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Preliminary Thermal Stress Analysis for Intermediate Heat Exchanger of Prototype SFR

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1. Introduction

In 150 MWe prototype sodium cooled fast reactor (SFR), four cylindrical-shaped intermediate heat exchangers (IHXs) are installed in the PHTS (primary heat transfer system) along with two primary pumps. They are a shell-and-tube type heat exchanger with counter-current flow heat exchanger mechanism. Each IHX is rated at 98.175 MWt to accommodate the core heat load of 392.6 MWt. For the interactive heat exchange within the IHX, the secondary sodium (non-radioactive sodium) of 324 °C goes into the IHX inner cylinder from a steam generator and the primary sodium (radioactive sodium) of 545 °C enters into the outside of tube bundle from the hot pool as shown in Fig. 1. Due to the temperature difference between the primary sodium and secondary sodium, the thermal expansion differences inevitably occurs so that it is necessary to introduce a bellows so as to absorb the thermal expansion.

In this study, we investigated a problem for the structural integrity of the IHX which is conceptually designed by using the thermal and structural analysis. In addition we proposed acceptable design concept, and confirmed its structural integrity following the same procedure.

2. Methods and Results

In this section, the geometric shape and boundary conditions of the IHX to calculate its temperature and stress distribution are described. The analysis results include the maximum thermal expansion displacement in the upper region of the IHX where a bellows is installed, and maximum stress in the upper tubesheet.

2.1 Boundary Conditions

The IHX is vertically supported on the reactor head with IHX support flange structure as shown in Fig. 1. A vertical co-axial support cylinder is connected to the IHX flange with skirt type support structure. So the fixed condition is applied at the bottom of the IHX flange as a boundary condition. Fig. 2 shows the temperature conditions in the IHX. The primary sodium inlet/outlet temperatures are applied to the upper tubesheet, lower tubesheet, and discharge structure. The secondary sodium inlet/outlet temperatures are also applied to the inner cylinder and chamber. At the IHX cylinder, the temperature data obtained from a CFD analysis performed by STAR-CCM+ is mapped to the structure model.

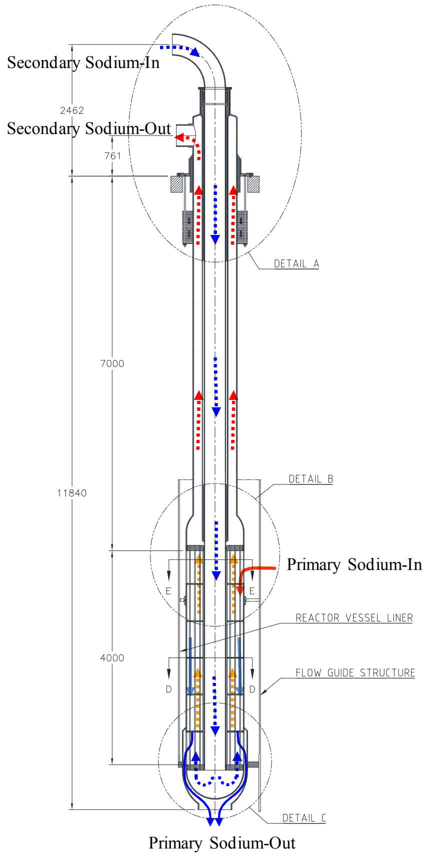

Fig. 1. Primary and secondary sodium flow paths in the IHX.

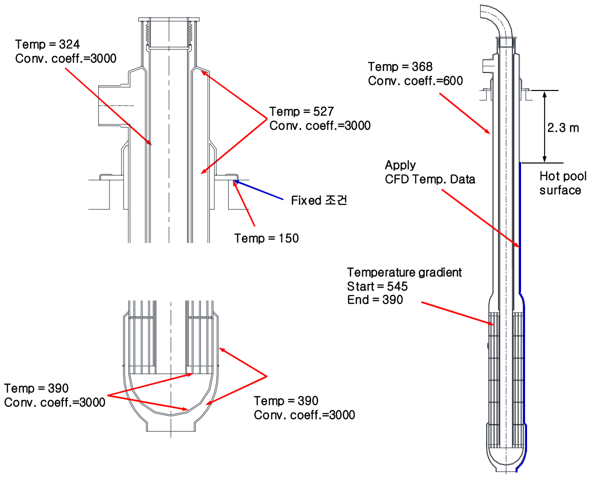

Fig. 2. Thermal and structural boundary conditions.

