Estimation of Moderator Temperature Coefficient using Wavelet Transform

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ABSTRACT

Recently, a new method using Fourier transform has been introduced in place of the conventional method in order to reduce the time required for the measurement of moderator temperature coefficient in Japanese PWRs. The basic concept of these methods is to eliminate noise in the reactivity signal. From this point of view, wavelet analysis is also known as an effective method. The basic idea of the reactivity coefficient estimation is similar to that for Fourier transform procedure in which the analyzed reactivity component is divided by the analyzed component of the relevant parameter. We carried out numerical simulations of moderator temperature coefficient measurement by using wavelet transform and good results were obtained. Using this method we estimated moderator temperature coefficient for measurement data in actual PWRs. The results have proved that the method is applicable for estimation of moderator temperature coefficients in the actual PWRs. It is expected to reduce the required data length during the measurement. We expect to estimate the other reactivity coefficients with the data of short transient.

1.INTRODUCTION

Moderator temperature coefficient is defined as the reactivity change per unit moderator temperature change. In PWRs it is usually measured at each start up after refueling. A new method using Fourier transform has been introduced[1)] in place of the conventional linear fitting procedure to reduce the time required for the measurement [2),3)].

On the other hand wavelet analysis can analyze time-frequency localization. In time-frequency localization we can analyze not only frequency but also the time dependent frequency distribution. Some authors have reported the wavelet analysis in the nuclear reactor physics [4),5)] or power plant application [6),7),8)]. In the latter the wavelet transform is used to eliminate signal noise and this concept is similar to that of the moderator temperature coefficient measurement using linear fitting procedure or Fourier transform.

We carried out numerical simulations of moderator temperature coefficient measurement by using wavelet transform and good results were obtained[9)]. Using this method we evaluated moderator temperature coefficient for measurement data in actual PWRs. The results have proved that the method is applicable for estimation of moderator temperature coefficients in the actual PWRs. It is expected to reduce the required data length during the measurement.

2.BASIC THEORY OF WAVELET TRANSFORM

In wavelet transform analysis a function is expressed as the sum of sub-functions of level j, which indicates the number of decomposition process. Basic theory of wavelet transform is introduced as follows;

Firstly, two basic functions, Scaling Function $f(x)$ and Wavelet function $y(x)$ are defined, which satisfy so called “two-scale relation”.

$$f(x) = \sum_k p_k f(2x - k) \tag{1}$$

$$y(x) = \sum_k q_k f(2x - k) \tag{2}$$

where p_k, q_k are given and k is an integer.
With the scaling function $f(x)$ defined, sub-function of level j are determined as

$$f(2^j x - k)\,. \tag{3}$$

It changes the frequency of the scaling function $f(x)$ by 2 ^{j} times and translates the position on the x-axis in parallel.

Then arbitrary function $f_j(x)$ can be expressed as

$$f_j(x) = \sum_k c_k^{(j)} f(2^j x - k)\,. \tag{4}$$

And with the wavelet function $y(x)$ defined, arbitrary function $g_j(x)$ can be also expressed as

$$g_j(x) = \sum_k d_k^{(j)} y(2^j x - k)\,. \tag{5}$$

With regards to these functions, the following relations hold.

$$f_j(x) = f_{j-1}(x) + g_{j-1}(x)\,. \tag{6}$$

In other words function $f_j(x)$ is decomposed to $f_{j-1}(x)$ and $g_{j-1}(x)$. This relation is used recursively and we get following expression.

$$f_j(x) = g_{j-1}(x) + g_{j-2}(x) + ... + g_{j-n}(x) + f_{j-1}(x)\,. \tag{7}$$

This means that any function $f(x)$ can be expressed as a sum of functions $g_j(x)$ for infinite j. That is

$$f(x) \approx \sum_j g_j(x) = \sum_j \sum_k d_k^{(j)} \psi(2^j x - k)\,. \qquad (8)$$

The expansion coefficients $c_k^{(j)}$ and $d_k^{(j)}$ are determined according to the basic requirement for the scaling function and wavelet function. The fundamental expansion coefficients are already evaluated for various scaling functions and wavelet functions[10)]. In the data analysis we selected the wavelet function of Cardinal B Spline of the order 4 from the point that the computation is simple and the frequency resolution is good, which is given as follows;

p_k ; p_0 = 1/8 , p_1=1/2 , p_2=3/4 , p_3=1/2 , p_4=1/8

q_k ; q_0 = q_{10} = 1/40320 , q_1 = q_9 = -31/10080 , q_2 = q_8 = 559/13440

q_3 = q_7 = -247/1260 , q_4 = q_6 = 9241/20160 , q_5 = -337/560

The functions are plotted in Fig. 1 and 2, respectively.

