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Introduction of MHI Geothermal Power Plant

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ABSTRACT

This paper introduces our latest geothermal steam turbines supplied for Darajat geothermal power plant in Indonesia and Hellisheidi geothermal power plant in Iceland. Darajat Unit#3 geothermal turbine is introduced as the largest capacity geothermal steam turbine with a single cylinder in the world and Unit#1 and Unit#2 are also introduced for comparison.

Hellisheidi Unit#1 to #4 geothermal steam turbines are introduced as an axial flow single cylinder turbine.

1. Introduction of the Projects

1.1 Darajat Geothermal Power Plant

Darajat geothermal power plant is located 150km southeast of Jakarta in Indonesia. Major specifications are listed in Table 1.

Maximum continuous output of Darajat Unit#3 is 121MW and this is the largest output with single cylinder geothermal turbine in the world. Commercial operation date of Unit#1, #2 and #3 are December 1994, January 1999 and August 2007 respectively. Although single cylinder double flow design was applied to all units, the output of Unit#2 and Unit#3 was significantly increased from Unit#1 by applying 30 inches length integral shroud blades (ISB) for the last stage as indicated in Table 1. Refer to Figure 1, overleaf, for turbine sectional assembly.

1.2 Hellisheidi Geothermal Power Plant

The Hellisheidi geothermal power plant was constructed at the 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 four turbine generators, each with a rated output 40 MW and maximum output of 45 MW. Thus, it will have a total power generation capacity of 180 MW after completion of Unit#3 and Unit#4.

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. 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. In addition, Unit#3 and Unit#4 are under construction

Table 1. Specification of Plant.

	Darajat#1	Darajat#2	Darajat#3	Hellisheidi 1~4
Type	・Single Flash ・Condensing ・Double Flow ・Single Cylinder (SC2F-23)	・Single Flash ・Condensing ・Double Flow ・Single Cylinder (SC2F-30)	・Single Flash ・Condensing ・Double Flow ・Single Cylinder (SC2F-30)	・Single Flash ・Condensing ・Single Flow ・Single Cylinder (SC1F-30AX)
Exhaust type	Down Exhaust	Down Exhaust	Down Exhaust	Axial Exhaust
Rated output	55,000 KW	81,300 KW	110,000 KW	40,000 KW
Maximum continuous output	57,750 KW	100,700 KW	121,000 KW	45,000 KW
Rated speed	3000 rpm	3000 rpm	3000 rpm	3000 rpm
Steam pressure	1.00 MPa	1.33 MPa	1.52 MPa	0.75 MPa
Steam temperature	179.9 degree C	192.7 degree C	198.9 degree C	167.8 degree C
Exhaust pressure	0.011 MPa	0.006 MPa	0.008 MPa	0.010 MPa
Number of stages	6	8	8	6
Last blade height	584.2 mm (23 Inch)	762.0 mm (30 Inch)	762.0 mm (30 Inch)	762.0 mm (30 Inch)
Type of last blade shroud	Group	ISB	ISB	ISB

