of the UST plant on a vessel is shown below (**Fig. 2**). The space required for a UST plant is the same as a conventional steam turbine plant.

3. UST turbine

3.1 Components of UST turbine

The UST turbine is an MHI high performance turbine based on the latest technology and which has a good track record for land use. It consists of a high/intermediate pressure turbine (**Fig. 3**), a low pressure turbine, a main condenser and a reduction gear unit located in a single casing and on a single shaft.

3.2 Adoption of the latest technology

3.2.1 Thermal shield

While HP and IP turbines are located in the same single casing, we should remember that the operation mode of the UST turbine is different from land use turbine. That is, the UST turbine requires both start and stop operations within one voyage and the HP/IP turbine casing in particular is subjected to repeated thermal loads.

The severe difference between HP turbine inlet steam temperature and LP turbine inlet steam temperature may cause uneven deformation of the casing and consequent steam leakage from the horizontal flange of HP/IP casing. For that purpose, a thermal shield structure has been applied, which has been proven in MHI land-use turbines (**Fig. 4**).

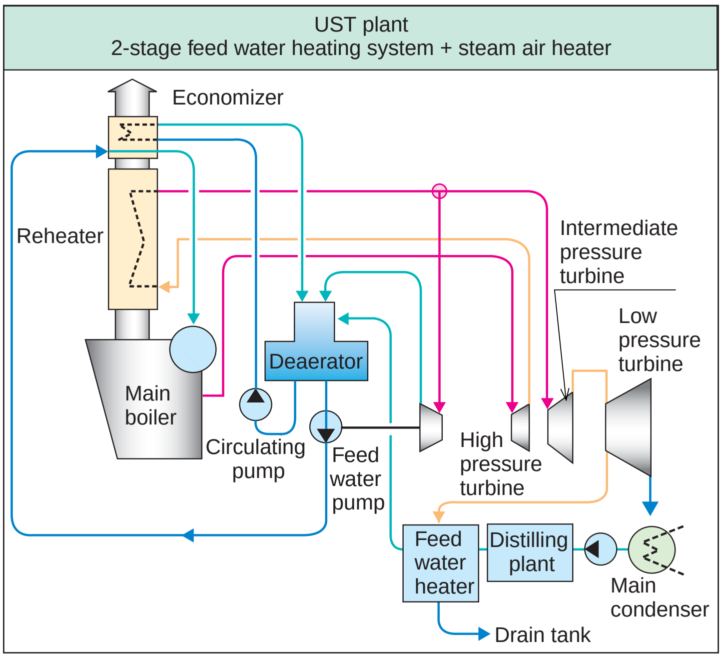

Fig. 1 Configuration of UST plant

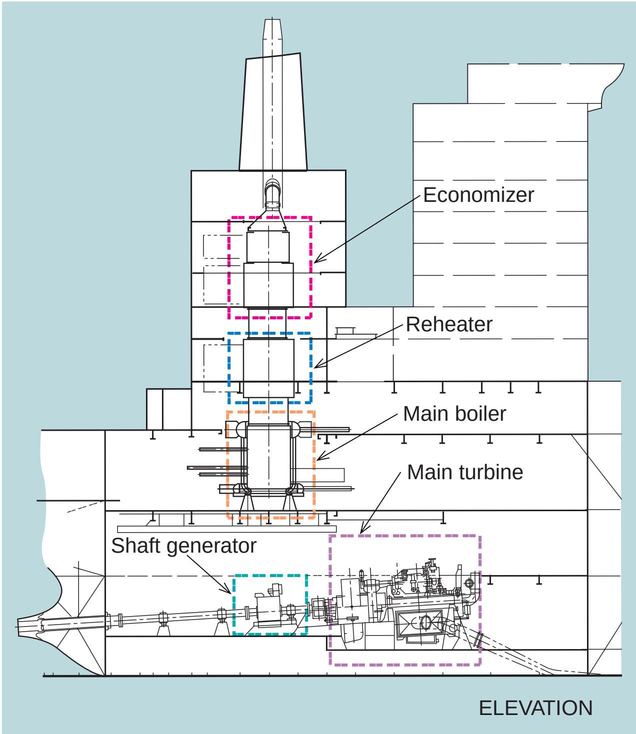

Fig. 2 Layout of UST plant

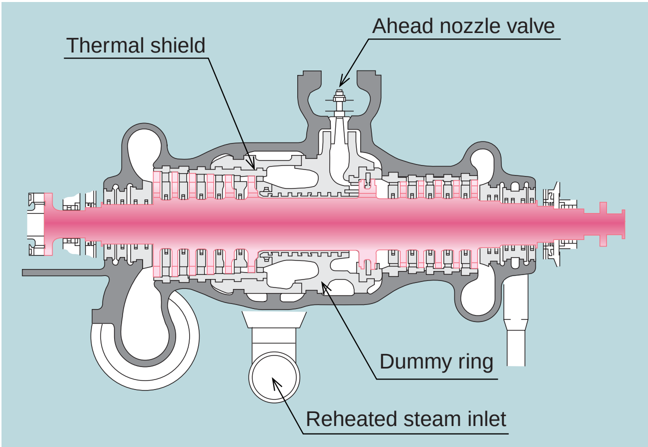

Fig. 3 Cross-section of UST high/intermediate pressure turbine

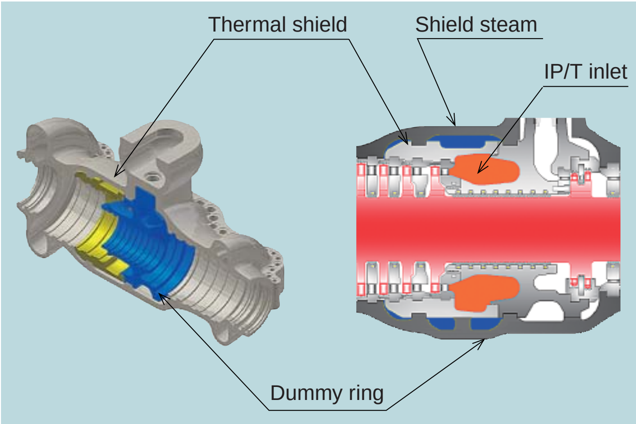

Fig. 4 Thermal shield and dummy ring

