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# CONSTRUCTION OF THE LARGEST GEOTHERMAL POWER PLANT FOR WAYANG WINDU PROJECT, INDONESIA

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**ABSTRACT**

Sumitomo Corporation, Japan obtained the Engineering, Procurement and Construction (EPC) contract with Magma Nusantara Limited (MNL), Indonesia for Wayang Windu Geothermal Power Plant including power station and Steamfield Above Ground System (SAGS) in June 1997. MNL, as an Independent Power Producer (IPP) will operate the plant and sell electricity to Persahaan Listrik Negara (PLN) for 30 years. The plant will include 2 units of 110MW power generation facilities and another 2 units of 110MW as an option in the future. Fuji Electric, Japan, as the subcontractor of Sumitomo Corporation, supplied steam turbines, generators, condensers and ancillary equipment as well as constructing and commissioning the plant.
The geothermal steam turbine manufactured at Fuji Electric, Kawasaki, Japan is the largest capacity (rated 110MW, max. 115MW) in the world as a single flash and single casing with 27.4-inch- long last stage blades (LSB).
The first set of 110MW power generation facilities including the power station and SAGS was ready for synchronization in August 1999 and second unit is awaiting notice to proceed from MNL.

## 1. INTRODUCTION

Wayang Windu geothermal power plant is in Pangalengan located approximately 40 km south of Bandung, West Java in Indonesia, as presented in Fig.1, and named after Mt. Wayang and Mt. Windu near the plant. Fig.2 presents the plant overview. The site is surrounded by a tea plantation and its altitude is approximately 1700 m above sea level.
Since the plant is an IPP project, low capital cost and reliable operation with high efficiency are essential from an economical point of view. The plant has several distinctive characteristics including large-capacity turbine, two-phase flow pipelines with central separators, and integrated pressure control designated to meet such requirements.

## 2. DISTINCTIVE CHARACTERISTICS OF THE PLANT

### 2.1 Large Capacity Turbine

It is well known that larger capacity means higher efficiency for a geothermal steam turbine as well as a conventional one. The largest capacity of 110MW geothermal turbine of single casing is used here.

### 2.2 Two Phase Flow Pipelines

A mixture of steam and water from production wells is led to a central separator station as two phase flow. Piping material and construction costs decrease because of the smaller bore piping.

### 2.3 Integrated Pressure Control System

Stable separator pressure is essential to maintain steam quality. The integrated pressure control system uses the turbine governor valves to achieve this by varying at the same time as controlling flow at the production wells. Consequently, release of geothermal steam to atmosphere can be minimized.

## 3. POWER STATION

Fig.3 presents schematic diagram of power station.

### 3.1 Steam Turbine

The turbine is a single-cylinder, double-flow condensing type. Major specifications are the following;

| | |
|---|---|
| Output | 110 MW (MCR 115MW) |
| Inlet steam pressure | : 10.2 bara |
| Inlet steam temperature | : 181°C |
| Exhaust steam pressure | : 0.12 bara |
| Number of stage | :2 (flows)X 8 |
| Length of LSB | : 697 mm (27.4 inches) |
| Bearing span | : 5800mm |
| Speed | :50 c/s |

The turbine casing is of single-shell construction and is composed of two blocks in the axial direction; i.e., the front and rear parts. Upper half of the casing is shipped as one block, bolted at the vertical joint flange of the front and rear parts assembled with the upper half of stationary holder and/or stationary blade rings, so as to decrease the work at job site. Lower half is also designed as one block in the factory. The casing is directly supported by foundation at both sides of the exhaust. The bearing pedestals are independent from the casing and directly fixed on the foundation. This construction secures the vibration stability of the turbine rotor with large inertia moment.
As the turbine uses reaction blades, the turbine rotor has a drum

