Uncertainty of Temperature Measurement in Working Environment

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Abstract: The uncertainty of measurement is a key component of expressing of measurement result. Knowledge of uncertainty is needed for balance of the process reliability. Every measurement device is not perfect and producer has to declare the maximum accuracy of the device and this can be used as a part of uncertainty. Paper deals with uncertainty analysis of temperature process measurement inside the working environment.

Keywords: *uncertainty of measurement, temperature, error, gauge, reliability.*

1. Introduction

Measurement results are very often basic leading point for making of decision and these results often influence the other phenomena's and processes. This paper deals with expression of with uncertainty of measurement and also about the including of them into the engineering measurement process. If we want to express measurement result, it is necessary to obtain the selected quantitative indicators of quality of results. This evaluation shows the reliability of measurement results. Comparison of results can be executed only in case, if there is also available uncertainty of these measurement. This is a reason for existence of generally accepted process of determination of measurement uncertainty [1, 2].

Almost all areas of science need experimental works with expressing of measurement results. Also production process has to be checked for the quality of process and measurement results are as the base for the decision making for intervention into the production process. Measurement uncertainty has direct impact to achieved production quality.

There are several national and international standards for evaluation of measurement uncertainty and calibration process [3-7].

2. Measurement of temperature using the resistive sensors

Temperature is very frequently measured quantity in industry. Various sensors are currently used for this measurement. These sensors change the any quantity as electrical resistance, volume, length, pressure and shape in accordance with temperature change. Consequently, the measurement of temperature is based on measurement of changes influenced by temperature. It is necessary to select suitable principle of sensor according to concrete application and expected range of measured temperature. Resistive sensors are one of the possible way for industrial conditions. As material are used platinum, nickel, cooper or semiconductors.

Platinum has excellent properties as large and time stabile temperature coefficient. It is usable in temperature range from -190°C up to +630°C. There are available various versions of platinum resistive sensors for industrial application (Fig. 1).

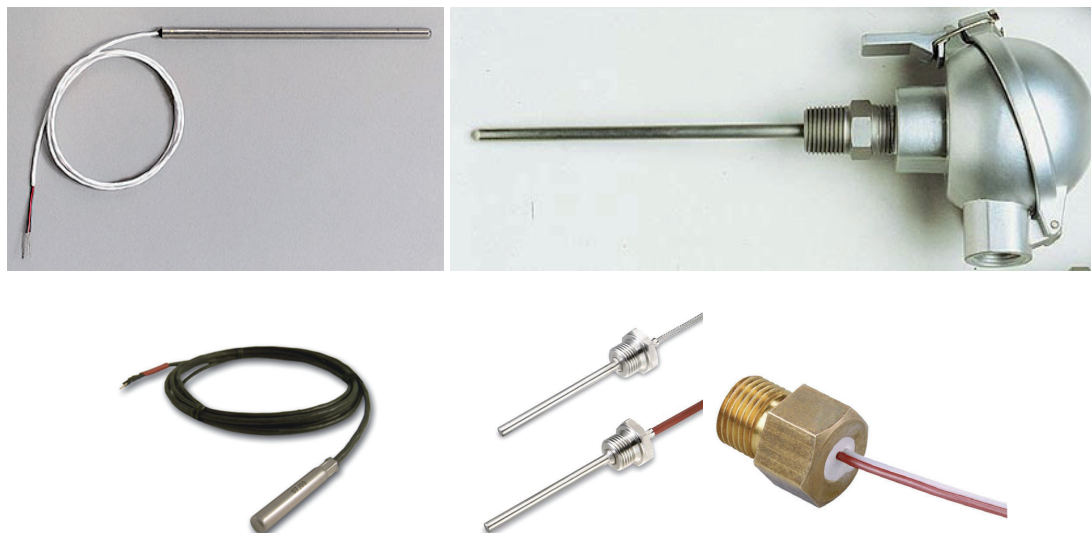*** Corresponding author:** Michal Kelemen, *E-mail address:* michal.kelemen@tuke.sk

Figure 1: Platinum resistance sensors – various variants for industrial application.

Industrial application includes also environment with chemically aggressive substances with high temperatures and moisture. Sensors for these application are protected with insulation and case with suitable covering of the terminal block. Sensors are applied with thread, screw contact or sticker connection.

