Stability Of Cable Thermocouples At Upper Limit Of Working Range Of Temperatures

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Abstract. Experimental results of EMF stability research for MIMS thermocouples of types K and N of external diameters 1.5; 3.0 and 5.0 mm are presented. All thermocouples had heat resistant sheath and were not used before the tests. They were subjected to every-day cyclic heating and cooling and during each cycle there was 6 h annealing on air at the temperature 1200 ºC. Results show, that stability of a cable thermocouple on air at the temperature 1200 ºC depends, mainly, on its diameter, instead of on thermocouple type or metal sheath material. Admissible time of operation in a thermal cycling mode for cable thermocouples of 1.5 mm diameter is limited by 15÷16 h, and for thermocouples of 3 mm diameter it is equal to 40÷45 h. Besides, the effect of a signal shunting of the thermocouple under heating of its average part to the temperature 1200 ºC is shown in the work. Experiment has shown that use of long cable thermocouple of 1.5 mm diameter at temperatures above 1000 ºC can lead to serious errors in temperature measurement. Heating of 400 mm thermocouple length to 1100ºC causes positive EMF of the 1.5 mm cable thermocouple to +3.4 degrees and +18 degrees at 1200ºC. With 3 mm cable thermocouple EMF value at 1200 ºC reaches +2.3 degrees, but double increase in heating length makes EMF greater to +13.5 degrees. The given facts are always necessary to consider while using of thin (1-3 mm) cable thermocouples at temperatures 1100÷1200 ºC.

Keywords: mineral insulated metal sheathed thermocouple, EMF stability, signal shunting.

INTRODUCTION

Mineral insulated metal sheathed (MIMS) or cable thermocouples are widely applied in industry, including high-temperature applications. In practice, manufacturers of cable thermocouples or equipment suppliers often recommend their use up to the upper limit of a measured temperature range (1370 ºC for type K thermocouples and 1300 ºC for type N thermocouples), that is not always acceptable. In the temperature range 1100÷1300 ºC the determinant factor of working capacity of a thermocouple is its electromotive force (EMF) stability during working process. EMF drift in these conditions is quite possible and even is inevitable. It is clear, that stability of the cable thermocouple should be higher with increase in external diameter when diameter of thermoelements and the distance between them and a sheath is more.

However, there is a variety of problems in the field of laboratory and scientific researches at high temperatures, investigation of processes with quickly varying temperature, inspection of industrial furnaces, when it is necessary to use cable thermocouples of small diameter (1.0÷3.0 mm) at very high temperatures (to 1200 ºC) and under cyclic mode of "heating-cooling". For these cases it is necessary to estimate time, during which measurements can be considered as reliable within initial accuracy of the thermocouple.

EXPERIMENTAL PROCEDURE

There are known a few results on continuous high-temperature annealing of cable thermocouples of small diameter with low EMF drift values (/1/ and /2/), but cyclic operation of a thermocouple in a "heating-cooling" mode always will cause the raised EMF drift (/3/ and /4/).

Authors had made an experimental research of stability of cable thermocouples of types K and N of 1.5; 3.0 and 5.0 mm outer diameter with heat resistant sheath made of Nicrobell and Inconel600 alloys. Thermocouples had simple design without mounting elements with length to 800 mm and extending wires. All thermocouples were made from the cables having the state "as delivered", no one special demand was directed to a supplier while cables ordering. Thermocouples were subjected to every-day cyclic heating and cooling and during each cycle there was 6 h annealing on air at the temperature 1200 ºC. Through one to three "heating-cooling" cycles a new calibration curve was defined and its deviations from initial and reference EMF values for the given thermocouple were also specified. The thermal cycling parametres described correspond to a real mode of thermocouples operation while surveying of industrial furnaces and in short-term research experiments.

Heating and annealing of the thermocouples were made in horizontal tubular furnace with total length of a heating zone 400 mm (Fig.1a). Periodic calibration of the thermocouples was carried out in vertical tubular furnace (Fig.1b) by a comparison method with type S reference thermocouple.

Immersion depth of a thermocouple in a furnace in both cases was identical, though temperature profiles along the thermocouple could differ.

a) b)

Figure 1. Annealing (a) and calibration (b) furnaces used in the experiments.

