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Calibration Technique of the Irradiated Thermocouple using Artificial Neural Network

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1. Introduction

To develop a new nuclear fuel, an irradiation test is carried out in the research reactor to evaluate the performance of the nuclear fuel. In particular, a test rig should be fabricated, and it is installed in the irradiation hole of the research reactor. During irradiation test, irradiation characteristics are measured in a timely manner using the sensors instrumented in the test rig. If there is error in measuring the exact characteristic of the fuel, it accumulates error in evaluating the performance of the nuclear fuel. Therefore, accuracy of the measurement sensors is very important in irradiation test. However, as the irradiation period increases, sensors instrumented in the test rig are degraded owing to the neutron fluence. Signal delivered from the sensors are then weakened owing to the degradation. To correct the signals, the degradation rate of sensors needs to be analyzed, and re-calibration of sensors should be followed periodically. In particular, because thermocouples instrumented in the nuclear fuel rod are degraded owing to the high neutron fluence generated from the nuclear fuel, the periodic re-calibration process is necessary. However, despite the re-calibration of the thermocouple, the measurement error will be increased until next re-calibration.

In this study, based on the periodically calibrated temperature – voltage data, an interpolation technique using the artificial neural network will be introduced to minimize the calibration error of the C-type thermocouple under the irradiation test.

2. De-calibration of thermocouple during the in-pile irradiation test

2.1 Degradation mechanism of C-type thermocouple

When the thermocouple instrumented in a test rig is exposed to the high temperature and the high radioactive rays for a long period, several degradation phenomena, such as exposure of junction part, crystallization of refractory metal, electrolytic response of insulator, response of impurity in the wire, response of wire insulator, etc., can be caused. In those case, a C-type thermocouple instrumented in the nuclear fuel rod is de-calibrated, and the measured voltages show different values from the calibrated voltages at each sampling points.

2.2 De-calibration rate of C-type thermocouple

Previous studies to assess the de-calibration of thermocouples during irradiation test have been carried out by Vitanza, Pratt, Conroy, and Sandefour[1-4]. Nieuwenhove summarized the de-calibration effect of the previous studies[5], and proposed a function to correlate the de-calibration rate(D) according to the thermal neutron fluence(φ, 10^{21} nvt) as shown in equation (1) ~ (3).

$$D = 0 \quad \text{for } 0<\varphi\leq 0.25 \tag{1}$$
$$D = 100\cdot[1- e^{0.067\cdot(0.25-\varphi)}) \quad \text{for } 0.25<\varphi\leq 1 \tag{2}$$
$$D = 100\cdot[1- e^{0.104\cdot(0.52-\varphi)}) \quad \text{for } 1 < \varphi \tag{3}$$

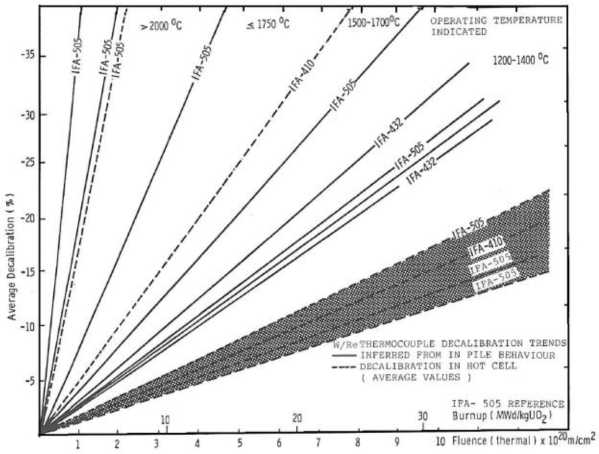

Fig. 1. De-calibration trend of W/Re thermocouple according to the thermal neutron fluence [6]

2.3 Construction of interpolation function with artificial neural network

Firstly, experimental data at sampling points is necessary to interpolate the temperature at a certain voltage and thermal neutron fluence. Then, basis functions need to be constructed to make interpolation function. In this study, radial basis function (RBF) is constructed for N numbers of sampling data as equation (4), and inverse multiquadrics are used as a basis function (equation (5)). Because inverse multiquadrics is bounded and positive definite, it is possible to obtain a unique solution for N numbers of distinct data by making an inverse matrix.

$$F(x) = \sum_{i=1}^{N} w_i \varphi\left(\left\| x - x_i \right\|\right) \tag{4}$$

where w_i is weight factor, and x_i is the position of i-th sampling data.

$$\varphi(r) = \frac{1}{(r^2 + c^2)^{1/2}} \tag{5}$$

where r is distance from the origin, and c is a correction factor. In general, most studies have employed the Taylor's series and the Fourier's series as a basis function. However, because these are defined in the global domain, there are severe oscillations between sampling points as shown in Fig. 2. On the other hand, RBF is locally defined and there is no oscillation between sampling points. That is, RBF can interpolate discrete data more exactly than the Taylor's series and the Fourier's series.

