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LABORATORY RADIATION FURNACE FOR HIGH TEMPERATURES

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Abstract: In the field of calibration of temperature measurement devices, the comparison method is usually used. To improve the uncertainty of the method, a number of specific conditions should be taken into account, such as temperature stability and the homogenous field inside the working area of the heating device. It is more difficult to realise those demands at higher temperatures in excess of 1000°C. We discuss the commercial heating furnace, carry out the reconstruction of the heating element and improve regulation, attaching importance to the location of the sensors. The isothermal 600-mm-long cylindrical block, with holes for testing and a reference probe, is linked with a special cylindrical heating element to compensate for heat flow at the front of the furnace and to improve uniformity.
Keywords: calibration, furnace, temperature uniformity.

1 INTRODUCTION

The activities of this laboratory include the calibration of contact temperature sensors for temperatures up to 1100 ^{0}C. For this purpose a laboratory radiation furnace was developed for calibration using the comparison method. When employing the comparison method, a number of conditions concerning the stability and uniformity of the temperature field must be fulfilled. The requirements are more difficult to fulfil at higher temperatures. This paper focuses on several solutions for the development of the radiation furnace and on experimental work.

2 REQUIREMENTS FOR THE EXPERIMENTAL DEVELOPMENT OF THE RADIATION FURNACE

2.1 Comparative calibration method

When using the comparative calibration method we must ensure that the reference probe and the probe being calibrated are at the same temperature. The corrections for the probe being calibrated are determined from readings of the temperature values for both probes. Various media, into which the probes are inserted, are used for generating the temperature conditions. Radiation furnaces are used for temperatures in excess of 600 ^{0}C [1]. In order to fulfil the basic requirement that both probes must be at the same temperature during the calibration procedure, the largest possible uniform temperature field with the smallest possible temperature gradient must be generated in the working area of the furnace [2]. This ensures that the measurement elements in probes with different construction characteristics are at the same temperature during the calibration procedure. The probes must be inserted to a sufficient length in order to minimise heat loss flow along the structure of the sheath, from the sensing area into the ambient, and their effect on the measured value. It is important to maintain stable stationary temperature conditions in order to avoid dynamic errors in the calibration procedure. The latter is a consequence of the diverse dynamic properties of the temperature probes being calibrated [3, 4]. In the development of the laboratory radiation furnace, requirements have been set concerning the stability of the temperature in a stationary state (± 0.3 ^{0}C in a time interval of 20 min) and the uniformity of the temperature field along a length of 100 mm (uniformity ± 1.5 ^{0}C).

2.2 Construction characteristics of the laboratory radiation furnace

The development of the laboratory radiation furnace was based on a standard 3-kW, square-shaped laboratory furnace with a 250 x 300 x 120 mm working area. An isothermal cylindrical block with longer measurement tubes for probes calibration, additional cylindrical heating coils and a double PID temperature regulator was subsequently installed in the radiation chamber. No changes were made to the heating coils mounted around the side walls of the radiation chamber. A PID regulator with a phase-controlled power level was chosen for achieving a time-stable temperature field inside the radiation chamber.

An isothermal block (Fig. 1) was installed in the centre of the radiation chamber in order to fulfil the general requirements concerning the uniformity of the temperature field when using the comparative calibration method. The block consists of a 60-mm outer-support ceramic tube and four built-in ceramic tubes of different dimensions, inside which the comparative calibration method is performed. The inside of the support ceramic tube is filled with heat-conducting media along the length in which the calibration is performed. This improves the uniformity of the temperature field between all ceramic tubes.

