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Improved Fast Fourier Transform Based Method for Code Accuracy Quantification

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1. Introduction

In the past few years, various methodologies for quantitative assessment of thermal-hydraulic system codes have been proposed. Among them, the fast Fourier transform based method (FFTBM) introduced in 1990 has been widely used to evaluate a code uncertainty or accuracy [1]. Prošek et al., (2008) identified its drawbacks, the so-called "edge effect" [2]. To overcome the problems, an improved FFTBM by signal mirroring (FFTBM-SM) was proposed and it has been used up to now. In spite of the improvement, the FFTBM-SM yielded different accuracy depending on the frequency components of a parameter, such as pressure, temperature and mass flow rate. Therefore, it is necessary to reduce the frequency dependence of the FFTBMs.

In this study, the deficiencies of the present FFTBMs are analyzed and a new method is proposed to mitigate its frequency dependence. The capability of the proposed method is discussed.

2. The Limitation of the FFTBM

Average amplitude (AA) is the most important information in the FFTBM. It means the magnitude of error derived from experimental and calculated signals, is that represents an accuracy of parameter. When the both signals are equal, the AA becomes zero characterizing perfect agreement and, inversely, the AA=1 means 100% of error. The AA is defined as:

$$AA = \frac{\sum_{n=0}^{2^m} \left| \widetilde{\Delta F}(f_n) \right|}{\sum_{n=0}^{2^m} \left| \widetilde{F}_{exp}(f_n) \right|}. \qquad (1)$$

where m is the exponent determined by the number of data, the numerator in Eq. (1) is the sum of amplitude spectra for the fast Fourier transform of error function, and the denominator in Eq. (1) is the sum of amplitude spectra for the fast Fourier transform of experimental signal [3].

A few years ago, the drawbacks of FFTBM were reported in literature. If the value of the first data point of the investigated signal differs from the last one, the periodically extended signal by the discrete Fourier transform (DFT) becomes to contain artificial discontinuity. Therefore, the FFTBM produces poor accuracy and, the FFTBM-SM is proposed in order to give consistent accuracy [2]. However, it was found that the FFTBM-SM often cannot give consistent judge on accuracy, because the FFTBM fundamentally evaluates the accuracy depending on the frequency components of signal [4]. As a typical example, the integrated break flow signals are investigated as shown in Fig. 1. The average values of the experimental and noise-reduced experimental signal are almost same and, however, the both signals have different frequency components. Comparing the both signals and the calculation one, the AA_{SM}s obtained by the FFTBM-SM are 0.34 and 0.17 respectively, as presented in Table I. The results are considerably different due to the inherent frequency dependence of FFTBM. Therefore, the FFTBM needs to be improved to reduce the frequency dependence for more objective judgement.

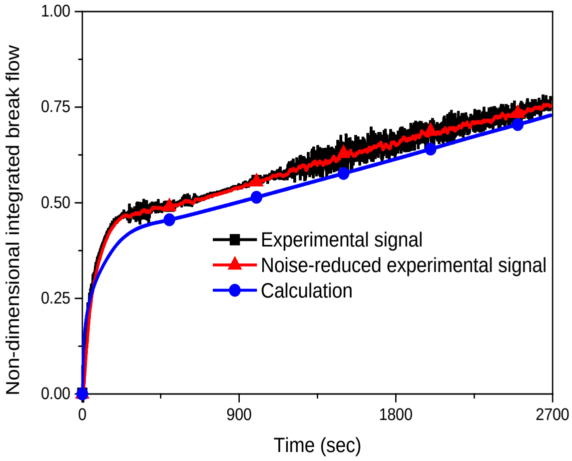

Fig. 1. Non-dimensional integrated break flow signal.

Table I. The AA_{SM} results of FFTBM-SM for the integrated break flow

Signal	AA_{SM}
Cal. /Exp.	0.34
Cal./ noise-reduced Exp.	0.17

3. An Improved FFTBM

In this section, the experiment and the calculation results applying the method are described and, then, new method will be explained.

3.1 ATLAS MSLB Test and Calculation

Main steam line break (MSLB) experiments were conducted using the ATLAS facility at KAERI. Among a series of the MSLB experiments, the SLB-GB-02T was selected and it was calculated using the MARS code [5]. These data were utilized to demonstrate the merit of new method.

A total of 11 parameters were selected as shown in Table II and, their accuracies were produced by FFTBM application. In addition, further calculations were performed by adjusting the break size (0.0346, 0.0306 and 0.0266 cm) and the results were compared with the reference calculation (break size; 0.0386 cm). In summary, a total of 44 cases were taken into account for FFTBM application.

Table II. List of parameters for applying FFTBM

ID	Variable
P1	Pressurizer pressure
P2	SG-1 pressure; affected steam generator
P3	SG-2 pressure; unaffected steam generator
P4	Core inlet temperature
P5	Core outlet temperature
P6	Mass flow rate of hot leg-1 for affected steam generator
P7	Mass flow rate of hot leg-2 for unaffected steam generator
P8	Integrated break flow
P9	SG-1 water level
P10	SG-2 water level
P11	Pressurizer water level

3.2 New Methodology

The existing FFTBMs (FFTBM and FFTBM-SM) calculated the AA up to 0.5 Hz of frequency components because the AA almost converges when the cut-off frequency is higher than 0.5 Hz as shown in Fig. 2.

