Stress Integrity Evaluation for RCP Pressure Barrier under Design Pressure and Dead Weight

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1. Introduction

The System-integrated Modular Advanced Reactor (SMART) is an integrated reactor system. Main components like a steam generator and reactor coolant pump are installed in one reactor pressure vessel, and it does not have piping connections between major components. The SMART uses a canned motor Reactor Coolant Pump (RCP) to circulate the reactor coolant inside the reactor pressure vessel. The RCP is a canned motor type which means that all the RCP components (rotor, stator, bearing, etc.) are submerged in the reactor coolant, thus the RCP frame is considered as a pressure boundary which shall be designed in accordance to ASME class1[1]. Evaluating the mechanical integrity of SMART RCP is done by using finite element analysis with the commercial software ANSYS 17.0. In this paper, the mechanical integrity of the RCP is evaluated due to the pressure and dead weight. The thermal load and seismic load on the RCP are to be considered later for the RCP mechanical integrity. In addition, a fatigue analysis is also to be performed later.

2. Design Methodology

This analysis is done by using numerical finite element method with the commercial program ANSYS 17.0. The design pressure for SMART RCP is 17 MPa and the pressure barrier of RCP should withstand this pressure as shown in Fig.1. The RCP pressure barrier material is MDF A182 Grade F321 (SA-182 Grade F321) with properties shown in Table 1[2]. Two loading types considered to evaluate the mechanical integrity of RCP pressure barrier, the design pressure and dead weight which acting to gravitational direction. On considering the RCP dead weight, the total weight of internal components is conservatively assumed that RCP is filled with stainless steel having the same weight as the internals. As shown in Fig. 1 the RCP pressure boundary is connected to the reactor pressure vessel by stud bolts, and it is assumed that these bolts are the only method to withstand the whole RCP. For building up meshes on the RCP pressure barrier, several options in ANSYS are adopted. The mesh size option is set to adaptive, fine relevance center and the element size option is 40 mm with the total number of nodes and elements are 287,157 and 162,358, respectively. Fig. 2 shows the finite element model for the RCP pressure barrier.

Table 1. Material Properties of RCP Pressure Barrier

Material	Elastic Modulus (GPa) at 360 ˚C	Stress intensity (MPa) at 360 ˚C	Density (kg/m^3)
MDF A182 Grade F321	172.0	122.0	7586.9

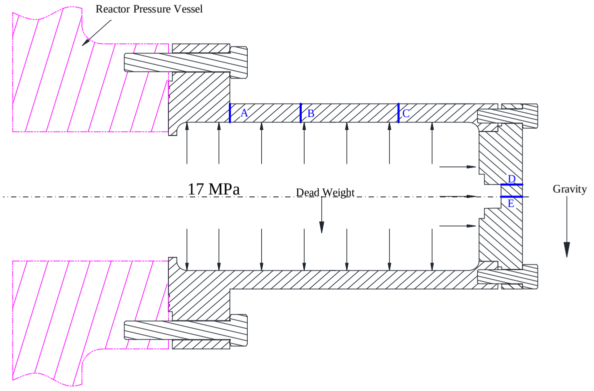

Fig. 1. RCP cross sectional view showing the loading conditions and stress classification lines.

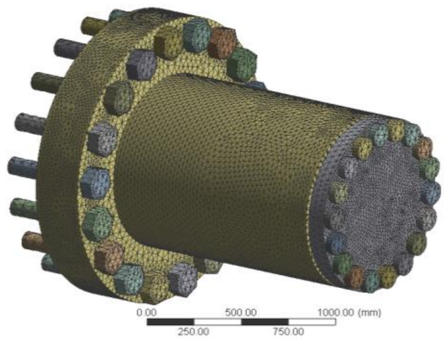

Fig. 2. Finite Element Model of RCP Pressure Boundary.

3. FEM Analysis

Stress intensities for SMART RCP pressure barrier are evaluated using linearized stress intensity method. Several stress classification lines chosen across the thickness as shown in Fig. 1. The results for primary general membrane stress, local membrane stress, and primary (general or local) membrane stress plus primary bending stress are evaluated through the FE analysis in accordance with ASME NB 3221.

3.1 Primary General Membrane Stress Intensity

As shown in Fig. 1, paths B, C, and E are the regions on which the primary general membrane stresses occur at the RCP pressure barrier. The path B is chosen because it is the region that endures maximum stress due to moment. Table 2 shows the stress intensity results (P_m) calculated by finite element model and the stress intensity limitations (S_m) of the pressure barrier material.

