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Structural Integrity Evaluation of the UIS for Transients

S. H. Kim [a*], S. G. Kim [a], G. H. Koo[a]
[a]*Korea Atomic Energy Research Institute, Daejeon 305-600, The Republic of Korea*
[*]*Corresponding author: shkim5@kaeri.re.kr*

1. Introduction

The design configurations and dimensions of the upper internal structure (UIS) in this analysis are presented in the design drawing of the Fig. 1. The UIS in a PGSFR is the structure suspended from the rotating plug, which includes the instrument sensors to measure the outlet temperature of the reactor core and the plates to support the guide tubes of the control rod drive lines. As shown in the figure, three support plates are located inside the UIS and the flow holes considering the geometrical interference with the control rod drive lines and the instrument sensors are designed. In addition, the circumferential flow holes and the slot which is the moving passage of the IVTM pantograph arm as shown in the figure are arranged in the shroud tube of the UIS.

The purpose of this study is to evaluate the structural integrity for the design configurations and dimensions of the UIS in the PGSFR, which is performed for the loading condition including the thermal transients according to the ASME Div.5-HB.

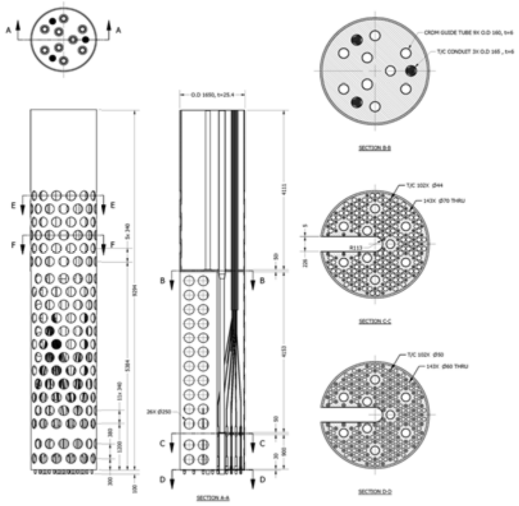
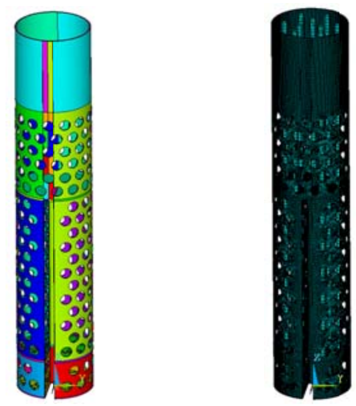


Fig. 1 Design configurations of the UIS in the PGSFR

2. Modeling of the UIS

Fig. 2 indicates the finite element model for the structural analysis of the UIS using the ANSYS code [1], which includes the shroud tube, the support plates and the guide tubes of the control rod drive lines. The dead weight is considered as the primary load and the control rod drive lines located inside the UIS are coupled with the support plates. In the thermal boundary condition, the convection heat transfer coefficient of 1.E4 W/^{o}C·m^{2} is applied in the sodium hot pool region and that of 2.278W/^{o}C·m^{2} is used in the reactor cover gas region. The thermal load for the transient analysis is the refueling cycle in which the maximum and minimum temperature are 545 ^{o}C and 200 ^{o}C, respectively, and the number of the occurrences is 180 during the lifetime of 60 years. Table 1 shows the loading condition for transients



(a) 3D model (b) Finite element model

Fig. 2 Model for the structural analysis of the UIS

Table 1 Loading condition for transients

Operating Level	Event	Design Lifetime (Years)	Number of Occurrences	Max./Min. Temp.(°C)
Design Condition	- Dead Weight	60	-	545/200
Service Level A&B	- Dead Weight - Refueling Cycle for Transients	60	180	545/200

3. Results and Discussions

Fig. 3 shows the analysis results of the primary stress for the dead weight. The maximum stress is 2.39 MPa, which occurs in the geometrical discontinuity of the upper part of the UIS slot.

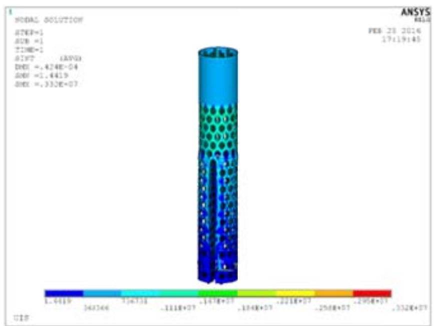
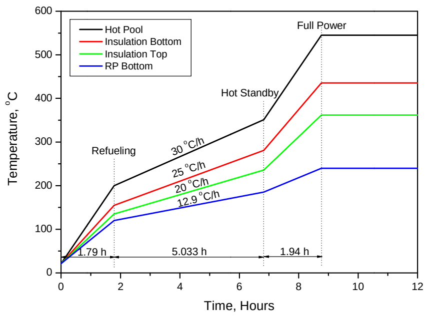
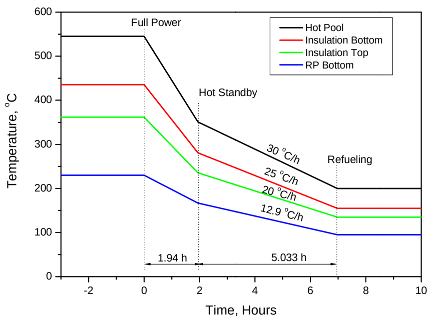