The Fig. 3 shows the amplitude of the fast Fourier transform (FFT) result of the parameter P1. Amplitudes are relatively high at very low frequency range and, they are very important values to represent the characteristic of signal. However, the amplitudes of high frequency components are very low and meaningless. In the FFT of the whole transient calculation, these meaningless values (high frequency components) are thousands. They considerably affect the sum of amplitudes when a signal contains a lot of high frequency components caused by the noise, discontinuity or sharp change and,

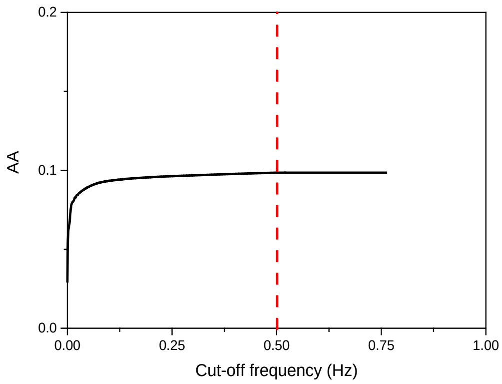

Fig. 2. Impact of the cut-off frequency on AA; P1.

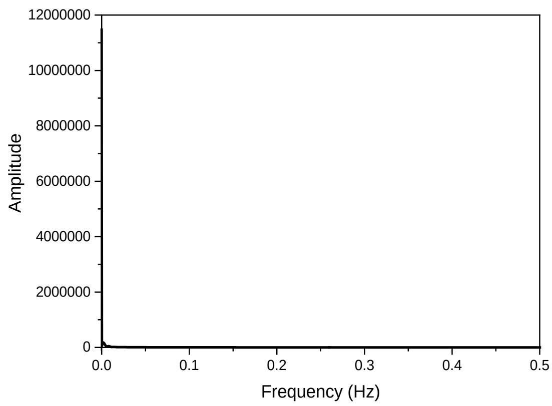

Fig. 3. The FFT results of experimental signal; P1.

they also influence on the AA as shown in Table I. Namely, the present FFTBM methodology (set to the cut-off frequency; 0.5Hz) significantly possesses the frequency dependence caused by high frequency components. Therefore, a new FFTBM methodology using reduced cut-off frequency is proposed to relieve the drawback of FFTBM.

To explain the effect of new method, the correction factors are derived from dividing FFTBM-SM results by FFTBM results. If the correction factor is closer to 1.0 (both results are consistent), it can be said that the frequency dependence of FFTBM is reduced, because the AA results from FFTBM and FFTBM-SM are different caused by the frequency dependence of FFTBMs.

4. Application Results and Discussions

The advantage of the proposed method is verified by the following example. The numbers of cases within ±20% error between FFTBM and FFTBM-SM ($0.8 \leq$ correction factor ≤ 1.2) are presented in Table III, in a total of 44 cases. As shown in the trend of total number which is satisfies the condition, the frequency dependence is reduced by lowering the cut-off frequency. In addition, the drawback of FFTBM is noticeably mitigated for four attempts, compared with the previous FFTBM methodology. However, when the cut off frequency close to zero, it is similar to the classical concept of percentage error. In the case, the benefit of FFTBM is that, the non-dimensionality among parameters fades away. Therefore, the selection of appropriate cut-off frequency is important.

Table III. The numbers of cases within 20% error between FFTBM and FFTBM-SM

Signal	Cut-off frequency (Hz)				
	0.005	0.01	0.05	0.1	0.5
Cal./Exp.	7	7	7	6	3
Cal.(3.46 cm) /Cal.(Ref)	10	7	6	7	4
Cal.(3.06 cm) /Cal.(Ref.)	7	6	6	4	2
Cal.(2.66 cm) /Cal.(Ref.)	4	6	6	4	2
Total	28	26	25	21	11

5. Conclusions

In this study, the limitations of the FFTBM were analyzed. The FFTBM produces quantitatively different results due to its frequency dependence. Because the problem is intensified by including a lot of high frequency components, a new method using a reduced cut-off frequency was proposed. The results of the proposed method show that the shortcomings of FFTBM are considerably relieved.

REFERENCES

[1] W. Ambrosini, R. Bovalini and F. D'Auria, Evaluation of Accuracy of Thermal-Hydraulic Code Calculations, Energia Nucleare, 7, 5-16, 1990.

[2] A. Prošek, M. Leskovar and B. Mavko, Quantitative Assessment with Improved Fast Fourier Transform Based Method by Signal Mirroring, Nucl. Eng. Des., 238, 2668-2677, 2008.

[3] A. Prošek, F. D'Auria, B. Mavko, Review of Quantitative Accuracy Assessments with Fast Fourier Transform Based Method (FFTBM), Nucl. Eng. Des., 217, 179-206, 2002.

[4] T. W. Ha, Analysis of the ATLAS Main Steam Line Break Experiment Using the MARS Code and Improvement of Code Accuracy Quantification Method, Master Thesis, Pusan National University, 2015.

[5] T. W. Ha, B. J. Yun, J. J. Jeong, Analysis of the ATLAS Main Steam Line Break Experiment Using the MARS Code, Proc. NUTHOS-10, Okinawa, Japan, December 14-18, 2014.