Effects of Pressure Tube 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 research, utilizing the finite element method (FEM) code, the sagging effect is analyzed in a 3-dimensional space. Using GMSH software which will be used as a modeling 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

To obtain a finite element solution, the mesh generation should be conducted and for the mesh generation, modeling should be done prior to the modeling. In this research, the GMSH utility is used for both modeling and mesh generation [4].

2.1 Deformation

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].

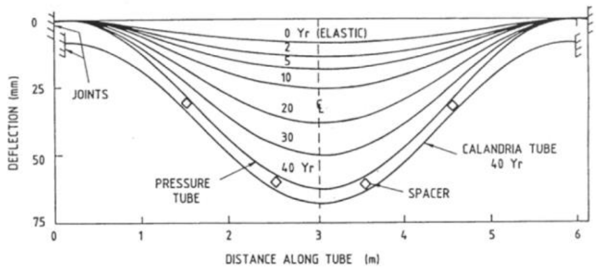

Fig. 1 Sagging of Pressure Tube and Calandria Tube with Time

Not the sagging data but also the ballooning data is based on the same assumption about channel to ensure conservatism. The data from wolsong unit 1 which has been operated for more than 30 years is taken. But in this paper the values are requested not to open from the source, thus the exact values will not be listed here in this paper. Note that the ballooning values belong to the range which is between 0 to 5mm for radius.

2.2 Modeling

In reality, every channel has its own irradiation and power. Thus, every channel has a different deformation. Practically, however, to ensure a sufficient accuracy of the result, it is expected that a million of elements is necessary for a single channel analysis. Considering that the total number of channels in the core is 380, a total of 380 million elements which is too big to analyze are necessary. Thus, a channel that has the maximum deformation is analyzed based on the assumption that all channels have the maximum deformation owing to the modelling difficulty. At this point modeling errors occur. However, we can regard this modelling error as a conservative approach. Fortunately, the GMSH utility has a modeling capability to model the deformation of the pressure tube. Although thinning and elongation also occur, only ballooning and sagging are modelled in this research because of their priority. To see separate effects of ballooning and sagging, four models are used: the initial state model, ballooning only model, sagging only model and combined deformation model

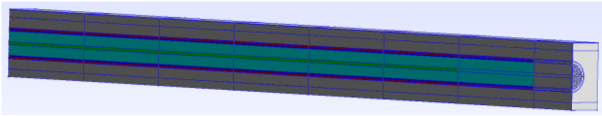

Fig. 2 Modeling of Initial State

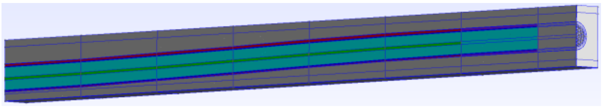

Fig. 3 Modeling of Combined Deformation

2.3 Mesh Generation

As mentioned before, the number of elements is one-million for a channel. For example, 2-3 million elements are used for the CANDU moderator analysis which was conducted at KAERI. Thus quite a long time is required. Most of all, to apply the periodic boundary condition for the sagging analysis, a limitation exists for the mesh generation. In this research, the 'meshadapt' algorithm for a 2D meshing procedure is used for the periodic boundary conditions.

3. Numerical Results

Only 3D results are introduced in this research. The multiplication factors and power errors are included 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.

Table I. Mesh Data for FEM Analysis

	Nodes	Elements	Avg. Vol. (cm^3)	Avg. Pitch (cm)
Case 1	193,539	1,067,193	0.142	0.580
Case 2	194,771	1,073,844	0.141	0.579
Case 3	190,754	1,044,661	0.145	0.584
Case 4	191,273	1,047,168	0.145	0.583

Table II. K_{eff} Calculations for 3D CANDU Channel

	McCARD Multi-group	FEM P1	FEM SP3
Case 1	1.09688	1.10843	1.09895
Case 2	N/A	1.10641	1.09711
Case 3	N/A	1.10852	1.09925
Case 4	N/A	1.10660	1.09725

In Table II., the number of 1,000,000 particles and 1,000 cycles including 200 inactive cycles are used. The standard deviations for the McCARD results are 2pcm.

Table III. Power Error Calculations for 3D CANDU Channel

		Case 1	Case 2	Case 3	Case 4
3D FEM P1	RMSE	1.76	1.78	1.77	1.79
	MAXE	2.81	2.81	2.89	2.89
	Position	Pin 1	Pin 1	Pin 4	Pin 4
3D FEM SP3	RMSE	1.20	1.22	1.23	1.25
	MAXE	2.14	2.13	2.23	2.23
	Position	Pin 3	Pin 3	Pin 4	Pin 4

In Table II., a 2mk difference occurs in the multiplication factor for 3D results with the maximum deformation data, which is same as in previous 2D research. In addition, almost a 2mk difference occurs in the multiplication factors for the 3D results in the case of combined deformation with the maximum deformation data. The sagging effect is negligible in the case of multiplication factor results. In table 3, because half of the lattice is modelled in this research to save the mesh, the number of pins is also reduced from 37 to 19. If pins are in the same array, the index numbering will start in the clock-wise direction. The followings are the power distribution results.

In fact, to exactly model the fuel rod, the mapping scheme which allowed us to use the FEM code for the curved geometry should have been used in this research. But due to the extremely large number of unknowns causes extremely large value of calculation time, necessarily. Thus to avoid this situation, it is assumed that the volume loss due to the mesh is negligible to the result.

For the circular geometry which is perfectly 2^{nd} order equation such as pin, cladding, pressure tube and calandria tube, the mapping scheme gives almost 0% volume loss with radius dimension of several centimeters.

If we change the geometry to conserve volume of pin and et al., that is same as changing problem itself essentially, because of spatial self-shielding and fuel to moderator density.

Fig. 4 Power Errors for 3D CANDU Channel for Case 1

Fig. 6 Power Errors for 3D CANDU Channel for Case 3

Fig. 5 Power Errors for 3D CANDU Channel for Case 2

Fig. 7 Power Errors for 3D CANDU Channel for Case 4

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 analyzed.

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