An Evaluation of Normal Contact Analysis of CSB and RV Outlet Nozzle

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1. Introduction

Among the various reactor designs, the APR1400 stands out as a notable example of pressurized water reactors known for their reliability and safety features [1]. The core support barrel (CSB) is one of the Reactor Internals of Reactor Vessel (RV) [2]. There is an opening between the outlet of the CSB and the inside surface of hot-leg pipe of the RV, this gap serves in facilitating the insertion and removal of reactor internals during installation, periodic inspections and maintenance operations [3]. Unfortunately, the presence of this gap results in the significant bypass flow that presents degradation of thermal efficiency of the reactor during normal operational phases. The diversion of coolant through this gap creates a scenario wherein the thermal efficiency of the reactor is adversely impacted, potentially leading to inefficiencies in the overall heat transfer process [5-6].

2. Development of Insertion Tool

In this section some of the techniques used to model the CSB insertion tool are described.

A tool for insertion was developed to facilitate the precise and regulated installation of CSB in the nuclear reactor of APR1400. The objective of developing this insertion tool was to enhance the CSB installation and placement, guaranteeing correct alignment, an accurate fit, and compliance with safety regulations throughout the procedure. The insertion tool primary features and capabilities are as follows: Function of alignment assistance, the tool offers methods for precisely aligning the CSB with the RV and other vital parts to guarantee ideal alignment of the fuel assembly. Decreasing the space between the RV and the CSB during installation is another possible goal of the tool. Minimizing this gap can improve thermal efficiency, decrease bypass flow, and increase effective coolant flow to the core. In order to provide a smooth integration into the reactor environment, the tool is made to work with the current systems and structures of the reactor. Fig. 1 shows an illustration of the CSB insertion tool.

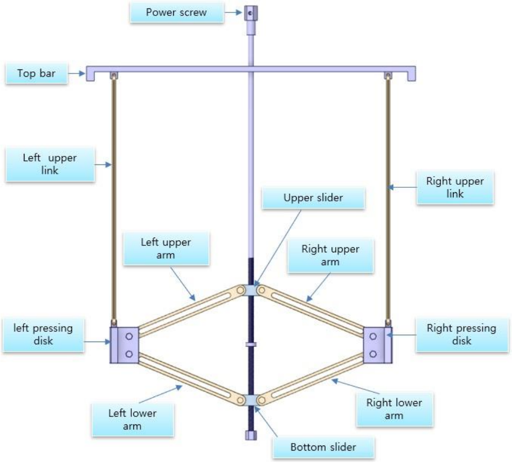

Fig. 1. Core Support Barrel insertion tool

3. Contact analysis between CSB and RV

Once CSB is installed within RV analyzing the contact condition between CSB and RV outlet nozzle is important. Depending on the gap between them, we can categorize contact condition into with gap, in contact, and with overlap. This contact analysis between the CSB and RV is vital for nuclear reactor safety, integrity, and performance, preventing structural damage and material failure.

Following descriptions are for three different scenarios.

i. **Case with Gap**: There is a clearance between the CSB and RV outlet nozzle, allowing for the removal and insertion of RV internals but causing bypass flow.
ii. **Case in Contact**: The CSB is in direct contact with the RV outlet nozzle, potentially reducing bypass flow. However, this condition demands thorough examination to avoid issues like undue pressure, stress concentrations, and potential wear or damage, especially in seismic scenarios.
iii. **Case with Overlap**: The CSB overlaps with the RV outlet nozzle, indicating a tight fit and potential for enhanced structural stability. Nonetheless, the implications of this overlap on the reactor's safety, integrity, and performance, especially

concerning structural and material integrity during operation and seismic events, must be rigorously assessed.

3.1. Conditions considered in the contact analysis between CSB and RV

These scenarios were examined with respect to two conditions which includes:

i. Installation conditions: This is when the insertion tool is exerted inside the CSB and displacement is exerted.
ii. Installed condition: This is when the tool is removed from the CSB.