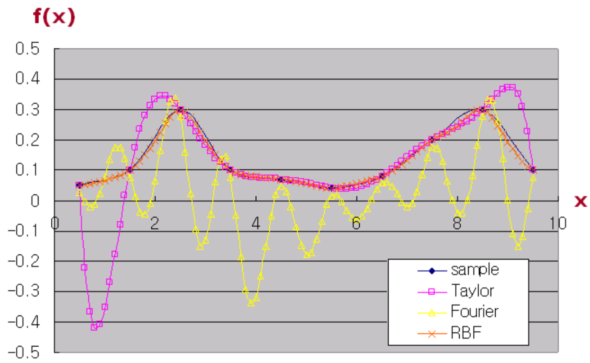

Fig. 2. Comparison of basis function for 10 sampling data

2.4 Compensation of de-calibrated signals

In this study, equation (1) ~ (3) is used to get a sampling data as a test input. As shown in Fig. 3, temperature range from 0 to 500 is uniformly divided into 50 points, and 50 sampling data are obtained using equation (1) ~ (3) at the thermal neutron fluence of 0, 0.5, 1, and 1.5 (10^{21} nvt), respectively. In particular, sampling data at the zero thermal neutron fluence are obtained from the specification table of C-type thermocouple.

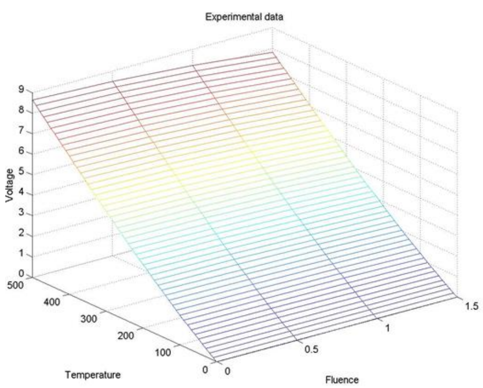

Fig. 3. Experimental voltage delivered from the C-type thermocouple at the sampling points

RBFs are then constructed for 204 sampling data, and calculate the inverse matrix. Thus, the weight factors (w_i) are derived by solving the matrix, and this is the learning process of artificial neural network.

Finally, the range of the temperature is divided into 100, and the range of the neutron fluence is divided into 6. Fig. 4 shows the calculated voltage from the RBFs at each temperature and neutron fluence. As shown in Fig. 4, the voltages at the sampling points are nearly the same with the sampling data. In addition, the voltages at the other points are smoothly interpolated.

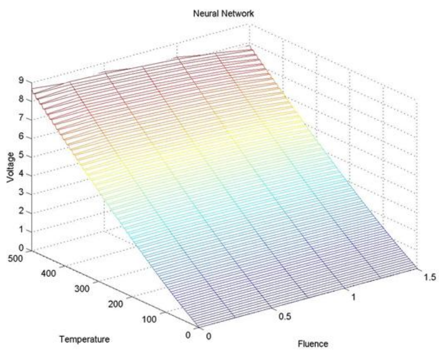

Fig. 4. Calculated voltage using RBFs

3. Conclusions

In this study, an interpolation technique using an artificial neural network has been developed to calibrate the de-calibrated signal of the C-type thermocouple. For N numbers of experimental sampling data, N numbers of RBF were constructed. And weight factor is derived by solving the matrix. The developed functions are then used to interpolate the experimental sampling data of the C-type thermocouple. The test result shows that the calculated voltages derived from the interpolation function have good agreement with the experimental sampling data, and they also accurately interpolate the voltages at arbitrary temperature and neutron fluence. That is, once the reference data is obtained by experiments, it is possible to accurately calibrate the voltage signal at a certain neutron fluence and temperature using an artificial neural network. The developed technique will be used in compensating the degraded signals of thermocouples owing to neutron fluence

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