Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Successful Repaired the Broken Rotor-Shaft of Darajat 55 MW Power Plant with Stubbing Welded Built-Up And Remove the 6th Stage Turbine Blades

Dwi HANDOYO, M. Hanafi NUR RIFA'I, Sugeng TRIYONO, Budi WIBOWO

PT. Indonesia Power,: Centennial Tower fl 7 & 8, Jl. Gatot Subroto No.Kav. 24-25, Jakarta – Indonesia 12930

dwihandoyo@indonesiapower.co.id; hanafi.nurr@indonesiapower.co.id; sugeng@indonesiapower.co.id; budi.wibowo@indonesiapower.co.id

Keywords: crack, vibration, shaft-bending, blades-removal, shaft-stubbing, fatigue, corrosion

ABSTRACT

The Darajat Geothermal Field is located in the West Java province of Indonesia, about 150 km and 35 km southeast of Jakarta (capital city of Indonesia) and Bandung (capital city of West Java), respectively. The Darajat field is one of the largest dry-steam geothermal energy reserves with total installed capacity of 271 MW. The existing 3 units are unit 1, which is 55 MW, is owned and operated by PLN, the National State Electricity Company of Indonesia, while unit 2 with a capacity of 90 MW, and unit 3 with 121 MW is owned and operated initially by Chevron Indonesia, and further transferred to Star Energy Indonesia.

Up until October 2017, all the operation data recorded for Darajat 1 was in normal parameters. Therefore, since November 2017, the operation data indicates excessive trend vibration on the bearing generator-side. Investigation during operation indicated the unbalance and intermittent rubbing between stator and rotor. The unit was stopped in early December 2017 for further inspection. The disassembled turbine rotor was sent to the workshop for thorough inspection. Fact finding showed rotor bend and signs of rubbing on shroud 1 to 3. Major works were rotor shaft straightening and repaired shroud, before being sent back for operation on January 4, 2018.

Within 2 weeks in operation, it was March 2018, the sharp trend of vibration increase occurred on the same bearing area. The 2nd shut down, then the turbine rotor was sent to the workshop for further thorough inspection. Fact finding showed more damages than the previous inspection, shaft-bending, a crack on the governor side and generator side, signs of rubbing rotor and stator with the 4th shroud lost from its position.

Considering commercially clause on steam take or pay "TOP" basis, option to recover as soon as technically possible was chosen to repair the turbine rotor and send back for operation. Therefore, while machining removed cracks from the shaft, the crack was actually deep enough up to center of the shaft, then rotor shaft was broken down into two pieces.

Option to buy a new rotor will take long lead item. The broken shaft then was connected by welded stubbing. The last 6th blades was lost during machining. Darajat unit 1 stopped for 4 months before a complete stubbed rotor was back in operation, without the 6th row of blades. Therefore, capacity output is now back on 55 MW.

1. INTRODUCTION

The vapor dominated Darajat geothermal field is located in the West Java province of Indonesia, about 150 km southeast of Jakarta. The field is situated along a range of volcanic centers extending nearly 30 km in lengths and is adjacent to the Kawah Kamojang and Wayang Windu geothermal fields. Geothermal evaluations at Darajat began in the early 1970's when surface scientific reconnaissance conducted in the area indicated the existence of a vapor dominated reservoir in a hydrological setting similar to the nearby Kamojang field.

Three exploratory wells drilled in 1978-79 verified the geothermal field's existence. Wells drilled into the reservoirs encountered temperature and pressure gradients similar to that of static vapors. Ten years later, Amoseas Indonesia Inc. drilled four additional delineation wells and confirmed a commercial reserve. The first commercial unit has been generating 55 MW of electricity since October 1994. Since then, additional construction of power generation plants with capacity of 90 MW and further the 3rd unit with capacity of 121 MW, adding up to a total capacity of 266 MW. Power plant of Darajat 1, belong to PT. Indonesia Power, under steam supply contract with steam field developer. The second and third unit are owned and operated by the steam field operator.

Electricity evacuation from power plants hook on 150 KV Java – Bali grid. The important role of Darajat power plants among others are to increase voltage drop in 150 KV southern area of Java island, which is a lower number of power plants installed in comparison with north cost Java island. Since Darajat init 1 COD on July 1994, this power plant serves electricity with a high availability rate (average 95%). This unit is among the best geothermal units in Indonesia.

Darajat Unit 1's turbine using an impulse and reaction double flow condensing turbine with 180 °C and 10 bar (abs) steam inlet. Meanwhile, its output generator is rated at 55 MW, 50 Hz and 13.8 K.