From the physic viewpoint, the resistive temperature sensor is as transducer or converter of temperature to other quantities. Dependence of resistive on temperature of the material is used for the measurement. This dependence is known and expressed with table and math model mentioned in standard IEC751 [1]. Marking of this sensors is coming from convention used in practice. For example, Pt100 means that used material is platinum with resistivity 100ohms at temperature 0°C. Also it is available Pt1000 sensor which has resistivity 1000ohms at 0°C. The standard also provides the math approximation with polynomial function. The standard also includes detailed table about the values of resistivity for relevant temperature value. After measurement of sensor resistivity, you can find the related value of temperature. There are only finite number of values. If your value falls between the values in the table, it is necessary to do linear interpolation to obtain searched value:

$$T_{OKOLIA} = T_1 + x$$

Where T_1 is the nearest value from table in IEC751 related to measured value of resistivity R_S; x ix

interpolation temperature increment obtained using the linear interpolation according to data in table from IEC751 [1]

| t [°C]	R_F [Ω]	t [°C]	R_F [Ω]	t [°C]	R_F [Ω]	t [°C]	R_F [Ω]
–60	76.28	30	111.67	125	147.94	220	183.17
–55	78.27	35	113.61	130	149.82	225	185.00
–50	80.25	40	115.54	135	151.70	230	186.82
		45	117.47	140	153.57	235	188.64
–45	82.23	50	119.40	145	155.45	240	190.46
–40	84.21			150	157.32	245	192.27
–35	86.19	55	121.32			250	194.08
–30	88.17	60	123.24	155	159.18		
–25	90.15	65	125.16	160	161.04	255	195.89
–20	92.13	70	127.07	165	162.90	260	197.70
–15	94.10	75	128.98	170	164.76	265	199.50
–10	96.07	80	130.89	175	166.62	270	201.30
–5	98.01	85	132.80	180	168.47	275	203.09
		90	134.70	185	170.32	280	204.88
0	**100.00**	95	136.60	190	172.16	285	206.68
		100	**138.50**	195	174.00	290	208.46
				200	**175.84**	295	210.25
5	101.95					**300**	**212.03**
10	103.90	105	140.39				
15	105.85	110	142.28	205	177.68		
20	107.79	115	144.18	210	179.51		
25	109.73	120	146.06	215	181.34		
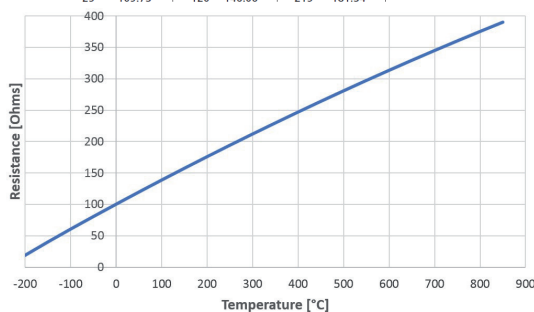
Figure 2: Electrical resistance vs. measured temperature of Pt100 sensor by standard IEC751.

Interpolation temperature increment is a function of

$$x = f\left(R_S, R_1, k_{RT}\right)$$
$$x = \frac{R_S - R_1}{k_{RT}} \tag{2}$$

Where - k_{RT} is transformation coefficient, which is as slope of straight line crossing the points with coordinates of discrete temperature values and related values of electrical resistivity of temperatures sensor. For transformation coefficient is possible to find relationship from function

$$k_{RT} = f\left(R_1, R_2, T_1, T_2\right)$$
$$k_{RT} = \frac{R_2 - R_1}{T_2 - T_1}$$
(3)

R_S is electric resistivity of temperature sensor.

R_1, R_2 are the value from table (IEC751) and our measured value of resistivity R_S is placed between these values.

T_1, T_2 are value from table, which are related to values of electric resistivity of sensor R_1 and R_2.

3. Estimation of temperature value

Model of measurement system (Fig. 3) consists of several devices:

– *Resistive temperature sensor Pt100 for measurement range 0-600°C with maximum accuracy U_S=±0.2Ω.*

– *Volt meter with data transfer to computer with maximum accuracy 0.000004V.*

– *Reference etalon for electric resistivity with nominal value of resistivity R_E=10 Ω with maximum accuracy U_{RE}=±0.01 Ω.*

– *Power supply with stabilization of electric current.*

Resistive temperature sensor Pt100 is connected in series with resistivity reference etalon. During the measurement, the constant current with values 1mA flows through the both these parts (sensor and etalon). Principle of measurement is based on simultaneously measurement of potential drops on both these parts (sensor and etalon). Measurements of voltages are realized with four channel voltmeter connected to computer. For obtaining of the resistivity of temperature sensor Pt100 is possible to use equation:

$$R_S = \frac{V_S}{V_E} \cdot R_E$$
(4)

where V_S is volt drop on temperature sensor Pt100; V_E is volt drop on etalon of electric resistivity; R_E is electric resistivity of resistivity etalon; R_S is electric resistivity of temperature sensor Pt100.

