Sediment Wear and Protective Measures for Turbine Overflow Components of a Hydropower Station

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Abstract. At a power station, the turbine experiences high sediment content and operates under complex and challenging conditions. It has been operating under unstable conditions for an extended period. The overflow components have suffered significant abrasion due to the combined effects of sediment abrasion and cavitation, posing a significant safety hazard and seriously compromising the safe and stable operation of the power station. This article discusses the technological updating of the overflow components at this power station, examines the causes of sediment abrasion and cavitation, and outlines the effective protective measures implemented during the technical, to provide valuable experience for future sediment abrasion resistance efforts at multi-sediment river power stations.

Keywords: component; sediment-laden rivers; sediment abrasion; cavitation

1 Introduction

China, a country with significant river sediment content, faces turbine erosion due to the varying sizes, hardness, and shapes of solid particles carried by the water, especially in regions with high sediment levels [1]. If timely measures are not implemented, the damage will escalate, compromising the safe and stable operation of the units and significantly diminishing the technical and economic benefits of the power station. Domestic power stations have long struggled with sediment abrasion, finding it difficult to address the problem fundamentally. For instance, upstream of the Yellow River, power stations like Liu Jiaxia Taohekou have attempted to mitigate this issue by adopting anti-abrasion measures. These include reducing the specific rotational speed, optimizing hydraulic design, lowering the turbine installation elevation, and increasing suction height. They also focus on structural design improvements for buried parts, the water-guide mechanism, and rotating components [2]. The Daitengxia Hydropower Plant has effectively reduced turbine wear by taking preventive measures in hydraulic design, structural design, material selection, and operation optimization [3].This paper describes a power station on the Fuling River has been plagued by sediment abrasion since its commissioning, and proposes two kinds of wear-resistant etching materials

Y. Qiu et al. (eds.), *Proceedings of the 2024 7th International Conference on Civil Architecture, Hydropower and Engineering Management (CAHEM 2024)*, Advances in Engineering Research 256,
https://doi.org/10.2991/978-94-6463-650-5_42

with excellent performance. The preparation and performance analysis of the fusion cladding layer are completed, which can be applied to the power station wear protection.

2 Overview of the Power Station

This power station is located in the section of Muguadun-Tielongbao River in Pingwu County, Sichuan Province, which is the third level of the power station in the upstream gradient development of Fulingjiang River. The design head of the power station is 98 m, and the total installed capacity of the power station is 2×38 MW. the annual utilization hours are 5002 h, and the average power generation capacity is 380.14 million kWh. The hydropower station operates at a normal water level of 1117.5m, with an over-machine sand content of 0.335 kg/m^3, and a median grain size of 0.178mm.

3 Runner Overhaul Situation

The turbine-generator unit, since its commissioning in December 2009, has undergone a number of Class B overhauls and Class C overhauls, with Unit 1# undergoing a Class A overhaul and a technical modification of the turbine's overflow components in 2015 and 2017, respectively, and Unit 2# undergoing a Class A overhaul and a technical modification of the overflow components in 2019. Abrasion was found to have occurred in the overflow components during each overhaul.

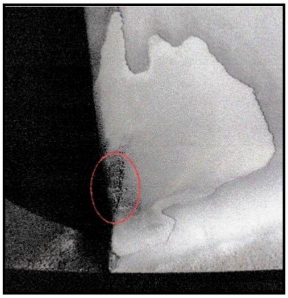

Fig. 1. Cavitation damage on the backside of the discharge side after the modification of Unit 1#

Fig. 2. Grooved erosion on the upper edge of the lower ring of Unit 1#

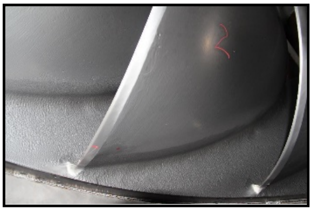

Fig. 3. Runner sediment wear

The most serious abrasion situation appeared after the first technological updating of the unit 1#, after the turbine carried out operation for two cycles, the back of the 13 blades near the lower edge of the water outlet edge have a regular and consistent typical honeycomb damage, and the surrounding anti-abrasive spray layer shedding serious, the location is shown in Fig. 1, the region is also a typical cavitation damage area of the mixed-flow rotor. The wear and erosion of the upper and lower edges of the lower ring as well as the lower edge of the upper crown are more complicated, with both fish scale-like sediment wear traces as well as deeper grooves after erosion, as shown in Figure 2. The improvement in the wear of the runner before and after the modification is not obvious, and the wear traces appear on the over-water surface of the rectified runner, especially in the lower ring, the weld seam between the blade and the lower ring, and the near weld region of the blade, where the herring-bone form sediment wear characteristics are very obvious, as shown in Fig. 3.

