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Gravity Support Design and Manufacturing of the JT-60SA Vacuum Vessel
JT-60SA真空容器用重力支持脚の設計と製造

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In the operation of Tokamak device, such loads as electromagnetic and seismic are assumed to be imposed on the vacuum vessel (VV), and not a little thermal expansion takes place when VV is baked. The gravity support (GS) has to support the loads described above in addition to the dead weight of VV including in-vessel components and compensate deformation. The GS is equipped with flexible plate that has both stiffness and flexibility. In this study, the FEM analysis-based design and assembly procedure of the GS is reported. The manufacturing process of GS components is also reported with trial manufacturing results.

1. Introduction

The Japan Atomic Energy Agency is building the JT-60SA Tokamak device in cooperation with EU. In this project, Toshiba has received an order to manufacture torus type VV sectors, GS and their assembly to confine plasma. The VV sector manufacturing started in March, 2008 and finished in April, 2014 [1-3] and their assembly by weld-connection is now under way [3].

2. Components of GS and Assembly Procedure

2-1. Components of GS

As is shown in Fig. 1(a), a GS is divided into upper and lower part (UP and LP). The upper part consists of cylindrical column (CC), trapezoidal hollow stem (TS) and upper mid flange (UMF). The lower part is composed of lower mid flange (LMF), flexible plate (FP) and bottom flange (BF). The material is SUS316 except CC that is made of SUS304N2. A FP has nine leaves whose thickness, width and height are 15mm, 600mm and 500mm, respectively.

2-2. Assembly Procedure

The CC has external thread of M210 on it. After 340-degree VV sector weld-connection, internal thread cutting is applied to the GS stubs of VV and the UP is assembled through thread connection. As are shown in Fig. 1(b) and (c), BF is connected with the gravity support base (GSB) through eighteen bolts of M36. An insulated plate (IP) and an extension plate (EP) are also placed between them for VV insulation and height adjustment. Two column shape keys (CK) and toroidal, poloidal keys (TK, PK) are inserted. Finally, the UP and the LP is connected by site welding of both mid flanges.

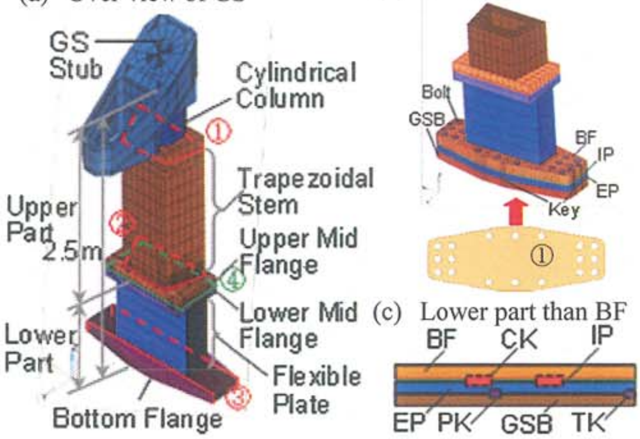


Fig. 1 Structure and components of GS

3. FEM analyses – Lower Part –

The primary design of GS components was followed by confirmation and optimization by FEM analyses. The analysis model is shown in Fig. 2(a) and (b). The nine GSs are installed in the bottom of VV toroidally in every 40 degrees. The horizontal electromagnetic load (EML) and seismic load (SL) are assumed to be directed perpendicular to the line that connects torus center and GS No.7. The load and temperature conditions and their combination for FEM analyses are shown in Table 1 and 2.

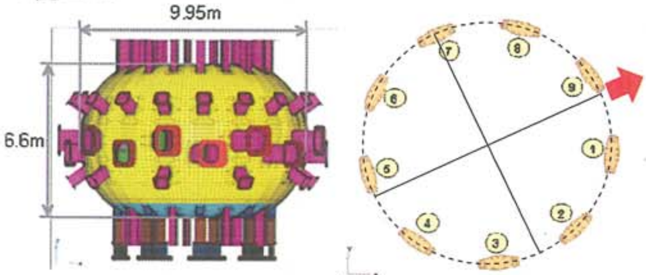
3-1. Flexible plate

Large stress is produced in GS that is at nearly perpendicular position to the direction of horizontal load. The largest primary stress (Pm+Pb) was detected in the outermost plate in GS No.8 as

124MPa that is within the allowable of the 1.5Sm (207MPa) in case6. For primary plus secondary stress (Pm+Pb+Q), the largest value was observed in the outermost plate in GS No.7 as 314MPa in case2 that is within the allowable of the 3Sm (414MPa). Both results meet with the design criteria of ASME Sec. III.

3-2. Connection bolts with cryostat base

The load imbalance among eighteen bolts was observed. The stress produced in the bolt near the plate is larger than those in other positions. Assuming that initial screw strength is 129MPa, in case 3 and 5, the largest stress was observed in No.1 bolt of GS7 as 457MPa, 504MPa, respectively. The latter value exceed the design criteria of 2/3Sy in ASME Sec.ⅢNB where Sy is defined based on the measured value of 722MPa (not the nominal value of SUH660). However, as case 3 is categorized in service condition III where repair is approved if any damage, this claim could be applied.



(a) VV and GSs (b) GS arrangement

Fig. 2 FEM model and GS arrangement

Table 1 Load and temperature conditions

Mass including in-vessel components (ton)		400
Load (MN)	Electro magnetic force	7.5 (ver.), 2.5 (hori.)
	Seismic force	0.51 (ver.), 2.4 (hori.)
Temperature (℃)	Baking	−10 (at BF), 50 (at VV)
	Normal operation	−10 (at BF), 200 (at VV)

Table 2 Load combinations of FEM analyses

Case	Gravity force	Heat load (N.O.)	Heat load (Baking)	EML	SL
1	○	○			
2	○		○		
3	○	○		○	
4	○	○			○
5	○		○		○
6	○			○	

4. Product manufacturing

4-1. Manufacturing process

The welds between CC and TS (weld line ① in Fig. 1), TS and UMF (weld line ② in Fig. 1) have a single U and J groove, respectively, and both welds are carried out by narrow gap TIG welding.

The FP is manufactured by electric discharge machining (EDM) to avoid distortion by welding. Manufacturing of components is shown in Fig. 3.

(a) CC and TS weld-connection (b) Flexible plate

Fig. 3 Manufacturing of GS components

The LMF and BF of LP are manufactured by connecting rectangular block with both side flanges (weld line ③ in Fig. 1) by electron beam welding.

4-2. Welded joint test and EDM specimen

a) Tensile and bend test

As is shown in Table 3, obtained tensile strengths are larger than the nominal value of 520MPa for three welded joints. No deterioration was observed by EDM in comparison with the mother material's tensile strength of 555MPa. All test specimens passed bend tests.

Table 3 Tensile and bend test results

Test specimen	Tensile strength (MN)	Bend test result
1) CC and TS welded joint	546	No crack or crevice 1)
2) TS and UMF welded joint	551	
3) Flange and rectangular block welded joint	539	
4) Electric discharge machining	559	No crack or crevice 2)

Note: 1) Root and side bend test, 2) Face and root bend test

b) Surface characterization of EDM specimen

The macrostructure observation showed that the carburized layer ranges from the surface to the depth of 10 micrometer. However, that has no effect on the strength of the material. Surface roughness measurement showed that Ra=6.5 for straight part of the plate and 1.6 for the joint area between plate and flange were obtained.

5. Summary

The structural integrity of GS is confirmed through FEM analyses. The manufacturing process was also established through mechanical test of each specimen.

References

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