Overlapping Local/Global Iteration Method for 2-D Hexagonal Whole-Core Transport Calculation

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1. Introduction

Diffusion nodal method is a common way for analyzing whole core in the current reactor design process. Isolated single-assembly lattice physics calculations provide homogenized parameters. Major approximation originates from the net current zero boundary condition which does not reflect inter-assembly transport effect. Therefore, the whole-core diffusion nodal method results in inaccurate solutions compared to the whole-core transport calculation. Half-assembly overlapping local/global (OLG) method was proposed to overcome this limitation of conventional diffusion whole-core calculation [1-3]. Here, the boundary condition for local calculation is iteratively updated by p-CMFD based whole-core calculation which preserves transport partial currents when it is converged. It was shown that in OLG framework the solution converges to whole-core transport solution within several iterations in simple 1-D slab geometry problems [2] and also in 2-D heterogeneous rectangular geometry problems [3]. In this paper, the OLG framework is implemented for 2-D hexagonal high temperature gas-cooled reactor (HTGR) core.

2. Basic Concept and Method

A flow chart of the local/global framework with p-CMFD is given in Fig 1. Detailed scheme of OLG method is explained in previous works [2, 3].

In the case of deterministic local problem, partial currents from global calculations are used to update the angular binwise incoming angular flux at the local calculation boundary and the local problem is solved with the updated boundary condition and fixed k_{eff} (fixed-k problem formulation). Eq. (1) describes the way of angular flux update:

$$\psi_{\pm n,g}^{\text{new,local}}(\vec{r}) = \frac{\psi_{\pm n,g}^{\text{local}}(\vec{r})}{\bar{J}_G^{\pm,local}} \bar{J}_G^{\pm,global}. \qquad (1)$$

2.1 Overlapping Local/Global Method in Hexagonal Geometry

Fig. 2 shows calculational mesh for OLG framework. The hexagon with blue dotted line indicates local calculation boundary for highlighted block. In this work, local calculation was done using diamond difference scheme for equilateral triangular fine mesh cells. Global p-CMFD parameters are obtained by homogenization and condensation using the local calculation results on coarse-mesh cell (green line) and in few groups.

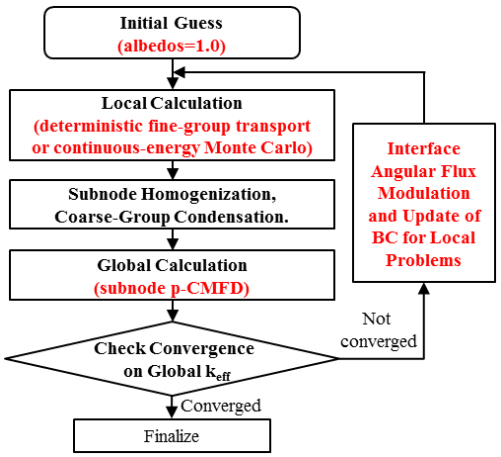

Fig 1. Flow chart of the local/global iteration framework with p-CMFD

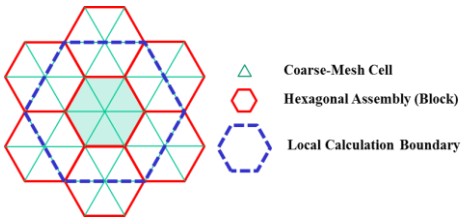

Fig 2. Calculational mesh for hexagonal geometry

2.2 p-CMFD Method for Whole-Core Transport Solution

Angle-integrated form of the general neutron transport equation with standard notations is written as

$$\nabla \cdot \vec{J}(\vec{r},E) + \sigma_t(\vec{r},E)\phi(\vec{r},E) = \int_0^\infty dE' \sigma_{s0}(\vec{r},E' \to E)\phi(\vec{r},E') + \frac{\chi(E)}{k_{eff}} \int_0^\infty dE' \nu\sigma_f(\vec{r},E')\phi(\vec{r},E'). \qquad (2)$$

