Computer-based System for Temperature Measurement Calibration of Type-K Thermocouple

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***Abstract*— Using the temperature calibration instrument, the purpose of this paper is to design the uncertainty calculation system. The test was conducted using Type-K thermocouple temperature sensor and repeated for three times. The data acquisition (DAQ) card is used to interface the temperature instrument and the computer. In order to determine the uncertainty of the temperature measurement, graphical user interface (GUI) software has been developed in Visual Basic(VB) programming language. The developed software shows that the uncertainty of the Type-K thermocouple temperature measurement can be calculated by interfacing the instrument to the computer through DAQ card. The study focuses on manual temperature measurement and concentrates only on Type-K thermocouple temperature measurement. The results provide the confidence limits of five-point calibration that could improve the teaching techniques using computer-based system of the temperature measurement.**

Keywords-calibration, uncertainty, confidence limits, temperature measurement.

I. INTRODUCTION

Technological advancements in process monitoring, control and industrial automation over the past decades have contributed greatly to improve the productivity of virtually all manufacturing industries throughout the world. A temperature measurement method in multiple points situated on turning around axis bodies shows it still requires performing equipment, supplied from voltage source on moving part with some strict to reduce disturbances. Besides, it is a necessity to calibrate the system after it was assembled, which could be done by the implementation of computer, data acquisitions board to process the signal from the instruments [1]. Nowadays, calculation of measurement uncertainty can be incorporated in virtual instruments; unfortunately so far there are very few mechanisms incorporated in software offered by software products. [2]. Uncertainty of measurement is the doubt that exists about the result of any measurement. By quantifying the possible spread of measurements, the confident of the result can be determined. In many cases results of temperature measurements have to be presented together with the uncertainty of these measurements. Uncertainty calculation has been presented by Korczynski in virtual instruments using the DAQ card, Analog to Digital Converter (ADC) and front-end elements [2]. The detailed procedure for uncertainty calculation enable an evaluation of temperature measurement of electronic microcircuits, but it shows that the camera and emissivity have the largest influence on uncertainty [3]. An error evaluation of temperature measurement system has also been proposed by using temperature sensor based on thermocouples, with controlled profile of temperature field along electrodes [4]. The best measurement capabilities in temperature calibrations by comparison strongly relate to some particular and some typical uncertainty contributions. The repeatability, uncertainty of a calibration bath or furnace, uncertainty of a reference thermometer and uncertainty of measuring devices are the main contributions of the uncertainties in calibration of thermometers based on comparison [5]. The performance benefits such as reduced measurement uncertainty, increased robustness and failure prediction and detection has been implemented through a smart thermocouple system. Currently, the standard limit of error for most thermocouples in industrial measurements is 0.75% with special limits of error at 0.4% across the range. Since most competent labs can calibrate with an uncertainty of better than 1°C, the typical temperature measurement can be vastly improved by utilizing information from a custom calibration [6]. Optical temperature measurement has been calibrated based on pixel-wise and the accuracy of the measurement has been calculated. However, the accuracy of the measurement reveals more compared to the need for pixel-wise for the calibration process [7].

This paper is organized as follows. In Section II, a brief description of the temperature calibration instrument is performed. Section III describes the uncertainty calculation that would be used in the development of the software using VB while the interfacing technique via DAQ card is discussed in Section IV. In Section V, simulation studies on temperature monitoring for five-point calibration and uncertainty calculation are presented. Conclusions are made in Section VI.

II. TEMPERATURE CALIBRATION INSTRUMENT

For the Five-point calibration of the thermocouple as considered in this study is shown in Fig. 1. The span of the

Unit Under Test (UUT) is divided into five equal parts with the first point at the Lower Range Value (LRV) and the top point at the Upper Range Value (URV).

