

## Unit 1 Turbine Rotor 110 MW Replacement

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### ABSTRACT

Unit 1 steam turbine of Wayang Windu geothermal power plant with capacity 110 MW has been operated since plant commissioning in 2000. A periodic Turn Around (TA) program such as turbine inspection and overhaul was conducted at a 3 year interval. During the 2006 turbine inspection program, erosion damage defects were found on the rotor body between each of the reaction stages. Several of the “J” seal strips in these sections had been peeled off through the erosion from the parent metal surrounding the caulking groove. The erosion damage was found to have become worse during turbine inspection in the 2009. As a result, there was a high potential for the seal strip caulking being dislodged in the future after the rotor was returned to service with its current condition which could result in catastrophic damage to the turbine.

Star Energy Geothermal Wayang Windu Ltd. (SEGWWL) conducted an engineering study and decided to replace the existing turbine rotor with a new turbine rotor with the aim to avoid potential major problems and provide long reliability of operation which would minimize cost and shutdown time, in the event that site repair was required.

The new turbine rotor replacement was conducted in Unit 1 TA 2012 with a planned shutdown schedule of 16 days. In order to achieve the target, the planning and preparation work of the TA team was very essential. The TA team started the preparation work 1.5 years before work execution by preparing the budget proposal, detailed work package & specification, detailed work schedule, regular Safety Health and Environment (SHE) & coordination meetings. This huge effort had a significant impact on the completion of this TA program where the actual Unit 1 shutdown schedule was 12 days (4 days ahead of schedule), within budget and no Lost Time Accidents (LTA) by providing high plant availability and reliability for long term plant operation.

### 1. INTRODUCTION

Wayang Windu Geothermal Power Plant Unit 1, which has a capacity of 110 MWe, was the largest single cylinder turbine in the world when it was commissioned in May 2000. Electricity from the Power Plant is supplied to PLN (Perusahaan Listrik Negara, Indonesia’s state electricity company).

#### 1.1 Process Overview

The separated main steam containing some non-condensable gases is supplied from two 36 inch steam lines to a 48 inch header after liquid droplets are removed from the steam through the steam scrubbers. The steam supply design conditions are 10.6 bars absolute at 182°C and flow rate of 211 kg/second.

The turbo generator is supplied from the steam header via a 44 inch line through steam strainers, steam turbine main stop valves and steam flow control valves. To control the output of the turbo generator, the turbine governor operates the steam flow control valves.

The FUJI 110 MW steam turbine is directly coupled to the FUJI two-pole 137.5 MVA 13.8 kV generator. The steam turbine is a single casing, double-flow, reaction type with eight stages in each flow. The generator is three phase 50Hz air cooled with forced air cooling using water.

The generator electrical output is supplied to the PLN grid via a generator transformer that increases the voltage to 150kV. An additional connection to the generator output is used to supply the power station electrical plant through a 13.8 kV to 6.3 kV unit transformer. A circuit breaker and an earthing switch are installed between the generator and transformer. The generator can be synchronized to the PLN grid using low voltage or the high voltage circuit breakers.

After doing the work in the turbine, the steam is exhausted to a direct contact spray type condenser mounted beneath the turbine. Cooling water delivered from the cooling tower through the condenser spray nozzles is used to condense the steam through direct contact. The condenser cooling water and condensed turbine exhaust steam collect in the condenser hotwell as condensate. Two 50% duty hotwell pumps remove condensate from the hotwell and deliver it to the cooling tower.

In the cooling tower, heat is removed from the condensate by the air flowing through the tower. The cooling tower is a counter flow, forced draught type with motor driven fans to provide the forced draught.

The loss of cooling water that is carried away in the water vapor plume of the cooling tower is not enough to counter the additional condensed steam. A cooling tower level control system is used to remove excess condensate to the Steam Above Ground System (SAGS) condensate re-injection system.

Noncondensable gases are collected and removed from the condenser by the gas removal system. The gas removal system is a hybrid system using steam ejectors and liquid ring vacuum pumps to remove non-condensable gases and deliver them to the cooling tower. The steam supply to gas removal system is from the main steam header by a 10 inch supply line separate to the turbo generator supply. The non-condensable gases are discharged to the cooling tower beneath the fans and are carried away in the thermal plume of the cooling tower.

An auxiliary cooling water system supplied from the cooling tower basin outlet pipe is used for cooling turbine lube oil, generator air coolers and the gas removal system inter and after condensers. Two 100% duty auxiliary cooling water pumps are installed for circulation of the auxiliary cooling water.

The plant compressed air systems use three rotary screw compressors to supply two general air receivers that supply the instrument air and utility air supplies. Instrument air is supplied via heat less air dryers and filters to control valves and other instruments that require clean dry air. Utility air is supplied via an auto shut off valve that will close if instrument air pressure falls.

