20PB-098

Design of top lid structure in JT-60SA Cryostat
JT-60SAクライオスタットの上蓋構造の設計

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JT-60SA has a cryostat to provide vacuum insulation for cryogenic systems. The cryostat consists of a base, a lateral body and a top lid. This presentation focuses on the structural integrity of the cryostat top lid. The top lid is divided into 2 parts for transportation. The divided parts are assembled and jointed to a cryostat body with flange structure on Naka site. The joint flanges are welded for vacuum sealing. The integrity of the top lid structure was confirmed by FEM analysis in normal operation i.e. vacuum pressure and accidental overpressure of 0.02MPa. In both cases, the highest stress was induced at sealing welds. However, the stress was lower than allowable stress. Furthermore, the integrity of the structure at seismic event was also confirmed.

1. Introduction

JT-60SA is under construction toward the first plasma planned in 2019 [1]. The JT-60SA tokamak machine consists of a vacuum vessel (VV), 18 toroidal field coils, 6 equilibrium field coils, a central solenoid, thermal shields and a cryostat. Figure 1 shows the cryostat and top lid structure. The cryostat provides radiation shielding and vacuum insulation for the superconducting magnets [2]. The cryostat is made of 304 stainless steel with low cobalt content of less than 0.05 wt %. The cryostat consists of a base, a lateral body and a top lid. The cryostat base and the lateral body are designed and manufactured by CIEMAT in Spain [3], and the top lid is designed and manufactured by Japan. All the parts are assembled on Naka site [4].

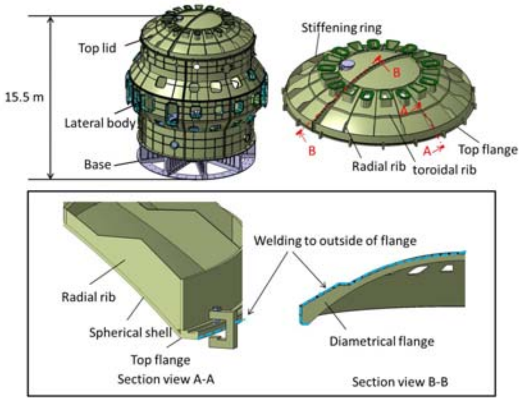

Fig.1. Cryostat and top lid structure

Structural integrity of the top lid in normal operation was evaluated by finite element method (FEM) regulated by ASME code 2010, section Ⅷ in previous study [5,6]. The top lid is closed with welding to outside of flanges for vacuum sealing, because the cryostat is treated as a vacuum vessel. However, stress was not derived on evaluation cross-section in the weld, because the FEM model of flanges and welds were made of shell elements and stiffness springs, respectively. In this presentation, the flanges and the welds are made of solid elements to improve contact analysis on the flanges and classify the stress on the cross-section of depth or throat length in the welds. The top lid is reinforced as needed. Structural integrity of the top lid is confirmed in normal operation, accidental pressure, and seismic event.

2. Top lid of cryostat in JT-60SA

The top lid consists of a spherical shell, radial and toroidal ribs, and stiffening rings. The top lid has 18 vertical ports for diagnostics and/or cooling pipes for in-vessel components. The spherical shell has a curvature of 8.0 m in radius and a thickness of 34 mm. The spherical shell is divided into two parts with the diametrical flanges due to a transport limitation in size on road. The diametrical flanges are fastened by bolts with spacers in an assembly hall in Naka site. The top lid is jointed to the lateral body with the top flange and fixed with 18 clamps. The outside of these connection flanges are welded for vacuum sealing. The diametrical flange has a thickness of 40 mm. The stiffening ring has the thickness of 30 mm and height of 506.6 mm. The stiffening ring is connected to the top flange. The radial ribs are attached to the stiffening rings.

