A New Geothermal Steam Turbine with a "Single-Cylinder Axial Exhaust Design" (Outline of the Hellisheidi Geothermal Turbine in Iceland)

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1. Plant outline

The Hellisheidi Geothermal Power Plant was constructed at the skirt of a mountain in a geothermal field 20 km to the east of Reykjavik, the capital of Iceland. In addition to supplying electricity to aluminum smelters and other industrial facilities, the plant supplies hot water to the city of Reykjavik.

The plant consists of two turbine generators, each with a rated output 40 MW and maximum output of 45 MW. Thus, it has a total power generation capacity of 90 MW.

Uniquely for a geothermal power plant, a shell & tube type condenser is adopted for the cooling water system to enable the use of not only cooling water from cooling tower, but also clean well water. The condenser also functions as a primary heater for the hot-water supply equipment, to heat well water and simultaneously condense the turbine exhaust. The capacity of the hot-water supply to the city of Reykjavik is 1,084 kg/sec.

Unit 1 was handed over on October 1, 2006. Unit 2 was handed over exactly a month later, on November 1 of the same year. Both are now in commercial operation.

This paper describes the advantages of the world's first geothermal turbine with an axial exhaust design, the unit installed in Hellisheidi Geothermal Power Plant. Various elemental technologies are also introduced.

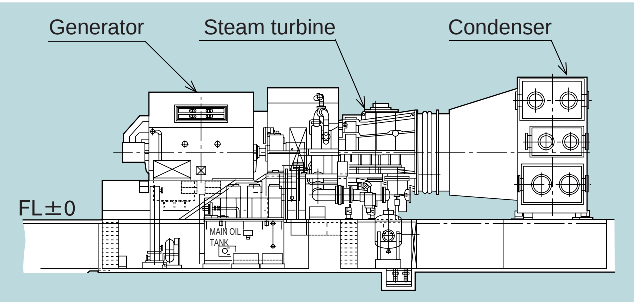

Fig. 1 Layout

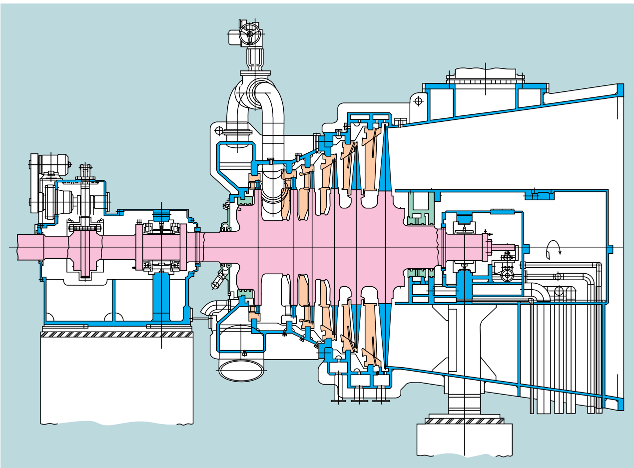

Fig. 2 Turbine sectional assembly

2. Introduction of turbine with single-cylinder axial exhaust design

Table 1 shows the specification of the Hellisheidi Geothermal Power Plant. The layout in **Fig. 1** illustrates the installation configuration for the turbine, generator, and condenser. **Fig. 2** shows a turbine sectional assembly. To cover output up to 50 MW with the single flow turbine, the turbine adopts a 30-inch ISB (integral shroud blade– one of the largest of its type ever used for a geothermal turbine) applied as the last blade.

Table 1 Plant specifications for Hellisheidi

Type of plant	Single flash, condensing
Rated output (MW)	40 x 2 units
Steam conditions	
Pressure (MPa)	0.75
Temperature (°C)	167.8
Exhaust pressure (MPa abs.)	0.01
Type of turbine	SC1F-30" AX (Single-cylinder, single flow, impulse-reaction axial exhaust condensing turbine)
Exhaust type	Axial exhaust
Rated speed (min^{-1})	3 000
Number of stages	6
Last blade height (mm)	762 (30 inches)
Type of condenser	Shell & tube (surface cooling type)
Type of cooling tower	Mechanical draft, counter flow

To avoid stress corrosion cracking, a material with low strength was purposefully adopted for the rotor of the geothermal turbine. The 30-inch blade and low-strength rotor material could be successfully combined in the system by drastically suppressing the stress of the blade groove via two strategies, i.e., reducing the number of blades and adopting a large blade root.

