Effect of Pressure Sagging and Ballooning on Reactivity of CANDU6

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1. Introduction

Although two major phenomena of radial expansion and axial sagging are the most important for pressure tube deformation, the sagging effects are not studied much because of its modelling difficulty. Thus, quantitative research on sagging should be discussed for a precise estimation of the sagging effects. There have been several studies on pressure tube ballooning. HELIOS was used for a calculation of the multiplication factors, coolant void reactivity (CVR), plutonium production and pin power [1, 2].

Naturally, a comparison between the effects of sagging and ballooning has never been done before. In this study, utilizing the finite element method (FEM) code, the sagging effect is analyzed in a 3-dimensional space. Using GMESH software which will be used as a meshing and meshing tool, the pressure tube and sagging can be simulated. The multi-group cross sections for each region are provided using the McCARD code [3]. To analyze the pressure tube sagging phenomenon, the periodic boundary condition should be implemented into the FEM code for a more close realization of the problem. Data acquisition from the Wolsong site is done for this study. Among various channels, the channel that gives a conservative result is selected, namely, the channel that goes through extreme circumstance is chosen. To save the mesh and calculation time, a quarter of the channel is analyzed under reflective boundary conditions. Thus, it is assumed that all channels have symmetry on the axial direction.

2. Deformation, Modeling and Mesh Generation

In this section, the pressure tube dimensions are introduced briefly to a sense about scale and modelling. Also, the phenomena of pressure tube deformation, and the contributions of each phenomenon are summarized for the analysis. Finally, to know the importance of the pressure tube, the relation between pressure tube aging and CANDU reactor safety margin is analyzed.

In this paper, the sagging and the radiation expansion-ballooning- are taken into account to the modelling. To retain conservatism, the most aged core is decided to study. Because the maximum life expectancy of the pressure tube is about less than 30 years, it is assumed that all channels are experiencing same burnup and all channels have gone through 30 years old operation of the plant. So, the results of this paper has quite high conservatism due to the approximations which is underlying in this paper. In the following graph, we can observe that the maximum amount of sagging at the center of the pressure tube is just about 30mm [5].

3. Numerical Results

Only 3D results are introduced in this research. The multiplication factors and power errors are excluded in this paper. Of course, the ballooning effect is solely considered because of its dimensional limitation. The reference provided us with the result of the multi-group McCARD code. The command `fispower` which only considers the fission power is used for the reference power data. In addition, results based on the quadratic basis functions are excluded in this research.

Although a lattice calculation of the McCARD code which uses a continuous cross section, is the most precise among the various results, the multi-group calculation of the McCARD code is used as a reference because of consistency. During the group constant generation procedure, reactions that can contribute to the production of neutrons such as \((n,2n)\) and \((n,3n)\), are regarded as absorption, and the multiplication factor will be quite different from a lattice calculation. The following is the multiplication factor results for 3D. In this paper, case 1, case 2, case 3 and case 4 indicate before a deformation, ballooning only, sagging only and combined models, respectively.

4. Conclusions

It is well known that the neutrons in a CANDU lattice are too well moderated and thus their population will decrease when a greater coolant volume is given around the fuel pin because of an over moderation. Thus, as shown in Figs. 3 through 6, the pin power surrounded by more coolant has a smaller power level compared with the others.

Comprehensively, the ballooning affects both the multiplication factor and the power distribution. The sagging merely affects the power distribution. In addition, it seems that the ballooning effect is larger than that of the sagging. In contrast, the sagging effect cannot be neglected from the result of this paper. Due to the sagging, the pin power distribution can be different from the reference state. In the future, the neutronics and thermal-hydraulics coupled simulation with the FEM code and the CUPID code will be conducted and

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**Table 1. Mesh Data for FEM Analysis**

<table>
<thead>
<tr>
<th>Case</th>
<th>Nodes</th>
<th>Elements</th>
<th>Avg. Vol. (cm³)</th>
<th>Avg. Pitch (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>193,539</td>
<td>1,067,193</td>
<td>0.142</td>
<td>0.580</td>
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<tr>
<td>Case 2</td>
<td>194,771</td>
<td>1,073,843</td>
<td>0.141</td>
<td>0.579</td>
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<tr>
<td>Case 3</td>
<td>190,754</td>
<td>1,044,561</td>
<td>0.145</td>
<td>0.584</td>
</tr>
<tr>
<td>Case 4</td>
<td>191,273</td>
<td>1,047,168</td>
<td>0.145</td>
<td>0.583</td>
</tr>
</tbody>
</table>

**Table 2. Power Error Calculations for 3D CANDU Channel**

<table>
<thead>
<tr>
<th>Case</th>
<th>McCARD Multi-group</th>
<th>FEM P1</th>
<th>FEM SP3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>1.09688</td>
<td>1.08641</td>
<td>1.09711</td>
</tr>
<tr>
<td>Case 2</td>
<td>N/A</td>
<td>1.09825</td>
<td></td>
</tr>
<tr>
<td>Case 3</td>
<td>N/A</td>
<td>1.10652</td>
<td></td>
</tr>
<tr>
<td>Case 4</td>
<td>N/A</td>
<td>1.10650</td>
<td>1.09712</td>
</tr>
</tbody>
</table>

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Fig. 1. Sagging of Pressure Tube and Calandria Tube with Time

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Fig. 2. Power Errors for 3D CANDU Channel for Case 1

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Fig. 3. Power Errors for 3D CANDU Channel for Case 2

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Fig. 4. Power Errors for 3D CANDU Channel for Case 3

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Fig. 5. Power Errors for 3D CANDU Channel for Case 4