Table 2: Primary General Membrane Stress Results

Stress Classification Lines	Primary General Membrane Stress Intensity, P_m (MPa)	Stress Intensity Limit, S_m (MPa)
B	85.0	122.0
C	77.5	122.0
E	50.0	122.0

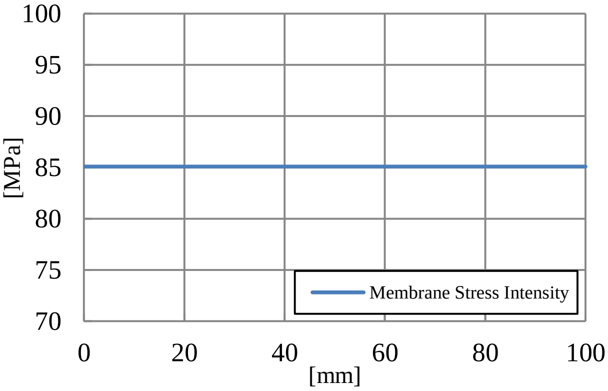

Fig. 3. Primary membrane stress intensity along path B.

The calculated membrane stress intensity shall be less than the material stress intensity (S_m). The maximum value of primary general membrane stress occurs at path B shown in Fig. 3 and is below the stress intensity limit of the pressure barrier material. Therefore, the primary general membrane stresses of the RCP pressure barrier satisfy the stress limit of ASME NB 3221.

3.2 Primary Local Membrane Stress Intensity

A local stress occurs at the transition section of path A and D shown in Figure 1. The calculated primary local membrane stress (P_L) shall be less than 1.5 S_m in order to maintain the mechanical integrity of the pressure barrier. The primary local membrane stress along path A and D are calculated using FE model shown in Figure 2. The maximum primary local membrane stress occurs at along path A shown in Table 3. The stress intensity is below 1.5 Sm of the material stress intensity limit. Therefore, the primary local membrane stresses of the RCP pressure barrier satisfy the stress limit of ASME NB 3221.

Table 3. Primary Local Membrane Stress Results

Stress Classification Lines	Primary Local Membrane Stress, P_L (MPa)	Stress Intensity Limit, $1.5S_m$ (MPa)
A	70.4	183.0
D	51.0	183.0

3.3 Primary Membrane (General or Local) plus Primary Bending Stress Intensity

A bending stress shall be considered for a given section where bending moment occurs. The primary bending stress (P_b) plus primary membrane stress is calculated along the path A and D Figure 1. The results are shown in Table 4 and Fig. 4. The calculated $P_b + P_L$ shall be less than 1.5 S_m in order to maintain the mechanical integrity of the pressure barrier.

Table 4. Primary Membrane Stress plus Primary Bending Stress Results

Stress Classification Lines	Primary Membrane Plus Primary Bending Stress, P_m(or P_m) + P_b(MPa)	Stress Intensity Limit, $1.5S_m$ (MPa)
A	90.0	183.0
D	110.5	183.0

The maximum value of primary membrane plus primary bending stress (P_m (or P_L) + P_b) is observed at stress classification line D and is less than 1.5 Sm. Therefore, the primary membrane plus primary bending stresses stress of the RCP pressure barrier satisfy the stress limit of KEPIC MNB 3221.

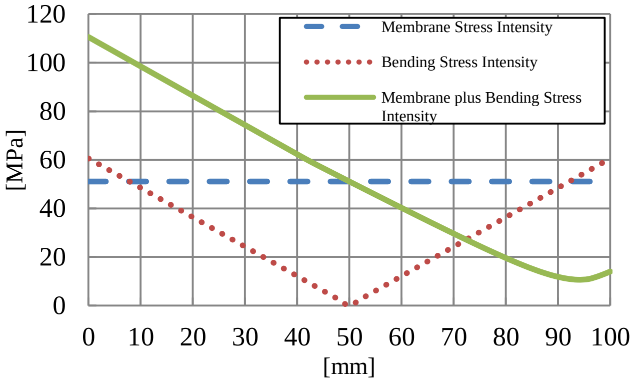

Fig. 4. Stress Linearization Results Graph for Stress Classification Line B

3. Conclusions

The stress intensity of RCP pressure barrier has been evaluated through FE analysis using commercial software ANSYS 17.0. All the stress intensities of the

RCP pressure barrier less than the stress limits of the given material according to ASME NB. The pressure barrier maintain its mechanical integrity under design pressure and dead weight. Further calculation with thermal and seismic loads will be continued for evaluating the stress integrity of the RCP pressure barrier.

REFERENCES

[1] KEPIC MNB, Class 1 Components, 2005 Edition.
[2] S-180-NC403-001, System Description of Reactor Coolant Pump (KAERI Internal Document).