Plant fire protection systems include automatic and manual sprinklers, fire hydrants and portable fire extinguishers. Fire detection is by heat sensors and smoke sensors. Two water pumps, a diesel and an electric are installed to supply sprinkle and hydrant systems.

Plant electrical systems use 6.3 kV supplies for major auxiliary plant supplies and 6.3kV/380 V transformers to supply general auxiliary equipment. An 1100 kW emergency generator supplies the 380 V systems. DC systems of 125V and 230V use batteries and battery chargers for essential supplies. Essential no-break AC equipment such as the DCS plant control systems are supplied by a UPS that uses rectifiers, batteries and inverters.

The plant is controlled from a central control room adjacent to the turbine hall. A distributed control system is used for all start, stop, and on line operations and monitoring. Automatic turbine start, synchronizing, loading and shut down are achieved by use of the plant control systems. Automatic control of critical and important process conditions such as the SAGS power station interface, steam pressure is included in the distributed control system functions. Remote switching of electrical equipment and automated sequential starting and stopping of major auxiliaries are other features available to the operators in the control room.

## 1.2 Unit 1 TA Program

In Wayang Windu Geothermal Power Plant, the TA program is carried out with three objectives as follows:

1. Perform essential inspection on major equipment and protection system to ensure high plant availability and capability.
2. Perform necessary repairs on major equipment to ensure high plant integrity and reliability.
3. Induce optimization to improve plant performance during normal running conditions.

The objectives aim to achieve Star Energy business objective which is to optimize net income and zero harm operation.

The first Unit 1 inspection program after plant commissioning in 2000 was conducted in 2001 as a part of a warranty claim closing process. There were no major issues found during the inspection and Unit 1 plant was back in operation after a short time. In 2003, after Unit 1 Turbine Generator (TG) had been running for 3 years, the TA program was conducted to meet the above objectives. The TA date was 23<sup>th</sup> April to 5<sup>th</sup> May 2003. All major parts (turbine rotor, casing, control valve, stop valve etc.) were disassembled and inspected. The turbine rotor, steam line, strainers, valves, and internal parts were in very good condition, with no unexpected or unusual wear or damage. Table 1 shows the specification of Unit 1 Turbine Rotor and Figure 1 shows a sectional drawing of Unit Turbine Rotor.

**Table 1: Specification of Unit 1 Turbine Rotor.**

|                                                                         |                                        |
|-------------------------------------------------------------------------|----------------------------------------|
| <b>Product Manufacturer</b>                                             | <b>Fuji Electric System</b>            |
| <b>Part Name</b>                                                        | <b>Turbine Rotor</b>                   |
| Turbine type                                                            | Single casing, dual flow, condensing   |
| Application                                                             | Geothermal steam                       |
| Rated output at the generator terminal                                  | 117,000 kW                             |
| Inlet Steam pressure/ temperature at inlet flange of the steam strainer | 10.7 bar abs/ 182.8 °C (dry saturated) |
| Exhaust pressure                                                        | 0.11 bar abs                           |
| Rated speed                                                             | 3,000 rpm                              |
| Direction of rotation (view from generator side)                        | Clockwise                              |
| Number of blading stages                                                | Reaction stage, 8 × dual flow          |

