Steam-Turbine Equipment for Qinshan Phase-III Nuclear Power Station in China

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OVERVIEW: In February, 1997, Hitachi, Ltd., received an order from AECL (Atomic Energy of Canada Limited) for two sets of 728-MW steam turbines for Qinshan Phase-III Nuclear Power Station in China, for which CNNC/TQNPC (China National Nuclear Corporation/Third Qinshan Nuclear Power Company Ltd.) is the end user. Hitachi completed manufacturing the No. 1 steam turbine in April 2000 and the No. 2 steam turbine in October 2000. These are Hitachi's first large-scale steam turbines for an overseas nuclear power station that use 1,500-rpm 52-inch(132-cm)-long last-stage blades. To improve the thermal efficiency, we used an improved MSR (moisture separator reheater). The condenser tubes were arranged for higher heat-exchange efficiency, and advanced debris filters were used. To promote the local production of power-station equipment in China, Hitachi and CNNC founded a joint venture of DHME (Dalian Hitachi Baoyuan Machinery & Equipment Co., Ltd.) in Dalian, China, to manufacture heat exchangers and other equipment for the project including condensers, MSRs, and feed-water heaters.

INTRODUCTION

IN China, electricity is largely generated by coal-fired power plants. However, recently, the Chinese government has started to promote nuclear power generation. The nuclear power station project of CNNC/TQNPC (hereinafter referred to as the "Qinshan Project") is a multinational project involving China, Canada, Japan, and the United States to construct a Canadian-type nuclear power station at Qinshan on Hangzhou Bay in Zhejiang Province. The project started in February, 1997.

As the main contractor, AECL took charge of most of the construction of the reactor and other auxiliary equipment. As a subcontractor of AECL, the Hitachi and Bechtel (U.S.A.) consortium took charge of the BOP (balance of plant), which is mainly in the Turbine Building. Hitachi supplied steam turbines, generators, condensers and feedwater heaters, while Bechtel was in charge of the system design, plant layout plan, and the supply of auxiliary equipment, such as piping and pumps.

The equipment design and manufacturing took 38 to 42 months. Hitachi finished manufacturing the No. 1 steam-turbine equipment in April 2000 and the No. 2 steam-turbine equipment in October 2000, which was followed by approximately 22-month period of installation and a 13-month period of commissioning. Thus, the No. 1 steam-turbine equipment is scheduled to be put into commercial operation in February, 2003 and the No. 2 steam-turbine equipment will be put into commercial operation in November, 2003.

This article describes the No. 1 and No. 2 steam-turbine equipment for the Qinshan Project.

PLANT PLAN

Hitachi designed and manufactured many steam turbines for nuclear power stations, where Hitachi's large-capacity turbines were used mainly for boiling-light-water reactors (BWR). The turbines that Hitachi recently designed for the Qinshan Project are the company's first large-capacity turbines for a pressurized-water reactor (PWR).

From the viewpoint of the turbine design, the difference between a heavy-water reactor for Qinshan project and a light-water reactor lies primarily in the difference in the modes of reactor operation (see Table 1).

In the case of CANDU (Canadian deuterium uranium reactor) for this project, xenon (Xe) starts accumulating in the reactor, one hour after the reactor trip, making it difficult to restart the reactor quickly. To enable a prompt restart, the turbine is kept running

Table 1. Heavy-Water Reactor and Light-Water Reactor
The differences in the reactor operation modes and minimum load factors are reflected in the design of the turbines for the Qinshan Project.

Item	Heavy-water reactor	Light-water reactor
Motoring operation	Max. 90 minutes	Max. 90 seconds
Minimum turbine load	60%	25%
After reactor trip	Turbine is kept running	Turbine trip

Table 2. Comparison with Model Turbines
The main steam pressure of the turbines for the Qinshan Project is lower than that of the model turbines. 52-inch-long blades are used at the last stage.

