DETERMINATION OF THE STANDARD RESISTOR TEMPERATURE COEFFICIENTS AND THEIR UNCERTAINTIES

Penentuan Koefisien Suhu Resistor Standard dan Ketidakpastiannya

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Abstract

SNSU TK-BSN's capability in determining the temperature coefficients of a standard resistor has been improved. The temperature coefficient is one of the important parameter in determining the definition of the standard resistor. Currently, the measurement result has been reported together with the measurement uncertainty. The determination itself is based on a numerical approach of Taylor Series Approximation (TSA) instead of based on a fitting to a certain equation. And by this determination, the uncertainty was calculated. The determination was validated by comparing the measurement result committed by SNSU TK-BSN to that of by the manufacturer. The equation for the temperature coefficient follows the parabolic equation with an alpha coefficient of -5.30 x 10-8 Ω/Ω/°C and beta coefficient of -4.70 x 10-8 Ω/Ω/°C^2, with the respective uncertainties of 2.4 x 10-8 Ω/Ω/°C and 1.6x 10-8 Ω/Ω/°C^2, respectively. SNSU TK-BSN measurement results in determining the temperature coefficient in agreement with the manufacturer's measurement results show an appropriate value. This correspondence has an equivalent degree of 0.20 for the alpha temperature coefficient and 0.27 for the beta coefficient.

Keywords: determination of temperature coefficient, standard resistor, uncertainty evaluation, validation

Abstrak

Kemampuan Laboratorium SNSU TK-BSN dalam menentukan koefisien suhu dari resistor standar telah ditingkatkan. Koefisiens suhu merupakan salah satu parameter penting dalam mendefinisikan nilai standar resistor. Saat ini, hasil pengukuran telah dilaporkan bersama dengan nilai ketidakpastian pengukuran. Penentuan itu sendiri didasarkan pada pendekatan numerik Taylor Series Approximation (TSA), yang berdasarkan fitting untuk persamaan tertentu. Sehingga nilai ketidakpastian dapat dilakukan perhitungan. Penentuan ini divalidasi dengan membandingkan hasil pengukuran yang dilakukan oleh SNSU TK-BSN dengan yang dilakukan oleh pabrikan. Persamaan untuk koefisien suhu mengikuti persamaan parabolik dengan koefisien alpha sebesar of -5,30 x 10-8 Ω/Ω/°C dan koefisien beta sebesar -4,70 x 10-8 Ω/Ω/°C^2, dengan ketidakpastian masing-masing secara berturut-turut adalah 2,4 x 10-8 Ω/Ω/°C dan 1,6x 10-8 Ω/Ω/°C^2. Hasil pengukuran SNSU TK-BSN dalam menentukan koefisien suhu yang sesuai dengan hasil pengukuran pabrikan menunjukkan nilai yang berkesesuaian. Kesesuaian tersebut memiliki derajat ekuivalensi sebesar 0,20 untuk koefisien suhu alpha dan 0,27 untuk koefisien beta.

Kata kunci*: evaluasi ketidakpastian, penentuan koefisien suhu; resistor standar, validasi*

1. INTRODUCTION

In previous paper, we had discussed a measurement method performed by the Directorate of National Measurement Standards for Thermoelectricity and Chemistry—National Standardization Agency of Indonesia (SNSU TK-BSN) (previously Research Centre for Metrology—Indonesian Institute of Sciences (RCM-LIPI)) in characterizing a standard resistor due to temperature variations in order to determine temperature coefficients with high accuracy and good precision using a direct current comparator (DCC) bridge (Khairiyati, Azzumar dan Faisal, 2015). The determination of the thermal coefficient of resistance for precision resistor has been offered as a special test.

Calibration laboratories in the industry have a similar set of standard resistors and DCCBs as well, and usually, the set of resistors are immersed in temperature-controlled oil baths to avoid temperature fluctuation effects to the resistance (Abe, Oe, Kumagai, Zama and Kaneko, 2018). However these test required prior arrangements and the temporary inclusion of various components into the measuring system, thereby increasing both measurement uncertainty and the time required for the calibration (Jones and Elmquist, 2007).

