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TIME INSTABILITY OF BASE METAL THERMOCOUPLES

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Abstract: *Measurements of temperature have a great importance in wide range of industrial applications. As temperature affects the quality, safety and effectives of many of these applications, a great effort has been made to enhance the precision and reliability of temperature measuring sensors. One of the main types of temperature sensors that are used in industry are thermoelectric sensors, more commonly known as thermocouples. These sensors play a irreplaceable role in high temperature industrial measurements. Their robust construction, the ability to withstand high temperatures and harsh conditions had made them popular among many users. As thermocouples are active sensors, they work on the principle of the Seebeck effect. This effect is dependant from wire material purity and composition thus any change in these properties will result in change of their voltage output thus temperature. These changes of Seebeck coefficient can be caused by many factors, like chemical impurities, changes in metal lattice of the wire material, reaction between the materials of which the thermocouple consist of etc. This work deals with the analysis of various factors that can effect the Seebeck coefficient of the thermocouple wire material. Influences that affect the long term stability of the thermocouple voltage output have been analysed and a measuring procedure to determine the level of contribution to the Seebeck coefficient is presented. Furthermore the paper deals with the time stability of base metal Type N thermocouples in the MIMS (Mineral Insulated Metal Sheathed) configuration. The presented results determine the level of Seebeck coefficient change during a long time exposure to temperatures from 1200°C to 1250°C. This work was realized thanks to the support of National Physical Laboratories, Slovak Institute of Metrology, the Slovak University of Technology, grant agency VEGA - grant number 1/0120/12, APVV – grant number 0090-10 and program KEGA grant number 005STU-4/2012.*
Keywords: *thermocouples, time stability, base metal*

INTRODUCTION

Metrological procedures and measuring techniques of temperature affect a wide variety of application that include engineering ,metallurgy, chemical, food, aerospace industry and medical applications. In the field of contact measurement of temperature thermocouples are one of the most used sensors today. This is thanks to their robust construction, reliability and temperature range. As every sensor their precision and reliability directly affect the quality, safety, effectiveness of the manufacturing processes and applications. Due to their wide use and their irreplaceable role in contact high temperature measurements it is of great interest to investigate the behaviour of these sensors in boundary conditions. One of these boundary situations is when a thermocouple in introduced to high temperatures over a long periods of time. This paper is focused on the effect that a long term high temperature exposure has on the thermocouple output. It furthermore deals with the possible relationship between the thermocouple thermoelements (of which the thermocouple consists of) diameter and the drift rate of the voltage output. The thermocouples tested in this study are of type N in a MIMS (Mineral Insulated Metal sheathed) configuration. This work also presents the proposed experimental setup that will be used for the future measurements.

STABILITY PROBLEMATIC IN THERMOCOUPLES

The stability of voltage output of thermocouples is one of the significant issues that occur in each type of thermocouples. This process is caused by many different factors that alter the Seebeck coefficient value. This material constant is unique for each individual material and for its combinations. By changing its value the voltage output of the thermocouple changes as well. These changes are caused by altering the physical and chemical properties of the thermocouple wire material. These changes can be of a temporary or of a permanent nature. There are three cases in which the tested MIMS thermocouples Seebeck coefficient is affected. The first case that occurs is the annealing effect by which the thermocouple is exposed to temperatures above 600°C (changes in the inner material structure occurs). Hysteresis is the second effect that occurs in thermocouples and it can be experienced at temperatures up to 1000°C. In the third case the EMF (Electro Motive Force – the generate voltage by the thermocouple) is altered by chemical contamination. This last mentioned case occurs at temperatures above 1000°C. This study is going to deal with the chemical induced changes thus the permanent change in Seebeck coefficient. These permanent changes arise in nickel based thermocouples (type N and K) at temperatures above 600°C. An increasing voltage output can be seen when thermocouples without a protective sheathing are exposed to these temperatures. This positive drift can be seen in

