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Buckling Analysis of Gravity Support Legs for JT-60SA Vacuum Vessel
JT-60SA真空容器の重力支持脚座屈解析

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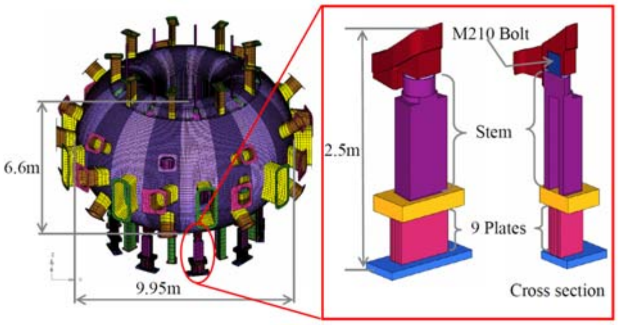
In the operation of tokamak, such loads as electromagnetic and seismic are assumed to be imposed on the vacuum vessel (VV), and not a little thermal expansion takes place when VV is baked. The gravity support leg (GS) has to support the loads described above in addition to the dead weight of VV including in-vessel components and compensate deformation. The GS is equipped with plate spring (PS) to have both stiffness and flexibility. In this study, the buckling strength of the PSs was evaluated. The effect of the initial imperfection of the PSs which is assumed to result from machining or welding process on the buckling strength was also studied. It is concluded that GS has sufficient buckling strength against assumed initial imperfections.

1. Introduction

JT-60SA is a combined Japan-EU satellite tokamak program. The manufacturing of VV and the design of GS are making progress[1]. The height and outer diameter of the VV are 6.6m and 9.95m respectively. 9 GSs are installed in the bottom of VV toroidally in every 40 degrees. The buckling analysis of GSs was carried out by using finite element method.

2. Structure of GS and its FEM model

As is shown in Fig.1, a GS is divided into M210 bolt, stem, flanges and PSs and its height is about 2.5m. A plate spring consists of 9 plates whose thickness, width and height are 15mm, 600mm and 500mm respectively. The PSs are picked up as the analysis object out of the constituent components of GS because of its weakest stiffness against buckling. The mass of in-vessel components(270tons) is distributed homogeneously into the wall of VV.



(a) VV and GSs　　(b) GS
Fig.1 Structure of GS and its FEM model

3. Analysis method and conditions

3.1 Method

We have adopted ABAQUS code(ver.6.6.3) for this analysis. The load at the proportionality collapse point between applied load and resultant displacement is defined as buckling load. Buckling load is obtained by solving the eigenvalue buckling equation (see eq.(1)). Each mode of deformation corresponds to the eigenvalue of eq.(1). Obtained buckling load divided by actual load is defined as load factor which is safety index against buckling.

According to the design criteria of buckling strength for the design conditions in the structural design code of ASME[2], the load factor is prescribed to be larger than 3.

$$[K^{NM}_{(b)} + \lambda_i K^{NM}_{(Q)}]\phi^M_i = 0 \quad \cdot\cdot(1)$$

Where,

$K^{NM}_{(b)}$: the base state stiffness

$K^{NM}_{(Q)}$: the differential stiffness

λ_i : eigenvalue (refers to the *i*th mode)

ϕ^M_i : eigenvector (refers to the *i*th mode)

3.2 Conditions

The initial and boundary conditions are as follows.

(1) Load condition

Horizontal direction: 3.3MN (seismic),

Vertical direction: 14.2MN (seismic + electro -magnetic:10MN, dead weight:4.2MN)

As is shown in Fig.2, horizontal load is imposed in the x direction. All GSs are arranged as the normal line of each PS passes through the torus center.

(2) Temperature condition (when baking)

VV: 200deg., GS: 20deg.

(3) Boundary condition

The lower flange of the PS is fixed perfectly.

(4) Initial imperfection condition of PSs

Four types of initial imperfection pattern were selected and analyzed as shown in Table 1. Except for baking (ID.1), all initial imperfections of PSs are imposed on GS03.

The shapes of initial imperfections are shown in Fig.3. The bow-shaped deformation is imposed according to the results obtained by the analysis for the case without initial imperfection for ID.2～4.