Steam turbine	Qinshan Nuclear Power Station No. 1 & No. 2	Chubu Electric Power, Hamaoka Power Station No. 4	Tokyo Electric Power, Kashiwazaki-Kariwa Power Station No.4
Output	728 MW	1,137 MW	1,100 MW
Type	TC4F-52	TC6F-43	TC6F-41
Rotating speed	1,500 rpm	1,800 rpm	1,500 rpm
Main steam pressure	4.51 MPa	6.55 MP	6.55 MPa
Steam cycle	Reheat	Reheat	Non-reheat

at the rated speed by motoring operation using the power supply from the system. In addition, when the reactor load is 60% or less, the reactor cannot be operated continuously because of the Xe accumulation in the reactor.

Pressurized-Water Reactor and Boiling-Water Reactor

The basic difference between the pressurized-water reactor and the boiling-water reactor is that the pressurized-water reactor uses a steam generator, which means that the steam in the secondary system is not contaminated with radiation. Unlike the boiling-water reactor, the pressurized-water reactor does not require sealing the end of the turbine rotor shaft with a separate source of clean seal steam. Because of this, the pressurized-water reactor is somewhat simpler in construction than the boiling-water reactor. On the whole, however, the design of the steam turbine for the pressurized-water reactor is basically the same as that for the boiling-water reactor.

Comparison with Model Turbines

In designing the turbines for the Qinshan Project, we used the Hamaoka Power Station No. 4 turbine of the Chubu Electric Power Co., and the Kashiwazaki-Kariwa Power Station No. 4 turbine of the Tokyo Electric Power Co., as models. The most conspicuous feature of the turbines for the Qinshan Project is the adoption of 52-inch-long blades. Because of their high reliability and high efficiency, the half-speed (1,500-rpm) turbines for the nuclear power station were the first to be adopted in China (see Table 2).

Table 3. Specifications for 52-Inch- and 43-Inch-Long Blades
The 52-inch-long blade obtained by proportional extension of a 43-inch-long blade ensures high reliability, with the same vibration characteristics against the operation speed and centrifugal stress as those of the 43-inch-long blade.

Item	52-inch-long blade	43-inch-long blade	Comparison
Rotating speed	1,500 rpm	1,800 rpm	1 : 1.2
Length	132 cm (52 inches)	109.2 cm (43 inches)	1.2 : 1
Centrifugal stress	1.0	1.2 : 1	Same
Material	12Cr stainless steel	12Cr stainless steel	Same
Natural frequency	1:1.2	Base (= 1.0)	Similarity rule

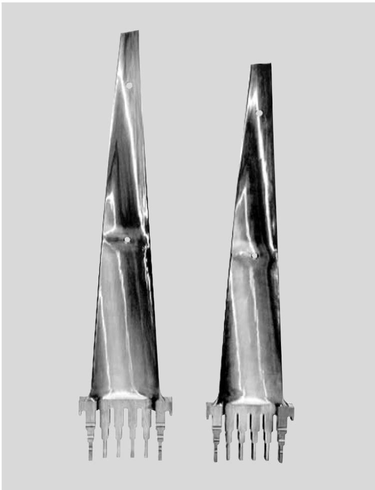

Fig. 1— 52-Inch-Long Blade (Left) and 43-Inch-Long Blade (Right).
The 52-inch-long blade is similar in shape to the 43-inch-long blade to ensure the same reliability.

NEW TECHNOLOGIES INCORPORATED IN THE STEAM TURBINES

The new technologies that were incorporated in the design of the steam turbines for the Qinshan Project are described below.

52-Inch-Long Blades

To increase the capacity and minimize the size of nuclear turbines, the turbine blades must be longer. Using the 43-inch(109.2-cm)-long blade for a 1,800-

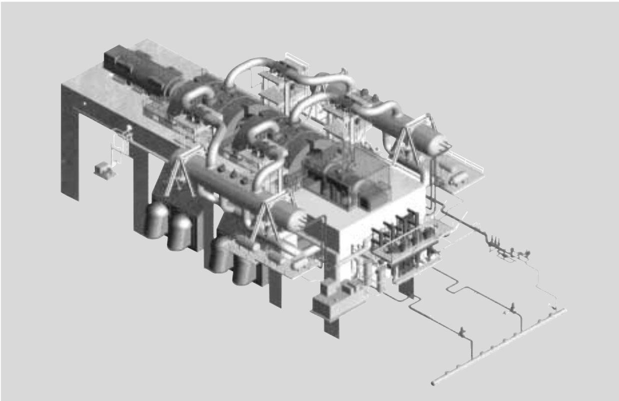

Fig. 2— 3-D CAD Model of Steam-Turbine Equipment.
Three-dimensional CAD made it possible to design the steam-turbine equipment efficiently and accurately.

