Structural analysis of the In-pool Assembly in Cold Neutron Source

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1. Introduction

The In-pool Assembly is composed of the vacuum chamber, the heat exchanger, the hydrogen and helium piping, the moderator cell and the connection flanges. The moderator cell and vacuum chamber are main components of the In-pool Assembly for the pressure boundary. The structural analyses of the moderator cell and the vacuum chamber were carried out to verify the design for the In-pool Assembly of Cold Neutron Source in HANARO. The conditions for the transient operation were defined to provide the design data of the load combination, which is needed for the fatigue analysis and the component design for the In-pool Assembly. The material for the moderator cell and vacuum chamber is AL6061-T6. The material properties were prepared by ASME Sec. II, Part D, but those over the given temperature range were made using the extrapolation and the conservative value. Code Case N-519 was applied to provide the material properties in condition of low temperature [1]. The material properties used in the moderator cell and vacuum chamber are presented in Table 1 ~ Table 3.

2. Methods and Results

2.1 Configuration and Design Data

The moderator cell is located in the lower part of the In-pool Assembly. The configuration of the cell is cylindrical type and the structure is divided into the outer cell and the inner cell. The outer cell is 298.7 mm in height, 130 mm in inner diameter and 1mm in thickness.
The vacuum chamber was designed with two parts of the different diameters. The upper part of the vacuum chamber is 1590 mm in height, 250 mm in outer diameter and 5mm in thickness. The upper and lower parts are connected with the fan type flange in the middle position. The lower part of the vacuum chamber is 1110 mm in height, 156 mm in outer diameter and 5mm in thickness.

2.2 Analysis model

The moderator cell and vacuum chamber were modeled by ANSYS Code. The total element number of the moderator cell is 31,232 and the element type is solid 45. In the boundary condition, all DOFs(Degree of freedoms) for the upper part connected to the pipe are constrained and the symmetric conditions were applied to the cross sectional area of the half part model as shown in Fig 1. The material of the moderator cell and vacuum chamber is AL6061-T6. The material properties were used on the basis of ASME Sec. II, Part D and those which exceeds the given temperature range were evaluated with the extrapolation and the given conservative data. The total element number of the vacuum chamber is 21,597 and the element type is solid 45. The finite element model is presented in the Fig. 2 and the four elements were created in the radial direction. In the boundary condition, all DOFs of the charge flange of the vacuum chamber were constrained and all DOFs except the axial direction were fixed to the top surface of the vacuum chamber.

2.3 Analysis Results

The conditions of the transient operation which is needed for the fatigue analysis and the component design of In-pool Assembly were defined and the detail structural analyses were carried out by using the load combination for the service level. The number of stress linearization paths of the cross section for the stress evaluation in the moderator cell is ten as shown in Fig. 3 and the structural integrity was verified by the satisfaction of the design stress limits in ASME design procedure. The Maximum stress position is located in the cross section C for the design condition, Level A, Level B and test condition and the maximum value of CUF (Cumulative Usage Factor) was evaluated as 0.00034 in the cross section H [2]. The vacuum chamber was classified as SC-3, but the structural integrity was evaluated by the ASME Sec. III NB like the moderator cell. The number of stress linearization paths of the cross section for the stress evaluation in the vacuum chamber is thirteen as shown in Fig. 4 and the maximum stress position is located in the cross section B for the design condition, Level A, Level B and test condition. The maximum value of the CUF was evaluated as 0.00034 in the cross section B [3].

3. Conclusion

The evaluation of the structural integrity for the moderator cell and the vacuum chamber was performed by the design procedure of ASME Sec. III, NB based on the concept of the design by analysis. The detail analyses were performed in the condition of the design loads of Service level A, B, C and D. The calculated stresses satisfied the ASME SC-1 component design and analysis rules. Thus, the structural integrity was verified in the moderator cell and vacuum chamber [4].

Acknowledgements

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REFERENCES

[1] ORNL, High flux isotope reactor cold neutron source reference design concept, ORNL/TM-13498, May 1998.

[2] GNEC, The design report of the moderator cell, HAN-CNS-311-DC-G002, March 2006.

[3] GNEC, The design report of the vacuum chamber, HAN-CNS-315-DC-G001, March 2006.

[4] S.H. Kim, Y. S. Joo, G. H. Lee, Structural analysis of the moderator cell and vacuum chamber in CNS, KNS, May 2004.