Besides, authors investigated the signal shunting effect for a thermocouple while heating of its average part to the temperature 1200 ºC. There is known reseach /5 / where considerable change in indications of a cable thermocouple was noted at elevated temperatures and under the presence of bias voltage between thermoelectrodes of the thermocouple and metal sheath. Change of thermocouple indications was caused by decrease in insulation value of magnesia at raised temperatures.

In the given work the experiment scheme was very simple. The cable thermocouple of 3÷4 m length was passed through a horizontal tubular furnace. The working junction and free ends of the thermocouple were at identical ambient temperature, and the average part of the thermocouple was heated up in the furnace. Free ends of the thermocouple were connected to millivoltmeter of high accuracy where thermocouple indications were fixed (once per a second). Heating of average part of a thermocouple while working junction and free ends have identical temperatures, according to the basic law of thermoelectric chains, should not lead to EMF appearance of the thermocouples. EMF appearance will testify to decrease in electric insulation of the thermocouple and shunting of its signal. The EMF value will be proportional to shunting degree of the thermocouple signal.

EXPERIMENTAL RESULTS

On Fig. 2 the deviations of EMF curves from nominal values are presented for different calibration points depending on annealing time of a cable thermocouple (type K, diameter of 3 mm, Inconel 600 sheath) in tubular electric furnace. The first calibration of all thermocouples was made after initial 4 h annealing at the temperature 1200 ºC.

It is visible on Fig. 2, that EMF of the cable thermocouple falls outside the negative deviation limit for the first accuracy class at temperature 1200 ºC (±0.004·t) approximately after 20 h annealing, and for the second accuracy class limit (±0.0075·t) - in 45 hours. One can see that the lower is the calibration temperature, the less is EMF deviation from nominal value (reference table). Already at 900 ºC EMF deviation from reference table is twice less than deviation at 1200 ºC.

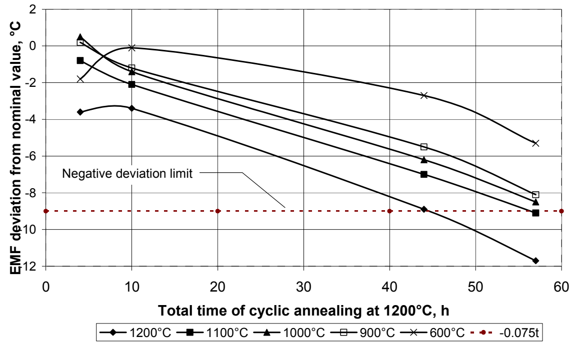

Figure 2. EMF deviations from reference table at the temperatures of calibration points 1200, 1100, 1000, 900, 600 ºC for type K cable thermocouple of 3 mm diameter , Inconel 600 sheathed, - depending on the time of cyclic annealing at the temperature 1200 ºC.

Comparative graphs of EMF deviations from reference table at the temperature 1200 ºC are presented on Fig. 3 and 4 for types K and N cable thermocouples with various sheaths.

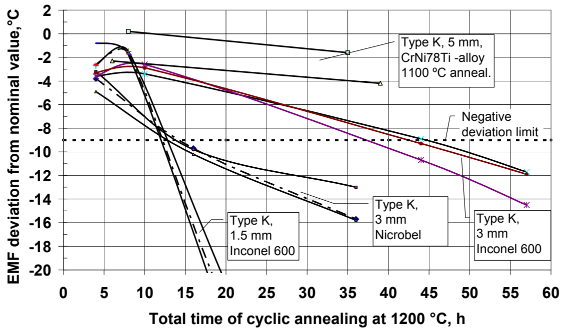

Figure 3. EMF deviations from reference table for type K cable thermocouples at the calibration temperature 1200 ºC during the time of cyclic annealing at 1200ºC. EMF deviations for 5 mm cable thermocouples are given at 1100 ºC for cyclic annealing under the same temperature.

Cable thermocouple of type K having outer diameter 1.5 mm and sheathed by Inconel 600, falls outside the deviations limit of the first accurasy class at the temperature 1200 ºC for 10 h of annealing, and becomes behind the second accuracy class in 12 hours. For this time it falls outside the deviation limits almost in all points of calibration down to 600 ºC. Actually, it is not correspond to the type K reference table after indicated annealing time. This fact testifies that high-temperature annealing of a thermocouple cable of small diameter leads to its fast degradation in all range of working temperatures. For comparison, on the same graph EMF deviations of 5 mm thermocouples with heat resistant sheath are presented, but they cyclically annealed at the temperature 1100 ºC. EMF deviations from initial values almost for 40 hours have not exceeded 2 degrees.

