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A Study on the Application of Analytic Nodal Method to a CANDU-600 Reactor Analysis

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1. INTRODUCTION

The analysis of flux distribution under stead-state in large power reactors with assymetry reactivity insertions requires the use of three-dimensional diffusion calculations. For the purpose, consistently formulated modern nodal methods based on higher order interface techniques have become popular tools for flux distributions in large commercial nuclear reactors. Among the earlier developments, the nodal Green's function method obtains its nodal interface equation from the transverse-integrated integral diffusion equation using a finite-medium Green's function. In this method, the outgoing current from a node surface is formulated as a response of the incoming currents and the spatially integrated neutron source within the same node. The well-known nodal expansion method is also based on an interface partial current formulation. Nodal methods high-level interface variables, i.e., interface net current and flux, may be more computationally efficient than the nodal Green's function method because they have one fewer unknown per interface. The Analytic Nodal Method(ANM), which can be classified as an interface net current technique and , was faster in solving some standard benchmark problems than the other two methods.

The advantage of the nodal methods is that their computer storage requirements are modest; they are fast-running, and their predictions of nodal flux are fairly accurate. For those reasons they are much used by the utility industry. Especially, the geometrical complexity of a CANDU core is so great that the application of analytic nodal method is a good approach for full-core analysis. The approach that is generally taken to alleviate this difficulty is to treat large spatial regions as homogenized. The homogenization in a CANDU core is performed for regions which contain one or several bundles or control devices in a radial or axial plane. A conventional homogenization method was introduced in the study

The objective of the study was to propose an efficient, economical, and accurate method for three-dimensional, two-group, full-core analysis of CANDU core. And as a result, ANM could be proposed as an alternative to the computationally inefficient finite difference techniques.

2. THEORY AND METHOD

2.1 ANM Theory

The static multigroup equation in conventional matrix form used in the study can be written as

$$\nabla \cdot [D_g(\vec{r})] \nabla [\phi_g(\vec{r})] + [\Sigma_T(\vec{r})][\phi(\vec{r})] = \frac{1}{\gamma}[x][\nu\Sigma_f(\vec{r})]^T[\phi(\vec{r})]. \qquad g = 1, 2, 3, \ldots\ldots\ldots. G \tag{1}$$

The static solution to Eq. (1) can be obtained by varying a critical eigenvalue such that a nontrivial solution to the static multigroup equations exists

The first step in the derivation of the nodal diffusion equation is to integrate Eq.(1) over the volume of an arbitrary node. the utility of the integrated equation is limited by the fact that without additional relationships between the face-averaged currents and the node-averaged fluxes, the spatial flux distribution cannot be determined. To obtain a differential equation from which the spatial coupling can be determined, Eq.(1) should be integrated over the two direction transverse to a direction. Eq.(2) derived from Eq.(1) by using several integrals, definitions, and notations can be cast in the form

$$\begin{aligned} -[D_{l,m,n}]\frac{\partial^2}{\partial u^2}[\phi_{u_{l,m,n}}(u)] + ([\Sigma_{T_{l,m,n}}] - \frac{1}{\gamma}[x][\nu\Sigma_{f_{l,m,n}}]^T[\phi_{u_{l,m,n}}(u)]) \\ = -[S_{u_{l,m,n}}(u)] = \frac{1}{h_v{}^m}[L_{v_{l,m,n}}(u)] + \frac{1}{h_w{}^n}[L_{w_{l,m,n}}(u)]. \end{aligned} \tag{2}$$

To obtain relationships between the node-averaged fluxes and the face-averaged net leakages, one need only solces Eq.(2) and integrate the one-dimensional flux over the node. Unfortunately, the dependence of the transverse leakage source term on the RHS of Eq.(2) on a direction must be known or approximated if the solution of the equation is to be found. The condition makes necessary the first, the only, approximation of the ANM

The geometrical complexity of a CANDU core as shown Fig. 1 is so great that direct representation of full geometrical heterogeneity is precluded for reasons of practicality. The approach that is generally taken to alleviate this difficulty is to treat large spatial regions as homogenized. The homogenization in a CANDU core is performed for regions which contain one or several bundles or control devices in a radial or axial plane. The full core reactor calculation is thus reduced to that of determining the spatial flux distribution within a reactor containing several thousand homogenized regions. In the study, the approximation values of the homogenized parameters are determined from Eq.(3) as a conventional homogenization scheme.