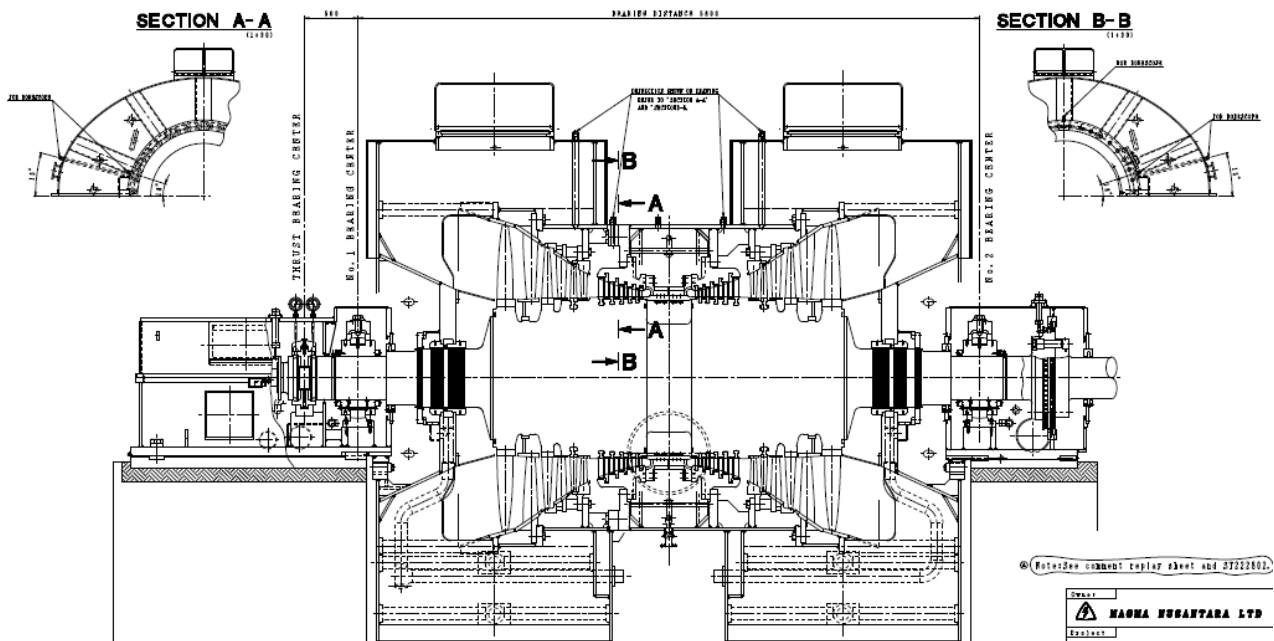


Figure 1: Sectional Drawing of Unit 1 Turbine Rotor.

In 2006, the second Turn Around Program for Unit 1 was conducted from shut down on 1<sup>st</sup> August until start up on 12<sup>th</sup> August. The inspection of the turbine rotor revealed that the turbine blading was observed to be clean with only minor scaling. The Co-Cr alloy strip on the last rows of blades was found to be in excellent condition with very little signs of erosion damage. However, mostly, all “J” seal strip groove areas on the rotor, especially on the HP side of the rotor, were found to have heavy erosion. Each of inter stage seal #2, #3, #4 and stage #5 area were found to have seal strips missing and eroded heavily (see Figure 2 and Figure 3). With information from a Fuji Electric engineer about the anticipated power loss and the plant economics, it was determined not to repair this until the next major overhaul. Mostly all turbine disks showed signs of major erosion/corrosion on the turbine disks and shrouds of the blades. The journals, oil seal areas and thrust bearing collar had light radial rub marks. The gland packing areas had heavy erosion/corrosion pitting and major radial rubs.

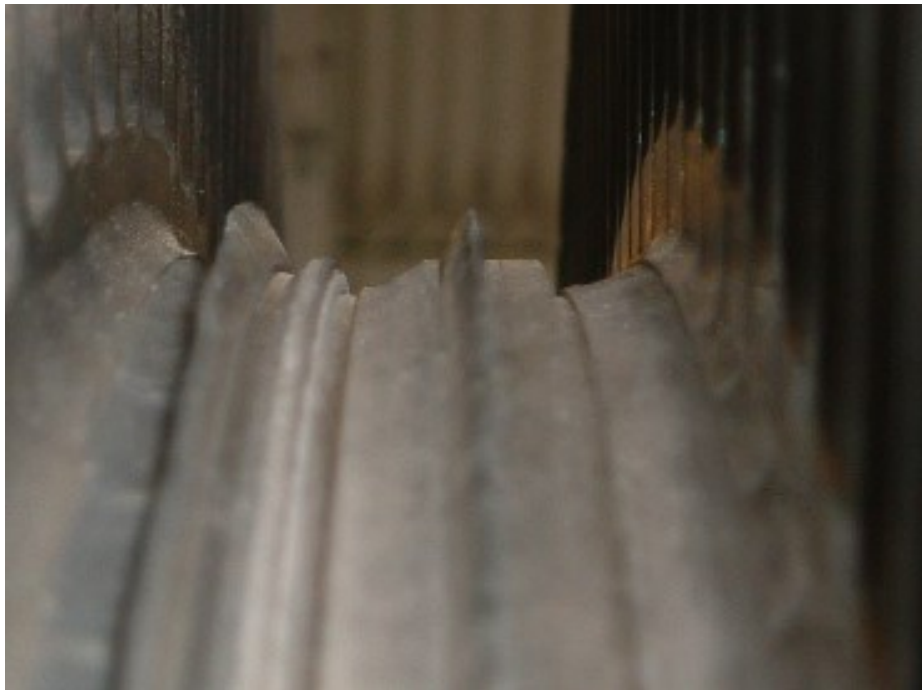
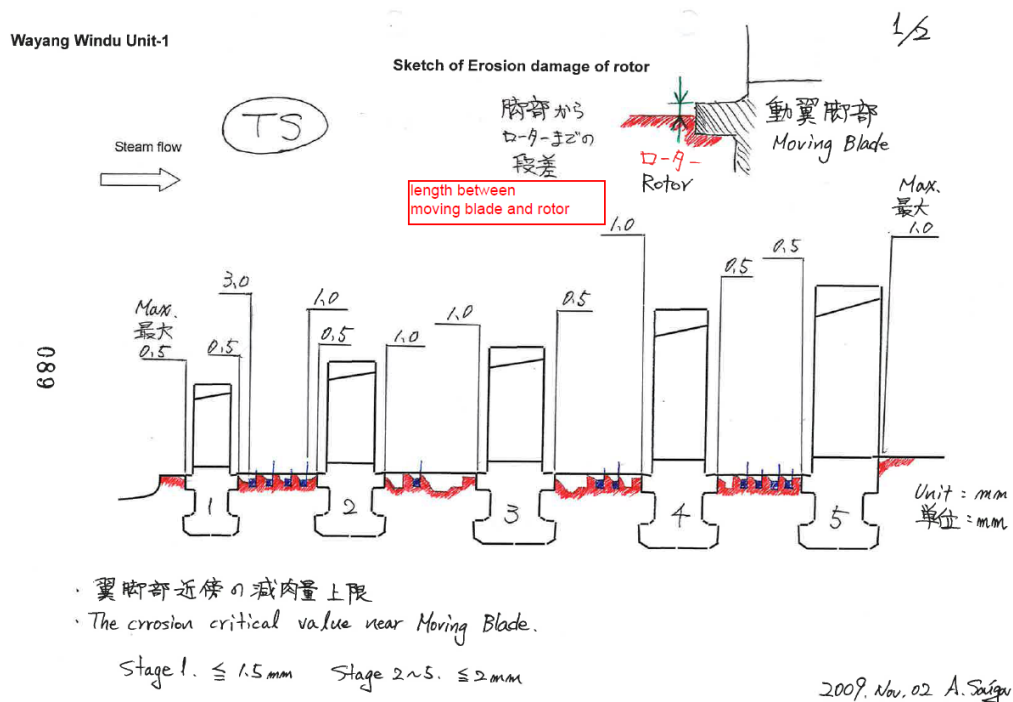


