Fracture Analysis of high strength bolt in wind turbine

Feng Yun1*, Xiaochun Zhao2, Chunyu Liu3, Jun Liu4

1Inner Mongolia Electric Power Research Institute, Inner Mongolia autonomous Region, Hohhot, 010010, China
2Inner Mongolia Electric Power Research Institute, Inner Mongolia autonomous Region, Hohhot, 010010, China
3Inner Mongolia Electric Power Research Institute, Inner Mongolia autonomous Region, Hohhot, 010010, China
4Inner Mongolia Electric Power Research Institute, Inner Mongolia autonomous Region, Hohhot, 010010, China

*Corresponding author’s e-mail: yunfeng7@impc.com.cn

Abstract. During the operation of a wind turbine in a wind power generation limited liability company, the bolt connecting the blade and the paddle bearing broke. In order to find out the cause of fracture, a comprehensive test analysis was carried out on the connection bolt between the blade and the variable blade bearing by means of macro morphology analysis, chemical composition analysis, mechanical property testing, microstructure testing and fracture micro-area analysis. Experiments show that: the blade and blade bearing joint bolt fracture was the main cause of the bolt in the operation process of changing, repeated impact of wind load and the effects of the alternating load blade rotation, along the severe stress concentration of thread form ascend a crack source and extension in fatigue, until the whole fracture failure.

1. Introduction
In a certain month in 2018, the inspection personnel of a wind power company successively found that the connecting bolts between two fan blades and the variable blade bearing were broken during their quarterly inspection of fans. In order to find out the fracture cause of the bolt, the methods of macro morphology analysis, chemical composition analysis, mechanical property testing, microstructure testing and fracture micro-area analysis were carried out. There is a total of 1 broken bolt for sample analysis, and the detailed information is shown in Table 1.

Table 1. Details of blade and paddle bearing connection bolts

| The sample name                          | Gauge                        | Material is qualitative level | For note      |
|------------------------------------------|------------------------------|-----------------------------|---------------|
| Connecting bolt between fan blade and variable blade bearing | M30×330mm double head stud | 42CrMo                      | The fracture  |
2. Test method for fracture study of blade - paddle bearing connection bolts
The macro morphology of the fractured blade and the blade bearing connecting bolt was observed to determine whether there were mechanical damage, original defects and other damage traces, and the cracking reason was further analyzed combined with other test methods. The fracture surface of the bolt connecting the blade and the rotor bearing was analyzed by scanning electron microscope (SEM) to determine the fracture mode and fracture mechanism. SPECZROMAXx benchtop direct reading spectrometer was used to analyze the chemical composition of the broken blade and rotor bearing connection bolts to determine whether the chemical composition meets the standard requirements. Using Axio observer. Alm metallographic microscope, samples of blade and paddle bearing connection bolts were examined to determine whether their metallographic microstructure was normal. Using low temperature impact testing machine, the sampling of the incoming bolt was tested at -20°C to determine whether its impact toughness met the standard requirements. In tuKON2500-6 automatic Vickers hardness tester for hardness test, to determine whether the hardness of the material meets the standard requirements. The sample bolts were sampled and tensile test was carried out at room temperature on CMT5305 electronic universal test machine to determine whether the yield strength, tensile strength and elongation after breaking of the material met the standard requirements.

3. Test results and discussion

3.1 Macroscopic morphology observation and analysis
The macro morphology of the connection bolt between the fractured blade and the variable blade bearing was inspected. The high strength bolt is M30×330mm, class 10.9 double head stud. The bolt is broken at the bottom of the first and second thread of the self-flexible rod of the bolt, which is in the stress concentration zone of the whole bolt.

On the bolt fracture surface, crack initiation zone, crack propagation zone and transient fracture zone are clearly identified. Except for the transient fault area, the fracture surface is flat without plastic deformation, and the color is bright gray. No obvious corrosion products and mechanical damage defects are found. The fracture originated at the bottom edge of the thread teeth, and most areas of the fracture showed fatigue fracture characteristics [1-3], with obvious "beach-like" fatigue bands observed, as shown in Figure 1.

FIG. 1 Macro morphology of fracture surface of connecting bolt between blade and paddle bearing

3.2 Observation and analysis of fracture microarea
Scanning electron microscopy (SEM) was used to detect the microscopic morphology of the fracture surface of the connection bolt between the blade and the paddle bearing [4-7]. It can be seen that the crack initiation zone is relatively flat, and no obvious defects such as cracks and slag inclusions are found, but obvious tearing steps formed under the action of stress concentration can be observed. The clear fatigue striation can be observed in the extension area, which has the typical fatigue crack
propagation characteristics of quenched and tempered steel. The whole fracture surface shows obvious fatigue fracture characteristics.