2. OUTAGE MANAGEMENT OF DARAJAT 1 POWER PLANT

Commissioning of Darajat unit 1 was July 4, 1994. It has been operating for 24 years. Before the year 2000, the power plant inspections period depended on the operation-hour, time-based criteria. It was about 30 days off for inspection every single year, or about 8000 hours of operation between overhaul. Since the year 2000, the company applied condition-based maintenance “CBM”, in average the operating hour between overhaul is prolonging up to 2 years, as per shown in table – 1.

Table 1: the outage management based on CBM method to prolong operation between overhaul.

No	Year	Outage History	Main Scope
1	October 1995	Re-blading stage 1, 2, and 3 LH/RH side	Re-blading stage 1, 2, dan 3 LH/RH at First Year Inspection by MHI
2	September – October 1996	Simple Inspection	Cleaning, by PT IP.
3	October – November 1997	Simple Inspection	Cleaning, by PT IP.
4	March – April 1999	Simple Inspection	Cleaning, by PT IP.
5	May - June 2000	Simple Inspection	Cleaning, by PT IP.
6	May - June 2002	Major Inspection	Cleaning, by PT IP.
7	October 2003	Simple Inspection	Cleaning, by PT IP.
8	April 2006	Simple Inspection	Cleaning, by PT IP.
9	June 2008	Major Inspection	Cleaning, by PT IP.
10	April 2010	Simple Inspection	Cleaning, by PT IP.
11	Mei - July 2011	Major Inspection	– Inter-stage area repair (due to corrosion) stage 1, 2, 3 with under-sizing cut. – Seal area repair with HVOF coating – Diaphragm repair and workshop Balancing PT. Sulzer
12	October 2013	Simple Inspection	Cleaning, by PT. IP
13	July - September 2016	Simple Inspection	– Repair gland area by welding build up – Vertical PWHT (Post Weld Heat Treatment) – Workshop Balancing – PT. TAKA
14	December 2017 - January 2018	Maintenance Outage	– Repair Shroud – Straightening Coupling Area – Workshop Balancing – Manufacture Nut M46 (20 Pcs.) – Repair Diaphragm #6 Governor-Generator sides – KSO PT. TAKA

Other than first year inspection, corrosion problems in turbine blades were found in 2011, or about 16 years after operation. Cleaning was done manually and by adding some anti-corrosion liquid to avoid further corrosion during outage duration.

3. VIBRATION ANOMALY DURING OPERATION OF DARAJAT 1 POWER PLANT

Before November 2017, Darajat unit 1 had a satisfying vibration record and no operator report regarding vibration in turbine side.

Since November 2017, existing displacement vibration sensors in Unit 1, showed an increasing vibration level in the generator bearing area. Figure 1 shows a comparison of vibration level among all bearing in Unit 1.

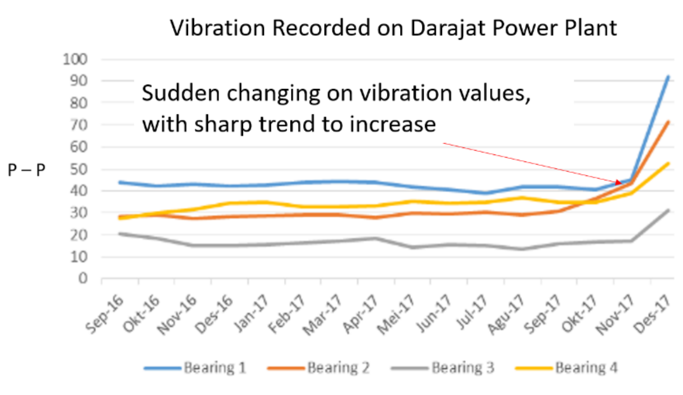


Figure 1: Vibration level at Darajat power plant (Bearing 4: Generator Bearing area) using peak to peak displacement sensor in µm.

The vibration level is measured using a peak to peak displacement sensor in µm.

Sudden changing on vibration for all bearing, start to increase with a sharp trend. Alarm value is set in 125 µm. Peak to peak vibration in November 2017 was 50 µm at bearing no 1, and trend to increase at a level of 92 µm by Dec 2017.

To ascertain valid data of the risen vibration bearing abnormality, predictive maintenance team conducted data gathering with a portable vibration tool, and the result was the same. By using vibration spectrum, it found that the cause of the vibration is unbalance (1x rpm). In Dec 2017, Unit 1 was shutdown to find out the root cause of the unbalance itself.

During shutdown, the turbine rotor was sent to a local workshop for further serious inspection. There were some discoveries during the workshop inspection, which happened in December 2017. Rotor Bow was about 0.22 mm at Turbine End Side and heavy corrosion at gland seal area. The previous vibration data may have been caused by rotor bow.