Figure 2: Erosion and missing seal strips found at inter stage between stage 2 and stage 3 Turbine End side.



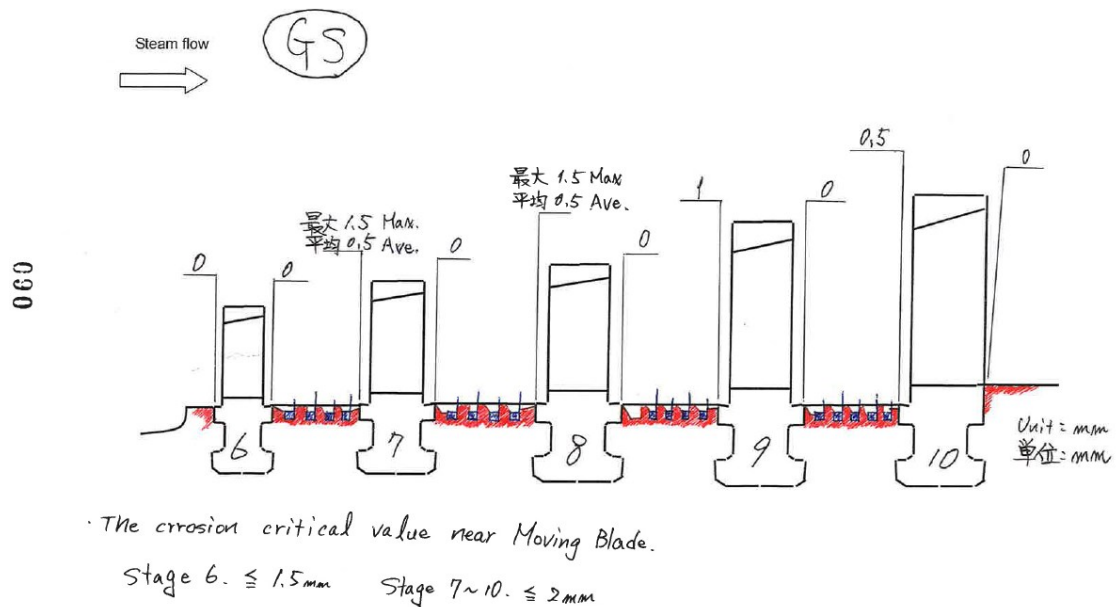
**Figure 3: Erosion and missing seal strips found at inter stage between stage 4 and stage 5 Turbine End side.**

