

## TEMPERATURE FIELD SHAPING IN SYSTEMS FOR THERMOMETRIC SENSORS CALIBRATION

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*Abstract: For the thermometric sensor calibration by the method of comparison in the range of 300°C to 1300°C a uniform temperature field should be maintained in a metal insert for each temperature level selected. The insert containing measurement pockets is located in a tubular electric furnace. The functionality of calibrating system pertaining to the time of measurement requires appropriate dynamic properties of electrothermal system. To get a suitable static temperature field in the measurement insert some real electrothermal systems of similar class were investigated and the results have been augmented with a 3-dimensional computer simulation of a tubular furnace with an insert. To obtain good dynamic properties during the calibration temperature changes a predictive controller of the insert temperature was used. The obtained accuracy enables precise calibration of industrial thermometric sensors.*

*Keywords: thermometric sensors, calibration, temperature field modelling, control*

### 1. INTRODUCTION

Tubular furnaces are frequently used for the calibration of thermometric sensors by comparison method in the range of 300°C to 1300°C. The accuracy required for the sensors of Class 1 of Type S (Pt-PtRh10%) for 1000°C is 1 K, so the supported accuracy should be reasonably better. For the horizontal tubular calibration furnace Model 9112 made by Hart Scientific, the uniformity of temperature distribution for 1000°C is  $\pm 0.25^\circ\text{K}$ , while in the Pegasus' device with a vertical furnace of Isotech the real accuracy is worse than 2 K [7].

This work concerns, among the others, the investigations of static temperature field in a solid insert (a solid metal block) situated in a horizontal tubular furnace. More precisely it concerns the physical electrothermal systems designed on the basis of computer modelling that took into consideration three forms of heat exchange inside the furnace: conduction, convection and radiation. Considering the range of working temperature (300°C to 1300°C) the radiation plays an essential role in the exchange process, as its intensity depends on the fourth power of the absolute temperature. In order to determine the heat exchange by radiation it is necessary to find the angle dependant coefficients for each combination of all discrete surfaces inside the furnace chamber containing the insert. The insert itself not only obstructs the radiation heat exchange by shielding, but also by its eccentric location deforms the temperature field in the insert.

Another important problem of the insert temperature field shaping is the process dynamics. As we take into consideration the calibration of industrial sensors in rather wide scale, the setting time for each of the temperature calibration points is significant. By control of the heater temperature only, the temperature setting with appropriate accuracy can take longer than an hour for each temperature point, which much reduces the system throughput. This paper describes a predictive temperature control of the insert, based on the measurements of both the insert temperature as well as that of the heater.

### 2. STATIC MODEL

Fig.1 shows an outline of a tubular electric furnace used for calibration. The furnace is equipped with a heater of variable power concentration along the furnace axis. There is a metal insert inside with pockets containing both the examined sensors and a reference sensor.

The temperature all over the insert should be possible uniform for the whole range of working temperature, i.e. 300°C-1300°C. Particularly, the temperature differences should be kept lower than 0.1 K within the part of the insert containing the junctions of the thermocouples, and the temperature gradient along the insert axis should not exceed 0.5 K/cm on a distance at least 5 cm. To design a furnace like this we resorted to the computer modelling of a thermal system illustrated in Fig.1.

