Modal analysis of CSB and RV assembly in case of CSB slanted contact with RV outlet nozzle

Pham Quang Hieu and Ihn Namgung *
KEPCO International Nuclear Graduate School
658-91, Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan, South Korea
Corresponding author: inamgung@kings.ac.kr

***Keywords :** Core Support Barrel (CSB), Reactor Vessel (RV), bypass flow, slanted contact, modal analysis.

1. Introduction

In the field of nuclear engineering, ensuring the integrity and performance of components under various operational conditions is paramount [1]. Modal analysis is an effective method for examining the vibrational properties of these intricate systems and components under varied operating conditions [2]. A key challenge in current reactor design is a gap between the outlet opening of the CSB and the outlet nozzle of the RV. This gap creates what is known as bypass flow, a phenomenon leads to reduced heat transfer to the coolant, ultimately diminishing the reactor's overall heat exchange efficiency [3, 4]. In response to this issue, this research undertakes a comprehensive modal analysis of a slanted contact interface between the CSB outlet opening and the RV outlet nozzle. The primary objective of the redesign effort is to reduce bypass flow and strength the horizontal seismic restraint for the reactor internals. Hence, they aim to enhance the performance and improve the safety of reactor under seismic stress.

2. Methods and Results

The methodology adopted in this study follows a systematic approach, as shown in Fig. 1.

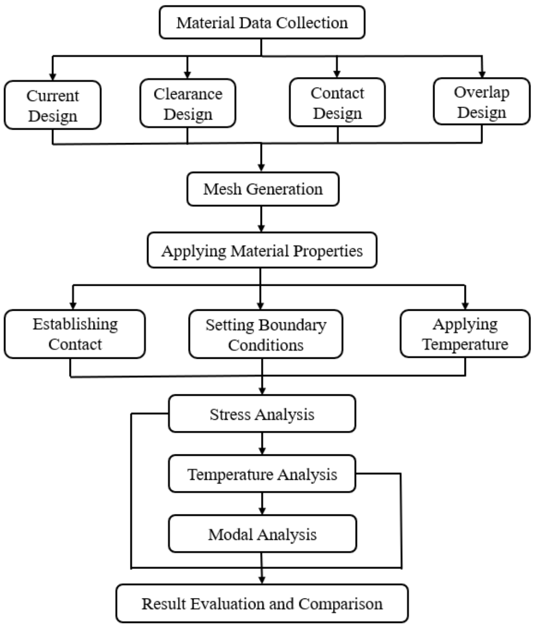

Fig. 1. Process flow of modeling

2.1 Geometric model

In the initial step, the model construction, refinement, and adjustments were carried out using CATIA software. Subsequently, the finalized model was saved in CATIA Product format and imported into the SpaceClaim environment within the Ansys software. The design of slanted contact between RV outlet nozzle and CSB outlet opening is shown in fig. 2.

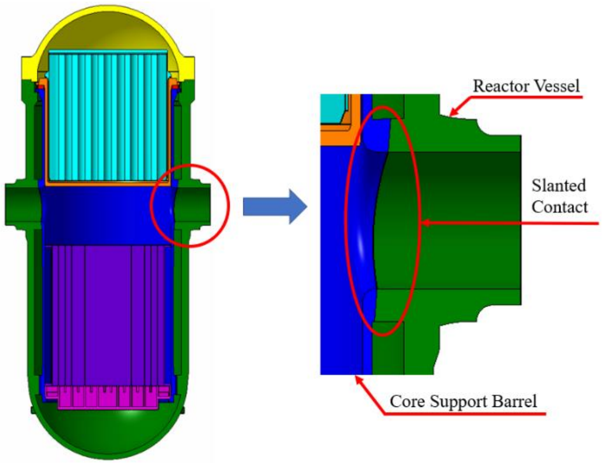

Fig. 2. Slanted contact between RV outlet nozzle and CSB outlet opening

2.2 Material declaration and assignment

Mechanical and thermal properties were characterized for each material in accordance with ASTM standards. SA-508 Grade 3 Class 1 was assign for the RV. CSB was applied by SA-182 Ty.F304L [5 ,6]. These material properties, including moduli of elasticity, poison's ratio, density, design stress intensity, thermal expansion coefficient, thermal conductivity and thermal diffusivity.