After the straightening process and balancing, in January 2018, unit 1 was back to normal operation. Vibration of the bearing as per shown in Table 2, is good and acceptable. The vibration of all bearings was back to normal condition except bearing no 2, which had 30% higher than previous vibration data before turbine was shut down. The process of straightening and balancing is seemed successful.

Table 2: Vibration level at all Bearing in January 2018 (after straightening and balancing).

Bearing 1	Bearing 2	Bearing 3	Bearing 4
29,38 µm	67,2 µm	36,2 µm	24,7 µm

Therefore, normal operation of Darajat 1 after shut down lasted only 2 months. Due to some reason, vibration level rose again at all bearings as shown in Figure 2 within 2 weeks in March 2018. Bearing 1 and bearing 2 are located on turbine side, while bearing 3 and 4 are located on generator side.

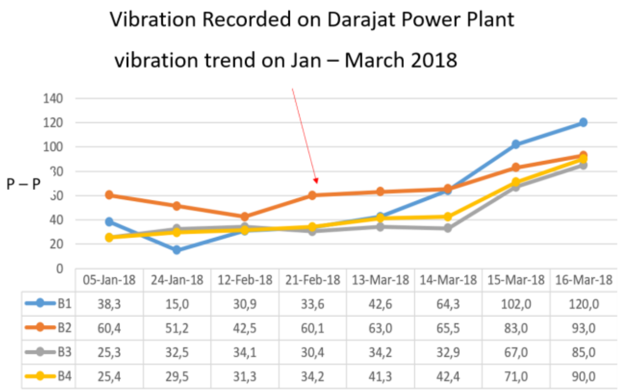


Figure 2: The 2nd Vibration problem at Darajat power plant 2 months after shut down, using peak to peak displacement sensor in µm.

With reference on vibration data as shown in Table 2, in January 2017, within the period of 5 January – 12 February 2018, the vibration trend is flat, event tend to smaller peak to peak displacement. Within 12 February to 13 March, all bearing vibrations had almost no change in magnitude.

Therefore within 5 days, from 13 – 16 March 2018, all bearing vibration increased almost 50% higher, bearing no 1, had double vibration increase from 40 μm in March 13, jump to 120 μm in March 16.

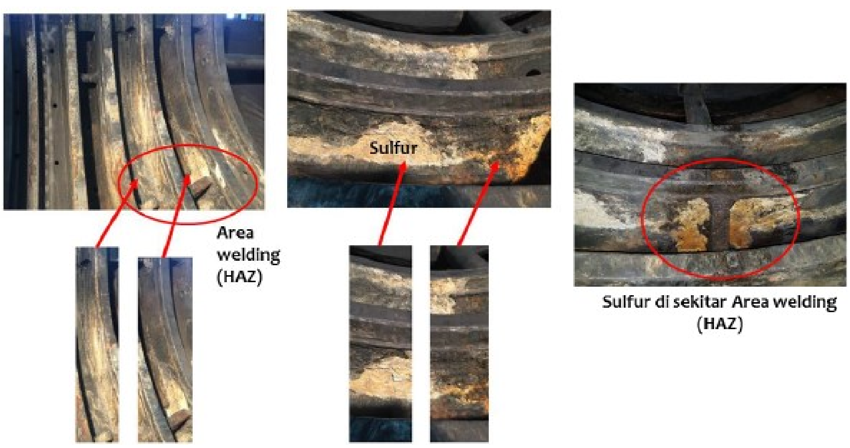
The dramatic increase of all bearings, it was decided to stop Darajat power plant immediately. Further detailed investigation was needed and its corrective action.

In comparison with vibration data in 2017 before unit shut down due to high vibration, all the data is similar, whereas the highest vibration occurred on bearing 1, followed by bearing no 2.

4. FACT FINDING DURING DECEMBER 2017 & MARCH 2018 OF DARAJAT INSPECTION

4.1. Severe corrosion at turbine casing

Visual inspection during December 2017 and March 2018, founded major damages as following;

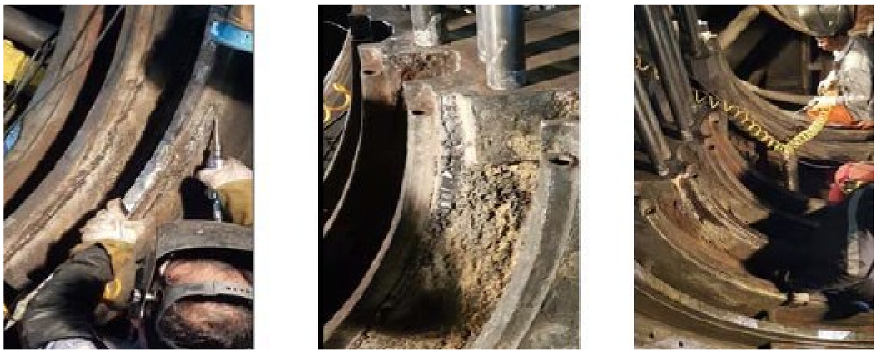


Heavy corrosion found mainly on the welding area, on the heat affected zone – HAZ.

