

Fracture Analysis and Repair of Last Stage Blade Reinforcement Boss for Low Pressure Cylinder

Rotor of 330 MW Unit

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Abstract: The lace convex table of the final stage blade of a 330 MW turbine fractured. The reason was analyzed by fracture analysis, chemical composition analysis and metallographic analysis. It showed that the overload was the main reason for the fracture. Deformation of guide ring caused by fracture of guide ring bolt was the main reason of the overload. The analysis of the guide ring bolt showed that the brittleness of the guide ring bolt was the main reason for its fracture. It was suggested to strengthen the supervision of the manufacturing process of the guide ring bolt. The lace convex table was repaired by surfacing welding. A reasonable welding process was developed and the repair was successful.

Abstract, Final stage blade, Lace convex table, Surfacing welding, Welding repair

Key words, Last stage blade, Reinforcement boss, Fracture, Analysis, Bead welding, Weld repair

1. Introduction

The #1 unit of a power plant was a 330 MW sub-critical coal-fired generating unit equipped with turbine models N330/C260-16.67/0.9/538/538. During operation, abnormal vibrations were detected in the low-pressure rotor of the turbine. Therefore, the low-pressure rotor was checked after shutting down. It was known that abrasion marks on the final stage blade and shunt ring of the low-pressure rotor could be observed, in the meanwhile, there were other phenomena could be found which like a broken bolt part in the shunt ring, broken tensile ribs in eight locations on the final stage blade and a crack discovered upon expansion. The final blade of the low pressure rotor was fabricated from 0Cr17Ni4Cu4Nb, or 17-4PH alloy, a precipitation-hardened martensitic stainless steel containing copper and niobium, which commonly used in condensing turbine low pressure final stage moving blades. Furthermore, the material of the splitter ring fixing bolt was 25Cr2MoV.

Inspired by the above consideration, the fracture causes of the lace convex table and guide ring bolts were analyzed in this paper. What's more, the welding repair technology was developed to repair the lace convex table of the final stage blade.

2. Analyses of tension fracture causes of the final stage blade

As illustrated in Figure 1, the tension fracture position of the final stage blade was at the variable section of the boss. Figure 2 displayed the fractured boss, while Figure 3 depicted the macro morphology of the fracture of the boss. In Figure 2, region 1 represented the contact position of the boss between two blades; and the bosses of the two blades will contact during operation. It was also found that the contact position of the fractured boss exhibited distinct crimping which only slight wear should occur in this area under normal circumstances, indicating that the boss had been subjected to excessive forces. Based on the macroscopic morphology of the fracture in Figure 3, the fracture process extended from regions 2 and 3 to region 4. Besides of these, a small number of fatigue lines were observed in region 3 with steps between regions 2 and 3, which suggested a rapid expansion speed. Furthermore, it could be known that region 4 was the shear lip, which was the final fault region.

Based on the above analysis, the contact surface of the lace convex table experienced excessive stress, initiating its fracture process with fatigue cracking at region 3 as shown in Figure 3. In

addition, cracking propagates from region 2 and rapidly expanded to region 4 due to the insufficient strength of the surrounding areas.

In order to get more structural information, chemical composition analysis and metallographic structure inspection were conducted on the lace convex table. As shown in Table 1, there were nothing abnormal could be detected while the metallographic structure (refer to Figure 4) revealed a tempered martensite structure, indicating no abnormalities too.



Fig. 1 The tension fracture position of the final stage blade

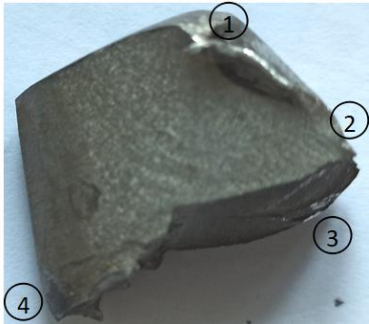


Fig. 2 The fractured boss



Fig. 3 The macro morphology fracture of the lace convex table

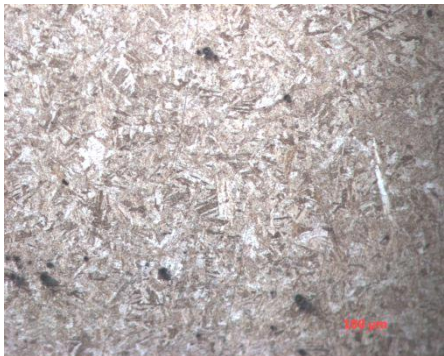


Fig. 4 The micrographs of the lace convex table

Table 1 The corresponding analyses of spots in the lace convex table. (%)						
Number	Cr	Ni	Cu	Mn	Nb	Co
Spot 1	14.93	4.16	3.12	0.46	0.23	0.15
Spot 2	14.90	4.78	4.15	0.43	0.22	0.16

Spot 3	15.42	4.13	3.29	0.37	0.22	0.16
Average	15.08	4.36	3.52	0.42	0.22	0.16
Standard	15-16	3.8-4.5	3-3.7	≤0.5	0.15-0.35	/
Requirements GB/T 8732-2014						

3. Analyses of cause of fracture of diversion ring bolt

The fractured diversion ring fixed bolt was selected for further analysis (refer to Figure 5). In Figure 5, the fracture position of bolt 1# was at the junction between the displacement bolt and the thread, while the fracture position of bolt 2# occurred within the thread. Chemical composition analysis and hardness testing were performed on the bolt, and it could be known that the chemical composition meeting standard requirements but the hardness was too high.

