Design of a scanning thermocouple inhomogeneity

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Abstract. Inhomogeneities are known to develop within thermoelements exposed to elevated temperatures, resulting in temperature measurement errors and reduced energy efficiency. During process, it is important to determine how much the inhomogeneities affect the measurement result. Thermoelectric inhomogeneity is important factor of the calibration for budget uncertainty calculation. It is normally assessed by gradual, insertion of a thermocouple into a furnace or liquid bath. But, the length that can be scanned by using this equipment typically limited. It need an equipment to scan more length of wire thermocouple to see characteristic of thermocouple. This paper described development design double gradient method for measurements of inhomogeneities in type K and T thermocouples with various diameter and temperature scanning using hot air that can produce heating process up to 600 °C with some sensor to detection real temperature output from hot air source. Therefore, an equipment with a short, movable heating zone to scan along the thermocouple while both the measuring and reference junctions using ice bath are kept at 0 °C. The design of the equipment system was focused on measuring the stability of hot air and controlling the movement of the stepper motor control using a microcontroller. Interpretation of the measurement results and calculation of inhomogeneity using movable heating zone of type K and T thermocouples of the uncertainty budget is presented.

1. Introduction
Thermocouples are used in various industrial applications for temperature measurement, such as for the monitoring and control processes, to uphold safety, ensure product quality, and regulate their properties [1]. Measurement and compare is a very important part of physics. As measurements are important, rules are set in place to ensure that measuring is consistent. Often their accuracy predetermines the quality of the production, its reliability and service life [2].

The thermoelectric inhomogeneity of wires is one of the main components of the measurement uncertainty when using thermocouples. During calibration, it is important to determine how much the inhomogeneities affect the measurement result [3]. Inhomogeneities are known to develop within thermoelements exposed to elevated temperatures, resulting in temperature measurement errors. The temperature gradient or exposed to mechanical processes can affected seebeck coefficient drift for base metal thermocouple along the length of the thermocouple that vary according to the nature and magnitude of the processes [4].
Base-metal thermocouples play a significant role in industrial measurements, and among the many varieties and formats, bare-wire Type K is often preferred. The reason for this preference is its low cost, durability and tolerance of high temperature.

In the calibration of thermocouples, thermoelectric inhomogeneity constitutes a major contribution to calibration uncertainty [5]. One of the most important influences in thermocouple calibration is the inhomogeneities of the thermoelements which causes changing in Seebeck coefficient along the length of wires. It is recommended that this characteristic is taken into account in calculating the uncertainty of the thermocouple calibration.

This paper review investigates the change in seebeck coefficient as a function of temperature for Type K and T thermocouple by using moving zone of homogeneity scanner. The results show that most wires have very different drift behaviors [6]. These inhomogeneities are one of the main components of the measurement uncertainty and must be taken into consideration for accurate measurements [7].

2. Inhomogeneity in Thermocouples

A thermocouple consists of two homogeneous metal wires of dissimilar materials that are connected at one end (the measuring junction) [8]. When there is a temperature difference between the measuring junction and the reference junction, a small voltage appears between the wires at the reference junction. This voltage is then conveyed to the voltage-measuring instrument by wires of identical composition (usually copper). If dissimilar materials of the metal wires of the thermocouple are homogeneous with respect to their thermoelectric properties, then the voltage difference depends only on the temperature difference between the measuring junction and the reference junction. If the wires are not homogeneous, the measured thermoelectric voltage depends not only on the temperature difference between the measuring junction and the reference junction, but also on the position of the temperature gradient along the wires. This is because the emf is not formed at the reference junction, but wherever temperature gradients occur between the reference junction and the measuring junction. Therefore, to measure inhomogeneity effects, it is necessary to expose the thermocouple to a defined temperature gradient.