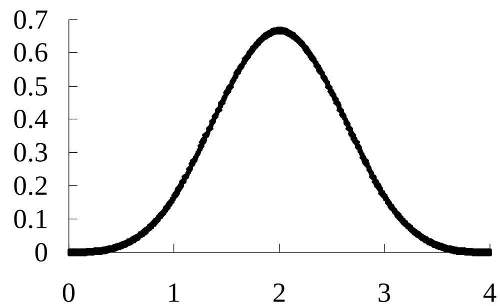

Fig.1 Scaling function $f(x)$

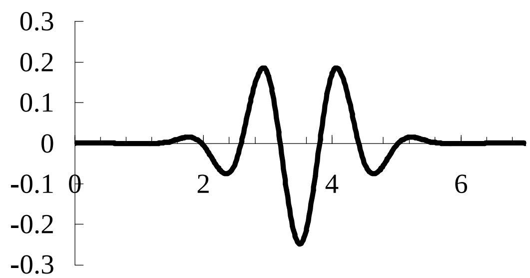

Fig.2 Wavelet function $\psi(x)$

The expansion coefficients $c_k^{(j)}$ and $d_k^{(j)}$ are calculated recursively using $c_k^{(0)}$ and the decomposition sequences g_k and h_k as follows;

$$c_k^{(0)} = \sum_l b_{k+2-l} f(l)\,, \qquad (9)$$

where

$$b_k = \sqrt{3}\left(\sqrt{3}-2\right)^k \approx 0 \quad \text{for} \quad |k| > 5 \,, \qquad (10)$$

$f(l)$; discrete values of function $f(x)$ at x = l.

Then $c_k^{(j)}$ and $d_k^{(j)}$ are obtained as

$$c_k^{(j-1)} = \frac{1}{2}\sum_l g_{2k-l} c_l^{(j)} , \quad (11)$$

$$d_k^{(j-1)} = \frac{1}{2}\sum_l h_{2k-l} c_l^{(j)} . \quad (12)$$

The decomposition sequences g_k and h_k are analytically obtained according to the basic requirements for the scaling function and wavelet function such as normalization. In this analysis we used the given sequences in reference 10).

In summary, when time-frequency localization is carried out the following steps are taken.

(1) Input time sequence data $f(l)$; $0 \le l \le n$

(2) Calculate $c_k^{(0)}$; $-7 \le k \le n+3$

(3) Calculate $c_k^{(j)}$ and $d_k^{(j)}$ as required; j<0, the range of k is dependent on j

(4) Calculate $g_j(x)$ by using these expansion coefficients.

The characteristics of the input function $f(l)$ are investigated using this information.

3.PRINCIPLE OF REACTIVITY COEFFICIENT EVALUATION

As described above, arbitrary function can be decomposed to wavelet function of different levels. In time-frequency localization analysis, the level j, which decreases from zero, means that it changes the frequency of the scaling function $f(x)$ by 2^j times. When the data to be analyzed have noise, the noise components are taken into $g_j(x)$ of low j's such as j= -1, -2, -3, and so on. When the decomposition process progresses the noise components decrease and thus are eliminated. On the other hand data without noise can also be decomposed but the $g_j(x)$'s have no components of noise. When reactivity is proportional to the other parameter, then it is clear that the decomposed functions at the same level of reactivity and the parameter are also proportional to each other. As explained above, the quantity of information of $g_j(x)$ that can be calculated using $d_k^{(j)}$ is thought to be identical to each other. Based on this concept we expected that the moderator temperature coefficient could be calculated as the ratio of the $d_k^{(j)}$'s for the reactivity and the temperature.

In the numerical simulation the number of the time sequence data pair was $2^7 = 128$, which was less than the number of the actual reactor data acquisition. As seen in Fig.2 the wavelet function $y(x)$ has values for $0 \le x \le 7$. The common $d_k^{(j)}$'s for all levels used for the calculation of $g_j(x)$ for $0 \le x \le 128$ are eight such that from k = -7 to k = 0. At first we used all of these expansion coefficients for each level for the ratio calculation and then averaged the eight ratios. However the result was not necessarily correct. In the case that $d_k^{(j)}$ was too small, the error of calculated moderator temperature coefficients became very big. So we took the largest six $d_k^{(j)}$'s in the absolute value and calculated the average of the ratios. As a result we obtained good estimation for selected levels. For the selection of the levels we calculated the moderator temperature coefficient in all levels. The standard deviation of the error of the estimated moderator temperature coefficient became small when decomposition level is less than -7. Based on the results we used data of two decomposition levels that give smaller standard deviation for the moderator temperature coefficient estimation. It is found that the analysis can estimate or reproduce the given moderator temperature coefficient within the relative error of 4% using less length of time sequence data.

