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Structural Integrity Evaluation for the Dual Rotating Plug in PGSFR

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1. Introduction

The design configuration and dimension of the PGSFR dual rotating plug for the structural integrity evaluation are based on the design drawing in Fig. 1 [1]. The PGSFR dual rotating plug is the structure supported by the reactor head. The in-vessel transfer machine which can handle fuel assemblies inside the reactor, the control rod drive mechanism, the upper internal structure and the upper shielding structure are suspended inside it. The scope of the analysis includes the small rotating plug, the large rotating plug and the flanges. The mechanical load applied in the analysis consider the dead weight, the component loads applied to the dual rotating plug and the reactor internal pressure, and the thermal load for the steady state uses the temperature distribution during the reactor normal operation. The purpose of this study is to evaluate the structural integrity according to the ASME Code design rule for the design configuration and dimension of the PGSFR dual rotating plug.

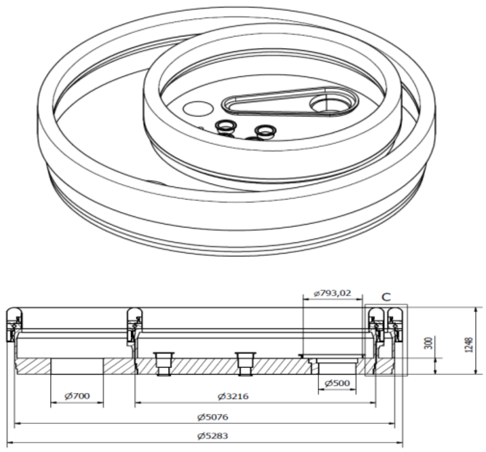

Fig. 1 Design of the dual rotating plug in the PGSFR

2. Modeling of the Dual Rotating Plug

Fig. 2 shows the finite element model for the structural analysis of the dual rotating plug [2]. In the boundary condition for the mechanical load analysis, the semicircular end part of the large rotating plug is constrained in the y-direction and the frictionless condition is applied in the contact surfaces between the small rotating plug and the large rotating plug as shown in Fig. 3. The mechanical and thermal loads are considered for the stress analysis of the dual rotating plug. Fig. 4 indicates the boundary condition for the thermal analysis. As shown in this figure, the temperatures of 115°C and 108 °C are applied on the bottom surface and the top surface of the dual rotating plug, respectively.

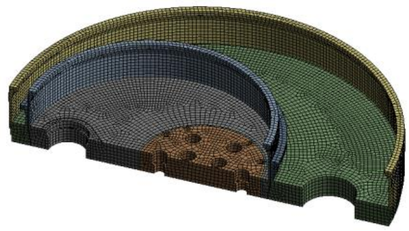

Fig. 2 3D FE model of the dual rotating plug

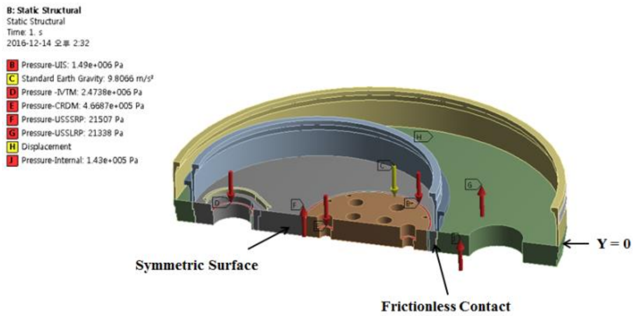

Fig. 3 Boundary condition for the mechanical load

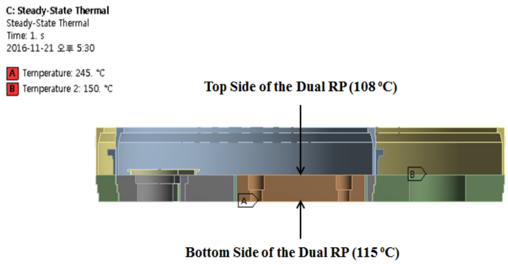

Fig. 4 Boundary condition for the thermal load

3. Results and Discussions

Fig. 5 represents the primary stress analysis result for the mechanical loads. The maximum stress is 48.3 MPa, which is generated at the ledge seal of the semicircular end part of the large rotating plug. Because this part supports the total weight applied to the dual rotating plug, the stress concentration for the mechanical load is predicted. The maximum displacement for the mechanical load is 0.5 mm, which occurs at the middle part of the small rotating plug as shown in Fig. 6.