The inhomogeneity is defined as the percentage of the average amplitude (Δemf) divided by the measured emf at given temperature. It was calculated considering the maximum emf difference (E_{max} – E_{min}) obtained for all depths of immersion.

\[
\text{Inhomogeneity} \% = \frac{\Delta \text{emf}}{E_{\text{meas}}} \times 100
\]

(1)

When a thermocouples is used at high temperatures, processes of oxidation, recrystallization, diffusion of impurities, defect migration, etc., (these can be referred to as degradation processes) are activated in the legs of the thermocouples. These processes cause changes in the seebeck coefficient. During time operation, these degradation processes of a thermocouples can identify in two ways:

- At a constant uniform temperature profile which is introduced along the thermocouples legs a continuous change in the thermocouples electromotive force (emf) occurs. This results in the gradual change of an initial Seebeck coefficient.
- In a temperature profile where changes can occur along the thermocouples legs, different sections of a thermocouples are operated at their respective temperatures and degradation processes their Seebeck coefficient with respect to their operation temperatures since a change of Seebeck coefficient depends on operating temperature of a thermocouples section and time. Therefore, after long operation, thermocouple legs become inhomogeneous with regard to thermoelectric properties. This dependence on the temperature field profile is a major source of errors. This error is referred to as error due to inhomogeneity [9][10][11].

Most thermocouples are susceptible and sensitive to mechanical damage, chemical environment and also affected by heat treatment [12]. As the temperature changes, the alloy will slowly change structure, sometimes permanently, to the one that offers the lowest energy state at that temperature. Typically, the
different phases have different Seebeck coefficients so the phase changes give rise to hysteresis effects (where the reading depends on previous temperature exposure).

3. Material and Method

3.1 Base metal thermocouples

Base-metal thermocouples types K and T was used to scanning, all of which use nickel in some form. Because they all oxidise easily, they are not easily annealed to remove mechanically induced inhomogeneities. In addition, at higher temperatures the more complex alloys under microscopic metallurgical changes that may not be reversible. Overall, base-metal thermocouples do not make as good thermometers as rare-metal thermocouples. However, their lower cost can offset this, especially for harsh environments where frequent replacement is required.

Type T (copper-copper nickel), with temperature range -200 °C to 400 °C, is useful for temperature surveys in applications such as performance tests on electrical appliances. It is also the preferred thermocouple for low-temperature work. Beside that type K (chromel-alumel), with temperature range -270 °C to 1372 °C as a general-purpose thermocouple. Therefore, other thermocouple types should always be used where they are suitable.

Figure 1. Method measurement temperature using ice bath 0 °C

Figure 1 show the measurement to make sure the voltage and ice bath was in 0 °C temperature. Ice bath was used for immersion the sensor thermocouple both reference junction and measuring junction.

3.2 Measurements with a Short Movable Heating Zone - double gradients

Unfortunately, many industrial applications require longer thermocouples and it is therefore necessary to use a different technique. By using equipment for single gradient, the length that can be scanned is typically limited. The implementation of the double gradient method uses a moving stability heater scanning over length of temperature. This method can assess thermoelectric inhomogeneity over greater lengths.
Figure 2. Schematic representation of the measuring equipment for inhomogeneity using movable zone

Figure 2 show the development of the schematic representation for measuring equipment for inhomogeneity by adding some sensor to detect temperature output from hot air/heat gun. By using sensor thermocouple near the head of heat gun, so it can make sure the stability temperature from heat gun. Temperature from output heat gun and sensor thermocouple can be similar and real. Motor stepper will be controlled by microcontroller and display status of length.

Figure 3. Software development to measurement the temperature and voltage

Figure 3 show the software development to measurement voltage and temperature using nanovoltmeter. It can measure real time while scanning. Both the reference junction and measuring junction are kept at 0 °C. To produce rapid heating over a limited length of the thermocouple, a high-temperature heating fan (max 600 °C) was used with an minimum diameter outlet nozzle to guide and limit the air flow. The heat gun are mounted on a horizontal moveable slide, which is fastened to a linear positioning unit controlled via a stepping motor connected to a computer. The temperature of the hot air is thermostatically controlled and continuously variable. This temperature is measured with a thermocouple placed in the center of the airflow, close to the investigated thermocouple. Both of the thermocouples use ice baths (0 °C) as their reference temperature and connect to a scanner and then to a nanovoltmeter and computer. To be able to make controlled and precise movements, a control and measuring program was developed for the computer. It permits scanning in both directions with selectable step size and scanning time. The scanning guide of heat gun was used 10 mm diameter outlet
nozzle. The Seebeck coefficients were measured as a percentage deviation from the relative Seebeck coefficient (SI) from the reference values:

