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Short communication

A residual compensation method for the calibration equation of negative temperature coefficient thermistors

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ABSTRACT

We propose a calibration equation for negative temperature coefficient thermistors. This equation is modified from the basic thermistor equation by a residual compensation method. The residual compensated equation includes a 2nd order error correction term. This equation is convenient for converting temperature to resistance and vice versa. Calibrations of various thermistors were performed in a high precision temperature bath to test the resistance–temperature relation. The thermistors were calibrated in glass tubes using a reference thermometer. Most calibrations are performed in a temperature span (15–35 °C). From the resistance–temperature curves, the fitting function of the basic thermistor equation and the residual compensated equation were evaluated and their fitting errors were compared. Standard fitting errors (1σ) in temperature of the basic equation and the residual compensated basic equation were 8.131 mK and 0.151 mK respectively. The residual compensated equation showed about 1/54 smaller fitting errors than the basic thermistor equation.

1. Introduction

In the radiation measurement field, calorimeters are used to evaluate the absorbed dose, measuring the temperature rise of the irradiated body. When the temperature rise produced by irradiation is very small, a high sensitivity temperature sensor is needed to measure the temperature change. In such cases, thermally sensitive resistors – thermistor – are used for precise temperature measurement. Thermistors are temperature dependent resistors with a high resistance temperature coefficient [1,2]. Their high coefficient and very small size are good characteristics for a calorimeter system. In practice, thermistors with a negative temperature coefficient (NTC type) are frequently used for temperature measurement [3].

Because of their non-linear response, the thermistor resistance-to-temperature (R–T) relationship has been explained by several researchers. Considering the electrons in an n-type material and carrier mobility, it was shown that the resistivity of the n-type material is proportional to $T^{-c}e^{(k/T)}$ where c is a constant and k is a material constant [4–6]. Another study showed that the best fit to these R–T relationships gives a simple relation to the R–T property, $R_T = R_{T\rightarrow\infty}e^{(\beta/T)}$ [3]. R_T is thermistor resistance at T, T is temperature in K, R_∞ is the limit value of R_T as T approaches to infinity, B is a constant depending on the thermistor material, in K. Because R_∞ cannot be measured, this equation is modified in terms of resistance R_0 at reference temperature T_0 [7]. Eq. (1) is a widely used simple form for the thermistor response.

$$R_T = R_0 e^{\beta(1/T - 1/T_0)} \quad (1)$$

The most frequently used reference resistance of thermistors R_0 is determined at 25 °C, i.e. 298.15 K. In a narrow temperature span, this simple exponential relationship will be a good approximation with its satisfactorily small residuals. But this equation still results in slight temperature errors of several mK, which is called the "plus-minus-plus" effect [8]. This error behavior of the basic equation already was shown by Bosson et al. [9]. If one needs a more precise fitting result with sub milli-Kelvin accuracy, especially for fine temperature control and measurement, this equation needs to be modified. Otherwise, other thermistor equations which include higher order terms are usually applied to the fitting equation. Unfortunately high order polynomial thermistor equations have difficulty in converting temperature to resistance or vice versa because the solutions of the high order equations are in a very complicated form.

To address these issues, we introduce a method to compensate the errors of the basic thermistor equation using resistance and its

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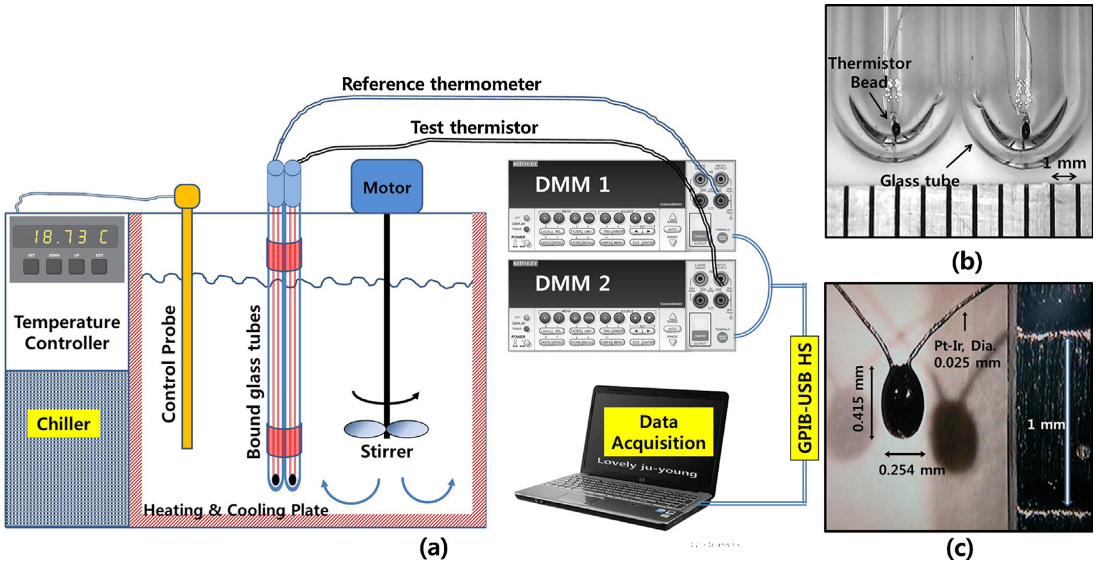