In 2009, the third Turn Around Program for Unit 1 was conducted from shut down on 28<sup>th</sup> October until start up on 11<sup>th</sup> November. The inspection of the turbine rotor revealed that the erosion and corrosion issue at each of inter stage seals of the HP side rotor had become worse. Mostly all “J” seal strips on the inter stage areas of the rotor were missing or damaged. This left few seal strips remaining. At the inter stage areas of the 1st and 2nd stages of the Turbine end side, it was found that the caulking wire had peeled off and only 1 seal strip remained at the inter stage area of the 2nd and 3rd stages and only 2 seal strips remained at inter stage areas of the 3rd and 4th stages. At the 4th and 5th stages only 1 seal strip was missing. On the Generator End of the unit, only 1 seal strip had torn at 3rd and 4th inter stage area. The Fuji engineer recommended to leave it “as it is” and only removed the broken/damage seal strips. Theoretically, the turbine could be operated safely unless the depth of the erosion-corrosion around the platform of the moving blades exceeded the corrosion allowance (ca.) of 2mm. Considering that erosion corrosion seemed to have rapidly progressed from 2006 to 2009, it was a matter of concern that the depth of the erosion corrosion could have reached the limit value of ca. 2mm in a few years. Sketches of erosion inspection mapping are shown in Figure 4 and Figure 5.



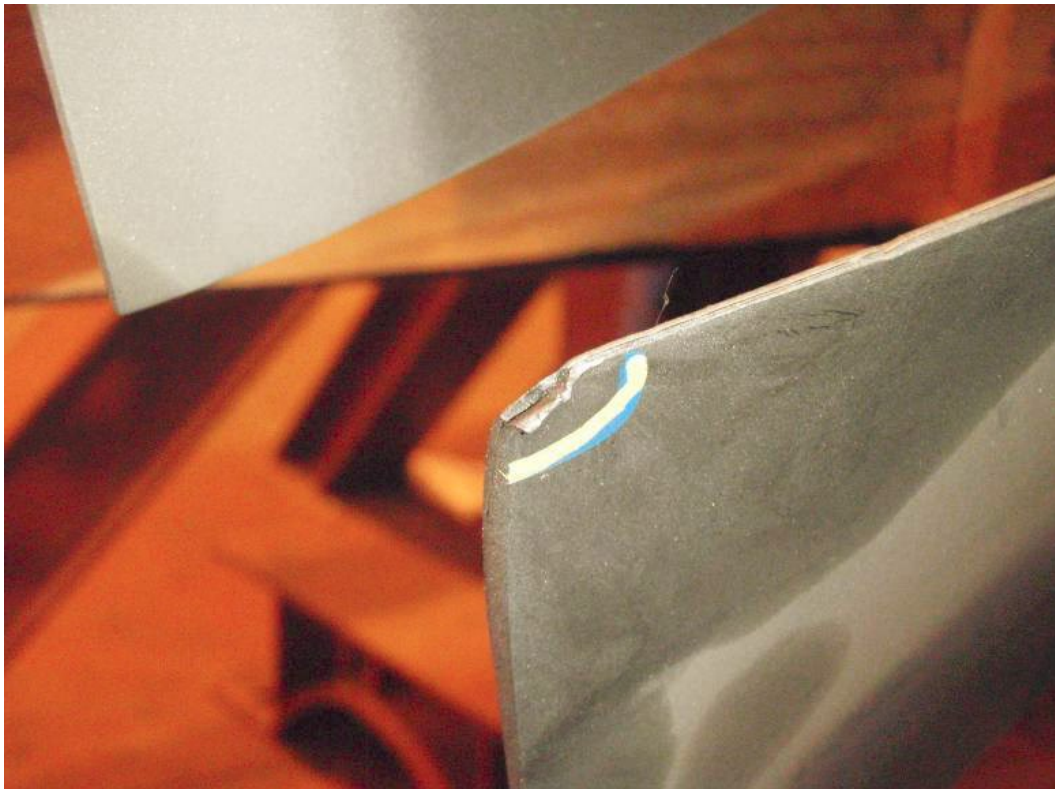
**Figure 4: Sketch of erosion mapping at Turbine End side.**

Wayang Windu Unit-1

Sketch of Erosion damage of rotor  $\frac{2}{2}$ 

**Figure 5: Sketch of erosion mapping at Generator End side.**

Another inspection result revealed the Co-Cr alloy strips on the last rows of blades (stage 8) to be in good condition with slight erosion on the leading edge and light pitting on the blades. A light dent by foreign object damage (FOD) was also found on the leading edge with missing material on the blade tip (stage 8). Fuji recommended to conduct polishing by sandpaper. Figure 6 shows a small dent found at a stage 8 blade tip of turbine end side caused by FOD.



