Assembly Based Modular Ray Tracing for Rectangular and Hexagonal Lattices

Min-Jae Lee, Yeon-Sang Jung and Han-Gyu Joo.
Department of Nuclear Engineering, Seoul National University, San 56-1, Sillim-dong, Seoul, 151-742

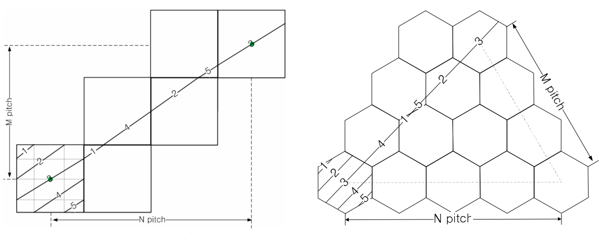
1. Introduction

The pin cell based modular ray tracing (CMRT) can be applied to solve the MOC equations efficiently, but there is a limitation that it can not model the gap cells appearing between assemblies. Thus assembly based modular ray tracing (AMRT) is essential for practical applications. Since most reactors involve either rectangular or hexagonal fuel assemblies, a whole core transport code employing AMRT can be applied widely as long as it can treat both geometries. nTracer is a such code being developed at Seoul National University for applications to VHTR, SFR as well as commercial PWRs. This paper is to describe the unique features and performance of the AMRT of the nTracer code.

2. Formulation of AMRT

2.1. Determination of modular ray

In a rectangular lattice, a modular ray can be constructed such that a ray passing through the center of the rectangle at a certain position in the core passes another center point at a different core position after traveling *n* pitches horizontally and *m* pitches vertical.



(a) Rectangular lattice (b) Hexagonal lattice

Fig 1. Determination of modular rays

The ray spacing and azimuthal angle are adjusted from the desired input ray spacing and angles. The adjusted azimuthal angles and ray spacing can be determined following manner:

$$\tan(\alpha_l) = \frac{N^l{}_x}{N^l{}_y} \text{ and } \Delta^l{}_R = \frac{P}{\sqrt{(N^l{}_x)^2 + (N^l{}_y)^2}}$$

where

$$N_x^{\ l} = \mathrm{int}\left(\frac{P}{\Delta_R^{\ l0}}\left|\sin(\alpha_{l0})\right|\right), \quad N_y^{\ l} = \mathrm{int}\left(\frac{P}{\Delta_R^{\ l0}}\left|\cos(\alpha_{l0})\right|\right)$$

Here α_{l0} and $\Delta_R^{\ l0}$ is the initial angle and ray spacing determined by user input, $\Delta^l{}_R$ and P stand for the ray spacing and unit lattice pitch.

In hexagonal lattice, main idea of determination of modular ray is similar to rectangular case. There can be *n* ray angles in $\pi/6$. For the even azimuthal weighting, the k^{th} ideal angle would be $(2k-1)\pi/12n$. A test of various n and m pairs can be made to determine ray angle as closely as possible to the ideal value.

2.2. Hierarchical structure of rays

In order to improve the efficiency of memory usage, a hierarchical structure in the ray was devised. It consists of core rays, modular rays, cell rays and ray segments. The ray starting from one exterior boundary point and ending at the other boundary point is called a core ray. The modular rays are the part of core rays divided by each assembly. The ray inside the pin cell is the cell ray. The cell ray is further divided into segments by the pin cell internal structure. These four levels of rays are constructed efficiently considering various symmetries of the rays.

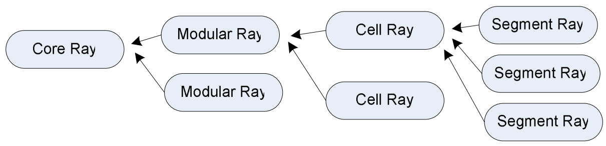
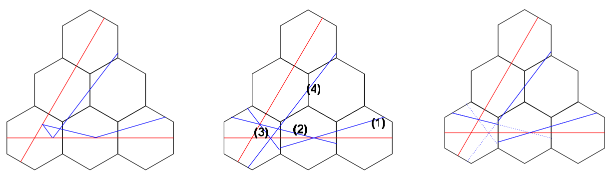


Fig 2. Hierarchical ray structures

2.3. Incorporation of reflections

As an effort to reduce the memory required for storing the angular flux at the reflective boundaries, a ray tracing procedure was devised such that the ray tracing continues until the ray reaches to an external core boundary. The complication of this once-through ray tracing scheme encountered when the reflective boundary is located at the center of assembly was resolved by the memory allocation and access based on pointer variables employing the modular rays defined for the full size assembly.