The fracture was analyzed using a scanning electron microscope. Intergranular fracture, as shown in Figure 6, was discovered in the fracture of bolt 1#, indicating the presence of secondary cracks and high brittleness of bolt. Similarly, it could be observed that intergranular fracture also existed in the fracture of bolt 2# as shown in Figure 7, and the fracture analysis results revealed brittleness as well. The reason for this phenomenon may be attributed to the lack of strict control over bolt processing.

The guide ring bolt was processed directly with round steel after blanking, forging, heat treatment, thread processing and other processes, which was not conditioned adjusting the round steel first and then process the thread according to the rules.

According to DL/T 438-2016 "Thermal Power Plant Metal Technical Supervision Regulations" and DL/T439-2018 "Thermal Power Plant High Temperature Fasteners Technical Guidelines", low pressure cylinder bolts were not subject to power metal supervision. Therefore, only a spectral inspection of the alloy bolts was required prior to factory entry and no specific supervision requirements for subsequent maintenance. Based on the discussion above, it would be recommended to reinforce the supervision of the manufacturing process of the alloy bolts for the low pressure cylinder and strictly adhere to a process of initial conditioning followed by final finishing due to the lack of attention often given to these bolts.



Fig.5 The fractured diversion ring bolt

Table 2 The corresponding analyses of spots in different samples. (%)

Number	Cr	Mo	V	Mn	Cu
Bolt-1#	1.70	0.26	0.22	0.57	
Bolt-2#	1.70	0.27	0.23	0.56	
Standard	1.5-1.8	0.25-0.35	0.15-0.35	0.4-0.7	≤0.25
Requirements DL/T439-2018					

Table 3 The results of hardness measurement. (HBW)

Number	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Average
Bolt-1#	288	290	292	292	293	291

Bolt-2#	295	292	295	295	293	294
Standard	25Cr2MoV, 248~293HB					
Requirements						
DL/T439-2018						

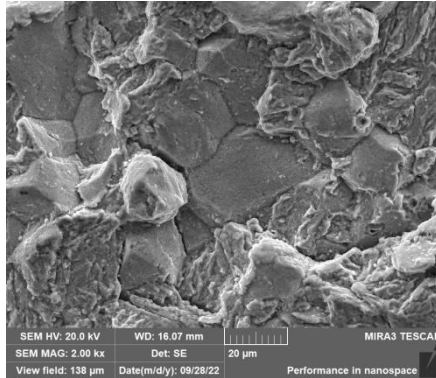


Fig. 6 The fracture of bolt 1#

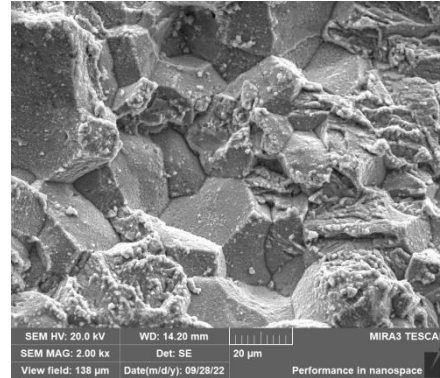


Fig. 7 The fracture of bolt 2#

4. Synthetic Analysis

The curled contact surface of the fracture lace convex table on the final blade indicated the presence of greater tension on the part, which could be observed that the fracture process initiating from the crack at the variable section of the boss and rapidly expanding to the fracture. In the meanwhile, the fastening bolt of the diversion ring fractured due to brittleness during long-term low load operation. Subsequently, upon the breakage of the fixed bolt of the guide ring, the guide ring collided with the steam inlet side of the final stage blade, leading to the tension between the two sections of the lace convex table of the final stage blade and the fracture of the final stage blade. Furthermore, it could be inferred that the vibration frequency of the second pitch diameter of the final stage blade increased post-fracture, which affected the dynamic balance of the low-pressure rotor and exacerbated vibration finally.

