Annals of Nuclear Energy 69 (2014) 25–36

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Effect of including corner point fluxes on the pin power reconstruction using nodal point flux scheme

F. Khoshahval *, A. Zolfaghari, H. Minuchehr

Engineering Department, Shahid Beheshti University, G.C, P.O. Box 1983963113, Tehran, Iran

ARTICLE INFO

Article history:
Received 9 October 2013
Received in revised form 29 December 2013
Accepted 8 January 2014
Available online 19 February 2014

Keywords:
Pin power reconstruction
Intra nodal
NEM
Corner point

ABSTRACT

Although there have been well established transport based codes for core neutronics analysis, it is yet impractical to implement them in the real core treatment because their performance is not so great on ordinary server computers. For this reason, most of neutronics codes for core calculation are subject to two steps calculation procedure which consists of homogenized group constant generation and flux distribution generation which is the main concern of this work. This paper brings out a 2 dimensional nodal code based on point flux algorithm and implements two schemes for pin power reconstruction. In the first scheme, pin power reconstruction is obtained without considering corner point fluxes in the fuel assemblies but in the second method corner fluxes are included to assess their effect on pin power reconstruction. To obtain corner point fluxes, Smith's procedure and the method of successive smoothing are used. Improvement in pin power reconstruction by including fuel assembly corner fluxes is illustrated in this paper and assessed by Monte Carlo simulation.

1. Introduction

Fuel pin power information is important for the safety assessment of a core fuel loading since it is required in the determination of the peak linear heat generation rate and the minimum departure from nucleate boiling ratio (DNBR). Nodal expansion method (NEM) is one of the most widely used methods in modern neutronic codes. NEM provides a fast and accurate method of calculating flux and power distribution in a reactor core. The core is divided into large homogenized nodes (Typically the size of a node is a 20 cm × 20 cm). A large core may typically be represented in half-core geometry by using 10,000 nodes. The NEM solution gives the node average flux, power etc., but no information about the detailed structures inside the nodes (Hojerup, 1990).

A reconstruction method can be used for rebuilding pin powers from reactor core calculations performed with a coarse-mesh finite difference diffusion approximation and single-assembly lattice calculation. This method assumes that the detailed flux shape in an assembly can be approximated by superposing detailed inner assembly form function on a smoother intra-nodal shape function. The assembly form functions are obtained from single-assembly lattice calculation and the intra-nodal flux distribution are computed using polynomial shapes constrained to satisfy the nodal information approximated from the node-average fluxes (Na Gyun et al., 2001).

Several researches have been focused on the pin power reconstruction method (Koebke and Wagner, 1977; Boer and Finnemann, 1992; Bahadir and Lindahl, 2006; Joo et al., 2009; Dahmani et al., 2011). In this paper, we try to investigate the effect of including the corner point flux on the pin power prediction. Doubtless, the accuracy of the pin power predictions depends on the accuracy of the intra-nodal flux and cross section values and form factors. In this work we develope a NODAL code in FORTRAN programming language capable of implementing pin power reconstructions in square structures. Two different methods for intra-nodal flux approximation are presented (one without considering corner point fluxes and the other with considering corner point fluxes). In addition, two different schemes for computing corner point flux approximation are implemented (Smith's method and method of successive smoothing). The procedure is applied on PWR reactor core fuel assemblies (see Section 4) and results are compared to those attained by Monte Carlo calculations.

2. Nodal expansion method

During the operation of nuclear reactors, fast calculation of the neutronic parameters is necessary. Nodal methods are fast tools for reactor calculation. These methods were developed in the 1970s for numerical reactor calculations, especially for neutron diffusion applications, Lawrence (1986). Nodal methods now have taken a

* Corresponding author. Fax: +98 21 29902546.
E-mail addresses: f_khoshahval@sbu.ac.ir, f_khoshahval@yahoo.com (F. Khoshahval).

http://dx.doi.org/10.1016/j.anucene.2014.01.012
0306-4549/

firm place in the current production codes for reactor design as a main computational engine. These methods use coarse meshes with dimensions as large as fuel assemblies approximately resulting in dramatic reduction in computing time compared to the finite difference methods. They attain very high accuracy by careful treatment in discretizing the diffusion equations to enforce neutron balance, Cho (2005). Nodal equations are obtained by integrating the multi-group diffusion equation over a homogeneous region or node and then relating the net currents across the surfaces to the outgoing and incoming partial currents. Spatial coefficients are then used to relate the average fluxes and the average outgoing partial currents on surfaces. Alternatively, the spatial coupling coefficients can be defined in terms of the net currents across a surface and the average fluxes in two adjacent nodes. The elimination of the interface current in favor of the coupling coefficients yields a 5 point equation in two dimensions for nodal fluxes.

The nodal expansion method, NEM, is a class of nodal techniques in which the average interface partial currents are treated explicitly. Integrating the multi-dimensional diffusion equation over transverse directions will lead to a coupled set of one dimensional equation from which additional equations to relate the partial currents on the surfaces of a node to the flux within the node using polynomial expansion technique are obtained. Weighted residual procedures are used to calculate the coefficient expansions, Bennewitz et al. (1975a,b), Turinsky (1994). Procedures in this scheme involve approximation of the one dimensional equations obtained by integrating over transverse directions. The fluxes expanded in quadratic polynomials with coefficients being interpreted as the nodal flux and the average partial currents on the surfaces. The flux expansion method Langenbuch et al. (1977b), is developed by integrating the neutron diffusion equation over a node and evaluating the resulting integral by expanding the flux in products of higher order polynomials.

