Tensile Thermal Stress Finite Element Analysis of ITER Axial Composite Insulation Break

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Abstract. Thermal stress analysis was conducted using ANSYS software for ITER composite insulation breaks withstanding cryogenic the tensile load. Low-temperature shock impact, the inner pressure shock impact and tensile stress impact were analyzed. Analysis results show that: As a result of the different thermal expansion coefficient of the interface metal and insulating body, the interfacial thermal stress is the main factor affecting the performance of insulating tightness when the temperature dropped to liquid helium temperature.

Introduction

Low-temperature high-pressure helium tightness composite axial insulation breaks are key components of ITER magnet systems, the axial insulation breaks through the pipe and the corresponding components constitute cryogenic cooling circuit in the device operation, assume the entire magnet system solution helium and liquid nitrogen channel. During the assembly and operation of the apparatus, the large superconducting magnet and the return temperature of the cooling process of the cold shrink, and the electromagnetic interaction during charging and discharging of the insulator member easily tensile stress, causing damage hermetic insulator, which led to the proliferation of the cryogenic liquid into the vacuum system, prone PASCHEN discharge, the entire apparatus will have a devastating damage [1-5].

Using ANSYS software, composite axial insulation breaks in the pressure and the tensile stress under thermal load were analyzed. And low-temperature impact, the impact pressure and tensile stress impact the performance Analysis results show that: the thermal expansion coefficient of the metal-insulator and conductor insulator is different, when the temperature dropped to liquid helium temperature interfacial thermal stress is the main factor affecting the performance of insulators airtight.

ITER Axial Insulator Structure Design

ITER schematic design of ITER axial insulator can be divided into three parts: stainless steel electrodes, insulation inner pipeline and the outer insulation strengthened layer. Both ends of the electrode material is 316L stainless steel seamless pipe, intermediate insulating inner pipeline composite materials, stainless steel threaded pipe with both ends of the adhesive sealing resin adhesive with low connection; the outer insulation strengthened layer is the use of pre-impregnated with epoxy glue and by the low-temperature glass fiber wire wound to the design size[5]. According to 56kV electrical performance requirements, ITER optimized axial sectional insulator specific dimensions shown in Figure 1.
Finite Element Analysis for GFRP Composite Insulation Break Performance

Material Properties and Design Standards

The material properties. ITER insulator is made of stainless steel 316L material and glass fiber reinforced epoxy composite material, its performance parameters as shown in Table 1, the specific design principles and design criteria are as follows:

Table 1. Stainless steel and insulation material performance parameters.

| Performance parameters | FRP   | SS316L |
|------------------------|-------|--------|
| Modulus of elasticity(GPa) | EX    | 23.6   |
|                        | EY    | 35.0   |
|                        | EZ    | 37.0   |
|                        | GXY   | 6      |
| The shear modulus (GPa) | GYZ   | 6      |
|                        | GXZ   | 6      |
|                        | PRXY  | 0.4    |
|                        | PRYZ  | 0.25   |
|                        | PRXZ  | 0.2    |
|                        | THSX  | 0.39   |
|                        | THSY  | 0.33   |
|                        | THSZ  | 0.16   |

Note:
- X is the thickness direction
- Y axis is the insulator
- Z is the winding direction

Design reference standards. For metal materials, the maximum equivalent Mises promise according to the formula Sm = Min (2/3Sy, 1/3Su) determine stress Sm, Sy, and Su, which is the maximum stress and the maximum yield strength. 316L stainless steel is the material corresponds, in the 4.2K temperature Sm is 287MPa, as shown in Table 2. GFRP thickness direction of the strength of an equivalent composite material yield stress. As shown in Table 2.
Table 2. SS316L and GFRP material strength design criteria [5-6].

| Material    | Temperature (K) | 4.2  | 300 |
|-------------|-----------------|------|-----|
| SS316L      | maximum strength (MPa) | 144  | 485 |
|             | Yield stress (MPa)    | 431  | 170 |
|             | Allowable stress (MPa)| 287  | 113 |
| GFRP        | layer thickness direction compressive strength (MPa) | 600  | 237 |
|             | Design strength (MPa) | 400  | 160 |
|             | Allowable shear stress (MPa)| 30   | 25  |

**Thermal Stress Finite Element Analysis for Insulation Break**

![Figure 2. ITER insulator thermal stress analysis of finite element model.](image)

ANSYS structural analysis method using the ITER insulator mechanical performance. Since the insulator and the load is axially symmetric distribution, so the use of two-dimensional 8-node quadrilateral plane axis of symmetry analysis unit PLANE82 respectively insulated stainless steel pipe and tube solid modeling, as shown in Figure 2 for the symmetry axis Y, the finite element model shown [5-6].