Fig. 3 Stress analysis result for the dead weight



(a) Heatup



(b) Cooldown

Fig. 4 Boundary condition for the stress analysis

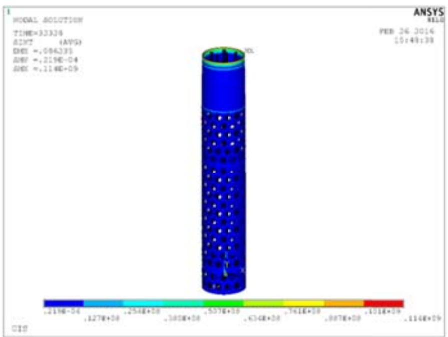


Fig. 5 Analysis results of the thermal stress for the transient heatup condition

The refueling cycle is considered as the thermal load for the transient stress analysis, and the surrounding coolant temperatures of the UIS are shown in Fig. 4. Fig. 5 shows the analysis results of the thermal stress for the transient heatup condition. In this figure, the maximum stress of 114 MPa occurs in the top surface of the UIS because of the steep temperature gradient.

3.1 Evaluation Sections

In the decision of the evaluation sections, Fig 6 shows the maximum stress positions for the primary stress and three sections are selected as shown in the

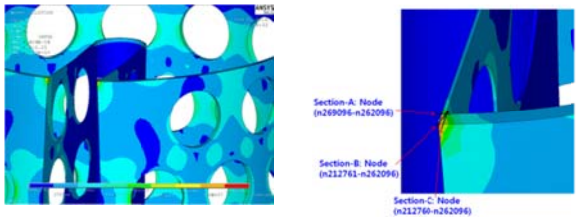


Fig. 6 Evaluation sections for the primary stress

figure. Fig 7 shows the maximum stress position for the thermal stress and a section is selected as shown in the figure. The total four evaluation sections for the structural integrity check according to the ASME code design rules are selected as shown in the figures.

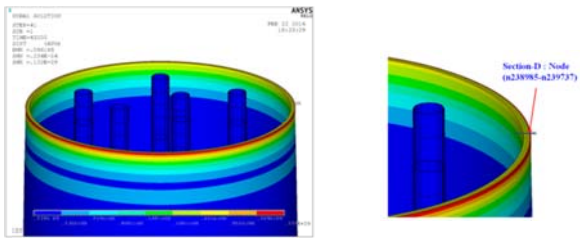


Fig. 7 Evaluation section for the thermal stress

3.2 Structural Integrity Evaluation Results

(1) Design evaluation of the low temperature region

Table 2 shows the structural integrity evaluation result of the UIS for a low temperature region. The metal temperature of the evaluation section for the design check use the analysis results of the temperature distribution for transients. Because the maximum temperature of the evaluation section D is under 427°C of the creep temperature, ASME Div.5-HBA rules are used [2]. From the evaluation results in the table, we can see that the UIS satisfies the design limits.

Table 2 Structural integrity check result for the low temperature region (Section D)

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	[illegible]	Temperature (°C)	C&S
Section-D	Inner (238985)	Pm	0.43	Smt = 76.3	176.47	240	ASME Sec III Div5-HBA
		PL + Pb	0.22	1.5Sm = 191.4	869.00		
		PL + Pb+Q	74.5	3Sm= 382.8	4.14		
		Fatigue Evaluation (No. of Cycles)	180	4021638	**		
	Outer (239737)	Pm	0.43	Smt = 76.3	176.47	240	ASME Sec III Div5-HBA
		PL + Pb	0.66	KSm = 158.5	289.00		
		PL + Pb+Q	75.8	St = 76.3	4.05		
		Fatigue Evaluation (No. of Cycles)	180	3659431	**		

(2) Design evaluation of the high temperature region

Because the maximum temperatures of three evaluation sections A, B and C are above 427°C of the creep temperature, ASME Div.5-HBB rules are used. Table 3 ~ Table 5 summarize the structural integrity evaluation results according to the Service Level A&B for the evaluation sections of the high temperature region of the UIS. As shown in the evaluation results, the UIS satisfies the design limits for the design condition and the Service Level A&B.