4 Analysis of the Causes of Abrasion

4.1 Sediment Content

The power station is located in the upper reaches of the Fuling River, the lot is located in the Longmen Mountain folded belt, the rock body is seriously denuded, the river erosion of the suspended sediment is more serious, multi-year average sand content of 1.18kg/m^3, the average sand content during flood season is as high as 2.13kg/m^3, there are data showing that, the power station gate at the average annual sand loss of the suspended mass 2.44 million t, the average sand content of the suspended mass for many years 1.18 kg/m3, the average sand loss of 366 million t. The reservoir is dominated by sand siltation of the pushed mass, the reservoir sand ratio is only 6.13, the project sediment problem is more prominent. The average annual sand transport of the nudge mass is 366,000 t, and the reservoir is dominated by the silt deposition of the nudge mass, and the reservoir sand ratio of the nudge mass is only 6.13, which makes the sediment problem of the project more prominent. Therefore, under the action of high sand content water, the metal abrasion of rotor is larger.

After the first technological updating of unit 1#, serious and typical wing cavitation occurred, due to the serious cavitation damage in the region, which led to the damage of the region and the surrounding coating morphology showing loose, shedding phenomenon; if the operation in the non-flood season, then the coating in the region will also slowly suffer from the destruction of the substrate in the shedding area of the honeycomb cavitation traces will be enlarged. If running in the flood season, under the combined effect of sediment abrasion and cavitation, the cavitation damage in the region will be accelerated by the abrasion, and the local damage situation will be more serious, and it is possible to occur deeper groove-like damage phenomenon.

4.2 Runner Structure

Due to the obvious angularity of the rotor blades at the water's edge and the square shape of the root, a serious defluxing cavitation damage zone occurs in this area, and this form of cavitation damage is also a typical cavitation damage phenomenon [5]. If in the later development, will produce localized deep pit type damage traces in the inner wall of the lower ring of the rotor. This is due to the first technological updating of the unit #1 redesign of the runner structure caused by the second technological updating to learn from the first lesson, back to the original runner design, operation did not occur again cavitation [4].

4.3 Operating Conditions

Operating conditions have a large impact on the wear of the hydraulic turbine water guide mechanism. Since the power station has been put into AGC, it often undertakes peak and frequency regulation, and has been running under non-optimal operating conditions for a long time, with a large deviation from the designed operating conditions for a long time, which also leads to the aggravation of the phenomenon of abrasion and damage. The turbine output force has a greater impact on the wear of overflow components, and the wear of the movable guide vane and seat ring is more serious under different output force conditions and deviation from the optimal operating conditions [6].In the head area of the movable guide vane, impact wear is caused by sediment impact, in the back water surface of the movable guide vane and the water edge, due to the large velocity of sediment, resulting in cutting wear, and in the position of the nose end of the seat ring, due to the turbulence of the flow pattern, sediment particles in the position of the impact, deposition, which also caused more serious wear.

5 Anti-Abrasion Measures

5.1 Sample Preparation and Analysis Method

In this project, we utilize laser cladding technology to create wear-resistant coatings on Q235 steel substrates. The process involves applying nickel-based powders containing tungsten carbide (WC), which are melted and bonded to the steel by a 3.3 kW laser. The laser beam, with a diameter of 2 mm, quickly heats and melts the powder, which is simultaneously supplied by a powder feeder. This results in a metallurgical bond with the base material, forming a cladding layer. For the experiment, the laser power is set to 2.5 kW, the scanning speed to 6 cm/s, and the laser step to 0.7 mm. Two different cladding powders, W88-0C and W88-8C, were used in the process. The chemical composition of each layer is presented in Table 1.