Corrosion material product mostly sulphur and metal oxide.

Location of corrosion is in the lower casing, that may speculate driven by condensate in the area.

Figure 3: Corrosion at turbine's lower casing in HAZ area due to sulfur.



In this photo of figure 4, is showing heavy corrosion product located at lower casing turbine. Soft powder sticky material may conclude that corrosion has been happening for a long time.

Corrosion material product mostly Sulphur and metal oxide.

Figure 4: Corrosion product founds at lower casing Turbine.

4.2. Corrosion on turbine diaphragm

Figure 5: Corrosion at Diaphragm's support plate and Lock Pin. This corrosion makes wear in the diaphragm area.

Corrosion also happened in the diaphragm that lead to loosening on the sitting area of the turbine diaphragm.

Corrosion made wear on the diaphragm area.

4.3. Turbine shroud rubbing

Figure 6: Rubbing at Shroud #4 turbine.

Damages on shroud number 4 of the turbine, because of rubbing between blades and casing. The damage rubbed area is about three tips of turbine blades.

4.4. Turbine shroud rubbing

The intermittent rubbing also left rubbing tract on seal strip area.

Figure 7: Rubbing at Seal Strip area

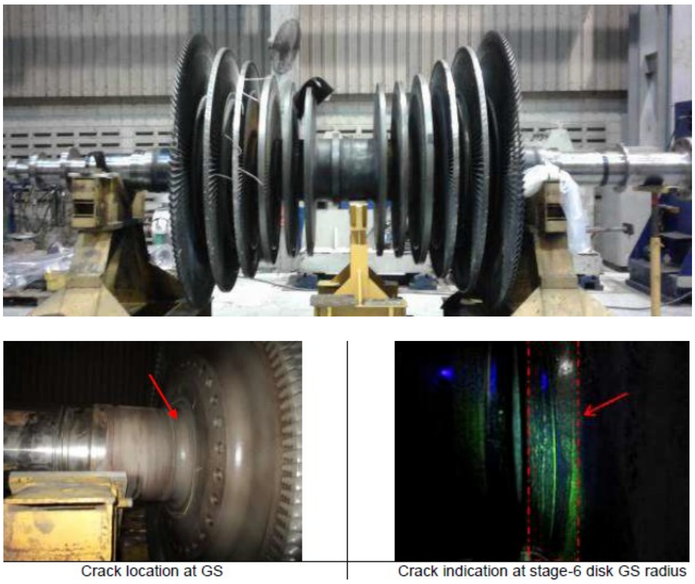
4.5. Rotor bow was indicated by run out on the generator area of 0.31 mm.

4.6. Blades erosion

Minor damages on stellite blade row no 5 and row no 6, indicates water droplet in this area. The appearances of water droplet may indicate lesser efficiency of turbine after years of operation.

Figure 8: Erosion at Stellite Blade row #5 and #6.

4.7. Turbine Crack



The major problem of the turbine rotor found during inspection was cracks on several areas of the turbine rotor, concentrated in radius between gland seal area and last stage disk at generator side.

Other crack indications are also appearing at the other side (Turbine side) at radius area between gland seal area and last stage disk.

By using fluorescent MPI (Magnetic Particle

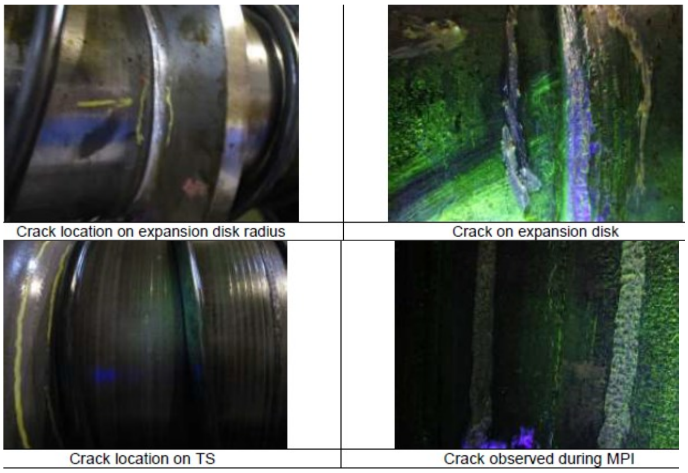


Figure 9: Crack indications appear at several area at rotor.