3.2. Boundary conditions for contact analysis between CSB and RV

For the static structural analysis examining the contact between the CSB and the RV in the installation condition, the following boundary conditions were established: Fixed support was applied at the base of the vertical supports attached to the cold leg. Bonded contact was designated at the RV flange where the CSB is connected, and frictionless contact was assigned at the interface between the bottom of the CSB and the RV. frictionless support was applied on the surfaces interfacing with other components as shown in Figure 2. Additionally, input displacement was applied perpendicularly to the direction of the hot leg nozzle. These boundary conditions remained consistent in the installed condition, with the modification that no input displacement was applied only the CSB nozzle was extended so as to contact and overlap with the RV respectively. The simulation focused on evaluating contact pressure, expansion and contraction of CSB under these specified conditions.

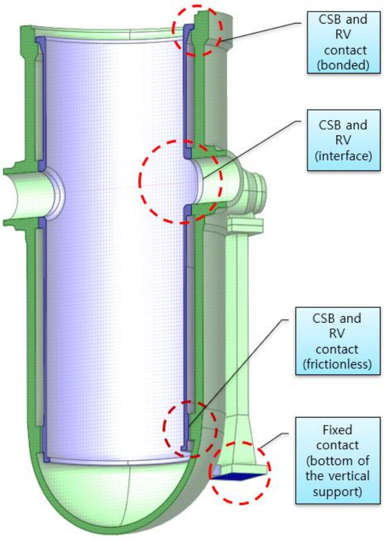

Fig. 2. Boundary condition used for FEM simulations.

3.3. 1st Case with Gap (Current design)

In this scenario no tool is needed since there is a gap of about 2.5mm between the CSB and RV interface this represent the current design. Figure 3 shows the horizontal section of the CSB and RV with the clearance to allow insertion and removal of the CSB.

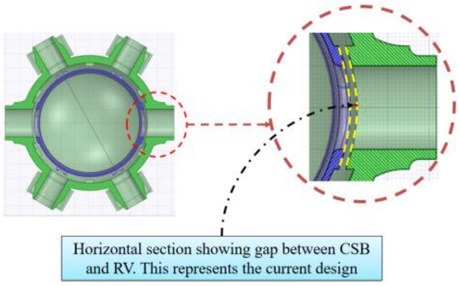

Fig. 3. Horizontal section showing gap between CSB and RV.

3.4. 2nd Case with no Gap (Proposed design 1)

In this particular case, the insertion tool was used for accurately aligning and pressing the CSB outlet nozzle towards the RV hot leg nozzle to ensure direct contact between the RV and the CSB, input displacement of various magnitudes was applied to allow the expansion of the CSB until it touches the RV hot leg nozzle as depicted Fig 4.

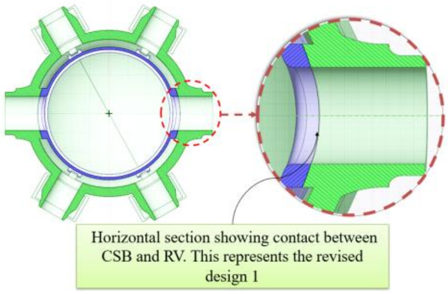

Fig. 4 Horizontal section showing contact between CSB and RV.

3.5. 3rd Case with overlap (Proposed design 2)

In this particular scenario, the utilization of the tool is essential for pressing the CSB outlet nozzle towards the RV hot leg nozzle further beyond the direct contact until overlapping is realized, Same procedure and boundary conditions as used for contact case was used

4. Finding optimum values of CSB input displacement for insertion operation

4.1. Installation Condition

Installation conditions denote the critical set of criteria that must be satisfied to guarantee the safe, accurate, and efficient positioning of the CSB within the RV. The process employs a specialized CSB insertion tool, which is crucial during the installation phase. As illustrated in Figure 5, the CSB undergoes deformation, assuming a shape that results from being precisely pressed by the insertion tool. This action is essential for generating the required clearance, thereby ensuring the CSB is installed correctly. Figure 8 also provides a sectional view, showcasing the CSB's expansion and contraction during the installation stage

