Application of Code Accuracy Quantification Method Based on FFT to Standard Problems

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1. Introduction

The FFTBM (Fast Fourier Transform Based Method) developed by the University of Pisa (DCMN) has been widely applied to the international standard problems (ISP) in order to quantify the accuracy of the code prediction for a given problem. Recently, KAERI has been organizing a domestic and an international standard problem with the achieved integral effect database for the DVI line break scenarios. In order to assess the prediction accuracy quantitatively, the FFTBM was applied to those standard problems. This paper deals with the major results for the applications.

2. Theory and Methodology

The FFTBM is an integral method using the Fast Fourier Transform (FFT) in order to represent the code discrepancies in the frequency domain. This method has been successfully applied to the past international standard problems (ISPs) or standard problem exercises (SPEs) organized by CSNI or IAEA in order to quantify the prediction accuracy of the codes used in the program [1]. A good review can be found in the literature [2].

Both experimental discrete signal, $F_{exp,k}$ and error signal, $\Delta F_k=F_{cal,k}-F_{exp,k}$ are required for calculation and they signals can be transformed into the frequency domain by

$$\tilde{F}_{\exp}(f_n)=\tau\sum_{k=0}^{N-1}F_{\exp,k}e^{2\pi ikn/N}, \quad (1)$$

$$\Delta\tilde{F}(f_n)=\tau\sum_{k=0}^{N-1}\Delta F_k e^{2\pi ikn/N}, \quad (2)$$

These spectra of amplitude together with frequencies are used for calculation of average amplitude (AA) and weighted frequency (WF) that characterize code accuracy. The AA is defined as the sum of error function amplitudes normalized to the sum of experimental signal amplitude as follows:

$$AA=\frac{\sum_{n=0}^{2^m}\left|\Delta\tilde{F}(f_n)\right|}{\sum_{n=0}^{2^m}\left|\tilde{F}_{\exp}(f_n)\right|}, \quad (3)$$

$$WF=\frac{\sum_{n=0}^{2^m}\left|\Delta\tilde{F}(f_n)\right|\cdot f_n}{\sum_{n=0}^{2^m}\left|\Delta\tilde{F}(f_n)\right|}, \quad (4)$$

A cut-off frequency (f_{cut}) is introduced to cut off spurious contribution to accuracy quantification. In the present application, 1.0Hz was applied as the cut-off frequency by sensitivity study. The overall accuracy of the code calculation can be obtained by defining average performance indices, total weighted AA and total WF as follows:

$$AA_{tot}=\sum_{i=1}^{N_{var}}(AA)_i\cdot(w_f)_i, \quad (5)$$

$$WF_{tot}=\sum_{i=1}^{N_{var}}(WF)_i\cdot(w_f)_i, \quad (6)$$

$$\sum_{i=1}^{N_{var}}(w_f)_i=1, \quad (7)$$

where, N_{var} is the number of the variable analyzed, and $(AA)_i$, $(WF)_i$, and $(w_f)_i$, are AA, WF and weighting factors for i-th analyzed variable, respectively. The weighting factor can be further sub-divided into three components to take into account experimental accuracy, safety relevance and primary pressure normalization. In the present application, the weighting factors which were applied to the previous SBLOCA scenarios and were accepted internationally were used.

Finally, the accuracy of a given calculation is characterized by the following criteria;

AA_{tot}=0.3 : very good prediction
0.3< AA_{tot}<0.5 : good prediction
0.5< AA_{tot}<0.7 : poor prediction
AA_{tot}>0.7 : very poor prediction

3. Application Results and Discussions

3.1 Domestic standard problem (DSP-01)

As the 1st DSP, the 100% DVI line break test data was selected and ten domestic organizations eventually participated in the exercise. Most organizations used the MARS-KS or RELAP5/MOD3.3 code to predict the test data.

Table 1 Selected time of interval for the present FFTBM analysis

Time of interval	Phase relevant to PIRT	Phenomena observed	# of data	Max. frequency (Hz)
0~24 s	Pre-trip	Before the core deca	512	10.66
0~230 s	Post-trip	Before the SIT injection	1024	2.23
0~1000 s	Refill and long term cooling	All the interesting phenomena are included in this time frame	2048	1.02

A total of 86 thermal-hydraulic parameters were requested by the operating agency. The full FFTBM method requires 20-25 parameters selected representing relevant thermal-hydraulic aspects. By communication with Prof. D'Auria's group, 22 parameters were selected to characterize all the relevant phenomena that were measured during the experiment. Similar parameters which would affect the analysis results and the parameters which have much measurement uncertainties were avoided in this selection process.