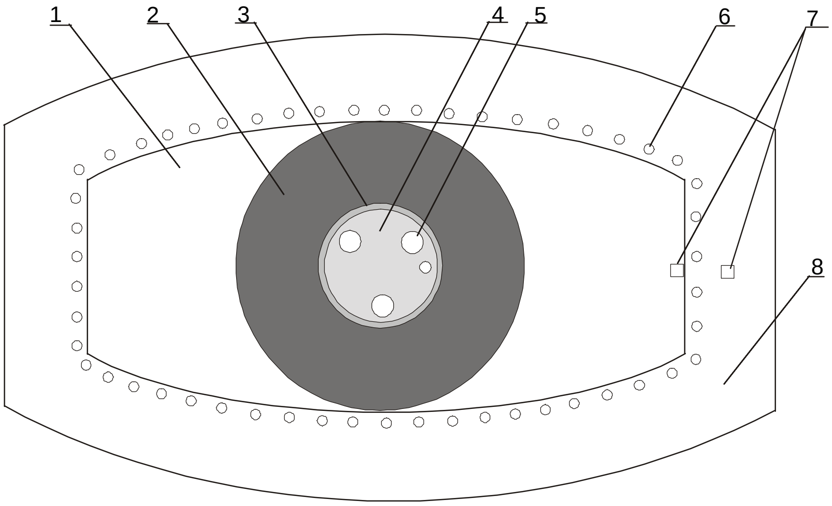

Figure 1. Diagram of the cross-section of the furnace and the radiation chamber: 1 - radiation chamber; 2 - cylindrical heating coil; 3 - support ceramic tube of the isothermal block; 4 - MgO filling; 5 - ceramic tubes of various dimensions; 6 - the furnace's heating coils; 7 - the locations for installing the main regulator sensor in the lining and in the wall of the radiation chamber; 8 - insulation lining in the furnace.

2.3 Choosing the location for installing the temperature regulator sensor

The requirements are to generate a time-stable temperature field inside the isothermal block with a permissible temperature fluctuation pf ± 0.3 ^{0}C in a time interval of 20 min. The emphasis was on choosing the location for installing the temperature sensor of the regulator for the heating elements in the walls of the radiation furnace (hereinafter: main regulator). The main regulator sensor is a type-S thermocouple protected with a thin ceramic sheath. In the first phase of the experiment, the main regulator sensor was built into the insulation lining on the outer side of the heating coils (Fig. 1).

After some time the required temperature stability in a stationary state was achieved, but with a initial major temperature surge, despite the swift achieving and maintenance of the set temperature at the installation location of the regulator sensor. The reason for this is the delay of the heat flow through the insulation lining in which the sensor was inserted, between the heating coil to the outer wall of the furnace.

To avoid the effects of changes in the temperature gradient in the outer insulation lining of the furnace and the subsequent temperature surge, the regulator sensor was installed in the inner wall of the radiation chamber (Fig. 1). The temperature surge was eliminated; however, the time needed for establishing a stationary temperature condition inside the ceramic tubes in which the calibration is performed increased.

In the next phase of the experiment the regulator sensor was installed inside the isothermal block with the aim of achieving temperature stability in the shortest possible time. This improved the system's response time, yet, despite searching for the optimum parameters for the PID regulator, it took a long time for the required temperature stability to be achieved.

On the basis of these experiments, we designated the outer side of the isothermal block as the optimum location for installing the regulator sensor.

2.4 Analysis of the stability and uniformity of the temperature field

A measurement system with a type-S thermocouple without a protective tube, for better dynamic characteristics, was used for the analysis of the temperature conditions. The generated electomotive force was measured using a millivoltmeter with a built-in Pt 100 resistance temperature sensor at the meter's input measurement terminals. The meter was connected to a PC via a serial communication RS232 for the monitoring, graphic presentation, archiving and statistical processing of the measurements.

The analysis of time stability and temperature fluctuation during a stationary state was done at a distance of 40 mm from the bottom of the ceramic tubea. The measured temperature fluctuations in a 30-min time interval were below ± 0.2 ^{0}C. Fig. 2 shows the sequence of the temperature measurements in the ceramic tube of the isothermal block at a distance of 40 mm from the bottom of the tube, at a set temperature of 1000 ^{0}C in the main regulator. High temperature stability was achieved using an optimum choice of PID parameters for the main regulator, the choice of the installation location of the regulator sensor and the use of the isothermal block.