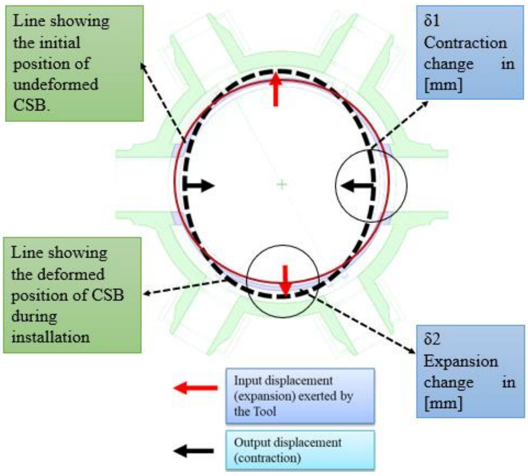

Fig. 5 The sectional view of the expansion and contraction of CSB during installed condition

Fig. 6 illustrates a linear increase in CSB contraction values corresponding to the increase in input displacement (expansion) values. This linear trend shows that the CSB is behaving elastically, this can be explained with the following two variable linear equation:

(i) $\delta y = \alpha \delta x$

(ii) $\alpha = \frac{\delta y}{\delta x}$

Where:

δy is the change due to the contraction of the CSB it is dependent variable

δx is the change due to expansion of the CSB it is independent variable,

α is the constant coefficient of proportionality (slope)

δy is directly proportional to δx That means expansion and contraction values changes in a manner that is directly related to the amount of input displacement. Given a constant coefficient of proportionality α.
using equation (ii) and values in the plot in Fig. 9 the (α) during installation can be calculated as follows:

$$\alpha = \frac{\delta y}{\delta x}$$

$$\alpha = \frac{6}{6} = 1$$

The (α) is =1 during installation when the Tool is exerted signifying a direct and linear relationship between two variables where the change in one variable is exactly matched by the change in the other indicating a one-to-one correspondence between the variables.

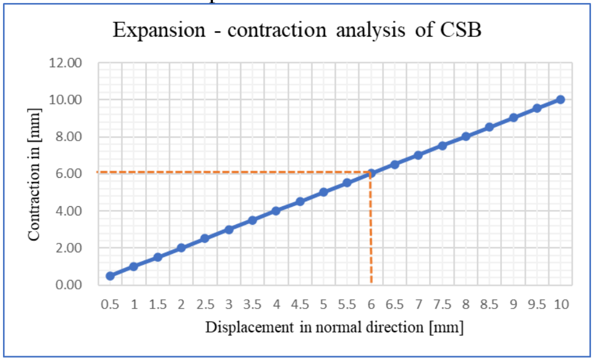

Fig. 6 Expansion - contraction of CSB during installation condition.

4.2. Installed Condition

Installed condition" refers to the scenario in which the CSB has been successfully inserted into its designated position using the specialized tool, which is then removed, allowing the CSB to transition into a state of equilibrium. This transition initiates a relaxation of the previously applied displacement load, enabling the CSB to elastically rebound. Table 1 shows the mechanical properties of CSB and RV, while Table 2 shows their respective equivalent stress with regards to different overlapping cases. 4mm overlapping case gives the best results since its within the acceptable margin.

Table 1: Mechanical properties for CSB and RV

Reactor Component	CSB (Austenitic SS 304)		RV (SA 508 Gr.3 Cl.1)	
Minimum Yield Strength (MPa)	170	Max temp limit (649℃)	344.738	Max temp limit (700℃)
Minimum Tensile Strength (MPa)	485	Max temp limit (649°C)	551.581	Max temp limit (700°C)

