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Preventing Turbine High Vibration by Upgrading the Balance Weight Material at PLTP Darajat*

O. Ropandi*, **M.M. Hakim, M.A. Baraka**

PT. Indonesia Power Kamojang POMU
Garut, Indonesia
*E-mail: opan.ropandi@plnindonesiapower.co.id

Abstrak
Karena kontak langsung dengan uap bertekanan tinggi, rotor turbin merupakan bagian penting dari pembangkit listrik tenaga panas bumi. Bobot penyeimbang yang terletak pada tahap kelima rotor turbin berfungsi untuk mencegah ketidakseimbangan awal pada rotor turbin. Akibat erosi dan serangan belerang, bobot penyeimbang PLTP Darajat sering mengalami kerusakan, yang dapat dilihat dari terbentuknya ketidakseimbangan. Pada Desember 2020, saat shutdown, PLTP Darajat mengalami gangguan getaran yang cukup besar, pada putaran 1400 RPM mencapai 104 m [P-P]. Penting untuk menyeimbangkan rotor turbin dengan menambahkan bobot keseimbangan baru setelah uji borescope menunjukkan bahwa erosi pada bobot keseimbangan mencapai 50%. Pemeriksaan terhadap bentuk, ketahanan erosi, dan ketahanan terhadap sulfur pada material bobot penyeimbang turbin dilakukan untuk mengurangi kemungkinan terjadinya gangguan erosi. Pada suatu waktu, PLTP Darajat menggunakan material antara lain SS-410, Tungsten Alloy, dan 17-4PH. Dalam penelitian ini, kami menggunakan material Inconel 625 untuk bobot keseimbangan. Selanjutnya, kami menguji material tersebut berdasarkan nilai Kromium (Cr), Tembaga (Cu), dan kekerasan material (HB). Inconel 625 dengan komposisi 23% memiliki komposisi material terbesar berdasarkan nilai Cr, 17-4PH dengan 4% berdasarkan nilai Cu, dan 17-4PH dengan nilai HB sebesar 298, menurut temuan penelitian. Dengan kombinasi Cr 23%, Cu 0%, dan HB 255, material Inconel 625 memiliki kombinasi terbaik. Kami menyimpulkan bahwa ketahanan material terhadap erosi dan sulfur akan meningkat seiring dengan meningkatnya kadar Cr dan Cu. Dibandingkan dengan material lainnya, Inconel 625 menunjukkan ketahanan yang lebih unggul terhadap erosi dan belerang. Dengan mengaplikasikan material ini, kami dapat menghindari peningkatan getaran pada turbin dan peningkatan jam servis sebanyak 281 jam.

Kata kunci : turbin, belerang, erosi, material, keseimbangan berat.

Abstract
Due to its direct contact with high- pressure steam, the turbine rotor is an essential part of geothermal power plants. A balance weight located in the fifth stage of rotor turbine to prevent initial unbalance in the turbine rotor. Due to erosion and sulfur attacks, the balancing weight of PLTP Darajat is frequently damaged, which is evident by the formation of unbalance. On December 2020, when shutting down, PLTP Darajat encountered considerable vibration disturbance, at 1400 RPM rotation, it reached 104 m [P-P]. It was essential to balance the turbine rotor by adding a new balance weight after a borescope test revealed that balance weight erosion was 50%. An examination of the shape, erosion resistance, and sulfur resistance of the turbine balancing weight material was done to reduce the likelihood of erosion disturbances. At one time. PLTP Darajat utilized materials including SS-410, Tungsten Alloy, and 17-4PH. In this research we used the balance weight of Inconel 625 material. Next, we tested the material based on the Chromium (Cr), Copper (Cu) and material hardness (HB) values. Inconel 625 at 23% had the greatest material composition based on Cr value, 17-4PH at 4% based on Cu value, and 17-4PH at 298 based on HB value, according to the study’s finding. With a combination of Cr 23%, Cu 0%, and HB 255, Inconel 625 material had the best combination. We conclude that a material's resistance to erosion and sulfur will increase with increasing Cr and Cu levels. Compared to other materials, Inconel 625 exhibits superior resistance to erosion and sulfur. By applying this material we were able to avoid an increase in vibration in the turbine and an increase in service hours of 281 hours.

Keywords: ; turbine, sulfur, erosion, material, balance weight.

