Export of High-performance & High-quality Components

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Owing to the experience of the cracking of high nickel alloy 600 due to the effects of aging, European and US power utilities are planning and executing the replacement of PWR plant primary components, including steam generators, reactor vessel closure heads and pressurizers. Mitsubishi Heavy Industries, Ltd. (MHI) has been exporting steam generators, reactor vessel closure heads and pressurizers to Europe and the United States since 2003. This paper focuses on major improvements to overseas replacement components. Steam generators have been improved to upgrade output and prevent tube corrosion, reactor vessel closure head penetrations have changed their material to high nickel alloy 690 to support canopy-less control rod drive mechanisms (CRDM) and high-quality J-groove welding for CRDM nozzles, while pressurizers use high wattage density heaters. These components were delivered in a short time frame and introduced the latest technologies, while conforming to all laws, regulations, codes and customers' specifications.

1. Introduction

With the cracking to high nickel alloy 600 due to the effects of aging being a turning point, European and US utilities are replacing major components of PWR plant primary systems. Damage to high nickel alloy 600 was detected in the J-groove welding of penetrations on the reactor vessel closure heads and the heat transfer tubes of steam generators. The replacement of components have been executed or planned as corrective or preventive measures. Upgrading of power is also one of the purposes of replacement for steam generators and pressurizers.

In 2003, MHI installed replacement reactor vessel closure heads at Surry 2 owned by Dominion Generation, Inc. USA. Since then MHI has exported four steam generators, 14 reactor vessel closure heads and one pressurizer to European and US utilities. Steam generators have been improved to upgrade output and prevent tube corrosion, reactor vessel closure head penetrations have had their material changed to high nickel alloy 690 which support canopy-less CRDM and high-quality J-groove welding, and modified reactor vessel closure head penetrations and CRDMs are shipped together, and pressurizers use high wattage density heaters. These components were delivered in a short period employing state-of-the-art technologies while conforming to all laws, regulations, codes and customers' specifications.

2. Replacement steam generators

2.1 Background and record of exports

Steam generators (SG) have been replaced in PWR plants worldwide for more than 20 years. Since power utilities replacing their SGs are apt to want to increase their electric output by improving efficiency and equipment reliability, an increase of the heat transfer area is often required for the replacement SGs. It is technically challenging to enhance the performance and improve reliability even using the latest technology due to the strict restrictions on the interface dimensions of the replacement equipment.

Despite this tough situation, MHI has been increasing its exports steadily, and has already supplied four units since 2003 (two to Belgium and two to the USA), and is in the process of designing or manufacturing 12 more units (two to Belgium, four to the USA, and six to France). These achievements show that MHI's advanced technology, quality, and process control capability are acquiring the reputation for high reliability among European and American utilities.

2.2 Major items of improvement

There is no standard design for a replacement SG because the specifications and plant requirements vary among customers. **Figure 1** compares the dimensions of recently exported SGs, in which widely varied specifications were applied. However, by applying the following latest advanced technologies to all SGs, improvements were made which cope with all past problems such as tube corrosion, vibration and wear, fatigue, and water hammer, and products which satisfy customers' advanced demands for heat transfer capability and moisture content are being supplied.

(1) Tube material of high nickel alloy TT690 with excellent corrosion resistance.

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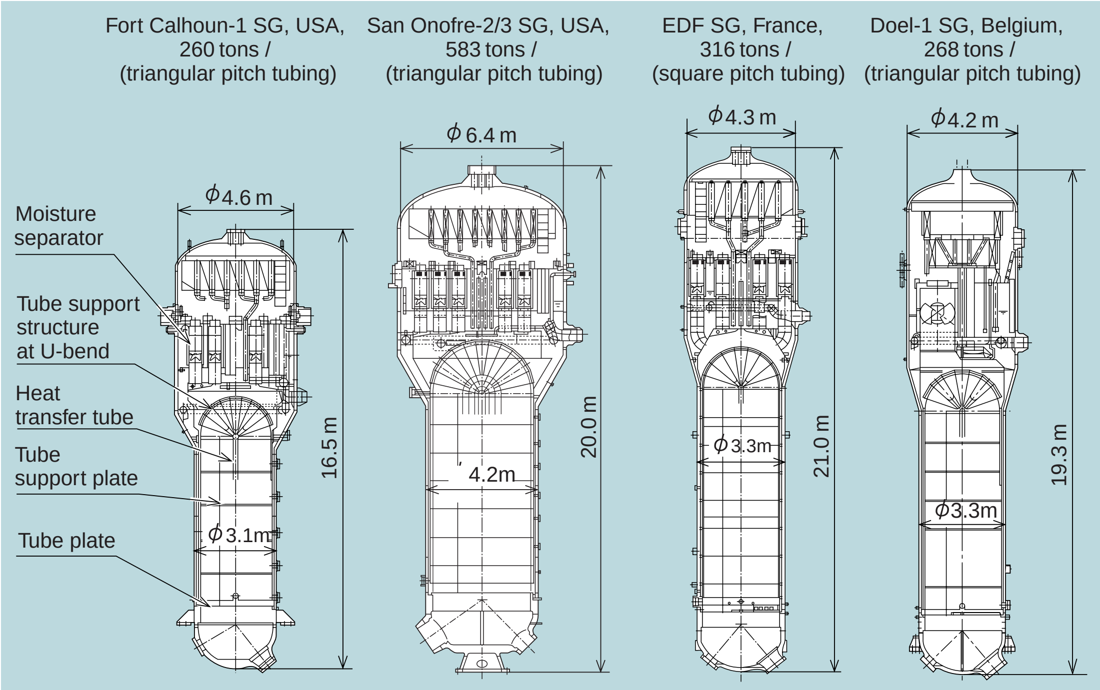