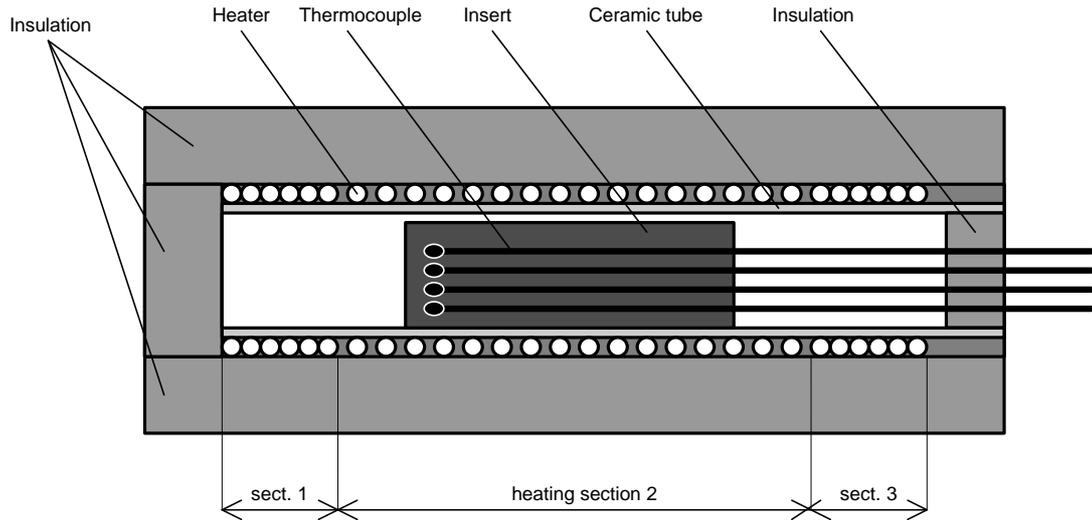


Fig.1. Scheme of furnace with insert

There is a wide choice of professional software available, intended for the temperature distribution calculations, as for example QUICKFIELD, FLUX, NISA, OPERA, or PROFI. Taking into consideration a possibility of calculations of the radiation heat exchange with regard to multiple reflections, we have chosen the NISA programme of Engineering Mechanics Research Corporation from USA [1] that employs the finite element method.

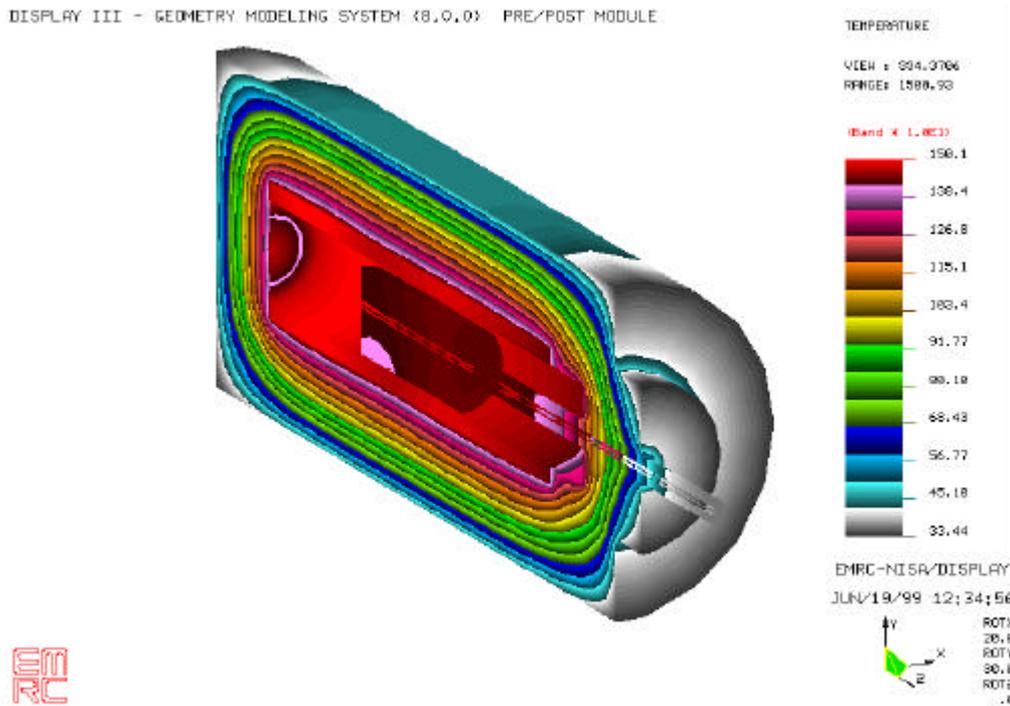


Fig.2. Temperature distribution in the furnace

The furnace with an insert (Fig.1) was modelled in 3 dimensions and we divided its body into 20000 finite elements [2]. Fig.2 shows an initially calculated temperature field in a cross-section of the furnace with a measurement insert at 1000°C (the picture scaled in Kelvin degrees). Fig. 3 presents the temperature field on the insert surface at the set temperature about 600°C. The irregularity of temperature reaches 0.8 K in the vertical axis of the front surface on the side of the pockets, while on the opposite surface it does not exceed 0.1K, and along the insert axis it is 1.4K. Considering these results we redesigned the furnace heating system, changing the power distribution among the heater sections. The correction resulted in a significant improvement, and we obtained a satisfactory temperature distribution in the area where the junctions of the thermocouples were located.

