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Structural Integrity Evaluation of Rotating Plug in a Steady State Condition

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1. Introduction

The rotating plug (RP) is a non-integral, but mechanically attached, part of the reactor head governed by the reactor head design criteria. Its basic structure is much the same as that of stationary portion of the reactor head. The RP is has many penetration holes for control rod drive mechanism (CRDM), the in-vessel transfer machine(IVTM) an in-service inspection (ISI) instruments. In addition, the RP has supports the upper internals structure (UIS) and the IVTM.

In this study, the steady state analysis for the rotating plug was performed and the structural integrity was assessed. in accordance with ASME Section III, Division 5 HB[1].

2. Methods and Results

2.1 Primary Stress Analysis

The outer diameter of the RP is 3.317m. For applying the load conditions, weights of main components are converted as pressures and they were applied to the area where they are installed. Table 1 shows masses of the main components. Material property of Type 316 stainless steel is applied to the rotating plug finite element analysis model.

Table 1 Masses of the main components

component	quantity	Mass(kg, 1EA)
Upper Internal Structure	1	4900
CRDM	9	1200
In-Vessel Transfer Machine	1	8000

To perform the stress analysis, the 3-D finite element model was built by using the FEA software ANSYS[2]. Fig. 1 shows 3D finite element model and Fig. 2 shows loading conditions. The rotating plug is vertically supported on the reactor head.

For the calculation, SOLID186 element was used and total number of nodes and elements were 224,000 and 49,678, respectively. A numerical analysis is performed for the given conditions.

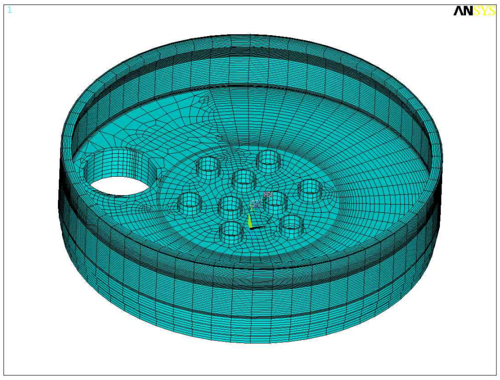

Fig. 1 Finite element model of the rotating plug

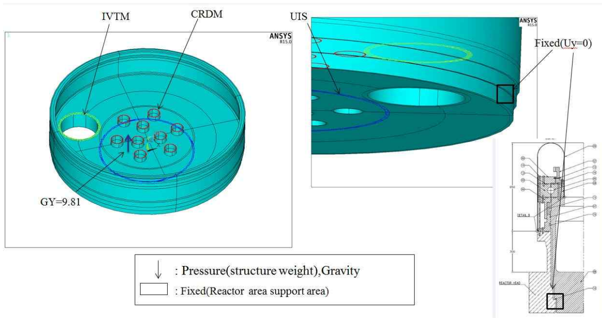

Fig. 2 Loading conditions of the rotating plug

Fig. 3 and Fig. 4 represent the stress intensity distribution results. As shown in Fig.4, the maximum stress intensity is 13.2MPa at the reactor head support region.

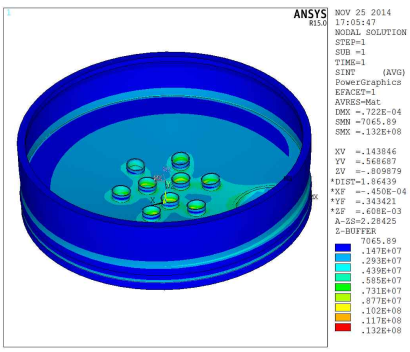

Fig. 3 Primary stress intensity for distribution of the rotating plug

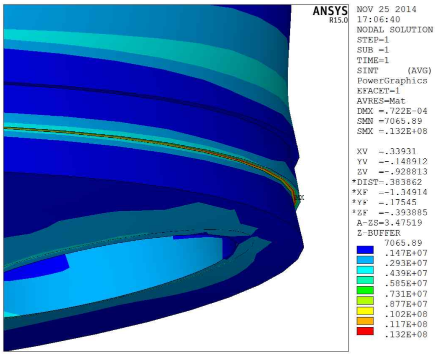

Fig. 4 Maximum stress intensity of the rotating plug

2.2 Thermal Stress Analysis

Fig. 5 shows the thermal boundary conditions of the rotating plug in the steady state condition. Temperatures of the top surface of the rotating plug and cover gas region are 150℃ and 350℃, respectively. It is assumed that thermal film coefficient at bottom surface is 2.2783 W/℃-m^2.