or flat configuration. Stress concentration and deposition of corrosive components are eliminated by the flat configuration, so that the possibility of stress corrosion cracking (SCC) is avoided. Because the rotor has the longest LSB for geothermal use, its maximum diameter is quite large and stresses on the blade groove are large. To reduce the maximum stresses on the blade groove, the newly designed low stress groove is adopted.
The turbine blades of Fuji's geothermal steam turbines are all reaction type blades. The reaction type blades are highly efficient as well as highly reliable. First to fifth stage blades are the integral shroud blades machined from one block of material. They are assembled in the rotor and/or the stationary blade holders so that the shroud and root have compression stress on each contact surface to the adjoining blades of both sides. When assembled in such a manner, no gaps between the adjoining blades will be produced under any operational conditions and the high vibration damping effect due to dry friction will be produced. The sixth stage moving blades have the integral shroud of zigzag contour which assures a good damping effect as above using twist back of the blades. The profiles of the first to fifth stage stationary blades are the same as those of the moving blades but the size in dimension changes. These stationary blades are assembled in one stationary blade holder, which is bolted to the stay flange of casing. The stationary blade holder has the horizontal joint flange. Fig.4 presents a cross section of the turbine.
Since the steam velocity through the reaction stage is as low as half of that through impulse stage, solid particle erosion is avoided. The blades of the geothermal turbines are designed so that the design stresses are kept at a lower level as compared with those of the conventional turbines. This design feature eliminates the possibility of SCC and corrosion fatigue.
Furthermore this makes the throat, the minimum channel width of the blade row, large. A large throat area is particularly advantageous for the geothermal turbine, since scaling easily occurs on the turbine blades. Having a large throat area means that, even if scaling occurs, the output reduction will be kept at a smaller level. As one of the other countermeasures against scaling, the blade wash system is provided, which washes the turbine blades during normal operation by injecting condensate water.
The last three stages are provided with LP blades. They are the advanced LP blades designed using the fully three-dimensional (3-D) flow calculation method. The last (L-0) stationary blades are leaned in the radial direction to reduce the losses near the root. And the airfoils near the tip of LSB figure so called *convergent-divergent* channel that minimizes the shock wave losses. Employing the advanced LP blades means that the turbine efficiency will be improved by 1.5%.
L-0 and L-1 moving blades are free standing without shroud or lacing wires. Since any additions like boss for the lacing wire are not provided on the airfoils, they are designed to be aerodynamically optimum. The vibration characteristics of the free-standing blades are so simple that resonance frequencies are easily avoided with a proper margin in the design stage to allow continuous operation at ±5% of nominal speed (47.65 ～52.5 1/s).
Stellite shields are brazed to L-0 and L-1 moving blades on the tip to protect from erosion by water droplets. To reduce the erosion by water droplets, proper drainages are provided as well at the inlet chamber, fifth stage outlet, and inter-stage of LP-blade row, by which the water droplets will be discharged to the condenser.
The turbine adopts dual entries of steam to perform a full stroke stem free test of the main stop and governor valves. Two main stop valves of swing check type are provided. The bore size of main stop valve is 800 mm. Two governor valves of butterfly type are provided downstream of each main stop valve, that is, total 4(four) governor valves with 600 mm bore size are provided for this turbine in order to maintain the proper governing speed.

### 3.2 Generator

Delivery of the largest capacity air cooled turbogenerator for geothermal power plant

Air cooled turbogenerator for this plant is the largest capacity unit among the air cooled Turbogenerator units for geothermal power plants developed by Fuji Electric, Kawasaki.
Major specifications are the following:

| | |
|---|---|
| Type | : Three-phase horizontal cylindrical revolving field total-enclosed type synchronous generator. |
| Ventilation | : Self-ventilation |
| Cooling | : Totally enclosed water-to-air cooled (TEWAC) |
| Rating | |
| Output | : 137500KVA |
| Voltage | : 13800V |
| Power factor | : 0.8（lag） |
| Frequency | : 50Hz |
| Number of phases | : 3 |
| Speed | : 3000rpm |
| Insulation class | : F |
| Excitation | : Brushless excitation |

Major corrosion protection

| | |
|---|---|
| Stator coil and insulation | : Global vacuum pressure impregnation insulation |
| Stator core | : Special coating |
| Rotor coil and insulation | : Special coating |
| Purification of circulating air | : Purified by special filter |
| Make-up air | : Purified by special filter |

Introduction of Fuji’s latest compact/light weight air cooled turbogenerator

Fuji has been in the development work of new series for 2 years to make this 2-pole air cooled turbogenerator more compact in

size and lighter in weight by 30%. To verify the development work, a 120MVA Prototype Generator was built.
In designing this Prototype Generator, a considerable number of improvements were made to achieve compact and light weight unit, and more than 1000 items have been measured for various conditions to confirm its performance and safety as well as finding items for further improvement.
Data logger and optical slipring method were developed for measuring temperature at each part of rotor coil during rated operation.