Inspection), it found that many cracks appeared at the rotor, described as follows.

- Stage 6 Generator Side Disk Radius with up to 130 mm depth
- Stage 6 Turbine Side Disk Radius with up to 40 mm depth
- Expansion Disk, surface cracks.

5. CRACK RELIEVING AND ROTOR STUBBING

5.1. Crack relieving

Rotor repair is a short-term solution. A long term solution may include the rotor replacement with a completely new set of turbine rotor. Considering continuous operation of the power plant is very important to generate revenue, as well as to alleviate unnecessary payment on purchasing geothermal steam with take or pay clauses, then installing new rotor shall have been well prepared and well managed, to include long lead item of purchasing new turbine rotor.

As per shown in Figure 10, rotor repair includes crack removing by machining the crack and re-welding to the original size diameter. Therefore during machining through the crack on the generator side, the crack was deep enough to the center of the shaft, resulting the rotor shaft broken into two different pieces. Rotor weight is 22 ton.

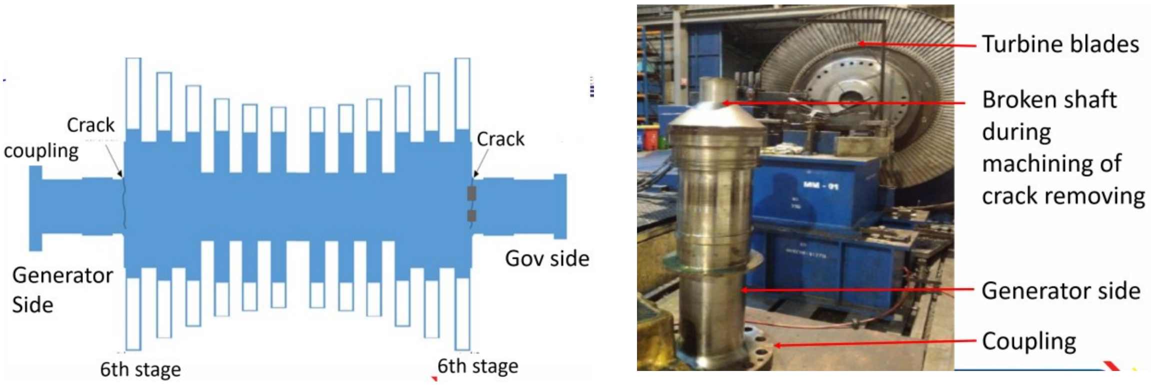


Figure 10: Rotor crack both at end side of 6th blades, both in generator side and governor side. Right picture is a broken shaft after machining to remove crack.

5.2. Rotor stubbing

Due to the broken shaft being unexpected during machining to remove the crack, there was no preparation to change rotors to either a new rotor or the used rotor. Re-connecting the two pieces of the broken shaft was inevitable, arising from the risk of unsuccessful repairs to the rotor. The repair process to connect those two pieces of rotor, known as stubbing welded rotor, consist of process as described below.

a. Blade Disassembly
b. Weld Repair Crack at Generator Side by weld up stage 6 disk to expansion disk area
c. Weld Repair Crack at Turbine Side by weld up stage 6 disk to Journal Shaft area
d. Weld repair lip seal stage 5, Turbine side and Generator Side
e. Kiss grind thrust collar
f. Mechanical insert coupling bolt holes
g. Run out Correction on coupling spigot, axial face and radial flange
h. Install blade
i. Grind and burnish probe area
j. NDT as final inspection via Magnetic Particle Inspection, Penetrant test and Ultrasonic test

k. Low Speed Balancing of the rotor
l. Demagnetize rotor before shipping to site. Demagnetize process is needed to release all magnetize properties at rotor.

As per illustrated in Figure 11, the stubbed connection rotor to include removing the 6th turbine blades then followed by building up the whole disks to avoid placing heat affected zone (HAZ) in this high stress area. Weld material used was 12% Cr Stainless steel with addition of Nickel and Molybdenum alloy. This weld material will improve the corrosion and erosion resistance properties, as well as mechanical properties.