As the actual data in a PWR is quite similar to the ramp case it is expected that this method can give suitable results. We used data of the deviation from the equilibrium state in the numerical simulation. However the actual data does not always contain deviation data from the equilibrium state. In such case the data have some bias. In order to examine the effect of the bias, several biases were added only to the reactivity signal in the ramp cases and calculated the moderator temperature coefficients. The result of the numerical simulation is shown in Fig.3.

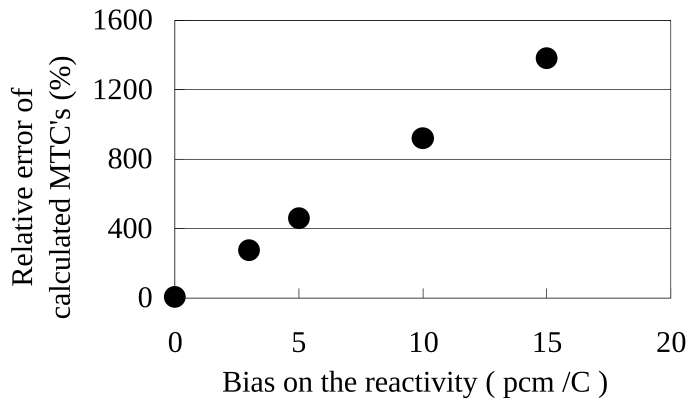

Fig.3 The relation of the bias and the error of calculated MTC's

From the result it is known that we must remove the bias. Firstly we assumed that the bias can be the first value. Secondly we assumed that the bias is given as the average of five values from the beginning of the data. However in any cases the biases are not estimated correctly. Therefore we used the average of all the data as the bias. Good results are obtained as shown in Table.1.

Table.1 Bias decision method and calculated MTC's

The first value (pcm/C)	Average of five values (pcm/C)	Average of all the data (pcm/C)	Expected (pcm/C)
-2.57	-2.53	-2.08	-2.00
-4.26	-4.53	-4.09	-4.00
-6.25	-6.53	-6.08	-6.00

4. ACTUAL PLANT DATA ANALYSIS

With the actual data of temperature and reactivity for the moderator temperature coefficient in actual PWRs, we calculated the moderator temperature coefficient and compared with the linear fitting procedure for 28 cases. The number of sequential data pair with the wavelet transform was 128 and that with the linear fitting procedure was about 500. The sequential data of 128 pairs are taken out from various points of about 500 pairs. The calculated value depended on the position of the data of 128 pairs, however the difference is negligible small. The average of error between the linear fitting procedure and the wavelet transform is $0.1\times10^{-5}(\Delta k/k)/C$ and the standard deviation of the error is $0.2\times10^{-5}(\Delta k/k)/C$. The results of 28 cases are shown in Fig.4.

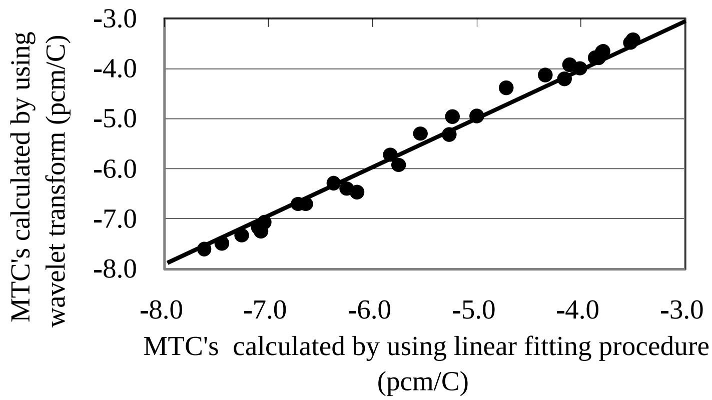

Fig.4 Comparison of MTC's calculated by using wavelet transform with those by using linear fitting procedure

It shows that the wavelet transform method gives as accurate results as that of the linear fitting procedure with smaller number of data.

CONCLUSIONS

Based on numerical simulation it is found that the analysis can properly estimate moderator temperature coefficient with less length of time sequence data. Further it has been shown that the wavelet transform for estimation of moderator temperature coefficients in the actual PWRs is applicable. It is expected to reduce the required data sequences during the measurement. It helps to obtain data for the other reactivity coefficient of shorter time transient.

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