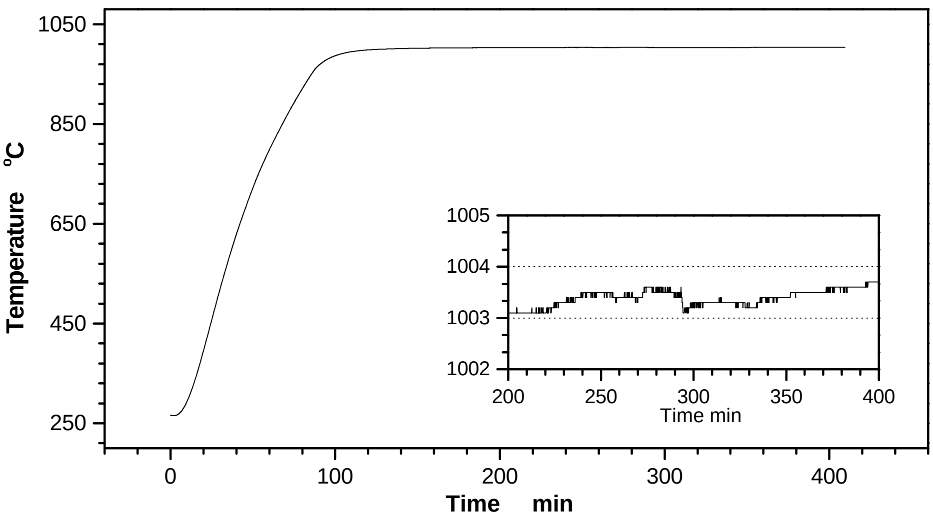

Figure 2. Temperature sequences measured in the ceramic tube of the isothermal block.

Since the front side of the radiation furnace does not have a heating coil and the heat loss is greatest due to less insulation, the temperature in this part of the radiation chamber is lowest. The result is reduced uniformity of the temperature field along the ceramic tubes in which the calibration is done (Fig. 3).

After the temperature probes of various construction characteristics and dimensions have been inserted into the ceramic tube inside the furnace's isothermal block, heat flow occurs along the construction of the probe [5]. From the measurement part of the probe (location of the sensing element), which is at a higher temperature, the heat flow runs towards the part of the probe which is at a lower temperature, or outside the furnace. This results in changes in the temperatures of the sensor inside the probe, which are lower than the temperature of the medium into which the probe is inserted, and are therefore treated as the reference value in the comparative calibration procedure. It is measured using the reference probe. The heat flow and reduced uniformity of the temperature field cause an increase in the measurement uncertainty of the calibration.

2.5 The effect of installing an additional heating coil

An additional 300-W cylindrical heating coil was mounted on the exit side of the support ceramic tube of the isothermal block in order to reduce the temperature gradient along the ceramic tubes and to compensate for heat loss. The heating power of the additional coil is controlled using a special PID controller and an electronic switch, based on temperature measurements with an additional type-S thermocouple. The thermocouple is fitted inside the isothermal block, where the additional cylindrical heating coil is mounted. Fig. 4 shows the temperature sequences along the ceramic tubes at various temperature settings of the regulator of the cylindrical coil for cases where the temperatures in the main regulator are set at 1000 ^{0}C.