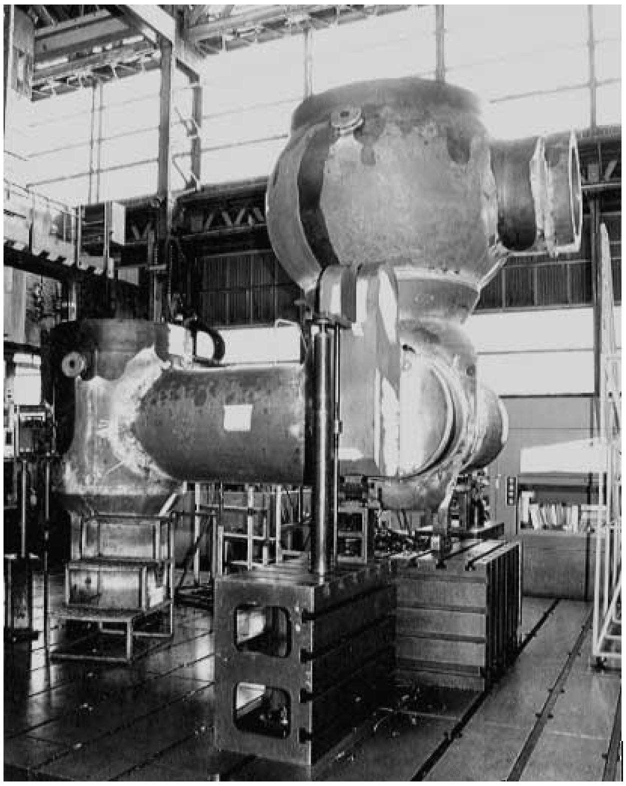

Fig. 4— Main Stop-Valve/Control-Valve Casings.
Instead of conventional cast casings, welded-type casings were used to eliminate the possibility of the casings having casting defects and improve the turbine reliability.

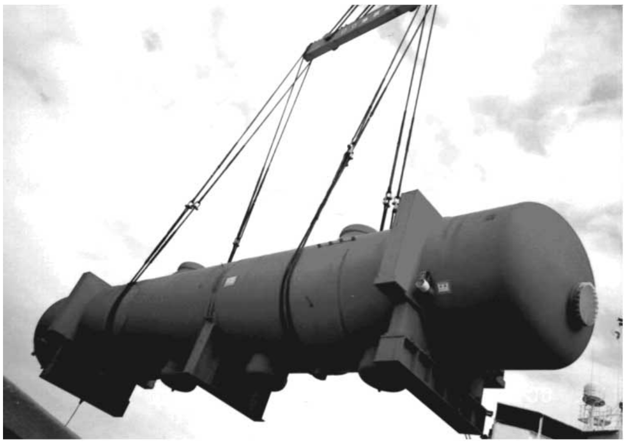

Fig. 3— Improved-Type MSR.
The overall length could be reduced by increasing the steam flow velocity and separating the drain tank from the MSR.

rpm turbine as a model, Hitachi developed a 52-inch-long blade for the 1,500-rpm turbines by proportional extension of the model. (see Table 3 and Fig. 1).

Three-Dimensional CAD

We use a three-dimensional CAD to design the steam-turbine equipment efficiently and ensure a smooth design interface with the Bechtel Corp, AECL, and CNNC/TQNPC (see Fig. 2).

Moisture Separator Reheater (MSR)

MSR is an important piece of equipment, which removes moisture from the high-pressure turbine exhaust steam and reheats the steam, thereby improving the turbine thermal efficiency. The higher the volume flow rate of the steam, the larger the size of the MSR. To design a compact steam reheater, we separated the drain tanks from the MSR proper and increased the steam flow velocity in the MSR reheater tubes. As a result, the overall length of the MSR could be reduced by 28% (see Fig. 3). In addition, by installing the newly-designed moisture separator, we could increase moisture-separation efficiency to more than 98%.

