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# Sensitivity Analysis of Power Distribution Synthesis Method for Failed Incore Detector

Bon-Seung Koo, Jin-Young Cho and Kyo-Youn Kim
*Korea Atomic Energy Research Institute, 1045, Daedeokdaero, Yuseong-gu,Daejon, 305-353, Korea*
bskoo@kaeri.re.kr

## 1. Introduction

A 3-dimensional power distribution synthesis method (called DPCM3D)[1] has been developed by KAERI. RCOMS(Real-time calculator for COre Monitoring System) adopts the method instead of Fourier expansion method being used in COLSS of conventional PWRs. COLSS generates level-averaged detector responses from incore detector signals and fits core average axial power shape. Thus, COLSS inevitably includes considerable fitting error in itself.

However, DPCM3D produces a synthetic 3-D power distribution by coupling a neutronics code and measured incore detector signals without any fitting. In this paper, performance of RCOMS 3-D power distribution synthesis method is evaluated and sensitivity analysis for the number of failed detector is tested.

## 2. Methods and Results

### *2.1 3-D Synthesis Method*

In DPCM3D, detected(or instrumented) node powers are determined from the detector powers by using power sharing factors and the un-detected node powers are determined by using power connection factors. A coefficient library for the 3-D power synthesis is functionalized as a function of the burnup, core power and control rod position and provided by neutronics code.

Eq. (1) explains how to detected node power is calculated. A power sharing factor and a detector signal are used as seen in Eq. (1). A power sharing factor is provided through the approximating calculation by neutronics code.

$$P_{l,k}^{d} = \frac{1}{w_k} \sum_{k'} F_{l,kk'} P_{l,k'}^{d} \qquad (1)$$

where,

$P_{l,k}^{d}$ = detected node power of node *(l,k)*

$F_{l,kk'}$ = power sharing factor from det. *k'* to node *k*

$P_{l,k'}^{d}$ = incore det. power of det. unit *k'*

$w_k = \sum_{k'} w_{kk'} \ (w_{kk'} = h_{kk'} / h_{k'})$

$h_{k'}$ = height of det. unit *k'*

$h_{kk'}$ = height of plane *k* included in det. unit *k'*

A un-detected node power is determined from the neighboring node powers using the approximated power connection factor, $C_{l,k}^{C}$ which couples the node (*l*,*k*) power with the neighboring node powers. A power connection factor is also calculated by using neutronics code and can be defined by Eq. (2).

$$C_{l,k}^{C} = \frac{1}{P_{l,k}(N_l^{nb} + N_k^{nb})} \left( \sum_{j=1}^{N_l^{nb}} P_{L_l^{nb}(j),k} + \sum_{j=1}^{N_k^{nb}} P_{l,K_k^{nb}(j)} \right) \qquad (2)$$

where, $N_l^{nb}$ and $N_k^{nb}$ are the number of neighboring nodes in the radial and the axial directions. $L_l^{nb}(j)$ and $L_k^{nb}(j)$ are the neighboring node and plane indices for node *(l,k)*, respectively.

Fig. 1 shows synthesized core power distribution by using incore detector signals and power synthesis coefficients. RCOMS synthesizes radial power distribution per each axial plane and axially integrated radial power distribution. Moreover, RCOMS provides radially integrated axial power shape as well as various core peaking factors (i.e., Fr, Fxy, Fq) and axial offset. In addition, RCOMS calculates azimuthal tilt from spatially located incore detector signals.

### *2.2Sensitivity Test for Failed Detector*

Sensitivity test for the number of failed incore detector is tested. Detector signals are made to 0.0(zero) compulsorily to simulate failed detector and then 3-D power distribution is synthesized. The number of failed detector is increased to about 80% condition. Fig. 2 shows the simulated incore detector configuration. Each detector's height per level is assumed to 20.0cm, which includes 3~4 neutronics node. Table 1 shows calculational result for 3-D power synthesis errors as a function of failed detector numbers. In case of all detectors available (Case No. 1), radial power distribution error (axially integrated 2-D power) shows the maximum 0.006% which is negligible value. These trivial errors are less than the truncation error of about 0.02% caused by the number of digits for the power distribution and detector signals[2]. In addition, for the most severe case (12 detectors available out of 72 detectors), maximum 3-D error is less than 0.05% compared with reference MASTER result.