**Figure 6: Small dent on stage 8 blade tip of turbine end side**

## 2. ENGINEERING REVIEW

Further engineering review and discussion with other geothermal plant operators and turbine engineers were conducted to study the condition of the Unit 1 turbine rotor. There were some potential causes revealed as common causes to the deterioration of the geothermal turbine rotor. One of the causes was erosion corrosion. Erosion corrosion is a kind of the corrosion accelerated by the steam flow. The degree of the erosion corrosion is affected by many factors such as amount of corrosive impurities, pH of the steam, wetness of the steam, etc. Erosion corrosion is one of the inevitable deterioration mechanisms observed in geothermal steam turbines that have been operated for a period of years. Another potential cause is foreign object damage (FOD). It was suspected that losing materials from the rotor caused the FOD on the blade or turbine rotor parts (as shown in Figure 6) as rocks or hard materials were not found in the main strainer during inspection.

It was proposed to replace the existing turbine rotor with a new turbine rotor with the aim to avoid major problems and to provide long term reliable operation which would minimize cost and shutdown time, and to avoid risk of a major site repair. Based on the study, there were some improvements to the design of the new turbine rotor as follows:

1. In order to have excellent corrosion and erosion resistance, seal fin area of turbine rotor should be coated with WC-10Co4Cr (as same as design of Unit 2 turbine rotor which was commissioned in 2009) as shown in Figure 7.
2. In order to have excellent corrosion and erosion resistance, rotor surface at outlet of moving blade stage 5 (TS) and stage 10 (GS) should be coated with WC-10Co4Cr as proposed by Fuji Electric.
3. The Co-Cr alloy coating for erosion shield at tip of each 7<sup>th</sup> stage moving blades (TS and GS) to be lengthened 15 mm to improve corrosion/erosion resistance and its reliability.

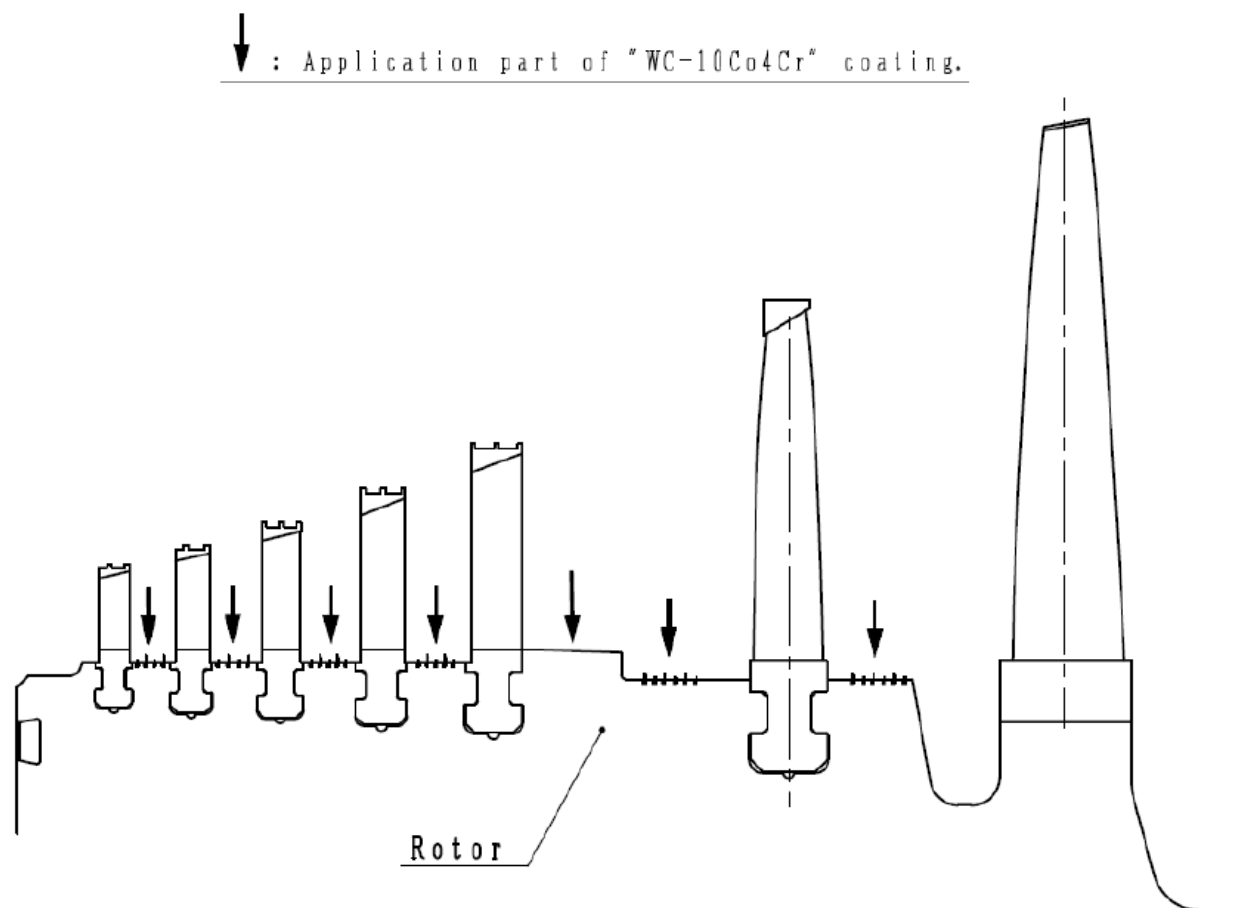


Figure 7: Application of WC-10Co4Cr coating to new turbine rotor design.

