Evaluation of the contribution to uncertainty due to Joule self-heating effect in the temperature measurement using Platinum Resistance Thermometers.

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Abstract

Temperature measurement using Platinum Resistance Thermometers (PRT) of the Pt100 type is very common in industry. These devices vary their ohmic resistance as a function of temperature. In order to assure that their measurements meet the required accuracy they must be calibrated periodically. The PRTs require excitation to measure, usually, a direct current flowing through them. There is no way to assure that the current used to excite the PRT during calibration be the same as that which is used at work. Joule self-heating effect occurs when a current flows through a resistance, so a contribution to uncertainty in measurement appears. The amount of dissipated power is proportional to the square of the current. In this work, the error that can be expected due to this difference in excitation currents, was estimated in the range of -30 to 130 °C. A PRT was excited with several current values in the range of 0.5 to 5 mA and the resistance was measured via a four wires connection. This range of currents is typical for industrial PRT applications. Equivalent temperature was then calculated using the Callendar-Van Dusen formulae, and the contribution of uncertainty was evaluated, for the whole range. All measurements are traceable to international standards. It was found that no important errors occurs when the excitation current is kept in the range from 0.5 to 2 mA, and that the self heating effect begins to be appreciable at higher currents. This procedure can be applied to any PRT which mW/°C coefficient is unknown, in order to evaluate the uncertainty due to different excitation currents. It is also applicable to other types of resistance temperature detectors.

Keywords: platinum resistance thermometer, Joule self-heating effect, excitation current, uncertainty.

Introduction

Temperature measurement using PRT of the Pt100 type is very common in industry. These devices vary their ohmic resistance as a function of temperature. In order to assure that their measurements meet the required accuracy they must be calibrated periodically. The PRTs require excitation to measure, usually, a direct current flowing through them. There is no way to assure that the current used to excite the PRT during calibration be the same as that which is used at work.

Joule self-heating effect occurs when electric current flows through a resistance, so another contribution to uncertainty in measurement appears [1], if the current used during calibration differs from the current used to excite the PRT on its working circuit. The amount of dissipated power is proportional to the square of the current.

On some PRT, we are able to know the mW/°C coefficient, so this deviation can be calculated with a small uncertainty component. But very often you don't know such coefficient, or maybe, due to aging of the PRT, that coefficient has varied and is no longer accurate, so we can't know the contribution to the uncertainty in the measurement of this PRT. The aim of this work is to provide knowledge about the uncertainty contribution that could be considered while measuring temperature using PRTs with excitation currents different to that used during its calibration.

Materials and Methods.

A four wires PRT was excited with a constant direct current through the current leads. Both the PRT under test and the temperature standard were immersed in a controlled temperature medium [1]. Once temperature was stable, we read the voltage across the voltage leads of the PRT (see Figure 1). Then current was varied to the following value, we waited 5 min for stabilization, and read the new value of voltage. We repeated this for the rest of the selected current values. Then both the PRT under test and the temperature standard were placed in another controlled temperature medium and the whole procedure was repeated.

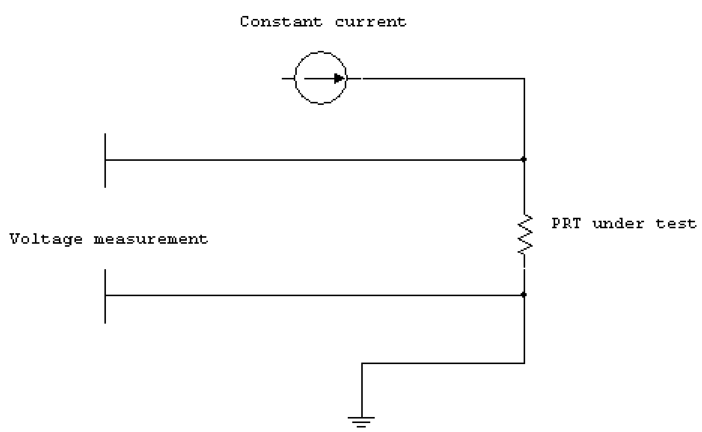

Figure 1. Wiring diagram

The selected current values were: 0.5; 1.0; 2.0; 3.0 and 5.0 mA. These are the most common values of current used on industrial measurement.
The selected temperature values were: -30; 0; 25; 60 and 130 °C. These values covers the range at which the PRT under test is expected to work.