3. Numerical analysis condition

There are 3 load conditions to be analyzed, case 1: normal operation, case 2: accidental overpressure, and case 3: seismic event. External pressure of 0.1 MPa is loaded to the top lid for vacuum insulation in case 1. Gauge overpressure of 0.02 MPa is loaded, caused by helium leak inside the cryostat in case 2. Maximum vertical acceleration of 6 m/s^2 and maximum horizontal acceleration of 4 m/s^2 are loaded in case 3. Dead weight of 51.8 tons and every even port weight of 858 kg is loaded in each of the cases. The symmetrical model of a top lid and a part of lateral body, and the model of only clamps are analyzed. Clamps don't effect reinforcement of the top flange in case 1. Clamps withstand in case2, hence the analysis of case 2 focuses on the integrity of the weld. Both of the FEM models are analyzed in case 3. Structural members of the top lid including botls and clamps except the weld are evaluated in Sm of 137 MPa and 1.5 Sm of 205 MPa. The allowable stress of the weld is applied to 1.5 Sm of 205 MPa.

4. Structural integrity of the top lid

4.1 Normal operation

The top lid is deformed with radial expansion and vertical displacement. Local bending around toroidal axis is induced in the top flanges. The inner side of the diametrical flanges is opened around both ends, which is caused by downward deformation of the spherical shell.

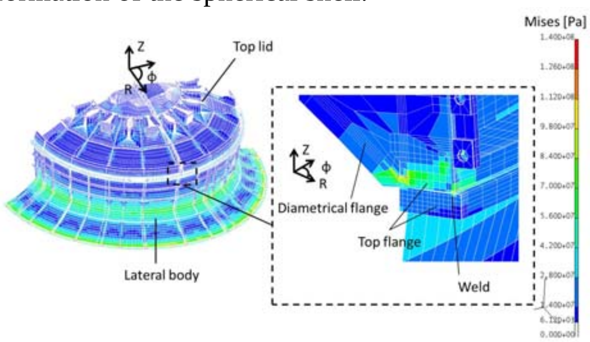

Fig.2. Contour of Mises stress in normal operation

Figure 2 shows contour of Mises stress in normal operation. The highest stress, however, is induced in fillet weld at the intersection of the diametrical flange and the top flange. The highest stress is classified into σ_m of 72.4 MPa and σ_b of 23.5 MPa on cross-section of throat length at the weld. The combined stress is lower than the 1.5 Sm stress. All other parts of the top lid structure are in lower stress than allowable stress. The stiffening ring also suppresses the opening of the diametrical flanges and reduces stress in the weld at the top flange. Connection of the spherical shell at the bottom of the top flange suppresses the radial expansion. The top lid has sufficient structural integrity.

4.2 Accidental overpressure

The top lid is deformed upward by inner overpressure. The spacers, the stiffening ring, and the ribs suppress the opening of the flanges. Figure 3 shows contour of Mises stress in accidental overpressure. Maximum stress is induced in weld at the diametrical flange. Combined stress ($\sigma_m + \sigma_b$) of 137.8 MPa on cross-section of depth length in the weld is also lower than the 1.5 Sm. The main structure of the top lid also withstands the overpressure.

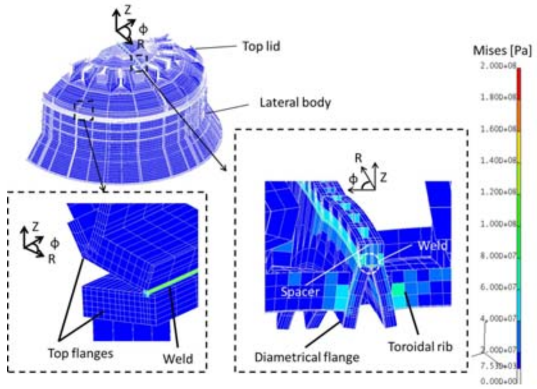

Fig.3. Contour of Mises stress in accidental overpressure

4.3 Seismic load

Induced stress in clamps is lower than allowable stress. The stress in weld is very low: ~6 MPa in Mises stress. The structure of the top lid has sufficient strength.

5. Summary

Structural integrity is analyzed by FEM regulated by ASME code 2010, section Ⅷ. The top lid is closed with welding to outside flanges for vacuum sealing, because the cryostat is dealt with a vacuum vessel. Structural members except welds are evaluated in Sm and 1.5 Sm. The weld is evaluated in 1.5 Sm. The top lid with vacuum sealing has sufficient structural integrity in normal operation, accidental overpressure, and seismic event.

References

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