A development has been carried out in determining the temperature coefficients. Currently, the measurement result of the temperature coeficient is reported together with their uncertainties. Determination based on a numerical approach of Taylor Series Approximation (TSA). The TSA approach in determining the temperature coefficients allows some errors when performing the characterization measurements. So that these results need to be validated against a value that is considered correct.

The test resistor used in this experiment was a 1 Ω Fluke 742A Series, where the temperature coefficients of this test resistor are reported by the manufacturer on its calibration certificate. Besides, the temperature coefficients considered to not change over time (Fluke, 1988). So the manufacturer’s result may be used as a reference in validating the determination of the unknown standard resistor temperature coefficients.

2. BASIC THEORY

Resistor Standard

Maintenance of electrical resistance standards and calibration services are needed standard resistors. Basically most of the national metrology institutes (NMIs) maintain a set of standard resistors. Those resistors are to be traceable to a primary standard, namely a quantized Hall resistance standard (QHRS). For the resistance values of 1 Ω and 10 Ω, wire-wound standard resistors immersed in a temperature stabilized oil bath has been traditionally and widely utilized in many laboratories. (Kaneko, Takehiko, Takayuki, Masaya and Matsuo, 2016).

The 742A Series used in this paper is small, light, rugged resistance standards. The standards require no temperature-controlled air or oil bath. The 742A Series are well suited for use as the following: working standards and Portable transfer standards. The 742A Series are constructed of arrays of Fluke wire wound precision hermetically-sealed resistors. No adjustable resistors of any kind are used. Each 742A is built with a temperature coefficient near zero at 23 °C. To further reduce errors caused by temperature changes, the binding posts are constructed of low-thermal emf material. Figure 1 shows a front panel view of the 742A series (Fluke, 1988).

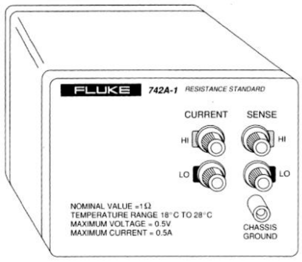

Figure 1 Typical front panel view.

Taylor Series Approximation (TSA)

A Taylor series approximation (TSA) uses a Taylor series to represent a number as a polynomial that has a very similar value to the number the neighbourhood around. Engineers have long used the Taylor Series Approximation (TSA) as a tool to simplify problems. (Canfield, 1989). The Taylor series is a mathematical tool applied in different areas of engineering including signal processing, control, and voice recognition (Rios, 2017).

Direct Current Comparator Bridge (DCCB)

The conventional DCC Ratio Bridge error is ranges of 0.1 ppm to 0.05 ppm accuracy level for ratios of 1:1 to 10:1 (Brown, Wachowicz and Huang, 2016). DCCB is equipment used to measure a value that is known in the form of a ratio of resistance whose value is unknown. The DCCB is built on a transformer with a dual toroidal magnetic core modulator, a magnetic shield that surrounds the modulator core and with multiple winding. The two ratio windings link to the modulator and the magnetic shield which carries the currents to be compared. When the modulator output is zero the current ratio is equal to the turns ratio to a high degree of accuracy (Guildline, 2001). At ampere-turn balance in Equation 1,

$$(N_X)\times(I_X)=(N_S)\times(I_S) \quad (1)$$

Where :

N_X : number of truns in variable comparator winding

I_X : current in the variable comparator winding and Rx

N_S : number of truns in slave fixed comparator winding

I_S : lave winding and Rs

In this situation, the second balance condition must be fulfilled, wherein the I_X current flowing through the N_X and R_X windings have the same potential as the I_S current flowing through the N_S and R_S windings ($V_X = V_S$), so that R_X, R_S, I_X, and I_S will be interrelated. Mathematically the second balance can be expressed in the following equation:

$$I_X \cdot R_X = I_S \cdot R_S \qquad (2)$$

Where :

I_X	:	current in the variable comparator winding and Rx
R_X	:	the resistance as a uknown
I_S	:	current in the slave winding and Rs
R_S	:	the resistance as a reference

So based on Equation 1 and 2, the relationship between R_X and R_S can be avowed as a ratio (Γ). And Γ is the ratio displayed on DCCB when measuring (Azzumar and Faisal, 2015).