Resistance of the PRT at any temperature was obtained by the formula:

$$R = V/I \quad (1)$$

Where:

- R : resistance of the PRT, in Ω.
- V : voltage that appears across the voltage leads of the PRT, in mV.
- I : excitation current, in mA

With the value of resistance, we used the Callendar-Van Dusen formulae, to obtain the equivalent temperature value [3].

Room temperature and relative humidity were measured during the test, using a Control Company 4184 digital thermohygrometer. Temperature remained in the range 20 to 25 °C and relative humidity remained within the range of 60 to 70 %.

It was used a PRT serial number 8245035 from a GETINGE autoclave, as the instrument under test. This PRT is used to control the temperature inside the sterilization chamber of the autoclave, and its measurement must be very accurate (± 0.5 °C) [4]. As a temperature standard, it was used a HART-Scientific SPRT, type 5416, and a FLUKE 1502A Tweener.

To generate the constant current and to measure the voltage across the PRT, it was used a BEAMEX MC5 portable calibrator. All measurements are traceable to Mendeleyev Institute for Metrology (VNIIM). To generate the temperatures -30 °C and 130 °C, it was used a FLUKE 9011 dual-well dry block. For the 0 °C it was used an ice bath, with distilled water in two phases (both solid and liquid) in thermal equilibrium. To generate the temperatures 25 °C and 60 °C; it was used an ERTCO TCS 35-200 stirred controlled bath with distilled water as thermometric fluid.

Results and Discussion

The values for resistance and temperature were obtained for each excitation current and each temperature point. The data is shown on Table 1.

Table 1. Millivoltage, resistance and equivalent temperature for different excitation currents

Thermometric medium	Temperature (°C)	Excitation current (mA)				
		0,5	1	2	3	5
Air (Dry Block)	-30,01	44,06 mV	88,12 mV	176,26 mV	264,42 mV	440,87 mV
		88,12 Ω	88,12 Ω	88,13 Ω	88,14 Ω	88,17 Ω
		-30,26 °C	-30,26 °C	-30,24 °C	-30,21 °C	-30,23 °C
Distilled water (Ice bath)	-0,02	49,99 mV	99,99 mV	199,99 mV	299,99 mV	500,17 mV
		99,98 Ω	99,99 Ω	99,99 Ω	99,99 Ω	100,03 Ω
		-0,05 °C	-0,03 °C	-0,03 °C	-0,03 °C	0,08 °C
Distilled water (Stirred bath)	25,00	54,87 mV	109,74 mV	219,49 mV	329,28 mV	548,96 mV
		109,74 Ω	109,74 Ω	109,74 Ω	109,76 Ω	109,79 Ω
		25,01 °C	25,01 °C	25,01 °C	25,07 °C	25,14 °C
Distilled water (Stirred bath)	59,97	61,63 mV	123,26 mV	246,53 mV	269,83 mV	616,57 mV
		123,26 Ω	123,26 Ω	123,26 Ω	123,28 Ω	123,31 Ω
		60,05 °C	60,05 °C	60,05 °C	60,1 °C	60,18 °C
Air (Dry block)	129,99	74,95 mV	149,91 mV	299,85 mV	449,86 mV	750,24 mV
		149,9 Ω	149,91 Ω	149,92 Ω	149,95 Ω	150,05 Ω
		130,18 °C	130,21 °C	130,23 °C	130,31 °C	130.58 °C

Analyzing these results we found that the maximum difference in the range from 0.5 to 2 mA was 0.05 °C at 130 °C. This value is only 10 % of the acceptance criterion of 0.5 °C , and is considered acceptable [4], once combined with the contribution of uncertainty reported in the PRT calibration certificate [2]. If calibration of this PRT was performed in our Metrology Lab, then this contribution of uncertainty must be considered together with all the other contributions.

In the range from 2 to 3 mA the maximum difference is 0.08 °C at 130 °C, which is higher than the difference of the previous range, and exceed the 10 % of acceptance criterion. Nevertheless, this value of excitation current would be acceptable too, if the other contributions of uncertainty are small [2]. In the range from 3 to 5 mA the difference is significant, with a maximum of 0.27 °C, which put this PRT out of tolerance. This value of excitation current must be avoided.

Conclusions

It is possible to determine the amount of uncertainty contribution due to Joule self-heating effect in industrial temperature measurement. This procedure can be applied to any PRT which mW/°C coefficient is unknown, in order to evaluate the uncertainty due to different excitation currents.

It is also applicable to other types of resistance temperature detectors (RTD), such as Pt1000 or Ni1000, which are widely used in industrial temperature measurement. The procedure can also be applied to thermistors, both PTC and NTC.

References

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