Major analysis techniques
- 3-D electro magnetic field analysis
- 3-D flow analysis and temperature analysis
- Vibration analysis
- Strength analysis

Major measurement and verification items
- Generator power
- Stator and rotor temperature
- Generator flux
- Generator vibration

### 3.3 Condenser

The condenser is of direct contact, low level type. Cooling water from the cooling tower is directly injected into the exhaust steam through the jet nozzles by differential pressure between cooling tower and condenser, and the normal water level in the condenser is maintained by the control valves located downstream of the hot well pumps.
The condenser is composed of the steam inlet connections, upper shell, lower shell and hotwell. The steam inlet connections are constructed with the stainless expansion joints to prevent deformation of the turbine casing and the condenser. The lower shell is composed of a condensing zone and three gas cooling zones.
The shell and hotwell plates are made of type 316L stainless clad steel and other internal parts including nozzles are made of type 316 or 316L stainless steel.
The condenser is pre-assembled to 10 blocks at the factory. Major specifications of the condenser are the following;

| | |
|---|---|
| Condensing pressure | : 0.12 bara |
| Steam flow(incl. NCG;2 wt%) | : 733,300 kg/h |
| Cooling water flow | : 16,700m$^3$/h |
| Cooling water temperature | : 23.5°C |
| Weight (empty) | : 200 ton |

### 3.4 Auxiliary Equipment

Specifications of major equipment are presented as below.

Cooling tower

| | |
|---|---|
| Type | : Wet type, Counter flow |
| Number of cell | : 8 |

Gas removal system

| | |
|---|---|
| Type | : Hybrid system (combination of steam ejector and vacuum pump) |
| Capacity | : 2X50% + 50% ejector stand by |

Generator Transformer

| | |
|---|---|
| Rating | : 134 MVA (ONAF)<br>92 MVA (ONAN) |
| Voltage | : 150 kV / 13.8 kV |

Overhead crane

| | |
|---|---|
| Type | : Overhead traveling crane |
| Rating | : 60 ton (main hoist)<br>5 ton (aux. Hoist) |
| Span | : 25 m |

## 4. STEAMFIELD ABOVE GROUND SYSTEM (SAGS)

Steamfield Above Ground System, so called SAGS, is the generic name of facilities other than the power station in geothermal power plant, such as steam pipeline, brine/condensate pipeline, separator, scrubber, rock muffler, etc. Fig.5 presents schematic diagram of SAGS.

### 4.1 Production and Injection Wells

Production and injection wells were developed by MNL prior to commencement of the work for the power station and SAGS. There are three production wellpads and three brine/condensate injection wellpads for unit No.1. Each production wellpad has three or four wells ranging from 1800m to 2500m.
The altitude of a production wellpad is approx. 1850m above sea water level (aswl) being higher than that of power station by 150m while injection wellpads is approx. 1500m aswl being lower by 200m. Fig.6 presents a production wellpad.

### 4.2 Pipeline

Geothermal steam & fluid from production wells is piped downhill from the separators as two phase flow. Pipelines from each wellpad to separator are made of carbon steel being 36 inches nominal bore. The distance between them is approx. 4km.
Steam pipeline from the separator to the power station is made of carbon steel being 40 inches nominal bore. The distance between them is approx. 1km and vertically displaced by 70m.
Brine pipeline from the separator to each injection wellpad is made of carbon steel being 30 inches nominal bore. The distance between them is approx. 8km and gravity reinjection is used.
Condensate pipeline from the cooling water piping to the injection wellpad is made of carbon steel being 28 inches

nominal bore. The distance between them is approx. 9km.
Necessary pipe loops are provided on those pipelines to absorb thermal expansion.

### 4.3 Separator, Scrubber and Rock Muffler

Three cyclone-type separators are used to separate steam from two-phase liquid coming from production wells. Steam goes to power station while brine to injection wells.
Two scrubbers of corrugate type are provided just before the power station to eliminate further moisture.
Surplus steam is released to the atmosphere through vent valves. Two rock mufflers are provided near the separator station to reduce the noise level of the released steam.

## 5 PROJECT SCHEDULE

Fig.7 presents a project schedule including engineering/design, manufacturing, transportation, construction and commissioning. The contract was effective in June 1997 and the plant was ready for synchronization in August 1999.

Engineering/Design and Manufacturing
Critical equipment such as turbine, generator and condenser were shipped from Fuji Electric Kawasaki Factory 12 months after notice to proceed was given by MNL. Major auxiliary equipment such as hotwell pumps, cooling tower, gas removal system, main transformer and Distributed Control System (DCS) were shipped from Japan, USA, Australia, Singapore, etc. 12 to 16 months after the contract signing. SAGS piping materials designed by Kingston Morrison Limited (KML) were shipped progressively from Japan, USA, Korea, etc., 8 to 16 months after the contract signing.

Construction and Commissioning
Civil and construction works were sublet to local subcontractors. Proposals for the works were thoroughly evaluated in the points of technical, commercial and financial views. The site work for power station started in June 1997.
SAGS site works started in December 1997. Local engineering company, subsidiary of an engineering company in New Zealand, has been employed for managing and supervising such subcontractors.