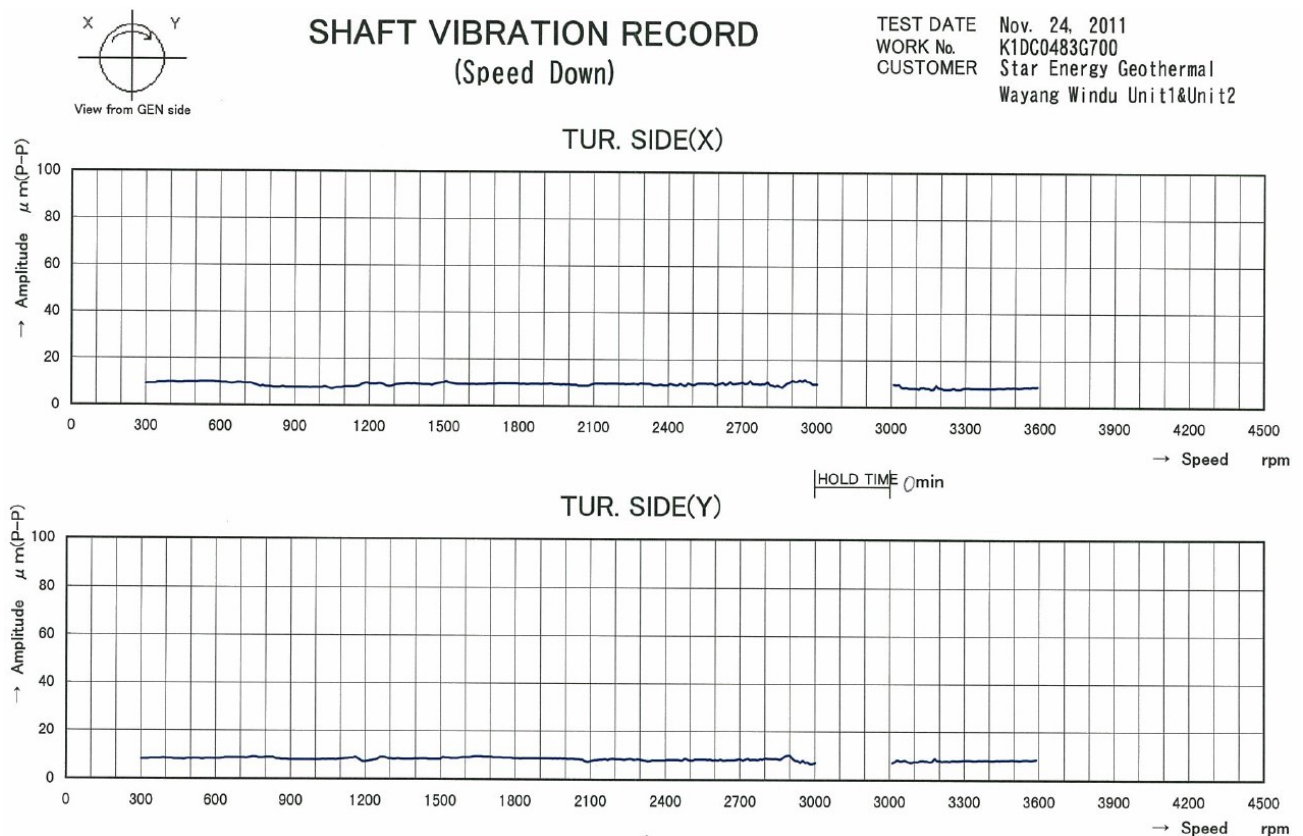
## 3. TURBINE ROTOR MANUFACTURING & ACCEPTANCE TEST

Manufacturing of the new turbine rotor was conducted at Fuji Electric (FE) in Kawasaki, Japan from December 2010. The work was completed within 13 months as planned. Excellent coordination and cooperation between SEGWLL and the FE team during initial contract phase until shipment of the turbine rotor to Wayang Windu site contributed highly for the successful outcome of this project. Figure 8 shows the turbine rotor in machining process in Fuji Electric factory.



