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Preliminary Stress Analysis for Receptacle of Prototype Sodium-cooled fast Reactor

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1. Introduction

The sodium-cooled fast reactor (SFR) module consists of the vessel, containment vessel, head, rotating plug (RP), upper internal structure (UIS), intermediate heat exchanger (IHX), decay heat exchanger (DHX), primary pump, internal structure, internal components and reactor core [1]. The receptacle, a one of the internal components, consists of the outer body, inner body and orifice like Fig. 1.

The receptacle is responsible for supporting the weight of the fuel assembly and retaining the primary sodium flow path up to the fuel assembly. In terms of preventing the core meltdown, it is important to make the receptacle design have enough structural integrity.

The purpose of this paper is to evaluate the integrity of the receptacle regarding the weight loads of the dead weight and the fuel assembly following ASME code.

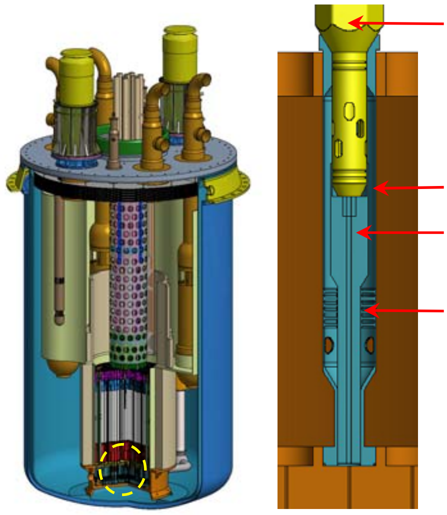


Fig. 1. Configuration of the receptacle of SFR

2. Methods and Results

2.1 Methods to Evaluate the Integrity

The evaluation applies ASME B&PV Code Sec. III Div. 5-HB [2]. According to the code, the design criteria for the evaluation are determined by metal temperature. In case of the receptacle which is made of 316 stainless steel, the design criteria applies the subsection HB subpart A if the metal temperature is less than 427℃. it applies the subsection HB subpart B if it is more than 427℃. Also, the code has been defined that the subsection HB subpart A applies Div. 1-NB.

The evaluation was performed to use SIE-Div5 code which is a computerization code regarding ASME B&PV Code Sec. III Div. 5-HB [3]. The stress analysis for the evaluation was calculated by using the FEM.

2.2 General Assumptions

1) The fuel assembly weight assumes 300kg.
2) The weight of the fuel assembly is given uniformly on the upper area of the inner body.

2.3 FEM Model

The FEM program used ANSYS APDL v.15.0 [4]. Flow holes of the receptacle and orifice were excluded from FEM model. Details are below.

- Model type : 2-D Axisymmetric Model
- Element type : plane183, plane77

2.4 Load and Boundary Condition

The load condition considered the design condition and the Steady-state condition of the level A condition following the load combination like table I. All loads operate the receptacle at the same time so that it should combine the stress components calculated by the stress linearization. In table I, details of each load are below. Load-3 at Level A is not considered in the evaluation because of the uniform temperature.

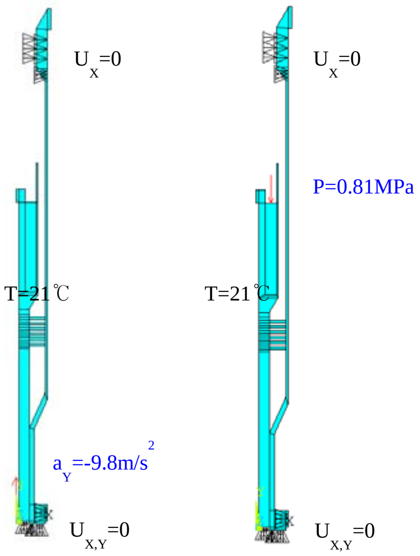
<u>Structural Load</u>
1) Load-1 : dead weight of the receptacle.
2) Load-2 : dead weight of the fuel assembly.
<u>Thermal Load</u>
3) Load-3 : 100% output operation temperature.

Table I: Receptacle normal operation load condition

Service Level	Event Name	Service Time	Max./Min. Temp’
Design	Load-1, 2	60 years	390/390
Level A	Load-1, 2	60 years	390/390

Fig. 2 shows the load and boundary conditions of the each load case. In Fig. 2 (b), the load-2 case applied the uniform pressure (0.81MPa) which is equal to dead weight of the fuel assembly on the upper area of the inner body. Temperature applied the room temperature in the load-1, 2 cases.