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1. INTRODUCTION

Penjelasan terlalu panjang, penjelasan terkait material terlalu panjang, disarankan ditambahkan terkait latar belakang dan permasalahan yang muncul serta ada rumusan masalah dan tujuan penelitian ini

On December 2020, when shutting down, PLTP Darajat encountered considerable vibration disturbance, at 1400 RPM rotation, it reached 104 m [P-P]. It was essential to balance the turbine rotor by adding a new balance weight after a borescope test revealed that balance weight erosion was 50%.

To fix the degradation of the turbine balance weight, Kamojang POMU conducted maintenance outage activities for 12 days in January 2021. This activity resulted in 281 hour drop-in service hours, or 0.48% less availability.

A study was conducted to examine the form, erosion resistance, and sulfur resistance of the balance weight of the PLTP Darajat turbine to lessen the effects of future service hours and availability reductions.

The following research works are connected to various literatures on materials and how they relate to PLTP turbine operations: Books about turbines and generators manuals (Mitsubishi, 1994). from the operating philosophy for turbine operations (Hakim, 2020). Design of turbines (Chaplin), (Scweizer, 2007) Associated with material deterioration (Roberg, 2008), (Ridwan, 2020). In addition, materials science, and engineering (Callister), (Zhang, 2016), (Siracusa, 2004) are discussed.

Due to its direct contact with high-pressure steam, the turbine rotor is an essential part of geothermal power plants. A balance weight is inserted to prevent initial unbalance in the turbine rotor. Due to erosion and sulfur attacks, the balancing weight of PLTP Darajat is frequently damaged, which is evident by the formation of unbalance.

By adding balance weight to create a centrifugal force that is the opposite of the initial unbalance, it is possible to lower the vibration intensity caused by unbalance.

Figure 1. Erosion of the balance weight of the turbine

Figure 1 shows erosion in the balance weight of the PLTP Darajat turbine. The turbine balance weight materials used at the Darajat PLTP are SS-410, tungsten alloy, 17-4 PH, and Inconel 625.

A martensitic form of stainless steel with good corrosion and wear resistance is grade 410 stainless steels. Although martensitic stainless steel is less resistant to corrosion than austenitic stainless steel. This material's corrosion resistance can be improved through the operations of hardening, tempering, and polishing. The SS-410 material category is typically used for materials requiring high strength, excellent corrosion resistance, and resistance to high temperatures. Numerous bolts, screws, nuts, shafts, pumps, valves, and turbine parts are coated with SS-410. Heat treatment is necessary to increase the strength and ductility of SS 410 material. The maximum operating temperature for this type of material is 1300 oF (705 oC) for settings where it is constantly exposed, and 1500 oF (815 oC) for conditions where it is exposed for a predetermined amount of time.

SS-410 material is equivalent to UNS No S41000, BS 410S21, EN X12Cr13, Swedish SS 2302 and JIS SUS 410. The chemical make-up of the SS Grade 410 material is listed in the following table.

Table 1. Material Composition of SS 410 (Test report, 2023)

C	Si	Mn	Ni	Cr	Fe
Max 0,08	Max 1.00	Max 1.00	Max 1.00	11.5-13.5	85

Tungsten is the most ductile, strong, and dense metal, and is used to make tungsten alloys, also known as heavy alloys. These alloys typically contain 90–97% tungsten with the remaining metal matrix increasing the ductility of the final product. The reinforcing phase, which can be intermetallic or carbide, typically influences hardness. Due to its extreme hardness, tungsten carbide does not erode.

Table 2. Material Composition of tungsten alloy (Test report, 2023)

C	Si	Mn	Ni	Cr	Fe
0,003-6,5	0,001-3,1	0,002	0,002-56	0,002-25	0,003-13,5

A martensitic stainless-steel composition known as 17-4PH has undergone a precipitation hardening procedure to increase its ductility, strength, and hardness as well as its corrosion resistance. Up to a temperature range of roughly 600oF (316oC), this material has good mechanical characteristics. In general, this material is used in components where high strength and good corrosion resistance are required, such as in a number of applications in nuclear reactors, gas and steam turbines, the petroleum industry, components that carry out chemical operations, and so forth. When compared to the majority of hardenable stainless-steel standards, such as SS type 304, alloy 17-4PH exhibits good corrosion resistance in mosts mediums. The structure of this material will experience stress-relief during the heat treatment process until it is hardened, making it more resistant to SCC conditions.

There are various designations that are equivalent to the SS Grade 17-4 PH material type, including AISI 630, AMS 5643, ASTM A564 (630), ASME SA75, and MIL C-24111. SS 17-4 PH material has the following chemical makeup, according to industry data.

