Analysis and research on fracture cause of connecting bolt of wind turbine spindle

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Abstract. On a certain day in 2018, the main shaft connecting bolt of a wind turbine in a wind farm broke and failed during operation. In order to find out the cause of fracture, the fractured spindle connecting bolt was comprehensively detected and analyzed by means of appearance state analysis, chemical element composition analysis, mechanical property detection analysis, microstructure detection and fracture micro area analysis. The results show that the main reason for the fracture of the main shaft connecting bolt is that the hydrogen penetrates into the bolt surface due to improper process control during the production process, resulting in hydrogen embrittlement in the local area of the thread root. Thus, during the operation of the fan, under the combined action of bending, shear and tensile stress, the connecting bolt of the main shaft cracks at the bottom of the first thread on the side of the self rigid rod with the most concentrated stress, and expands in the form of "herringbone" brittle fracture until the overall fracture failure. It is recommended to check the bolts in the same batch to prevent hydrogen embrittlement in the whole batch.

1. Introduction
In 2018, during the operation of No. 86 wind turbine in a wind farm, the operation and maintenance personnel found that one of the main shaft connecting bolts was broken and failed. In order to find out the cause of the fracture of the connecting bolt of the main shaft, the wind farm entrusted a power research institute to analyze the cause of the bolt fracture. There is one spindle connecting bolt for sample analysis, and its details are shown in Table 1.
2. Background and test method of research on fracture causes of connecting bolts of Wind Turbine Spindle

A wind power plant has an installed capacity of 110.1mw and a planned capacity of 400MW, which is divided into three phases. The first phase of the project started construction in March 2007, with an installed capacity of 30.6mw. A total of 36 wind turbines with a single unit capacity of 850kW produced by Vestas company of Denmark are installed. Two sections of 35kV Power collection lines are built to collect electric energy to 110kV booster station. The lines of 35kV section IA and 35kV section IB are 7.003km long and 6.354km long respectively. The power is transmitted and connected to Mengxi power grid through 110kV Duotang line I. The construction of phase II project was started on August 6, 2008, with an installed capacity of 30MW. A total of 20 1500kW wind turbines produced by Guangdong Mingyang company were installed. Two sections of 35kV Power collection lines were built to collect electric energy to 110kV step-up stations. The lines of 35kV IC section and 35kV ID section are 7.787km long and 6.031km long respectively. The power transmission is still connected to Mengxi power grid through phase I 110kV Duotang line I. The construction of phase III project was started on August 20, 2009. The installed capacity of the project is 49.5mw. A total of 33 1500kW wind turbines produced by Guangdong Mingyang are installed. There are 3 sections of 35kV Power collection lines to collect electric energy to 110kV booster station, which are 10.647km long in 35kV IIE section, 9.507km long in 35kV IIF section and 10.97km long in 35kV IIG section, The power is sent to Luanhe 220kV substation through 110kV Luanda line and incorporated into Mengxi power grid. 110kV Duotang I line is 9.088km long and 110kV Luanda I line is 8.307km long.

According to the requirements of metal technology supervision of wind power plant, in order to find out the fracture causes of main shaft connecting bolts, prevent the recurrence of similar fracture failures, and ensure the safe, stable and continuous operation of the unit, entrusted by Datang Duolun Daxishan wind farm, a power research institute adopts external morphology analysis, chemical element analysis, microstructure detection, impact toughness experiment. The failure causes of the broken spindle connecting bolts were analyzed by hardness test and fracture morphology analysis.

3. Test results and discussion

3.1 Macroscopic morphology observation and analysis

Macroscopic morphology inspection was carried out on the broken spindle connecting bolt. The bolt was 10.9 high strength connecting bolt, and the surface was treated by Dacromede anticorrosion method. The main shaft connecting bolt was fractured at the base of the tooth of the first thread at the self-rigid rod of the bolt, which was in the stress concentration area of the bolt[1-3], the section is rough, the color is bright gray, and no obvious corrosion products are observed. There are obvious "hermite-shaped" stripes extending from the initial fracture zone to the expansion zone, as shown in figure 1.
3.2 Observation and analysis of fracture microarea

It can be seen that there are obvious "rock sugar block" intergranular fracture morphology in the initial fracture zone of the bottom of the thread tooth, and there are many holes on the crystal plane, accompanied by intergranular secondary cracks. In the extension zone, obvious river pattern and a few dimples were observed, accompanied by secondary cracks, which showed typical quasi-cleavage fracture characteristics. The fracture is characterized by hydrogen embrittlement[4-6].

3.3 Chemical composition detection and analysis

Take samples of broken bolts for chemical composition test. See Table 2 for test data. The results show that. The chemical composition of the bolt meets the requirements of the standard.

| Detecting element               | C   | Si  | Mn  | Cr  | Ni  | Mo  | P   | S   |
|--------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Spindle connection bolt        | 0.41| 0.28| 0.79| 0.98| 0.02| 0.18| 0.014| 0.011|
| GB / T 3077 - 2015             | 0.38| 0.17| 0.50| 0.90| 0.15| 0.25|     |     |
|                                | 0.45| 0.37| 0.80| 1.20| 0.30| 0.30|     |     |

3.4 Microstructure detection and analysis

Metallographic microstructure detection was carried out on the samples of the broken spindle connecting bolts. The microstructure of the thread and matrix were fine tempered soxaustenite evenly distributed in
equiaxed shape, and no obvious decarburization layer was found at the top and bottom of the thread, as shown in Figure 3.

![Microstructure morphology of spindle connecting bolt thread](image)

**Figure 3** Microstructure morphology of spindle connecting bolt thread

### 3.5 Testing and analysis of mechanical properties

The mechanical properties of the failed bolts of the main shaft connection are tested by sampling, and the test results are shown in Table 3. It can be seen that the Vickers hardness value of the bolt is 379, and its low-temperature impact toughness meets the requirements of regulations and standards.

| The test items       | Vickers hardness /HV30 | Low temperature shock absorption energy (-20℃) AKV /J |
|----------------------|------------------------|---------------------------------------------|
| Spindle connection bolt | 379                    | 42                                          |
| GB/T 3098.1-2010     | 320~380                | ≥ 27                                        |

### Table 3. Test results of mechanical properties of spindle connecting bolts

### 4. Conclusion

According to the fracture morphology analysis, there are obvious "rock sugar block" intergranular fracture morphology in the initial fracture zone of the screw bottom fracture, and there are many holes on the crystal plane, accompanied by intergranular secondary cracks. In the extension zone, obvious river pattern and a few dimples were observed, accompanied by secondary cracks, which showed typical quasi-cleavage fracture characteristics. The fracture is characterized by hydrogen embrittlement.

From the analysis of mechanical properties, the vickers hardness value of the spindle connecting bolt is close to the upper limit of the standard requirements, and the low temperature impact toughness meets the standard requirements.

Based on the above analysis, it is believed that the main reason for the fracture of the spindle connecting bolt is that the high strength connecting bolt in the production process due to improper process control, so that hydrogen infiltration into the bolt surface, resulting in hydrogen embrittlement in the local area of the thread root. Thus, in the process of fan operation, under the combined action of bending, shear and tensile stress, the main shaft connecting bolt cracks at the bottom of the first thread on the side of the self-rigid rod with the most concentrated stress, and expands in the brittle fracture mode of "hermitage" until the overall fracture failure.

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