**Analysis by pure 2000N tension at 300K.** The initial state of the insulator of 300K temperature, thermal stress is zero at this time, the stress in the tensile force of 2000N analysis, boundary conditions and stretching action under load as follows: One end of the Y-direction constraints applied to the other end in the Y direction 16.5MPa pressure load, according to the cross-sectional area of 1.21E-4m², equivalent 2000N tensile force load, unified field temperature 300K.

![Figure 3. Insulator at room temperature tensile stress distribution.](image)

(a) the metal parts equivalent Mises stress

(b) GFRP composite part shear stress
The results showed that: insulator metal part of the maximum equivalent Mises stress at room temperature tensile force 2000N located outside the arc transition at the stainless steel tube, the maximum stress of 17.4MPa, insulated portion of the maximum shear stress 2.36MPa, shown in Figure 3. According to the mechanical design criteria, at room temperature, pure tension is very safe.

**Pure Thermal Stress Analysis at 300K.** The initial state of the insulator of 300K temperature, thermal stress is zero at this time, the thermal stress analysis considered only from room temperature to liquid helium temperature insulators, boundary conditions and the load as follows: One end of the Y-direction constraints and the other end free, uniform temperature field 4.2K.

![Figures](image.png)

(a) the metal parts equivalent Mises stress  
(b) GFRP composite part shear stress

Figure 4. Room temperature tensile stress distribution insulators.

The results showed that: the insulator metal part located outside the maximum equivalent Mises stress at the transition of the arc tube of stainless steel, the maximum stress of 188MPa, the insulating portion of the maximum shear stress 13.3MPa, the maximum stress is located at the top of the metal electrodes and the insulating material at the interface, shown in Figure 4 shown. According to the mechanical design criteria, at room temperature, pure tension is very safe. However, compared with the case of pure tension stress distribution, thermal stress are the main factors that affect performance, the study design thermal shrinkage of composite insulators is a key design issues.

**Thermal stress analysis at 2000N tension, 4MPa pressure from 300K to 4.2K.** In the role of thermal stress analysis under tensile force 2000N, 4MPa the pressure and temperature of 4.2K, the initial state of the entire insulator for 300K temperature, thermal stress is zero at this time, boundary conditions and loads stretching effect as follows: end Y direction of the constraint, and the other end in the Y direction is applied to the load pressure of 16.5MPa, according to the cross-sectional area 1.21E-4m3, the equivalent load of 2000N tensile force, loading surface within the internal gas pressure 4MPa insulator, uniform temperature field 4.2K.

The results showed that: the insulator metal part located outside the maximum equivalent Mises stress at the transition of the arc tube of stainless steel, the maximum stress of 180MPa, the insulating portion of the maximum shear stress 12.3MPa, the maximum stress is located at the top of the metal electrodes and the insulating material at the interface, shown in Figure 5. According to the mechanical design criteria, at low temperature 4.2K, the pressure 4MPa, and 2000N action under tension insulators are very safe. However, compared with the thermal stress analysis, the position of the maximum stress and the maximum stress is very close to
the thermal stress in the described case is designed to meet, 2000N tensile loads on the mechanical strength of the insulation is small.

![Graphs](a) the metal parts equivalent Mises stress (b) GFRP composite part shear stress

Figure 5. insulators at room temperature tensile stress distribution.

**Conclusions**

Thermal stress using ANSYS software for finite element analysis. Simulation analysis results show that: The maximum thermal stress the metal electrodes and the insulating material located at the top of the interface, thermal stresses caused by thermal shock is a major factor affecting the performance of the hermetic insulator. The maximum stress and maximum thermal stress positions very close, indicating that in the case of thermal stress design meet, 2000N tensile loads on the mechanical strength is small. So design insulator at low temperature 4.2K, the pressure 4MPa, under the action of tension insulators 2000N is very safe.

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