Verification of the DEFENS Code through the CANDU Problems with Rectangular Geometry

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1. Introduction

Because a finite element method (FEM) based code can explicitly describe the core geometry, it has an advantage in a core analysis such as the CANDU core. For the reactor physics calculation in the CANDU core, the RFSP-IST code is used for the core analysis, and the RFSP-IST code is based on the finite difference method (FDM). Thus, the convergence with the mesh size and the geometry shape is not consistent. In this research, the convergence with the mesh size of the RFSP code is investigated, a method comparison between the FEM and FDM is done for the usefulness of the FEM based code with the same rectangular geometry. The target problems are the imaginary core and initial core with the uniform parameter, which is produced by the WIMS-IST code based on the parameters of Wolsong unit 1 [1]. The reference solution is generated by running the multi-group calculation of the McCARD code.

2. Convergence of the RFSP Code

2.1 Case Description

A total of 7 cases are tested for the investigation of the convergence of the multiplication factor and the power errors. Among 7 independent runs for the RFSP code including reference case which is containing regular mesh structure. The total volume of the core is about 252m^3. The average mesh size is calculated by assuming that the shape of the element is a cube. The following tables are the case description of the remaining 6 cases and the mesh data of these cases [2].

Table I: Case Description of the RFSP Running

	Number of Mesh for X-direction	Number of Mesh for Y-direction	Number of Mesh for Z-direction
	Uniform Width for X-direction	Uniform Width for Y-direction	Uniform Width for Z-direction
Case 1	15	15	15
	51.0466	51.0466	39.6240
Case 2	20	20	20
	38.2850	38.2850	29.7180
Case 3	25	25	25
	30.6280	30.6280	23.7744
Case 4	30	30	30
	25.5233	25.5233	19.8120
Case 5	35	35	35
	21.8771	21.8771	16.9817
Case 6	38	38	38
	20.1500	20.1500	15.6410

Table II: Mesh Data of the Cases

	Number of Elem.	Avg. Vol. of Elem.(cm^3)	Avg. Pitch of Elem.(cm)
Ref.	38,016	6,628	19
Case 1	3,375	74,657	42
Case 2	8,000	31,496	32
Case 3	15,625	16,126	25
Case 4	27,000	9,332	21
Case 5	42,875	5,876	18
Case 6	54,872	4,592	17

2.2 Multiplication Factor and Power Errors

The standard deviation of the McCARD code are 2 and 3 pcm for two problems. The number of particles is 400,000, the number of active cycles is 800 and the number of inactive cycles is 200. For the power error calculation, the root mean square error (RMSE) and the maximum absolute relative error (MARE) are used. The followings are the tables of the multiplication factor in PCM and power errors for the two problems.

Table III: K_{eff} in PCM of the Cases for 2 Problems

		Imaginary Core	Initial Core
McCARD		1.06687	1.05979
RFSP	Ref.	1.06737(50)	1.06053(74)
	Case 1	1.06843(156)	1.06167(188)
	Case 2	1.06811(124)	1.06128(149)
	Case 3	1.06788(101)	1.06100(121)
	Case 4	1.06772(85)	1.06079(100)
	Case 5	1.06775(88)	1.06084(105)
	Case 6	1.06774(87)	1.06085(106)

Table IV: Power Errors of the Cases for 2 Problems

	Imaginary Core		Initial Core	
	RMSE(%)	MARE(%)	RMSE(%)	MARE(%)
Ref.	0.74	4.43	0.91	5.33
Case 1	5.94	28.66	6.18	28.38
Case 2	3.98	18.82	4.28	18.98
Case 3	2.63	13.75	2.93	13.73
Case 4	2.17	12.15	2.36	12.31
Case 5	2.37	12.69	2.63	12.91
Case 6	2.32	11.37	2.53	11.49

3. Method Comparison

The average mesh size of the regular mesh structure of the RFSP code is about 20cm. Because the convergence with the mesh size of the RFSP code is not ensured, making the average mesh size of the DEFENS code the same as that of the RFSP code is meaningless. The multiplication factor and power errors are estimated for the investigations.

Table V: Mesh Data of the DEFENS Code for 2 Problems

	Basis. Ftn.	Node	Element	Avg. Pitch
Imaginary Core	Linear	12,239	67,927	10.83cm
	Quadratic	94,878		
Initial Core	Linear	12,193	67,673	10.84cm
	Quadratic	94,528		

The core total power is 2061.4MW and the average channel power is 5424kW. For the convenience of the calculation, a 1/4 core is used, and the axially integrated channel power is used for the power error calculation.

