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Variety of Steam Turbines in Svartsengi and Reykjanes Geothermal Power Plants

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ABSTRACT

This paper introduces the geothermal steam turbines supplied to Svartsengi Power Plant and Reykjanes Power Plant from 1980 to 2010. Every time a new turbine was designed, a new unique feature was added in an effort to extend effective utilization of the geothermal resources.

The first turbine-generator unit was supplied for Svartsengi Unit 3; the turbine is a simple back-pressure 6 MW type and its exhaust steam has been contributed to the production of district heating water. The second one was for Svartsengi Unit 5, the turbine is condensing type and equipped with two steam extractions which drastically extended the capabilities of both power generation and heated water production of the plant. The third supply was for Reykjanes Geothermal Power Plant, where the steam admitted to the turbines has the world-highest pressure for the geothermal power generation. Also this power plant is unique by its usage of the seawater. The forth one was for Svartsengi Unit 6, the turbine is condensing type and has a controlled extraction which allows large variation in flow rate of the extracted steam and enabled advanced optimization of geothermal resource usage in Svartsengi Geothermal Power Plant.

1. INTRODUCTION

Iceland has for decades utilized its abundant geothermal resources for power generation as well as district heating. About 18% of electricity in Iceland is now generated from the geothermal resources, in parallel with district heating of around 90% of the nation's housing.

HS Orka hf (former Hitaveita Sudurnesja hf, hereinafter "HS") is one of the two companies in Iceland who have Combined Heat and Power (CHP) geothermal plants producing both district heating water and electricity. HS owns and operates two geothermal power plants; one is Svartsengi Geothermal Power Plant, the basic building block of the Svartsengi Resource Park consisting of three back pressure turbine-generator units, seven binary units and two condensing turbine-generator units. The second is Reykjanes Geothermal Power Plant, constructed in another resource park located about 20 km away from the Svartsengi Geothermal Power Plant, consisting of three condensing turbine-generator units. Locations of these power plants are shown in Figure 1.

Fuji Electric Systems Co., Ltd. (hereinafter "FES") has supplied several turbines-generator units to those two geothermal power plants as listed below:

Svartsengi Unit 3: 6 MW back-pressure turbine

Svartsengi Unit 5: 30 MW condensing turbine with non-controlled extractions

Svartsengi Unit 6: 33 MW condensing turbine with controlled extraction

Reykjanes Unit 1 - 3: 50 MW condensing turbines

Figure 1: Location of Svartsengi and Reykjanes power plants in Iceland.

It is just 30 years from the first supply (Svartsengi Unit 3) in 1980 and the last one (Reykjanes Unit 3) in 2010, and every time a new turbine was designed, a new unique feature was added. In this paper, the four different designs of these steam turbines are introduced.

2. SVARTSENGI UNIT 3

Svartsengi Unit 3 is a 6 MW generating unit with a back-pressure Curtis turbine manufactured in 1980 and it started commercial operation in 1981. Before this unit was installed, Svartsengi power plant operated with two 1 MW turbine-generators and 50 MJ/s heat exchange system for district heating. To extent the plant capability, a new heat exchange system (Unit 2) and a steam turbine-generator (Unit 3) were planned simultaneously.

The system was designed so that the exhaust steam from the Unit 3 turbine was used as heat input to the Unit 2 heat exchangers. To make the exhaust steam enthalpy high as required, heat loss through the turbine was to be limited. Therefore, a Curtis type turbine was selected although the mainstream of Fuji turbines was reaction type.

2.1 Turbine Specification

The major design parameters of Svartsengi Unit 3 steam turbine are listed below.

Rated Output	: 6 MW
Main Steam	: 5.0 bar abs (152 deg.C), 37 kg/s
Exhaust	: 1.2 bar abs
Speed	: 3000 rpm

Figure 2 is a turbine sectional drawing, and the picture in Figure 3 shows an outer view of the turbine.

