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CALIBRATION OF NON-CONTACT THERMOMETERS

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Abstract: In the paper a development of an accredited temperature calibration laboratory in the field of non-contact thermometry is presented. The laboratory was first accredited for calibration by comparison of contact thermometers and calibration baths and furnaces in the range from -55 °C to 1250 °C. It also became a holder of national standards for thermodynamic temperature thus providing the traceability of temperature in Slovenia. After a strong demand for calibration of non-contact thermometers was expressed by mostly export oriented industry in Slovenia, the laboratory has started a set of activities with an objective to establish a facility for calibration by comparison of radiance thermometers. These activities included besides a purchase of the equipment also an extensive training of experts, which have developed, written and implemented the procedures for evaluation and calibration of blackbody sources, and determined the best measurement capabilities with the existing equipment.
Keywords: calibration, traceability, radiation thermometer

1 INTRODUCTION

The Laboratory of Metrology and Quality was granted an accreditation in January 1996 for calibration by comparison of contact thermometers (resistance thermometers, thermocouples, liquid-in-glass thermometers, digital and analog indication thermometers) in the range from –55 °C to 1250 °C. Shortly after calibration activities have started there were customers who have shown an interest in calibration of non-contact thermometers (radiation thermometers, pyrometers). These customers had various demands regarding the dynamic range of calibration and an uncertainty. The demands were increasing therefore we have decided to establish a laboratory for calibration by comparison of radiation thermometers. To cover the Slovenian needs for traceable non-contact temperature measurements we were running an inquiry among our customers for three years. It turned out that for example medicine radiation thermometers require a calibration range from 35 °C to 42 °C with an uncertainty of 0,1 °C, electric distribution companies require the range from –10 °C to 120 °C with an uncertainty of 1 °C, power plants require approximately the same uncertainty in the range from 80 °C to 200 °C, the range from 500 °C to 1000 °C is required in glass industry with an uncertainty of 0,5%, while the steel industry and production of magnets require the range from 300 °C to 1500 °C with uncertainties of 0,5%.

2 EQUIPMENT

The equipment for calibration of radiation thermometers consists of five blackbody sources, which cover the range from –10 °C to 1500 °C, five reference thermometers, two reference radiation thermometers and a nanovolt/microohm meter. Additionally a reference light source will be used to determine an uncertainty of a radiation thermometer due to the size of source effect.

2.1 Blackbodies in liquid-baths

Three of our blackbody sources, which cover the ranges from –10 °C to 60 °C (water), 60 °C to 150 °C (light viscosity silicon oil) and 150 °C to 250 °C (heavy viscosity silicon oil), respectively, were made in our laboratory under the supervision of experts from the Netherlands Meetinstituut, Delft, the Netherlands. For all blackbody sources copper cavities were made as shown in Figure 1. The cavities were painted twice with a special black paint Pyromark [1], which sustains high temperatures. The paint was dried after each painting for several hours at 560 °C. All cavities painted with the Pyromark paint have a calculated effective emissivity of 0,9989 ± 0,0013, as described in [2]. The cavity in a blackbody source with water has a special inlet for argon gas, which prevents condensation on the walls of the cavity when operating at temperatures below the dew point temperature of an ambient air and a wrapped zinc cathode, which prevents oxidizing of a copper valve.

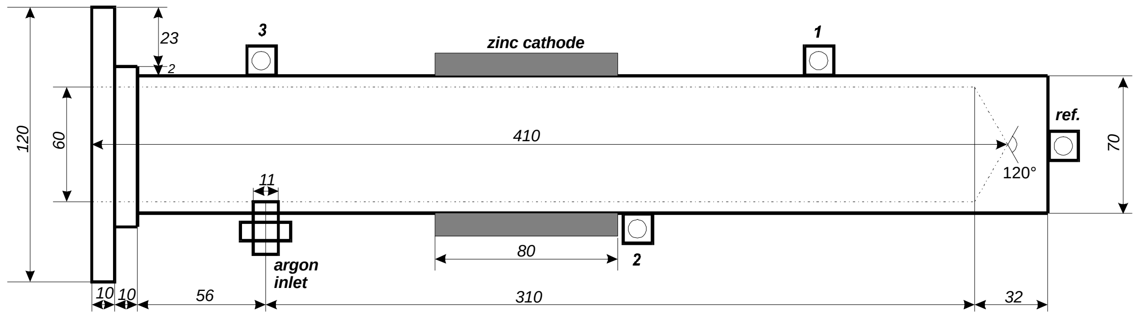

Figure 1. The scheme and dimensions of blackbody cavities made in the LMK

All cavities have special holders for platinum resistance thermometers (marked as *ref.*, *1*, *2*, and *3*). In these holders the thermometers are inserted during the process of evaluation of a blackbody. The position at the bottom of the cavity (*ref.*) is used by the reference thermometer during the calibration of radiation thermometers. Namely, the traceability of calibrated radiation thermometers in the whole range is linked to the contact thermometers (platinum resistance thermometer or/and thermocouples).

