Metrological Self-Check of Platinum Resistance Thermometer

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Abstract. *The procedure for developing a sensor with metrological self-checking is shown by the example of a platinum resistance thermometer (PRT). The efficiency of the method suggested is grounded by results of the theoretical analysis and experimentally confirmed by the example of the PRTs with a sensing element of the "strain free design". The sensors developed enable to carry out checks of their metrological serviceability and correction of measurement results directly in the process of operation.*

Keywords: Metrological Self-check, Platinum Resistance Thermometer, Measurement Relliability

1. Introduction

To provide the reliability of measurements results obtained from temperature sensors as well as to decrease costs of the metrological maintenance of these sensors, it is necessary to automate the metrological serviceability check of the sensors in the process of their operation. The well-known decisions [1]-[6] have some significant disadvantages.

The most promising solution of the problem indicated is the self-check of sensors (metrological self-check) [7], [8]. The metrological self-check can be implemented in two forms: a direct metrological self-check using an embedded measuring instrument of a higher accuracy and metrological diagnostic self-check realized without application of means of such a kind. The metrological diagnostic self-check is accomplished on the basis of evaluating a deviation of the parameter characterizing a critical uncertainty component from an accepted reference value of this parameter. By the critical uncertainty component they imply a dominating uncertainty component or that tending to rise quickly.

In the paper the procedure for developing a sensor with metrological diagnostic self-check is illustrated by the example of a platinum resistance thermometer (PRT).

2. Theoretical grounds of the method applied

The development of a PRT with the self-check was carried out on the basis of a sensing element (SE) of the well-known "strain free" design suitable for performing experimental researches. The SE includes a ceramic tube with longitudinal holes, where the spirals of platinum wires filled up with ceramic powder are located. The tube is hermetically sealed. Leading-out wires are soldered to the ends of the spirals [9]. The technology of manufacturing the sensors of such a type contains a noticeable part of manual operations. To control the quality of each operation is extremely difficult. The character of the processes generating an increase of the PRT uncertainty, irrespective of the design and technology of manufacturing, significantly changes depending on a working temperature range.

If one sums up the known data [9]-[11] and others, then within the working temperature range up to T_{max}<(0,25 – 0,30)T_m, where T_{max} is its upper limit and T_m is the melting point of platinum (which corresponds to T_{max}≈(450 - 500)°C), the main processes affecting the change of the PRT uncertainty in the process of operation can be divided into two main groups.

The first group includes the processes leading to destruction of a thin surface layer of conductors and variation of its conductive properties with regard to all SEs of the sensors:

- surface oxidation;
- sublimation of surface substances;
- contamination of the surface layer by the diffusion of oxides and mixtures;
- mechanical damage of the surface, and so on.

Under the influence of the uncertainty sources, which refer to the first group, in the course of time the specific resistance of the surface layer begins to exceed significantly the specific resistance of a conductor material. This can be represented as a certain equivalent decrease of an area of the cross-section of the platinum wire, which correspondingly increases its resistance. Other processes (which are not connected with the destruction of the surface layer) leading to an unexpected change of resistance of some SEs refer to the second group:

- consequences of the technological spoilage, which have not been detected in the production process (a change of contact resistance caused by low-quality welding or soldering, origination of mechanical strains and deformations as a result of heating or cooling of a SE in case of its poor fixation, and so on);

- variation of those parameters of the sensor elements, which are external with respect to the SE spirals (drop of the specific resistance of the sealing layer, increase of its gas- and/or humidity permeability, e.g., due to cracking, etc.).

The influence of the processes, which refer to the second group, on the sensor uncertainty to a great extent depends on the accepted design and technology of manufacturing the PRTs, as well as on the efficiency of the quality control of the production process. When the processes of the first group dominate, a critical uncertainty component is the deviation of the platinum wire resistance, which is caused by variation of the properties of the wire surface layer.

In [12] it is proposed to use the redundancy for realizing the function of metrological diagnostic self-check, i.e., to make a SE of two or a number of parts differently sensitive to factors influencing on the growth of the critical uncertainty component.

To realize the function of metrological diagnostic self-check in the process of operation, the diagnostic function (DF) β that depends on the values of signals coming from various parts of the SE is calculated. For example, β is equal to the ratio of the wire resistance values.

At the stage of the original calibration of the temperature sensor, which corresponds to the start of operation, a nominal value β_0 of the DF is determined. A relative deviation $\delta\beta$ of the DF from the nominal value is rigidly connected with the sensor uncertainty. In the process of operation the check of the metrological serviceability is performed by determining $\delta\beta$ at a temperature measured and comparing it with a permissible relative deviation.

When the value $\delta\beta$ exceeds the permissible limits or approaches to such a limit, it is necessary to perform an unscheduled calibration of the sensor even if the specified interval has not come to its end. When the specified calibration interval comes to the end and $\delta\beta$ does not exceed a permissible value, then this fact can become an argument for significant increasing the corresponding interval and using the sensor further.

In the general case (for various designs of the PRT), it is necessary to provide a different ratio of the cross-section area to the perimeter of the cross-section of the SE parts.

In each part of the SE the destruction rate (rate of resistance variation) of the conductor surface layer weakly depends on the geometrical parameters of the conductors themselves, and the depth of the destructed layer is small as compared to linear dimensions of the conductor cross-section. For the version of the SE including two parts made of the wires of various diameters

$$\delta\beta = \left| \frac{\beta - \beta_0}{\beta_0} \right| \approx 4a \left| \frac{d_1 - d_2}{d_1 d_2} \right|, \tag{1}$$

where

a assumed thickness of the surface layer subjected to the destruction;

d_1 and d_2 wire diameters.