The advantages obtained by application of axial exhaust design are as follows:

- High performance
- Reduced turbine building height
- Shortened period for site erection work

(1) High performance

Fig. 3 shows the outline structures of various turbine exhaust designs. For the top exhaust, the turbine exhaust is discharged upward at the exhaust flange, whereupon the exhaust changes direction by 90 degrees, passes through horizontal exhaust pipe, changes direction again, and flows into the condenser. The relatively long length of the horizontal exhaust pipe and the two turns in the direction of the exhaust flow lead to a pressure loss of about 10% in the exhaust pipe, thereby compromising the turbine performance. Though no major pressure loss takes place in the down exhaust, the pressure recovery in the turbine exhaust duct cannot reach a level comparable to that in the axial exhaust. The axial exhaust is discharged in the turbine axial direction, hence there are no conversions in the flow direction that cause pressure loss. Furthermore, a large pressure recovery in the turbine exhaust duct can be expected by applying a diffuser shape for turbine exhaust duct. Out of the three exhaust designs, the axial exhaust design suppresses the exhaust loss to the lowest level and achieves the highest performance in the single flow turbine construction.

Given that the condition of the main steam of the geothermal turbine is very low and the condenser pressure is high in comparison with those of a steam turbine for a thermal power plant, thermal energy (adiabatic heat drop) of only 400–600 kJ/kg (440 kJ/kg in case of Hellisheidi) can be converted into the work in the turbine, and the ratio of exhaust energy to the adiabatic heat drop is relatively large.

Thus, the rate of improvement in the turbine performance attributable to the reduced exhaust loss of the axial exhaust design in the geothermal turbine is far higher than the rate of improvement in a steam turbine for a thermal power plant.

(2) Reduced turbine building height and shortened period for site erection work

When the axial exhaust design is adopted for the turbine, the condenser can be installed on the same level as that of the turbine shown in Fig. 1. As shown in **Fig. 4**, the height of the turbine building can be reduced dramatically in comparison with the heights for the other exhaust types, and the construction cost can thus be reduced commensurately. Regarding the period for site erection work, a down exhaust turbine cannot easily improve the site construction schedule since the turbine casing must be installed after the condenser is installed. With the axial exhaust, the installation work of the condenser and turbine can be implemented in parallel, thus making it possible to further shorten the construction period.

Because the cost of site erection work is very high in Iceland, it is important to reduce the amount of site erection work in order to reduce the total cost of the project. In the Hellisheidi project, the site erection work was largely reduced by delivering a completed turbine module in which the turbine was assembled completely before shipment from the shop.

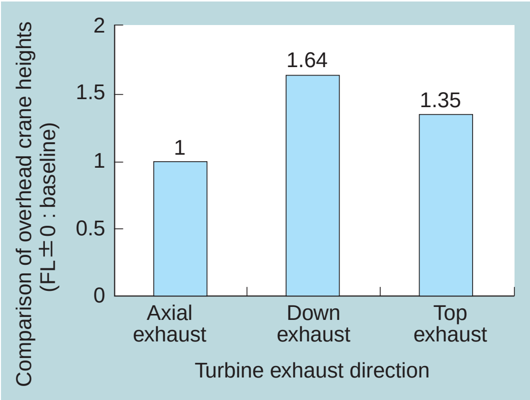

Fig. 4 Comparison of heights of overhead crane in various exhaust types

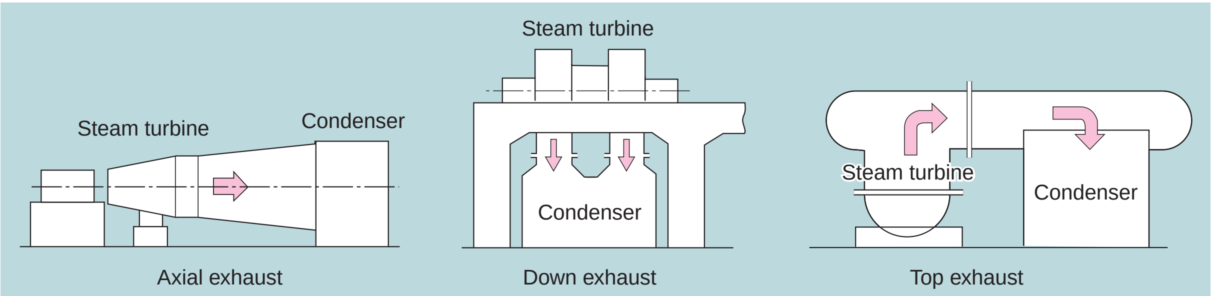

Fig. 3 Comparison of various exhaust types

Fig. 5 Appearance of application of integral shroud blades (ISB)