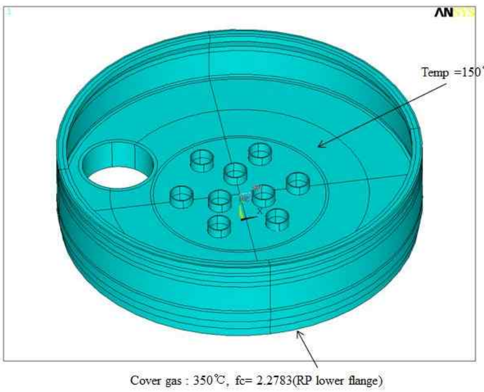

Fig. 5 Thermal boundary conditions of the rotating plug

As a result of the analysis, Fig. 6 shows the temperature distribution of the rotating plug. The maximum temperature is 158℃, which occurs in the RP lower flange.

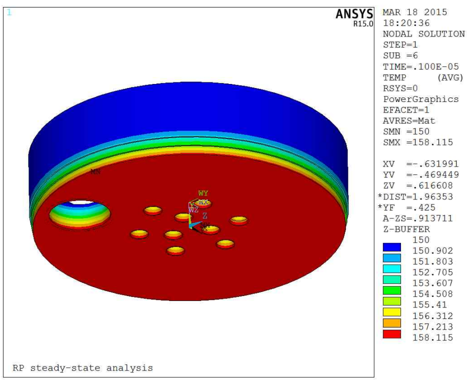

Fig. 6 Temperature distribution of the rotating plug during the steady state condition

Fig. 7 shows the stress intensity distributions of the rotating plug for the steady state condition. As shown in Fig.7, the maximum stress intensity is 106MPa at the reactor head support region.

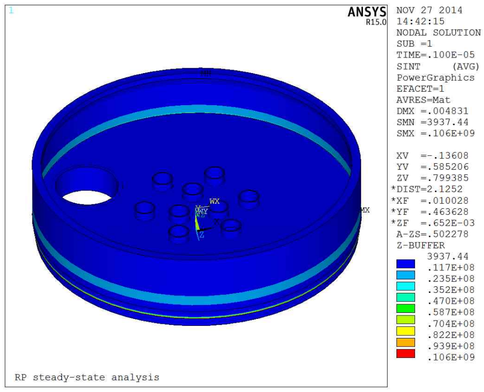

Fig. 7 Stress intensity distribution of the rotating plug during the steady state condition

3. Structural Integrity Evaluations

The structural integrity of rotating plug was evaluated for the given primary and thermal loads in design condition and Service Level A according to ASME Section III, Division 5 HB procedure using SIE-Div5 code [3].

3.1 Evaluation Sections

In order to evaluate the structural integrity of the rotating plug, the locations of maximum stress region are chosen as an evaluation section [4]. Fig 8 shows the selected evaluation sections and their section informations are as follows:

- Section A: maximum primary stress region #1, N87409-N87044.
- Section B: maximum primary stress region #2, N87407-N87042.
- Section C: maximum thermal stress region #3, N86369-N85983
- Section D: maximum thermal stress region #4, N86367-N85981

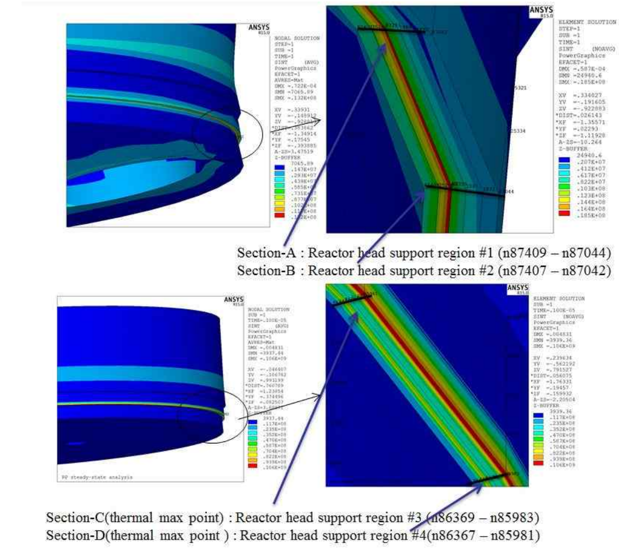

Fig. 8 Sections for structural integrity evaluation of the rotating plug

3.2 Design Condition

Table 2 shows the results of structural integrity for the design condition. The results of the section with the minimum design margin are as follows.

➢ Section-A, Inner(87409), (temperature=263℃)
- Pm=4.5 MPa < Sm =124 MPa: satisfied. (design margin ≒ 26.5).
- PL+Pb=9.9 MPa < 1.5Sm =186 MPa: satisfied. (design margin≒ 17.8)

The results reveal that all primary stresses in sections are satisfied with the design criteria for the design condition.