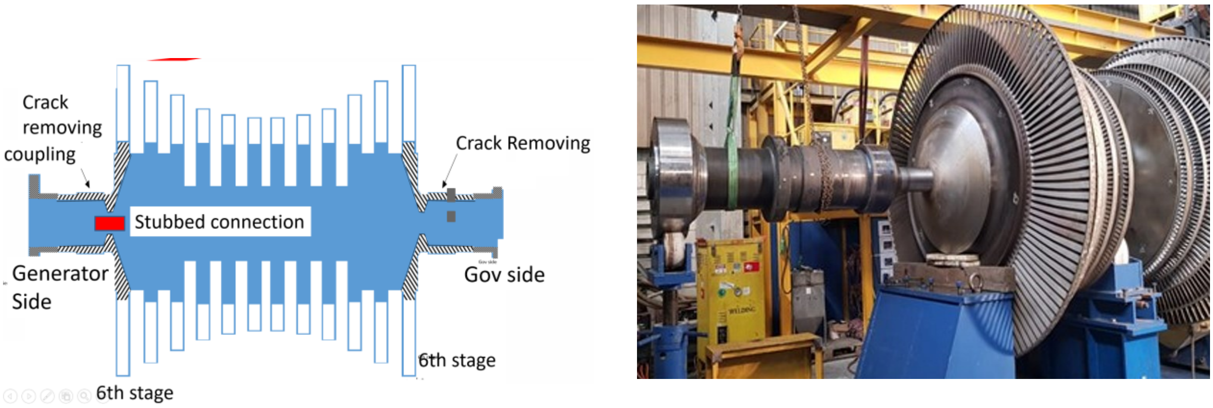


Figure 11: Rotor crack both at end side of 6th blades, both in generator side and governor side. Right picture is generator side after stubbing.

The stress analysis was done prior to the stubbed rotor connection, by means of finite element software. As per illustrated in Figure 12, and Figure 13, the finite element analysis shown the critical area located on the stubbed area.

Figure 12: Finite element analysis on stubbed rotor connection. Red color shown the critical area of stubbed material.

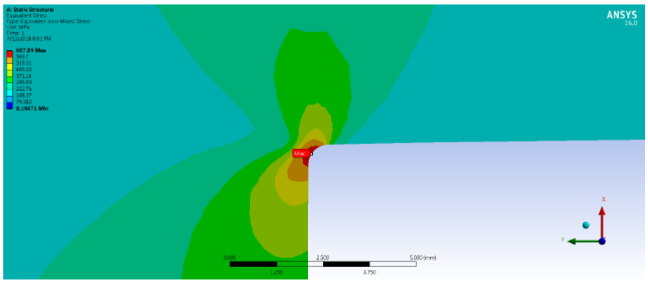


Figure 13: Zoom in of critical area on the stubbed area.

Load is given in finite element of stubbed area and is described as follows.

a. Rotary load up to 121% of operational rotation as mentioned at API 612 (Rotor design shall withstand 121% operational rotational – 3630 rpm)
b. Centrifugal load of Blade 5 and 6

The load results show a Von Mises load peak stress 667 MPa at the critical area shown in the red notch of Figures 12 & 13. This stress value is still secure, since it still below the permitted peak stress value in the rotor design (2 times rotor yield strength of 2 x 567 MPa).

The stubbing process also makes the shear stress from the twist load, which will be higher since there is a hole at the center of the shaft, which reduces its inertia moment. Simple calculation with 121% operational load (3630 rpm) and Net Capacity Load of 55 MW, so the twist load reached 144.7 kNm. This value will generate maximum shear stress at rotor surface is 9.4 MPa.

From the load analysis by finite element, shown that stubbing rotor repair is secure for operational mode.

6. HYPOTHESIS OF ROOT CAUSE ANALYSES

6.1. Construe the original possible cause and mechanism of crack on rotor turbine.

To construe the original cause of the crack on the turbine based on the information that most of corrosion product found was located at the lower casing Turbine. This corrosion may be caused by the presence of condensate in this area. The product of corrosion to block the hole of the drain catcher, cover up and clogged up the drain line of lower casing. The presence of acid condensate and accumulation of corrosion product lead to further accelerate the corrosion in the area of the lower casing. As per illustrated in Figure 14, the drain hole to release condensate was blocked by corrosion product.