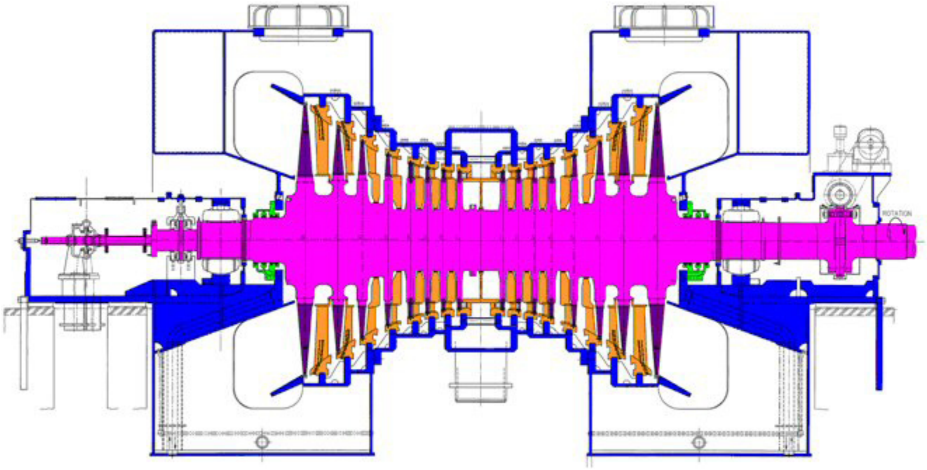


Figure 1. Turbine Sectional Assembly of Darajat Unit #2 & 3.

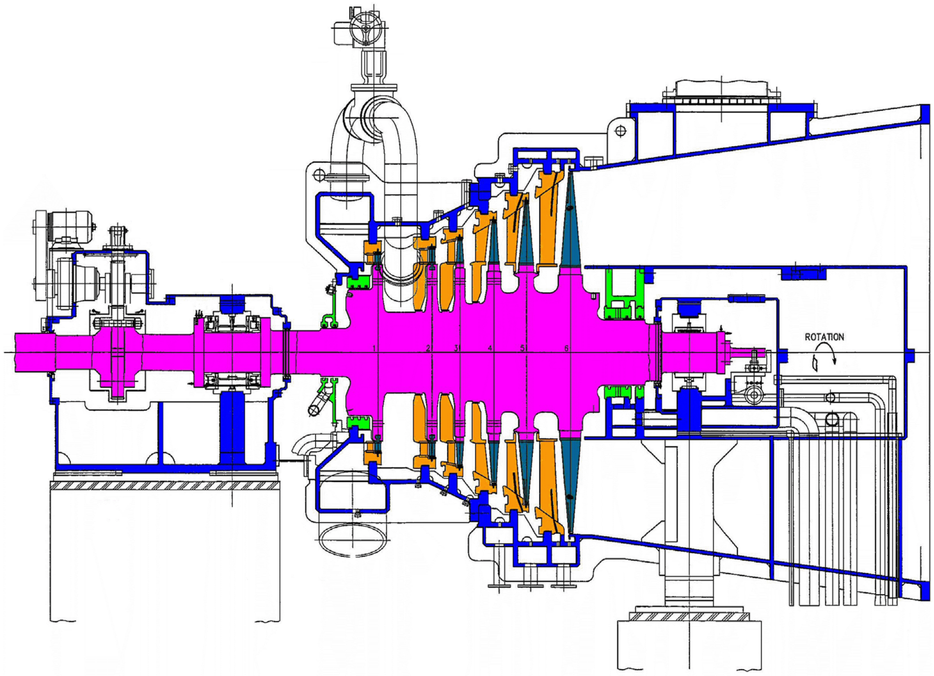


Figure 2. Turbine Sectional Assembly of Hellisheidi.

as of May, 2008 and will start commercial operation in September and November, 2008 respectively. Major specification is listed in Table 1 and turbine sectional assembly is shown in Figure 2.

2. Turbine Exhaust Type

2.1 High Performance

Figure 3 shows the outline structures of turbine exhaust designs. 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. The axial exhaust design suppresses the exhaust loss to the lowest level and achieves the highest performance in the single flow turbine construction as summarized in Table 2.

Table 2. Feature of Turbine Exhaust Type.

	Down Exhaust	Top Exhaust	Axial Exhaust
Turbine House	Tall	Short	Short
Pressure Loss in Exhaust	Low	High	Very Low
Number Exhaust Flow	Any	Any	Only for 1 flow

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 loss 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.

Therefore, in case that the output is in the range of 50MW which depends on the steam conditions and single flow turbine is applicable, the axial exhaust design can be selected and we can enjoy the advantage of axial exhaust design in terms of turbine efficiency. In case of higher output and double flow turbine should be selected, axial exhaust design can not be applied.