Table 2 Structural integrities under design condition

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	Margin	Temperature (ºC)	C&S
Section-A	Inner (87409)	Pm	4.5	Sm = 124	26.5	263	ASME Sec III Div5-HBA
		PL	4.5	1.5Sm = 186	40.3		
		PL + Pb	9.9	1.5Sm = 186	17.8		
	Outer (87044)	Pm	4.5	Sm = 124	26.5	263	ASME Sec III Div5-HBA
		PL	4.5	1.5Sm = 186	40.3		
		PL + Pb	6	1.5Sm = 186	30		
Section-B	Inner (87407)	Pm	1.1	Sm = 124	111.7	263	ASME Sec III Div5-HBA
		PL	1.1	1.5Sm = 186	168.1		
		PL + Pb	1.4	1.5Sm = 186	131.9		
	Outer (87042)	Pm	1.1	Sm = 124	111.7	263	ASME Sec III Div5-HBA
		PL	1.1	1.5Sm = 186	168.1		
		PL + Pb	0.9	1.5Sm = 186	205.6		
Section-C	Inner (86369)	Pm	1.9	Sm = 124	64.3	263	ASME Sec III Div5-HBA
		PL	1.9	1.5Sm = 186	96.9		
		PL + Pb	5.2	1.5Sm = 186	34.7		
	Outer (85983)	Pm	1.9	Sm = 124	64.3	263	ASME Sec III Div5-HBA
		PL	1.9	1.5Sm = 186	96.9		
		PL + Pb	3.5	1.5Sm = 186	52.1		
Section-D	Inner (86367)	Pm	1.9	Sm = 124	64.3	263	ASME Sec III Div5-HBA
		PL	1.9	1.5Sm = 186	96.9		
		PL + Pb	5.2	1.5Sm = 186	34.7		
	Outer (85981)	Pm	1.9	Sm = 124	64.3	263	ASME Sec III Div5-HBA
		PL	1.9	1.5Sm = 186	96.9		
		PL + Pb	3.5	1.5Sm = 186	52.1		

3.3 Service Level A condition

Table 3 shows the results of structural integrity for the service level A. The results of the section having the minimum design margin are as follows.

➢ Section-C, Inner(85983), (temperature=158℃)
- PL+Pb+Pe+Q=59.6 MPa < 3Sm =412 MPa: satisfied, design margin = 5.9.

The results show that all primary and secondary stresses in sections are satisfied with the design criteria for the service level A condition.

Table 3 Structural integrities under service level A condition

Sections	Nodes	Linearized Stress	Calculated Stress (MPa)	Allowable Stress (MPa)	Margin	Temperature (ºC)	C&S
Section-A	Inner (87409)	PL + Pb + Pe + Q	42.7	3Sm = 412	8.6	158	ASME Sec III Div5-HBA
		Thermal Ratcheting	8.8	y*Sy = 5585	633.7		
	Outer (87044)	PL + Pb + Pe + Q	57.1	3Sm = 412	6.2	158	ASME Sec III Div5-HBA
		Thermal Ratcheting	102.6	y*Sy =5585	53.4		
Section-B	Inner (87407)	PL + Pb + Pe + Q	4.6	3Sm = 412	88.6	158	ASME Sec III Div5-HBA
		Thermal Ratcheting	7.6	y*Sy =			
	Outer (87042)	PL + Pb + Pe + Q	2.9	3Sm = 412	141.1	158	ASME Sec III Div5-HBA
		Thermal Ratcheting	3.5	y*Sy =			
Section-C	Inner (86369)	PL + Pb + Pe + Q	39.5	3Sm = 412	9.4	158	ASME Sec III Div5-HBA
		Thermal Ratcheting	8.9	y*Sy =			
	Outer (85983)	PL + Pb + Pe + Q	59.6	3Sm = 412	5.9	158	ASME Sec III Div5-HBA
		Thermal Ratcheting	105.7	y*Sy =			
Section-D	Inner (86367)	PL + Pb + Pe + Q	39.6	3Sm = 412	9.4	158	ASME Sec III Div5-HBA
		Thermal Ratcheting	9	y*Sy =			
	Outer (85981)	PL + Pb + Pe + Q	59.7	3Sm = 412	5.9	158	ASME Sec III Div5-HBA
		Thermal Ratcheting	105.7	y*Sy =			

4. Conclusions

In this paper, the structural integrities of the rotating plug under the design condition and service level A condition have been assessed according to ASME code. As a result, it was confirmed that the structural integrity of the rotating plug was secured for a steady state condition. For the future work, a transient analysis and a seismic analysis need to be performed by combining the different design loads.

Acknowledgement

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