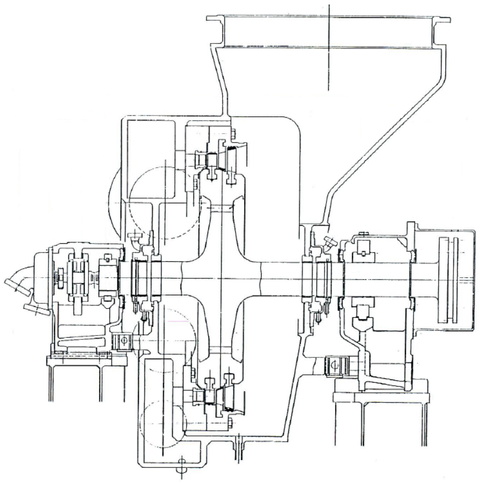

Figure 2: Sectional drawing of Svartsengi Unit 3 turbine.

Figure 3: Picture of Svartsengi Unit 3 turbine.

3. SVARTSENGI UNIT 5

The turbine and generator of Svartsengi Unit 5 were manufactured in 1998 and started operation in 1999.

As similar to the other units in Svartsengi power plant, Unit 5 was also intended to use for both power generation and district heating water production. To enable efficient cascading water heating, the steam turbine was designed to be equipped with two steam extractions. The flow diagram of Unit 3 is shown in Figure 4.

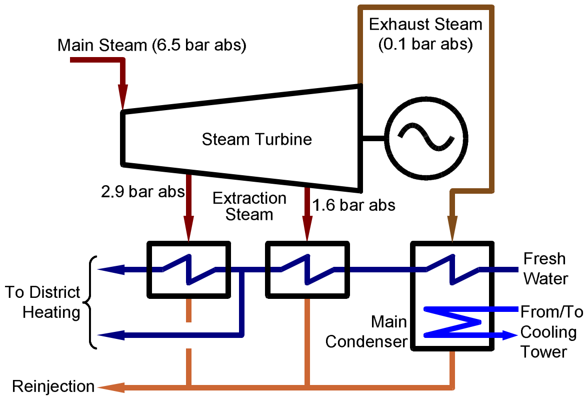

Figure 4: Flow diagram of Svartsengi Unit 3.

As shown in the diagram, the water heating system consists of three heat exchangers; the first one is the main condenser, and the second and third ones are heaters using the extracted steam. This cascaded water heating enables to produce different temperature waters of district heating for different areas. And use of turbine extracted steam for water heating, which is commonly adopted to the feed-water heating in conventional thermal power plants to increase plant cycle efficiency, is considered one of the most efficient methods to obtain relatively high temperature (above 100 deg.C) water by heat exchanges.

3.1 Turbine Specification

The major design parameters of Svartsengi Unit 5 steam turbine are as follows:

Rated Output	: 30 MW
Main Steam	: 6.5 bar abs (163 deg.C), 73 kg/s
No. 1 Extraction	: 2.9 bar abs, 0 - 11 kg/s (rated 4 kg/s)
No. 2 Extraction	: 1.6 bar abs, 15 - 30 kg/s (rated 27 kg/s)
Exhaust	: 0.1 bar abs
Speed	: 3000 rpm

The flow rates of No. 1 and No. 2 extractions are modulated by external pressure control valves. (This type of extraction is called as *uncontrolled extraction*.) The turbine sectional drawing and outer view are shown in Figure 5 and 6.

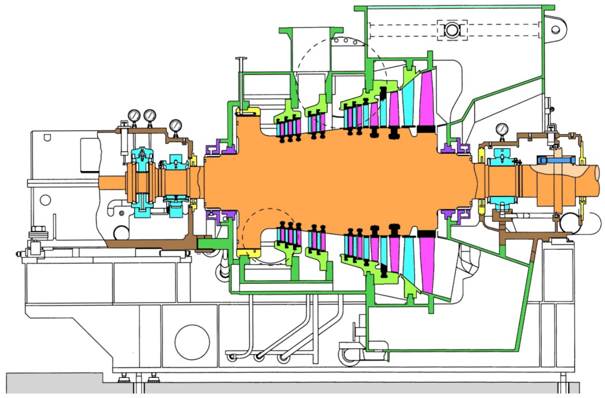

Figure 5: Sectional drawing of Svartsengi Unit 5 turbine.

