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INFLUENCES TAKEN INTO CONSIDERATION DURING CALIBRATION OF CONTACT THERMOMETERS AIMED FOR MEASURING TEMPERATURE OF A SOLID SURFACE

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Abstract. *Measurements, calibrations of contact thermometer have benn conducted on prototype/standard – apparatus for calibration of contact thermometers on solid surface (in following text just prototype). In order to make the calibration obtained result whole an estimation of measurement uncertainty is done.*
The possibility to vary parameter of influence of ambient temperature just above the reference surface is used. This parameter is directly derived from the construction of the prototype.
Key words*: Calibration, contact thermometers, measurement uncertainty.*

1. INTRODUCTION

To be sure in contact thermometer measurement result, each instrument and the sensor has to be checked, calibrated. Calibration is the operation that, under certain conditions, in the first step, defining the relationship between the value of the size with uncertainty of measurement standards and corresponding indications with associated measurement uncertainties, and in a second step, uses this information to establish a relation for obtaining a measurement result from the readings. [1]
Contact thermometers for measuring at solid surface are calibration subject on prototype. Those have their part into contributions during estimation of measurement uncertainty.
Contact thermometers have wide application such as food industry, cooking, and various branches of industry where is needed to measure solid surface temperature. For example coatings based on secretion of resin can not be applied at temperatures below the dew point or the temperature below 5°C. Contact thermometers are used for this purpose as well as in the auto industry and other branches of the paint, where the coatings or layers are applied only after checking the temperature using a contact thermometer. The same also have application in the monitoring of temperature heat pipes, construction and many other purposes.
Contact thermometers are generally calibrated using temperature-controlled hot plate. In such a device, the reference temperature is the one on the upper surface of the metal body, and it is determined by linear extrapolation from the readings of calibrated sensors (probes) that are drawn into the body at different depths and distances from the reference surface. The actual temperature of the reference surface depends largely on the interaction of the sensor to the surface. [3, 4]

2. PROTOTYPE - APPARATUS FOR CALIBRATION OF CONTACT SENSORS FOR MEASURING TEMPERATURE OF SOLID SURFACES

The research focused on measuring the variation of the parameter that can not be ignored, and that came out of the construction characteristics of the prototype. Parameter is related to the impact on the ambient temperature just above the surface and ocured as the result of the number, arrangement and position of the heater in the prototype.
One position of the reference board is when the same is in the "top" position and then practically the reference plate is in height (aligned) with the upper rim of the upper (annular) heater. In this case this heater is heating the reference board around (Fig. 1).

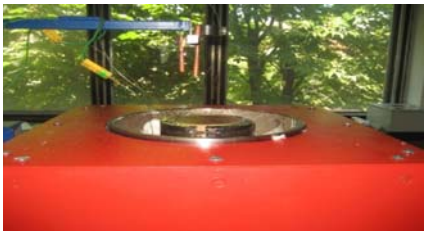

Figure 1. The upper position of the reference body/ plate

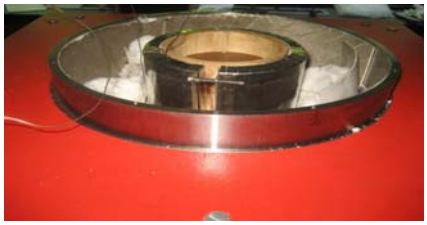

Figure 2. the lower position of the reference body/ plate

The second situation is when the reference plate in the "lower" position and then the lower (the ring, and the middle of the three) heater heats the reference plate around, and the upper heater is in a higher position relative to the reference plate and thus has influence on the ambient temperature, just above the surface of the reference plate (Fig. 2).

This is an important fact because this is a new on a prototype meaning that is one of the improvements of the apparatus. This information is important even more because it would be used to compare the results obtained in one and in the second position of the apparatus at the same temperature calibration points.

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The assumption was that the difference of temperature readings read out with a thermometer and the reference board (obtained by extrapolating) and measured at the higher calibration points to be much higher.

The assumption was that the temperature difference would be particularly marked in the case when there was no influence of ambient temperature just above the surface of the reference block or when there is no "preheat" of the reference surface and the contact thermometer.