\[ S_1 = \frac{S_{\text{meas}} - S_{\text{ref}}}{S_{\text{ref}}} \]  

(2)

where \( S_{\text{meas}} \) and \( S_{\text{ref}} \) are the measured and reference Seebeck coefficients calculated from the EMF generated directly across the narrow temperature step (kernel) of the homogeneity scanner.

4. Result and Discussion

The results of paper design for inhomogeneity and method in this study show that base-metal thermocouple types do display characteristic trends by using double gradient method, but the temperatures and rates for these changes are highly dependent on the specific product of thermocouples manufacturer’s formulation. This makes it difficult to make quantitative statements about the generic behavior of different thermocouple types. Though not explicitly tested, there may also be inter-batch variability for the same supplier. The motor can move smoothly by using mikrokontroller and software to control movement to set the time and length of movement of heating source. To make sure the real temperature was used for sensor test, here was the result of scanning result temperature heat gun.

![Figure 4. Stability temperature heat gun](image)

Figure 4 show the trend temperature characteristic of heat gun output until 400 °C. When the temperature was reached to 400 °C, the sensor thermocouple started to scanned with this temperature with controlled motor stepper along thermocouple length of 1 meters. It has stability ± 1 °C due to effect of air temperature while scanning.
Figure 5. Seebeck effect thermocouple type T

Figure 5 show the characteristic of scanning thermocouple type T. Scanning thermocouple was 80 centimeter of length. It has been variation voltage between -12 µv to 3 µv.

Figure 6. Seebeck effect thermocouple type K

From different scan method, it has been found that the thermoelectric inhomogeneity, expressed as a ratio of maximum emf change within the working segment to the total emf generated, decreased at high temperature. It can be concluded that some basic metal thermocouples may have inhomogeneity that depends on temperature and heating time which is the results can increase budget uncertainty.

Hardware could move smoothly by using microcontroller and driver TB 6600 to control stepper motor nema 23 with variation pulse/step with power supply DC 12 volt. This is connected to software to control pulse/step of stepper motor. To detect the voltage thermocouple, it was using nanovoltmeter, temperature data logger have 8 channel and voltage accuracy ±0.2 % of reading and ± 10 µV. This logger can read any type of thermocouple sensor such as Type K, J, E, T, N, S, B with resolution 20 bits and temperature accuracy was 0.2 % of reading and ± 0.5 °C and noise free resolution 16.26 bits.
5. Conclusion
The paper described the design to detect inhomogeneity base metal thermocouples type K and T using moving zone or double gradient method. The uncertainty components for a single measurement point in the movable heating-zone measurement arise mainly from the ice baths, the scanner, the nanovoltmeter and the temperature change in the heated zone. The inhomogeneity that causes slow changes in the seebeck coefficient will be difficult to resolve with the removable zone heating method. For further research, it is important to see the characteristics various thermocouple on the market using scanning method to calculate budget uncertainty. The scanning process is used for variation thermocouple in diameter, temperature and heating time to get the characteristics of each thermocouple. The results of these measurements can be used as a reference for industry or metrology laboratory in determining budget uncertainty and selecting the best thermocouple to be used in the heating equipment, because inhomogeneity is a very important thing that affects the determination of the thermocouple due to aging when using in heating process. Some studies show research about scanning inhomogeneity thermocouple using moving zone. This method concern about stability of heat gun or hot air output and the temperature must detection using sensor temperature, automation detection and little diameter of nozzle with time variation scanning and temperature detection using software has been done.

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