Figure 6: Picture of Svartsengi Unit 5 turbine.

4. REYKJANES UNIT 1 - 3

Reykjanes Geothermal Power Plant is the second geothermal resource park for HS, and its development started in 2004. Currently only power generation takes place here.

This plant has two major unique features; one is the turbine inlet steam pressure which is highest in the world, and the other is usage of the seawater.

Unit 1 and 2 started commercial operation in 2006, and Unit 3 is now under construction and its turbine will be shipped in 2010.

4.1 High Steam Pressure

Chemical tests of the geothermal fluid in Reykjanes area carried out before the plant construction showed that the steam pressure should be as high as 18 bar gauge otherwise silica scaling problem would occur. Consequently, the rated steam pressure and temperature at each turbine inlet were determined to be 19 bar abs and 210 deg.C, although they were higher than any geothermal steam turbines which had been ever operated.

High inlet pressure leads high moisture content at the turbine exhaust due to large heat drop between the turbine inlet and exhaust. Therefore, erosion of the low-pressure blades had to be carefully considered in the selection of turbine model. It was possible to adopt a single-flow turbine when only the rated steam flow rate and required power output were counted, but decision was made to employ double-flow type so that the turbine can equip shorter low-pressure blades whose tip speed is slower than the long blades.

4.2 Turbine Specification

The major design parameters of Reykjanes Unit 1 - 3 steam turbines are as shown below:

Rated Output	: 50 MW
Main Steam	: 19 bar abs (210 deg.C), 80.3 kg/s
Exhaust	: 0.1 bar abs
Speed	: 3000 rpm

The turbines for Unit 1 - 3 have identical design except for the material of 1st stage blade; the Unit 1 turbine has titanium (Ti-6A1-4V) blades on the 1st stage, and the Unit 2 & 3 turbines have 13% Cr stainless steel blades. This material difference enables to evaluate the advantage of titanium blades against corrosion and scale deposition. At this moment, Unit 1 and 2 turbines have been operating for about 3 years but no significant difference is observed.

The sectional drawing and outer view of Reykjanes turbines are shown in Figure 7 and 8.

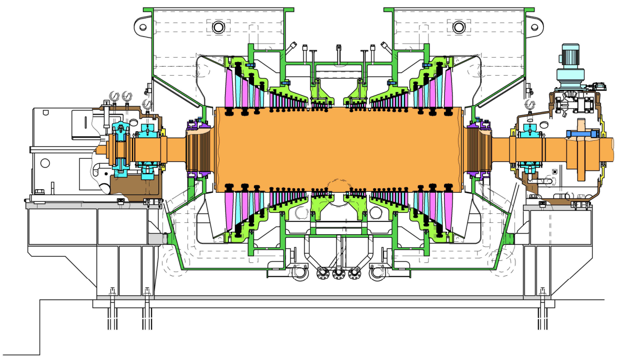

Figure 7: Sectional drawing of Reykjanes turbines.

Figure 8: Picture of Reykjanes turbine.

4.3 Usage of Sea Water

Figure 9 is a simplified flow diagram of each unit of Reykjanes power plant. As shown here, the seawater is used as the coolant of the main condenser. Also the auxiliary coolers of turbine-generator are cooled by the seawater, so their heat-exchange tubes are all made of titanium.

The seawater is pumped from water wells with 50 - 60 meters depth, and the natural lavas are used as filters to purify the seawater. This arrangement enabled to eliminate large equipment such as the cooling tower, seawater intake facility, etc.

And the seawater also contributes to reducing silica and other minerals in the fluid disposed to the sea, by mixed with the condensate and brine in the Brine Cooler.

