Buckling Analysis of Gravity Support Legs for JT-60SA Vacuum Vessel

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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.

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.

\[ K_{(b)}^{NM} + \lambda_i K_{(Q)}^{NM} \phi_i^M = 0 \quad \cdots (1) \]

Where,

- \( K_{(b)}^{NM} \): the base state stiffness
- \( K_{(Q)}^{NM} \): the differential stiffness
- \( \lambda_i \): eigenvalue (refers to the \( i \)th mode)
- \( \phi_i^M \): 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 + electromagnetic: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)

(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.

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).

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].

References