DISPLAY III - GEOMETRY MODELING SYSTEM (8.0.0) PRE/POST MODULE

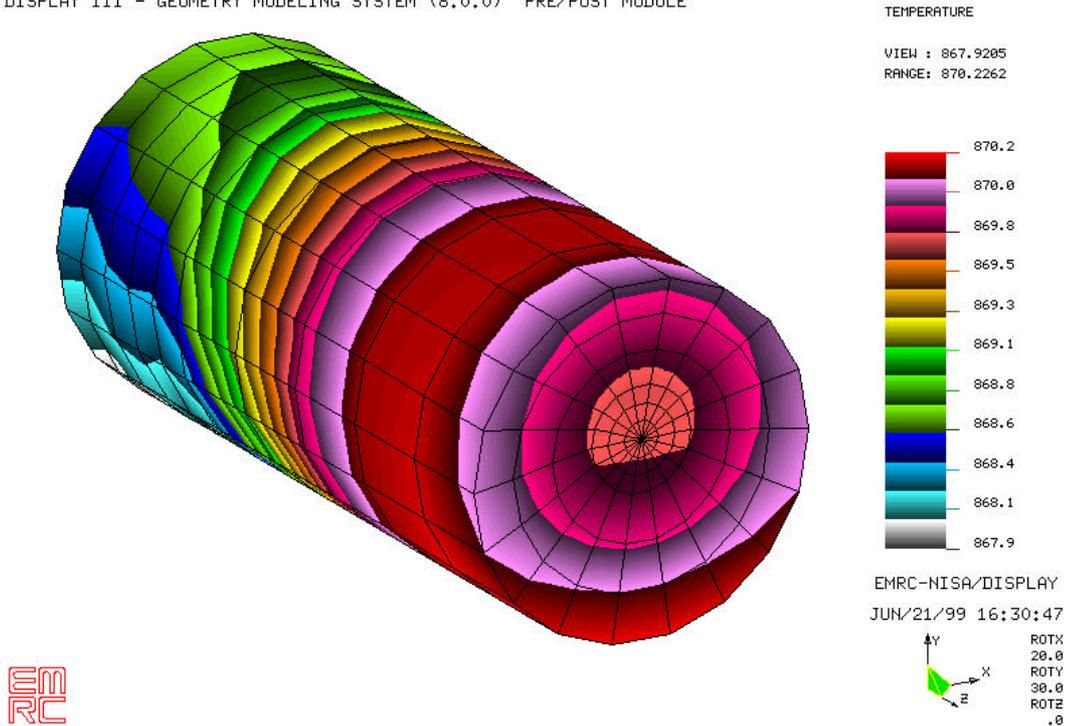


Fig. 3. Temperature distribution in the insert

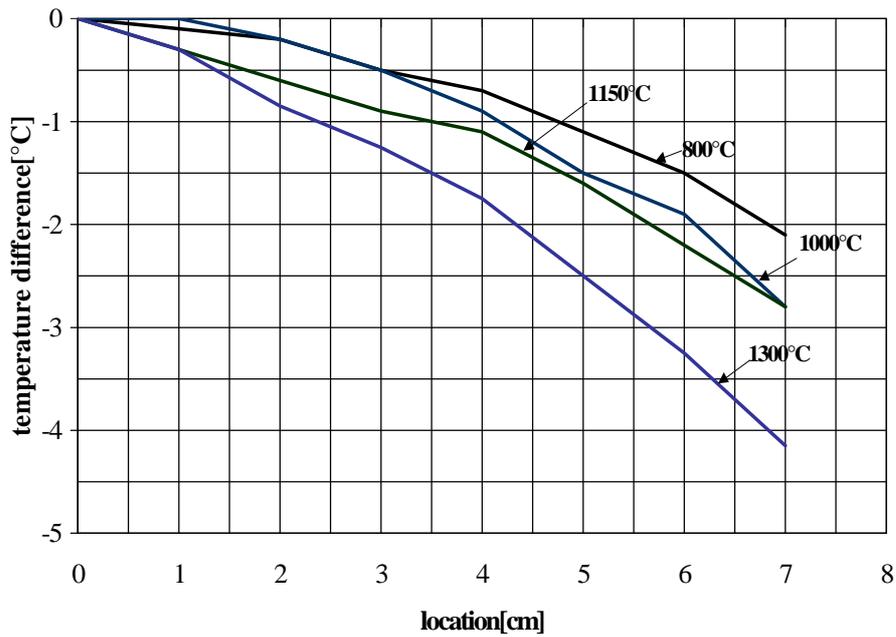


Fig. 4. Temperature distribution in Kanthal insert. The furnace plugged with a 100 mm thick insulation

Fig. 4 and 5 show the temperature field in the measurement insert – after the heater correction. Fig. 4 shows the temperature change along the middle pocket in the measurement insert (which altogether has 9 pockets of two different diameters). Fig. 5 shows the difference of temperature between the uppermost and the lowest pocket of the insert versus the distance from the respective pocket's bottom. It can be concluded that the combination of experimental investigations with computer calculations enabled us to obtain the static temperature distribution in the measurement insert compatible with the requirements.