Using volume-weighted cross sections, Eq. (2) is rewritten as

$$\frac{1}{V_i}\sum_{is=1}^{3} A_{i,is}(\bar{J}^{+}_{g,is}-\bar{J}^{-}_{g,is})+\bar{\sigma}_{tg,i}\bar{\phi}_{g,i}=\sum_{g'=1}^{G}\left(\bar{\sigma}_{gg',i}+\frac{\chi_g}{k_{eff}}\nu\bar{\sigma}_{fg',i}\right)\bar{\phi}_{g',i}, \quad (3)$$

for 2-D triangular coarse-mesh cell *i* in Fig. 3.

In the p-CMFD method, $\hat{D}^{\pm}_{g,is} \leftrightarrow \bar{J}^{\pm}_{g,is}$ "correspondence device" is used; for details, see the review paper [4] and references therein.

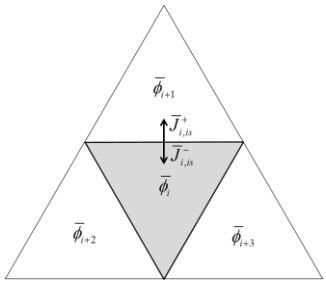

Fig 3. Coarse-mesh cell *i* and its neighbor cells

3. Test Problem and Numerical Results

The OLG framework for hexagonal geometry is tested using a test problem. The problem is described in Fig. 4 with 60 degrees of symmetry. The problem consists of three types of blocks with heterogeneity in fuel block. Configuration of the problem is simplified from the Zhang's benchmark problem [5]. Side length of the assembly is $20/\sqrt{3}$ cm and the local calculation uses triangular fine-mesh cells of 1.25cm height (64 fine-mesh cells per coarse-mesh cell). At every iteration step, after local calculation, the materials are homogenized within each coarse-mesh cell and energy group is condensed from six-group to two-group.

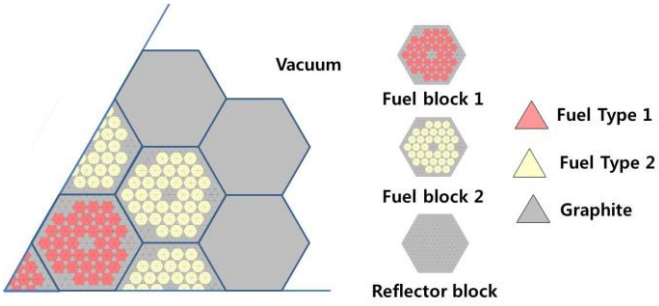

Fig 4. Configuration of the test problem

Table I shows the results. Under local/global iteration, the solution converges to the reference result of direct whole-core transport calculation. However, the convergence speed is slow in this problem compared to the previous work [3]. This seems to be coming from the problem size and the geometrical effect, but needs to be checked further.

Table I: Numerical results of the test problem

Iteration number	k_{eff}	Rel. Err. (pcm)*	Iteration number	k_{eff}	Rel. Err. (pcm)
0	0.618105	-4289.86	6	0.645788	-3.24
1	0.635816	-1457.37	7	0.645798	-1.66
2	0.642915	-448.13	8	0.645802	-1.07
3	0.644864	-146.37	9	0.645803	-0.88
4	0.645647	-25.13	10	0.645804	-0.83
5	0.645756	-8.24	-	-	-

* Reference k_{eff} = 0.6458097

4. Conclusions

The overlapping local/global iteration framework is extended to the 2-D hexagonal geometry in HTGRs. A heterogeneous problem with six energy groups is analyzed with the OLG method and the solution converges to the reference solution but with somewhat slow convergence speed.

As a future study, Monte Carlo method will be applied to the local calculation with albedo boundary condition. With this approach, we expect the OLG framework will be preferable to the direct whole-core transport calculation.

Acknowledgement

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