Table 1. Design stress intensity for Al6061-T6

°F	-20 to 100	150	200	250	300
ksi	14.0	14.0	14.0	13.4	11.3
MPa	96.5266	96.5266	96.5266	92.3898	77.9108

Table 2. Modulus of the elasticity for Al6061-T6

Al6061	-434°F	-325°F	-200°F	-100°F	70°F	200°F	300°F	400°F	500°F
$\times 10^6$ (psi)	11.6	11.1	10.8	10.5	10.0	9.6	9.2	8.7	8.1

Table 3. Thermal expansion coefficient for Al6061-T6

Al6061	-434°F	70°F	100°F	150°F	200°F	250°F	300°F	350°F	400°F
$\times 10^{-6}$ (in/in/°F)	9.45 ※13)	12.52	12.70	13.01	13.31	13.62	13.92	14.22	14.53

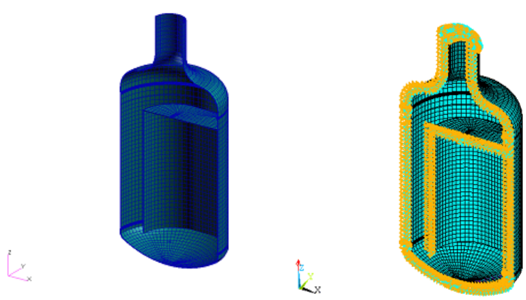

Fig. 1 Finite element model and boundary condition of the moderator cell

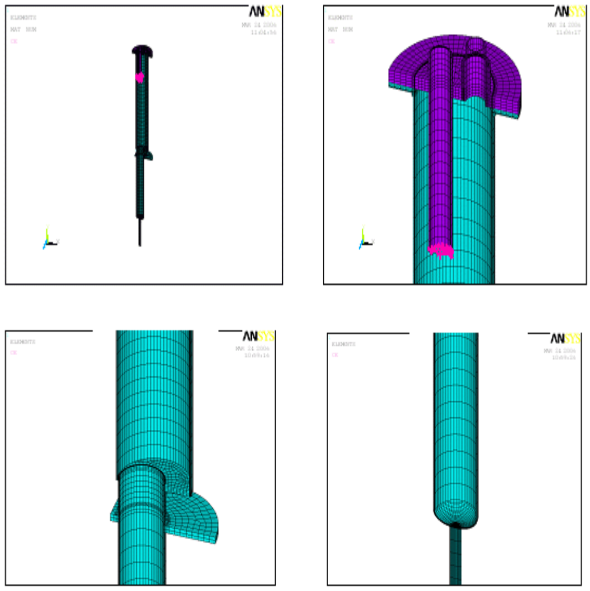

Fig. 2 Finite element model of the vacuum chamber

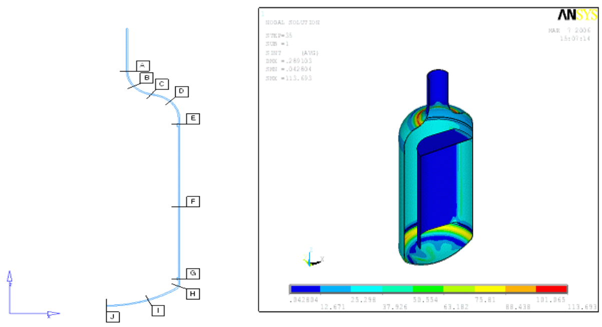

Fig. 3 Cross section and the result for the stress analysis of the moderator cell

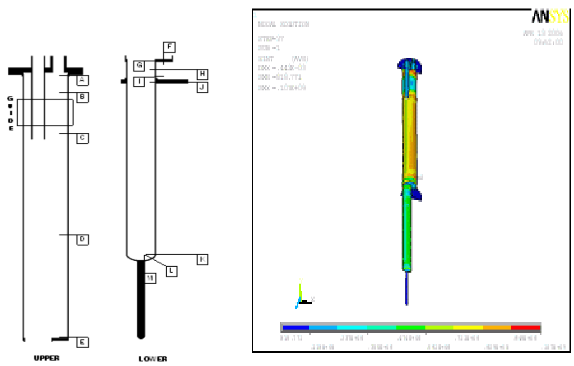

Fig. 4 Cross section and the result for the stress analysis of the vacuum chamber