Effect of structural modelling on seismic response of PFBR IHX

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ABSTRACT: This paper deals with the detailed seismic analysis of Intermediate Heat Exchanger (IHX) of 500 MWe Prototype Fast Breeder Reactor (PFBR). Structural integrity is assessed for both S1 (OBE) and S2 (SSE), since IHX is classified as seismic category 1 component. The effect of different modeling features of tube bundle, piping mass and Fluid Structure Interaction on seismic response of IHX are highlighted. It is concluded that IHX meets the codal and functional requirement.

1 INTRODUCTION

IHX is one of the main components of a FBR, operating at high temperature (Figure 1). For ensuring long term reliable operation of this component, it is required to investigate thoroughly the structural integrity under all possible loading condition. In this paper the structural integrity of IHX for PFBR is assessed under seismic excitations. Apart from meeting the stress limits, certain functionail requirements are also need to be satisfied in order to avoid any mechanical interaction with Inner Vessel (IV). Towards this, a detailed finite element modelling of IHX has been done and response spectrum method is used for determining the deflection and stress in the component under both S1 and S2 seismic excitations. The structural modelling of IHX is complex because of the presence of gap between shroud shell of IHX and stand pipe of IV, about 1782 straight tubes in the tube bundle with intermediate supports, Fluid Structure Interaction (FSI) etc. The required Floor Response Spectra (Figure 2) at IHX support has been obtained from the first phase of analysis (Ravi 1989) in which a time history analysis of reactor components including containment building and base raft is performed.

The allowable stresses are taken according to RCC-MR (1987). The deflection limit becomes the gap between associated shells. The calculation of natural frequencies, mode shapes and response have been carried out by using ‘INCA’ of CASTEM codes.

2 STRUCTURAL MODELLING OF IHX

The structural modelling of IHX (Figure 3) consists of central tube, the top and bottom tubesheets, the inner and outer shells of hot sodium collector, the biological shielding with
its inner and outer shells, windows for entry and exit of primary sodium, the tube bundle, the bottom dome, the shroud shell, stand pipe, and the supporting flange. Only horizontal excitation is considered in this analysis as contribution from vertical excitation is negligible. Thus the following modelling holds good only for horizontal excitation. The properties of various shells are given in Table-1.

Table-1 Properties of various shells modelled.

<table>
<thead>
<tr>
<th>Description</th>
<th>OD mm</th>
<th>Thickness mm</th>
<th>Length mm</th>
<th>Density Kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central tube</td>
<td>390</td>
<td>7</td>
<td>13390</td>
<td>17252</td>
</tr>
<tr>
<td>Hot sodium collector</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- inner shell</td>
<td>444</td>
<td>12</td>
<td>4820</td>
<td>7800</td>
</tr>
<tr>
<td>- outer shell 1</td>
<td>920</td>
<td>10</td>
<td>1405</td>
<td>7800</td>
</tr>
<tr>
<td>- outer shell 2</td>
<td>800</td>
<td>8</td>
<td>1815</td>
<td>7800</td>
</tr>
<tr>
<td>- outer shell 3</td>
<td>1600</td>
<td>15</td>
<td>1600</td>
<td>29209</td>
</tr>
<tr>
<td>Tube bundle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- inner shell</td>
<td>444</td>
<td>5</td>
<td>6790</td>
<td>26346</td>
</tr>
<tr>
<td>- outer shell</td>
<td>1548</td>
<td>5</td>
<td>5500</td>
<td>136079</td>
</tr>
<tr>
<td>Biological shielding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- inner shell</td>
<td>1600</td>
<td>15</td>
<td>1815</td>
<td>7800</td>
</tr>
<tr>
<td>- outer shell</td>
<td>2100</td>
<td>5</td>
<td>1750</td>
<td>163706</td>
</tr>
<tr>
<td>Top closure</td>
<td>1300</td>
<td>5</td>
<td>3195</td>
<td>7800</td>
</tr>
<tr>
<td>Shroud</td>
<td>2045</td>
<td>5</td>
<td>3200</td>
<td>50320</td>
</tr>
<tr>
<td>Standpipe</td>
<td>1810</td>
<td>12</td>
<td>3200</td>
<td>53314</td>
</tr>
</tbody>
</table>

** Density is adjusted to take care of liquid sodium

The following are the salient features of modelling:
The various components of IHX like shells of hot sodium collector, biological shielding, tube bundle, shroud and stand pipe and central tube are modelled by two noded axisymmetric shell elements (COQUE). Since the piping and bellows are flexible, they are not included in the modelling. However their inertial effects (due to mass) have been taken care after doing parametric studies. The windows for entry/exit of primary sodium have been modelled by equivalent shells. Equivalence in cross sectional area and moment of inertia are maintained. The tube sheets have been modelled realistically using equivalent E' and ν' as per perforated plate theory. The tube bundle has been modelled by four equivalent shells. The equivalent properties have been arrived after parametric studies (Table-2). The equivalent moment of inertia for tube bundle has been calculated as follows

\[ I_{eq} = \frac{A}{2} \Sigma R_i^2 N_i \]

where \( R_i \) - mean radius of the ring 'i'
\( N_i \) - number of tubes in th ring 'i'
\( A \) - cross sectional area of one tube
Table-2 Properties of equivalent shells of tube bundle