Table 3. Material Composition of 17-4 PH (Test report, 2023)

C	Si	Mn	Ni	Cr	Cu	Ti	Fe
Max 0.04	Max 0.60	Max 0.28	Max 4.25	Max 16.00	Max 3.30	0.05	remainder

With a melting point of about 1300 oC and a thermal expansion coefficient of 128x105 K (at 20 oC), Inconel 625 is resistant to a range of extreme temperatures, from very cold to very hot. At hot temperatures, the number of oxidants in the oxide film on Inconel 625 increases noticeably, creating a protective layer that is naturally formed in the material. Inconel 625 is extremely resistant to corrosive chemicals thanks to its unit. Following is a list of the chemical components of inconel 625.

Table 4. Material Composition of Inconel 625 (Test report, 2023)

C	Si	Mn	Ni	Cr	Cu	Ti	Fe
0,1	0,5	0,5	58	21,5	0	0,4	5

The corrosion-erosion process involves mechanically removing the protective layer, which increases the rate of chemical or electrochemical corrosion of a material. Several causes of erosion of materials,

- Turbulent type flow.
- There are fluctuations in shear stress.
- Subject to high pressure loading.
- Collisions with solid particles.
- Collisions with liquid droplets in high velocity gas flows

The random flow of fluid that strikes the material's surface during turbulent fluid flow mechanically erodes the protective layer. The figure 2 that follows displays the correlation between fluid flow rate and the metal loss process in various materials.

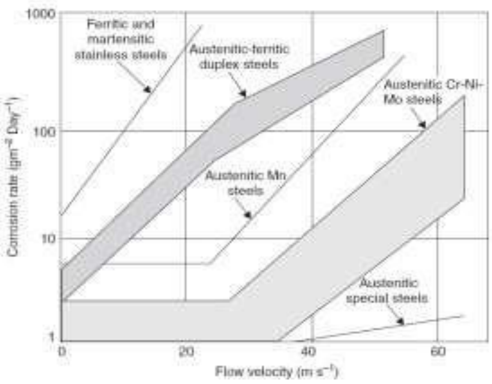

Figure 2. Relationship between Fluid Flow Speed and Mass Loss (Ridwan, 2020)

Metals that are used in situations where hydrogen sulfide (H2S) is present experience the Sulfide Stress Cracking (SSC) process. Although the H2S molecule is not actively involved in the SSC process, its existence is a prerequisite for hydrogen atoms to enter and diffuse into the base metal. Hydrogen embrittlement is the process of the crystal structure becoming more fragile because of hydrogen diffusion into the base metal. The leftover sulfide will combine with the metal and produce FeS in the interim.

A steel material's resistance to SSC is highly correlated with its hardness value. The longer the material must last before fail due to SSC, the harder it is. The temperature factor has a significant impact as well. When the temperature is between -7 and 49 degrees Celsius, the SSC procedure will be quite difficult. Hydrogen diffuses through a material quickly over 49 oC due to the high rate of hydrogen diffusion, preventing it from reaching the critical concentration. The critical concentration will not be achieved at temperatures below -7 oC due to the low hydrogen diffusion rate.

The protective oxide layer that forms on the surface has a significant impact on the stainless-steel material's ability to resist corrosion. However, several factors, including sulfur- induced corrosion, can result in the protective oxide layer being lost and the base metal component being exposed directly to the atmosphere. The SIC process on metal is illustrated in the diagram below.

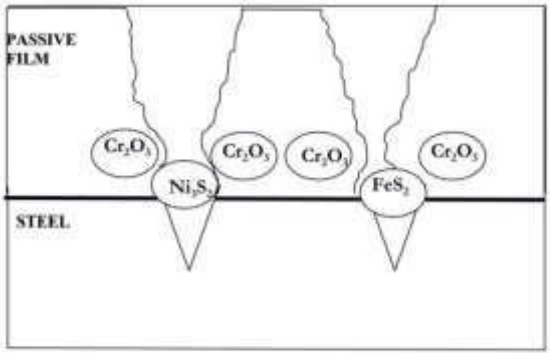

Figure 3. Sulphur Induced Corrosion mechanism (Siracusa, 2004)

It is necessary to use a material with a high Cr element content, high strength, and high hardness to boost a material's resistance to sulfur attack.

Stress corrosion cracking (SCC) must also be reviewed in addition to the sulfide stress cracking (SCC) procedure. SCC is metal corrosion caused by the interaction between a unique environment and static tensile stress. Tensile tension, corrosive environments, and high temperatures all contribute to this type of corrosion, which is highly prevalent in the SCC industrial world.