Casing of Welded Construction

A casing of welded construction was earlier developed for high-pressure casings of turbines for thermal power stations. For this project, not only the high-pressure casings but also the main stop-valve/control-valve casings are of welded construction, rather than of conventional cast construction. This eliminates the possibility of the casings having casting defects and improves the turbine reliability (see Fig. 4).

NEW TECHNOLOGIES INCORPORATED IN THE STEAM-TURBINE AUXILIARY DEVICES

The new technologies applied in the design of other equipment for the Qinshan Project are described below.

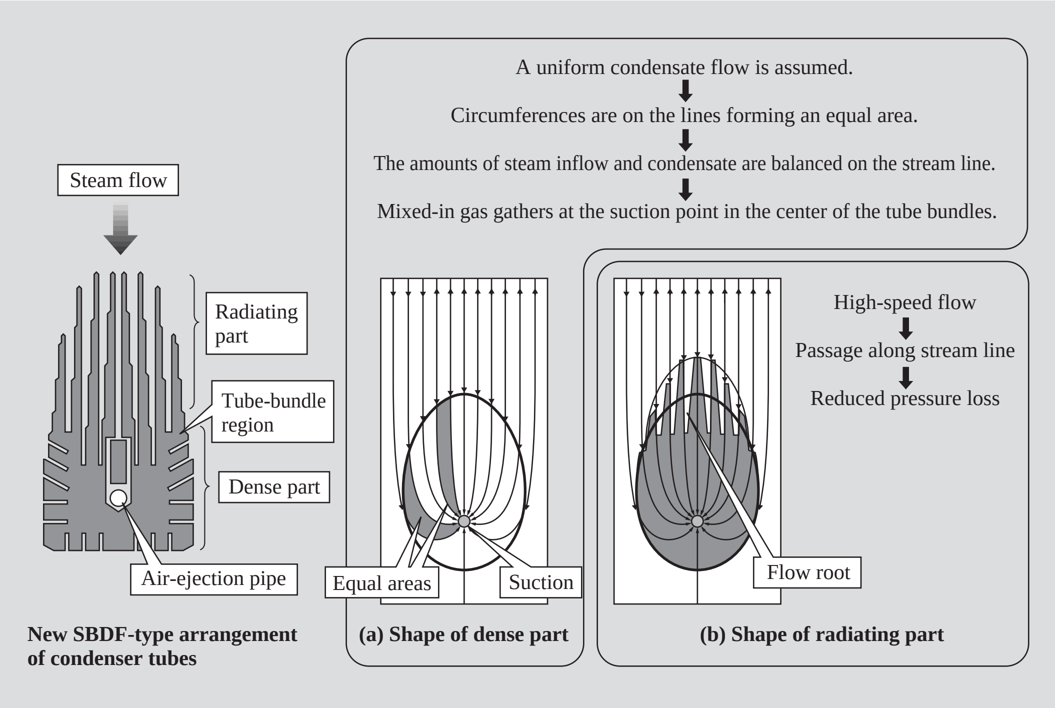

Fig. 5— Concept behind the Tube Arrangement Based on the "Suction Flow" Theory.
The radiating part is linear to the flow of steam, and the circumference of the tube bundle is on the lines forming nearly an equal area.

Condenser

One of the factors that determine the performance of a condenser is the shape of the condenser tube bundles and the arrangement of the titanium tubes.

To further improve the condenser performance, Hitachi developed and used a new arrangement of condenser tubes, called the SBDF (super balanced down flow), which is based on the fluid-dynamic similarity theory according to which the steam inflow along the streamline of the suction flow is proportional to the condensing steam.

Hitachi's new standard arrangement of the tube bundles, the SBDF, with its superior performance, was used in more than 15 thermal power plants. Adopting the SBDF-type arrangement of tubes for the Qinshan Project should increase the condenser heat-exchange efficiency by about 10% compared to that generated by the conventional BDF (balanced down flow)-type arrangement. Fig. 5 shows the new SBDF-type tube arrangement and its fluid-dynamic theory.

Equipment for Removing Impurities

To ensure that the above condenser maintains its high performance for a long time, the clogging of the condenser tubes by seaweeds or debris and the staining of the tubes' inner surfaces caused by the condenser cooling water, or seawater, must be prevented.

