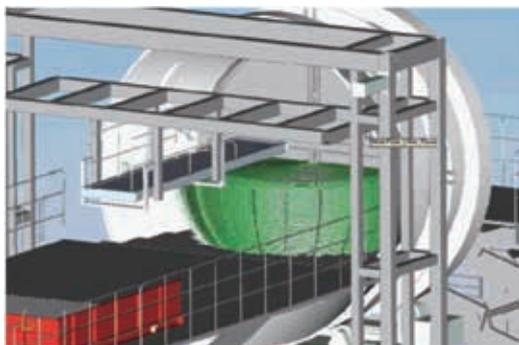
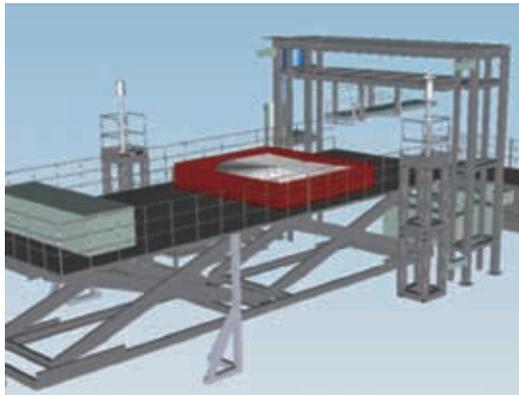


# Supreme Heat Exchangers: Key Equipment in Electric Power Plant

## Achieving quick delivery of high quality steam generators with thorough automation

IHI, which is proud to hold the world-class record for most deliveries of nuclear reactor pressure vessels, has been taking on the new challenge of manufacturing a Steam Generator (SG) that is one of the main pieces of equipment in a pressurized-water reactor nuclear power plant. This article introduces our efforts to achieve this SG manufacturing for which the highest degree of reliability is required.

Nuclear Power Operations,  
IHI Corporation



Assembly of tube bundle for steam generator



Steam generator

## Growing global energy demand

Global energy demand continues to increase and energy sources have been diversified. There is not a lack of energy-related topics in our lives, for example the practical application of non-conventional fossil fuels such as shale gas and shale oil and the acceleration of utilizing renewable energy. In contrast, the use of nuclear energy has been much debated internationally since the accident at Fukushima-Daiichi Nuclear Power Plant due to the Great East Japan Earthquake. However, nuclear power generation is still one of the important options for energy security to reliably supply energy and for realizing a low carbon society as countermeasures against global warming.

Going forward, both renewable and nuclear energy will be the important energy sources to realize a sustainable society.

The major types of reactors internationally used are Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR). IHI has been manufacturing nuclear reactor pressure vessels for domestic BWRs for more than 40 years. On the other hand, looking at overseas markets, PWRs are being adopted in most of the nuclear power plants planned for construction going forward. Thus, considering the expansion of IHI's business fields to overseas markets, the Nuclear Power Operations has been developing manufacturing technology for SG, which is the main equipment for PWR.

## Large and sophisticated equipment dedicated to harsh working conditions

Both PWRs and BWRs generate electric power in a manner that drives turbines using steam produced by heating water with nuclear energy. In PWRs, steam is produced by: extracting primary cooling water from a reactor as pressurized water having a temperature higher than 300°C; and transferring the heat of the primary cooling water to secondary cooling water

in the SG. In the BWR, steam is directly produced in a reactor and sent to turbines. Thus, the SG plays a key role in the PWR and requires sophisticated manufacturing technologies.

Generally, one nuclear power plant has two to four SGs. Each SG is a huge heat exchanger having a diameter and height of about 5 m and 20 m respectively. The SG is provided with an arrangement of many fine tubes, called heat transfer tubes with a diameter of about 10 mm, where secondary cooling water heated by primary cooling water. The number of heat transfer tubes exceeds 10 000 in some large-scale SGs. How sophisticated the structure of an SG is can be easily understood by imaging a 1/100 scale model of the SG. The entire shape of the miniature model looks like a vertically-placed 500 ml plastic bottle. Then, the bottle is filled with more than 10 000 strands of U-shaped hair as miniaturized heat transfer tubes or more than 20 000 strands of hair are arranged in a cross-section of the bottle with precise intervals. Three-dimensionally precise positioning of respective heat transfer tubes is required in order to prevent a decline of heat exchange efficiency and also prevent heat transfer tube's vibration caused by fluid flow. Thus, assembling SGs requires strictly monitoring the accuracy and this is the reason why completed structures are called works of art.

A thin wall thickness of the heat transfer tubes is advantageous in terms of high heat exchange efficiency due to low heat resistance. However, the heat transfer tubes also need to play the role of boundaries separating the primary system from the secondary system. Therefore, the required thickness is carefully designed taking into account the plant's operation. The heat transfer tubes also need to be carefully designed and delicately handled while an SG is manufactured because any possible damage to them might cause a serious accident such as contaminating the secondary system with the radioactive substances generated in the primary system.