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nickel based thermocouples with metal sheathing and mineral insulation (MIMS) but only at temperatures between 600°C to 900°C. By higher temperatures a significant and constant voltage drop occurs. This behaviour was described in various publication [1, 2, 3] with the same results for type N and type K thermocouples. The mentioned publications describe the process of drift by the migration of particles between the thermocouple thermoelements and the mineral isolation material and the metal sheath. The main source of contamination according to publications [1, 2] is considered manganese (Mn) as the main element that causes drift. This elements can be found in the sheathing material of the thermocouple and at temperatures over 1100°C it contaminates the thermocouple thermoelements affecting the Seebeck coefficient. The publications [1, 2] also points out that the concentration of manganese in the sheathing material also determine the level of the drift. For instance when a Inconel 600 which has a 1% concentration of manganese was used as sheathing material the voltage output drop wasn't so high as when a AISI 310 material with 2% manganese concentration was used. Publications [4, 5] show a decrees of indicated temperature of type N and K MIMS thermocouples with a 3mm outer diameter. At temperature of 1100°C the measured temperature difference form the initial state was 10°C and at temperature of 1200°C the drop was 24°C. These results were obtained after a 1000 hour testing cycle.

Several publications deals with the thermocouple drift and time stability in which they point out that a considerable degree of long term stability of nickel based thermocouples is an issue that needs further investigation. In this presented paper we are going to deal with this drift problematic but in a relation to the diameter of the thermocouple thermoelements wires.

EXPERIMENTS PROCEDINGS

The drift of the voltage output and diameter relationship was measured on type N thermocouples in MIMS configuration. The sheath material for the tested thermocouples was made of Inconel 600 and with mineral insulation inside the sheath. Eight thermocouples of the highest precision class for the mentioned type were tested. The outer diameters together with the corresponding wire diameter are presented in Tab. 1. One pair of the same thermocouple diameter and type from the same manufacturer was tested to avoid possible error caused by the manufacturing process. Furthermore two runs of the drift testing were planned to proof the repeatable behaviour of drift for individual diameter of sensors.

***Table 1**: Outer and lead diameters of tested type N thermocouples*

Outer diameter of Type N thermocouples (mm)	Thermo element wire diameter (mm)
0.5	0.085
1.0	0.140
1.5	0.280
2.0	0.340

One of the main issues that needed to be deal with was ensuring the temperature stability and homogeneity of the testing furnace. To determine these crucial factors initial furnace homogeneity scans with a calibrated noble metal type R thermocouple was made. After establishing the temperature profile the ideal depth for the thermocouples was determined and was set for 550mm (position of the tip of sensor from the opening of the furnace). Temperature time stability was also determined with the same type R thermocouple. The resulting stability over a 5 hour test was not more than 0.11°C which was considered as sufficient for our study. Furthermore to be confident about the furnaces temperature stability a calibrated type R thermocouple was used to monitor the temperature inside the furnace.

All the initial tests were done at work temperature of 1200°C which was the later used testing temperature as well. The temperature stability of the reference point is also of great importance because it determines the voltage output of the thermocouple and its temperature instability would result in the voltage output instability of the thermocouple which would make the drift detection difficult. This reference point temperature stability was ensured by a dry block cell with a high long term stability of ± 0.005°C.

To be able to determine the level of drift from the thermoelements diameter the thermocouples had to be exposed to an identical temperature conditions. This was ensured by putting all the tested sensors to a narrow ceramic tube which ensured that the temperature conditions would be sufficient for our measurement.

After setting up the measuring equipment and the initial testing phase the first batch of thermocouples was exposed to a temperature of 1200°C for a time period of more than 80 hours. The results of this continuous testing are presented in the following part of the paper.

RESULTS

The data presented was recorded using an automatic recording system which consisted of a switch system, multimeter device and PC with recording software. The recording interval of all the sensors voltage output was set for one minute. By this quick and automatic recording we ensured the comparability of the data from each sensor due to virtually identical data record time. The recorded data has a certain level of noise which was compensated using mathematical filtration methods. After this initial filtration an average value vas calculated for each five hour sections to make the interpretation of the drift level clearer. The results of the measurements that were obtained at temperature of 1200°C are presented in Figure1. The figure shows the voltage output difference of type N thermocouples of different diameters from the initial state of the voltage.