$$\Sigma_{ag_{i,j,k}} = \frac{\int_{V_{i,j,k}} \Sigma_{ag}\phi_g(\vec{r})d\vec{r}}{\int_{V_{i,j,k}} \phi_g(\vec{r})d\vec{r}} \tag{3}$$

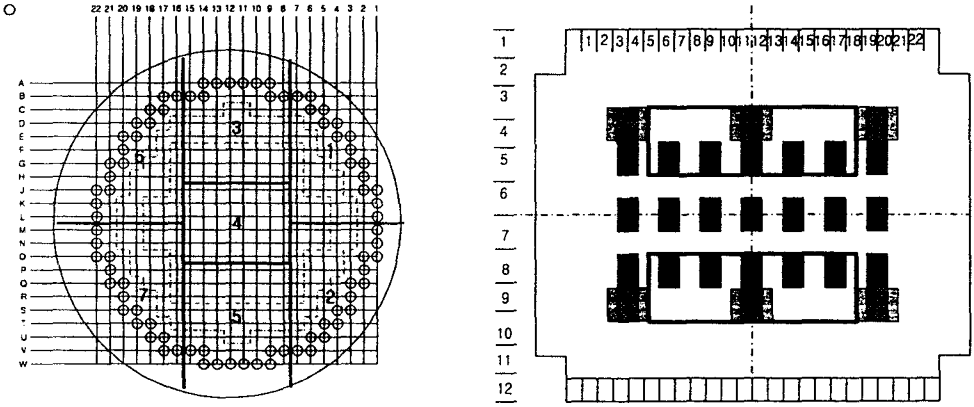


Fig.1 Geometry of CANDU core in X-Y plane and X-Z plane

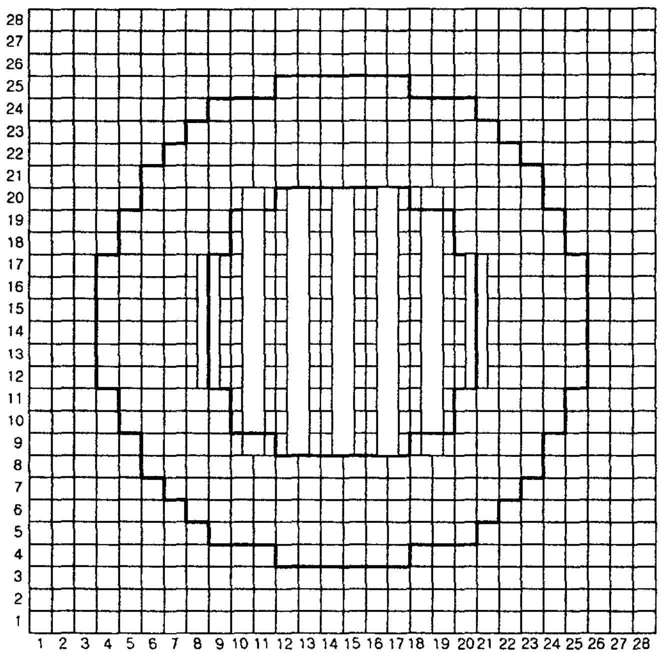


Fig.2 Example of Coarse Meshes used in ANM calculations

2.2 Method

The procedure and method in applying ANM to a CANDU core analysis was as follows:

1) The IAEA2D Benchmark problem and two-dimensional CANDU core were used for benchmark calculations.

a. IAEA2D Benchmark Problem

b. Comparison with results of ADEP(FDM; 113X113, ANM; 28X28(Fig(2))

The compatability between two-dimensional X-section and three-dimensional X-section should be given in the comparison of three-dimensional calculation with two-dimensional calculation. The assumption in the calculation is given in Eq. (4)

$$\Sigma_R \ (of \ \ 3-Dimension) \approx \Sigma_R + DB^2 \ (of \ \ 2-Dimension) \tag{4}$$

2) X-section tables of CANDU core was generated by homogenizing nodes using Eq.(3) in each perturbed plane and two-dimensional core analysis and error estimation were executed(Use of basic lattice, reflector, incremental X-section in equilibrium state)

a. In case of dividing into 784 nodes in a radial plane including Adjusters

b. In case of dividing into 441 nodes in a radial plane including Adjusters

c. In case of dividing into 256 nodes in a radial plane including Adjusters

d. In case of dividing into 100 nodes in a radial plane including Adjusters

e. In case of dividing into 100 nodes in a radial plane including Liquid Zone Controllers(LZCs) being fully filled with water

f. In case of dividing into 100 nodes in a radial plane including LZCs drained(50%)

4) Three-dimensional CANDU core(10X10X12) was analyzed by ANM and errors compared with the results by using more fined meshes(28X28x12) were estimated.