This demonstrates that RCOMS 3-D power synthesis algorithm is robust and less sensitive to the number of available detectors compared with conventional COLSS algorithm. Also RCOMS can synthesize 3-D power distribution exactly with a minimum available detector numbers.

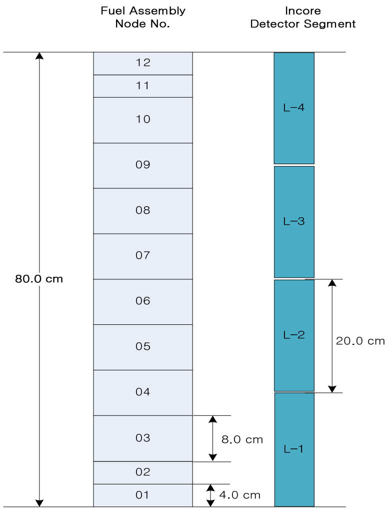


Fig. 2. Simulated Incore detector configuration and neutronics node

Table 1. 3-D power synthesis errors as a function of failed detector numbers

| Case No. | No. of Det.[a] | | Failed Det.(%) | Max. Error(%)[b] | |
|---|---|---|---|---|---|
| | Avail. | Failed | | Error(a)[c] | Error(b)[d] |
| 1 | 72 | 0 | 0 | 0.0161 | -0.0062 |
| 2 | 68 | 4 | 6 | 0.0162 | -0.0063 |
| 3 | 64 | 8 | 11 | 0.0167 | -0.0078 |
| 4 | 60 | 12 | 17 | 0.0176 | -0.0094 |
| 5 | 56 | 16 | 22 | 0.0178 | -0.0099 |
| 6 | 52 | 20 | 28 | -0.0203 | -0.0110 |
| 7 | 48 | 24 | 33 | -0.0208 | -0.0119 |
| 8 | 44 | 28 | 39 | -0.0207 | -0.0128 |
| 9 | 40 | 32 | 44 | -0.0208 | -0.0128 |
| 10 | 36 | 36 | 50 | 0.0225 | -0.0137 |
| 11 | 32 | 40 | 56 | 0.0237 | -0.0133 |
| 12 | 28 | 44 | 61 | 0.0231 | -0.0134 |
| 13 | 24 | 48 | 67 | 0.0240 | -0.0135 |
| 14 | 20 | 52 | 72 | 0.0219 | -0.0134 |
| 15 | 16 | 56 | 78 | 0.0247 | 0.0159 |
| 16 | 12 | 60 | 83 | 0.0326 | 0.0238 |

a) total No. = 18*4
failed detectors are assumed as ICI assembly unit (4-level)
b) error(%) = (RCOMS-MASTER)/MASTER·100
c) max. error for 3D node-power
d) max. error for 2D node-power (axially integrated)

## 3. Conclusions

The performance of a 3-dimensional power distribution synthesis method (DPCM3D) was evaluated for the digital core monitoring system (RCOMS). RCOMS shows negligible power distribution errors and less sensitive to the number of available detectors compared with COLSS. By employing a DPCM3D method in RCOMS, it is judged that a core power distribution could be synthesized more accurately by eliminating the fitting error with a minimum available detector numbers and it would lead to thermal margin increase.

## REFERENCES

[1] J.Y. Cho, et al., "3D Power Synthesis Methodology for SMART Core Monitoring System", KAERI/TR-3399, 2007.
[2] J.Y. Cho, et al., "A Power Synthesis Module of DPCM3D Coupled by the Neutronics Code of ASTRA", Transactions of KNS Spring Meeting, Jeju, May 22, 2009.