Fig. 1. (a) The thermistor calibration water bath and the *R–T* measurement system. (b) An enlarged picture of the glass tube tip with a scaler. (c) A microscopic image of a thermistor bead for estimating its size.

residual values. This method uses just a 2nd order form and provides easy conversion of resistance to temperature and vice versa. This residual compensated basic (RCB) equation is modified from the basic equation, Eq. (1), using the compensation method of resistance residuals. We explain the procedures for researchers who are interested in this method.

2. Materials and method

2.1. Materials and apparatuses

We prepared the following thermistors: VECO (Victory Engineering Corporation) NTC thermistors (Part No.: 32A130, G32A173, 43A70, 33A83, R_{25}: 1.5–20 kΩ, Temperature coefficient at 25 °C (α_{25}): −3.4%/°C to −4.0%/°C), Measurement Specialties, Inc. NTC thermistors (Part No.: GAG22K7MCD419, R_{25}: 22 kΩ, α_{25}: −3.9%/°C).

We used a temperature control water bath, and its specifications were as follows; Model: HART SCIENTIFIC High Precision Bath R-12 system (Fig. 1). Control resolution: 0.002 °C, Temperature Stability: ±0.001 °C, Control probe: 100 Ω, 4 wire, Platinum Resistance Thermometer (PRT). This PRT control probe in Fig. 1 is only used for temperature control of the water bath.

We used two digital multi-meters (DMM), Keithley 2000, for the temperature and resistance measurement. The two DMM were calibrated with standard resistors in advance and each correction factor was applied to the raw measurement values.

For auto data acquisition, the DMMs are connected to a PC through general purpose interface bus (GPIB) cables. The temperature and resistance data were measured with 5 s sampling time. The *R–T* measurement software was developed using LabVIEW which was fitted for our measurement system.

For thermistor water sleeves, we used glass tubes with a sealed round tip which were 450 mm in length and 5 mm diameter. The glass tube setup used for the thermistor calibration consisted of a thermistor, 4 enamel copper wires and a Universal Serial Bus (USB) cable port. A USB cable was used for the signal cable because the cable consists of 5 wires including a guard cable that reduces noise signals. And the USB port is convenient when connecting the glass tube to the measurement apparatus. The 4-wire resistance measurement used separate pairs of current-carrying and voltage-sensing electrodes to make more accurate measurements than the 2-wire measurement.

Temperature sensing was done with a reference thermometer, and the reference thermometer was calibrated with a standard platinum resistance thermometer (SPRT, Rosemount 162CE, *S/N*: 4053) in Korea Research Institute of Standards and Science (KRISS). The resistance of the SPRT at the triple point of water is 25.554246 Ω and the deviation coefficients of International Temperature Scale of 1990 (ITS-90) are (a) -2.09509×10^{-4}, (b) -3.8047×10^{-5}, and (c) 9.610×10^{-6} respectively. The temperature calibration system consists of a precision thermometry bridge (F700 Tinsley—ASL) with a high precision standard resistor (GUILD LINE, 7334-100, 99.99979 Ω), a high precision water bath (Hart Scientific, Model 7012), and the SPRT. Measuring R_t/R_s ratio (the SPRT resistance vs. the standard resistance) from the thermometry bridge, the water temperature is calculated. This system was used for the *R–T* calibration of the reference thermometer. The calibration temperature range was 10–40 °C (11 measurement points with 3 °C step) in the water bath. The measurement were done in the stable temperature range of ±0.5 mK. The resistance of the SPRT that will be converted to temperature and the resistance of the reference thermometer were recorded automatically to instantly sense any slight change of the temperature water bath every second.

The calibrated reference thermometer had the following properties: the resistance value at 25 °C (R_{25}) was 1642.73 Ω, temperature coefficient at 25 °C (α_{25}) was −0.0345/°C. The reference thermometer was embedded and sealed in a glass tube. That tube had the identical size and shape as the glass tubes for test thermistors, so the reference thermometer underwent temperature changes close to the test thermistor. The two glass tubes for the reference thermometer and the test thermistors were closely arranged and contacted at each tip to make the temperature difference between the two tubes as small as possible. This temperature difference at every second between the two tubes was evaluated by using two calibrated thermistors which had smallest sizes for rapid responses. Although the temperature variation in the water bathe was about ±0.5 mK, the temperature difference between the two thermistor was very small (±0.126 mK). This uncertainty was included in Table 2 as the temperature gradient term. The above settings make the *R–T* curves more exact because the test thermistor simultaneously feels the temperature change when the reference thermometer feels the temperature change. The two combined glass tubes were located in the water bath, which was shown in Fig. 1.