As we can see from the Figure 1 a decrees of the voltage output is visible. The highest level of voltage decrees was noticeable on the smaller thermoelement diameters. This highest level of decrees can be seen on the thermocouple with the smallest outer diameter of 0.5mm. The level of decrees was 5°C from the initial state after 84 hour. Other diameters of thermocouples show a different maximum level of decrees and their values are presented in Table 2. The results have confirmed that the exposure of nickel based thermocouples to high temperatures causes a drop of voltage with time. These results *have also proven that the levels of voltage output decrease and thermocouple thermoelements diameter size are related.*

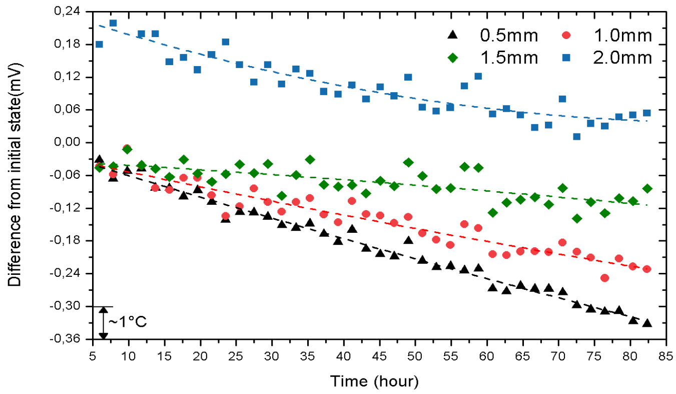

***Figure 1**: Voltage output difference form initial state for type N thermocouples of different diameters*

***Table 2**: Maximum temperature difference from the initial state for various thermoelement diameters at 1200°C.*

Thermo element wire diameter (mm)	*Temperature difference from the initial state after 84 hours (°C)*
0.085	*-5*
0.140	*-3*
0.280	*-2*
0.340	*-4*

Values of temperature decrees and the corresponding wire diameters have been used to establish a drift function for the type N thermocouples in MIMS configuration. This function that can be seen in Fig. 2 shows the dependence of average temperature decrees by one hour and the thermoelement diameter when thermocouples are exposed to a temperature of 1200°C. As can be seen from the Figure 2 the smaller thermoelement diameters show a higher level of average °C/hour decrease than the higher diameters. This is not the case for the 0.340mm thermoelement where an anomaly occurs that need to be further examined and analysed.

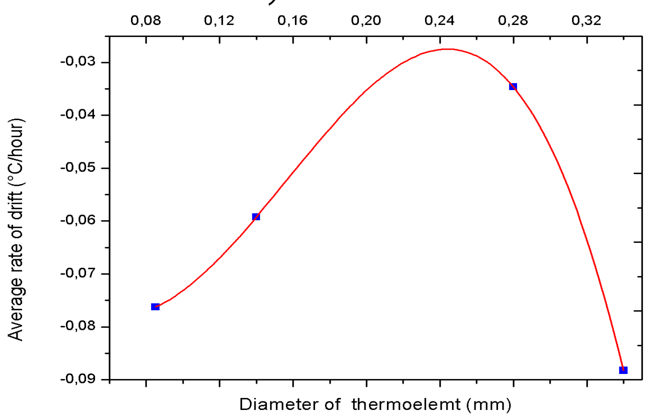

***Figure 2**: Function of type N thermocouple thermoelements diameter and an average temperature decrees in temperature from the initial state after one hour (measured at 1200°C).*

CONCLUSIONS

The measured data show a clear relationship between the level of voltage output decrease and the thermocouple thermoelements diameter. This drift behaviour was observed at temperatures above 1200°C. The sources form which this conclusion was determined can be seen in Fig. 1 and 2. These figures show the different trends of voltage decrease and average °C/hour drop for different thermoelements diameters. This behaviour of nickel based thermocouples in NIMS configuration agrees with the publications [1, 2, 3]. The publications describe the cause of the drift as a chemical contamination of the thermoelement material by manganese (Mn) which can be found in the sheath material of the thermocouple. According to the publications the contamination process starts to occur at temperatures above 1000°C. By analysing the previously made studies in this field we have come to the conclusion that the levels of drift for different thermoelement diameters rely from the amount of material that is contaminated. Smaller diameters are therefore naturally doped faster by the Mn than the larger diameter thermoelements.

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