2.2 Stress Analysis Result of IHX

In conceptual design of the IHX, the upper tubesheet is weleded to the IHX inner cylinder and IHX outer shell. Also the thermal shield cylinder is installed in the outside of IHX inner cylinder and is welded to the upper tubesheet. The function of the thermal shield cylinder is to prevent the heat transfer from outcoming secondary sodium (hot) to incoming secondary sodium (cold) so as not to decrease efficiency. Fig. 3 shows the stress distribution in the upper tubesheet of the IHX. As shown in the figure, the maximum stress increases up to 603 MPa which is not acceptable in the elevated service conditions. This phenomenon results in the temperature difference between the IHX inner cylinder and upper tubesheet.

In order to avoid this stress concentration, the design concept in the IHX inside was changed: The thermal shield cylinder extends to the lower tubesheet and the upper tubesheet is welded to the thermal shield cylinder and IHX shell. Owing to the thermal shield cylinder, it is possible to prevent the thermal expansion difference between the IHX inner cylinder and upper tubesheet. Fig. 4 shows the stress distribution in the modified tubesheet area. As shown in the figure, the maximum stress is only a 43.5 MPa. From this result, it is concluded that the new concept is feasible in the elevated service condition.

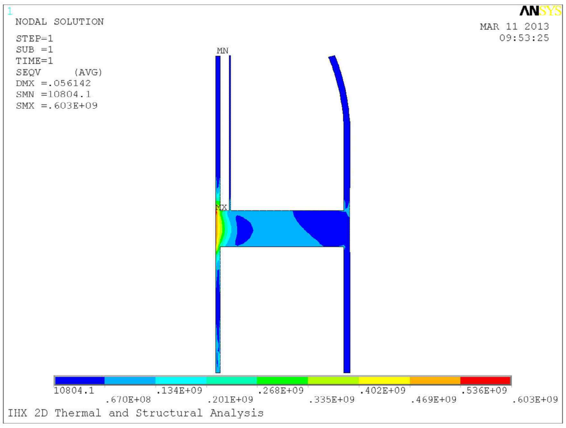

Fig. 3. Stress distribution of the upper tubesheet for the conceptual design concept.

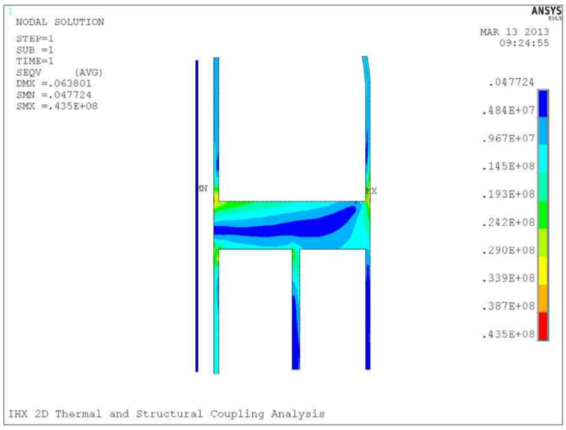

Fig. 4. Stress distribution of the upper tubesheet for new concept.

2.3 Development of Bellows Requirements

In order to develop the bellows design requirements we perform the thermal expansion analysis at the upper region of the IHX inner cylinder. Fig. 5 shows the result of the thermal expansion analysis. The "A" point extends about 9.6 mm to (+) Y axis direction and the "B" point extends about 29.9 mm to (–) Y axis direction. The total relative expansion difference between "A" and "B" point is about 37.6 mm. From this result, the bellows displacement requirement is set as follows.

○ Maximum relative displacement × design margin
= (37.6≒40 mm) × 2 = 80 mm.

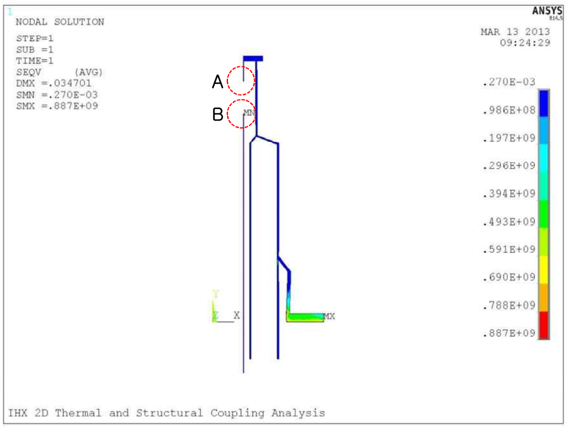

Fig. 5. Maximum thermal expansion displacement at the upper region of the IHX inner cylinder.

3. Conclusions

In this paper, the structural integrity about the conceptual design of IHX was reviewed and the design should be changed because of its high stress concentration in the upper tubesheet. In new design, the maximum stress decreases up to a reasonable level in virtue of the thermal shield cylinder to protect the heat transfer from the upper tubesheet to IHX inner cylinder. Also, the design requirement of a bellows for accommodating the thermal expansion of the IHX was developed.

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