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Calculation of Rayleigh Damping Parameters for Seismic Analysis of the HCCR TBM-set

Dong-Jun Kim [a,b], Seong Dae Park [b], Suk-Kwon Kim [b], Dong Won Lee [b*], Seungyon Cho [c]
[a]*Korea Univ., Mechanical Engineering Dept., Seoul, Republic of Korea*
[b]*Korea Atomic Energy Research Institute, Daejeon, Republic of Korea*
[c]*National Fusion Research Institute, Daejeon, Republic of Korea*
[*]*Corresponding author: dwlee@kaeri.re.kr*

1. Introduction

Helium Cooled Ceramic Reflector (HCCR) Test Blanket Module-set (TBM-set), which is the component installed in ITER facilities, has been designed in Korea [1]. During the design process, structural assessment of seismic loads is essential [2]. Response spectrum analysis is performed by seismic load evaluation for HCCR TBM-set. Response spectrum analysis is widely used to evaluate the dynamic response of structures under earthquake motions. From this analysis, the dynamic performances of a structure subjected to earthquake motion such as the maximum responses of displacement and stress can be estimated. The response spectrum analysis method is to combine several components of structural dynamics and design, such as modal analysis method, damping effect, earthquake ground motion, and so on. This paper focuses on the damping effect of HCCR TBM-set.

To consider the damping effect of HCCR TBM-set, the Rayleigh damping parameters of it is determined in this paper. First, Rayleigh damping is briefly introduced and the model used in finite element analysis for the modal analysis is described. The Rayleigh damping parameters of HCCR TBM-set is calculated by the modal analysis results.

2. Rayleigh Damping

Rayleigh damping provides a source of energy dissipation in analyses of structures subjected to dynamic loads [3-5]. When Rayleigh damping is considered, a viscous damping matrix $[C]$ is expressed by a linear combination of the mass and stiffness matrices.

$$[C] = \alpha[M] + \beta[K] \tag{1}$$

where $[M]$ is the mass matrix and $[K]$ is the stiffness matrix. α and β are Rayleigh damping parameters with units of s^{-1} and s, respectively to be estimated from the two given damping ratios that correspond to two unequal frequencies of vibration. Rayleigh damping parameters have the following relation.

$$\xi = \frac{\alpha}{2\omega} + \frac{\beta\omega}{2} \tag{2}$$

where ξ is damping ratio and ω is natural frequency. For a given damping ratio, the Rayleigh damping parameters can be calculated as follows,

$$\alpha = \frac{2\omega_i\omega_j\left(\omega_i\xi - \omega_j\xi\right)}{\omega_i^2 - \omega_j^2} \tag{3}$$

$$\beta = \frac{2\left(\omega_i\xi - \omega_j\xi\right)}{\omega_i^2 - \omega_j^2} \tag{4}$$

where ω_i and ω_j denote the minimum and maximum natural frequencies in which the Rayleigh damping curve equals the critical damping ratio. In this paper, the critical damping ratio (ξ) is assumed to be 4% [6].

3. Finite Element Models

In this paper, the geometry of HCCR TBM-set at the conceptual design phase is used. Fig. 1 shows the mesh model with the boundary condition used in modal analysis. The number of elements and nodes are A and B, respectively. As a boundary condition, the TBM-shield flange area bonded with the frame is given a fixed condition for all direction.

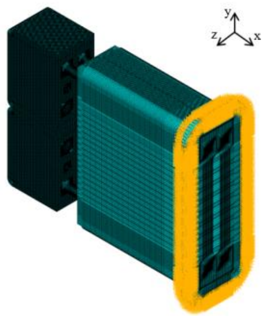

Fig. 1. The mesh model with the boundary condition used in modal analysis.

4. Estimating the Rayleigh damping parameters

4.1 Modal analysis

Before Rayleigh damping parameters are determined, modal analysis of HCCR TBM-set is performed using the commercial computer code ANSYS [7] to find the natural frequencies. In the modal analysis, the Preconditioned Conjugate Gradient (PCG) Lanczos method is applied for calculating the natural frequencies. The PCG solver is usually faster than other solver for structural solid elements [7].

Fig. 2 shows the effective mass ratio curve as per frequency for the x, y and z directions obtained from the modal analysis. And Fig. 3 shows the cumulative mass fraction for the x, y and z directions obtained from the modal analysis. In modal analysis, it is generally necessary to verify that the cumulative mass fraction is greater than 90%. The calculated number of natural frequency is 50 and the cumulative mass fraction in this natural frequency range is more than 90%. Rayleigh damping parameters are determined from these results.

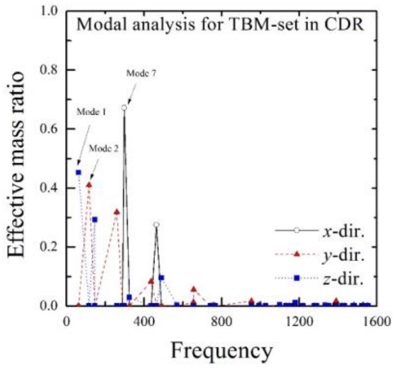

Fig. 2. The mesh model with the boundary condition used in modal analysis.

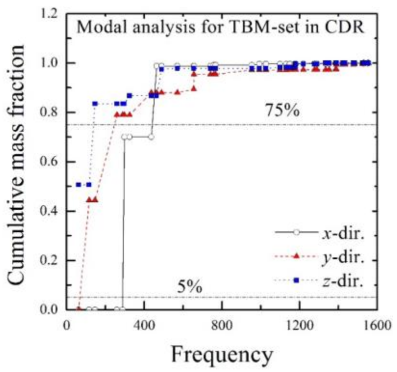

Fig. 3. The mesh model with the boundary condition used in modal analysis.

4.2 Rayleigh Damping of HCCR TBM-set

The minimum and maximum natural frequencies should be determined to estimate the Rayleigh damping parameters from the eqn. (3) and (4). The minimum natural frequency where the Rayleigh damping curve equals the modal damping is defined. It is recommended that the cumulative mass fraction should reach at least 5% of the total mass at the minimum [3]. The maximum natural frequency is defined by the iteration. It is also recommended where the cumulative mass fraction in the three directions are approximately 75% or higher [4].

The critical damping ratio should be defined to estimate the Rayleigh damping parameters. In this paper, the critical damping ratio is assumed to be 4% [6].

Rayleigh damping parameters α and β are evaluated by Eqn. (3) and (4) using the previously determined minimum and maximum natural frequencies and the critical damping ratio. The values of Rayleigh damping parameters α and β are 27.27 and 2.43×10^{-5}, respectively. The resultant Rayleigh damping curve estimated by Eqn. (2) is depicted in Fig. 4.

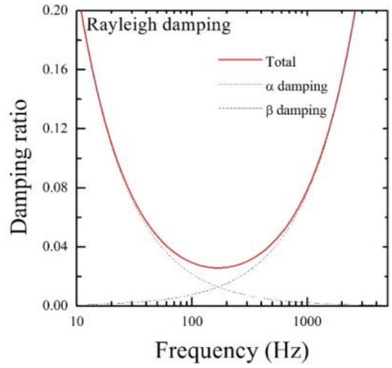

Fig. 4. The mesh model with the boundary condition used in modal analysis.

5. Conclusions

In this paper, the Rayleigh damping coefficients of HCCR TBM-set at CD phase was calculated by modal analysis and the process was examined. To consider damping effect of HCCR TBM-set at Preliminary design phase, the damping coefficient of the PD model can be defined through this calculation process and applied to the structural evaluation of seismic load.

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