3. RESULTS

To validate the benefit of the ANM, a global CANDU core with conventional homogenization cross-section library is solved by the fine mesh FDM and bundle sized nodal method. As shown in Fig.3, we can visualize the flux distribution calculated by two-dimensional ANM is resonable. Effective multiplication factor calculated by ANM was 0.9969916 and that calculated by FDM was 0.99618340. The difference of Effective multiplication factor between FDM and ANM was 0.8mk.

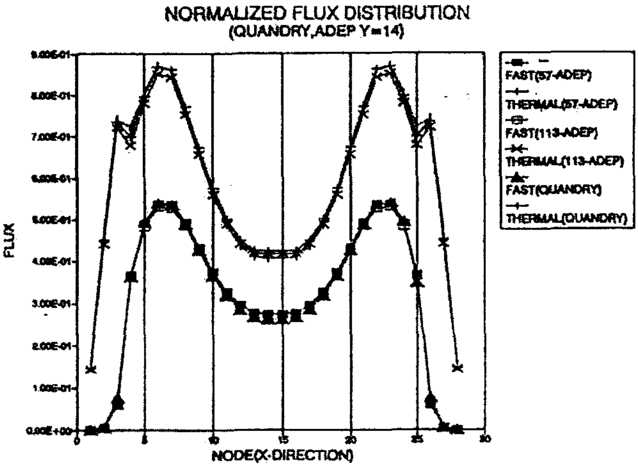
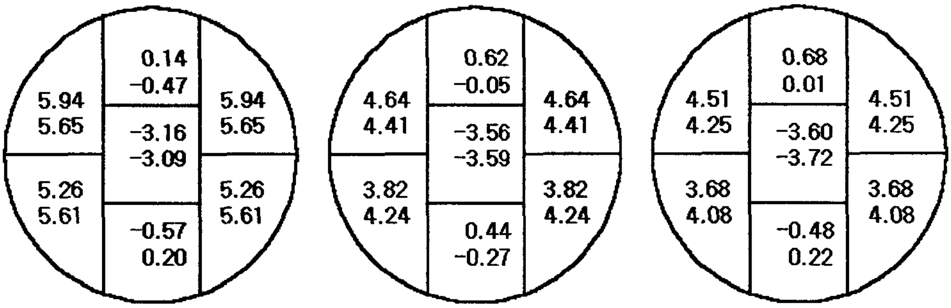


Fig.3 Comparison of the results by ANM and FDM

The errors in the results by using cross-section tables of CANDU core generated by conventional homogenization was also resonable. From the results, we could realize the conventional homogenization could be applied to three-dimensional CANDU core analysis.

Fig.4 shows zonal averaged errors, which are calculated by dividing the sum of node errors by the number of nodes in each zone.



Plane includinf LZCs **Plane without perturbation** **Plane including adjusters**

Fig.4 Error estimations in planes with perturbation or without perturbation(% error)

4. CONCLUSION

The geometrical complexity of a CANDU core is so great that the application of ANM would be a good approach for full-core analysis because they are fast-running, and their predictions of nodal flux are fairly accurate. The conventional homogenization in a CANDU core was performed for regions which contain one or several bundles or control devices in a radial or axial plane. The use of ANM and the conventional homogenization predicts nodal fluxes with maximum zonal averaged error of 5.94% and criticality within within 0.9% error error relative to the fine-mesh calculations. Possible error contributions from coarse mesh modeling are due to redefining fuel region boundary, homogenization from heterogeneous material properties, and domain transformation. Errors would be reduced by using discontinuity factors at node-interfaces and new homogenization theories.

In conclusion, ANM could be proposed as an alternative to the computationally inefficient finite difference techniques.

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