2.2 Turbine Building Height and Construction Considerations

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 Figure 4 in case that a condenser is of shell & tube type. As shown in Figure 3, the height of the turbine building can be reduced in comparison with the heights for the down exhaust types, and the construction cost can thus be reduced commensurately.

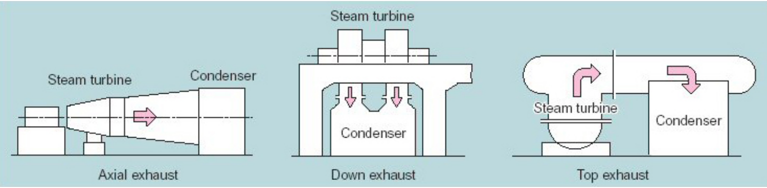


Figure 3. Comparison of Exhaust Design.

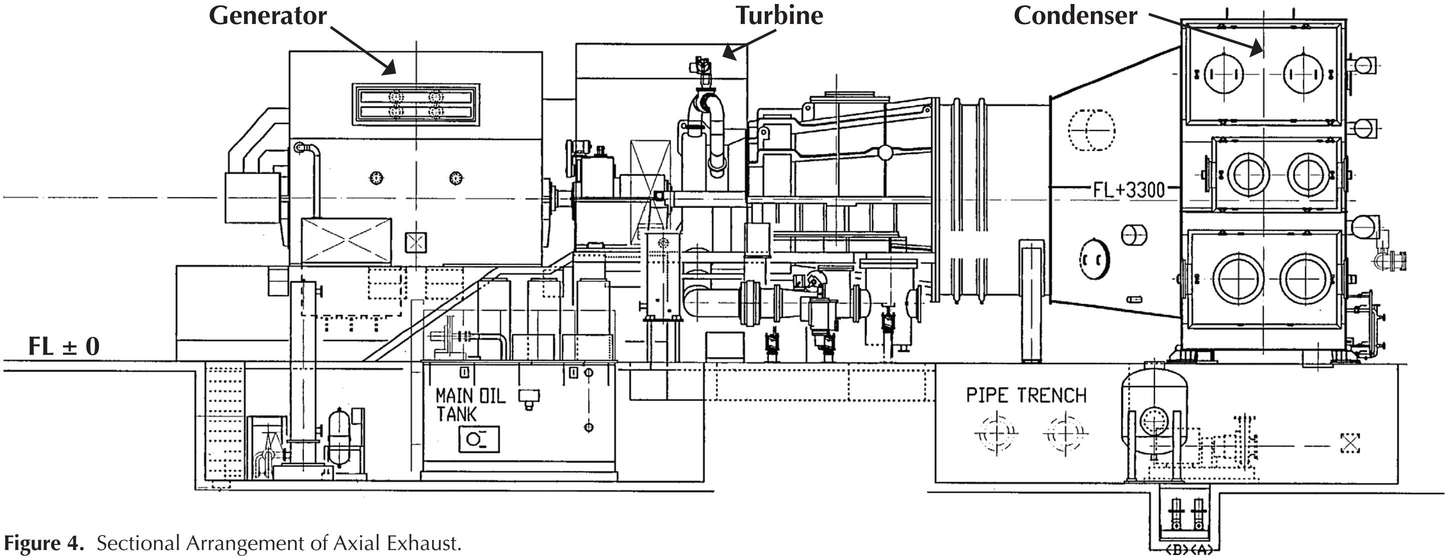


Figure 4. Sectional Arrangement of Axial Exhaust.

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. A completed turbine module can not be applied to a double flow turbine due to the limitation in size or weight during inland transportation.

3. Technology for High Performance

3.1 Bow Blade Application

The bow configuration (Figure 5) designed using fully three-dimensional fluid dynamic method reduces the secondary flow loss which is one of the major blade losses caused by the generation of a vortex in the boundary layer. In the conventional design, when main steam flow comes into the row of the blade, big secondary flow is generated and causes large vortices. Then, the vortices become the loss of blade efficiency. Bowed profile reduced the secondary flow because of pressing the steam flow against end walls at tip and blade base section.