Table VI: K_{eff} in PCM for 2 Problems

	McCARD	DEFENS		RFSP
Imaginary Core	1.06687	Linear	1.06671 (-16)	1.06737 (50)
		Quadratic	1.06688 (1)	
Initial Core	1.05979	Linear	1.05944 (-35)	1.06053 (74)
		Quadratic	1.05977 (-2)	

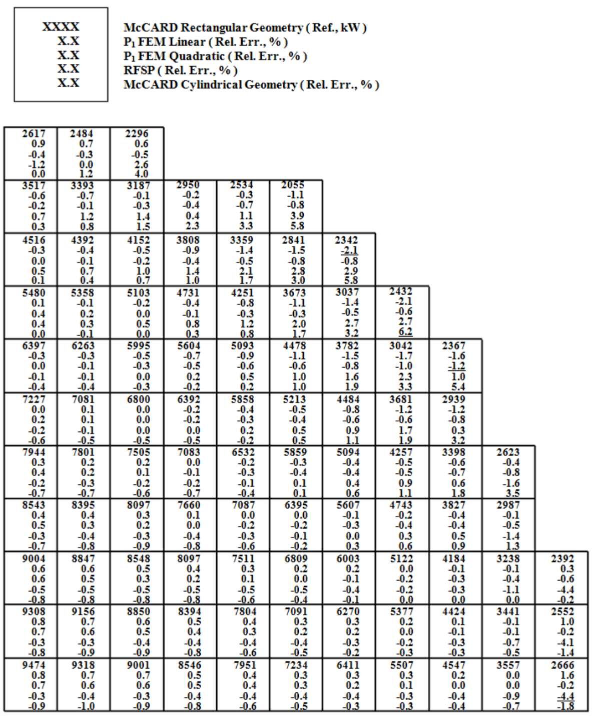

Fig. 1 Channel-wise Power Map for Problem 1

Table VII: Channel-wise RMSE and MARE for Problem 1

	DEFENS		RFSP
	Linear	Quadratic	
RMSE(kW)	30.90	23.17	39.91
RMSE(%)	0.57	0.43	0.74
MARE(%)	2.13	1.17	4.43

The trend of power error is similar with the trend of the multiplication factor error, as shown in Fig. 1 and Table VII. The DEFENS code with quadratic basis function option gives the best result.

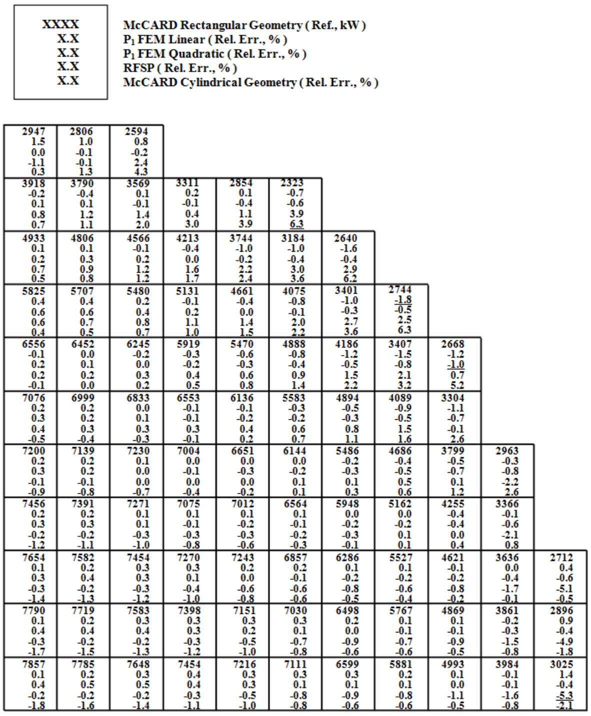

Fig. 2 Channel-wise Power Map for Problem 2

Table VIII: Channel-wise RMSE and MARE for Problem 2

	DEFENS		RFSP
	Linear	Quadratic	
RMSE(kW)	20.35	16.59	49.60
RMSE(%)	0.38	0.31	0.91
MARE(%)	1.77	0.95	5.33

In Fig. 2 and Table VIII, the error of the RFSP code becomes larger than that of problem 1. It seems that the heterogeneity of the core gives more errors of the RFSP code while the errors of the DEFENS code are quite stable with the heterogeneity of the core.

4. Conclusions

In this research, the convergence of the RFSP code is investigated and the DEFENS code is compared with the RFSP code for the imaginary and initial cores. The accuracy of the DEFENS code and the disadvantage of the RFSP code are verified.

5. Acknowledgement

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