For auxiliary equipment in seawater systems to prevent such problems, Hitachi uses a device for removing debris and a ball cleaning system. Hitachi can manufacture these devices as a whole system. We have supplied this equipment to many thermal and nuclear power plants.

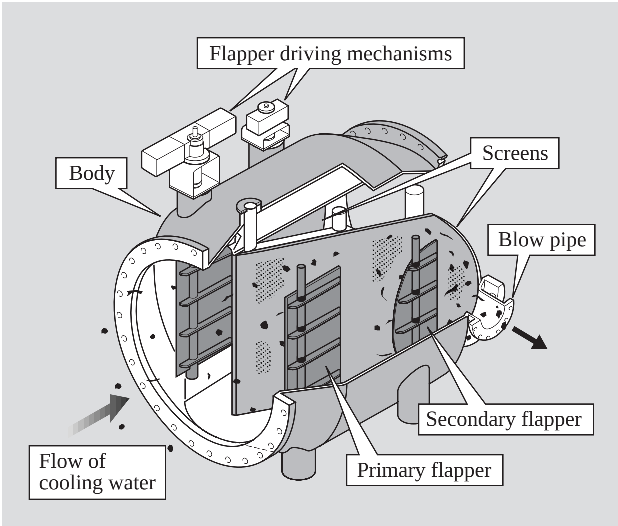

Fig. 6— Filter for Removing Debris.
This removable filter ensures high performance and high reliability of the condenser.

For the Qinshan Project, Hitachi supplied debris filter that has the following features (see Fig. 6).

(1) Capability to effectively remove debris in the form

of solids, strings, and membranes, and excellent resistance to the inflow of debris.
(2) Capability to produce powerful laminar and reverse flow to remove debris effectively.
(3) Capability to continue operation when the power plant is in service.
(4) Capability to protect condenser devices if the differential pressure rises during operation.

Ferritic-Stainless-Steel Heat-Exchanger Tubes for the Feed-Water Heaters

Austenitic stainless steel is normally used for tubes of a feed-water heater. From the heat-transfer performance point of view, however, ferritic stainless steel with its higher heat-transfer efficiency is superior in performance.

We tested ferritic stainless steel under various operation conditions and found that it is rather reliable. By using ferritic stainless steel for the tubes of the feed-water heaters in the Qinshan Project, we increased the heater performance and reduced the size of the feed-water heaters.

CONCLUSIONS

We described the steam-turbine equipment for Qinshan Phase-III Nuclear Power Station in China. This equipment is attracting attention as Hitachi's first large-scale turbine equipment for an overseas nuclear power station and as the first half-speed turbine equipment for a nuclear power station in China. Hitachi has already put into operation and is manufacturing a total of 14 steam turbines in China. And Hitachi intends to continue its effort to contribute to the development of China's power generation industry in the fields of both thermal power generation and nuclear power generation.

The Japan-China joint venture of Dalian Hitachi Baoyuan Machinery & Equipment Co., Ltd. (DHME) has successfully met the challenges of starting this new joint venture in China. And due to the strong ties between China and Japan at DHME, and to the generous cooperation of the customers, DHME could come up with first-class products in China, paving the way for the local production of turbine equipment for nuclear power stations.

We wish to express our gratitude to all the people of AECL and CNNC/TQNPC for their invaluable advice and to all the people of the Bechtel Corp., as our partner for their active cooperation. Without their advice and cooperation, it would not have been possible to successfully complete the steam turbine equipment for this project.

REFERENCES

(1) S. Moriya et al., "Recent Technology for BWR Nuclear Steam Turbine Unit," *Hitachi Hyoron* **72**, pp.1019-1026 (Jan. 1989) in Japanese.
(2) H. Urushidani et al., "Large Nuclear Steam Turbine Plants," *Hitachi Hyoron* **68**, pp.295-300 (Apr. 1985) in Japanese.
(3) K. Ikeuchi et al., "Development of 52 in. Blade for Large Steam Turbines," *Thermal and Nuclear Power* **37**, pp.34-43 (Jan. 1986) in Japanese.

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