2.3 Mesh generation

The process involved creating a finite element mesh for the geometric model within Ansys Mechanical. A quadratic element order was chosen for enhanced accuracy, and a sizing resolution of 6 determined the density of elements [7]. Mesh quality was thoroughly assessed, and refinement techniques were applied iteratively.

2.4 Setting contact tool

Two primary contact types are utilized: bonded contact and frictionless contact. Bonded contact signifies fully connected interfaces, while frictionless contact represents contact interactions without frictional resistance, enabling relative motion between surfaces [8].

2.5 Boundary condition setup

Boundary conditions were set to mimic realistic loading and support scenarios within the reactor core assembly. Fixed supports were placed on the four bottom faces of the RV's support structure, securing it to its base and limiting excessive displacement. Both the RV and reactor internals experienced a uniform pressure of 17.23 MPa on their inner surfaces, simulating internal coolant pressure during operation [9]. Frictionless supports were implemented at other supported locations, permitting relative motion without frictional resistance.

2.6. Temperature boundary assignment

During this step, temperatures were allocated to different components in the reactor core assembly to replicate thermal effects. The inner surfaces of the RV, outer surfaces of the CSB were assigned a cold leg temperature of 279.4°C [10]. Conversely, a hot leg temperature of 321°C was applied to the inner surfaces of the RV Outlet Nozzle, inner surfaces of the CSB.

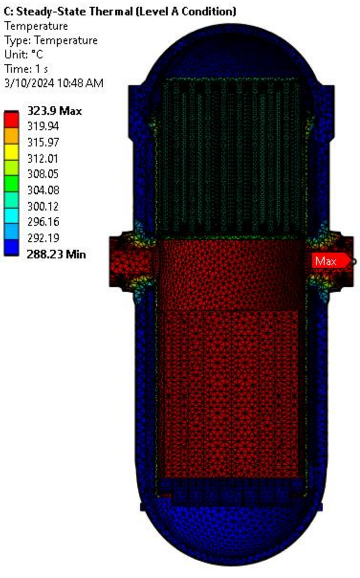

Fig. 3. Temperature analysis result of contact desgin

In the current design, a gap between the CSB and RV caused localized hot spots and uneven temperature distribution. Conversely, the proposed configuration with a slanted contact interface promotes efficient heat transfer, leading to uniform temperature distribution and reduced thermal stress on reactor components.

2.7 Total Deformation of CSB

The maximum total deformation obtained for the current CSB design was 36.631 mm, whereas for the contact CSB design, it measured 36.492 mm. Although the difference is small, it represents an improvement in seismic restraint for reactor internals.

Table 1. Results of Maxium Total Deformation of CSB

	Current Design	Clearance Design	Contact Design	Overlap Design
M.T.Def. (mm)	36.631	36.551	36.492	36.886

2.8 Equivalent Elastic Strain and Equivalent Stress of CSB

The analysis yielded a maximum equivalent stress of 87.6 MPa of CSB for the current design, whereas for the contact design, it reached 100.3 MPa. This increment in equivalent stress was attributed to the redistribution of loads resulting from the design modification. However, it falls within the acceptable limits prescribed by structural safety standards, affirming the structural adequacy of the proposed CSB design. Fig. 4 illustrates the equivalent stress distribution of CSB in the contact design.

Table 2. Results of Maxium Equivalent Strain and Maximum Stress of CSB

	Current Design	Clearance Design	Contact Design	Overlap Design
Max.E.E. Strain (mm/mm)	4.42e-4	3.78e-4	5.06e-4	5.25e-4
Max.E. Stress (MPa)	87.59	75.14	100.26	103.99

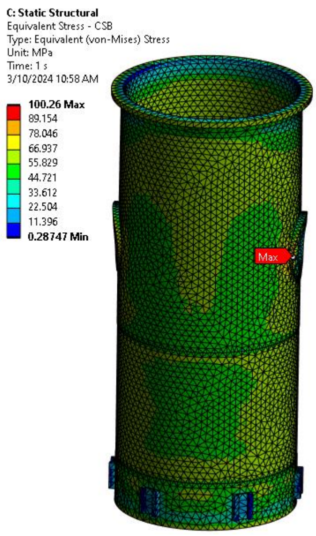

Fig. 4. Equivalent stress of proposed CSB design

2.9. Modal analysis

The modal analysis determines the vibration characteristics, including natural frequencies and corresponding mode shapes, of a structure. Based on the results shown in table 3, contact design and overlap design have better seismic resistance than the current design.