3. METHODS

Determination of the Temperature Coefficients

The resistor standard can be modelled as a function of environmental condition, method, and time. The environmental condition may include temperature, humidity, barometric pressure, and power dissipation (Jones, Pritchard & Elmquist, 2009). All measurements were performed with a direct-current comparator (DCC) bridge and a 1 Ω calibrated reference resistor in a thermostated oil bath (Callegaro, 2015). Meanwhile, the method consists the used of the DCC Bridge, of the reference standard, and the test resistor. On the other hand, the time is considered as the short term stability along the measurement. The subject of this topic focuses the temperature coefficient, so that the variability of the other input quantities is kept to be constant within a range of uncertainty. The only change remain is the temperature effect. The general characteristic of the resistor to temperature changes may have a relationship as the following Equation 3 (Dudek, Mosiadz, and Orzepowski, 2007).

$$R_T = R_{23} \cdot \left(1 + \alpha\left(T - 23\right) + \beta\left(T - 23\right)^2\right) \qquad (3)$$

Where :

R_T	:	resistance at temperature T
R_{23}	:	resistance at calibration temperature of 23 ^oC
T	:	test temperature
α, β	:	1st and 2nd order temperature coefficient

A number of 23 is the reference temperature of which it is usually maintained in a laboratory to calibrate the standard resistor. In this experiment, accordance to the labs temperature setup, Fluke 742A resistor is built-up with a temperature coefficient near-zero at 23°C, which means that the turning point from the quadratic equation is at reference temperature that is equal to 23°C.

On the measurement of a Fluke 742A standard resistor to temperature changes, the setup is consists of a DCC bridge, a reference standard resistor, an oil bath for the reference standard resistor and an air bath chamber for the Fluke 742A. And it is depicted as in Figure 2.

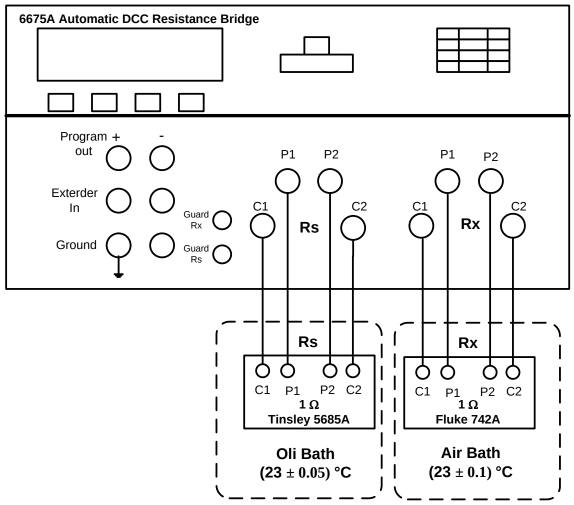

Figure 2 Measurement of a resistor to temperature change configuration.

The temperature of the oil bath is set to (23 ± 0.05) °C. The test temperature of the air bath is varied from 18 °C to 28 °C within ± 0.1 °C stability. Meanwhile the ambient room condition is at a temperature of (23 ± 2) °C, a relative humidity of (65 ± 10) %, and a barometric pressure of (1000 ± 10) Pa. The DCC bridge calculates the unity ratio of one as both at the reference arm and the under test arm measure the same rated current of (100 ± 0.02) mA. The aforementioned Fluke 742A resistor was used as a reference resistor for this measurement, and it was immersed in the temperature-controlled air bath (Domae et all., 2015). Through this setup, the observation of R_T is taken as ten repeated measurements for each consecutive temperature changes.

