Implementation of The Efficient Multigroup Solution in PARCS for Designing Innovative Cores

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1. Introduction

The CAMP (Code Application and Maintenance Program) is one of the regulatory researches directed by the US NRC in partnership with more than 20 countries and performs to exchange information on thermal-hydraulic safety issues related to reactor and plant systems. As a part of the international program, the advanced thermal hydraulic system code TRACE[1] has been being developed and qualified by an alliance of various institutions worldwide, in which the neutronics code PARCS[2] has a important role of calculating three-dimensional kinetics solution.

The major computational methods needed for solving spatial kinetics problems have been developed and implemented in PARCS to analyze phenonmenons occurred in the various reactor models with ensuring solution accuracy and providing high computational efficiency. Among these methods, the CMFD formulation coupled with analytic nodal method based on two-node kernel has been approved to provide the best performance in terms of computing time as well as accuracy for solving problems structured with two energy groups which is appropriate for analyzing the thermal reactors having descrite thermal and fast regions. PARCS also provides the numerical methods solving multigroup problems to be applied to the innovative cores such as reactors loading mixed oxide fuels or the fast breed reactors. However, they are not optimized and take a lot of calculating time as much as not applicable for real cores. So, it was planned to implement the efficient multigroup solution in order to improve capability of multigroup calculation in PARCS.

2. Methodologies

The source expansion nodal method (SENM)[3] based on two-node scheme that is one of the modern semi-analytic nodal methods and developed by Seoul National University has been employed into PARCS as a new multigroup nodal kernel. Characteristics of the source expansion nodal method are to predetermine the right hand side of the one dimensional neutron balance equation using an initial or the previous general solution so that the group-coupled neutron balance equations are divided into the decoupled equations and to employ source iteration that compensate the inaccuracy originated from the predetermination. Due to the decoupling, the computational time taken by nodal calculation isn't increased exponentially but linearly with respect to the number of energy groups in the source iteration. Moreover, the source expansion nodal method achieved good convergence and stability by applying two-node nodal scheme. The multigroup CMFD calculation is essentially necessary because the two-node scheme isn't able to update the global neutron flux, but it can't provide good performance compared to two-group calculation because of considering more energy groups. To resolve this issue, two-level CMFD[3] calculation that accelerates multigroup calculation with two-group calculation is introduced.

For the multigroup pin power calculation, the multigroup pin power reconstruction with source expansion approach[4] in which the same concept applied to the source expansion nodal method was employed has been implemented in PARCS. A key point of the method is also to perform polynomial expansion for the right hand side of the axially averaged two-dimensional neutron balance equation. Expanding to fifteen term polynomials, the general solution is determined as a set of polynomial and trigonometric functions. The fifteen polynomial coefficients of the particular solution are determined with the method of undermined coefficient and the eight trigonometric coefficients of the homogeneous solution are determined with eight boundary conditions which consist of four surface currents and four corner fluxes.

An additional feature of this method is to consider corner discontinuity. Modern PWR fuels are optimized with zoning technique that places low-enriched rod to edges or corners of an assembly. In this case flux discontinuity at corners can become too large to simulate properly. Therefore, the corner discontinuity factor was employed to reduce the numerical error originated from the discontinuity.

3. MOX Transient Benchmark Problem

Recently, The OECD/NEA designed a numerical benchmark problem[5] that consists of several parts covering from steady-state calculations in various conditions to the fast transient accident by rod ejection to provide the framework to evaluate the ability of modern reactor codes based on diffusion and transport theories. The problem is appropriate for assessing the performance of the new multigroup solution compared to the previous one, because the three sets of group constants with two, four and eight energy groups and the kinetics data such as the effective delayed neutron fraction are given.

The following tables show results for Part I, II and III of the benchmark problem in which the k-search calculation without feedbacks and the critical calculation at HZP and HFP. Compared with the reference solutions generated with the PARCS code in which the analytic nodal and nodal expansion methods

are used for two-group and multigroup calculation, differences are negligible. It is reasonable since all of the routines such as T/H calculation and feedback treatment except only nodal calculation are used. From the two-group results, it is verified that SENM guarantees the same accuracy to ANM.

Table 1.Multiplication factors and Rod worths

Nodal	Eigenvalue		Total Rod Worth [pcm]
	ARO	ARI	
ANM[1] 2G	1.06379	0.99154	7225
SENM[2] 2G	1.06379	0.99154	7225
NEMMG[3] 4G	1.06376	0.99137	7239
SENM 4G	1.06378	0.99135	7243
NEMMG 8G	1.06354	0.99115	7239
SENM 8G	1.06358	0.99115	7243

ANM[1] : Two-Node Analytic Nodal Kernel
NEMMG[2] : One-Node Nodal Expansion Kernel
SENM[3] : Two-Node Source Expansion Nodal Kernel (New)

Table 2. Critical Boron Concentation at HFP and HZP

Nodal	**PPM**	
	HFP	**HZP**
ANM 2G	1679	1341
SENM 2G	1679	1340
NEMMG 4G	1676	1337
SENM 4G	1675	1337
NEMMG 8G	1672	1334
SENM 8G	1673	1335

HFP[1] : Hot full power & All control banks out
HZP[2] : Hot zero power & All regulating banks in

Part 4 of the problem provides a specification of a control rod ejection accident at HZP condition which is adequate for evaluating transient capabilities of the new multigorup solution. We can expect a sharp power pulse in short time and the large power distortion around the location in which the target rod is ejected since the ejected rod worth over one dollar which means that the state of the core becomes super-prompt critical. Figure 1 shows the core power behaviors with the three sets of group constants in terms of the types of nodal calculations. While the two-group results which are calculated by the ANM kernel and the SENM kernel were almost same, the four-group results show the small differences between nodal kernels. It was identified that the NEM results approach to the SENM results with dividing fuel assembly to the more nodes. It is because the new nodal kernel has better performance than the original one.

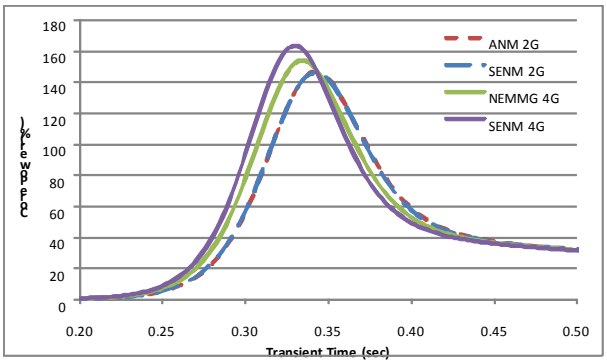

Figure 1. Transient Core Power Behavior

In addition, SENM provided excellent computing performance compared to the original kernel of PARCS. In case of four-group calculation, SENM kernel took only 632 seconds whereas NEMMG kernel took 2537 seconds. Unfortunately, eightgroup results was excepted because the NEMMG kernel of PARCS takes huge calculation time. It shows the numerical superiority of the two-level CMFD formulation coupled with the source expension nodal method.

4. Summary

The source expansion nodal method based on two-level CMFD formulation and the source expansion pin power reconstruction have been implemented in PARCS to improve performance of the multigroup calculation. The source expansion means that source terms on the right hand side of diffusion equation is approximated to a set of polynomial functions by applying the orthogonal expansion to the previous solution and takes an advantage to decouple the group coupling. The new routines of PARCS were evaluated with the OECD/NEA MOX transient benchmark problem. It is showed that the SENM kernel is more accurate than the NEM kernel and especially, the computing time was improved seriously when the SENM kernel was used.

References

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