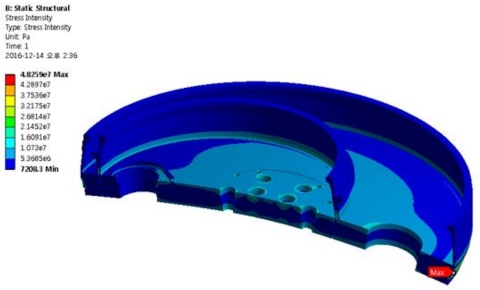

Fig. 5 Stress distribution for the mechanical load

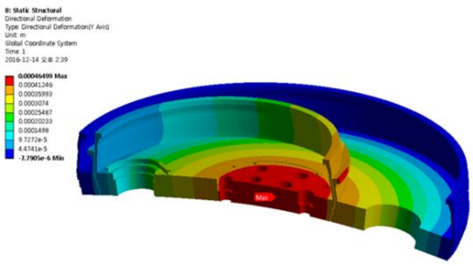

Fig. 6 Displacement distribution for the mechanical load

The temperature distribution of the dual rotating plug for the thermal analysis result of the steady state is shown in Fig. 7. Fig. 8 shows the thermal stress analysis result for the steady state condition. The maximum thermal stress is 12.9 MPa, which occurs at the flange of the small rotating plug. The maximum displacement in the y-direction due to the thermal expansion occurs as 1mm at the middle part of the small rotating plug as shown in Fig. 9.

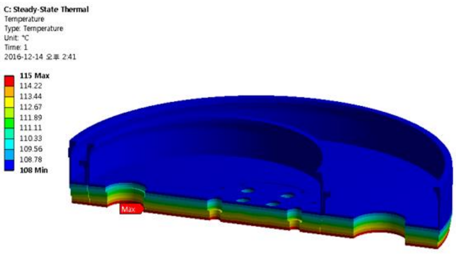

Fig. 7 Temperature distribution for the thermal load

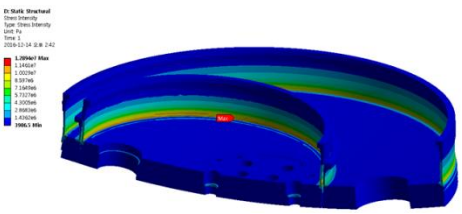

Fig. 8 Stress distribution for the thermal load

3.1 Evaluations Sections

For the evaluation according to the ASME design rule for the stress analysis results, the stress linearizations for the corresponding cross sections should

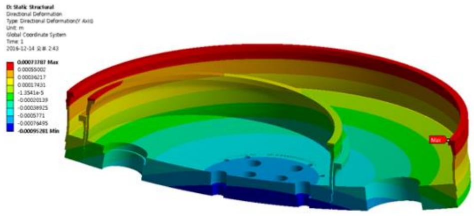

Fig. 9 Displacement distribution for the thermal load

be performed by selecting the evaluation sections on the high stress generation parts. Fig. 10 shows the maximum stress position and an evaluation section for the primary stress. Fig. 11 represents the maximum stress positions for the thermal stress. From this stress analysis result, two evaluation sections are selected. The total cross sections selected for the evaluation according to the ASME design rule are three parts, and the structural integrity evaluations are carried out in these sections.

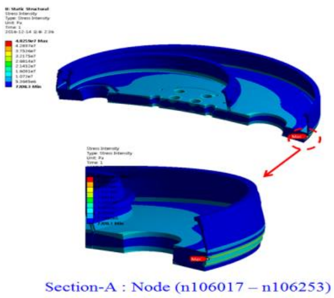

Fig. 10 Evaluation section for the primary stress

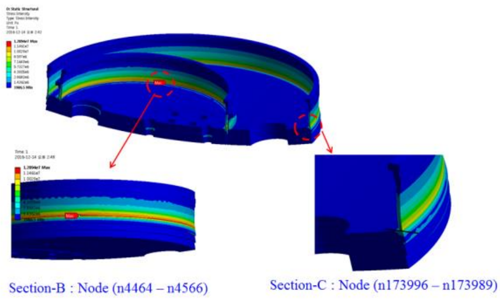

Fig. 11 Evaluation sections for the thermal stress

3.2 Structural Integrity Evaluation Results

(1) Design Condition

Table 1 shows the structural integrity evaluation result according to the design condition. The design rule of ASME B&PV Code Section III, Division 5 HBA is used because all metal temperatures at the evaluation sections are below 427 ^{o}C. We can see that the primary stress for the design condition satisfies the design criteria with the enough design margin in this table.

