Analysis and Research on Fracture Cause of Fixed Shaft of Torsion Arm of Wind Turbine Gearbox

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Abstract. In a wind power plant of a wind power plant limited liability company, the fixed shaft of the torsion arm of the gear box broke during the operation of a wind power generator set. In order to find out the cause of fracture, the fracture fixed shaft of torsion arm was comprehensively detected and analyzed by means of appearance morphology analysis, chemical composition analysis, mechanical properties testing, microstructure testing and fracture micro-area analysis. The results show that the main reasons for the fracture of the fixed shaft of the torsion arm of the fan gear box are as follows: improper heat treatment process of the fixed shaft of the torsion arm of the gear box causes a large amount of massive ferrite in the material structure, resulting in insufficient strength of the material; the inclusion in the material is serious, resulting in unqualified impact toughness; Shaft surface surfacing Cr - Mn stainless steel material causes the fusion zone C migration form brittle layer, at the same time the vast difference between the state of welding layer and substrate organization fusion zone caused by larger remnants stress, the embrittlement in bond layer to form the intergranular crack crack source, and in the process of the equipment operation under the action of cyclic torsional and impact load, Cracks propagate in a fatiguing manner and lead to eventual fracture.

1. Introduction
On a certain day in 2019, a wind farm of a wind Power Company limited liability Company. A turbine to "FSS measured and generator speed variation" failures and downtime, spot checks found torsion arm slightly backwards, gear box side to the other side fixed shaft torque arm fracture, high-speed shaft coupling of carbon steel lining deformation, before and after the gearbox high-speed shaft move, bearing circlip was out, high-speed shaft tooth surface exists partial indentation, coupling deformation, sound, generator slight displacement. Abnormal elastic support system was found in previous maintenance. The wind power plant analyzed the fracture cause of the broken fixed shaft of the torque arm of the gearbox for inspection, and the detailed information is shown in Table 1.
Table 1. Gear box torque arm fixed shaft details

| The sample name                  | specifications | Material is qualitative | For note    |
|----------------------------------|----------------|------------------------|-------------|
| Wind turbine gearbox torque arm fixed shaft | 160 mm diameter | 42CrMo                 | The fracture |

2. Test method for fracture study of fixed shaft of torsion arm of wind turbine gearbox

Combined with the field investigation and macroscopic morphology observation, the fixed shaft of gear box torsion arm was judged whether there were mechanical damage traces, original defects and other damage traces, and the fracture cause of fixed shaft was further analyzed with other test methods. According to the requirements of GB/T 4336-2016 Determination of Multi-element Content in Carbon Steel and Medium and Low alloy Steel by Spark Source Discharge Atomic emission Spectrometry (Conventional Method), SPECZROMAXx type bench direct reading spectrometer was used to analyze the chemical composition of all elements in the fixed axis sample of broken torque arm of gear box. Benchtop direct reading spectrometer was used to determine whether the chemical composition met the standard requirements. According to the requirements of GB/T 13298-2015 Metallographic Microstructure Inspection Method, Axio Obser.ALM metallographic microscope was used to test the microstructure of the fixed shaft sample of the torque arm of the gear box to determine whether the metallographic microstructure is normal. According to the requirements of "GB/T 229-2007 Charby Pendulum Impact Test Method for Metallic Materials", low-temperature impact testing machine was used to conduct impact tests on the fixed shaft of the torque arm of the gear box at room temperature and -20°C to determine whether its impact toughness meets the standard requirements at room temperature and low temperature. According to the requirements of "GB/T 228.1-2010 Tensile test of Metallic materials part 1: Test Method at room temperature", the fixed shaft of gear box torsion arm was sampled, and the tensile test was carried out on CMT5305 electronic universal testing machine at room temperature to determine whether the yield strength, tensile strength and elongation after fracture meet the standard requirements. According to the requirements of GB/T 231.1-2018 Brinell Hardness Test for Metallic Materials part 1: Test Method, hardness tests were carried out on the substrate, surface surfacing layer and fusion zone of the fixed shaft of the torque arm of the gear box on THE THBC-3000DA Image processing Brinell hardness tester to determine whether the hardness of each part meets the requirements. Scanning electron microscope (SEM) was used to analyze the fracture mode and fracture mechanism of the fixed shaft of torque arm of gear box.