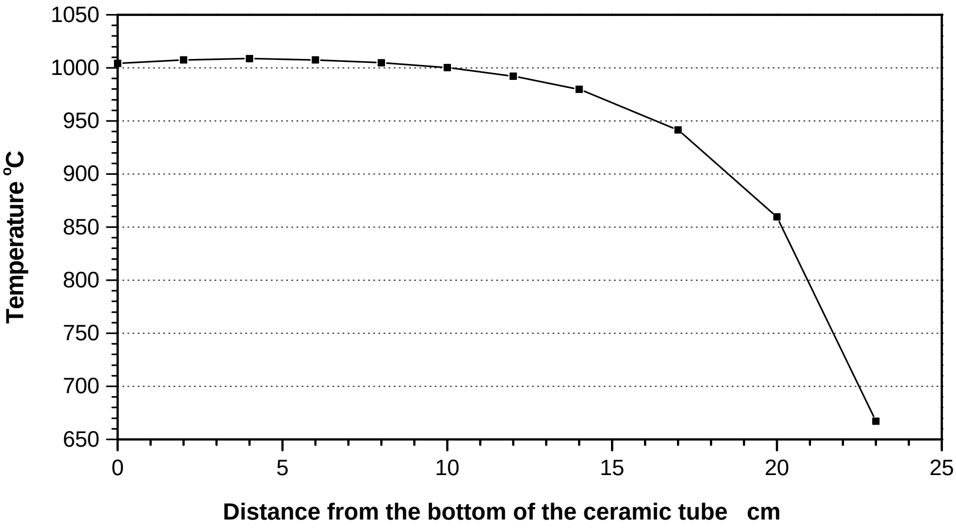

Figure 3. Temperature uniformity along the ceramic tubes of the isothermal block without an additional heating coil.

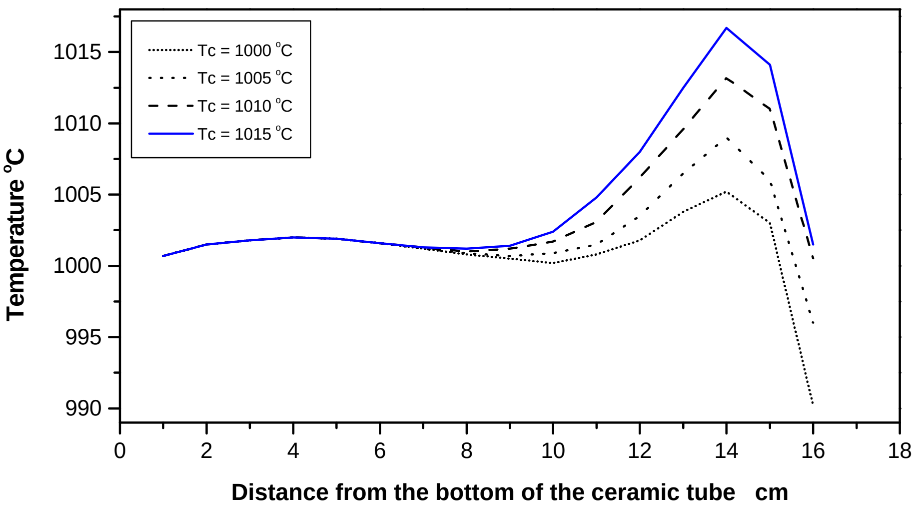

Figure 4: Temperature sequences along the ceramic tubes of the isothermal block in relation to the temperature set for the additional heating coil.

3 CONCLUSION

The uniformity and time stability of the temperature field were among the basic requirements for calibrating temperature probes using the comparison method. Ensuring the depth of insertion of the probes and the length of the working area of the isothermal block in which the above-mentioned criteria are met was of equal importance. An analysis of the measurement results showed that, with the installation of an isothermal ceramic block and an additional heating coil, the thermal characteristics of the furnace have improved significantly. The measured temperature fluctuations in a 30-min time interval were below ± 0.2 ^{0}C and the uniformity of the temperature field along a length of 100 mm was less then ± 1.5 °C. The study of the locations for measuring the control values and optimising the PID regulation parameters proved to be of great importance in designing the radiation furnace. The characteristics of the furnace could be further improved with continued studies of the additional heating coil, which we plan to do in our future experiments.

REFERENCES

[1] J. P. Holman. *Heat Transfer*, SI Metric Edition, McGraw-Hill Book Company, 1989.
[2] D. P. De Witt, Gene D. Nutter: *Theory & Practice of Radiation Thermometry*, John Wiley & Sons, Inc. 1988
[3] B. Lawton, G. Klingenberg: *Transient Temperature in Engineering and Science*, Oxford Science Publications, 1996
[4] G. W. Burns. *The Calibration of Thermocouples and Thermocouple Materials*, U.S. Goverment Printing Office, April, 1989.
[5] M. Pohl, B. Blagojeviæ, I Bajsiæ: *The Immersion Length of a Platinum Resistance Sensor*, *Proceedings of the forth Electrotechnical and Computer Science Conference ERK 95,* Vol. A 511-514, Portorož , Sept. 1995, Slovenia.

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