(2) Service Level A&B Condition

The structural integrity evaluation for Service Level A&B condition is performed by considering the mechanical load and the thermal load of the steady state temperature distribution. Table 2 shows the structural integrity evaluation result according to Service Level A&B condition about the evaluation sections of the dual rotating plug. From the evaluation result, it can be seen that the dual rotating plug satisfies the design criteria with the enough design margin.

Table 1 Structural integrity evaluation result for the design condition

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	[illegible]	Temperature (ºC)	C&S
Section-A	Inner (106017)	Pm	21.47	Sm = 138.00	5.43	123.4	ASME Sec III Div5-HBA
		PL + Pb	14.32	1.5Sm = 207.00	13.46		
	Outer (106253)	Pm	21.47	Sm = 138.00	5.43	123.4	ASME Sec III Div5-HBA
		PL + Pb	48.20	1.5Sm = 207.00	3.29		
Section-B	Inner (4464)	Pm	3.74	Sm = 138.00	35.90	123.4	ASME Sec III Div5-HBA
		PL + Pb	10.31	1.5Sm = 207.00	19.08		
	Outer (4566)	Pm	3.74	Sm = 138.00	35.90	123.4	ASME Sec III Div5-HBA
		PL + Pb	2.69	1.5Sm = 207.00	75.95		
Section-C	Inner (173996)	Pm	5.93	Sm = 138.00	22.27	123.4	ASME Sec III Div5-HBA
		PL + Pb	5.56	1.5Sm = 207.00	36.23		
	Outer (173989)	Pm	5.93	Sm = 138.00	22.27	123.4	ASME Sec III Div5-HBA
		PL + Pb	6.40	1.5Sm = 207.00	31.34		

Table 2 Structural integrity evaluation result for the Service Level A&B condition

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	[illegible]	Temperature (ºC)	C&S
Section-A	Inner (106017)	PL+ Pb+Pe+Q	14.00	3Sm = 414.00	28.57	110	ASME Sec III Div5-HBA
		Thermal Ratcheting	0.74	y*Sy = 1390.64	1878.24		
	Outer (106253)	PL+ Pb+Pe+Q	48.17	3Sm = 414.00	7.59	109.7	ASME Sec III Div5-HBA
		Thermal Ratcheting	0.84	y*Sy = 1392.19	1656.37		
Section-B	Inner (4464)	PL+ Pb+Pe+Q	8.34	3Sm = 414.00	48.64	108	ASME Sec III Div5-HBA
		Thermal Ratcheting	3.13	y*Sy = 8037.50	2566.89		
	Outer (4566)	PL+ Pb+Pe+Q	4.77	3Sm = 414.00	85.79	108	ASME Sec III Div5-HBA
		Thermal Ratcheting	5.44	y*Sy = 8037.50	1476.48		
Section-C	Inner (173996)	PL+ Pb+Pe+Q	5.16	3Sm = 414.00	79.23	108	ASME Sec III Div5-HBA
		Thermal Ratcheting	1.01	y*Sy= 5076.92	5025.65		
	Outer (173989)	PL+ Pb+Pe+Q	5.31	3Sm= 414.00	76.97	108	ASME Sec III Div5-HBA
		Thermal Ratcheting	2.96	y*Sy = 5076.92	1714.18		

4. Conclusions

The structural integrity for the dual rotating plug is evaluated for the steady state. The considered design loads are the mechanical load and thermal load for the steady state condition. The selected evaluation sections satisfy the design criteria of ASME B&PV Code Section III, Division 5 HBA.

Acknowledgements

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REFERENCES

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[2] ANSYS User's Manual for Revision 15.0, ANSYS Inc.