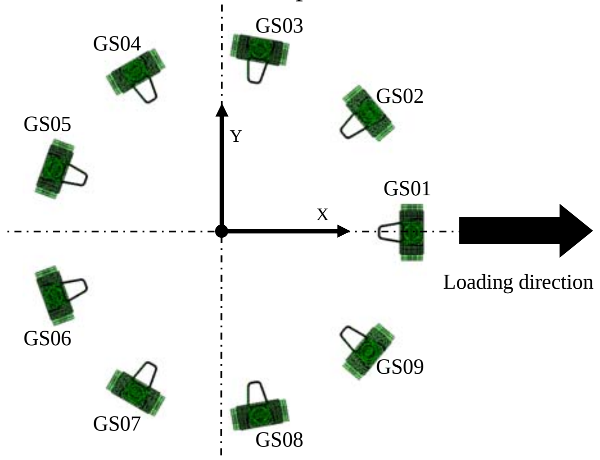
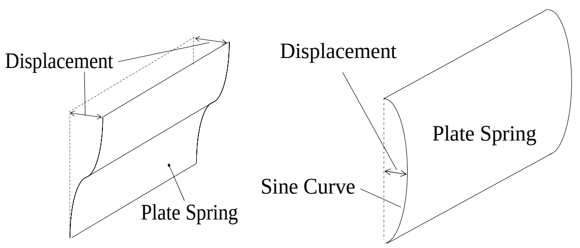


Fig.2 GS arrangement and loading direction

Table.1 Analysis cases (imperfection patterns of PSs)

ID	GS Location	Number of PSs	Displacement	Direction
Ref	Without imperfection			
1	GS01～GS09	81 (9×9)	About 10mm	outwardly
2	GS03	1 (outermost)	10mm	outwardly
3	GS03	9	2mm and 20mm	outwardly
4	GS03	9	1GS is assumed not to work. (The GS03 is deleted from the FEM model.)	



(a) Baking(ID.1)　　(b) Except for baking(ID.2～4)

Fig.3 Shape of initial imperfection

4. Results

4.1 Without initial imperfection

The minimum load factor was 8.31 and was observed in GS03 or GS08.

All buckling modes are surveyed in which load factor is less than 20. Buckling took place at the PSs in all modes.

4.2 With initial imperfection

Obtained load factors and according decrease rate compared with the load factor (8.31) in the case without initial imperfection are presented in Table 2.

－Buckling was not observed in the GS03 but in the GS08. Imposed load may be redistributed among 8 GSs besides GS03. The GS positioned symmetrically to the x-axis is buckled because it is susceptible to be buckled owing to its angle to the loading direction.

－Obtained decrease rates are small, and even if one of the GSs is assumed not to work, buckling strength is within the design criteria (see Fig.4).

Table 2 Analysis results

ID	Load Factor	Buckling Location	decrease rate
Ref	8.31	GS03 PS or GS08 PS	-
1	8.06		3%
2	8.31	GS08 PS	no decrease
3	8.30～7.94		0% ～4%
4	6.80		18%

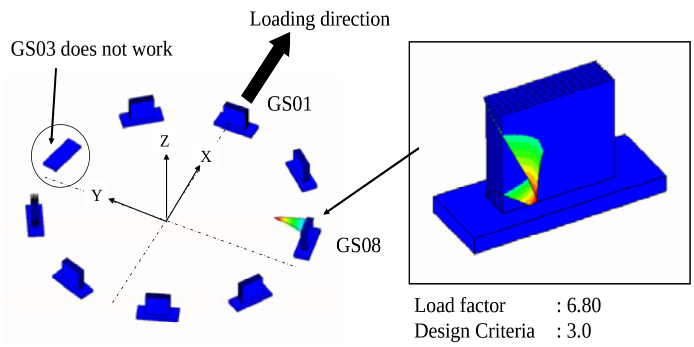


Fig 4 Buckling mode for ID.4 (1GS is assumed not to work)

5. Conclusion

As the results of FEM analysis, it is concluded that GS has sufficient strength against buckling as follows.

Several types of initial imperfections are assumed to take place in the PSs. Calculated load factors decrease only several percents compared with that of without initial imperfection case. Even if one of the GSs does not work, the decrease rate is 18%.

In the analyzed cases, obtained all load factors are larger than 3 and are within the design criteria prescribed in the structural design code of ASME[2].

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[2] ASME SEC.III-NH, Appendices-T(2007).