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                        0.7576  0.7563  0.7862  0.7566  0.7580
                  0.8559  0.8399  0.8381  0.8849  0.8850  0.8385  0.8404  0.8564
            0.8557  0.8687  0.8916  0.9164  0.9681  0.9871  0.9686  0.9169  0.8921  0.8693  0.8561
      0.7571  0.8394  0.8912  0.9412  1.0155  1.0664  1.0947  1.0955  1.0674  1.0158  0.9418  0.8918  0.8398  0.7573
    0.7556  0.8374  0.9156  1.0147  1.0670  1.1067  1.1366  1.1571  1.1473  1.1078  1.0678  1.0159  0.9161  0.8376  0.7557
  0.7853  0.8838  0.9670  1.0655  1.1053  1.1217  1.1475  1.1602  1.1697  1.1484  1.1224  1.1061  1.0661  0.9673  0.8839  0.7853
 0.7557  0.8839  0.9857  1.0931  1.1345  1.1472  1.1657  1.1730  1.1753  1.1733  1.1663  1.1480  1.1352  1.0933  0.9857  0.8838  0.7556
0.7573  0.8376  0.9673  1.0933  1.1448  1.1596  1.1729  1.0767  1.0746  1.0670  1.0693  1.1818  1.1688  1.1448  1.0931  0.9670  0.8373  0.7570
 0.8398  0.9162  1.0661  1.1352  1.1688  1.1836  1.0672  1.0844  1.0829  1.0764  1.0670  1.1836  1.1596  1.1345  1.0655  0.9156  0.8394
0.8561  0.8918  1.0159  1.1061  1.1480  1.1818  1.0670  1.0836  1.1073  1.1072  1.0836  1.0672  1.1729  1.1472  1.1053  1.0147  0.8911  0.8556
 0.8693  0.9418  1.0678  1.1225  1.1663  1.0693  1.0764  1.1072  1.1076  1.1073  1.0844  1.0767  1.1657  1.1217  1.0670  0.9412  0.8687
0.8564  0.8921  1.0158  1.1078  1.1484  1.1733  1.0670  1.0829  1.1073  1.1072  1.0829  1.0746  1.1730  1.1475  1.1067  1.0155  0.8916  0.8559
 0.8404  0.9169  1.0674  1.1473  1.1697  1.1753  1.0746  1.0844  1.0836  1.0764  1.0670  1.1753  1.1602  1.1366  1.0664  0.9164  0.8399
0.7580  0.8385  0.9686  1.0955  1.1571  1.1602  1.1730  1.0767  1.0672  1.0670  1.0693  1.1733  1.1697  1.1571  1.0947  0.9681  0.8381  0.7576
 0.7566  0.8850  0.9871  1.0947  1.1366  1.1474  1.1657  1.1729  1.1836  1.1818  1.1663  1.1484  1.1473  1.0955  0.9871  0.8849  0.7563
  0.7862  0.8849  0.9681  1.0664  1.1067  1.1216  1.1472  1.1596  1.1688  1.1480  1.1224  1.1078  1.0674  0.9686  0.8850  0.7862
    0.7563  0.8381  0.9164  1.0155  1.0670  1.1053  1.1345  1.1448  1.1352  1.1061  1.0678  1.0158  0.9169  0.8385  0.7566
      0.7576  0.8399  0.8916  0.9412  1.0147  1.0655  1.0931  1.0933  1.0661  1.0159  0.9418  0.8921  0.8404  0.7580
            0.8559  0.8687  0.8911  0.9156  0.9670  0.9857  0.9673  0.9162  0.8918  0.8693  0.8565
                  0.8556  0.8394  0.8373  0.8838  0.8839  0.8376  0.8398  0.8561
MAX. POWER =    1.1836  0.7571  0.7556  0.7853  0.7557  0.7573
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Fig. 1. Exemplary radial power distribution by DPCM3D method