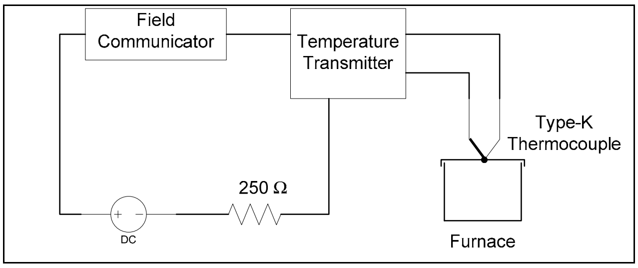


Figure 1. Temperature Calibration Instrument

For example the thermocouple has the calibration range of 50 – 200 °C. Therefore the span is 200 – 50 = 150 °C. Dividing the span by four will be 37.5 °C. Hence the five equal points are 50, 87.5, 125, 162.5 and 200 °C based. The desired output is calculated based on the 50 – 200 °C range using (1);

$$Desired\ output = \frac{x}{100}\left(URV - LRV\right) + LRV \tag{1}$$

where;

x = ith point (0,25,50,75,100%)
URV = Upper range value
LRV = Lower range value

III. Uncertainty Calculation

Standard uncertainty (2) is an uncertainty of the result of a measurement expressed as a standard deviation based on the three repeated measurement

$$s(x_k) = \sqrt{\frac{1}{(n-1)}\sum_{j=1}^{k}(x_k - \bar{x})^2} \tag{2}$$

Type A evaluation (of uncertainty) is a method of evaluation of uncertainty by the statistical analysis of series of observations, due to the repeatability or spread of measurement of the experiment, u_1 (3).

$$u_1 = \frac{s(x_k)_{highest/worst\ case}}{\sqrt{n}} \tag{3}$$

$$Degree\ of\ \ freedom = \gamma_1 = n - 1$$

Uncertainty Contribution Due to Master Standard Unit (MSU) Error, u_2 (4).

$$u_2 = \frac{MSU}{\sqrt{3}} \tag{4}$$

The degree of freedom for this uncertainty is assumed to be ∞ since the manufacturer is expected to provide the error data after a large number of tests.

$$Degree\ of\ \ freedom = \gamma_2 = \infty$$

Type B evaluation (of uncertainty) is a method of evaluation of uncertainty by means other than the statistical analysis of series of observations. Uncertainty due to Unit Under Test (UUT) resolution, u_3 (5).

$$u_3 = \frac{resolution\ of\ MSU\ or\ resolution\ of\ UUT}{\sqrt{3}} \tag{5}$$

The degree of freedom for this uncertainty is consider as ∞.

The combined standard uncertainty, u_c (6) is a standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariance of these other quantities weighted according to how the measurement result varies with changes in these quantities.

$$u_c = \sqrt{(u_1^2 + u_2^2 + u_3^2)} \tag{6}$$

Expanded uncertainty is a quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurement. To obtain the lower and upper confidence limits (7) about the measurements,

$$u = u_c k \tag{7}$$

where k is coverage factor , the numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty. K is determined from the t-distribution table found using the effective degrees of freedom v_e, given by (8).

$$v_e = \frac{u_c^4}{\frac{u_1^4}{\gamma_1} + \frac{u_2^4}{\gamma_2} + \frac{u_3^4}{\gamma_3}} \tag{8}$$

IV. The Interfacing Technique Via DAQ Card

Interfacing technique between temperature instrument and developed software is achieved by using USB-4716 DAQ Card which is manufactured by Advantech. USB-4716 DAQ Card use Universal Serial Bus (USB) to connect to computer. The Advantech Data Acquisition driver is designed to support programming language such as Visual Basic. It can be configured for 16 single ended or 8 differential inputs with 16-bit resolution, up to 200 kS/s throughput, 16 digital I/O lines and 1 user counter, and 16-bit analog outputs. Fig. 2 shows the DAQ card that used in this project. The analog output from the temperature instrument is connected to the analog input channel and the digital output from the DAQ is sent to the developed software.

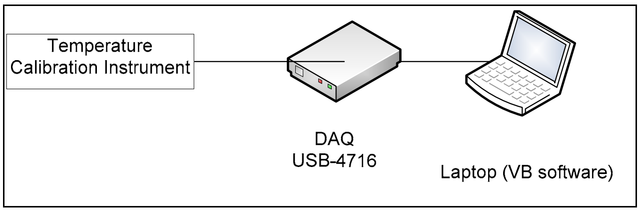


Figure 2. Interfacing Technique

V. Implementation & Result

An instrumentation software was develop and the user interfacing for uncertainty and confidence limits of five-point calibration are presented in Fig. 3 to determine the uncertainty contribution due to repeatability of the experiment as in Table 1.

