Fatigue Analysis of Dhrua Reactor Poison Tubes

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Abstract

The liquid poison tubes would be used as a secondary device for shutting down the 100 MW (thermal) Dhrua Reactor. The poison tubes are made of zircaloy and are arranged in a square array around the centre of calandria. A fatigue analysis of the piping system as per sub article NB-3600 of the ASME Sec. III code was performed. The analysis has been done using beam type mesh and supplemented by use of 3-D-shell elements in critical locations such as an elbow.

Introduction

Fatigue analysis of poison piping system has been done using beam model. Ovalization in zircaloy elbow which forms a part of this piping system, is taken into account by means of flexibility factors. In the development of stress indices and flexibility factors, the effects of end restraints which inhibit Cross Sectional Ovalization has been neglected. The stresses were calculated according to ASME Sec. III /1/. To assess the amount of conservatism involved in ASME calculation, the zircaloy bend was analysed using 3-D shell elements. The present paper describes the validity of the stress indices and flexibility factors used in beam model.

Geometry and Loading

The poison tube would be used as a secondary device for shutting down the Dhrua Reactor. There are 20 such tubes arranged in a square array of 180 mm pitch around center of calandria as shown in (Fig.1). The poison tubes are made of zircaloy-2 having 25 mm outside diameter and thickness of 1 mm. At the top, the poison tubes are rolled into lower part of the lattice tube of top plenum of calandria. At the bottom of calandria, the zircaloy tube extends into a service room. To isolate the Heavy Water boundary, a 45 mm outside diameter and 6 mm thick stainless steel sleeve surrounds the poison tube and is welded to the bottom tube sheet. The stainless steel sleeve is welded to the in-embedded sleeve fixed in the vault concrete. This sleeve then extends as a stainless steel bend pipe of 60 mm outside diameter and 5 mm thick and is welded to a stainless steel fitting in which zircaloy tube is rolled. The coxial bend is provided to accommodate the differential thermal expansion of two tubes as shown in (Fig.2). The bending of zircaloy tube has been done in situ because insertion of a bend tube would require higher head room. Since bending of zircaloy tube has been done in situ, it is not possible to replace zircaloy tube in its life time. Therefore, it was necessary to carryout its fatigue life estimation. The analysis has been done using STRAPS /2/ computer programme. The discretization is shown in (Fig.3). The poison tube assemblies have been analysed for following reactor conditions.

a) Case-I: The reactor is shut down and temperature of loop is 50°C. Top plenum moves upward due to change once from auxiliary pumps to main pumps. The number of such occurrences could be 500.

b) Case-II: The loop is at 50°C and main pump is working. The reactor goes to full power and zircaloy tube in calandria reaches a temperature of 70°C. The number of such occurrences could be 2000.
a) Case-III: This case takes care of power failure. When power fails, the main pump trips (before power failure the temperature of zircaloy tube in calandria is at 70°C). The auxiliary pump is switched on and the reactor is shut down and kept temperature is 50°C. The number of expected cycles for such power failure are 500.

d) Case IV: In accidental condition, the zircaloy temperature may reach from 70°C (full reactor power) to 150°C. The number of such occurrences could be 10 in lifetime.

The movement of zircaloy tube relative to top plenum at different conditions is shown in Table 1. These movement have been obtained by performing a stress analysis of top plenum.

**Table 1**

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Movement cm.</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.07 upward</td>
<td>Main pump on</td>
</tr>
<tr>
<td>50</td>
<td>0.25 downward</td>
<td>Auxiliary pump on</td>
</tr>
<tr>
<td>70</td>
<td>0.08 upward</td>
<td>Reactor is operating at full power</td>
</tr>
<tr>
<td>150</td>
<td>0.37 downward</td>
<td>Loss of structural coolant</td>
</tr>
</tbody>
</table>

The displacement of top plenum because of the movement of upper shell is not accounted.

**Calculations and Results**

The flexibility factor and stress index for zircaloy bend is 1.2 & 1.5 respectively. As expected the maximum moments occur in zircaloy bend and are 81, 923, 190 & 1910 kg.cm. for cases 1, 2, 3 and 4 respectively. The fatigue analysis has been done using ASME Sec.III class 1 stress equations. The detailed results presented in Table 2.

**Table 2**

<table>
<thead>
<tr>
<th>Cases</th>
<th>Reactor Condition</th>
<th>$S_p$ kg/cm²</th>
<th>$K_e$</th>
<th>Salt kg/cm²</th>
<th>$U = \frac{n_k}{n_k} /4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Auxiliary pump is working</td>
<td>500</td>
<td>1.0</td>
<td>1462</td>
<td>(between 1-2)</td>
</tr>
<tr>
<td>2</td>
<td>Main pump is working</td>
<td>3424</td>
<td>1.0</td>
<td>1272</td>
<td>(between 2-3)</td>
</tr>
<tr>
<td>3</td>
<td>Full power</td>
<td>880</td>
<td>1.0</td>
<td>190.0</td>
<td>(between 1-3)</td>
</tr>
<tr>
<td>4</td>
<td>Loss of structural coolant</td>
<td>6678</td>
<td>1.4</td>
<td>4375</td>
<td>(between 3-4)</td>
</tr>
</tbody>
</table>

**Total usage factor** 0.375
Since the above analysis uses beam model, the zircaloy bend has been also
analysed using flat shell element for unit inplane moment. The number of nodes and
elements were 301 and 280 respectively. The discretization is shown in (Fig.4). The
stress index for inplane moment was found to be 1.3. This shows that the calculation
based on ASME rules is conservative.

Conclusion

The result of stress and fatigue analysis of peison tube using beam elements shows
that the zircaloy elbow is the most highly stressed member and that calculated values
based on ASME stress indices are conservative.

References

1/ ASME Boiler Pressure Vessel code, Sec.III. 1980.


FIG. 1 GENERAL PILE BLOCK ARRANGEMENT
OF DHURVA REACTOR.

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