Table 1. Chemical composition of material

Materials	powder	Cr	W	B	Si	C	Fe	Ni
A	W88-0C	16±0.5	18±0.5	3.5	3.5	0.02	<1	margin
B	W88-8C	15	18	3.5	3.5	0.8	<1	margin

In the subsequent phases of the project, wire cutting technology is employed to precisely shape the laser-clad samples into designated sizes: a wear sample measuring 500 mm by 250 mm and a test sample sized 10 mm by 10 mm. To ensure the accuracy of the subsequent tests, the multi-layered coatings on these samples are carefully subjected to wet grinding and polishing until a smooth, reflective finish is achieved. Following this, the polished surfaces are thoroughly cleaned in an ultrasonic bath with distilled water to remove any remaining contaminants.For the examination of the microstructure and phase composition of the cladding layer, we apply a range of advanced analytical techniques. Energy-dispersive X-ray spectroscopy (EDS) and scanning electron microscopy (SEM) are utilized to analyze the sample's microstructure. In particular, we use a Hitachi S4800 SEM with an EDS attachment to capture detailed images and perform in-depth analysis of the cladding's microstructure. Moreover, X-ray diffraction (XRD) is used to determine the phase composition of the cladding layer. This analysis is carried out with a Rigaku D/max X-ray diffractometer, which utilizes Cu-Kα radiation to perform the phase analysis and provide valuable insights into the material's crystallographic structure. These analytical techniques are essential for assessing the quality and performance of the laser-clad coatings.

5.2 Material Properties Analysis

As illustrated in Fig. 4, the average surface hardness of the cladding layer on Sample A is 676.98 HV, while for Sample B, it is 869.81 HV. A clear stepwise hardness distribution is evident between the two materials. The hardness of the cladding layer is found to be 4 to 6 times greater than that of the base material. The three distinct hardness levels correspond to the cladding layer, the heat-affected zone, and the substrate, respectively. Notably, the hardness of Sample B is slightly higher than that of Sample A, which can be attributed to the higher carbon content in Sample B. This increased carbon content leads to enhanced hardness in Sample B compared to Sample A.

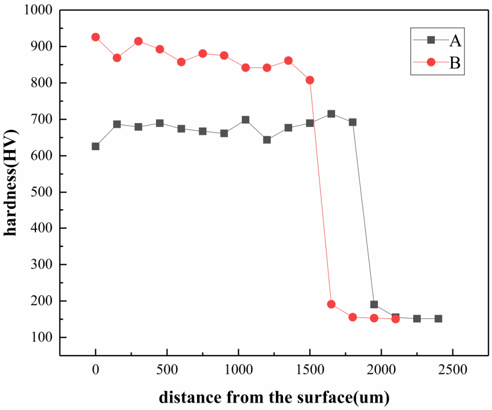

Fig. 4. Microhardness of A and B materials

6 Conclusions

This paper provides a detailed examination of a power station experiencing sediment abrasion and explores the underlying causes of both wear and cavitation damage. The primary factors contributing to the wear and cavitation of the runner include sediment content, runner design, and operational conditions. Additionally, the paper proposes the application of laser cladding technology to enhance the runner's resistance to wear and cavitation. The cladding layer has been successfully prepared, and the results indicate that the average hardness of the cladding layer reaches 869.81 HV, making it suitable for use in the power station’s overcurrent components to protect against wear and cavitation. While this paper does not address the on-site preparation process, future research could focus on investigating the field preparation techniques for cladding.

Acknowledgment

The authors acknowledge the cooperation and logistic support of Mr Liu, engineer at the power station, providing the information of power stations.

References

1. Peiyuan Yang, Zhifu He. Hydraulic turbine sediment abrasion hazards and protection measures JILIN WATER RESOURCES, 2017, 425(10):60-62.
2. Jiwen Zhu, Jianfu Chen. Exploration of anti-sediment wear measures for hydraulic turbines in multi-sediment power stations. Heilongjiang Science and Technology of Water conservancy, 2018, 46 : 140-142.
3. Xiaobin Chen, Ting Liu. Analysis of hydraulic turbine abrasion and preventive measures in Daitengxia hydroelectric power plant, Papermaking Equipment & Materials, 2022, 210(51):43-45.
4. Sahu, Rohit Kumar , and B. K. Gandhi . "Erosive flow field investigation on guide vanes of Francis turbine - A systematic review." Sustainable Energy Technologies and Assessments (2022).
5. Thapa, Biraj Singh , et al. "Design and development of guide vane cascade for a low speed number Francis turbine." Journal of Hydrodynamics (2016).
6. Quaranta, Emanuele , and P. Davies. Emerging and Innovative Materials for Hydropower Engineering Applications:Turbines, Bearings, Sealing, Dams and Waterways,and Ocean Power. Engineering. 008-001(2022).