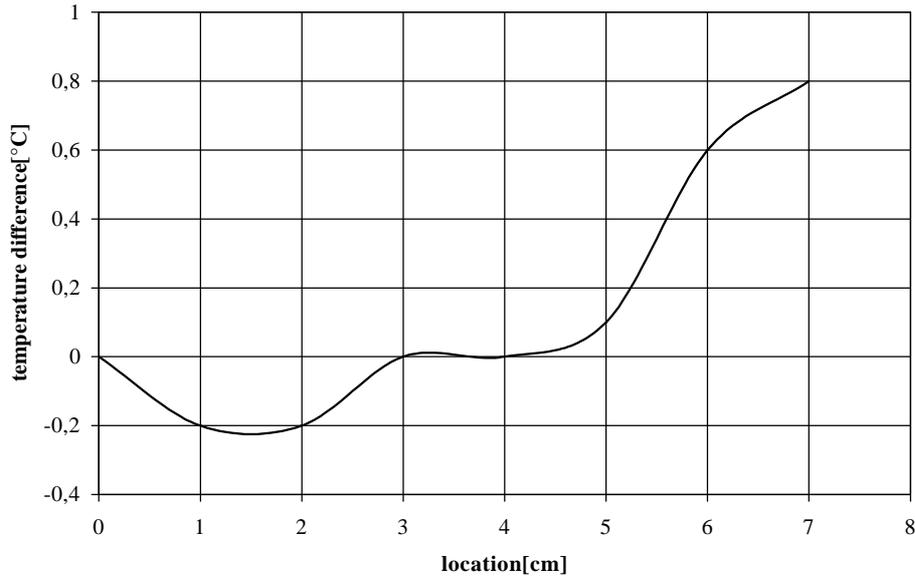


Fig. 5. Temperature difference between the top and the bottom pocket of the insert

The performed simulation and the measurements of physical systems enable to solve many problems associated with thermal system designing at the requirements difficult to satisfy, concerning the thermal field configuration in some working areas. For example it is possible to find solutions to the following problems:

- To find the influence of the material parameters and of the components geometry on the temperature field in the whole furnace, especially in the measurement insert,
- To determine the power distribution among the heater sections,
- To minimise the number of sections individually controlled,
- To find the optimal location of measurement insert in the furnace chamber,
- To determine the influence of 'thermal bridges' caused by the sensors inserted from outside into the measurement insert and by the probes of the control system. That effect is brought about by the wires of electrical connections going outside.
- To determine the furnace parameters necessary for the control system design,
- To investigate the influence of the material parameters and of the geometrical arrangement on the process dynamics – which requires a simulation of transient processes.

#### 4. TEMPERATURE CONTROL

For the temperature stabilisation of a measurement insert containing sensors and placed inside a reactor a predictive control is used [3,4]. This type of control is based on a plant model with delays and on dynamic programming [5,6].

The solution for the optimal predictive control of the described plant is based on both the actual and some earlier values of the heater temperature, the actual values of insert temperature and earlier values of heating power [5]. The previous values of the control vector and those of the heater temperature vector represent nonobservable variables of the state vector. The optimal control gain matrix for such a plant has usually very large dimensions. The use of nonobservable variables and large gain matrix leads to difficulties during practical implementation of such a type of control.

Because of this inconvenience a suboptimal control is used instead of the optimal. The suboptimal control in question is based on the observable variables only. The gain matrix in such a case is significantly smaller than that of the optimal [6]. Generally the predictive control of insert temperature in the furnace for thermometric sensors calibration can be described as a sophisticated form of cascade control.

As the criterion for calibration measurement commencement, the temperature drift of the insert (measurement block) lower than 0,2°C/10min was chosen. Investigated system had a single heater with sections of different power density. The block temperature was measured in the central insert pocket. For the predictive control the measurement start criterion was met after 41 minutes from the moment when the furnace temperature reached 1000°C, while the drift was still about 0.4°C/10min, after 100 minutes for the traditional control.

It can be seen that the predictive control much reduces the measurement time, which for example at 4 temperature levels was as long as 11 hours for the examined case. Additionally the predictive

control gives much better steady state temperature stability, because this arrangement better reacts to the block temperature fluctuations (for instance caused by changes in surroundings).