As shown in Table 1, three time intervals were used based on the PIRT results on the DVI line break. Final results are plotted in Fig. 1. On the whole, the prediction accuracy of each thermal-hydraulic phenomenon was quite satisfactory. In particular, prediction discrepancy of the Hot Leg 1, 2 flowrates was significant in most calculations. The SIT flow rate was also not properly predicted by most calculations. But, the break flow rate was predicted reasonably well although two-phase break flow itself has many uncertainties in measurement and model as well.

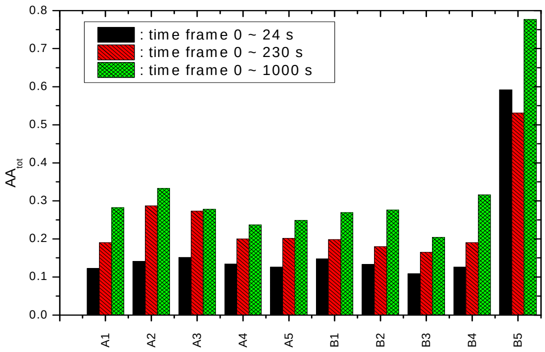

Fig.1 Accuracy quantification in the DSP-01

3.2 International standard problem (ISP-50)

In the ISP-50, the 50% DVI line break test data was selected. The ISP-50 consists of two phases: blind and open calculation. At the moment, the blind calculation was completed and the following open calculation is under way. Seventeen calculation results were finally submitted for the "blind" calculation. Seven different safety analysis codes were used: MARS-KS, TRACE, RELAP5/MOD3.3 series, KORSAR, TECH-M-97, APROS and ATHELET.

Similar to the DSP-01, 22 parameters were carefully selected to capture all major thermal-hydraulic phenomena and to avoid duplication of variables. Three time intervals were selected by taking into account the transient phases defined in the PIRT process. The first time interval corresponded to the pre-trip phase up to 24 s. The calculation results before the decay of the core power were considered. In the second time interval up to 300 s, the transient behavior before the injection of the ECC water from the SITs was considered. Finally, the transient up to 2000 s was taken to be the third time interval. The same weighting factors and cut-off frequency were used in the ISP-50. Results are shown in Fig.2. On the whole the accuracy was not better than the DSP-01 case. It was an expected result by taking into account the blind calculation characteristics. Most foreign organizations were not fully familiar with the ATLAS facility yet and the experimental data were hidden in this blind calculation. In order to get improved calculation results, correct implementation of the actual initial and boundary conditions should be carefully checked by all participants.

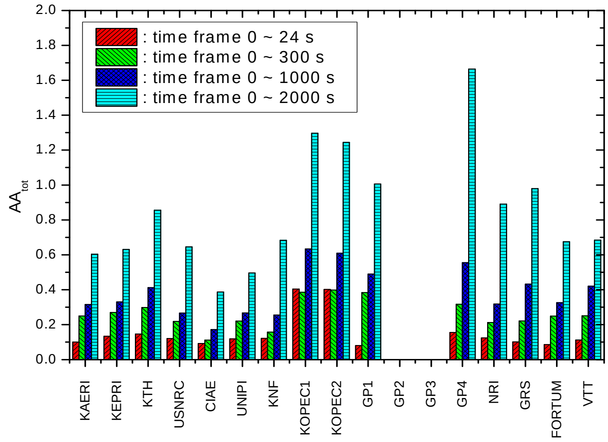

Fig.2 Accuracy quantification results in the ISP-50

It is noteworthy that it is not an objective of this assessment to rank the calculations based on the FFTBM. The present disagreement of calculation with the data is significantly affected by, so called, user effects. In the present phase, it is very hard to define the user effects quantitatively. Much improved calculations are expected in the following "open" calculation.

4. Conclusions

The FFTBM was practically applied to DSP-01 and ISP-50 for the first time in Korea. Though there still some argument on the reliability of this method, it is believed that this method can be used to quantify the prediction accuracy of the BE codes. Also, the variable which leads to the worst prediction can be quantitatively extracted and this information will be transferred to model developers for better codes.

Acknowledgements

The authors are grateful to all the domestic and international participants for their engagement in the DSP-01 and ISP-50 by contributing calculations, meeting, and comments made all along these exercises.

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