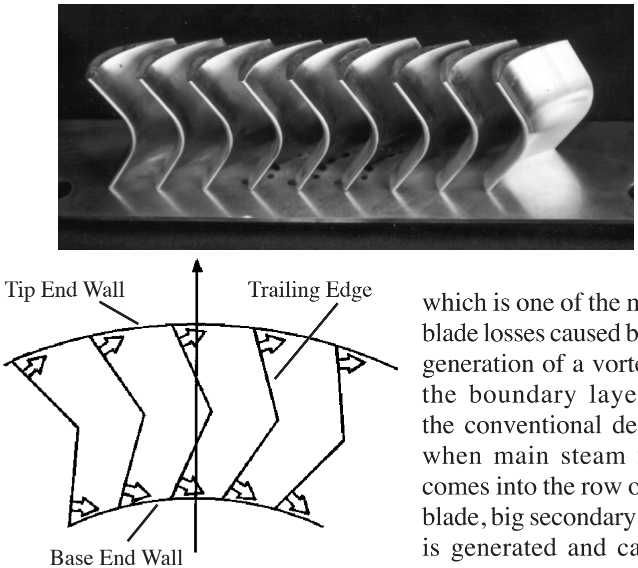


Figure 5. Bow Nozzle.

Therefore, bowed blade generates very small vortices, so it can take high performance in blade efficiency. The bow blade design is used on both stationary and rotating blades at impulse stages of Darajat and Hellisheidi geothermal steam turbine, thereby increasing the turbine efficiency.

3.2 Last Stage Blade Design for High Efficiecy

Turbine blade size is selected to minimize leaving loss at turbine exhaust. Leaving loss characteristics of a 23-inch blade and 30-inch ISB are shown on Figure 6. As turbine exhaust volume flow increases, larger size of the blade should be selected to keep leaving loss at reasonably low level and to maintain high turbine efficiency. If the design exhaust volumetric flow is at point "A" in Figure 6, 30-inch ISB's leaving loss is smaller than 23-inch blades leaving loss. Especially in geothermal turbine, the effect of the leaving loss on the turbine performance is significant as the heat drop in a geothermal turbine is much smaller compared to that of the turbine for fossil power plant.

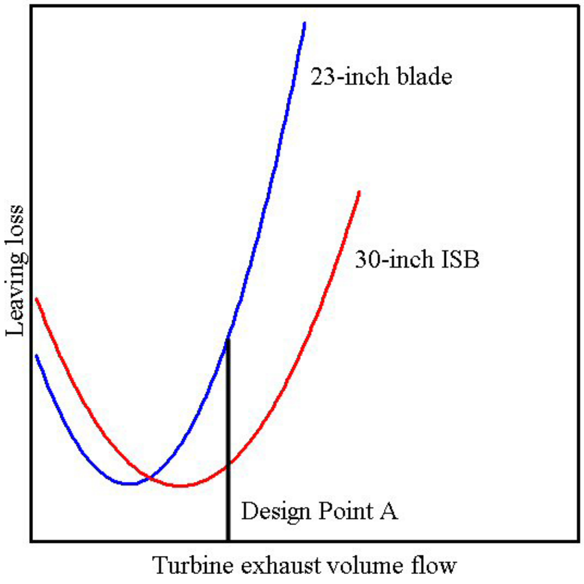


Figure 6. Leaving Loss Characteristics.

Thus, Darajat Unit#2 and Unit#3 with 30 inch ISB can maintain high efficiency with high steam flow rate or large output compared with Darajat Unit#1 as shown in Table 1.

4. Technology for High Reliability

4.1 ISB Blade Application

(1) Integral shroud blade (ISB)

As shown in Figure 7, ISB is applied to the rotating blades in the all stages of all units except last 3stages of Darajat Unit#1. 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.