## 6. TOPICS

### 6.1 Environmental Protection

The plant is surrounded by tea plantation and villages. During construction and commissioning periods, control of storm water discharge, soil disposal, dust, and water quality have been taken to ensure environmental impacts have been minimal. Periodic monitoring reports in accordance with AMDAL (Indonesian environmental regulation) were submitted to the government office every 3 months.

### 6.2 Weather

The period from May to October is usually the dry season. Civil works such as excavation, concrete pouring and backfilling were planned during the dry season. There was no dry season in 1998 due to the so called “La Nina phenomenon” which is a reaction of “El Nino phenomenon” in 1997. The progress of civil and structural works was significantly affected. Unexpected environmental protection works were carried out accordingly.

### 6.3 Economic Crisis in Indonesia

In Indonesia as well as other Southeast Asian countries, an economic crisis occurred in 1998. Local subcontractors had difficulty in raising funds resulting in the delay of progress of the works. Local subcontractors faced difficulty in purchasing materials from foreign countries because foreign companies did not accept Letters of Credit issued by Indonesian banks.
As countermeasures, we improved terms of payment for the subcontractors so as to assist a solution of their finance problem and we purchased necessary materials from foreign companies instead and supplied them to the subcontractors.

## 7. CONCLUSION

The largest capacity of geothermal turbine was manufactured at Fuji Electric, Kawasaki, Japan a company with extensive experiences in both geothermal and conventional power generation businesses.
Wayang Windu Geothermal Power Plant unit No.1 has been successfully completed in cooperation with MNL and local subcontractors. We hope that electricity generated at this plant contributes to development and improvement of life for local people in this area.

## ACKNOWLEGNENT

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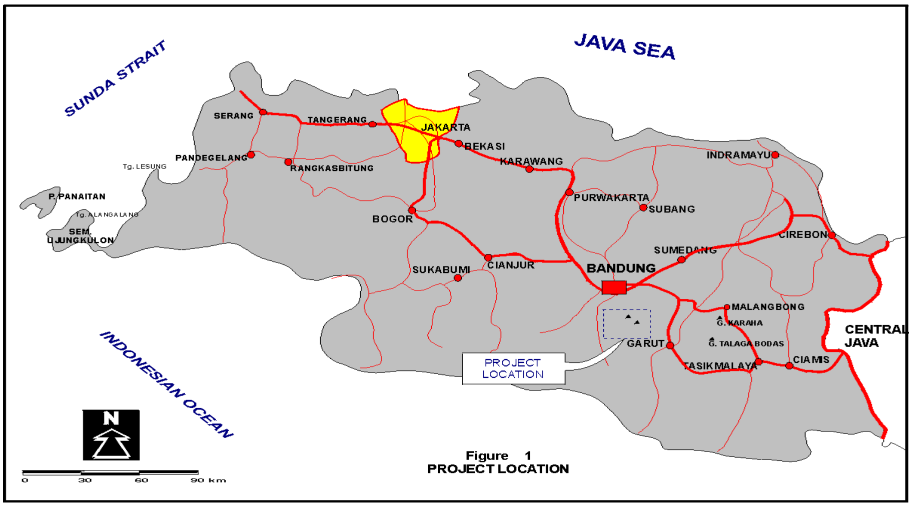