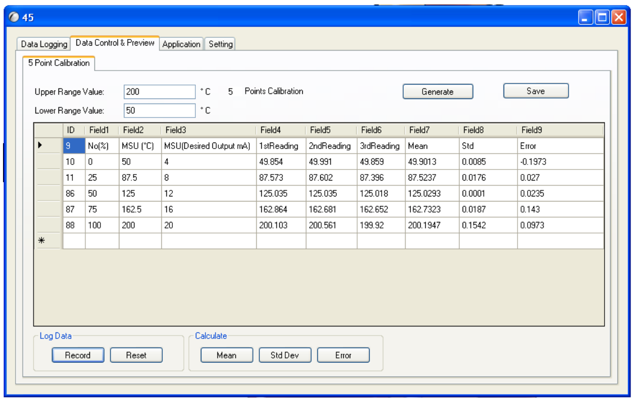


Figure 3. Five-point calibration of type-k thermocouple

TABLE 1. Five-point Calibration of Type-K Thermocouple

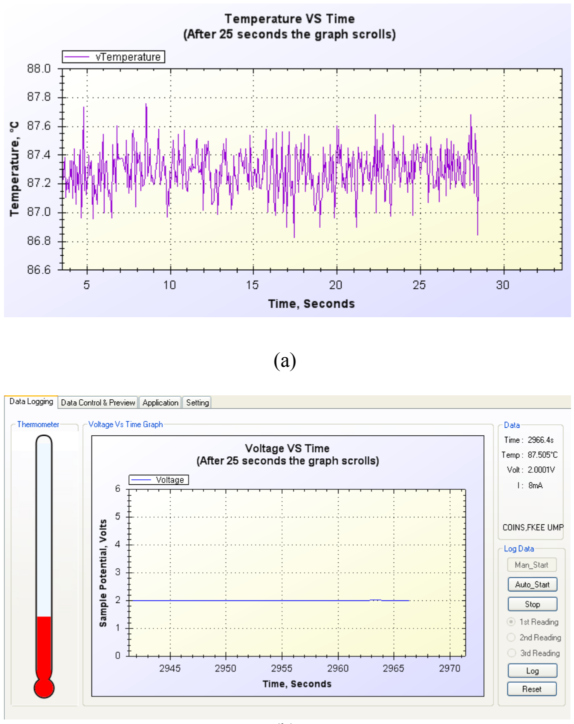
Point(%)	MSU (°C)	UUT$_1$ (°C)	UUT$_2$ (°C)	UUT$_3$(°C)
0	50	49.854	49.991	49.859
25	87.5	87.573	87.602	87.396
50	125	125.035	125.035	125.018
75	162.5	162.864	162.681	162.652
100	200	200.103	200.561	199.92

Implementations results in Table 2 show that the highest standard deviation is 0.1542 and produce an error of 0.143%. Standard deviation shows how much the recorded value deviate from desired value. The highest standard deviation recorded will be used to calculate u_1 as shown in Fig. 4.

TABLE 2. Mean, Standard Deviation & Error of Type-K Thermocouple

Point(%)	Mean	Standard Deviation	Error (%)
0	49.9013	0.0085	-0.1973
25	87.5237	0.0176	0.027
50	125.0293	0.0001	0.0235
75	162.7323	0.0187	0.143
100	200.1947	0.1542	0.0973

Fig. 4 shows the temperature and voltage reading over the stability of the time during the calibration process at 87.5 °C (a) which is equivalent to 2 V (b) and 8 mA (Fig. 3).



(a)

(b)

Figure 4. Temperature and voltage versus time

The combined standard uncertainty, u_c (Fig. 7) is determined from the individual uncertainties, u_1, u_2, and u_3 as shown in Fig, 5, Fig. 6 and Fig. 7 respectively.