2.1. Description of prototype

Calibrated thermocouples type K, (Fig. 3.) are located at different distances parallel to the surface of the reference body/ plate. The same thermocouples are connected to a digital thermometer with four channels Chub-E4 (Fig. 3.), in order to monitor the value of the reference temperature within the body, and using these data to extrapolate the temperature of the reference surface. This positioning of the sensors is characteristic in other apparatus, which are developed earlier. Not all the apparatures are using type K thermocouples as sensors.

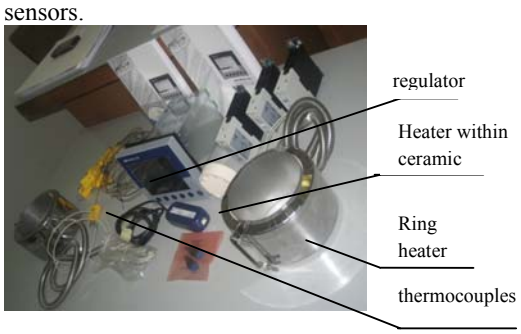

Figure 3. Thermocouples, heaters and regulator that are parts of apparatus

Thermocouple type K (shown in Fig. 3.), were also used for regulating the temperature of the heater and connected to the regulator Imago 500 (Fig. 3.) and thyristor switches manufacturer JUMO, type B 70.9040.0. Everything together makes a system for controlling the temperature of the reference body.

All thermocouples and a digital thermometer are pre-calibrated for the purpose of verification and traceability of the same.

Under the reference body is a heater in ceramics, and other two ring-shaped (Fig. 3.) are around and above or below and around the reference body/ plate.

2.2. Contact thermometers calibration procedure

There is no definined method or a norm for calibration of contact thermometers on a prototype or apparatus of this type. It is possible to give a general idea of how to sort the operations to be performed during calibration. For these reasons, a large part of the procedure performing calibration contact thermometer is taken from Project 635 Thermometry and partly modeled on a bilateral comparison between BNM-LNE (France) i OMH (Hungary).

Calibration procedure:

1. includes the first and finall determination of the surface temperature by extrapolating before applying the sensor ($t_{p\text{-}before}$) at a certain calibration point.
2. Leaning contact thermometer on the surface of the reference blocks for the purpose of obtaining measurements and data read from the thermometer.
3. After removing the contact thermometer (sensor), the surface temperature is once again determined by extrapolating ($t_{p\text{-}after}$). The average surface temperature is determined by extrapolating and define reference temperature (tp), which is the basic value between ($t_{p\text{-}before}$) and ($t_{p\text{-}after}$).
4. So temperature measurements of the reference surface and of the calibration object - contact thermometer (sensor) are performed as described. One cycle of measuring when the reference body is in the "lower" position (Fig. 2.), and another measuring at the same calibration point when the reference surface in the "top" position (Fig.1.).

3. MATHEMATICAL MODEL OF CALCULATING MEASUREMENT UNCERTAINTY

- **Dependence of the temperature sensor (Tc) of the surface temperature (Ts) and ambient temperature (T amb)**
  - $E = t_s - t_p$ (1)

Where:

t_p – surface temperature determined by extrapolation

t_s – read out temperature of sensor
Uncertainty related to deviation E is:

$$u^2(E) = u^2(t_p) + u^2(t_s) \qquad (2)$$

- **Infuence of reference surface temperature (t_p)**

Temperature t_p is determined by method of kstrapolation according to equation:

$$t_p = \frac{(t_{sup} - t_{inf})(e - h_{inf})}{(h_{sup} - h_{inf})} + t_{inf} \qquad (3)$$

Where:
t_{inf}, t_{sup} - Temperature within body (further and closer to reference surface)
h_{inf}, h_{sup} - Vertical position position of opening in the axis of the cylindrical reference surface
e - The thickness of the reference plate (body)
If: $t_{inf} = t_i + c_{i\text{-}cal} + c_{i\text{-}stab} + c_{i\text{-}hom} + c_{i\text{-}drift}$
and $t_{sup} = t_j + c_{j\text{-}cal} + c_{j\text{-}stab} + c_{j\text{-}hom} + c_{j\text{-}drift}$
Than:
t_x - Mean temperature measured by sensor x in reference plate (body),
x = i or j (sensor that is closer or further of reference surface
$c_{x\text{-}stab.}$ - Corrections to the calibration of sensor x
$c_{x\text{-}hom.}$ - Corrections to the inhomogeneity of the temperature around the sensor x
$c_{x\text{-}drift.}$ - Correction relates to the drift of sensor x
h_{sup}, h_{inf} - Vertical position of opening in the axis of the cylindrical reference surface
Measurement uncertainty related to the temperature of the reference surface (specimen) is determined in comparison to the contributions specified in [2].