3. Test results and discussion

3.1 Macroscopic morphology observation and analysis

The macroscopic morphology of broken fixed shaft of torsion arm of gear box was examined. The fracture of the fixed shaft of the torsion arm of the gear box is flush, and the fracture is perpendicular to the axis as a whole, without obvious plastic deformation. The surface of the fracture has a certain degree of extrusion wear, and there is no corrosion damage and other defects on the whole. There is a surfacing layer on the surface of the shaft body. The initial fracture zone, crack propagation zone and transient fracture zone can be clearly distinguished from the fracture surface. There are typical beach-like fatigue bands in the propagation zone, and the approximate location of the crack source can be determined from the propagation direction of the fatigue crack.

In terms of the proportion of each area on the fracture, the expansion area accounts for more than 90% of the entire section area, indicating that the fixed shaft of the torsion arm carries a small load during operation, and there is no overload. In addition[1-3], there is a variable section with a whole circle depth of about 0.2mm on the side of the axis at the fracture point, and the fracture initiation zone is exactly located at the variable section, as shown in Figure 1.
3.2 Observation and analysis of fracture microarea

Scanning electron microscope (SEM) was used to detect the fracture of the fixed shaft of the torque arm of the gear box. The microscopic characteristic morphology of each area of the fracture is shown in Figure 2.

It can be seen that the initial fracture zone of the fixed shaft fracture of the torsion arm of the gear box is located in the fusion transition zone between the surfacing layer and the shaft matrix, and the obvious "rock sugar" intergranular fracture morphology can be observed in this region [4-7]. The grain size is coarse-grained as it gets closer to the surfacing layer, and the grain size is smaller as it gets closer to the shaft matrix, and secondary cracks occur in local areas. The width of this area is about 0.5mm. In the extended zone, the fatigue striations of the quenched and tempered steel can be clearly observed.

3.3 Chemical composition detection and analysis

Samples were taken for chemical composition detection of the fixed shaft matrix and surface-surfacing layer of the torque arm of the gear box. The test data are shown in Table 4 and Table 5. The results show that the content of Mn in the matrix of fan gear box torque arm fixed shaft is higher than that of 42CrMo steel in GB/T 3077-2015 Alloy Structural Steel, and the content of other elements meets the requirements of the standard.
In the chemical composition of the surfacing layer on the surface of the shaft, the content of C is 0.23%, the content of Mn is 11.90%, and the content of Cr is 5.92%. Therefore, the cladding metal of the surfacing layer should be Cr-Mn austenitic stainless steel welding material.

Table 2. Chemical composition test results of 42CrMo matrix of fixed shaft of gear box torsion arm

| Detecting element | C  | Si  | Mn  | Cr  | Mo  | Ni  | P  | S  |
|-------------------|----|-----|-----|-----|-----|-----|----|----|
| GB/T 3077-2015    | 0.38 ~ | 0.17 ~ | 0.50 ~ | 0.90 ~ | 0.15 ≤ | ≤ | ≤ | ≤ |
| The measured values | 0.42 | 0.30 | 1.06 | 0.97 | 0.19 | 0.06 | 0.023 | 0.009 |

Table 3. Chemical composition test results of surfacing layer on fixed shaft surface of torque arm of gear box unit: %

| Detecting element | C  | Si  | Mn  | Cr  | Mo  | Ni  | P  | S  |
|-------------------|----|-----|-----|-----|-----|-----|----|----|
| The measured values | 0.23 | 0.23 | 11.90 | 5.92 | 0.09 | 0.07 | 0.030 | 0.016 |

3.4 Microstructure detection and analysis
The broken torque arm fixed shaft of the gearbox was sampled for metallographic microscopic examination. The inclusions in the tissue are more serious, which are class A sulfide and grade 2. In addition, there is a hardfacing layer with a depth of about 2.5mm on the surface of the shaft. The structure of the hardfacing layer is dendrite austenite, and the crystal direction is very coarse. There is a black transition zone between the hardfacing layer and the matrix, in which C element migrates to this position in the matrix structure. The initial fracture zone of the fracture is located in the black transition zone between the surfacing layer and the matrix, and the fracture extends from this zone to the surfacing layer and the axial matrix, as shown in Figure 3.