**Figure 8: Machining process of turbine rotor in Fuji Electric factory.**

Work Progress and QA/QC for this project were conducted closely and reported by the FE team in the monthly report. For the final acceptance test, dynamic balancing test and over speed test (111% rpm & 120% rpm) was conducted to assure the turbine rotor integrity. The test result showed the vibration level is still far below maximum allowable vibration level limit (80 $\mu$ m P-P) in accordance with ISO 7912-2 standard. Figure 9 shows turbine shaft vibration record measured at turbine end side and Figure 10 shows the new turbine rotor in Wayang Windu Geothermal Power Plant.



**Figure 9: Turbine shaft vibration record measured at turbine end side.**



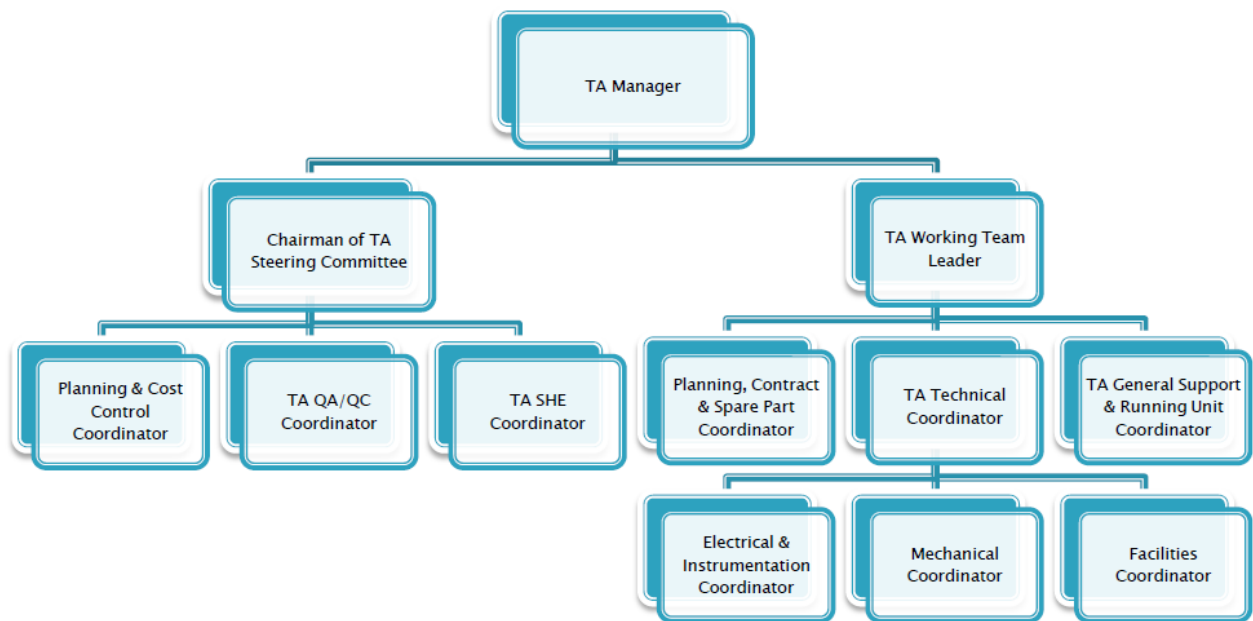
**Figure 10: New turbine rotor in Wayang Windu Geothermal Power Plant.**

### **3. NEW TURBINE ROTOR INSTALLATION**

The new turbine rotor installation was conducted in Unit 1 TA 2012 with a planned shutdown schedule of 16 days. In addition to the new turbine rotor installation, the other critical work included a generator rotor pull out and inspection. In order to achieve the target, the planning and preparation work of the TA team was very essential, SEGWLL organized a TA organization structure and assigned a dedicated TA team to meet the TA Key Performance Indicator (KPI). Figure 11 shows the TA KPI and Figure 12 shows the general TA organization structure.



**Figure 11: Turn Around KPI.**



**Figure 12: TA Organization chart.**

TA team started the preparation work 1.5 years before work execution by preparing budget proposal, detailed work package & specification, detailed work schedule, regular Safety Health and Environment (SHE) & coordination meetings. This huge effort had a significant impact on completion of this TA program where the actual Unit 1 shutdown schedule was 12 days (4 days ahead of schedule), within budget and no Lost Time Accidents (LTA) by providing high plant availability and reliability for long term plant operation. SEGWWL TA team are very proud of this achievement. Figure 13 and Figure 14 show some of the Unit 1 TA activities in 2012.



**Figure 13: Upper casing installation for top clearance check.**



Figure 14: Activities during Unit 1 TA 2012.

### **3. ACKNOWLEDGEMENTS**

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