Table 2: Overlap case equivalent stress for CSB and RV

Overlap Case [mm]	Equivalent Stress CSB Maximum [MPa]	Equivalent Stress RV Maximum [MPa]	Contact Pressure [MPa]
0.5	20.29	13.15	5.74
1	40.56	26.05	10.43
1.5	60.98	38.94	14.44
2	82.07	51.88	18.31
2.5	101.68	64.70	21.74
3	123.30	77.74	25.11
3.5	143.63	90.70	28.29

4	**163.19**	**103.69**	**31.57**
4.5	183.04	116.51	34.71
5	204.41	129.64	38.32
5.5	224.72	142.68	41.57
6	245.26	155.97	44.65
6.5	266.84	168.76	48.69
7	287.61	181.86	52.15

The results for contact static structural analysis for the tolerance between CSB and RV, during installed conditions are shown in Figure 7 and 8. When there is gap there is no effect of pressure, and stress since there is no contact between the CSB and RV. Whereas when there is no gap, between the CSB and RV, there is increasing linear relationship between the increased overlapping of the CSB and RV versus maximum contact pressure, and equivalent stress values respectively , suggesting the elastic properties of both CSB and RV, CSB having high stress values than RV.

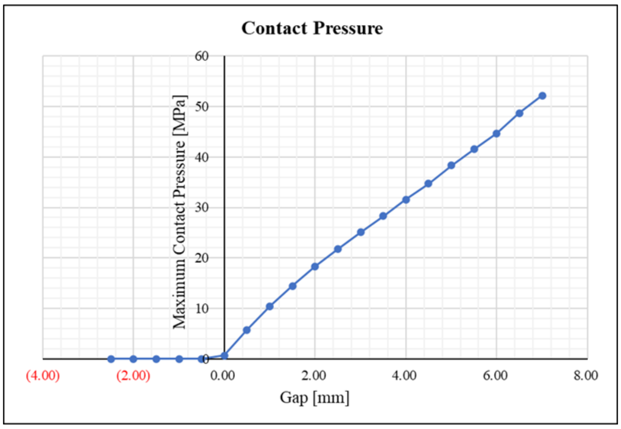

Fig. 7 The maximum contact pressure at contact area

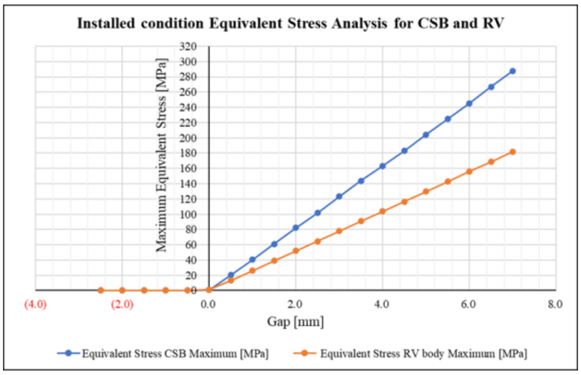

Fig. 8 Equivalent stress analysis for CSB and RV

5. Conclusion and further considerations

This research assessed the optimization of the installation of CSB using an installation tool for by pass flow reduction in nuclear reactor. The installation tool was modelled using FEA, and its operation was simulated and evaluated with ANSYS Rigid Body Dynamics. Subsequent static structural analysis on both the individual components and the tool as a whole was conducted to assess the tool's structural integrity during operation. the inputted reaction force from the structural analysis of CSB when subjected to input displacement showed a direct increasing linear relationship, i.e., as input displacement increases the reaction force also increases linearly, and the equivalent stress too increases proving that the tool can be used to install CSB be installed in a manner that allows it to come into contact with the hot leg nozzle of the RV. This approach effectively narrows the gap and consequently reduces bypass flow. The development of this specialized tool for the precise positioning and insertion of the CSB plays a crucial role in minimizing bypass flow, and enhancing the overall efficiency of the system.

Further studies regarding this assessment should factor in analyzing the mechanical impacts of the reduction of the tolerance gap between the outlet of internals and hot leg pipe of RPV. Also, external events, such as seismic events and thermal expansion tolerances of the reactor vessel internals, should be studied for a more accurate representation of the nuclear reactor core during its operational state.

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