In Fig. 2 (a) ~ (b), the axial degree of freedom of the lower region of the outer body and inner body was fixed. Also, the radial degree of freedom of the upper and lower regions of the outer body was fixed.



(a) Load-1 (b) Load-2

Fig. 2. Boundary conditions of FEM model

2.5 Analysis result

Fig. 3, 4 shows the equivalent stress distribution of each load case. According results, the maximum stress (0.21MPa) of the load-1 case occurs at the sloping region of the outer body and the maximum stress (3.18MPa) of the load-2 case occurs at the sloping region of the inner body.

Although the regions occurred the maximum stress at each load case are not similar, the sloping region of the inner body occurs the maximum stress in terms of the overall stress distribution.

2.6 Stress Linearization

In order to calculate the stress linearization, the evaluation section selects four positions distributed the maximum stress like Fig. 5.

- Section A-A: the upper region of the inner body
- Section B-B: the sloping region of the inner body
- Section C-C: the interface region between the inner body and the orifice (radial)
- Section D-D: the interface region between the inner body and the orifice. (axial)

2.7 Results

2.7.1 Design Condition

Table Ⅱ shows the evaluation results with respect to the design condition. The Design margin defines below.

Margin = (Allowable stress / Calculated stress)-1

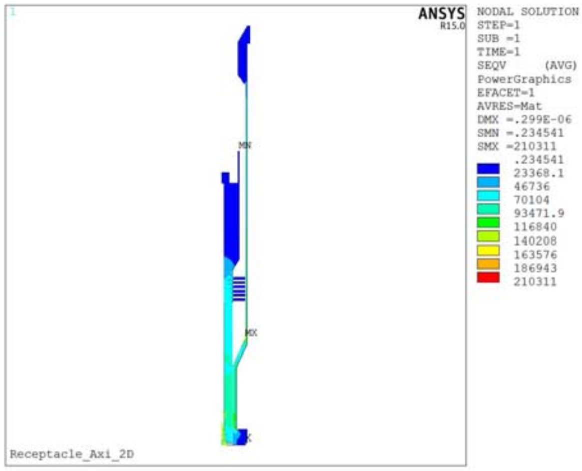


Fig. 3. Equivalent stress distribution of the load-1 case

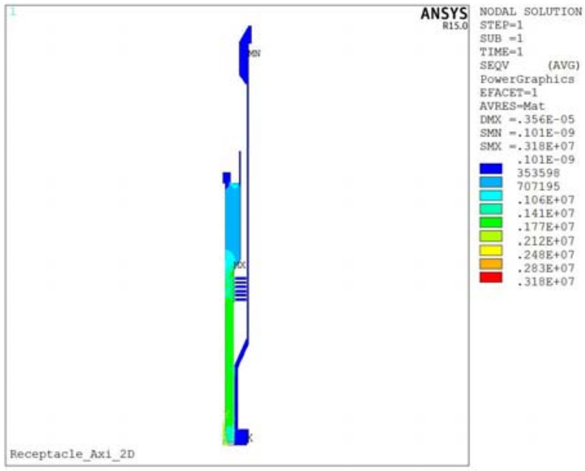


Fig. 4. Equivalent stress distribution of the load -2 case

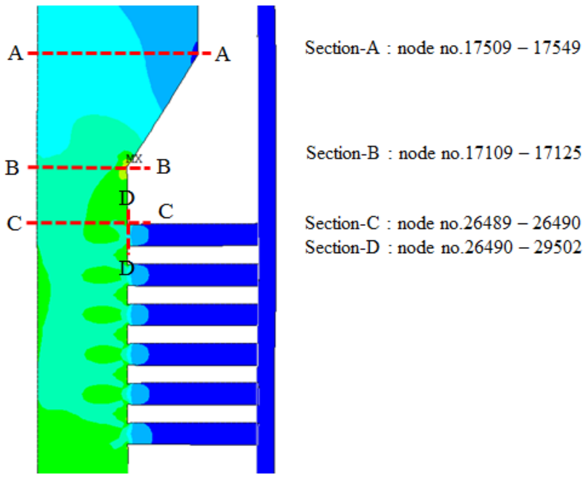


Fig. 5. Positions of section line for Stress linearization

The evaluation result having the minimum design margin is below.