3.2.2 Technology to improve turbine performance

Figures 5 and **6** show the latest technologies that were introduced for the UST to improve turbine performance.

4. UST boiler

4.1 UST boiler

The re-heater is designed to achieve a specified steam temperature by using the reheat burner (**Fig. 7**). The reheat burner stops automatically in low steam flow conditions (reduction of tube cooling effect), so that the tubes are not exposed to high temperature combustion gas. In this situation, there is no damaging effect on the reheater tubes because the combustion gas temperature from the main furnace will be low. Therefore, the reheater is thoroughly protected, simply by stopping the reheat burner.

In addition, high reliability is to be expected over long-term operation, because there are no moveable parts, gas damper etc., in the flow path of the combustion gas. Also, in order to ensure the main steam conditions, we have adopted the vertical twin header super heater system shown in **Fig. 8** to secure the heat transfer area and also use 18 Cr stainless steel which is resistant to high-temperature corrosion.

4.2 Boiler performance verification test

4.2.1 Boiler cold model test

For the development of the UST boiler, a cold boiler model test (fluid dynamic simulation test) was carried out using the 1/4 scale simulator at MHI Nagasaki's R&D Center (**Fig. 9**). In this test the distribution of the exhaust gas temperature at the boiler outlet could be analyzed and optimized. As a result, we ensured a uniform gas flow by using shielding material at the exhaust gas outlet.