2.1 Blackbodies in furnaces

Above 300 °C we have two different furnaces, which contain blackbody cavities. The first furnace contains a cesium heat pipe blackbody. It operates in the range from 300 °C and 600 °C. Its dimensions are shown in Figure 2. According to the [2], where a blackbody of the same producer and with similar dimension is studied, the effective emissivity of a blackbody is estimated to 0,998 ± 0,001. The emissivity was increased by sandblasting and oxidizing the surface inside the cavity. The achievable uncertainty of the blackbody temperature is expected to be 0,1 °C. The proper evaluation according to the procedure written in [3] has not been performed yet, because the thermometers used for preliminary evaluation were not calibrated in the specified temperature range.

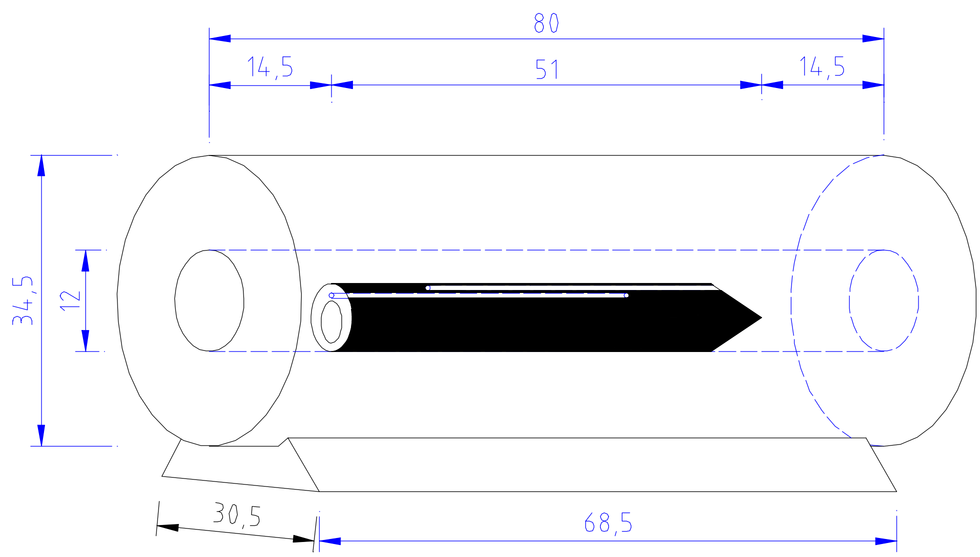

Figure 2. The scheme and dimensions of a cesium heat pipe blackbody and a furnace

The second furnace contains a blackbody cavity made of silicon carbide. The cavity inner diameter is 50 mm and its effective emissivity is 0,998 ± 0,001, as stated in [3]. Its scheme is shown in Figure 3.