Comparing the deviations of type K cable thermocouples of 1.5 and 3 mm diameters sheathed by Inconel 600, it is possible to notice, that within the first 10 h of annealing the thermocouples indications have about equal stability. Then EMF of the 1.5 mm thermocouples starts to fall sharply, reaching the rate of minus 2 degrees per hour, and after 55 h of annealing EMF deviation reaches values of minus 71 ºC at 1200ºC and minus 35 ºC at the calibration point 600ºC.

EMF drift for type N thermocouples (Fig. 4) has the same laws, but it is necessary to note twice smaller drift rate for 1.5 mm thermocouples than it was for type K. The EMF drift rates shown on Fig 3 and 4 for 3 mm thermocouples practically does not depend on thermocouple type and sheath material.

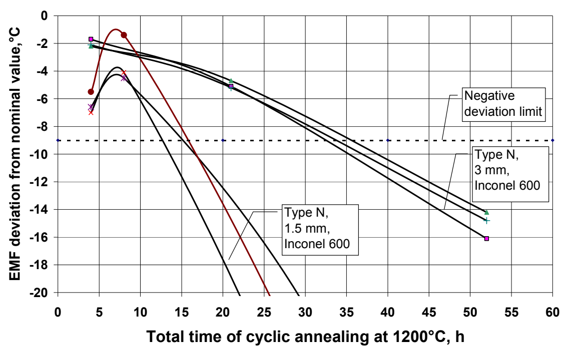

Figure 4. EMF deviations from reference table for type N cable thermocouples at the calibration temperature 1200 ºC during the time of cyclic annealing at the same temperature.

Having analysed the data obtained during the laboratory experiments described, it is possible to draw the following conclusions:

1. Cable thermocouples of types K and N of outer diameter 1.5 mm (sheathed by Inconel 600) under cyclic annealing at the temperature 1200ºC fall outside the deviation limit installed by the IEC 60584 standard for the 1-st accurasy class after 10 h on the average, and already after 15÷16 hours they mismatch the thermocouples reference tables. Average drift rate at 1200 ºC for 1.5 mm thermocouples was 1÷2 degree per hour (smaller rate for type N thermocouples). This fact does not suppose a reuse of 1.5 mm cable thermocouples at the upper limits of a working range of temperatures.

2. Cable thermocouples of types K and N of 3 mm diameter, Inconel 600 sheathed, under cyclic annealing at the temperature 1200ºC fall outside the deviations limits of the 1-st accurasy class (IEC 60584) after 20÷21 h on the average, after 40÷45 h of annealing they mismatch the reference tables of the standard. It should be noticed that stability of thermocouples of different types is approximately identical. Relatively great negative EMF drift for type K thermocouples sheathed by super heat resistant alloy Nicrobel (Fig. 3) was caused, probably, the big initial negative EMF deviation of the thermocouples from nominal value. The rates of negative drift of 3 mm thermocouples are approximately identical to all cable thermocouples of this diameter (0.25÷0.33 degree per hour). Repeated use of such thermocouples at 1200 ºC also is problematic, since steady negative EMF drift already through 10÷15 h makes minus 5 degrees per each 20 h. It will lead to ambiguity of results of consecutive measurements.

3. While use of cable thermocouples at the upper limit of a working range of temperatures the basic influence on the drift rate of a thermocouple's EMF will have the value of external diameter of a cable. Influences of a thermocouple type and sheath material are minor.

Thus, results of the work have shown that admissible time of operation in a thermal cycling mode under heating to 1200 ºC for cable thermocouples of 1.5 mm diameter is limited by 15÷16 h, and for 3 mm thermocouples 40÷45 h. Their further operation is impossible because of EMF drift behind the limits of permissible deviations installed by the standard IEC 60584.

However, the above-stated conclusions would be incomplete if we not consider other important factor directly influencing on indications of cable thermocouples, - EMF signal shunting on length of the thermocouple cable which is exposed to high temperature influence. From general point of view, the less is a cable diameter, the more remarkable should be this effect since thermocouple wires in 1.5 mm cable are at the distance 0.2÷0.3 mm from each other and from a cable sheath. They are insulated from each other by magnesium oxide which electric resistance considerably falls with temperature increase.