Table 3. Results of Frequency (Hz)

Mode	Current Design	Clearance Design	Contact Design	Overlap Design
1	6.703	6.701	6.702	6.702
2	10.576	10.570	10.572	10.571
3	30.659	20.753	27.469	30.669
4	31.160	30.656	30.670	34.399
5	37.084	35.542	39.581	39.832
6	40.200	35.624	40.030	42.380
7	40.619	37.979	41.592	44.666
8	43.965	40.187	44.532	45.332
9	44.807	44.424	44.795	45.813
10	49.211	46.140	53.951	55.247

Findings show reduced bypass flow and improved seismic restraint. FEA using Ansys software confirms the redesigned configuration's ability to withstand operational loads and seismic events, ensuring structural integrity and safety.

3. Conclusions

This study thoroughly investigates modal analysis of CSB and RV in case of CSB slanted contact with RV outlet nozzle. A gap between the CSB outlet opening and reactor vessel outlet nozzle causes bypass flow, reducing reactor core thermal efficiency. To address this, a design modification facilitating slanted contact is proposed. This design change was reduced the bypass flow and improved in seismic restraint. This research offers valuable insights for optimizing reactor vessel and CSB design, promising enhanced thermal efficiency and safety in nuclear reactor systems.

REFERENCES

[1] Porton M, Wynne BP, Bamber R, Hardie CD, Kalsey M. “Structural integrity for DEMO: an opportunity to close the gap from materials science to engineering needs”. *Fusion Engineering and Design*, 109:1247-55, Nov 2016

[2] Ubertini, Filippo, Carmelo Gentile, and Annibale Luigi Materazzi. "Automated modal identification in operational conditions and its application to bridges." *Engineering Structures*, 264-278, 2013

[3] Lu Q, Liu Y, Deng J, Luo X, Deng Z, Mi Z. "Review of interdisciplinary heat transfer enhancement technology for nuclear reactor," *Annals of Nuclear Energy*, 1;159:108302, Sep 2021

[4] Abinash Sahoo, Ramesh Chandra Nayak, Ajit K. Senapati, Manmatha K. Roul, 2022 "Validation of experimental results with theoretical by using ANSYS workbench on vertical tube subjected to natural convection heat transfer without internal obstacles," *Materials Today: Proceedings*, Vol. 52, pp. 1348~1353.

[5] Josina W. Geringer, Y. Katoh, S. Gonczy, T. Burchell, M. Mitchell, M. Jenkins, 2023 "Codes and standards for ceramic composite core materials for High Temperature Reactor applications," *Nuclear Engineering and Design*, Vol. 405, pp. 112~123.

[6] Namgun Ihn, 2024 "An investigation of structural strength of PWR ful assembly spacer grid with fuel rod clad," *Annals of Nclear Energy*, Vol. 195.

[7] Yonghua You, Sheng Wang, Wei Lv, Yuanyuan Chen, Ulrich Gross, 2021 "A CFD model of frost formation based on dynamic meshes technique via secondary development of ANSYS fluent," *International Journal of Heat and Fluid Flow*, Vol. 89, pp. 108~116.

[8] M. Karthick, Ch. Siva Ramakrishna, R. Pugazhenthi, Nitin Gudadhe, S. Baskar, Renu, Rajan Kumar "Contact stress analysis of xylon coated spur gear using ANSYS workbench," *Materials Today: Proceedings*, Vol. 156, pp. 57~66.

[9] Abinash Sahoo, Ramesh Chandra Nayak, Ajit K. Senapati, Manmatha K. Roul, 2022 "Validation of experimental results with theoretical by using ANSYS workbench on vertical tube subjected to natural convection heat transfer without internal obstacles," *Materials Today: Proceedings*, Vol. 52, pp. 1348~1353.

[10] T. Sathiyasheela, Rita John, A. Riyas, K. Devan, 2023 "A revised analysis towards accurate estimation of isothermal temperature coeffcients in fast reactors having different power levels and core sizes," *Nuclear Engineering and Design*, Vol. 415, pp. 702~728.