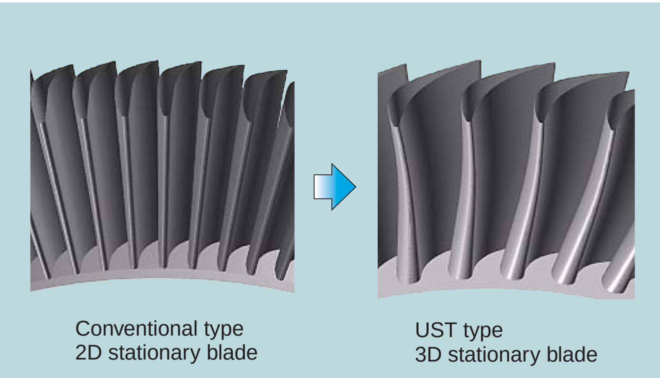

Fig. 5 3D stationary blade (low pressure turbine reaction stage)
Adoption of the 3D stationary blade which improves blade performance by optimizing the blade form three-dimensionally.

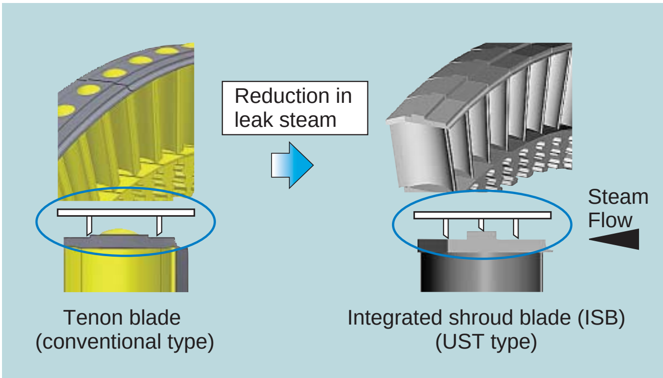

Fig. 6 Conventional tenon blade and UST type integral shroud blade (ISB)
The use of ISB reduces steam leaks at the blade periphery by improving the steam seal section as in the above drawing.

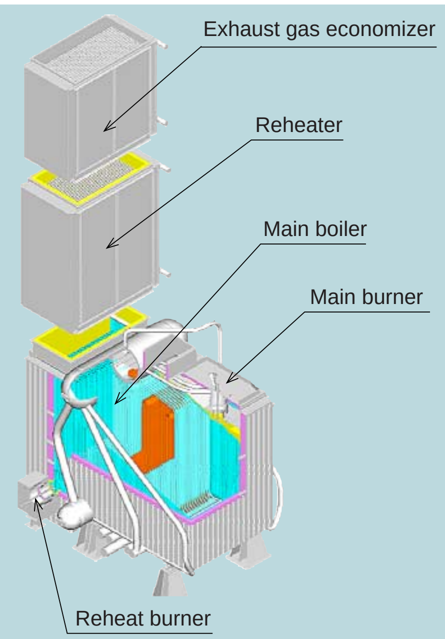

Fig. 7 Outline drawing of UST boiler

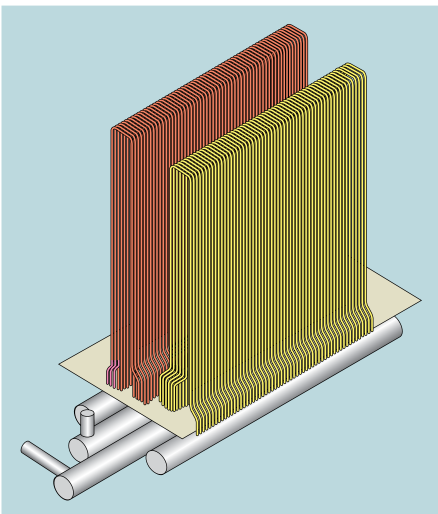

Fig. 8 Outline drawing of super heater

Fig. 9 Gas flow test model

4.2.2 Combustion test of reheat burner

The reheat burner of the UST boiler is installed in the path of the boiler exhaust gas flow. Therefore it was necessary to check the influence of the exhaust gas flow when burning the reheat burner, so an ignition test and a low load firing test were carried out using the test furnace of the burner manufacturer. As a result, an excellent state of combustion and ignition performance were confirmed in an extreme gas flow (**Fig. 10**).

4.2.3 Plant simulator

In order to understand the dynamic behavior of the UST plant, we built a plant model and developed a simulator which can deal with all kinds of load fluctuations.