Equation (3) and (4) create the math model of temperature measurement in working environment using the temperature sensor Pt100. This model shows that it is indirect measurement type.
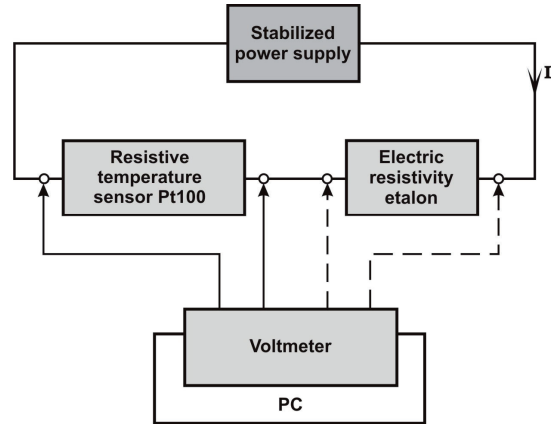

Figure 3: Scheme of the measurement system.

4. Evaluation of measured data

Ten measurement of voltage drop have been executed. Measured quantities were voltage drop on electric resistivity sensor and on temperature sensor Pt100. Estimation of average values and standard deviation have been made from obtained measured data. Sources of uncertainties are summarized in the next:

– *Standard uncertainty of electric resistivity etalon u_{BE}.*

– *Standard uncertainty of measurement of volt drop on temperature sensor obtained by method A labelled as u_{AVS}.*

– *Standard uncertainty of measurement of volt drop on temperature sensor obtained by method B labelled as u_{BVS}.*

– *Standard uncertainty of measurement of volt drop on resistive etalon obtained by method A labelled as u_{AVE}.*

– *Standard uncertainty of measurement of volt drop on resistive etalon obtained by method B labelled as u_{BVE}.*

– *Standard uncertainty of transformation coefficient labelled as u_{BkRT}.*

– *Standard uncertainty of temperature sensor resistivity R_1 and R_2 obtained from table included in IEC751 (this is uncertainty obtained by method B).*

– *Standard uncertainty of temperature T_1 and T_2 for sensor related to resistivity R_1 and R_2 obtained from table included in IEC751 (this is uncertainty obtained by method B).*

Combined standard uncertainty for measurement of voltage drop can be obtained as square root of quadratic sum of uncertainties obtained by method A and by method B. Standard uncertainty of temperature sensor resistivity results from math model and it is as function of partial uncertainties of all quantities mentioned in math model (4):

$$u_{RS} = f\left(u_{CVS}, u_{CVE}, u_{BE}\right)$$
(5)

Using the Law of uncertainty propagation, it is possible to write equation for uncertainty of measurement of temperature sensor resistivity:

$$u_{RS} = \sqrt{\sum_{i=1}^{n} A_i^2 \cdot u_i^2} \qquad (6)$$

Where A_i are the sensitivity coefficients of partial quantities mentioned in model (4) and u_i are the related uncertainties for these quantities.

Also from model (3) it is possible to obtain the standard uncertainty of transformation coefficient as function of partial uncertainties of all quantities in model (3):

$$u_{k_{RT}} = f\left(u_{BR1}, u_{BR2}, u_{BT1}, u_{BT2}\right) \qquad (7)$$

Analogically also uncertainty of interpolation temperature increment can be obtained as:

$$u_x = f\left(u_{RS}, u_{R1}, u_{k_{RT}}\right) \qquad (8)$$

Consequently, the final uncertainty for measurement of temperature via using the Pt100 sensor is as function

$$u_{TOKOLIA} = f\left(u_x, u_{BT1}\right) \qquad (9)$$

5. Conclusions

The paper brings the proposal for math model of the measurement using the Pt100 resistive temperature sensor with using the table of values mentioned in standard IEC751. This procedure is simplified and there is neglected the covariance between input quantities in math model of measurement (3) and (4). Covariance can deteriorate and also improve the final uncertainty value. It depends on math model and also on values of covariance. Analogically it is possible to do uncertainty balance also for other type of measurement of other quantities in practice [8-16].

Acknowledgments

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