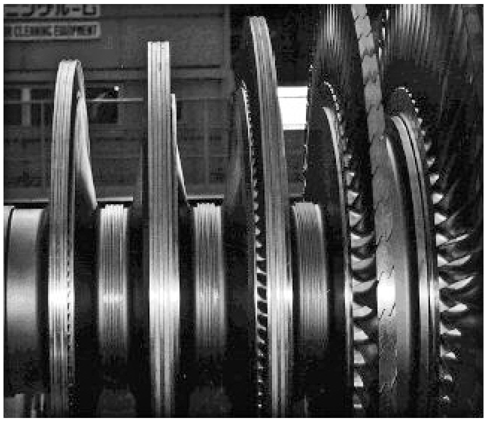


Figure 7. Appearance of Application of Integral Shroud Blades (ISB).

(2) 30-inch ISB last blade

23 inch conventional grouped blade was applied to last three stages of Darajat Unit#1. After that, 30 inch ISB were applied to Darajat Unit#2&#3 and Hellisheidi Unit#1 to #4.

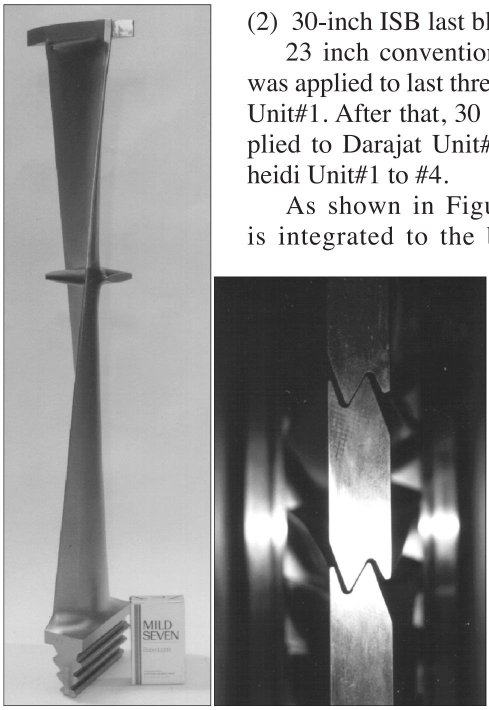


Figure 8. Integral Shroud Blade (ISB).

As shown in Figure 8, the shroud is integrated to the blade profile. As shown in Figure 9, 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. General comparative picture of ISB and grouped blade are shown in Figure 10. As a result, the vibration stress of the rotating blade is reduced to 20% or less in comparison with the conventional grouped blade as indicated in Figure 11, and the reliability against corrosion fatigue in the severe corrosion environment of geothermal steam is improved.

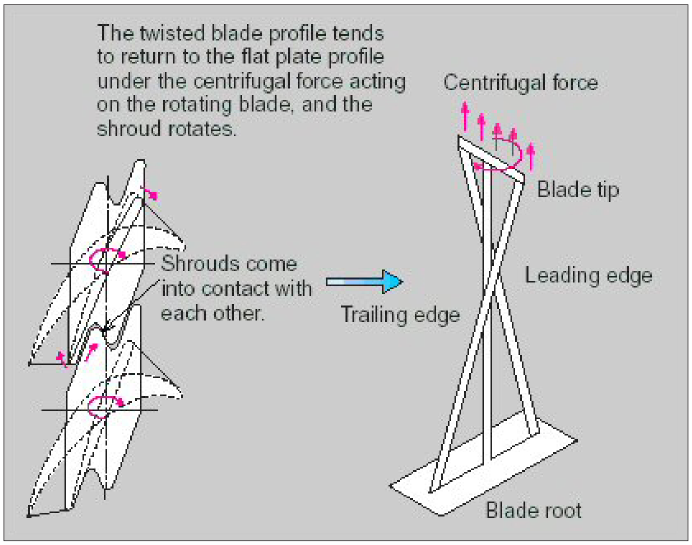
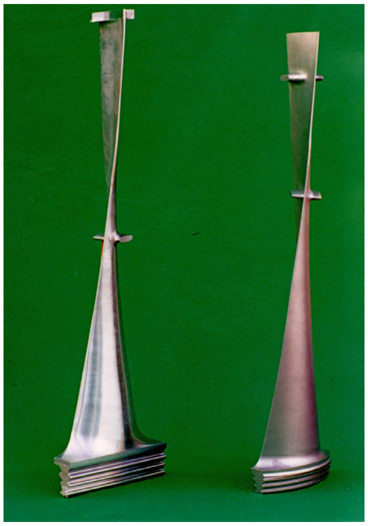