Deep hole-drilling machine for tube sheet BTA (Boring and Trepanning Association)

## Achieving high quality and low costs at the level of mass production

Generally, detailed equipment specifications differ site by site in nuclear power plants. Although there are basic designs for respective pieces of main equipment to be used, they have characteristics of made-to-order products. Therefore they inevitably require longer manufacturing lead times than other mass production equipment due to carrying out several inspections in respective manufacturing processes to secure a high level of safety and reliability. Thus, the following three concepts have been established for the production of SGs:

- (1) Elimination of human error as much as possible (by driving automation)
- (2) Prompt inspections and measurements, real time monitoring of manufacturing processes and utilization of data (to secure traceability)
- (3) Painstaking standardization of manufacturing processes

Regarding the first concept, human errors are expected to be reduced to the extreme degree by automating processing and welding works. Automation is also an effective means to maintaining uniform product quality. The second concept can be implemented in the form of feedback of real-time measurement results to manufacturing processes by reducing time lags between manufacturing and measuring. The third concept can be achieved by the process design and manufacturing methods to minimize the scope of works requiring people in charge and standardizing common works among made-to-order products, thereby contributing to increasing the level of professional skills and reliable process management.

In addition, manufacturing SG had four major technical issues: ① tube sheet drilling (deep hole drilling), ② tube support plate hole drilling (broaching), ③ heat transfer tube welding, and ④ heat transfer tube assembling. All of them were difficult tasks and require developing new manufacturing facilities and work procedures. It should be remembered that the development of these manufacturing technologies have been based on: the manufacturing technologies for BWR type

nuclear reactor pressure vessels, multitubular heat exchangers and reactors; processing technology for manufacturing jet engines; and basic technologies for inspection, measurement and welding.

## Eliminating human error through automation

The tube sheet of an SG for a large-scale PWR needs to allow more than 10 000 heat transfer tubes to penetrate it with their end sections welded to it. Also, the holes to be drilled on the tube support plates need to be processed into special shapes.

The tube sheet with a thickness of 800 mm to be a boundary between the primary and secondary systems needs to be honeycombed by more than 10 000 through-holes to allow the heat transfer tubes to penetrate it. Actually, the tube sheet needs to have more than 20 000 through-holes because the heat transfer tubes are bent into U-shapes in an SG to allow the primary cooling water cooled after transferring its heat to the secondary cooling water to be returned to a reactor. These heat transfer tubes cannot be installed on the tube sheet until not only the dimensions but also the position and angle of every single heat transfer tube conforms to design accuracy.

The tube support plates also need to have holes in trefoil and quatrefoil shapes. The secondary cooling water and bubbles flow inside the SG through the gaps between the holes in the trefoil and quatrefoil shapes and the heat transfer tubes. In order to precisely manufacture these holes, the manufacturing machines and tools exclusive to deep hole drilling and broaching were developed in collaboration with manufacturing machine and tool suppliers.

These holes in the tube support plates also need to be smooth to avoid damage to the heat transfer tubes when they are inserted. Thus, the surfaces of the tube support plates are subject to polishing after the plates are machined. Such a process is called deburring. Manual deburring may cause uneven pressing force and inconsistent polishing time. Thus, the deburring process has been automated. Also, other automated equipment which was developed for welding



Automation technology

to install the heat transfer tubes on the tube sheet at more than 20 000 locations and helium leak test contributes to establishing SG manufacturing with consistency of quality.

### Latest measurement technologies and standardization of works

All the heat transfer tubes are supported by plural tube support plates by penetrating them. In order to avoid damage to these heat transfer tubes from causing problems during operation, the tube penetration holes at more than 20 000 locations need to be aligned with a high degree of accuracy. Thus, the installation works conforming to required high accuracy is executed by confirming installation positions through 3D laser measurement and using newly developed special fastening tools when installing the tube support plates on an SG. Such accurate installations have become available through the integration of highly accurate measurement technology with real-time control technology.

Also, we took a proactive stance to resolve problems with made-to-order products which has a feature that makes standardization of manufacturing processes difficult. For the works to insert the heat transfer tubes into the tube support plates, for example, standardized work process good for workers and products is established by analyzing the work postures and work contents of workers. In a stage to finally confirm the appropriateness of the standardized work process, it was confirmed that general operators who have no experience inserting the heat transfer tubes can carry out the

process without any problems. Currently, the standardized process has been further stabilized through improvements based on the information obtained through the above verification stage. These efforts contribute to shortening the manufacturing lead time while maintaining product quality.

In addition to standardization and automation, craftsmanship that only skilled workers at IHI have mastered played a vital role in manufacturing SGs. The AVB (Anti-Vibration Bar) welding of the heat transfer tubes is a good example of this vital role. AVBs are the members that prevent the heat transfer tubes from vibration caused by the secondary cooling water flowing with boiling upward through the U-shaped parts of the heat transfer tubes. They play an extremely important role to maintain stable operation of nuclear power plants in a manner that prevents the heat transfer tubes from fatigue and abrasion due to long-lasting vibration. AVB welding, which is a difficult task requiring heightened sensitivity and extensive experience, has been carried out only by skilled welders.

### Conclusion

The several approaches introduced in this article have verified in the manufacturing of a mock-up (a full-scale prototype). The improved reliability of SGs can realize safer nuclear power plants and handle the expectations of electric companies and electricity users who need reliable base-load power sources.

The IHI's SG was approved by Westinghouse Electric Company (U.S.A.) which is a supplier of PWR plants. With the completion of a new factory exclusive for SG manufacturing, we are ready to take the first step for being a SG manufacturer. We remain firm in our commitment to establish safer and more reliable manufacturing using nuclear energy for the affluence of the world and the happiness of people as a motto.



3D laser measurement

#### Inquiries:

Nuclear Power Operations,  
IHI Corporation  
Phone: +81-45-759-2503  
Website: [www.ihico.jp/en/](http://www.ihico.jp/en/)