Stability Of A Cable Nichrosil-Nisil Thermocouple Under Thermal Cycling

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Abstract. The experimental data on stability of cable Nichrosil-Nisil thermocouples (type N) under step-by-step thermal cycling in the range of temperatures 20…1100°C and also under permanent heating in air at the temperature 1085±10°C are presented. The analysis of thermal cycling influence on thermal EMF drift is carried out. The conclusion that N type thermocouple can be used as the reference thermocouple while graduation of industrial base-metal thermocouples has been made.

INTRODUCTION

High stability of the Nichrosil-Nisil thermocouple (N-type) in comparison with base-metal thermocouples of other types is well known. It has been demonstrated in the paper [1] that, in oxidizing atmospheres, the thermoelectric stability of the N-type wire thermocouple is about the same, as that of the noble-metal thermocouples of types R and S up to 1200 °C. Research [2] gives the experimental data on thermal EMF drift of the N-type thermocouples under exposure at the temperature of 1100ºC during 2000 hours. The data testify to the better stability of the N-type cable thermocouple with nickel-based heat resistant sheath of 3 mm outer diameter in comparison with the N-type wire thermocouple with electrodes diameter of 1,6 mm. These materials make attractive the attempt to use the Nichrosil-Nisil cable thermocouple as a reference tool of temperature measurement under calibration of standard base-metal thermocouples of other types in the range of temperatures 300…1100°C.

However, any reference tool doesn't operate at high temperatures long time, but works, mainly, in thermal cycling regime within the limits of a calibration range. At the thermal cycling another factors may arise which influence on thermocouple stability, for example, thermal stresses and metal fatigue of the electrodes. The authors have made an attempt to investigate stability of the Nichrosil-Nisil cable thermocouple with heat resistant sheath under daily repeated thermal cycling within a working calibration range.

MATERIALS INVESTIGATED AND TEST METHODS

For the researches performance there were selected the samples of mineral insulated thermocouple cable manufactured by firm ABB Automation Products GmbH. Outer cable diameter was 3 mm, inside thermocouple of N-type (Nichrosil-Nisil), cable sheath material was Inconel 600 alloy.

The researches were carried out in the tubular furnace of a special design intended for thermocouples calibration. Internal diameter of working space of the furnace was 50 mm. The general view of the furnace is shown in Fig. 1. For maintenance of the minimal temperature gradients inside the working furnace zone, a nickel block was inserted to the zone. The block had one central blind hole by a diameter of 26 mm. Aluminium oxide ceramic tube test tube was inserted to this hole. Outside diameter of the tube was 25 mm and internal was 18 mm. Thermocouples assembly was placed inside the ceramic test tube. The assembly consisted of the reference S-type thermocouple in quartz glass (outer/inner diameters 10/7 mm) and four N-type cable thermocouples, adhered to the quartz glass by a nickel wire (Fig. 2). Hot junctions of the thermocouples were in one cross section. The maximal measuring error of the reference S-type thermocouple was 0,6°C at the temperature of copper freezing (1084,62°C), the total uncertainty of the measurements did not exceed 0,9°C.

FIGURE 1. Tubular Furnace for Calibration

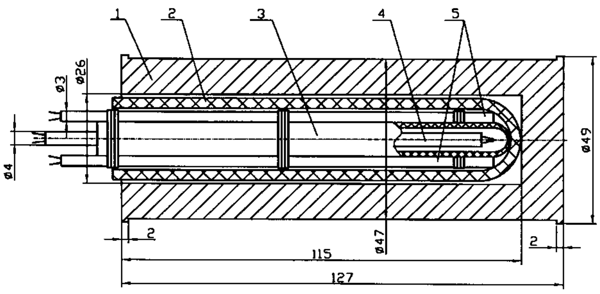

FIGURE 2. Thermocouples Assembly Inserted to Calibration Furnace, where:
1 – nickel block;
2 – ceramic test tube ∅25x18 mm (Al_2O_3);
3 – quartz test glass ∅10x7 mm;
4 – reference S-type thermocouple in two-channel ceramic tube (99,5% Al_2O_3);
5 – cable thermocouples ∅ 3 mm.

