Finite Element Analysis of Thermal Stress of GIS Shell in Sunlight Environment

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Abstract. In order to study the thermal stress of the GIS shell under normal internal pressure in the sunshine environment, First, the 24-hour temperature field on the surface of the GIS shell of a substation is detected for and the temperature change curve is plotted. Then the ANSYS software is used to carry out finite element stress analysis including temperature field on GIS shell. During the analysis, select the highest temperature and lowest temperature periods, fit the temperature distribution curve of the cross section of the shell varying with the angle under the two conditions, and apply the corresponding temperature load of the two conditions to obtain the stress distribution and stress amplitude distribution. The results show that under normal sunlight environment, the stress of the shell without stress concentration is less than 30Mpa, and the stress variation value caused by diurnal temperature difference in most areas of the shell is within 5Mpa, and it can reach about 10Mpa at the top where the stress concentration occurs. This study analyzes the stress distribution and fluctuation range of the GIS shell under the solar radiation, which provides important data support for the safety evaluation of the GIS shell.

1. Introduction

Gas Insulated Switchgear (hereinafter referred to as GIS) using SF₆ gas as the insulation and arc extinguishing medium has been widely used in domestic power grids. After consulting the data, it is found that the research on the stress and deformation of the GIS bus bar mainly focuses on the stress and strain caused by the internal pressure of the shell and the stress concentration caused by the bellows expansion joint [2].

However, in engineering practice, some GIS shells crack due to fatigue after a period of service. The main factor that causes fatigue failure is the periodic load that the actual equipment receives during service. Especially in places where stress concentration is prone to occur, such as welds, this kind of load with obvious cyclic changes is an important condition that causes fatigue failure. Therefore, this article will conduct field test on the temperature of GIS equipment under environmental load, and use the finite element method to analyze the stress distribution and fluctuation range of GIS shell under sunlight radiation, and provide important data support for the safety
evaluation of GIS shell, has an important engineering value for effectively grasping the operating status of the equipment.

2. GIS equipment sunshine temperature detection
GIS equipment is often placed outside the substation, and the shell will be affected by various natural environments such as solar radiation, temperature difference between day and night, seasonal temperature, and rain and snow [3]. The local deformation of the casing is large due to the different angles of sun exposure. This uneven deformation easily causes bending deformation and even torsional deformation and stress concentration of the GIS casing, which adversely affects the strength of the welding defects existing in the casing and the fatigue failure.

To this end, the project team measured the case temperature on the ZF6-1100 type GIS bus shell of a substation for 24 hours a day and night. Fig. 1 is the location and field test chart of the temperature measurement point of the GIS case. The temperature test uses K-type thermocouple, 16-channel temperature inspection instrument, and the range is 0 ~ 400 °C. Fig. 2 is the temperature curve of the measuring point below the center horizontal plane of the cylindrical shell, and Fig. 3 is the temperature curve within 24 hours of selecting a typical measuring point.

![Fig. 1 GIS case temperature measurement point location and field test chart](image)

The measuring points 1, 6, and 9 are all located below the horizontal centerline of the shell, and there is almost no sunlight. Therefore, the temperature changes are basically consistent with the ambient air temperature. Measurement point 8 and measurement point 2 are close to the upper half of the casing. Because measurement point 8 faces south and is susceptible to the sun, the temperature is relatively high during the corresponding period. Although measurement point 2 is in the upper half, but due to the northward direction, the sun exposure time is limited, but the temperature is slightly higher than the measurement point 1 in the lower part of the casing, as shown in Fig. 3. It can be seen from Fig. 2 and 3 that at noon, the temperature of the area exposed to the sun of the shell is the highest, and the area of the shell that is not illuminated by the sun varies with the ambient temperature. The temperature difference on the day of the test is 10 °C. The maximum temperature difference between day and night at 8 points is above 21 °C, and the temperature difference between day and night at other points is at least 10 °C.
3. Finite element analysis of GIS shell under sunshine temperature field

3.1. Basic parameters of shell material and calculation conditions

A certain type of GIS busbar housing studied in this subject is mainly divided into two parts. The size of the vertical cylinder on the right is Φ1460×25mm, and the size of the horizontal cylinder on the left is Φ1032×16mm. The shell is made of 5083-H112 aluminum alloy. The material's elastic modulus, linear expansion coefficient, and thermal conductivity properties in the finite element analysis are shown in Table 1, where the elastic modulus is taken from the measured value of the tensile test.