3.3 Chemical composition detection and analysis
Chemical composition testing was carried out on sampling of connecting bolts between blades and paddle bearings, and the test data were shown in Table 4. The results show that the content of each element in the chemical composition of the bolt conforms to the requirements of 42CrMo steel in GB/T 3077-2015 alloy Structural Steel standard.

Table 2. Test results of tempering components of connecting bolt between blade and paddle bearing

| Detecting element | C  | Si  | Mn  | Cr  | Ni  | Mo  | P | S |
|-------------------|----|-----|-----|-----|-----|-----|---|---|
| The measured values | 0.41 | 0.26 | 0.80 | 0.96 | 0.03 | 0.18 | 0.013 | 0.001 |
| GB / T 3077 - 2015 | 0.38 | 0.17 | 0.50 | 0.90 | ≤ 0.30 | 0.15 | ≤ 0.030 | ≤ 0.030 |

3.4 Microstructure detection and analysis
The connecting bolt between the fractured blade and the variable blade bearing was sampled at the fracture site for metallographic microstructure detection. The microstructure of the thread and the matrix are equiaxed and uniformly distributed fine tempered sostenite, and no obvious decarbonized layer and other defects are found at the top and bottom of the thread, as shown in Figure 2.

3.5 Mechanical properties testing and analysis
Mechanical performance testing was carried out on sampling bolts connecting blades and paddle bearings, and the test results were shown in Table 5 and Table 6. It can be seen that the Vickers hardness value, low temperature (-20°C) impact toughness, the specified non-proportional elongation of 0.2% stress, tensile strength and fracture elongation of the bolt all meet the standard requirements.
Table 3. Test results of hardness and low temperature impact performance of connecting bolt between blade and paddle bearing

| The test items                          | Vickers hardness /HV30 | Low temperature impact absorption work (-20℃) AKV /J |
|----------------------------------------|------------------------|----------------------------------------------------|
| Fan blade and paddle bearing Connecting bolts | 323                    | 90                                                 |
|                                        | 329                    | 89                                                 |
|                                        | 326                    | 89                                                 |
| The average                            | 326                    | 89                                                 |
| GB /T 3098.1-2010                      | 320~380                | ≥ 27                                               |

Table 4. Test results of tensile test for connecting bolt between blade and paddle bearing

| The test items                                      | Stress of 0.2% non-proportional extension (MPa) | Tensile strength (Mpa) | Elongation after break (%) |
|-----------------------------------------------------|--------------------------------------------------|------------------------|----------------------------|
| Connecting bolt between fan blade and variable blade bearing | 947                                               | 1074                   | 15                         |
| Standard requirement                                 | ≥ 940                                             | ≥ 1040                 | ≥ 9                        |

4. Conclusion

Based on the analysis of the above test results, the main reasons for the fracture of the connecting bolt between the fan blade and the variable blade bearing are as follows:

According to fracture morphology analysis [8], the connection bolt between blade and paddle bearing broke at the bottom of the first and second threads of the self-flexible rod of the bolt. The fracture showed typical fatigue fracture characteristics, and the fracture originated from the stress concentration at the bottom of the thread teeth.

According to the microstructure analysis, the thread and the matrix of the bolt connecting blade and rotor bearing are equiaxed and evenly distributed fine tempered sortensite, and no obvious decarbonized layer is found at the top and bottom of the thread.

According to the analysis of mechanical properties, the hardness, strength and toughness of the bolt connecting blade and paddle bearing all meet the standard requirements.

From the analysis of force state, in addition to the static stress such as tensile, shear and bending, the bolt connecting the blade and the variable blade bearing should also bear the impact of the changing wind load and the alternating load produced by the blade rotation during the operation of the fan, so the force situation is very complex. Under bad working conditions, it is easy to form a tear crack source along the bolt with obvious stress concentration at the bottom of the first and second threads of the flexible rod and expand in the form of fatigue.

To sum up, the fan blades with variable blade bearing joint bolt fracture: was the main cause of the bolt in the process of fan operation because of the changing impact of wind load and the effects of the
alternating load blade rotation, obvious stress concentration along the thread tooth form ascend a crack source and fatigue extend continuously, until the whole fracture failure.

First of all, we should strengthen the supervision of the metal technology of the fan equipment, check other high-strength connection bolts of the same type, and deal with the problems in time. Second, the bolt fastening process should be standardized, and qualified torque wrenches should be used for bolt fastening and maintenance. It is recommended to tighten the high-strength connection bolts in the manner of fixed time, fixed person and fixed equipment, so as to avoid the abnormal impact load or additional bending moment of individual bolts due to improper assembly. Finally, when selecting bolts, high-strength connecting bolts with smooth bottom structure should be used in the parts prone to fatigue fracture, such as circular bottom instead of flat bottom, so as to reduce the stress concentration of bolts, improve the fatigue limit of bolts, so as to avoid similar high-strength bolt fracture failure.

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