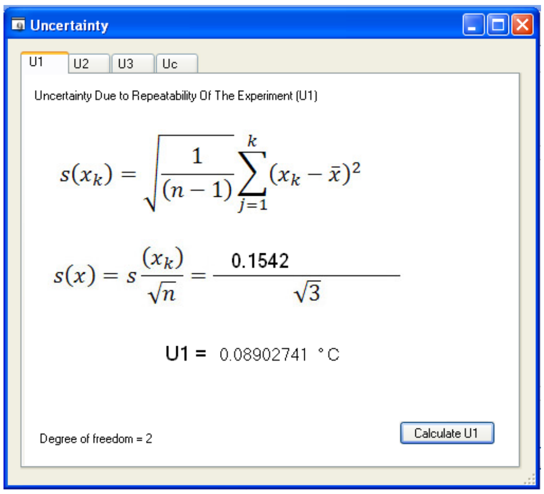


Figure 5. Type A evaluation, u_1

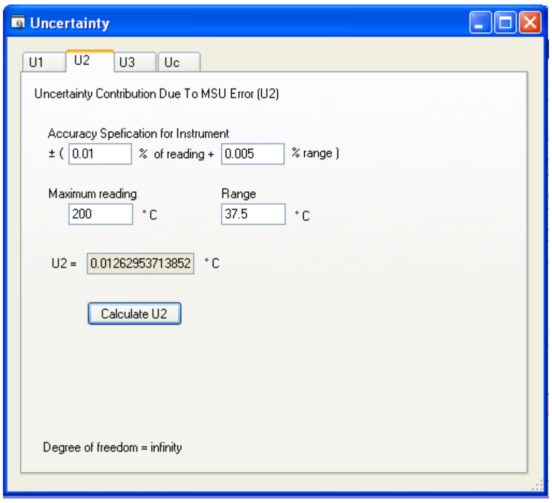


Figure 6. Uncertainty Contribution Due to Master Standard Unit (MSU) Error, u_2

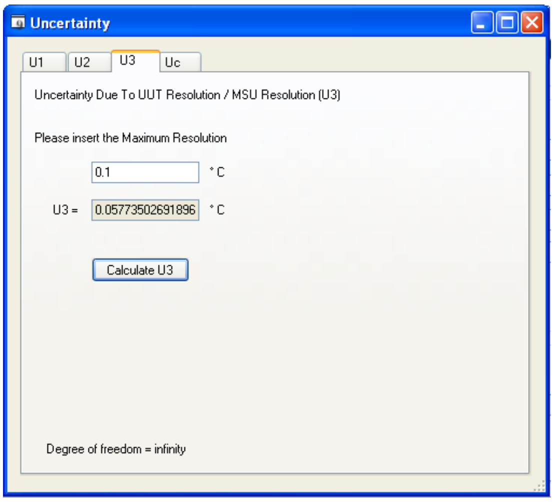


Figure 7. Type A evaluation, u_3

For the effective degrees of freedom 20.54948 ≈ 20, the coverage factor, $k = 2.13$ for 95.45% (Fig 8) and $k = 2.85$ for 99% (Fig. 9) confidence level is determine from the t-distribution table. The type-k thermocouple confidence limits of 95.45% and 99% are ±0.34 °C and ±0.45 °C respectively.

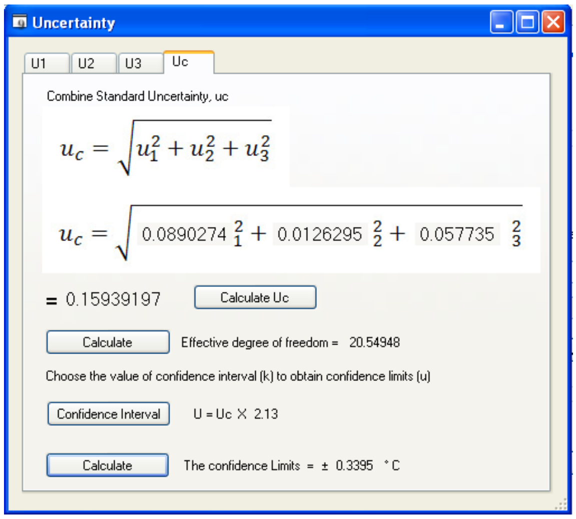


Figure 8. Combined standard uncertainty, u_c, effective degree of freedom and confidence limit of 95.45%