Figure 9. Contact Status of ISB Shrouds During Operation.



ISB Conventional Grouped Blade

Figure 10. ISB and Conventional Grouped Blade.

The comparison between the blade root shape of the conventional blade and that of the new design blade is shown in Figure 12. 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.

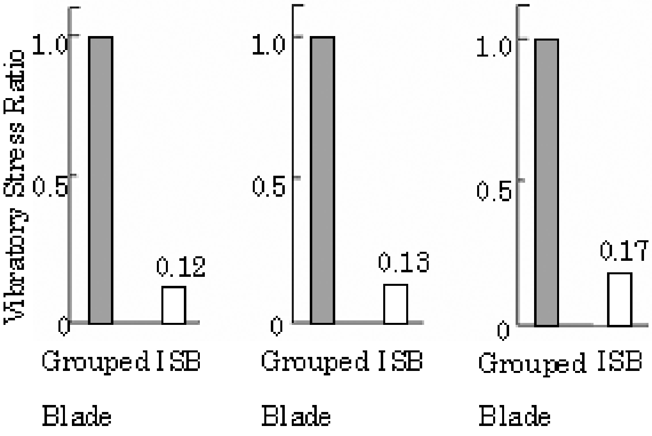


Figure 11. Comparison of Vibratory Stress.

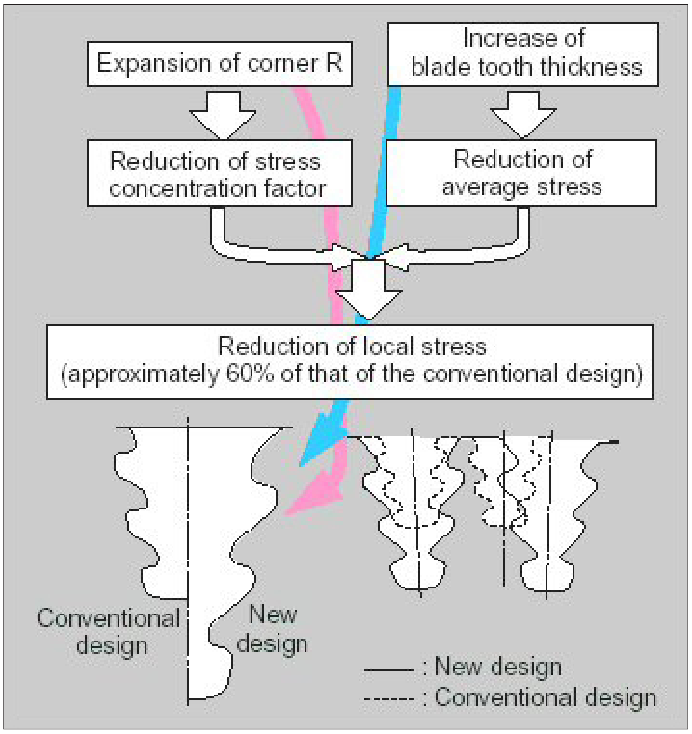


Figure 12. Comparison of Blade Root Shapes Between New and Conventional Designs.