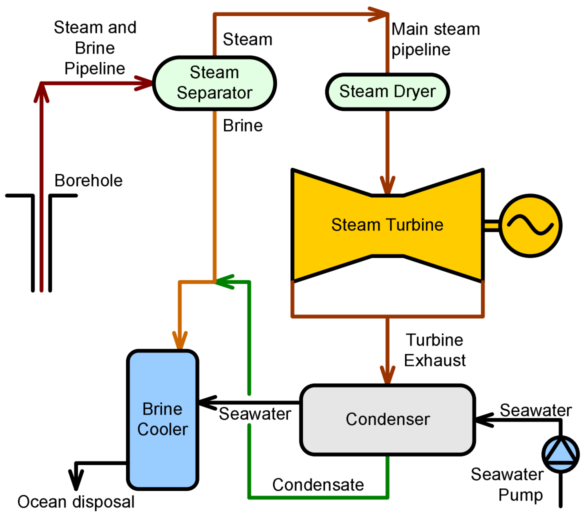

Figure 9: Flow diagram of power generation unit in Reykjanes Geothermal Power Plant.

5. SVARTSENGI UNIT 6

Development of new production wells had been made in Svartsengi Geothermal Power Plant to compensate the decrease of production by the existing wells. The new wells produced 16 bar abs steam but pressure reduction was required to admit the steam into Unit 3 and 5 turbines. For effective use of this high pressure steam, planning of a new power generation unit (Unit 6) was started in 2005.

5.1 Background of Employing Controlled Extraction

The concept of Unit 6 was a kind of top turbine of Unit 5; Unit 6 turbine admits the 16 bar abs steam, and from its midstream extracts 6.5 bar abs steam for Unit 5.

First, a condensing turbine with an uncontrolled extraction, same type as Unit 5 turbine, was considered. However, a serious difficulty came up because the required flow rate of 6.5 bar abs steam had large variation with the seasons. As illustrated in Figure 10, pressure profile in the extraction turbine is affected by the flow rate of extracted steam. The change of turbine pressure profile can be covered by an external control valve to some extent, but the operation range required for Unit 6 exceeded its capability.

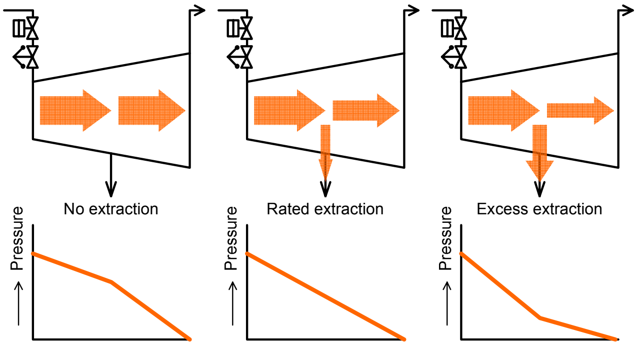

Figure 10: Illustration of pressure profile inside turbine (in case of uncontrolled extraction).

There were two options to solve the problem; to provide two turbines (one backpressure and one condensing), or to employ controlled extraction. "Controlled extraction" is a method to obtain extraction steam with constant pressure by modulating the inlet pressure of turbine lower part adjacent to the steam extraction port, and it is commonly employed for the steam turbines in industrial power plants for factories and mills. Although it was unprecedented to apply controlled extraction to a geothermal turbine, HS and FES decided to undertake it as a challenge for extended plant optimization.

In addition to the 6.5 bar abs extraction, the Unit 6 turbine was required to admit 1.2 bar abs steam from the Unit 3 turbine exhaust during the summer time when the steam demand by the water heating system decreases. As a result, the initial concept design of Unit 6 turbine was outlined as shown in Figure 11.

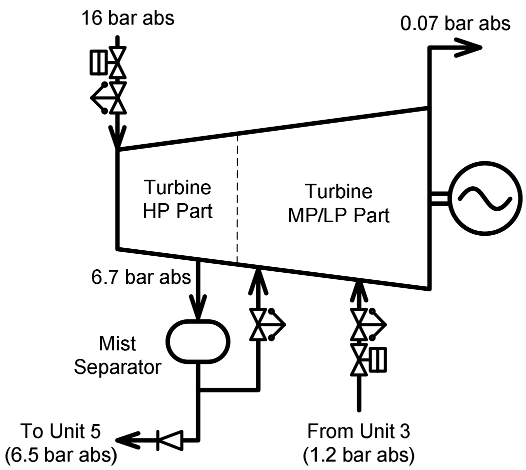

Figure 11: Initial concept design of Unit 6 turbine.