<table>
<thead>
<tr>
<th>Description</th>
<th>Mean radius mm</th>
<th>Thickness mm</th>
<th>Density Kg/m³</th>
<th>Total tubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell 1</td>
<td>334.6</td>
<td>12.43</td>
<td>17849</td>
<td>378</td>
</tr>
<tr>
<td>Shell 2</td>
<td>449.2</td>
<td>15.36</td>
<td>13880</td>
<td>480</td>
</tr>
<tr>
<td>Shell 3</td>
<td>563.8</td>
<td>12.05</td>
<td>14450</td>
<td>492</td>
</tr>
<tr>
<td>Shell 4</td>
<td>678.4</td>
<td>8.28</td>
<td>1535</td>
<td>432</td>
</tr>
</tbody>
</table>

The liquid sodium in the hot sodium collector and in the gaps of standpipe and shroud shells have been modelled by four noded liquid elements. The sodium in the central tube, dome, tube bundle have been taken care through added mass approach. The mass of bottom dome cover (487 Kg), distributor pipes (108 Kg), thermal shield (434 Kg), sodium outlet piping (13930 Kg), and mass of sodium inlet piping (20700 kg) are lumped at appropriate locations.

The connections between various shells have been modelled by using master slave option. The radial displacements at antivibration belts locations, and shells which support the biological shielding are made same. The horizontal displacement at top portion of hot sodium collector and inner shells are made same. Simply supported boundary condition has been used at IHX and roof slab flange location.

3 RESULTS OF ANALYSIS

The seismic analysis of IHX has been done for 0.078 g of S1(OBE) and 0.156 g of S2 (SSE). The damping values taken are 2% and 4% respectively.

3.1 Free Vibration Analysis

Natural modal behaviour of IHX has been done with/without including the piping mass. Natural frequencies and mode shapes upto 33 Hz have been determined. The important mode shapes including piping mass are given in figure 4. The central down comer and global bending of IHX contribute to the fundamental frequency of 2.29 Hz. The contribution from stand pipe is significant for first few modes. The stand pipe behaves as a cantilever structure from the bend portion as can be seen from the mode shapes.

3.2 Response Calculation

Results of the free vibration analysis is used to calculate the response of the structure like displacement and stress. Figure 5 and 6 give the displacement and stress intensity values at important locations. The maximum displacement values are 15.6 mm and 26 mm at bottom dome location for OBE and SSE respectively. The differential displacements values between shroud tube and stand pipe are 4.21 mm and 8.3 mm during S1 and S2 which is less as compared with the gaps. Thus there is no mechanical interaction between inner vessel and IHX. The maximum stress intensity (P1 + P2) values are 187 MPa and 132 MPa at stand pipe bend location for S2 (SSE) and S1 (OBE). Classifying S1 as level-B and S2 as level-D type of loading, the stress intensity values meet the RCC-MR codal limits.
3.3 Results of Parametric Studies

Parametric studies have been done to study the effects of tube bundle and piping mass. The modelling of tube bundle differs in computing bending moment of inertia. In the first case, the equivalent bending moment of inertia is the sum of the moment of inertia of all tubes (nxl) (EPRI 1978). This leads to additional modes for tube bundle. In the second case, contribution of bending inertia due to the position of the tubes with respect to symmetric axis of tube bundle is also accounted. But it is observed that the maximum stress intensity which occurs at stand pipe bend location is not changed.

The total piping mass including the mass of sodium in the piping between IHX inlet and pump is calculated. Half of this mass is lumped at IHX inlet location. Similarly half of the total piping mass between IHX outlet and surge tank is lumped at IHX outlet location. Addition of the piping mass decreases the fundamental frequency from 2.9 Hz to 2.29 Hz. Moreover some additional modes are also observed for central downcomer.

4 CONCLUSION

The detailed seismic analysis of IHX by response spectrum method has been done including the FSI effect, for S1 of 0.078g and S2 of 0.156g (ZPA). Parametric studies have been performed while modelling tube bundle, and piping mass. The functional requirement is met as there is no mechanical interaction between IHX and inner vessel during S1 excitations. The maximum stress intensity meets the RCC-MR codal limits.

REFERENCE


Design and construction rules for mechanical components of FBR Nuclear Islands (RCC-MR), AFCEN, Paris, France, 1985, with addenda-Nov.1987

CASTEM, 1985, A finite element software for structural analysis in nonlinear applications, CEN/DMT, Saclay, France.

Fig. 1 PFBR IHX

Fig. 2 Support spectra (horizontal) 0.1 g SSE

Fig. 3 IHX model for seismic analysis

Fig. 4 Natural mode shapes of IHX
Fig. 5 Displacement values at important locations  
Fig. 6 Stress intensity values at important locations