As shown in **Fig. 11**, the simulator has a function which displays the changes taking place in each part of the plant as the trend data and the dynamic behavior of each part become analyzable, thus contributing to the automation and instrumentation of the UST plant.

A dynamic condition analysis in all operations was necessary to analyze the dynamic behavior of the UST plant. This plant simulator can simulate all loads and operations.

The dynamic behavior of each parameter (for example, the steam temperature and pressure, fuel flow and M/T output) can be identified and they are displayed as trend data in the table below (Fig. 11).

It is very important to verify the dynamic condition of each parameter and this simulation is also useful for the development of the control and automation system for the UST plant (both turbine and boiler).

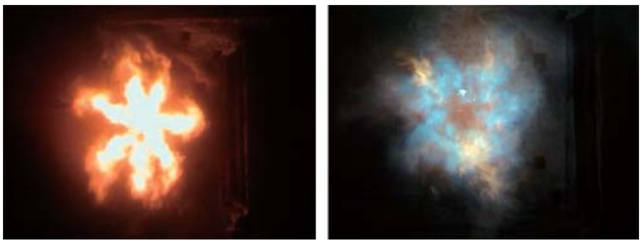

Fig. 10 Combustion of reheat burner at low load

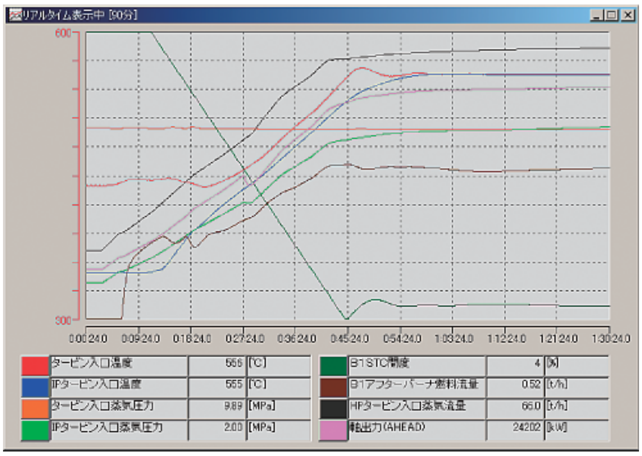

Fig. 11 Example simulator screen

5. Shaft generator

One shaft generator motor (SGM) is located on the intermediate shaft. Under normal operation, the SGM is used as a generator to improve the plant efficiency (SG mode). If the operator wants 100% MCR power when one re-heater is out of service, the SGM can be changed to assist motor mode (PAM mode). By this operation, the propulsion power will be recovered to 100% MCR (**Fig. 12**).

6. Influence on environment

6.1 Comparison of exhaust gas components during navigation (gas single fuel combustion mode)

Under normal sea going conditions in gas burning mode, SOx is not emitted at all from the propulsion plant, and the emission of NOx and CO_2 from the steam turbine plant is the smallest of all propulsion plants. The UST's emissions are smaller than conventional steam turbine plants due to fuel saving (**Fig. 13**).