Figure 1
PROJECT LOCATION

Figure 2 Plant Overview

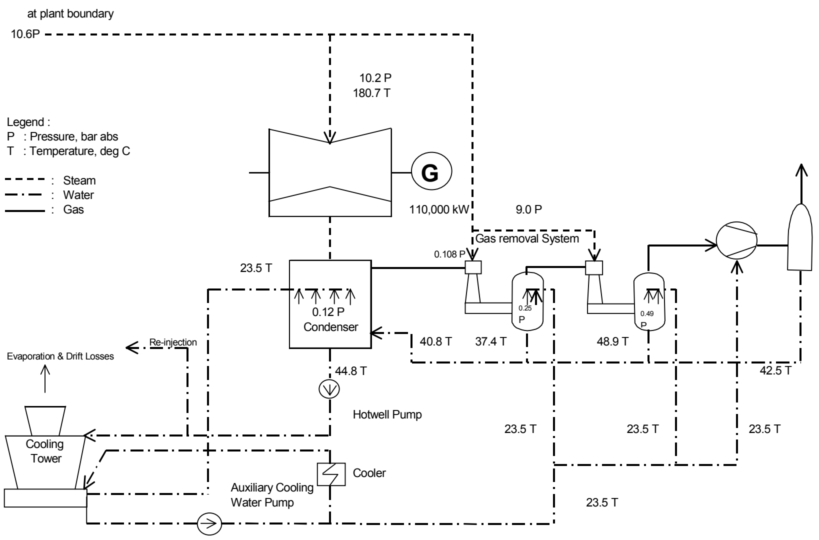


Figure 3 Power Station Schematic Diagram

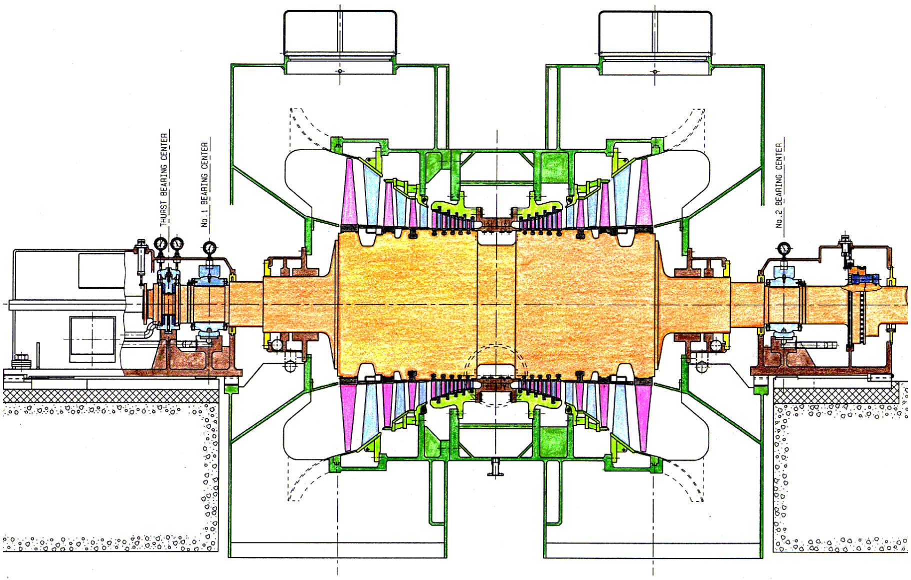

Figure 4 Turbine Cross Section

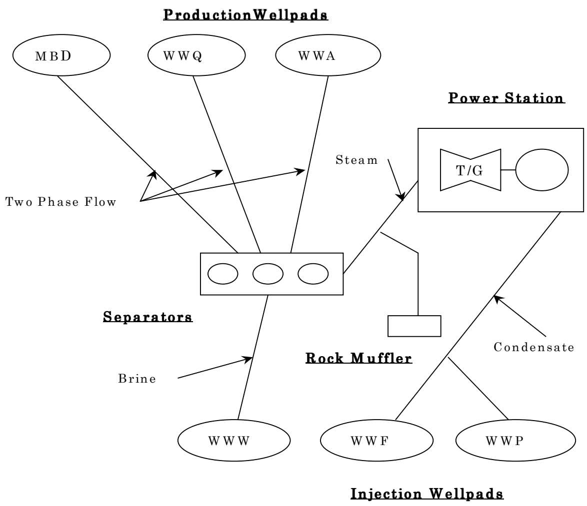

Figure 5 Schematic Diagram of SAGS


Figure 6 Production Wellpad

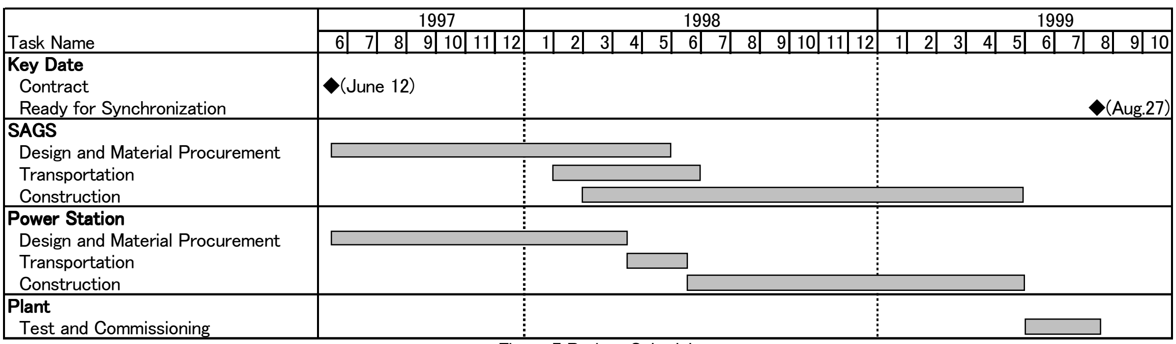

Figure 7 Project Schedule