2. METHODOLOGY

There are several methodologies used, literature study, troubleshooting damage to balance weight, analysis of erosion and sulfur resistance, design of balance weight, repair of balance weight, monitoring, and evaluation, as follows:

- Investigating erosion-related damage to the balance weight turbine.

  There are six factors that could possibly cause erosion of the turbine weight balance at the Darajat PLTP. Firstly, the quality of the steam, the quality of the steam is getting worse as the steam phase changes towards super-heated, secondly the quality of the material, the material balance weight which cannot withstand the force exerted by the steam and the characteristics of the steam, thirdly the design of the slot balance weight, the design is not in accordance with Current conditions, where the steam still has a fairly high flow rate and pressure compared to the previous design and is placed on level 6 blades, the fourth is an installation error, the fifth is a manufacturing error, and the dimensions are not suitable.
- Material composition analysis

  This analysis aims to ensure that the replacement material has a better composition compared to the material used previously, based on the Cr, Cu and HB values. The materials analyzed in this research were SS-410, tungsten alloy, 17-4 PH, and Inconel 625.
- Planning and designing improvements

  The fifth stage turbine blade has an improved balance weight shape that considers aerodynamic factors because there is no thread facility. In contrast, the sixth srage turbine blade has a thread facility, which allows the balance weight to be shaped like a screw.
- Analyzing and monitoring the outcomes of improvement efforts.

Following improvement, turbine vibration values are routinely checked using predictive and preventive maintenance. The boroscope inspection is carried out to determine the physical condition of the balance weight visually.

3. RESULT & DISCUSSION

A. Failure Analysis of balance weight erosion

The steps in troubleshooting balance weight erosion are as follows:

- Measure turbine vibration while it is shutting down.
- Conduct turbine vibration analysis. As show in figure 4, It was determined that the turbine had an unbalanced condition.

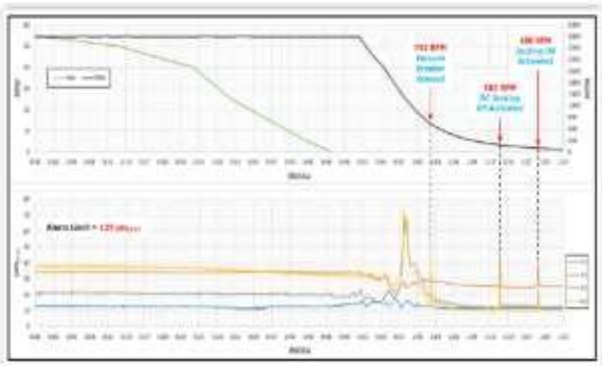

Figure 4. Vibration monitoring when shut down process (Prasetyo, 2020)

- Use a boroscope to inspect the balance weight's condition. The investigation revealed that the balance weight had lost up to 50% of its original weight.

At PLTP Darajat, the turbine balance weight may erode for one of three reasons:

1. Steam quality, steam phase change towards super- heated
2. Material Quality: Due to the properties of steam and the forces it exerts, the material cannot withstand steam.
3. Balance weight design, which is positioned on the sixth level blade and still has a high flow speed and pressure compared to the prior design, is not appropriate for the current environment.

B. Evaluation of erosion resistance and sulfur resistance in comparison

An evaluation of the balance weight material's resistance to sulfur and erosion was done to prevent recurrent problems. According to literature studies, the presence of the elements Cr, Mn, and Cu will affect erosion resistance, whereas the presence of the element Cr will affect sulfur resistance.

The following table 5, lists the findings of this comparison of balance weight material.

Table 5. Balance weight material composition (Test report, 2023)

	Material			
Prop	SS 410	Tungsten Alloy	17-4PH	Inconel 625
Cr	11.5 - 13.5 %	0,002-25 %	15 - 17.5 %	20 - 23 %
Cu			3.0 - 4.0 %	
Al				<= 0.40 %
C	<= 0.15 %	0,003-6,5 %	<= 0.070 %	<= 0.10 %
Co				<= 1.0 %
Fe	84.3 - 88.5 %	0,003-13,5%	>= 70.46 %	<= 5.0 %
Mn	<= 1.0 %	0,002 %	<= 1.0 %	<= 0.50 %
Mo				8.0 - 10 %
Ni		0,002-56 %	3.0 - 5.0 %	>= 58 %
Nb			0.15 - 0.45 %	3.15 - 4.15%
P	<= 0.040 %		<= 0.040 %	<= 0.015 %
Si	<= 1.0 %	0,001-3,1 %	<= 1.0 %	<= 0.50 %
S	<= 0.030 %		<= 0.030 %	<= 0.015 %
Ti				<= 0.40 %
Ta			0.15-0.45 %	

According to information on material composition, the 17- 4PH material has a Cr content of 16.00 wt% and 17-4PH has a Cu content from 3 to 4 wt%, on the other hand, has no Cu content.