- **The effect of temperature instruments (t_s)**

Sensor temperature t_s is determined according to:

$$t_s = t_{s\text{-}očit} + c_{rezol.} + c_{amb.} + c_{materijal} + c_{tp\text{-}nazad} + c_{deb.} + c_{pov.} + c_{operat.} \qquad (4)$$

Where:
$t_{s\text{-}očit.}$ – Mean temperature read out of contact thermometer Srednja očitana temperatura kontaktnog senzora
$c_{rezol.}$ – Corection related to instrument resolution
$c_{amb.}$ – Corection related on influence of ambient temperature to measurements during calibration
$c_{materijal}$ - Corection related to thermal conductivity related to the type of material used to construct the reference plate (body)
$c_{tp\text{-}nazad}$ - The correction in relation to changes in the temperature of the reference surface at steady state after redraw of sensor that is calibrated
$c_{deb.}$ - Correction due to differences in the thickness of the material in relation to the reference conditions
$c_{pov.}$ - Correction due to differences of the contact resistance in comparison to the reference conditions
$c_{operat.}$ - Correction in relation to the operator effect
(*) Uncertainties $c_{deb.}$, $c_{pov.}$, $c_{operat.}$ Not currently taken into account.

Based on the specified contributions the measurement uncertainty of sensor is determined according [2].

4. CALIBRATION RESULTS AND EVALUATION OF TOTAL MEASUREMENT UNCERTAINTY at calibration point of 300 °C

Measurements were made at several calibration points and calibration temperature 300 °C is chosen.
A) When the reference surface is in „low“ position.
Table 1: Measurement uncertainty contributions of reference surface at calibration point 300 °C when reference body/ surface is in „low“ position.

Veličina X_i	Procjena x_i	Raspodjela	St.nes $u(x_i)$	Koef.osjet. $\lvert c_i \rvert$	Dopr. $\lvert c_i \cdot u(x_i) \rvert$
t_i	300,57 °C	N	0,04 °C	0,391	0,02
$C_{i\text{-}cal}$	1,67 °C	N	0,42 °C	0,391	0,17
$C_{i\text{-}stab}$	0 °C	P	0,05 °C	0,391	0,02
$C_{i\text{-}hom}$	0 °C	P	0,05 °C	0,391	0,02
$C_{i\text{-}drift}$	0 °C	P	-	0,391	-
t_j	299,65 °C	N	0,03 °C	1,391	0,04
$C_{j\text{-}cal}$	1,67 °C	N	0,42 °C	1,391	0,59
$C_{j\text{-}stab}$	0 °C	P	0,05 °C	1,391	0,07
$C_{j\text{-}hom}$	0 °C	P	0,05 °C	1,391	0,07
$C_{j\text{-}drift}$	0 °C	P	-	1,391	-
e	50,0 mm	N	0,10 mm	0,027 °C/mm	0,01
h_{inf}	2,0 mm	N	0,10 mm	0,028 °C/mm	0,01
h_{sup}	36,5 mm	N	0,10 mm	0,037 °C/mm	0,01
t_p	300,96 °C	/	/	/	**0,63 °C**

Tabela 2: Measurement uncertainty contributions of contact sensor at calibration point 300 °C when reference body/ surface is in „low“ position