Due to larger flow area of 30 inch ISB compared with 23 inch conventional grouped blades, leaving loss at turbine exhaust is kept at reasonably low level or high turbine efficiency is maintained at higher steam flow rate or high output. In addition, ISB construction significantly improves blade strength against stress corrosion cracking and corrosion fatigue and design loading of 30 inch ISB comes 1.5 times it of 23 inch conventional grouped blades.

Thus, 30 inch ISB enable us to feed higher steam flow into turbine or realize higher output with high efficiency.

4.2 Hollow Nozzle Application

The drain on the stationary blade surface is evacuated through the slit on the blade surface and the drain hole on the inside of the blade (Figure 13). A hollow nozzle is more effective at removing the moisture, thereby protecting the rotating blade from erosion, than the typical groove on the blade surface. Hollow nozzle design is applied to all Darajat units and all Hellisheidi units, considering the high moisture content at the last stage of the turbine due to high main steam pressure and low exhaust pressure.

5. Operational Data

5.1 Plant Availability

Darajat plant availability rate is summarized in Table 3.

All units in the table have demonstrated high availability.

Performance tests conducted for each unit verified that actual performance exceeded the design performance.

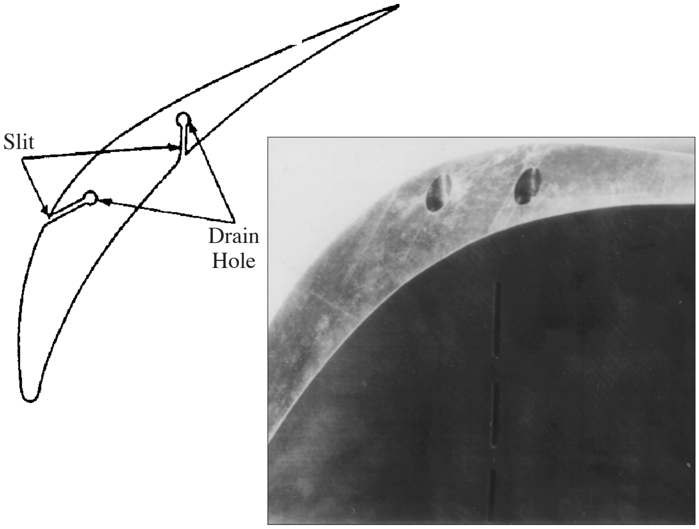


Figure 13. Hollow Nozzle.

As above, it has been verified that our technologies for high performance and reliability has worked well as expected.

Table 3. Availability of Darajat.

	Darajat #1	Darajat #2	Darajat #3
Operation Start	Dec.-94	Jan.-99	Aug.-07
Availability	98.82 %	94.98 %	97.78 %

5.2 Inspection Result on 30 inch ISB of Darajat Unit#2

Darajat Unit#2 inspection was carried out in 2002. Although moisture content at turbine exhaust is very high at the turbine exhaust, remarkable erosion at the leading edge of the last stage moving blades is not observed in this inspection (Figure14). We believe erosion had been effectively protected by hollow nozzle design applied to stationary blades at last stage and next to last stage.

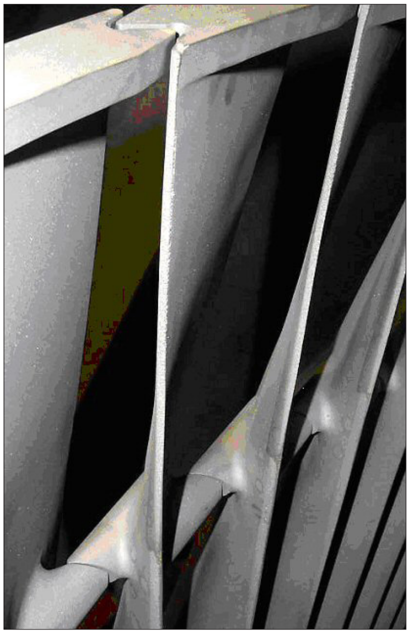


Figure 14. Last Blade Inspection Picture of Darajat Unit 2.