Step-by-step heating of an average part of long cable thermocouples of 1.5 and 3 mm diameter had shown that if the working junction and free ends of a thermocouple are at ambient temperature the resultant EMF is equal to zero according to the basic law of thermoelectric chains. However, this rule is observed only if the sheath temperature within the heated part of a cable does not exceed 1000ºC.

Measurement results are presented in Fig. 5. While the heated length of a cable has temperature below 1000ºC, the resultant EMF of a thermocouple fluctuates around zero value, having casual deviations. When the temperature reaches 1000ºC, the EMF of type K 1.5 mm thermocouple starts to grow and reaches +130 μV (~ 3,4 degrees) at 1100ºC and +670 μV (~ 18 degrees) at 1200ºC. EMF of 3 mm cable thermocouples starts to increase at 1100 ºC and remarkable growth occurs under heating to 1200ºC (+90 μV or ~ 2.3ºC). After decreasing of furnace temperature EMF came back to zero values.

When the length of heated part of the cables was double increased (thermocouples were passed through two tubular furnaces) 1.5 mm cable thermocouple has shown noticeable EMF value already at 1000 ºC, and at 1200 ºC EMF had reached values +5000 μV (~135ºC) through 2.5 h after the heating start that testifies to the minimum electric resistance between thermoelements in a heating zone. The cable thermocouple of 3 mm diameter in this case has shown EMF growth to +500 μV (~13.5 ºC), that in 5 times more, than the value showed while heating 400 mm of the cable length.

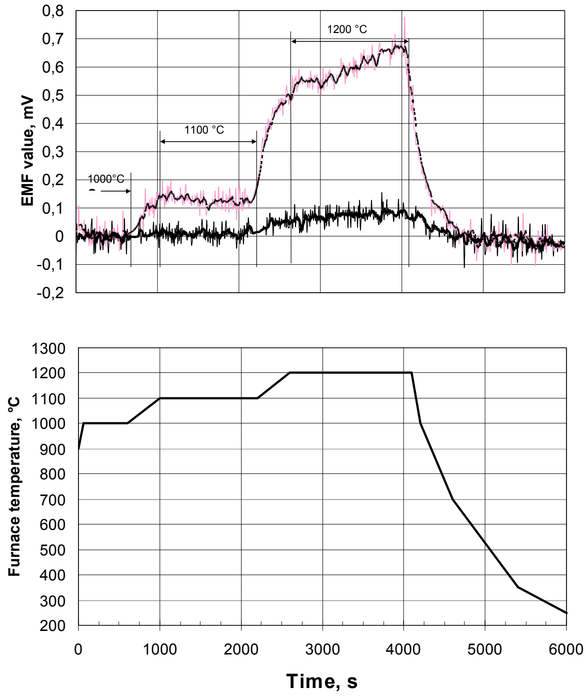

Figure 5. EMF curves of 1.5 (upper curve) and 3.0 mm cable thermocouples under step-by-step heating of average part of the cables of 400 mm length while working junction and free ends temperatures are equal to ambient temperature.

Thus, even simple heating of a part of the cable thermocouple to the temperature more than 1000 ºC, can cause distortion of a real signal of the thermocouple. If working junction of a cable thermocouple is under lower temperature, than the temperature of a local site along the thermocouple length the resultant EMF will be overestimated. In case of working junction has the maximum temperature, but considerable part of the cable thermocouple also will be at temperature above 1000 ºC the resultant EMF will decrease owing to signal shunting along the thermocouple. These factors always should be considered while use of long cable thermocouples in a furnace. They should be protected from direct temperature impact on length. In particular, such well-known method of inspection of the tunnel furnace as trailing of 3 mm cable thermocouples through the furnace together with a product or fixed on a frame can lead to essential errors in temperature measurement. Cable thermocouples should be protected on length from direct temperature impact if its value exceeds 1000 ºC. Cable thermocouples with heat resistant sheath, used for these purposes, should have external diameter 5÷6 mm.

CONCLUSION

To sum up, the results of the work have shown, that EMF stability of MIMS cable thermocouples on the top limit of working range of temperatures under cyclic "heating-cooling" mode depends, first of all, on external diameter of a cable. It defines admissible time of operation of the thermocouple at the set level of temperature. Heating of cable thermocouple on length to temperature 1000÷1100 ºC also can cause noticeable displacement of a thermocouple signal. The given facts are necessary to be considered while use of thin (1÷3 mm) cable thermocouples in the range of temperatures 1000÷1200 ºC.

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