Based on Equation 3, the resistor's characteristic to temperature changes in term of its temperature coefficients can be determined by the second-order Taylor Series Approximation (TSA). The Taylor Series approach is usually used to analyse the differential equation

(Chaptra, 2010). Considering that the standard resistor is a quadratic function of the temperature, the differential equation up to second order of the Taylor Series for afterwards and beforehand of the midpoint can be written as Equation 4 and Equation 5, respectively.

$$f(x_{i+1}) = f(x_i) + f'(x_i)\frac{(x_{i+1} - x_i)}{1!} + f''(x_i)\frac{(x_{i+1} - x_i)^2}{2!} \quad (4)$$

Where :

$f(x_{i+1})$: x function for the temperature variable i +1

x : temperature at 23 °C

i : value for temperature

$$f(x_{i-1}) = f(x_i) + f'(x_i)\frac{(x_i - x_{i-1})}{1!} + f''(x_i)\frac{(x_i - x_{i-1})^2}{2!} \quad (5)$$

Where :

$f(x_{i-1})$: x function for the temperature variable i -1

x : temperature at 23°C

i : value for temperature

By subtracting Equation 4 and Equation 5, then it will follow:

$$f'(x_i) = \frac{f(x_{i+1}) - f(x_{i-1})}{[(x_{i+1} - x_i) - (x_{i-1} - x_i)]} \quad (6)$$

Where :

$f'(x_i)$: first order differential

x : temperature at 23°C

i : value for temperature

And by summing Equation 4 and Equation 5, then it will follow:

$$f''(x_i) = \frac{f(x_{i+1}) + f(x_{i-1}) - 2f(x_i)}{\left(\frac{(x_{i+1} - x_i)^2 + (x_i - x_{i-1})^2}{2!}\right)} \quad (7)$$

Where :

$f''(x_i)$: second order differential

x : temperature at 23 °C

i : value for temperature

By this approximation the temperature coeficients of both alpha (α) and beta (β) can be calculated as follows:

$$\alpha_i = \frac{R_{Tref+i} - R_{Tref-i}}{((T_{ref} + i) - (T_{ref} - i))R_{Tref}} \quad (8)$$

Where :

αi : alpha coefficient of temperature to i

R_{Tref} : resistance at temperature T reference

Tref : Temperature reference

i : value for temperature

$$\beta_i = \frac{(R_{Tref+i} + R_{Tref-i}) - 2R_{Tref}}{(((T_{ref} + i) - T_{ref})^2 + (T_{ref} - (T_{ref} - i))^2)R_{Tref}} \quad (9)$$

Where :

βi : beta coefficient of temperature to i

R_{Tref} : resistance at temperature T reference

T_{ref} : Temperature reference

i : value for temperature

Since the temperature is varied from the midpoint of the temperature reference, T_{ref} = 23°C, by the increment of 1 for a range of 18 °C to 28 °C, The alpha (α) and beta (β) are averaged as follows.

$$(\alpha, \beta) = \frac{\sum_{i=1}^{5} (\alpha, \beta)_i}{5} \quad (10)$$

Where :

α, β : 1st and 2nd order temperature coefficient

Uncertainties of Temperature Coefficients SNSU TK-BSN's evaluation

The uncertainty evaluation is performed based on JCGM 100: 2008 (BIPM, 2018), by comprising of the 2 types of uncertainty contribution, namely type A and type B. The standard deviation from each averaged alpha (α) and beta (β) is considered as a source of type A uncertainty. Meanwhile, type B uncertainties are mainly influenced by a measurement in temperatures and resistances. The uncertainty in term of temperature is regarded as the temperature instability during the measurement at 18 °C up to 28 °C. On other hand, the uncertainty in term of resistance is regarded to random errors during measurement, the accuracy of the DCC bridge, the DCC bridge resolution in reading, the reference standard resistor calibration value, the reference standard resistor drift, and the temperature instability on the reference standard resistor. As discussed by Dudek (Dudek et al., 2007), the standard uncertainties of both alpha (α) and beta (β) can be written as follows:

$$u_B(\alpha) = \sqrt{\left(\frac{\delta\alpha}{\delta\Delta T}\right)^2 u^2(\Delta T) + \left(\frac{\delta\alpha}{\delta r}\right)^2 u^2(r)} \quad (11)$$

Where :

$u_B(\alpha)$: uncertainties of alpha

$\delta\alpha$: delta alpha

$\delta\Delta T$: delta difference between temperature of measurement and reference temperature

