Development and application of multi-functional wind turbine tower bolt strain test experimental platform

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Abstract. This paper designs a multi-functional wind turbine tower bolt strain test experimental platform, and introduces the design idea, main functions and features of the experimental platform. The experimental platform can perform a series of experimental studies on flange bolt strain.

1. Introduction
The wind turbine tower is the main supporting device of the wind turbine. Due to the complicated working mode of wind turbine, fan tower bears all kinds of aerodynamic loads of natural wind and gravity loads of engine room and wind wheel. Therefore, its safety is particularly important. As one of the hazards of fan tower, many scholars have carried out researches on the looseness of bolts. Ren kai [1] et al, of northwestern polytechnic university, based on the electromechanical impedance method, used the pretightening torque detection method for bolts in two-bolt overlapping beams. By using the electromechanical coupling effect, the electrical impedance of piezoelectric ceramics attached to the structure surface changed, and then the loosening of bolts was determined. Pan Pingping [2] of Shenyang University of technology established a finite element analysis model for bolt connection of tower, and concluded that the natural vibration frequency of bolt connection mechanism is sensitive to bolt damage. Li jun et al. [3] from Taiyuan University of technology established a detailed geometric model of flange bolt connection and calculated that the maximum stress of bolt and flange was less than the yield limit of material. Xu Wensheng [4] of Huazhong University of science and technology developed a multi-functional prestressing test platform, through which the experimental value can be compared with the theoretical value.

This experimental platform is a set of research system based on the principle and technology of strain electric measurement [5], using bolt pre-strained strain gauge to collect the internal strain of different pre-tightening bolts. It is designed to provide technical support for wind turbine tower bolt loose monitoring.
2. Construction of the experimental platform
The multi-functional wind turbine tower bolt strain test experimental platform mainly consists of a flange model, a strain gauge embedded bolt, a preload force loading device and a data acquisition system.

2.1. Flange model
The size of the flange model is selected from the middle part of the 80-meter-high tower of the Goldwind 2MW direct-drive permanent magnet wind turbine. The material of the flange is Q345 high-strength steel. According to the corresponding dimensions, as shown in figure 1. The flange model is machined by machine tool, as shown in figure 2.

![Figure 1. Flange model size](image1)

![Figure 2. Flange model](image2)

2.2. Strain gauge embedded bolt
The sensor uses a 350Ω resistive strain gauge. The hexagonal high-strength bolt has a size of M39, the material is 42CrMo, and the length is 210mm. A hole with a diameter of 5mm and a depth of 100mm is punched at the center. Then use solvent cleaning (acetone, etc.) [6] to clean the oil and dust inside the rotary hole with a solvent through a syringe, and wrap the solvent-laden thin cloth on the drill to completely remove the residue, repeat until the thin cloth is clean, and finally use a clean thin
cloth removes the remaining solvent in the pores. The strain gauge is then inserted into the position where the component variation is minimized because the insertion into the head of the bolt or the bottom of the hole can have a serious effect on the shape of the component. Note that the strain gauge is inserted and the distance between the bottom of the strain gauge and the bottom of the hole should be kept at 3-5 mm. Finally, the initially heated mixed adhesive was injected into the bottom of the hole, and then the strain gauge was inserted, and the bolt was placed in the electric furnace to maintain 140°C. After 3 hours, the bolt was cooled. The flowchart is shown in figure 3, and the final result is shown in figure 4.

Figure 3. Operation flow chart

Figure 4. Arrangement of strain gauges in bolts

2.3. **Preloading device**

By establishing the finite element model of the flange bolt and using ABAQUS software [7] to simulate, the pre-tightening force of the bolt is up to 4400Nm. Therefore, the hydraulic torque wrench is selected as the preloading device as shown in figure 5. Tight torque range: 215-77585Nm.

Figure 5. Hydraulic torque wrench

2.4. **Data acquisition system**

This experimental platform is used for static strain collection of bolts with different pre-tightening forces. The acquisition system [8] is based on DH3820 high-speed static strain data acquisition instrument tested by Donghua, as shown in figure 6. The highest sampling frequency is 100Hz, which is widely used in fatigue test and pseudo. The power test can capture the slow-changing signal of the
material entering the plastic zone from the elastic region, and communicate with the computer using the network port. The data acquisition system realizes the function of sampling, transmitting, saving and displaying the data in real time. The acquisition system is shown in figure 7. The technical route of the test system is shown in figure 8.

3. The main functions and features of the experimental platform

3.1. Main functions
On this experimental platform, the pre-tightening force and strain test of flange bolts in different states can be carried out. The relationship between the pre-tightening force and the strain can be analyzed through experiments, because the loosening of the bolt will cause the change of the pre-tightening force, but Tight force cannot be monitored in real time, and the relationship between the preload force of the bolt can be indirectly monitored by the relationship between strain and preload. The experimental projects that can be carried out for bolt strain are:

(1) Experiment on the relationship between different pre-tightening forces of bolts and internal strain of bolts.
(2) Experiments on the relationship between different depth strains of embedded strain gauges.
(3) Experiments on the effects of different strength potting compounds on internal strain collection of bolts.
(4) Theoretical bolt strain and actual bolt strain comparison experiment.

3.2. Main features
(1) The experimental platform constructed by the 1:1 physical model adopts high-precision strain gauges and specific strain gauge pre-buried schemes, as well as hydraulic torque wrenches that can precisely control the magnitude of the torsion, so that the experimental system has a large test scope and certain test accuracy, not only for scientific research, but also for experimental teaching.
(2) Different experiments can be carried out to carry out research and analysis according to different experimental conditions. Different strain compensation schemes can be adopted depending on the experimental environment.
(3) Through the preservation of real-time data, the data is drawn to plot the relationship between preload and strain. The preload force at different strains can be obtained by this curve.

4. Conclusion
By constructing a multi-functional wind turbine tower bolt strain test experimental platform, the research on wind turbine tower bolts was carried out, and a new research method was added to provide theoretical technical support for wind turbine tower monitoring. The results obtained from the experimental platform can provide relevant technologies for the development of wind turbine tower bolt looseness health monitoring system and wind farm monitoring and inspection methods, reduce wind farm accidents and increase the economic benefits of wind farms.

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