Two series of tests were carried out. The first tests were carried out as follows. Four cable thermocouples of N-type, made of one cable coil (No.3659), together with the reference thermocouple of S-type in quartz glass were inserted to the nickel block and then the whole assembly was immersed into the furnace. The depth of assembly immersion was 300 mm and it was measured from edge of the furnace to the end face of nickel block. After that the initial calibration of N-type thermocouples was carried out near the freezing points of copper, aluminium and zinc - the fixed points of the temperature scale ITS-90. The calibration of N-type thermocouples was performed in the following order:

– heating of the thermocouples assembly up to the temperature of 1085±10°C and aging at this temperature for 30 minutes;
– thermal EMF measurement of all thermocouples;
– temperature definition in the furnace by EMF value of the reference thermocouple;
– EMF value recalculation of N-type thermocouples for the temperature of copper freezing;
– definition of thermal EMF deviations of N-type thermocouples at the temperature of copper freezing;
– temperature decrease to the freezing point (±10°C) of aluminium, then zinc, aging at these temperatures and definition of thermal EMF deviations of N-type thermocouples in each point;
– cooling of the thermocouples assembly together with the furnace.

Further, the reference S-type thermocouple was taken off the furnace, and N-type thermocouples were exposed to step-by-step thermal cycling in the range of temperatures from 20 to 1100°C. The thermocouples were heated up in the furnace to temperature 1085±15°C and were maintained for 30 minutes at this temperature, then they were cooled together with the furnace down to the temperature 660±15°C and were maintained for 30 minutes at that temperature, by the same manner at the temperature of 420±15°C, and, finally, they were cooled together with the furnace. Intensity of the thermal cycling was one cycle per day. Through every 10 cycles the calibration of N-type thermocouples were performed with the help of reference S-type thermocouple being inserted to the furnace during calibration time. Total number of cycles was 120.

To compare the results the second series of experiments was carried out. It consisted in the thermocouples annealing at constant temperature of 1085±10°C. The thermocouples assembly consisted of four N-type cable thermocouples of 3 mm outer diameter. The thermocouples were manufactured of two cable coils No.3659 and No.3658 (two thermocouples were made of the same cable coil, as in the thermal cycling tests). The reference thermocouple was S-type thermocouple, which was permanently inserted to the furnace together with cable thermocouples. The experiment proceeded 270 hours. The furnace and thermocouples assembly designs were the same as in thermal cycling tests. Thermal EMF measurements of the cable thermocouples and definition of their EMF deviations from standard calibration curve were made every 8–10 hours.

RESULTS AND DISCUSSION

In Fig. 3 the results of the first series of experiences, namely, thermal EMF value of N-type thermocouples depending on thermal cycles quantity are presented. A horizontal line - nominal thermal EMF value at the indicated temperature, dashed lines - admitted thermal EMF deviations for the first and the second accuracy classes of the N-type thermocouple according to the standard IEC-584. It is visible, that the thermocouples are very stable up to 40 thermal cycles, then the smooth transition follows, and thermal EMF after 70 cycles stabilizes again.

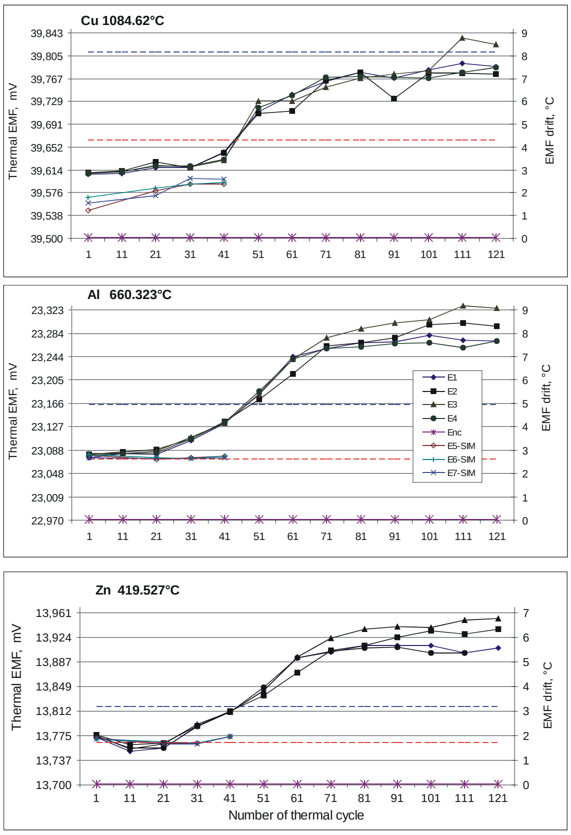

FIGURE 3. Thermal EMF Changes at the Freezing Points of Copper, Aluminium, Zinc for N-Type Cable Thermocouples of 3 mm Outer Diameter under Thermal Cycling in Air.