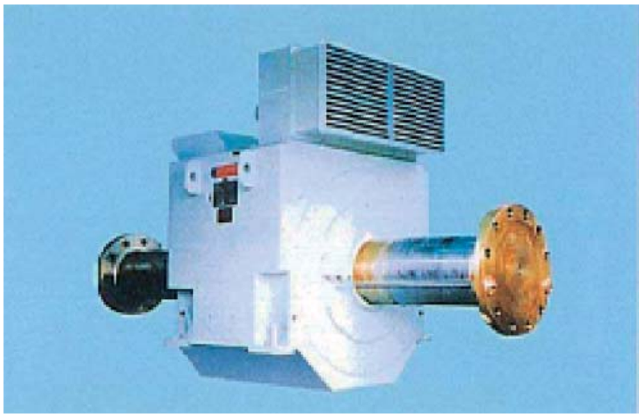

Fig. 12 Shaft generator

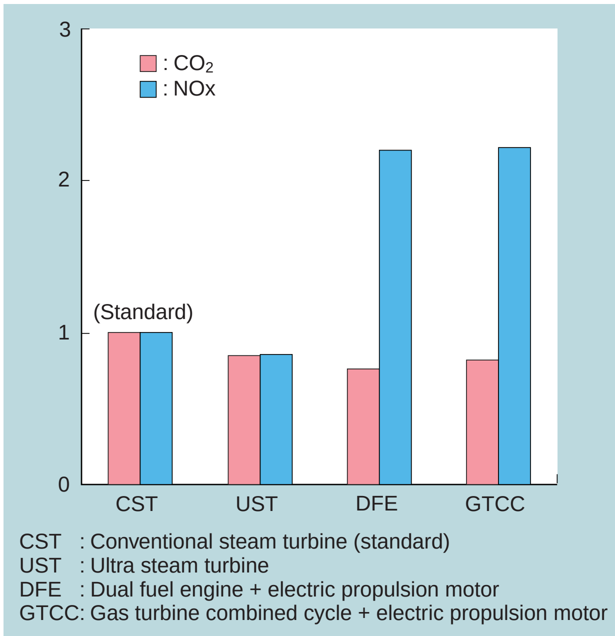

Fig. 13 Composition of exhaust gas components during navigation

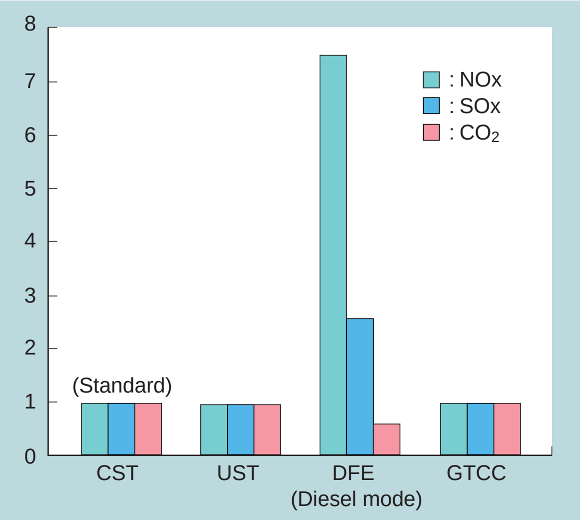

Fig. 14 Comparison of exhaust gas components during loading and unloading

6.2 Comparison of exhaust gas components during loading and unloading

During loading and unloading, steam turbine plants (CST and UST) have dual fuel burning modes. However, a DFE plant is restricted to diesel mode only, because gas mode cannot be used in low load conditions. Therefore the NOx and SOx emissions from a DFE plant are higher than other plants (**Fig. 14**).

The majority of emission regulations for current environmental measures are targeted at coastal zones and port areas including those of Europe and the west coast of the US. The introduction of stricter regulation is expected in the near future especially concerning exhaust gas components during loading and unloading. In this regard, the UST plant is the most outstanding compared with other plants.

7. Conclusion

This paper has introduced the UST plant which can achieve an efficiency equivalent to that of other diesel propulsion engines, while maintaining high reliability, which is the primary advantage of conventional turbine ships. Its major characteristics are summarized as follows:

(1) Higher plant efficiency: about 15% improvement in fuel consumption.
(2) High reliability and safety: the same high reliability and safety as conventional turbine plants.
(3) Low maintenance costs: similar low maintenance costs to conventional turbine plants.
(4) Environmentally friendly: about 15% decrease in emissions (NOx, SOx, CO_2)
(5) Flexibility of fuel selection: flexible burning of any fuel combination, oil only, gas only and dual.
(6) Extremely long plant life: operational for more than 40 years.

Finally, while hoping that the UST plant developed through the collective efforts of MHI will be actually realized in the near future, we would like to express our sincere appreciation to all parties concerned for the wide-ranging guidance and cooperation extended to us during the development period of about a year and a half.

Reference

(1) Ito, M., Development of Mitsubishi High Efficiency Marine Propulsion Plant (Ultra Steam Turbine), KANRIN (Bulletin of The Japan Society of Naval Architects and Ocean Engineers) Vol. 12 (2007) p.43


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