<u>Section B-B (inner, node 17109)</u>

Pm=1.32MPa < Sm=111.4MPa : OK

PL=1.32MPa < 1.5Sm=167.1MPa : OK
PL+Pb=1.70MPa < 1.5Sm=167.1MPa : OK

As a result, the receptacle design regarding the design condition has enough design margins and satisfies the design criteria.

Table Ⅱ: Evaluation result with design condition

Section	Node	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	Margin
Section A-A	Inner (17509)	Pm	0.79	Sm=111.4	140.01
		PL	0.79	1.5Sm=167.1	210.52
		PL+Pb	0.51	1.5Sm=167.1	326.65
	Outer (17549)	Pm	0.79	Sm=111.4	140.01
		PL	0.79	1.5Sm=167.1	210.52
		PL+Pb	0.51	1.5Sm=167.1	326.65
Section B-B	Inner (17109)	Pm	1.32	Sm=111.4	83.39
		PL	1.32	1.5Sm=167.1	125.59
		PL+Pb	1.70	1.5Sm=167.1	97.29
	Outer (17125)	Pm	1.32	Sm=111.4	83.39
		PL	1.32	1.5Sm=167.1	125.59
		PL+Pb	1.04	1.5Sm=167.1	159.67
Section C-C	Inner (26489)	Pm	1.45	Sm=111.4	75.83
		PL	1.45	1.5Sm=167.1	114.24
		PL+Pb	1.53	1.5Sm=167.1	108.22
	Outer (26490)	Pm	1.45	Sm=111.4	75.83
		PL	1.45	1.5Sm=167.1	114.24
		PL+Pb	1.45	1.5Sm=167.1	114.24
Section D-D	Inner (26490)	Pm	1.14	Sm=111.4	96.72
		PL	1.14	1.5Sm=167.1	145.58
		PL+Pb	1.50	1.5Sm=167.1	110.40
	Outer (29502)	Pm	1.14	Sm=111.4	96.72
		PL	1.14	1.5Sm=167.1	145.58
		PL+Pb	1.50	1.5Sm=167.1	110.40

2.7.2. Level A Condition

Table Ⅲ shows the evaluation results with respect to the steady-state condition of the level A condition. The evaluation result having the minimum design margin is below.

<u>Section B-B (inner, node 17109)</u>

Δ (PL+Pb+Pe+Q)=1.70MPa < 3Sm=334.2MPa : OK
Δ Q=0MPa < y*Sy=11,532.25MPa : OK

As a result, the receptacle design regarding the steady-state condition has enough design margins and satisfies the design criteria.

Table Ⅲ: Evaluation result with level A condition

Section	Node	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	Margin
Section A-A	Inner (17509)	PL + Pb + Pe + Q	0.51	3Sm=334.2	654.29
		Thermal Ratcheting	0	19,218.75	-
	Outer (17549)	PL + Pb + Pe + Q	1.10	3Sm=334.2	304.82
		Thermal Ratcheting	0	19,218.75	-
Section B-B	Inner (17509)	PL + Pb + Pe + Q	1.70	3Sm=334.2	195.59
		Thermal Ratcheting	0	11,532.3	-
	Outer (17549)	PL + Pb + Pe + Q	1.04	3Sm=334.2	320.35
		Thermal Ratcheting	0	11,532.3	-
Section C-C	Inner (17509)	PL + Pb + Pe + Q	1.53	3Sm=334.2	217.43
		Thermal Ratcheting	0	10,487.1	-
	Outer (17549)	PL + Pb + Pe + Q	1.45	3Sm=334.2	229.48
		Thermal Ratcheting	0	10,487.1	-
Section D-D	Inner (17509)	PL + Pb + Pe + Q	1.50	3Sm=334.2	221.80
		Thermal Ratcheting	0	13.370.1	-
	Outer (17549)	PL + Pb + Pe + Q	1.50	3Sm=334.2	221.80
		Thermal Ratcheting	0	13,370.1	-

3. Conclusions

This paper evaluated the integrity of the receptacle with respect to the design condition and the steady-state condition of the level A condition. According evaluation results, the receptacle design has enough design margins and satisfies the design criteria defined ASME code.

Acknowledgement

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