5. Welding repair of the lace convex table

During field inspection of the final stage blades, a total of 8 tension bumps were found to be broken (1 with cracks). In order to reduce rotor vibration and enhance blade force, the tension bumps required repair. The boss dimensions were approximately 30mm×20mm×10mm (length × width × thickness), with the boss material being 0Cr17Ni4Cu4Nb. The fractured blade lace convex table might potentially drop into the condenser due to the steam flow direction, resulting in only one boss being found on-site, while the other seven were missing. Given the complex shape of the boss and the extensive temporary processing time, repairing it by welding it back in its original position after grinding the groove was ruled out. To address the small size of the boss and the challenges associated with its intricate shape, an in-situ surfacing remanufacturing method was developed. This involved surfacing at the fracture position, reaching an appropriate height and thickness, and then grinding it to the boss's shape.

Surfacing could be done using the same material [1] or different materials [2]. When using the same material, ER630 wire of the same material as the broken boss was employed for surfacing welding. As the boss was martensitic steel, preheating was required prior to welding, followed by post-welding heat treatment after surfacing. In addition, the preheating temperature ranged from 250°C to 300°C, while the post-welding heat treatment temperature was controlled at 680°C±20°C. It was found that flame heating was the only available method, however, the flame heating temperature was difficult to control and higher operator experience was necessary to avoid deformation or even cracks due to poor heat treatment.

When using dissimilar materials for surfacing welding, nickel-based welding materials [3] with high nickel content in the weld could be employed. It was found that in this way the weld's toughness would be enhanced and the likelihood of cracking would be reduced, which while also eliminated the needing for heat treatment and facilitated easier on-site operation control. However, it was worth noting that the strength of nickel-based welds would be lower than that of the same material (similar to low matching), resulting in low-strength, high-plastic toughness welds.

Furthermore, based on the analysis of in-situ construction, the properties of the weld and the causes of fracture in the original tension-based boss, it was inferred that nickel-based welding materials were more effective in preventing cracks and in-situ construction. Provided that other unfavorable factors were optimized, the strength of nickel-based welding seams could meet the required specifications, therefore, nickel-based welding materials were employed for surfacing welding. The Cr content of ENiCr-3 wire was akin to that of the base material, with the remainder being other elements such as Ni and Mn, making this wire suitable for surfacing welding. The specific process involved the following steps:

(1) Rotating the rotor to an appropriate position, trimming and smoothing the fractured portion of the lace convex table, and removing discontinuous elements like sharp corners through grinding. The cracks in the tension rib boss which were discovered during expansion inspection should be polished to eradicate them. At the same time, the necessitating cutting out and resurfacing the boss should be conducted for the table was on the verge of breaking upon removal.

(2) Manufacturing a copper gasket, selecting the appropriate thickness of purple copper plate based on the gap between the two tension convex, cutting it to the suitable width, and processing it into an "L" type copper gasket.

(3) Pull the blade, securing the processed copper gasket on the convex surface requiring surfacing, with the base of the "L" type at the bottom of the convex surface surfacing.

(4) Surfacing welding. Utilizing tungsten argon arc welding, ERNiCr-3 welding wire, wire diameter 2.5mm, direct current connection, welding current 90~110A, argon flow rate 9~11L/min, interlayer temperature below 150°C. Welding sequence from inside to outside, from bottom to top, after welding the first layer of macro inspection, no defects were found in the subsequent welding.

(5) Post-welding, the surfacing convex surface was polished to a suitable shape.

(6) Employ the color-coding technique to identify surfacing welding components and no cracks were allowed. If any cracks be discovered, they necessitate re-welding.

Based on the above, no cracks were detected upon inspection following the repair, indicating a successful repair. The renovated boss was displayed in the Figure 8. It could be observed that the unit has logged approximately 300 hours of operation up to now and there were no irregularities reported. Besides, the next step is to further strengthen the vibration monitoring of the low pressure rotor during operation and make a plan to re-inspect the repair site during the next shutdown.

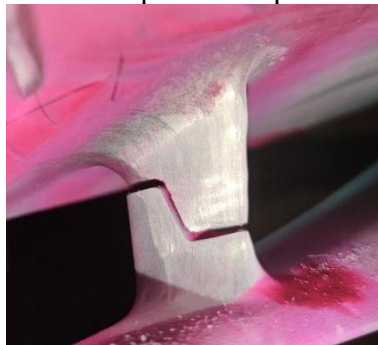


Fig.8 The repaired lace convex table

6. Conclusion

1) The primary cause of the failure of the lace convex table within the final blade of the low-pressure rotor was overloading, potentially triggered by the deformation of the guide ring due

to the fracturing of the guide ring bolt. It was worth noting that the absence of toughness in the diversion ring bolt was the root of its fracturing. Based on the above, it was advised to reinforce supervision of low-pressure cylinder bolts and follow the guidelines of high-temperature bolt supervision if necessary.

2) The implementation of nickel-based welding materials for surfacing welding and remanufacturing of the lace convex table resulted in the development of a suitable surfacing welding process, ensuring a successful repair.

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