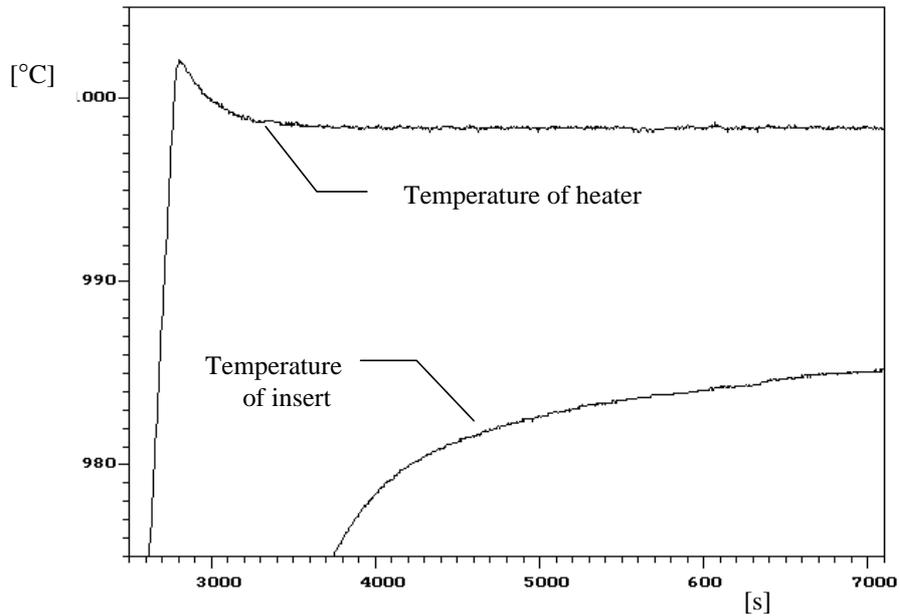


Fig. 6. Temperature stabilisation of insert during conventional control of heater temperature only

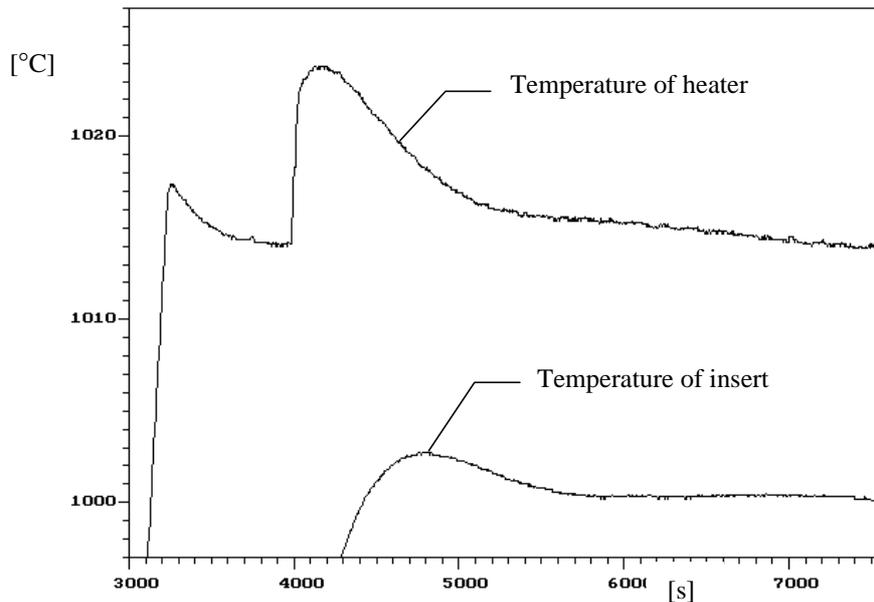


Fig. 7. Temperature stabilisation of insert during predictive control

## 5. SUMMARY

An accurate computer modelling of 3-dimensional thermal fields was used to design a furnace intended for the thermometric sensor calibration. It enabled us to investigate the influence of material parameters and model geometry on the temperature field in the furnace, and particularly on the field in the measurement insert. Having done that we were in the position to undertake rational decisions on the furnace design and its optimisation. The results of calculations have been fully supported by the tests of a physical model designed on the basis of the calculations.

A predictive controller of the measurement insert temperature was used to ensure good dynamic properties during the changes of the calibration temperature. The controller design is based on a plant model with delays and on dynamic programming.

The obtained uniformity of the static thermal field in the insert and short temperature setting time during the calibration temperature changes afford exact and effectual calibration of the industrial thermometric sensors.

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