The major turbine design parameters are listed below.

Rated Output	: 33 MW
Main Steam	: 16 bar abs (201.4 deg.C), 80.8 kg/s
Extraction	: 6.7 bar abs at turbine outlet,
	External supply 30 - 51 kg/s
LP Admission	: 1.2 bar abs, 0 - 15 kg/s
Exhaust	: 0.07 bar abs
Speed	: 3000 rpm

5.2 Countermeasure against Design Issues Caused by Medium-Pressure (MP) Separator

As shown in Figure 11, there is a mist separator between the exhaust of turbine high-pressure (HP) part and the inlet of medium-pressure (MP) part in order to remove the wetness contained in the HP exhaust steam. It is called as "MP separator". After the detail calculation, it was found that the required dimension of MP separator was much larger than assumed in the concept design.

The large capacity of MP separator required us to totally re-examine the designs around the steam extraction part of the turbine. FES turbine designers noticed that the situation was rather similar to reheat turbines, i.e. MP separator should behave like the reheaters in fossil-fired power plants. They categorized the design issues as follows.

5.2.1 Overspeed of Turbine

Overspeed possibly occurs at the timing of turbine trip or load rejection by inflow of large volume of steam accumulated in MP separator and associated pipes. To avoid such failure more reliably, emergency stop valves were added at upstream of the extraction control valves.

5.2.2 Blade Overheating of Turbine HP Part

The large volume of steam in MP separator may also cause blade overheating of the turbine HP part at the timing of turbine trip or load rejection by windage loss.

The windage loss is generated in rotating steam turbines when blades are under high pressure and less steam flow conditions. Therefore it was required to immediately depressurize MP separator when turbine trip or load rejection occurred, otherwise pressure of the turbine HP part is kept high whereas the steam flow stops. For this purpose, two depressurizing lines were added. Further, a transient simulation was made as shown in Figure 12 and confirmed that the blade overheating will not occur.

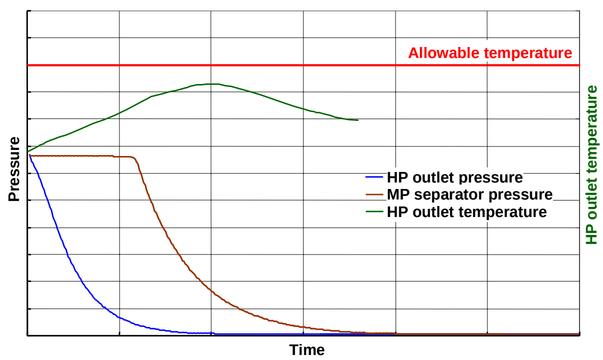

Figure 12: Transient simulation of load rejection characteristics.

5.2.3 Water Backflow from MP separator

Originally, a check valve was planned to be installed on the 6.5 bar abs steam supply line to Unit 5 as shown in Figure

11, according to the common arrangement adopted in the conventional extraction turbine plant. However, as the MP separator was designed to have a water level in it, the location of the check valve was changed to the outlet of turbine HP part as a countermeasure against possible water backflow.

Reflecting the countermeasures described in 5.2.1, 5.2.2 and 5.2.3, the system design was finalized as shown in Figure 13.

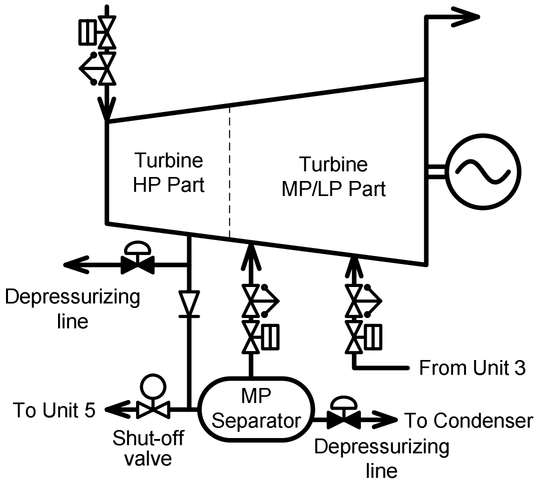

Figure 13: Final arrangement of Unit 6 turbine.