Under the contract between TESEY Company and Siberian Institute of Metrology (Novosibirsk) the institute has repeated the program of experiments with three N-type cable thermocouples, which were made of one of the cable coils available (No.3658). Cable thermocouples step-by-step thermal cycling was performed in a tubular furnace by the method described before, but the calibration was carried out in the furnaces reproducing standard freezing points of copper, aluminium and zinc according to the temperature scale ITS-90 (fixed-point furnaces). These installations have very high accuracy. The uncertainty of temperature reproduction at the point of copper freezing does not exceed 0,01 K. The depth of the thermocouples immersion while thermal cycling and calibration was 500 mm. Results are also presented in Fig. 3. Stability of the thermocouples within the 40 thermal cycles has appeared to be even better, as it was in our tests.

The increase of EMF drift for N type thermocouples between 40-th and 70-th cycles in our series of experiments can be caused by local structure transformations arising in the thermocouple wires within the temperature gradient zone. The structural defects, apparently, are accumulated in the wires while thermal cycling. One can see in Figure 3, that the drift increase of the thermocouple EMF occurs not only at the fixed point of copper, but also that of aluminium and zinc. The drift values at lower temperatures are closed to the EMF drift at the temperature of copper fixed point. To except possible methodical errors in our experiments the repeated precision calibration of thermocouples was required. After the experiments termination we had sent two cable N-type thermocouples and reference S-type thermocouple to the Siberian Institute of Metrology (SIM), where their calibration was carried out in the fixed-point furnaces. Thermal EMF change of the reference thermocouple at the temperature of copper fixed point had not exceeded 2 μV from the EMF value specified in the thermocouple certificate. It testifies about reliability of reference temperature definition in our experiments. The EMF values of N-type cable thermocouples were fixed at the level of initial EMF values before thermal cycling. The difference in EMF values before thermal cycling (measured in our furnace) and after thermal cycling (measured in the SIM furnace) had not exceeded 5-7 μV at the copper fixed point. We explain this small difference by the fact that the local zone of structure transformations in wires formed in our experiments was placed within uniform temperature zone of the fixed-point furnace because of greater immersing from 300 down to 500 mm. For this reason the difference in EMF indications fixed in our tests before and after thermal cycling practically has disappeared while measuring in fixed-point furnace. These facts confirm indirectly the absence of methodical mistakes in our experiments, and also confirm the conclusion about the opportunity of local structure transformations arising in N-type thermocouple wires under thermal cycling.

Results of the second test series with N-type cable thermocouples are presented in Fig. 4 after 270 hours of permanent annealing in air at the temperature 1085±10°C.

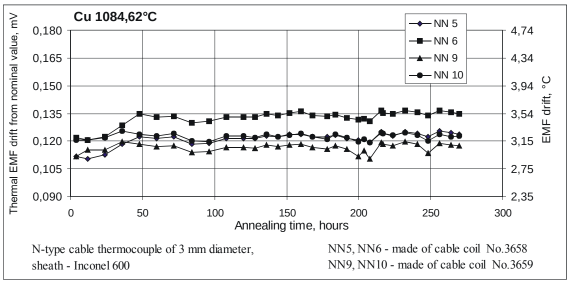

FIGURE 4. Thermal EMF Drift of N-Type Cable Thermocouples of 3 mm Outer Diameter Under Permanent Annealing in Air at Temperature 1085±10°C. Nominal EMF Value of N-Type Thermocouple at The Copper Freezing Point Equals to 39,502 mV.

The data testify to high stability of N-type cable thermocouples under permanent annealing in air at high temperature and coincide with test results of American researchers [2]. The EMF drift occurs only within the first 50 hours by the value of 10-13 μV.

CONCLUSIONS

Thus, the first results of the researches confirm the fact of thermal cycling influence on stability of the calibration curve of N-type cable thermocouple. Besides, our experimental data approves high stability of N-type thermocouple in comparison with other base-metal thermocouples under permanent annealing in air. Stability of N-type thermocouple is sufficient to its using as a reference thermocouple for calibration base-metal thermocouples of other types. In this case, the EMF drift value under thermal cycling becomes of great importance for N-type thermocouple. As our tests results show it is possible to use N-type thermocouple as a cheap reference means of temperature measurement under industrial thermocouples calibration in furnaces during 40 thermal cycles. N-type thermocouple cost, as the minimum, in 10 to 15 times is less than cost of S-type reference thermocouple.

N-type cable thermocouple can be used in metrological laboratories of the industrial enterprises for fulfillment various calibration works. In this case it is necessary to nominate the time interval between two consequent calibration procedures of the reference thermocouple not in calendar days, but in allowable number of calibration cycles. When the number of calibration procedures will reach this value the reference N-type thermocouple should have been subjected to next calibration.

REFERENCES

1. N.A. Burley, “*Nicrosil-Nisil type N thermocouples*”, Measurements & Control, April (1989), pp 130-133.

2. H.L.Daneman, “*The choice of sheathing for mineral insulated thermocouples*”, http:\\www.omega.com