![Table 1. Material performance parameters](image)

| Aluminum alloy number | Elastic Modulus $E$ (GPa) | Linear expansion coefficient $\alpha$ $(10^{-6} \text{mm/mm/K})$ | Thermal conductivity $(\text{W/mm/K})$ |
|-----------------------|---------------------------|-------------------------------------------------|---------------------------------|
| 5083—H112            | 66                        | 23.4                                            | 117                             |

3.2. Temperature field conditions

The following two case are selected: the first is the normal internal pressure when the case temperature is highest at 14:00 pm; the other is the normal internal pressure when the case temperature is lowest at 6:30 am Operating conditions.

The schematic diagram of the GIS shell is shown in Fig.1. The coordinate system is a cylindrical coordinate system, with the Y-axis direction as the starting point 0 °, the X-axis direction is 90 °, and the Z-axis direction of the shell is the north-south direction. Axial) The temperature is the same at each point. As shown in Fig.1, the temperature of the two sections with different axial positions was tested on the shell. The test temperatures of the two sections were plotted according to angular coordinates, as shown in Figures 4 and 5. The square black points in the figure are the scenes respectively. During the test period, the temperature of each case is the highest when the temperature is the highest and the lowest when the temperature is the lowest. According to the measured temperature value distribution, the temperature distribution curve for two times was fitted using the least square method. Table 2 shows the temperature distribution fitting equations for the maximum and minimum temperatures during the field test cycle.
3.3. Applied loads and boundary conditions

The shell is affected by the internal pressure of the insulating gas, so a pressure load of 0.52 MPa is applied to the entire inner surface of the model. A uniform load is applied to the section. Similarly, the outer sections of the three pipes on the horizontal shell also exert the equivalent force of the axial force generated by the pressure. The lower section of the left vertical housing is connected to the foundation.
base to limit displacement in three directions. The right horizontal casing takes two nodes at the support position shown in Fig.1 to limit vertical displacement. The boundary conditions and load settings are shown in Fig.8. In the stress finite element analysis, the unit of physical quantity is mm-N-MPa series unit.

3.4. Finite element analysis results
After setting the load and boundary conditions and importing the temperature distribution calculation results, start the calculation of the finite element software. After the calculation is completed, enter the post-processing module to extract the stress simulation calculation results. Under working load 0.52MPa, the stress distribution cloud diagram of the shell structure at the highest temperature (case 1) is shown in Fig.9; under operating load 0.52MPa, the stress distribution cloud diagram of the shell structure at low temperature (case 2) As shown in Fig.10; at a working load of 0.52 MPa, the distribution of thermal stress changes caused by the maximum temperature difference of the shell structure is shown in Fig.11.

It can be seen from the stress analysis cloud diagrams in Figs. 9 and 10 that the stress level of the shell without stress concentration is lower than 30 MPa. This part of the stress is mainly a primary stress caused by the gas internal pressure, which is consistent with the theoretical calculation results. The stress level is much smaller than the yield strength of the material. At the connection between the pipe and the cylinder, the local stress is concentrated due to the discontinuity of the structure. The
maximum stress occurs at the junction of the vertical cylinder and the horizontal cylinder, and the high stress range is very small. It can be seen from Fig.11 that the stress change value caused by the day and night temperature difference in most areas of the shell is basically within 5 MPa, and the top can reach about 10 MPa.

4. Conclusion
In this paper, typical GIS measurement points are selected from the site and the actual temperature at day and night is measured. Then, the temperature field distribution of the GIS shell under actual high and low temperature conditions is simulated by ANSYS, and the internal pressure load is applied to obtain the Stress distribution and stress amplitude distribution. conclusion as below:

1) The temperature of the GIS casing is greatly affected by sunlight radiation. When the sun is strong, the temperature at the top of the casing rises for a short time. In the summer when the temperature difference between day and night is 10 °C, the temperature difference between the day and night at the top can reach 21 °C or more;
2) The temperature and stress of the GIS shell show obvious periodicity, with a period of 24 hours per day;
3) After the internal pressure load and temperature field conditions are applied, the stress in the non-stress concentrated part of the shell is lower than 30Mpa, which is mainly caused by the internal pressure load;
4) The stress change caused by the temperature difference between day and night in most areas of the shell is within 5Mpa, and it can reach 10Mpa on the top where the stress concentration occurs.

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