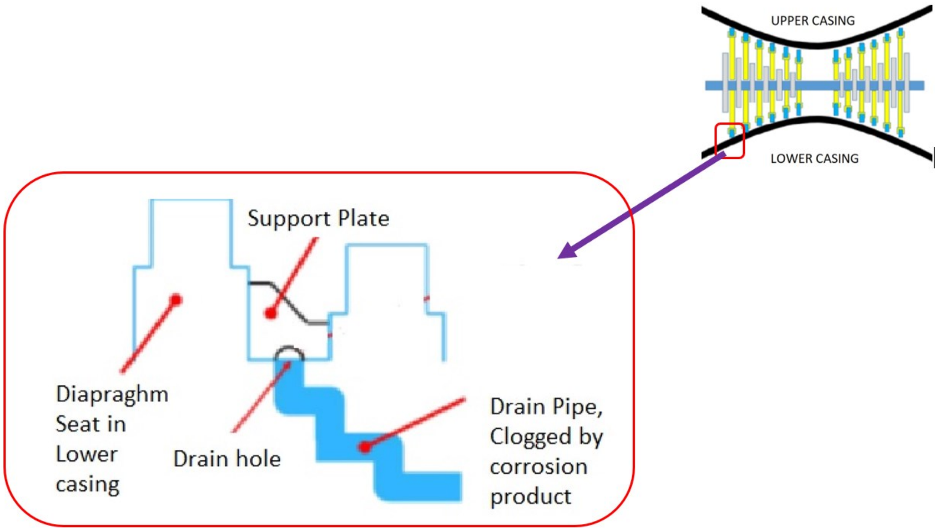


Figure 14: Drain hole of Darajat Power Plant, Turbine's Lower casing clogged up by the corrosion product.

When condensate was not able to be drained, where the condensate has low pH, then the corrosion will expand to the area surrounding, to include corrosion in the sitting of lower casing diaphragm. Eventually, corrosion wear will lead to loosening of the diaphragm. In the worst condition, the steam may also flow through the area gap on the wear of sitting diaphragm area. If this is the case, then combination between loosening diaphragm and leak flow of steam may cause vibration on turbine. Abnormalities of turbine vibration may cause cracks on some areas of the turbine rotor, in respect with concentration of pressure or mechanical turbine load. Figure 15 is showing a diagram to figure out the mechanism of diaphragm looseness (4 mm) due to severe corrosion, that leads to an unbalance situation.

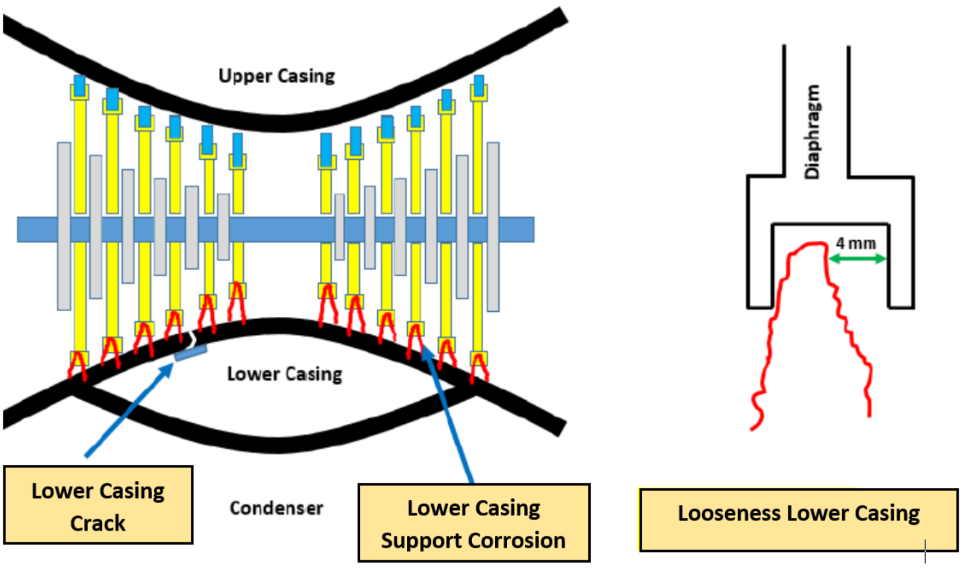


Figure 15: Diaphragm looseness (4 mm) due to severe corrosion, that leads to an unbalance situation.

6.2. Stress corrosion cracking "SSC".

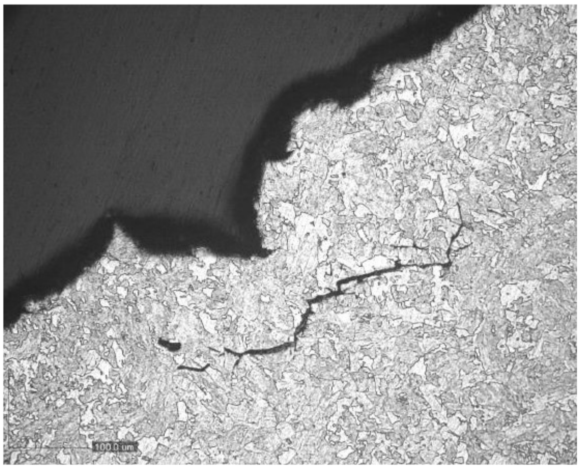


Figure 16: Micro structure from a branched crack at rotor.

Hydrogen sulfide H_2S is a common gas in the geothermal steam. In some cases, the presence of high hydrogen can lead to SSC. SCC is the growth of crack formation in a corrosive environment. It can lead to unexpected sudden failure of normally ductile metals subjected to a tensile stress, especially at elevated temperature.