In this work we use the NEM method which has been developed by the Putney (1984). This method enables the nodal equations to be written in terms of the average node fluxes. Specially, we focused on the point flux technique which has been described in detail in Section 2.1.

2.1. Derivation of nodal equations

In the nodal expansion methods the multi-group neutron diffusion equation is effectively solved by representing the neutron flux in each node by a polynomial expansion, and using a combination of weighted residual equations, i.e.:

$$\int_{\Pi^m} W_{gu}^{[k]} \left\{ -\text{div}\, D_g \nabla \phi_g + \Sigma_{tg}\phi_g - \sum_{g'=1}^{G} \Sigma_{gg'}\phi_{g'} - \frac{\chi_g}{k_{\text{eff}}} \sum_{g'=1}^{G} \upsilon \Sigma_{fg'}\phi_{g'} \right\} d\Pi^m = 0$$
$$m = 1,2,\ldots,M, \quad g = 1,2,\ldots,G,$$
$$k = 0,1,2,\ldots,K, \quad u = x,y \tag{1}$$

where m, g, u and k are node number, energy group, Cartesian axes and order of weighted diffusion equation respectively along continuity conditions to determine its coefficients.

In the zeroth order of the method, the nodal flux expansions is chosen to be quadratic along setting $W_{gu}^{[0]} = 1$. The necessary coefficients can be determined by forcing the expansions to satisfy the zeroth order ($k = 0$) weighted diffusion Eq. (1), i.e. the integral neutron balance in the nodes, and the continuity of neutron flux and net normal neutron current on their surfaces. In order to expand the neutron flux in each node, it is necessary to introduce a set, or sets, of axes in its dependent variables. For the case of 2D rectangular geometry, the most convenient approach is to reference the flux expansion in each node to the local Cartesian axes (x, y). The derivation can be further simplified if we define on these axes the local dimensionless variables:

$$\xi_u = \frac{u}{h_u^m}, \quad u = x,y \tag{2}$$

The local Cartesian axes form the basis for the following notations and a schematic view of definitions is illustrated in Fig. 1 where:

Γ_{us}^m, left ($s = l$)/right ($s = r$) u-surface of node Π^m, $u = x, y$
Φ_g^m, average flux for group g in Π^m
Ψ_{gus}^m, average flux for group g at Γ_{us}^m
Ψ_{gu}^m, one dimensional spatially averaged flux in the u-direction of node Π^m
λ_{gus}^m, value of boundary condition at Γ_{us}^m
Π^{mus}, node adjacent to surface Γ_{us}^m (of node Π^m)
h_u^m, thickness of node Π^m in the u direction

In this paper the point flux method is implemented as a core calculation module.

2.2. Point flux method

This method is the coarse mesh flux expansion method of Langenbuch et al. (1975, 1977a,b), later investigated by Rydin and Sullivan (1978). The point flux method is similar to the average flux method in that it is also based on the nodal integrated neutron diffusion equation, but employs a nodal expansion which is fitted to the center point flux of the node and the center point fluxes of its surfaces. The nodal equations are derived in detail in (Putney, 1984), which a quadratic polynomial flux expansion in each node is fitted to the node and surface center point fluxes to lead a "nodal balance equation" of the form:

$$-4D_g^m \sum_{u=x,y} \left[\frac{\Psi_{gul}^m - 2\Phi_g^m + \Psi_{gur}^m}{h_u^{m2}} \right] + \frac{1}{6} \sum_{rg}^{m} \left[\sum_{\substack{u=x,y \\ s=l,r}} \Psi_{gul}^m + 2\Phi_g^m \right]$$
$$= \sum_{\substack{g'=1 \\ g' \neq g}}^{G} \frac{1}{6} \sum_{gg'}^{m} \left[\sum_{\substack{u=x,y \\ s=l,r}} \Psi_{g'us}^m + 2\Phi_{g'}^m \right]$$
$$+ \frac{\chi_g}{K_{eff}} \sum_{g'=1}^{G} \frac{1}{6} \nu \sum_{fg'}^{m} \left[\sum_{\substack{u=x,y \\ s=l,r}} \Psi_{g'us}^m + 2\Phi_{g'}^m \right] \quad m = 1,2,\ldots M,$$
$$g = 1,2,\ldots,G, \quad u = x,y \tag{3}$$

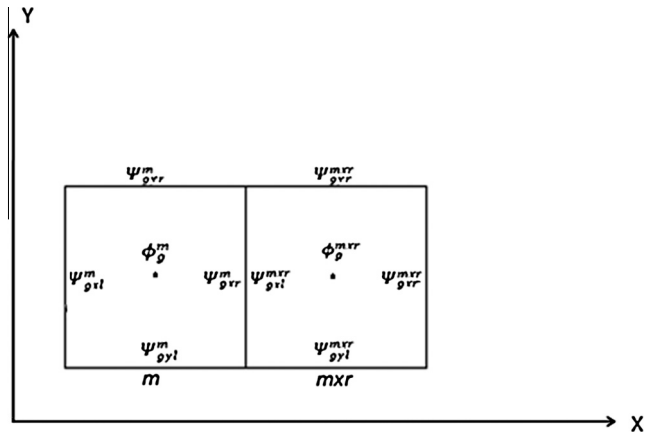

Fig. 1. Some defined notations for derivation of methods.