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Improved Radial Power Distribution Fitting Method in INCORE Code

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1. Introduction

Technical specifications on Westinghouse PWRs equipped with movable incore detectors require that the validity of the nuclear design 3D power distribution should be verified through every 31 EFPD measurement. The measured power distribution is calculated with the INCORE code by combining measured reaction rate data from the movable fission chambers with the ratios of analytic power to reaction rate from the nuclear core model [1]. In the case of 3-loop plant, the number of movable detectors is 50. So, the unmeasured assembly powers are inferred using the empirical fitting with the measured neighborhood assembly powers.

The empirical fitting method has given us reasonable inferred assembly powers using 50 measured powers. But, in the case of some movable detectors failure or deletion, since it is wondering if the empirical fitting method is still valid, the verification calculations of INCORE code are performed for 50% assumed deletion cases of 4 domestic 3-loop plants.

Empirical fitting method as a function of the distance and power deviation of the neighborhood assemblies is out of date to predict unmeasured assembly powers. It is expected that the inferred powers can be distorted, if there is no measured neighborhood assembly because of failure and deletion. So, surface spline fitting method is employed to improve radial power distribution fitting capability of INCORE code.

2. Surface Spline Fitting(SSF) Method [2]

A Surface spline is a mathematical tool for interpolating a function of two variables. It is based upon the small deflection equation of an infinite plate. The method was originally developed for interpolating wing deflections and computing slopes for aero-elastic calculations. The main advantages of the surface spline are that the coordinates of the known points need not be located in rectangular array and the function may be differentiated to find slopes.

A linear spline, which is based upon the small deflection equation of an infinite beam, has been quit useful for one-dimensional interpolation. A lattice of linear splines has been used to solve the two-dimensional problem. An advantage of the surface spline method is no requiring the user to locate the splines.

The surface spline depends upon the solution of a system of linear equations, and thus, will ordinarily require the use of a digital computer. The closed form of solution involves no functions more complicated than logarithms, and can be easily coded.

The resulting equations are made into a form useful for computation.

$$W(x,y) = a_0 + a_1 x + a_2 y + \sum_{i=1}^{N} F_i r_i^2 \ln r_i^2$$

where,

$$r_i^2 = (x - x_i)^2 + (y - y_i)^2$$

The N+3 unknowns are determined from

$$\sum_{i=1}^{N} F_i = \sum_{i=1}^{N} x_i F_i = \sum_{i=1}^{N} y_i F_i = 0$$

3. Employment of Surface Spline Fit in INCORE

In the prediction of target assembly power, empirical fitting calculation is performed using the measured data from all thimbles within a given distance d and weighted by $(A+Bx)^{-2}$ where A, B and d are input constants and x is the distance from the thimble center to the source center. Therefore a few neighborhood assemblies within d are only used to obtain the power of target thimbles. So, in the case of thimble deletion and failure, the inferred power is determined by the nearest neighborhood measured assembly. But, in the case of surface spline fit, all measured thimbles are used for the prediction of target thimbles through above resulting equations. INCORE code which has only empirical fitting method [3] is modified to be able to choose surface spline fit in this study. The calculation flow chart is shown in figure 1. This modified INCORE code is compiled to perform the accuracy and smoothening test of both fit methods. So, this code is not released to KHNP for flux map analysis yet.

4. Calculation Results

Test calculations are performed to confirm the accuracy and smoothening of surface spline fit for K3C15, Y1C14, U1C12 and U2C12. The flux map analysis results of above plants and cycles are used for the test run. 50% trace data deletion is assumed to prepare 2 movable detectors failure or deletion.

4.1. Accuracy and Smoothening Test Procedure

The INCORE inputs from 4 plants are re-run with surface spline fit and then it is confirmed that the measured assembly powers about 50 assemblies are the same each other for the verification of modification. After that 50% measured trace data are deleted randomly excluding reference and redundancy thimbles. The data are eliminated evenly from each quarter core to prevent unrealistic evaluation. Five eliminated cases for each plant are rerun with empirical and SSF methods for each plant and the results are compared with original INCORE outputs. The known deleted assembly powers, FDHs and FQs from original output are used as true value and each parameter's deviations are calculated with predicted values from five eliminated INCORE outputs for confirming accuracy improvement. The radial power distributions of 50% deletion are compared each other for confirming smoothening.

4.2. Test Results

Assembly power, root mean square (RMS), FDH and FQ deviations for 4 plants (total 20 cases) are shown in Table 1. The percent errors of SSF are less than those of empirical about 0.1~0.2% excluding FQ. The distributions of the radial assembly power deviation at the case 5 of Ulchin Unit 2 cycle 12 are shown in figure 2 for empirical method and figure 3 for SSF method. According to the results, many assemblies have high deviation (red) at inner core because of 50% deletion in figure 2, but the red assemblies are reduced by SSF. Therefore, the distribution of SSF is much smoother than that of empirical method.

5. Conclusions

The accuracy and smoothening of prediction for unmeasured assembly powers are improved by SSF method in INCORE code. The improvement of accuracy is less than we expected, but the smoothening of prediction is reasonable and reliable in the case of 50% detector deletion.

As the further study, SSF method is planning to be employed for on-line core monitoring to get real time radial power distribution through 39 thermocouple data because SSF has good capability of smoothening.

REFERENCES

[1] Baek, J. H., et al., Procedure for INCORE/CARIN Constant Generation, July, 1990.

[2] Harder, R.L., et al., Interpolation Using Surface Splines, Journal of Aircraft, October, 1971.

[3] Beatty, K.M., et al., INCORE 3D 7.4.3 and Higher Programmer Manual, Westinghouse, July, 1994.

