Study on the deflection control of suspended tubular bus in 750kV transformer substation

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Abstract. Because of the large span between bus bars and the big diameter and heavy weight of tubular buses, it has been a difficult issue to control the deflection of buses for the 750kV power distribution unit. Based on the hanging test on suspended tubular buses and the actual conditions in spot, finite models were established with different support types and rigidities to simplify the true hanging points and provide an effective reference for the optimization design of suspended tubular buses.

1. Introduction

Tubular bus is widely used in substation engineering due to its many advantages, such as large carrying capacity, low skin effect, small power loss, good heat dissipation, low temperature rise, large allowable stress and high mechanical strength[1-5]. The electric voltage in 750kV substation is higher, and the power distribution devices occupy a large area. At present, in domestic and foreign projects, the open-type 750kV power distribution devices usually adopt soft buses with good seismic performance[6]. In recent years, design institutes have also carried out many researches on 750kV power distribution devices using suspended tube-type bus bars, and the research results have been formed[7-8]. However, these analysis conclusions require that the deflection of the long-span suspended tubular bus should be controlled within 2-D range, which obviously does not meet the 1-D (D is the tubular bus diameter) requirements specified in the specification[9-10].

Based on the mechanics research of suspended tubular bus in 750kV substation, this project mainly includes the conductor selection, the development and design of new type of connecting fittings, the research on installation method, and the research on installation process control measures. The finite element models were established to simplify the connecting fittings, hanging points and supports, by which an effective reference for the selection and optimization of suspended tubular bus is provided.
2. Hanging test of inclined suspended tubular bus for 750kV power distribution devices

2.1. Project survey
Inclined suspended tube buses are adopted for the 750kV power distribution device. Due to the large span between buses, there are fewer engineering cases and experience for consulting. Besides, the tubular bus has heavy weight and large diameter, so it’s difficult to control the deflection of inclined suspended tubular bus. Consequently, a previous hanging test before the project implementation basing on the prophase research, analysis and calculation of tubular bus, processing and installation is necessary to be carried out to verify the feasibility of the design and construction schemes.

2.2. Layout of suspended tubular bus
Large-diameter and large-pan suspended tubular bus is used to support the 750kV bus bar. In the hanging test, the spans of buses are respectively 47m and 41m, and the section dimension is Φ300/270. The material properties are listed in Table 1.

| Density (g/cm³) | Elastic moduli (kg/cm²) | Passion’s ratio | Temperature linear expansion coefficient | Wire temperature under energized condition |
|-----------------|-------------------------|----------------|-----------------------------------------|------------------------------------------|
| 2.75            | 7×10⁵                   | 0.315          | 23.4×10⁻⁶ (1/℃)                         | 80~110℃                                 |

2.3. Assembly of tubular bus
Figure 1 is the schematic diagram of tubular bus in the hanging test. The buses were welded together into a large-span unity. Before welding, the chamfers were processed and the buses were cleaned with specified cleaner. Manual argon arc welding was applied and the buses were placed on a platform to ensure the straightness and welding quality.

The tubular bus has a crevasse with the angle of 60° to 75° and the blunt edge thickness of 2 to 3 mm made by an inner-support crevasse machine. In the processing, the crevasse machine is automatically centered with tripod inner supports to ensure that the section of crevasse is perpendicular to the axis of tube. The bottom of the breaker is equipped with a waste bin to recycle debris.

In order to facilitate the hoisting of the tubular bus and prevent the damage on it caused by lifting the barge length, the welded tubular bus was arranged near the installation area. Two gangplanks of 5000×300×40mm and 5000×300×40mm with upper plastic floors were placed under the assembly position to ensure the flat and tidy environment for installation and welding of the tubular bus. Small pulleys were arranged every 4 meters in the channel steel to fix the tubular bus. Multi-point and multi-surface measurements were conducted with wax line, tape measure and level, and the maximum deflection of tubular bus was controlled to be below 10mm by adjusting bolts of the pulley and moving the pulley.

Usually, the equispaced holes in the ring direction of tubular bus are 90 degrees and set to a straight line. As the diameter of tube increase, the 90-degree holes tend to slant the tube to one side when welding. Therefore, in this project, all holes are 60 degrees to ensure the uniform gap between the main tube and screened tube to further decrease the tortuosity of tubular bus.
2.4. Hanging test

Insulator strings were assembled on the ground first, then the connecting fittings were installed on the insulator strings. After checking, the fittings with insulator strings were installed on the tubular bus as their lifting lugs were in the same location. Next, the insulator strings were lifted to the tower and connected with the V-shaped plate to form a V string. Two cranes were used to lift the tubular bus and another crane was used to lift the V string, lock the fittings and remain the balance between tubular bus and string. Figure 2 and 3 shows the hanging process of 41m and 47m tubular buses.

![Figure 2. Hanging process of 41m tubular bus](image)

The deflection of 41m tubular bus was measured under the mere gravity condition without any balance weights, and the measured maximum deflection was 50mm.

![Figure 3. Hanging process of 47m tubular bus](image)

The deflection of 41m tubular bus was measured under the same loading condition as the 41m tubular bus, and the maximum deflection was 198mm.

3. Finite element analysis

3.1. Simplified finite element model

According to the structural analysis, the section dimension of tubular bus is far smaller that its length and, thus the tubular bus can be simulated with beam element. Because the hanging point has large stiffness and its location is unchangeable as it only function as connections between the tubular bus and the insulator strings, it can be considered as a hinge support first. Simultaneously on the basis of modal analysis, hanging point should possess a certain stiffness in the upright direction as a spring support. There are four symmetrically distributed hanging points in a tubular bus, so the simulation scheme is to vary the stiffness of different hanging points and remain the same stiffness of symmetrical ones, as shown in Figure 4.

![Diagram](image)

(a) Simplifying hanging points 7 and 10 to hinge support
3.2. Finite element results

The simulation results of tubular bus deflection are listed in Table 2. The fourth simplified method that the hanging points are replaced by spring supports is in good agreement with the measurement, and the stiffness can be adjusted according to true conditions.

| Simplified method | Hinge 7-free end and 10-hinge | 7-spring support and 10-hinge | Spring support |
|-------------------|-------------------------------|-------------------------------|----------------|
| Deflection         | 9.975                         | 66.125                        | 50.780         |
|                    | 10                            | 7                             | 7              |

Basis on the simulation, the hanging points are simplified with spring supports to adjust the maximum deflection of tubular bus through changing the stiffness. The schematic diagram of simplification is shown as Figure 5.

After a plenty of calculation, the stiffnesses of spring supports and the corresponding deflections of the 41m and 47m tubular buses are listed in Table 3.

Figure 5. Schematic diagram of simplified hanging point
Table 3. Comparison between the deflections obtained by finite element model and test

| Span | 7-stiffness (kN/m) | 10-stiffness (kN/m) | Deflection (mm) | Error (%) |
|------|-------------------|---------------------|-----------------|-----------|
| 41m  | 5                 | 35                  | 55.826          | 11.65     |
| 47m  | 5                 | 35                  | 175.583         | 11.19     |

4. Conclusion
According to the measurements of suspended tubular bus in hanging test, the maximum deflection can meet the requirements of related codes. In the finite element calculation, the hanging points can be simplified with spring support to shorten the computing time, and the finite element calculation error around 11% is acceptable. And this error can be further reduced through the simplification of connecting fittings in the tubular bus.

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