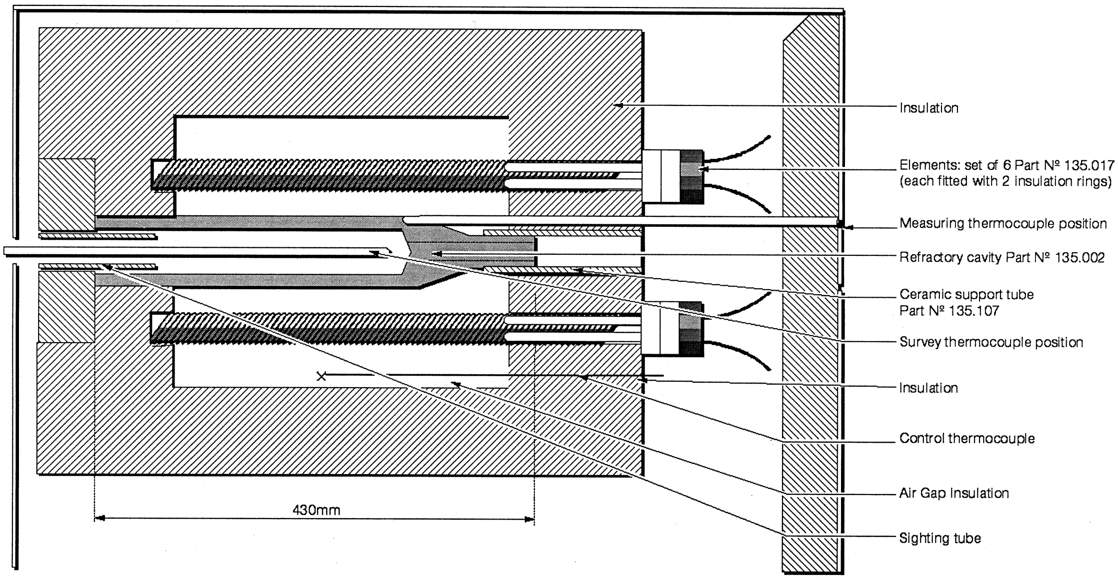

Figure 3. The scheme of a high temperature blackbody and a furnace

3 EVALUATION OF BLACKBODIES

The evaluation process was carried out to determine the uncertainty of temperature in all blackbodies, which is caused by temperature gradients along blackbody cavities. In general the uncertainty of a blackbody consists of two main uncertainty contributions, the uncertainty due to instability of temperature and the uncertainty due to inhomogeneity:

$$u_{blackbody} = \sqrt{u_{\text{hom}\,ogeneity}^2 + u_{stability}^2} \qquad (1)$$

The uncertainty due to inhomogeneity is determined as the greatest difference between the reference and any other thermometer, divided by the $\sqrt{3}$, according to [5]:

$$u_{\text{hom}\,ogeneity} = \frac{\max\left(T_{ref} - T_i\right)}{\sqrt{3}} \qquad (2)$$

The uncertainty due to instability is determined as the greatest difference in temperature deviation of the reference thermometer during at least 10 minutes.

$$u_{stability} = \frac{T_{ref-\max} - T_{ref-\min}}{\sqrt{3}} \qquad (3)$$

4 UNCERTAINTY BUDGET

Uncertainty budget in calibration of spectral band radiation thermometers, which nowadays represent the majority of non-contact thermometers, consists of the following uncertainty contributions:

1. $u_{\text{repeat (fit)}}$ is the uncertainty determined by the calibration and is calculated on a basis of a curve fit, which is either linear or quadratic. The uncertainty given is based on 2 standard deviations.
2. $u_{\text{blackbody}}$ is the uncertainty of a blackbody, which is determined according to the procedure for determination of the uncertainty of a blackbody, written in [3].
3. $u_{\text{reference}}$ is the uncertainty of a reference thermometer (resistance thermometer or thermocouple), which consists of an uncertainty due to its repeatability during calibration (based on 2 standard deviations) and of a thermometer's uncertainty according to its calibration certificate.
4. $u_{\text{meas.device}}$ is the uncertainty of a measuring device (µW/nV-meter) obtained from its calibration certificate
5. $u_{\text{gradient\&size-of-source}}$ is the uncertainty due to the temperature gradients in a blackbody cavity and due to the size-of-source effect

6. $u_{reading}$ is an uncertainty due to the reading of a radiation thermometer. For analog thermometers it is calculated as (1/3) or (1/5)* of the smallest scale division multiplied by ($2/\sqrt{3}$), while for digital thermometers it is calculated as the least sign digit multiplied by $1/\sqrt{3}$, according to [5].
7. $c_{orrection}$ is the uncertainty of the correction applied to a radiation thermometer reading, which measures a radiance temperature, while a reference thermometer measures a true temperature.

The total uncertainty of a radiation thermometer t_{otal} is determined by the calibration and is based on a probability level of 95%. It is calculated as a square root of the sum of quadrates of all uncertainty contributions.

In calibration of a pyrometer with a disappearing filament, which is one the first type of non-contact thermometers, the uncertainty of the correction is not applicable since the pyrometer measures a true temperature and not a radiance temperature.

5 CONCLUSIONS

Because the Laboratory of Metrology and Quality is a national laboratory for temperature in Slovenia we are obligated for dissemination of temperature in Slovenia according to the national needs. After the requirements for traceable non-contact temperature calibrations have been expressed by the Slovenian export industry, the activities have been launched to establish a laboratory for calibration of non-contact thermometers. The inquiry in the market has shown that a temperature range from –10 °C to 1500 °C is sufficient for the time being. In a relatively short time of two years the purchase of necessary equipment (measuring instruments, thermometers, blackbodies), education and training of experts, construction of blackbodies and necessary evaluation, calculation and documenting procedures were carried out. The final objective will be achieved by obtaining the accreditation for calibration by comparison of radiation thermometers. The accreditation is due in the first half of the year 2000. Therefore the acknowledged best measurement capabilities will be presented at the Congress in September.

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