Experimental Research of Mechanical Behaviour of GFRP Cross Arm of 500kV Transmission Tower

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Abstract. Glass fibre reinforced polymer (GFRP) material is used in the field of transmission tower structure because of its excellent electrical and structural performance. In this paper, a full scale GFRP composite cross arm of 500kV transmission tower is designed and a triaxial load-unload experiment is conducted to study the mechanical properties of it. Three kinds of the most unfavourable load cases of GFRP cross arm are loaded, and the strain changes of the upper, middle and lower parts of the cross arm are obtained. It is verified that the bearing capacity of GFRP cross arm meet the design requirements and GFRP cross arm can be used safely in the transmission tower engineering.

1. Introduction
Glass fibre reinforced polymer (GFRP) material is of excellent characteristics in both structural and electrical fields, such as light weight, high strength, good corrosion and fatigue resistance, easy processing, easy maintenance and great electrical insulation performance. At present, GFRP has been widely used in aerospace, automobile, electronics, building, fitness equipment and other fields [1-3]. In the design of transmission tower, steel, which is electric conductive, is the traditional material. As a result, to ensure the electric safety distance between ground wires, conductors and the ground, measures of using insulator strings and increasing tower height have to be applied. However, using GFRP instead of steel as the material of cross arm and even tower body can not only partially or completely remove insulator strings, decrease the probability of wind deflection flashover, improve the safety of transmission line, but also reduce the corridor width, tower height, steel consumption and project cost [4].

Several researches about the application of GFRP in transmission tower have been studied by scholars in recent years. A full-scale 220kV GFRP truss transmission tower was tested by Lin Shikai et al. [5] and a finite element method of GFRP tower was used to verify the rationality of materials and the structure design by Zhang Lei et al. [6]. Godat et al. [7] carried out axial compression and bending tests on GFRP members with non-circular section. An experimental research presented by Carra et al. [8] focused on the durability of pultruded GFRP composites applied in building construction.

However, there are few reports about the three-phase loaded mechanical behaviour of GFRP cross arms, which is the main load state in practical engineering. In this article, a full scale 500kV transmission tower cross arm made from GFRP material was manufactured and a triaxial load experiment was conducted on it. Three kinds of the most unfavourable load cases were loaded to the
GFRP cross arm to study the mechanical mechanism of it and verify whether it was safe enough in the whole tower structure.

2. Experiment Scheme
In order to ensure the safe and reliable operation of GFRP composite cross arm and further study its stress and deformation performance, based on the most unfavourable load value that may appear in the whole life cycle of design, construction and operation, a triaxial load test of 500kV composite cross arm was designed and conducted. The ultimate bearing capacity was determined by observing the stress and deformation of the GFRP cross arm.

2.1. Specimen Design
The outline design of the GFRP cross arm is shown in figure 1, and table 1 shows the dimensions of the specimen.

![Figure 1. Shape of GFRP composite cross arm.](image)

**Table 1. Specimen size.**

| Specimen type      | External diameter | Flange diameter | Flange height | Width of front metal parts | Length of front metal parts | Length |
|--------------------|-------------------|-----------------|---------------|----------------------------|-----------------------------|--------|
| Post insulator     | 320               | 470             | 275           | 390                        | 320                         | 5144   |
| Cable stayed insulator | 64           | /               | /             | /                          | /                           | 5612   |