5.3 Piping Arrangement around Turbine

Unit 6 turbine has eight inlets and outlets of the main pipes as listed below.

- 2 x HP inlets (ϕ 400)
- 2 x HP outlets (ϕ 600)
- 2 x MP inlets (ϕ 450)
- 2 x LP inlets (ϕ 500)

Since the turbine weight is relatively small compared to the piping force and moment, precise arrangement was required to secure stability of the turbine body.

Figure 14 - 16 show the turbine sectional drawing, 3-D view of the piping arrangement and photo of the turbine.

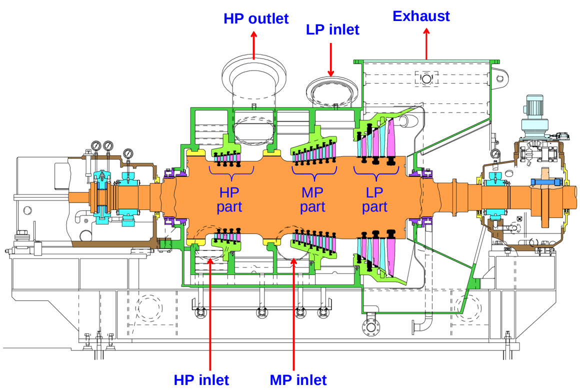

Figure 14: Sectional drawing of Svartsengi Unit 6 turbine.

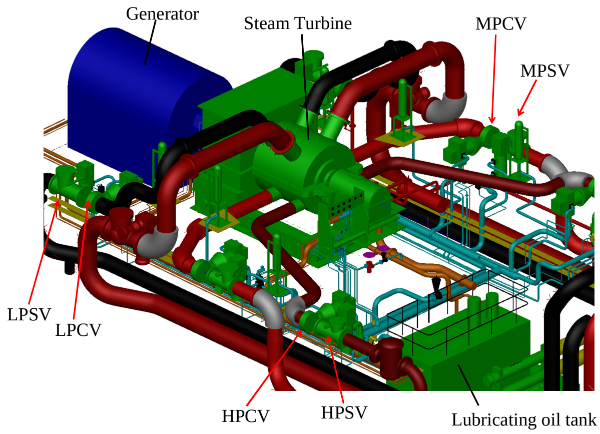

Figure 15: 3D view of Svartsengi Unit 6 turbine.

Figure 16: Picture of Svartsengi Unit 6 turbine (view from generator).

5.4 Monitoring of Operation Limit

As Unit 6 turbine has various steam inflows and outflows, the allowable operation range is defined by combination of the HP/MP/LP flows. To be easily understood by the operators, operation limit curves were developed and indicated in the SCADA display as shown in Figure 17. An alarm is raised when the turbine operation deviates from the allowable range.

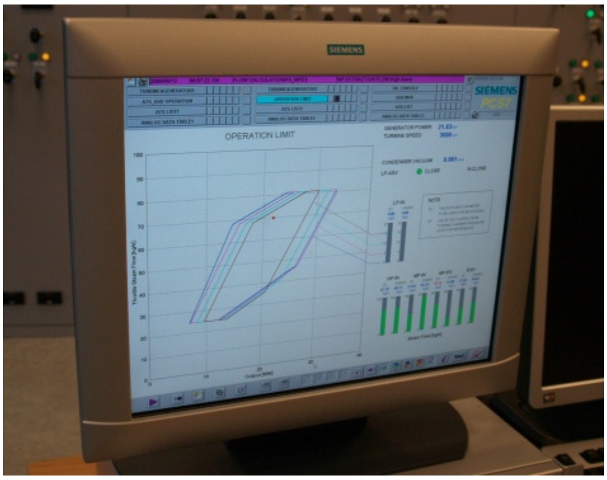

Figure 17: Operation limit curve in SCADA display.

6. CONCLUSION

The new designs developed for the turbines in Svartsengi and Reykjanes geothermal power plants showed us both potentials and difficulties of geothermal steam turbines. They also suggested that we should flexibly learn and incorporate the technologies developed for other industries.

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