Fig. 1 Comparison of steam generators for export
Designs differ between individual customers because the specifications of replacement components are determined for each individual power plant.

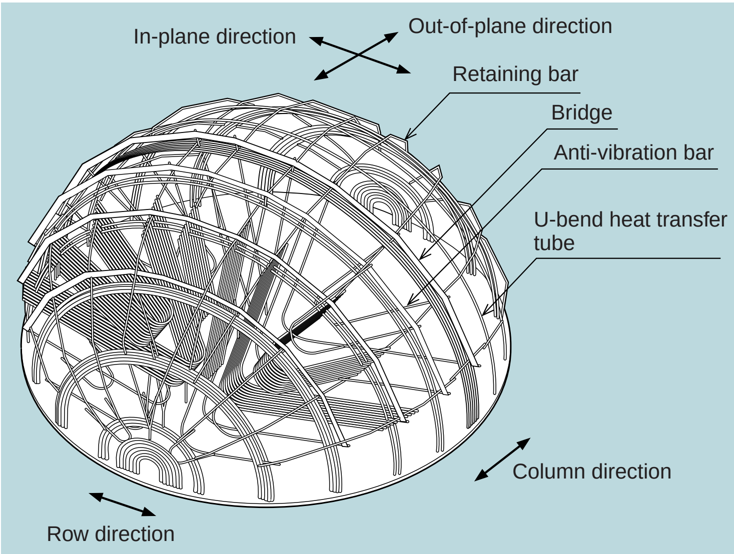

Fig. 2 Tube support structure at U-bend
Included in improvement designs, this is a vibration prevention mechanism for heat transfer tubes.

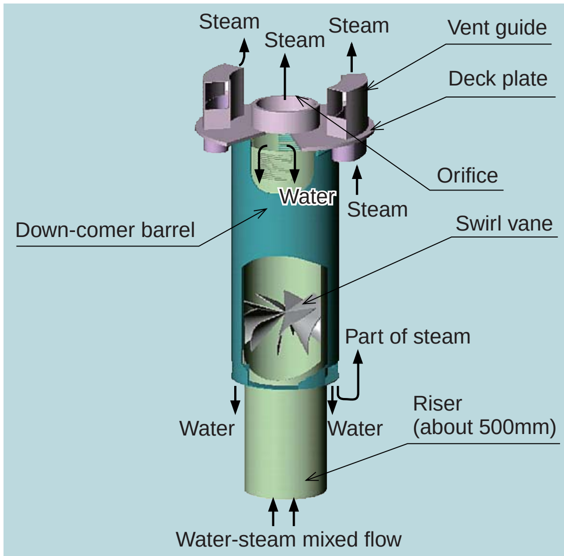

Fig. 3 High-performance small-size separator (single structure)
Another improvement design, this is a high-performance small-size separator.

(2) Outstanding tube support plate design, tube expansion technology in tube sheets.
(3) Tube support structure at U-bends with high support function.
(4) High-performance moisture separators.

Of these advanced demands for recent replacement SGs, items (3) and (4) deserve special attention.

2.2.1 Tube support structure at U-bends (3)

The tube support structure at a U-bend is shown in **Fig. 2**. This is a unique design with reduced flow resistance while assuring a high support function by increasing the number of support points. Together with excellent assembly technology during manufacturing, high reliability against vibration and wear of heat transfer tubes is achieved.

2.2.2 High-performance moisture separators (4)

MHI has developed a small, high-performance moisture separator by optimizing the geometry of the parts based on extensive field pressure tests (**Fig. 3**). As a result, replacement SGs corresponding to power up-rating and/or advanced moisture requirements can be designed.