2.2. Experiment Equipment

2.2.1 Connectors. The connectors A and B shown in figure 2 were connected with the front metal part of the cross arm through screws (see figure 2). The connector B was connected by seven screws to the front metal part, and the connector A was connected to the connector B by four screws, connected by four screws. Connected by four screws to the connector A, the MTS testing machine loaded the specimen by pulling. The lower ends of the specimen were provided with cross inserting plate connectors (see figure 3). The thickness and width of the cross inserting plate of the connectors were the same as that of the specimen. The cross inserting plate of the specimen and the connectors were longitudinally butted and transversely connected by eight steel plates with screws. The cross inserting plate of the connector was inserted and welded in the large plate at the same inclined angle as the specimen, and the large plate was fixed on the channel with ground anchors. The pull rods of the specimen were fixed by a pressure beam (see figure 4).
2.2.2 Loading and Measuring Equipment. The GFRP composite cross arm was designed as a three phase stressed member. In order to ensure the installation, loading and the correct stress state of the front joint, the reaction system was used to fix the specimen (see figure 5), which is composed of a reaction wall and a portal frame. The MTS hydraulic servo structure testing machine system was used to load longitudinally (see figure 3), including a 1000KN servo actuator and a digital controller FlexTest 100. The transverse and vertical load were respectively applied through the chain blocks with force transducers. The load scheme is shown in table 2. The TDS-602 data acquisition recorder made in Japan was adopted as the strain data acquisition system (see figure 6), and the BE120-3BC type orthogonal strain gauge was used as the strain flowers to measure the longitudinal and transverse strain of the specimen under different loads (see figure 7).
| Working condition | Vertical load (kN) | Transverse load (kN) | Longitudinal load (kN) |
|-------------------|-------------------|----------------------|-----------------------|
| 1                 | 264.36            | 7.85                 | 0                     |
| 2                 | 129.75            | 145.00               | 0                     |
| 3                 | 118.64            | 0                    | 635.00                |

2.2.3. Measurement Scheme. The layout of measuring points is shown in figure 8, with 14 sets of strain gauges symmetrically arranged in total. The plane of figure 8 is defined as the paper plane. In detail, the strain gauge sets were set at the upper, middle and lower parts of the post insulator pipes, the connection of both the upper and lower steel casings, the cross inserting plates and the cable stayed insulators. Each set of strain gauges was arranged with two strain measuring points on the outside and inside of the paper plane respectively. Each measuring point was arranged with orthogonal strain flowers to measure the longitudinal and circumferential strains, while one-way strain gauges were arranged on the cable stayed insulators. Through the strain data collected by strain gauge, the loading conditions and the internal stresses of GFRP post insulators, cable stayed insulators, steel connectors and steel casings in each loading stage would be obtained and monitored.

3. Experiment Results and Analysis

When the load of working condition 1 was applied to the specimen, no damage was occurred and there was no obvious test phenomenon. According to the strain data, the strain of all steels was in a small level, the maximum strain was 604 με, less than 2000 με, which is the yield strain of the steel. Therefore, the steel of the cross arm was in elastic working state.

When the load of working condition 2 was applied, the specimen was not damaged as well. Also, no obvious phenomenon was found. The strain value of each steel component was still far less than the yield strain of the steel. It was found that the strain value of post insulators increased from bottom to top, and the out-plane strain value was larger than out-plane strain value. There was a maximum strain of 3840 με at the top of the post insulator on the compression side.

When the load of working condition 3 was applied, small sounds made by the specimen could be heard from time to time. When the longitudinal load went to 635 kN, the specimen still was not damaged, so the load was further increased.

When the load reached 645 kN, the specimen was damaged with a loud sound. The test was terminated. The load displacement curve and the damage situation are shown in figure 9. The bolts at the flange were pulled out, leading to the failure of the specimen, which belongs to the form of connection failure. It can be seen that there are many small load drops in the load displacement curve caused by bolt slippage. The ultimate bearing capacity is 645 kN and the maximum displacement is 170 mm. The load strain curves of each part of cross arm are shown in figures 10-13. The maximum
longitudinal strain value of 9850 με appeared in the upper part of the post insulator, which is less than the failure strain of GFRP material of 12000 με [9].

Figure 8. The layout of measuring points.

Figure 9. Load displacement curve under working condition 3.

Figure 10. Load strain curves of upper post insulators.

Figure 11. Load strain curves of middle post insulators.

Figure 12. Load strain curves of bottom post insulators.

Figure 13. Load strain curves of cable stayed insulators.
4. Conclusions
In the triaxial loading test, the GFRP composite cross arm can meet the corresponding bearing capacity and deformation requirements under the loads of working condition 1 (vertical load 64.36 kN, transverse load 7.85 kN), condition 2 (vertical load 129.75 kN, transverse load 145 kN) and condition 3 (vertical load 118.64 kN, longitudinal load 635 kN). The ultimate bearing capacity of the cross arm is 645 kN and the displacement is 0.17 m. The bolts at the flange were pulled out, which belongs to connection failure. The maximum strain value of the post insulator did not reach the corresponding limit strain value. Therefore, the GFRP cross arm is structurally safe in the transmission tower engineering.

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