$u^2(\Delta T)$: uncertainties difference between temperature of measurement and reference temperature

δr : delta resistance value

$u(r)$: uncertainties of resistance value

$$u_B(\beta)=\sqrt{\left(\frac{\delta\beta}{\delta\Delta T}\right)^2 u^2(\Delta T)+\left(\frac{\delta\beta}{\delta r}\right)^2 u^2(r)} \quad (12)$$

Where :

$u_B(\beta)$: uncertainties of beta

$\delta\alpha$: delta alpha

$\delta\Delta T$: delta difference between temperature of measurement and reference temperature

$u^2(\Delta T)$: uncertainties difference between temperature of measurement and reference temperature

δr : delta resistance value

$u(r)$: uncertainties of resistance value

On the type B uncertainties, we are assuming that there are correlations among the measurement in term of temperatures, and in term of resistances either. The correlations are estimated to be equal to 1. Moreover, the average of them was taken from differences of each temperature set to the temperature of 23 °C and ratios of each resistance set at *T* °C to the resistance at 23 °C. By combining the type A and the type B, the combined standard uncertainties of alpha (*α*) and beta (*β*) can be written as follows:

$$u(\alpha)=\sqrt{u_A{}^2(\alpha)+\left(\frac{1}{10}\sum_{i=1}^{10}\sqrt{\left(\frac{1}{T-23}\right)^2 .\left[\frac{1}{R_{23}}.u(R_T)+\left(\frac{-R_T}{R_{23}}\right)u(R_{23})\right]^2+\left(\frac{-R_T/R_{23}+1}{(T-23)^2}-\beta\right)^2 .(2.u(T))^2}\right)^2} \quad (13)$$

Where:

u(α) : combine uncertainties of alpha

$u_A(\alpha)$: uncertainty of type A

$u(R_T)$: uncertainties of resistance at temperature T

$u(R_{23})$: uncertainties of resistance at calibration temperature 23 °C

$u(T)$: uncertainties of temperature)

R_T : resistance at temperature T

R_{23} : resistance at calibration temperature 23 °C

T : temperature

α , β : 1st and 2nd order temperature coefficient

$$u(\beta)=\sqrt{u_A{}^2(\beta)+\left(\frac{1}{10}\sum_{i=1}^{10}\sqrt{\left(\frac{1}{T-23}\right)^2 .\left[\frac{1}{R_{23}}.u(R_T)+\left(\frac{-R_T}{R_{23}}\right)u(R_{23})\right]^2+\left[\frac{\alpha}{(T-23)^2}-\frac{2[R_T/R_{23}-1]}{(T-23)^3}\right]^2 .(2.u(T))^2}\right)^2} \quad (14)$$

Where:

$u(\beta)$: uncertainties of beta

$u_A(\beta)$: uncertainty of type A

$u(R_T)$: uncertainties of resistance at temperature T

$u(R_{23})$: uncertainties of resistance at calibration temperature 23°C

$u(T)$: uncertainties of temperature)

R_T : resistance at temperature T

R_{23} : resistance at calibration temperature 23°C

T : temperature

α, β : 1st and 2nd order temperature coefficient

Fluke's evaluation

A common approach was used by Fluke to determine the temperature coefficients based on a fitting to a typical equation. As it was reported in calibration certificate, the temperature coefficients of both alpha (α) and beta (β) were calculated based on fitting coefficients to the quadratic equation of resistance value due to its temperature setting. However, it did not include the uncertainty of the temperature coefficients. To compare the measurement result, it is necessary to calculate the uncertainty of measurement following the measurement result.

Fortunately, Fluke reported sufficient information to evaluate the uncertainties. The calibration certificate reported each resistance value at each temperature settings, consecutively. The type A uncertainty is evaluated based on the standard error of the coefficients of the quadratic equation. The type B uncertainty is evaluated based on a similar approach as ours. The only differences were the uncertainty values in term of temperature and resistance. The combined standard uncertainties of alpha (α) and beta (β) can be calculated by using Equation 13 and Equation 14.