(a) (b) (c)

Fig 3. Implementation of ray reflections

Suppose a ray passing through cells that have reflection wall shown in Fig. 3-(a). To trace these rays, one must find reflected modular rays corresponding to the entering modular rays shown in Fig. 3-(b). Then ray tracing can be performed through the modular rays as in Fig 3-(c). In this scheme, the flat source regions which the rays pass after reflection line are not reflected regions. To overcome this problem, the original region and reflected region are forced to share the same memory. In this way, the result of ray tracing using the modular ray of Fig 3-(c) becomes the same as the real reflection ray tracing like Fig 3-(a).

3. Examinations of AMRT

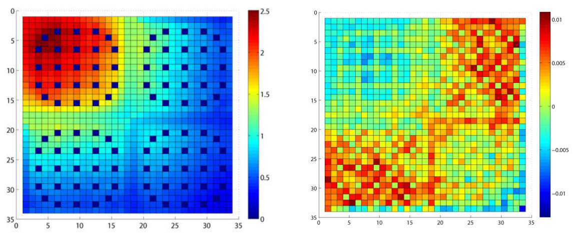
3.1. Verification through C5G7 problem

The accuracy of the nTracer ray tracing module was examined first with the C5G7 benchmark problem[1]. As shown in Table 1, the core multiplication factor of nTracer with default setting is slight different (37 pcm) comparing with the reference MCNP values. The assemblywise power distribution agrees within 0.25%.

Table 1. k-eff and Pin power errors for C5G7 benchmark problem

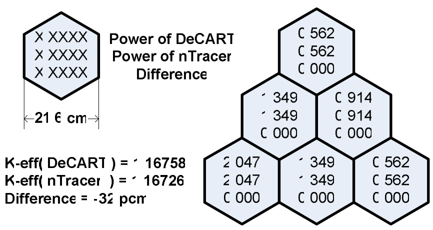
	nTracer
K-eff	1.18618
ε_k [pcm]	37
Max. pin power err.[%]	1.175
Rms power err. [%]	0.333

N_{pl}: 2, N_{az}: 8, Ray spacing : 0.05 cm, Ref : k–inf : 1.18655



(a) Pin power distribution (b) Pin power error distribution
Fig 4. Pin power comparison for C5G7 benchmark problem

The hexagonal transport kernel was examined for the C5G7 Hexagonal variation problem[2]. As shown in Fig. 5, the multiplication factor and assembly power distribution are very close to the DeCART values.



Npl: 2, Naz: 12, Ray spacing : 0.05 cm
Fig 5. Results of C5G7 Hex variation problems

In order to examine the performance of the elaborated reflection scheme, the problem was solved for the full core as well as for the 1/6 sized core. The result shows that the 1/6 case have exactly the same k-eff as the full core case at each iteration step, but with a 1/6 computing time.

2. Effect of gap in rectangular lattice

In order to examine the value of AMRT over the CMRT, the gap smearing effect in CMRT was examined for the KSNP type 16x16 fuel assembly. The cross sections for this calculation were borrowed from the C5G7 problem set. As shown in Table 2 and Fig. 3, the *k-inf* error of the water gap smeared case is not very significant, but the corner pin power error is about 6%. This proves the value of AMRT.

Table 2. Effect of water gap simulation

	No water gap	Water gap	ε_k (pcm)
k-inf	1.25510	1.25592	82

N_{pl}: 2, N_{az}: 8, Ray spacing : 0.05 cm

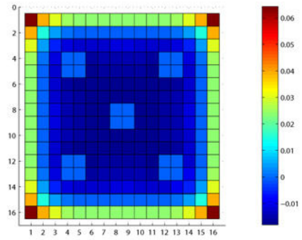


Fig 6 Pin power differences

4. Conclusion

Rectangular and hexagonal assembly based modular ray tracing modules were developed as the base for the whole transport calculations of various reactors types. As demonstrated by the solution of the C5G7 benchmark problem, the accuracy of the modules is comparable to others. It turned out that the implementation of the reflective condition using the whole assembly based modular rays and memory sharing technique is quite efficient.

Acknowledgments

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REFERENCES

[1] E. E. Lewis, et al., "Benchmark Specification for Deterministic 2-D/3-D MOX fuel Assembly Transport Calculations without Spatial Homogenization (C5G7MOX)," NEA/NSC/DOC(2001).
[2] J. Y. Cho et al. "DeCART Solutions for C5G7 Hexagonal Variation Problems" CR-ROM, *Proc. 2007 KNS Spring Meeting* (2007).