Table 3 Structural integrity check result for the high temperature region (Section A)

Sections	Nodes	Linearized Stress		Calculated Stress (MPa)	Allowable Stress (MPa)	[illegible]	Temperature (℃)	C&S
Section-A	Inner (269096)	Pm		1.2	Smt = 76.3	62.58	545	ASME Sec III Div5-HBB
		PL + Pb		1.47	KSm = 158.5	106.82		
		PL + Pb/Kt		1.42	St = 76.3	52.73		
		UFS(t/tm)		t=525600	tm=1662800	t/tm=0.316		
		UFS(t/tb)		t=525600	tb=1662800	t/tb=0.316		
		Inelastic Strain	Elastic	0.012	1.0	82.33		
			Simplfied	0.00 %	1.0 %	**		
		Fatigue Damage		0.00003	0.274	9132.33		
		Creep Damage		0.360	0.999	1.78		
	Outer (262096)	Pm		1.26	Smt = 76.3	59.56	545	ASME Sec III Div5-HBB
		PL + Pb		1.06	KSm = 158.5	148.53		
		PL + Pb/Kt		1.1	St = 76.3	68.36		
		UFS(t/tm)		t=525600	tm=1662800	t/tm=0.316		
		UFS(t/tb)		t=525600	tb=1665100	t/tb=0.316		
		Inelastic Strain	Elastic	0.008	1.0	124.00		
			Simplfied	0.00%	1.0%	**		
		Fatigue Damage		0.00003	0.275	9132.33		
		Creep Damage		0.359	0.999	1.78		

Table 4 Structural integrity check result for the high temperature region (Section B)

Sections	Nodes	Linearized Stress		Calculated Stress (MPa)	Allowable Stress (MPa)	[illegible]	Temperature (℃)	C&S
Section-B	Inner (212761)	Pm		1.84	Smt = 76.3	40.47	545	ASME Sec III Div5-HBB
		PL + Pb		2.59	KSm = 158.5	60.20		
		PL + Pb/Kt		2.44	St = 76.3	30.27		
		UFS(t/tm)		t=525600	tm=1653900	t/tm=0.318		
		UFS(t/tb)		t=525600	tb=1644900	t/tb=0.320		
		Inelastic Strain	Elastic	0.019	1.0	51.63		
			Simplified	0.00 %	1.0 %	**		
		Fatigue Damage		0.00003	0.273	9099.00		
		Creep Damage		0.363	0.999	1.75		
	Outer (262096)	Pm		1.84	Smt = 76.3	40.47	545	ASME Sec III Div5-HBB
		PL + Pb		1.13	KSm = 158.5	139.27		
		PL + Pb/Kt		1.27	St = 76.3	59.08		
		UFS(t/tm)		t=525600	tm=1053900	t/tm=0.318		
		UFS(t/tb)		t=525600	tb=1662600	t/tb=0.316		
		Inelastic Strain	Elastic	0.01	1.0	99.00		
			Simplfied	0.00%	1.0 %	**		
		Fatigue Damage		0.00003	0.275	9165.67		
		Creep Damage		0.359	0.999	1.78		

4. Conclusions

The structural integrity of the UIS for the transient operating condition is evaluated. The design load considered in the evaluation is the dead weight and the thermal load for transients. The selected evaluation sections satisfy the design criteria of the ASME Div.5-HB.

Table 5 Structural integrity check result for the high temperature region (Section C)

Sections	Nodes	Linearized Stress		Calculated Stress (MPa)	Allowable Stress (MPa)	[illegible]	Temperature (℃)	C&S
Section-C	Inner (212760)	Pm		1.53	Smt = 76.3	48.87	545	ASME Sec III Div5-HBB
		PL + Pb		1.92	KSm = 158.5	81.55		
		PL + Pb/Kt		1.84	St = 76.3	40.47		
		UFS(t/tm)		t=525600	tm=1658600	t/tm=0.317		
		UFS(t/tb)		t=525600	tb=1653900	t/tb=0.318		
		Inelastic Strain	Elastic	0.014	1.0	70.43		
			Simplfied	0.00 %	1.0 %	**		
		Fatigue Damage		0.00003	0.274	9132.33		
		Creep Damage		0.361	0.999	1.77		
	Outer (262096)	Pm		1.53	Smt = 76.3	48.87	545	ASME Sec III Div5-HBB
		PL + Pb		1.15	KSm = 158.5	136.83		
		PL + Pb/Kt		1.22	St = 76.3	61.54		
		UFS(t/tm)		t=525600	tm=1658600	t/tm=0.317		
		UFS(t/tb)		t=525600	tb=1663300	t/tb=0.316		
		Inelastic Strain	Elastic	0.009	1.0	110.11		
			Simplfied	0.00%	1.0 %	**		
		Fatigue Damage		0.00003	0.275	9165.67		
		Creep Damage		0.359	0.999	1.78		

Acknowledgements

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REFERENCES

[1] ANSYS User's Manual for Revision 15.0, ANSYS Inc.
[2] ASME B&PV Section III Division 5 Subsection HB, Class A Metallic Pressure Boundary Components, 2013.