3. Replacement reactor vessel closure heads

3.1 Background and track records abroad

Since 1990, primary water leakage caused by PWSCC (primary water stress corrosion cracking) has been detected in head penetrations in PWR reactor vessel closure heads around the world. As countermeasures, many utilities decided to replace the reactor vessel closure heads by employing high nickel alloy 690 which has excellent resistance to PWSCC.

MHI installed the replacement reactor vessel closure head at Surry 2 for Dominion Generation, Inc. in 2003, incorporating the state-of-the-art manufacturing technology and abundant experience as the leading company of PWR plant component engineering, design and supply. It also installed a total of 13 reactor vessel closure heads in European and US power plants in less than three years up to 2006. At present, four replacement heads ordered by US customers are undergoing engineering and design.

3.2 Major items of improvement

Integrated forging of reactor closure vessel head which eliminates the weld lines of head flanges and top domes has been realized. By reducing weld lines, future in-service inspections can be reduced, also shortening the duration of fabrication and pre-service inspection.

In head penetrations in replacement reactor vessel closure heads, high nickel alloy 690 with excellent resistance to stress corrosion cracking is used. This is the result of accumulated R&D studies of resistance to stress corrosion cracking.

In the J-groove welding of reactor vessel closure heads and head penetrations, narrow groove gas tungsten arc welding (GTAW) is employed. Compared with the traditional weld configuration, the residual stress of J-groove welding has been shown to be reduced by about 30%. Residual stress was also evaluated by mock-up tests simulating penetrations and J-groove welding. As a result, the head penetrations for replacement reactor vessel closure heads have been confirmed to have sufficient resistance to PWSCC.

The quality of J-groove welding has been highly evaluated by customers after excellent test results in pre-service inspection, conforming to the requirements of United States Regulatory Body and the requirements of the Electric Power Research Institute (EPRI).

In the pressure retaining housing of CRDMs, the existing thread joint and canopy seal welding have been eliminated, and a monoblock structure has been achieved by full-penetration welding. By reducing the number of canopy seal welds, which are highly potential sources of primary coolant leaks, the need for repairs by customers is greatly alleviated.

In the eight reactor vessel closure heads delivered and installed so far, the CRDMs were preinstalled on the reactor vessel closure heads in the factory, and the reactor vessel closure heads and CRDMs were shipped together. The installation work in the factory is shown in **Fig. 4**. Upon arrival at the site, following the receiving inspection, the combined assemblies were carried into the containment building and installed. The delivery of the head assembly substantially shortened the duration of pre-outage and outage work and gained a high level of customer satisfaction. The shipping and handling of preinstalled CRDMs on reactor vessel closure heads was realized by MHI for the first time in the world, and is now the standard process for replacement work in the United States. **Figure 5** shows a scene of the delivery of a reactor vessel closure head and CRDM assembly in the containment building at a plant site.

Fig. 4 Reactor vessel closure heads and CRDM
Reactor vessel closure heads and CRDM assembled in factory. Base nozzles of CRDM are shrunk-fit, assembled in reactor vessel closure heads, and joined by J-groove welding.

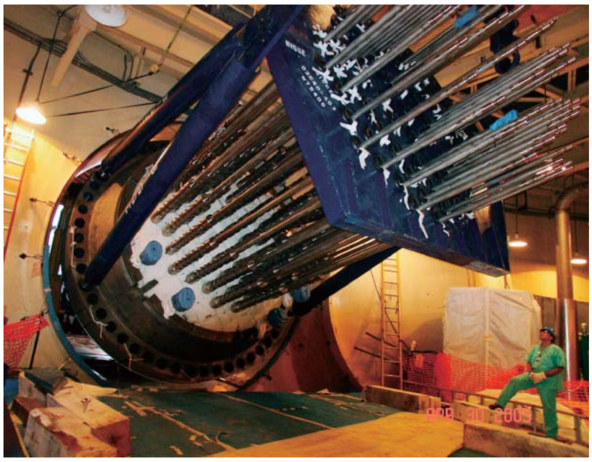

Fig. 5 Assembly delivery of reactor vessel closure heads and CRDM
A scene of assembly delivery of reactor vessel closure heads and CRDM in container, now standard field work in the US.

4. Replacement Pressurizer

4.1 Background and Experience

In line with the Fort Calhoun Station of the Omaha Public Power District's (USA) plan it was decided to replace all the primary components together, the steam generator, reactor vessel closure head and pressurizer during the 2006 refueling outage in order to extend the plant's operation period and increase its power output at the same time. The heater sleeves and nozzles installed in the existing pressurizer were made of high nickel alloy 600, which incurred the risk of damage by stress corrosion cracking. To eliminate such risks and augment the operational range corresponding to the uprated output, it was decided to replace the pressurizer.