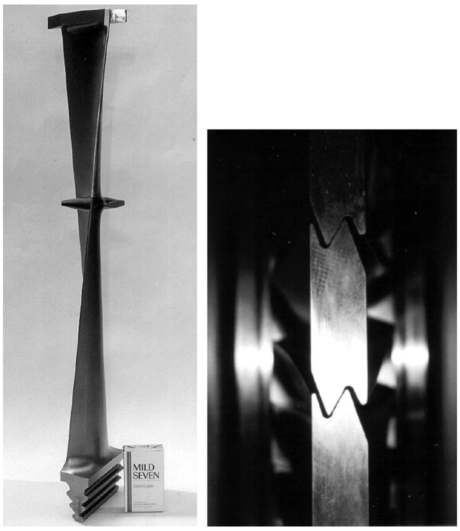

Fig. 6 ISB appearance

(3) Other elemental technologies

- Integral shroud blade (ISB)

As shown in **Fig. 5**, ISB is applied to the rotating blades in the all stages. Tenon riveting and welding at stubs of long rotating blades can be eliminated by applying the ISB. This makes it possible to suppress the stress corrosion cracking and corrosion fatigue that often appear at the tenon riveting part and the welds at the stubs of geothermal turbine. Thus, the reliability of the geothermal turbine is improved.

- 30-inch ISB last blade

As shown in **Fig. 6**, the shroud is integrated to the blade profile. As shown in **Fig. 7**, adjacent rotating blades come into contact with each other at the shrouds when the turbine rotor rotates at the rated speed, generating a large damping effect against the vibration of the rotating blade. As a result, the vibration stress of the rotating blade is reduced to 20% or less in comparison with the conventional grouped blade, and the reliability against corrosion fatigue in the severe corrosion environment of geothermal steam is improved.

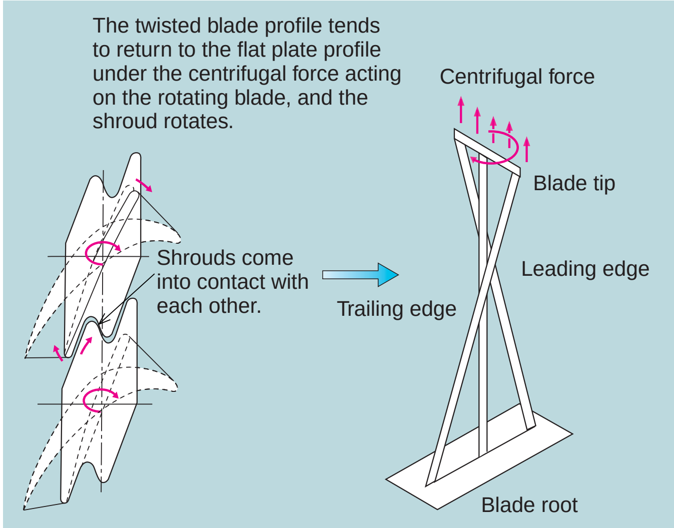

Fig. 7 Contact status of ISB shrouds during operation

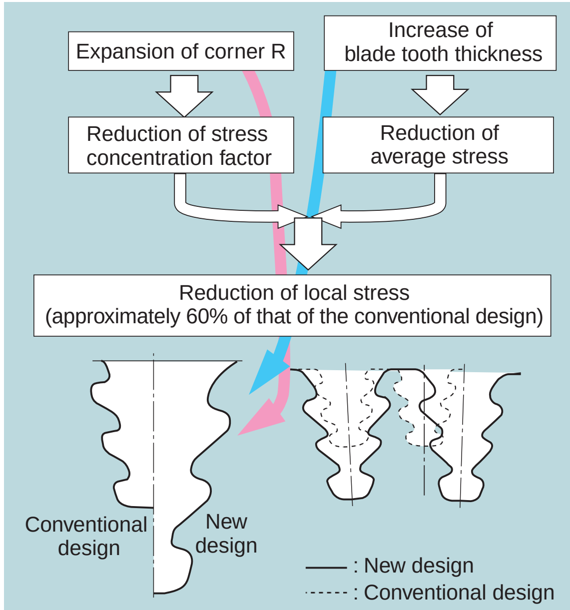

Fig. 8 Comparison of blade root shapes between new and conventional designs

The comparison between the blade root shape of the conventional blade and that of the new design blade is shown in **Fig. 8**. In the new design blade, the centrifugal stress generated in the blade groove is reduced dramatically by adopting a larger blade root, expanding the corner R, and increasing the thickness of the blade tooth. These design features significantly enhance the reliability against stress corrosion cracking.