Figure 3  Metallographic structure of each part of fixed shaft of torsion arm of broken gear box

3.5 Testing and analysis of mechanical properties
Various mechanical properties were tested by sampling the fixed shaft of torque arm of the gearbox, and the results were shown in Table 6. It can be seen that the tensile strength, yield strength and normal
temperature impact absorption energy of the fixed shaft of the torsion arm of the gear box are not qualified, far below the standard requirements. At low temperature (-20℃), the impact absorption energy is lower, and the material has no ability to resist notched impact fracture at low temperature. The hardness of surfacing layer and fusion zone is more than 150HB.

Table 4. Mechanical performance test results of fixed shaft of torque arm of gear box

| The test items | Lower yield strength /MPa | Tensile strength /MPa | Elongation after fracture /% | Impact absorption work (20℃) | Low temperature impact absorption work (-20℃) | Matrix hardness /HB | Fusion zone hardness /HB | Hardness of surfacing layer /HB |
|----------------|--------------------------|-----------------------|-----------------------------|------------------------------|--------------------------------|------------------|--------------------------|-----------------------------|
| GB / T 3077 - 2015 | ≥ 930                    | ≥ 1080                | 12                          | 63                           | --                            | 272              | 432                      | 434                         |
| The measured values | 697                      | 890                  | 14                          | 45                           | 32                            | 272              | 432                      | 434                         |

4. Conclusion

According to the fracture morphology analysis, the fracture surface of the fixed shaft of the torsion arm of the gear box is a typical "beach" fatigue fracture, and there is a surfacing layer on the surface of the shaft, and the crack source originates from the transition zone between the surfacing layer and the matrix. The extension area on the fracture takes up more than 90% of the whole section area, indicating that the fixed shaft of the torsion arm carries a small load during operation and does not have overload.

From the chemical composition analysis, the content of Mn element in the chemical composition of the fixed shaft of torque arm of gear box is higher than the standard requirement. Cr-mn austenitic stainless steel is the cladding metal for surfacing of shaft surface.

From the analysis of microstructure, there are a lot of massive undissolved ferrite in the matrix of the fixed shaft of the torsion arm of the gear box, indicating that the strength of the material will be reduced due to low heating temperature and insufficient austenitizing transformation. At the same time, the inclusion in the structure is more serious, which will seriously reduce the toughness of the material. There is a hardfacing layer with a depth of about 2.5mm on the surface of the shaft, and the dendrite austenite grains are very coarse, while the matrix microstructure is relatively small. The two phase materials and the large grain size difference will cause great organizational stress in the fusion zone. The black fusion zone between the surfacing layer and the matrix has the phenomenon of C element migrating to this position, which makes the fusion zone become the embrittlement zone with high carbon content and high hardness.

From the analysis of mechanical properties, the strength and toughness of the fixed shaft of the torsion arm of the gear box are far lower than the standard requirements, and the impact absorption energy is lower at low temperature (-20℃), so the material has no ability to resist notch impact fracture at low temperature.

From the perspective of force analysis, the fixed shaft of gear box torsion arm has complex force state in the process of use. In addition to the gravity load of gear box, it also bears the cyclic impact load generated by fan vibration and cyclic torsion load generated by fan yaw, especially in the variable section of shaft body, great stress concentration will be formed.

Based on the above analysis, it can be concluded that the main reasons for the fracture of the fixed shaft of the torque arm of the fan gear box are as follows: Improper heat treatment process of the fixed shaft of the torque arm of the gear box results in a large amount of massive ferrite in the material structure, resulting in insufficient strength of the material; The inclusion in the material is serious, resulting in unqualified impact toughness. Cr-mn stainless steel material was surfacing on the surface of the shaft,
resulting in the migration of C in the fusion zone and the formation of embrittlement layer. At the same time, the great difference between the microstructure of the surfacing layer and the matrix resulted in a large residual microstructure stress in the fusion zone, and the embrittlement layer in the fusion zone formed the crack source of intergranular cracking. Under the action of cyclic torsion and impact load during the operation of the unit, the crack expands in the way of fatigue and leads to the final fracture.

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