4. RESULTS AND DISCUSSION

Measurement Result

The measurement of a tested Fluke 742A standard resistor of 1 Ω in various temperature changes at the range of 18 °C to 28 °C was obtained at the condition of that mentioned in chapter above. The measurement result is listed together with the result reported by Fluke in Table 1. Meanwhile, the historical calibration result of the standard resistor calibrated at 23°C is tabulated in Table 2.

Table 1 The temperature dependence of the tested standard resistor.

Temp (°C)	$R_{SNSU\ TK\text{-}BSN}$ (Ω)	R_{Fluke} (Ω)	Diff ($\times 10^{-6}$)
18	1.0000194	1.0000106	8.8
19	1.0000197	1.0000110	8.7
20	1.0000200	1.0000113	8.7
21	1.0000201	1.0000115	8.6
22	1.0000202	1.0000116	8.6
23	1.0000202	1.0000116	8.6
24	1.0000201	1.0000115	8.6
25	1.0000198	1.0000112	8.6
26	1.0000197	1.0000109	8.8
27	1.0000193	1.0000105	8.8
28	1.0000190	1.0000099	9.1

Table 2 The calibration result of the tested standard resistor at 23°C.

Date	R	Ref. Lab
May 2007	1.0000116	Fluke
Feb 2009	1.0000146	SNSU-BSN
Apr 2010	1.0000157	SNSU-BSN
Jan 2014	1.0000188	SNSU-BSN

The temperature dependence of the tested standard resistor was following the similar curve of quadratic equation for both SNSU TK-BSN and Fluke results. The difference was appointed as the self-drift of the standard resistor. Based on Table 2, the acquired slop was 2.8×10^{-9} per day and it was around 8.7×10^{-6} Ω difference from the first calibration date to that of the temperature dependence measurement. From Table 1 it was shown that the difference between SNSU TK-BSN and Fluke results was equal to 8.6 μΩ/Ω at 23°C in around eight years evaluation.

Furthermore, for more clear visualization of the comparison in temperature dependence, we may see the Figure 3. The "•" symbol represents the measurements of SNSU TK-BSN, and in other hand the "◊" symbol represents the measurement of Fluke. The both of the measurements plotted in Figure 3 is the deviation from the based resistance value at the temperature of 23°C.

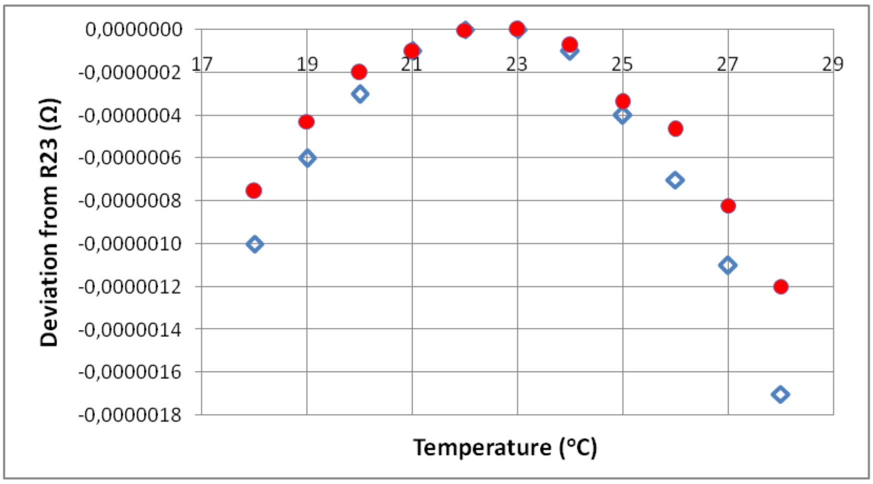

Figure 3 The temperature dependence of the tested standard resistor.