Provided the relationship between the $\delta\beta$ value and uncertainty δT of the temperature measurement is known, then, using a value of $\delta\beta$ determined experimentally, it is possible to introduce a corresponding correction into a measurement result.

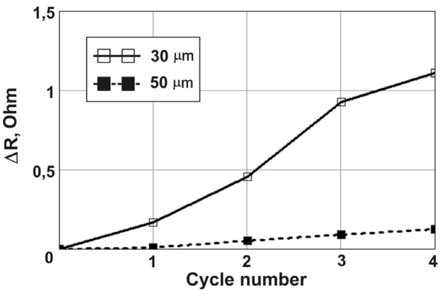
3. Experimental Results

For preliminary evaluation of the efficiency of the considered metrological self-check method, there were carried out experimental investigations of the SE prototypes. This was done in the mode of a forced load, "heating up to 600°C - cooling", with a cycle time of 70 – 80 hours. The prototypes contained a SE consisting of two spirals (each having a resistance of 100 Ohm) which were made of a platinum wire of 50 and 30 μm in diameter. In each cycle the resistance of each spiral was measured at temperature of 0, 450 and 600 °C determined with a reference thermometer. Then the values of β, $\delta\beta$ and resistance deviation (increment) ΔR for each spiral were calculated.

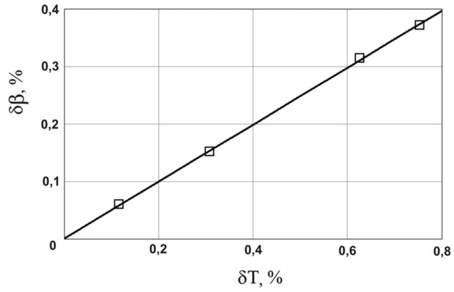
Before the experiments a preliminary annealing of the SEs was done at temperature of 800°C to stabilize the SE characteristics. After that, they were calibrated with uncertainty of ±0.2ºC. It was noticed that during the first cycles of the forced load the process of annealing was still in progress, its rate being different due to the fact that cold-hardening of the wires differed in diameter was not the same. Therefore, the characteristics obtained after annealing of both two spirals were taken as the calibration characteristics. A "zero" value was assigned to the corresponding cycle; the resistance increments ΔR for each cycle being determined with respect to the resistance value measured in the "zero" cycle. On the basis of the data obtained, the DF values β_0 for the "zero" cycle were calculated, and for the subsequent cycles the DF relative deviation $\delta\beta$ and relative uncertainty δT of temperature measurements were determined. The characteristic dependencies are illustrated in Fig.1a and 1b.

The type of these dependencies confirms that the SEs are predominantly influenced by the processes relating to the first group. However, in some prototypes among those investigated, there have been fixed up metrological defects caused by the processes of the second group.

The experiment performed has shown that the metrological self-check method enables a cumulative uncertainty to be evaluated and metrological defect to be revealed. However, the development of the sensor with two spirals of the wire of different diameters requires introducing some changes into the design and technology of the sensor. The PRT design with the metrological self-check should provide for the closeness of original resistance values of SE wires and closeness of the design parameters (values of a pitch, length and diameter of spirals). These conditions can be jointly satisfied if the first SE part is made of a single conductor and the second part contains several conductors connected in parallel. The analysis has shown that the optimal number of conductors in the SE part made of a thinner wire is 2. To increase mechanical strength and rigidity of this spiral, it is useful to make it of twisted wires connected in parallel.



a)



b)

Fig.1. The characteristic dependencies obtained in the experiment at temperature of 450°C
a) Dependence of the resistance increment in the SE parts on the cycle number;
b) Dependence of the relative DF deviation on the relative uncertainty of temperature measurements

4. Conclusion

A temperature sensor with metrological self-check can be implemented on the basis of the technologies applied in industry. Its advantages are:

- automatic check of the measurement information reliability in the process of operation and opportunity of automatic correction of uncertainties;
- availability of diagnostic information that allows the calibration to be realized according to a technical condition;
- possibility to increase by many times the calibration interval.

References

1. Hashemian H. M. Sensor Performance and Reliability. ISA, USA, 2005.
2. http://www.omega.com/pptst/TC-K-NPT_RTD-NPT.html
3. http://www.tesey.com
4. http://npk-etalon.ru/
5. http://www.electrotherm.de
6. Oleynik B. N., Sumerin V. M., et al. Temperature Measurement Using Thermonoise Thermometers, *Measurements, Control, Automation*, 1 (45): 22-29 1983.
7. Taymanov R., Sapozhnikova K. Metrological Self-Check and Evolution of Metrology, *Measurement*, 7 (43): 869-877, 2010.
8. GOST R 8.673-2009. Intelligent Sensors and Intelligent Measuring Systems. Basic Terms and Definitions.
9. Samsonov G.V., Kitz A.I., Kuzenia O.A., Lakh V.I., et al., Sensors for Measuring Temperature in Industry, Naukova Dumka, Kyev, 1972.
10. Berry R. J., Oxidation, Stability and Insulation Characteristics of Rosemount Standard Platinum Resistance Thermometers, *Temperature, Its Measurement and Control in Science and Industry*, AIP, New York, 5: 753-761, 1982.
11. Li X., Zhao M., and Chen D., A Study on the Stability of Standard Platinum Resistance Thermometer in the Temperature Range from 0°C through 720°C. http://www.hartscientific.com
12. RU2321829 G01 D 3/00. Gorokhov L. P., Sapozhnikova K. V. and Taymanov R. E., Mode of Control of Metrological Condition of Measuring Converter of Non-electric Value and Installation for its Execution, Bulletin, 10, 2008.