This SSCC is recognized by a microstructural branched crack shape as shown in Figure 16. To construe the original cause of the crack on the turbine based on the information that most of the corrosion product was located.

7. TO DATE OPERATION MONITORING OF STUBBED ROTOR

Successful turbine unit 1 rotor repair via stubbing and welding was monitored in its operational condition. Since August 2018 until May 2019, the unit 1 performed a satisfying conditions, especially in vibration sensor as displayed at Figure 19.

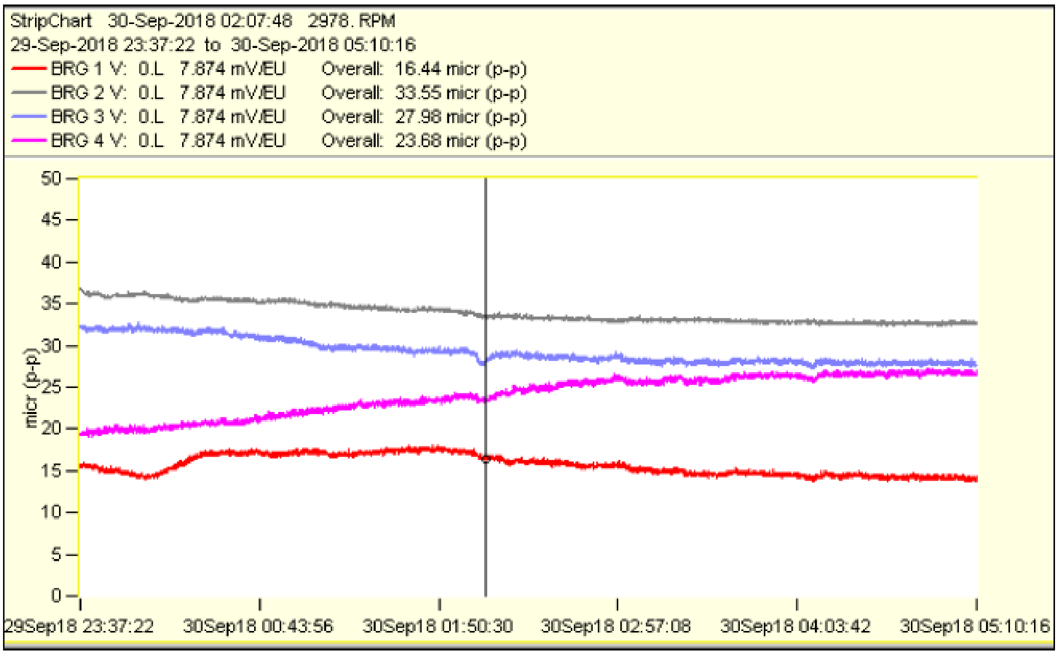


Figure 17: Vibration at 55 MW of Darajat Unit 1 after rotor repair via stubbed welding method.

Overall, operational performance of Darajat Unit 1 after repair process shows a distinguish result. The maximum load reaches 55 MW and up until now, its equivalent available factor (EAF) reaches 95% value. The quality rotor repair also being guaranteed up to 10 years by the workshop itself.

8. CONCLUSIONS

Stubbed and welding repair at geothermal Turbine Rotor has a satisfactory result and becomes a successful option of rotor replacement. Future monitoring and evaluation are needed, especially on root cause of crack's failure. Steam quality holds an eminent factor to assure that no crack builds up at the rotor.

9. REFERENCES

1) UJH, "Simple Inspection Report PLTP Darajat", PT Indonesia Power, September 2016

2) Fang Haitao, "Investigation of Localized Corrosion of carbon Steel in H2S Environment", Ohio University, 2012.

3) Sawicki et al., Vibration-based Crack Diagnosis in Rotating Shaft During Acceleration Through Resonance", Cleveland State University, Cleveland OH 44115.

4) Sulzer, "Turbo Docs P-02481 P-02492", PT Sulzer Indonesia, 2018.

5) Muttaqin J., Hapsoro A., "Sulzer Technical Report No. 10084/TR P02481/20183005, PT Sulzer Indonesia, 2018.

6) API RP 687, "Rotor Repair", American Petroleum Institute, September 2001.

7) Mursalov N., "Characteristic And Mechanism of Hydrogen Sulfide Corrosion of Steel", PPOR Vol. 18 No. 3, 2017.

8) NACE MR0175/ISO 15156-2.2009.

9) NACE TM0177-96

10) Ziaer S.M.R., et al, "Sulfide Stress Corrosion Cracking and Hydrogen Induced Cracking of A216-WCC wellhead flow control valve body", Elsevier, 2013.