Based on Equation 8 and Equation 9 can be found the value of temperature coeficients alpha and beta SNSU TK-BSN of alpha coefficient of -5,30 x 10-8 Ω/Ω/°C and beta coefficient of -4.70 x 10-8 Ω/Ω/°C2. The uncertainty for both temperature coefficients are calculated by using Equation 13 and Equation 14. The uncertainty budget of SNSU TK-BSN measurements for α and β can be found in Table 3 and Table 4, respectively. The expanded uncertainties at a confidence level of 95 % with coverage factor of k = 2, repectively, equal to 2.4 × 10-8 and 1.6 × 10-8.

Table 3 The SNSU TK-BSN's uncertainty budget of α temperature coefficient.

Quantity	Probability distribution /method of evaluation (A,B)	Standard uncertainty
X_i		$u(X_i)$
• Standard error of the mean for α determination	type A	7.4×10^{-9}
• Calibration uncertainty of the test resistor in each temperature	normal/ type B	2.0×10^{-7}
• Instability of temperatures	rectangular/ type B	5.8×10^{-2}

Table 4 The SNSU TK-BSN's uncertainty budget of β temperature coefficient.

Quantity	Probability distribution /method of evaluation (A,B)	Standard uncertainty
X_i		$u(X_i)$
• Standard error of the mean for β determination	type A	6.9×10^{-9}
• Calibration uncertainty of the test resistor in each temperature	normal/ type B	2.0×10^{-7}
• Instability of temperatures	rectangular/ type B	5.8×10^{-2}

In other hand, the temperature coefficients based on data from Fluke calibration certificate are equal to $(-6.9 \pm 7.6) \times 10^{-8}$ Ω/Ω/°C and $(-5.4 \pm 2.0) \times 10^{-8}$ Ω/Ω/°C^2, respectively for both alpha (α) and beta (β). The reported expanded uncertainties are stated at a confidence level of 95 % with coverage factor of $k = 2$. And the uncertainty budget of Fluke measurements for α and β can be found in Table 5 and Table 6, respectively.

Table 5 The uncertainty budget of α temperature coefficient evaluated from Fluke's calibration certificate.

Quantity	Probability distribution /method of evaluation (A,B)	Standard uncertainty
X_i		$u(X_i)$
Standard error of the mean for α determination	type A	3.8×10^{-8}
Calibration uncertainty of the test resistor in each temperature	normal/ type B	4.0×10^{-7}
Instability of temperatures	rectangular/ type B	5.8×10^{-3}

Table 6 The uncertainty budget of β temperature coefficient evaluated from Fluke's calibration certificate.

Quantity	Probability distribution /method of evaluation (A,B)	Standard uncertainty
X_i		$u(X_i)$
• Standard error of the mean for β determination	type A	8.2×10^{-10}
• Calibration uncertainty of the test resistor in each temperature	normal/ type B	4.0×10^{-7}
• Instability of temperatures	rectangular/ type B	5.8×10^{-3}

Validation of Temperature Coefficients Determination

A calculation was done to validate the temperature coefficients measurements based on SNSU TK-BSN's result to that of Fluke's. The validation was evaluated by using E_N number. It represents the degree of equivalency within a combined expanded uncertainty. The equation is written mathematically as follows:

$$E_N = \frac{(\alpha,\beta)_{Fluke} - (\alpha,\beta)_{SNSU-TK}}{\sqrt{U^2((\alpha,\beta)_{Fluke}) + U^2((\alpha,\beta)_{SNSU-TK})}} \quad (15)$$

Where :

E_N : En number

α , β : 1st and 2nd order temperature coefficient

It can be determined that E_N for both temperature coeficients of α and β are equal to 0.20 and 0.27. It implies that the measurements has shown a good agreement for $|E_N| \leq 1$.

5. CONCLUSION

A development has been carried out in determining the temperature coefficients together with their uncertainties. The determination is evaluated based on a numerical approach of Taylor Series Approximation (TSA). Even though the resistance value at each temperature points differs from its calibration certificate, however, it has been confirmed that it is contributed from the drift of the tested standard resistor. Moreover, the quadratic curve of resistance due to the temperature dependency may be same over time within a certain uncertainty. Either the SNSU TK-BSN measurement method or its evaluation result has shown a good agreement to those from the manufacturer result. that EN for both temperature coeficients of α and β are equal to 0.20 and 0.27.

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