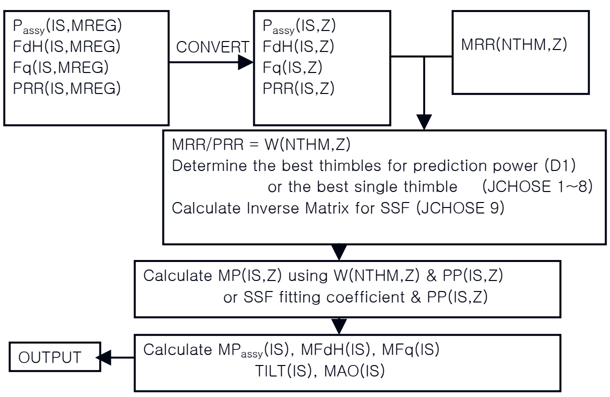

Figure 1. Calculation flow chart on SSF employment

Table 1. Calculation Results for 50% Deletion 20 Cases

Plants	Case	Empirical Fit ERR(%)				SSF ERR(%)			
		P bar	RMS	FDH	FQ	P bar	RMS	FDH	FQ
U1	1	1.200	2.298	−0.123	−0.797	1.160	2.378	−1.708	−3.952
	2	0.880	2.026	−1.667	−3.207	1.000	2.050	−2.200	−3.676
	3	1.080	1.958	−0.485	−0.797	1.080	1.931	−0.219	−2.202
	4	0.840	1.887	−0.109	−0.771	1.120	2.110	−0.738	−1.333
	5	0.760	1.723	−1.004	−1.286	0.680	1.789	0.184	−0.890
U2	1	2.000	2.909	−0.917	−0.440	1.480	2.309	−0.515	−0.143
	2	1.800	2.913	−1.017	−3.327	1.600	2.475	−0.702	−2.037
	3	1.480	2.486	−1.425	−0.758	1.120	1.968	−0.723	−0.036
	4	1.400	2.353	−0.776	−0.297	1.200	2.036	−0.669	−0.343
	5	1.720	2.634	−0.415	0.036	1.200	2.209	−0.408	−0.241
K3	1	1.240	2.269	0.027	0.251	1.240	2.196	0.288	0.431
	2	1.160	2.252	0.535	0.371	1.200	2.220	0.053	0.672
	3	0.920	1.842	−1.010	−0.672	0.840	1.651	0.869	0.847
	4	0.960	2.002	0.127	0.551	0.880	1.665	0.615	0.998
	5	1.280	1.996	−0.515	−0.185	0.880	1.607	0.147	1.048
Y1	1	1.960	2.952	−0.829	−0.085	1.560	2.570	−1.468	−0.375
	2	1.440	2.481	−1.363	−2.037	1.400	2.340	−1.093	−1.181
	3	1.560	2.633	−0.724	−0.230	1.640	2.709	−0.737	−0.456
	4	1.520	2.754	−1.159	−1.081	1.720	3.170	−1.264	−1.181
	5	1.880	2.833	−0.638	0.445	1.360	2.463	−1.106	−0.240
	AVG	1.354	2.360	−0.674	−0.716	1.218	2.192	−0.570	−0.715
	STD	0.322	0.335	0.447	0.762	0.226	0.292	0.614	1.074

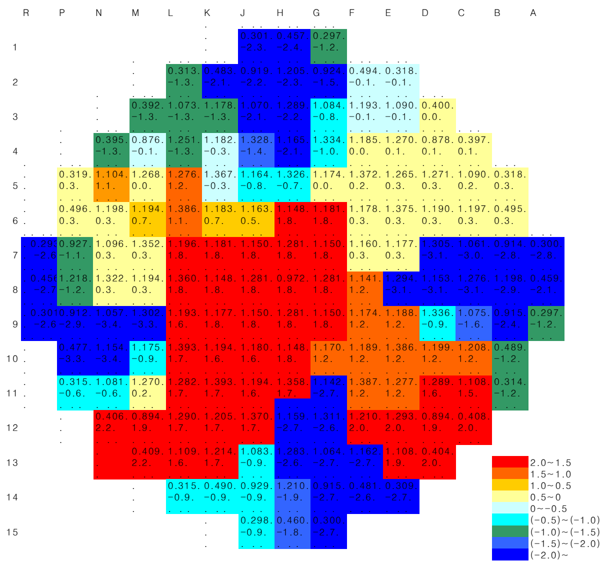

Figure 2. Empirical Fitting Results for 50% Deletion Case

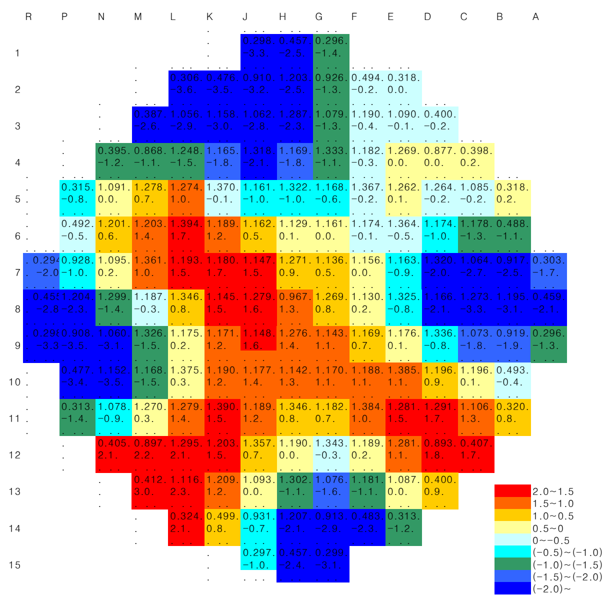

Figure 3. Surface Spline Fittng Results for 50% Deletion Case