In addition to composition, mechanical qualities, specifically the hardness value, can be used to compare erosion resistance.

The mechanical characteristics of a material are identified using the terms ultimate strength and yield point. The material's ultimate strength is calculated as equaation (1), if this value is converted to the gravitational constant of 9.81 m2/s (for 17-4PH material):

$$US = 105\ kg/mm^2\ 9{,}81 m^{2/s} \tag{1}$$
$$US = 1030{,}5\ Mpa$$

Table 6. The mechanical characteristics of a material [9]

Material	Ultimate Strength (MPa)	Yield Point (MPa)
SS 410	550-697	min. 343
Tungsten Alloy	980	750
17-4PH	min. 1030.5	min. 755
Inconel 625	880	460

The Brinell hardness value is used to calculate how resistant a material is to erosion, and the equation (2) formula can be used to translate a material's tensile strength value into a Brinell hardness value:

$$TS\ (MPa) = 3.45 \times HB \tag{2}$$

The calculation of the Brinell hardness of 17-4 PH material is shown in the equation below:

$$TS\ (MPa) = 3.45 \times HB$$
$$HB = \frac{TS(MPa)}{3.45}$$
$$HB = \frac{1030.5}{3.45}$$
$$HB = 298.78\ HB$$

Referring to the tensile strength value, the Brinell hardness is obtained as follows:

Table 7. Brinell hardness of Balance weight material (Ridwan, 2020)

Material	Ultimate Strength MPa	Yield Point MPa	Kekerasan (HB)
SS 410	550-697	min. 343	160-202
Tungsten Alloy	980	750	284
17-4PH	min. 1030.5	min. 755	298,7
Inconel 625	880	460	255

Based on the hardness value in table 7 and the presumption that the hardness is proportionate to the hardness value on the material's surface, the erosion resistance materials is calculated.

C. Improving Balance Weight Design

The next stage is to decide on the design and planning for balance weight replacement after choosing the balance weight material that is resistant to sulfur and corrosion. The following is a visual balance weight of the PLTP Darajat Turbine.

Figure 5. The balance weight design of the Turbine Rotor at PLTP Darajat

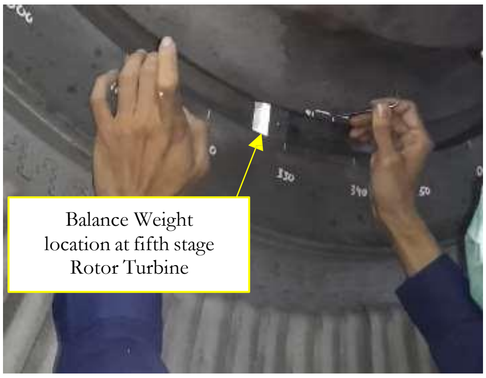

Figure 6. Location of balance weight rotor turbine

Prior to upgrading, the balance weight was attached to the sixth level blade as a thread. To optimize the aerodynamics of the steam flow and make the step more resistant to erosion problems, the balance weight was positioned on the fifth level blade and had a certain angle of inclination at the ends.

4. CONCLUSION

The chemical makeup of the material and its mechanical properties can be used to compare the resistance to erosion and resistance to sulfur attack in the balance weight turbine materials SS410 and 17-4PH. The content of Cr, Cu, and Mn elements can be used to determine erosion resistance based on the material's composition. Meanwhile, the element Cr exhibits resilience to sulfur assault. The erosion rate decreases with increasing Cr element. The hardness value and erosion resistance have a positive relationship. The resistance to erosion will increase with material hardness. It is clear from the discussion's findings that the Inconel 625 material is more resistant to sulfur attack and erosion than the SS410, 17-4Ph, and tungsten alloy material. By preventing the loss of 281 hours of service time due to disturbances in the balance weight of the turbine, analysis of erosion resistance and sulfur resistance in the balance weight material of this turbine favorably contributes to enhancing availability by 0.48%.

5. ACKNOWLEDGMENTS

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