The pressurizer at Fort Calhoun Station was the first pressurizer in the world ever to be replaced. It was delivered on schedule to the site in 2006, together with the steam generators and reactor vessel closure head.

4.2 Major items of improvement

As this was a replacement work in a limited area in an existing plant, it was decided to make as much use of the existing facilities around the pressurizer as possible. The overall dimensions of the replacement pressurizer were designed to be exactly the same as those of the existing component. The major items of improvement are explained below (refer to **Table 1**).

(1) Extension of operational range by use of high watt density heater.

The pressurizer's function is to control the volume and pressure of the PWR's primary water. By increasing the inner volume of the steam phase in the space above the heater, a wider volume control span is assured, thus expanding its operating range. For this purpose a heater with the same wattage but with a shorter heating element length is employed. By using heaters that are applicable to US code and standard requirements and which are high density compared with the usual type, a design that meets the customer specifications was made possible.

(2) Change of heater sleeve and nozzle material to stainless steel.

Nozzles of highly reliable type 316 stainless steel, used widely in Japan, are employed enhancing resistance to stress corrosion cracking.

(3) Improved in-service inspection by use of one-piece forged head with integrated nozzle.

Instead of the conventional welded nozzle structure, integrated nozzle forged heads were used to reduce the number of welds thus reducing the in-service inspection period.

The completed replacement pressurizer is shown in our shop in **Fig. 6**.

Table 1 Major items of improvement

Improvement point	Existing Pressurizer	Replacement Pressurizer
High watt density heater	–	Watt density about two times that of existing pressurizer
Volume of steam phase	–	About 1.2 times the volume of existing pressurizer
Heater sleeve and other nozzle materials	High nickel alloy 600	Type 316 stainless steel
Head material	Head made of plate material	Forged head with integrated nozzles

Fig. 6 Replacement Pressurizer
Completed state of replacement pressurizer.

5. Quality control and process management

MHI has constructed 23 PWR plants in Japan. On the basis of our experience of the manufacture of steam generators, reactors (including reactor vessel closure heads) and pressurizers used in all these plants, the quality control of our manufacturing technology has already been established. In the export business, further attention has been paid to accommodate enhanced quality control and process management.

In an export business series, the components must be manufactured under a quality control system which conforms to the local laws, regulations, and codes of each country. To start an export project, the careful training of staff members is indispensable before starting manufacture. In the process of manufacturing, experience and lessons are fed back, and the process is implemented while improving the quality assurance manual from time to time. The project is periodically monitored by quality assurance audits conducted by customers. In May 2006, MHI Kobe Shipyard & Machinery Works was surveyed by three utilities from the United States in the presence of two observers from the Nuclear Regulatory Commission. Their objectives were to audit the situation of quality assurance programs relating to design, inspection and manufacture of steam generators, reactor vessel closure heads, and pressurizers. The result was "satisfactory."

Quality records compiled in accordance with the quality assurance system and shipped together with the components all conform to the local and national standards, and the degree of completion has been highly evaluated by customers.

The delivery date was not delayed in all cases, and efforts are continuously being made to improve the process and shorten the term to meet the needs for even shorter delivery times.

MHI can meet requests by the customer for earlier replacement of the reactor vessel head. For instance, in the first project for an American utility, by adjusting each manufacturing schedule for plural components ordered at the same time, their manufacturing term was shortened by more than six months.

In addition, to comply with a request for pre-service inspection before shipping from factory by American customers, a system applicable to US regulations has been established: all the components are inspected, shipped and delivered within the due date, with a high degree of completion of high-quality components.

6. Conclusions

On the basis of the manufacturing technology, quality control and process management cultivated for decades in PWR plants in Japan, MHI has organized a system for shipping and delivering high-quality reactor products to overseas customers within a short period, as requested. In the export business, not only in terms of equipment quality but also through a quality assurance system for export, quality records conforming to local laws, regulations, and codes can be compiled and shipped together with products. Quality record documents including design drawings, manufacturing procedures, and inspection records are highly evaluated by customers.

The know-how of exports of PWR plant components obtained so far will be fully fed back to the replacement work of equipment in overseas plants and the construction work of new plants, and MHI is determined to fulfill its duties as a leading PWR plant equipment company to contribute to the stable supply of electric power all around the world.


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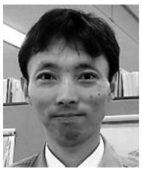
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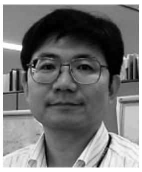
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