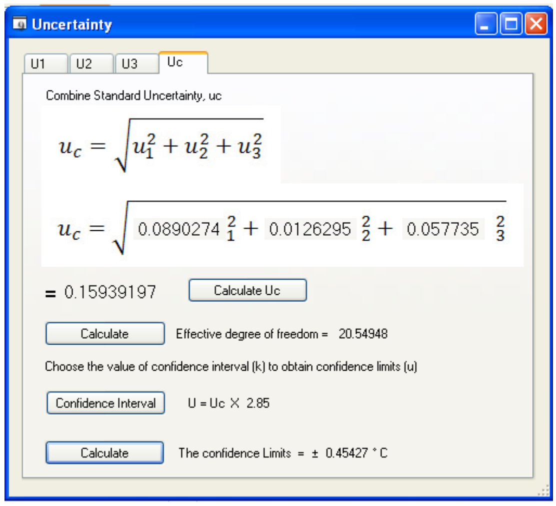


Figure 9. Combined standard uncertainty, u_c, effective degree of freedom and confidence limit of 99%

The five-points calibration curve and error curve of type-k thermocouple are shown in Fig. 10 and Fig 11 respectively.

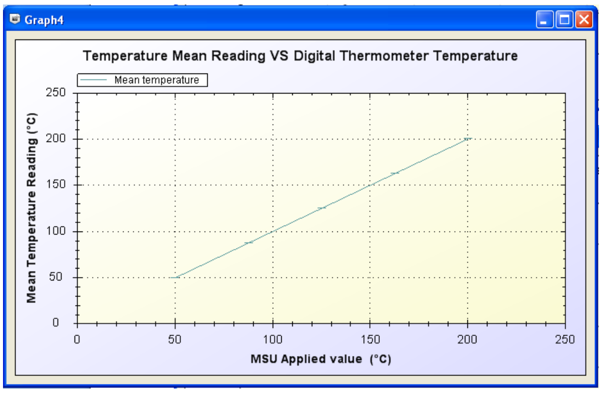


Figure 10. Calibration curve

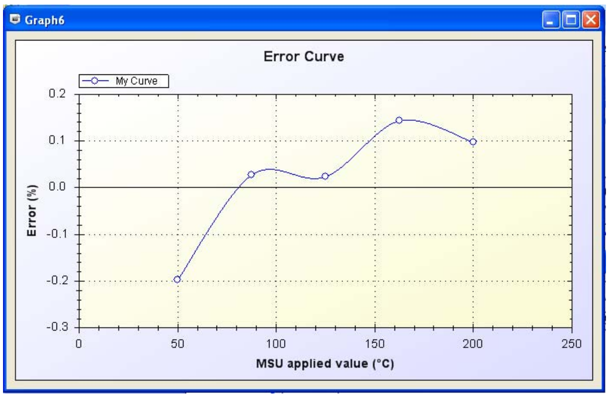


Figure 11. Percentage error curve

VI. CONCLUSION

The uncertainties calculation and confidence limits of temperature calibration is presented. The sample taken in this study, $n = 3$ should also be considered in calculation, because if more samples are taken, the lower uncertainty value will be achieve and if fewer samples are taken, the uncertainty value will increase. The uncertainties will be higher for the higher standard deviation. The data should be recorded in noise free environment by removing the Hart Communicator to reduce the error percentage. The noise occurs when the temperature instrumentation is connecting to Hart Communicator parallel with temperature transmitter. This causes, the current produced by temperature transmitter diverted to 2 junctions, therefore decreasing the actual current value. When the current changed, the voltage is also changed according to ohm's law and this causes the instability to the system. Nevertheless, by using the developed software, the uncertainties and confidence limits of type-k thermocouple for five-point calibration was determined manually. It is concluded that the developed software is capable for computerized calibration and could be improved for automatic computerized calibration.

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