Veličina X_i	Procjena x_i	Raspodjela	St.nes $u(x_i)$	Koef.osjet. $\lvert c_i \rvert$	Dopr. $\lvert c_i \cdot u(x_i) \rvert$
$t_{s\text{-}očit}$	299,88 °C	N	0,23 °C	1	0,23 °C
$c_{rezol.}$	0 °C	P	0,33 °C	1	0,33 °C
$c_{amb.}$	0 °C	P	0,11 °C	1	0,11 °C
$c_{materijal.}$	0 °C	P	0,05 °C	1	0,05 °C
$c_{tp\text{-}nazad}$	0 °C	P	0,07 °C	1	0,07 °C
t_s	299,88 °C	/	/	/	**0,43 °C**

$$u^2(E) = u^2(t_k) + u^2(t_p) =$$
$$u(E) = \sqrt{u^2(t_k) + u^2(t_p)} = 0{,}76\ °C$$

B) When the reference surface is in „upper“ position

Tabela 3: Measurement uncertainty contributions of reference surface at calibration point 300 °C when reference body/ surface is in „upper“ position

Veličina X_i	Procjena x_i	Raspodjela	St.nes $u(x_i)$	Koef.osjet. $\lvert c_i \rvert$	Dopr. $\lvert c_i \cdot u(x_i) \rvert$
t_i	295,71 °C	N	0,05 °C	0,391	0,02
$C_{i\text{-}cal}$	1,67 °C	N	0,42 °C	0,391	0,17
$C_{i\text{-}stab}$	0 °C	P	0,05 °C	0,391	0,02
$C_{i\text{-}hom}$	0 °C	P	0,05 °C	0,391	0,02
$C_{i\text{-}drift}$	0 °C	P	-	0,391	-
t_j	291,28 °C	N	0,03 °C	1,391	0,04
$C_{j\text{-}cal}$	1,67 °C	N	0,42 °C	1,391	0,59
$C_{j\text{-}stab}$	0 °C	P	0,05 °C	1,391	0,07
$C_{j\text{-}hom}$	0 °C	P	0,05 °C	1,391	0,07
$C_{j\text{-}drift}$	0 °C	P	-	1,391	-
e	50,0 mm	N	0,10 mm	0,129 °C/mm	0,02
h_{inf}	2,0 mm	N	0,10 mm	0,136 °C/mm	0,02
h_{sup}	36,5 mm	N	0,10 mm	0,179 °C/mm	0,02
t_p	291,22 °C	/	/	/	**0,63 °C**

Tabela 4: Measurement uncertainty contributions of contact sensor at calibration point 300 °C when reference body/ surface is in „upper“ position

Veličina X_i	Procjena x_i	Raspodjela	St.nes $u(x_i)$	Koef.osjet. $\lvert c_i \rvert$	Dopr. $\lvert c_i \cdot u(x_i) \rvert$
$t_{s\text{-očit}}$	289,87 °C	N	0,16 °C	1	0,16 °C
$c_{rezol.}$	0 °C	P	0,33 °C	1	0,33 °C
$c_{amb.}$	0 °C	P	0,11 °C	1	0,11 °C
$c_{materijal.}$	0 °C	P	0,24 °C	1	0,24 °C
$c_{tp\text{-}nazad}$	0 °C	P	0,13 °C	1	0,13 °C
t_s	289,87 °C	/	/	/	**0,41 °C**

$$u^2(E) = u^2(t_k) + u^2(t_p) =$$
$$u\,(E) = = 0{,}75\ °C$$

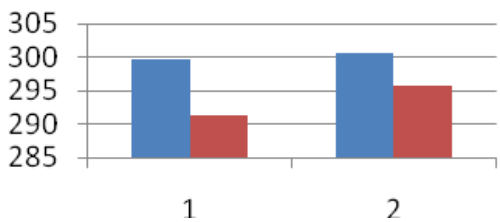

Diagram 1. Showing results of mean values of temperature for Ti and Tj (thermocouples further and closer to the reference surface) used to extrapolate the surface temperature when the reference surface is in „low“ (blue) and in the „upper“ (red) position for in 300 ° C point.

5. CONCLUSIONS

1) The study was conducted in order to establish own procedure for calibration of contact thermometers for measuring temperature of solid surface.
2) In order to clearly define and quantify the contributions to measurement uncertainty when calibrating contact thermometers for temperature measurement of solid surface.
3) The first calibrations using the prototype apparatus - standard for calibration of contact thermometers for temperature measurement of solid surface were performed in terms of preparation for validation of the apparatus itself.

LITERATURE

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