Simulation of Thermal Processes in High-Temperature Blackbodies and Fixed-Point Cells for Improving their Characteristics

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The finite element method (FEM) has been applied to develop a model of a high-temperature blackbody (HTBB) for simulation of thermal processes and the temperature distribution in HTBB and high-temperature fixed points (HTFPs) installed in HTBB as a furnace. This simulation instrument is being applied for further improvement of HTBB and for clarifying the parameters of HTFPs used in HTBB.

INTRODUCTION

25 year ago, the first high-temperature blackbody (HTBB) was developed at VNIIOFI and applied as a standard radiometric source [1]. Later, HTBBs were supplied to 15 National Metrology Institutes and used at national standard facilities for spectral irradiance and spectral radiance realization, as well as for photometry and radiation thermometry applications.

Unique HTBB parameters, such as wide operating temperature range (up to 3500 K), large radiating cavity, high stability, uniformity, and emissivity make it the best planckian metrological source and a convenient furnace for high-temperature fixed points (HTFPs) [2]. However, further improvement of HTBB is desirable in order to increase the emissivity and/or decrease its uncertainty, which is currently estimated as about 0.9995±0.0005. The HTBB emissivity significantly depends on temperature uniformity of the radiating cavity. Therefore, the HTBB design should be modified in such a way as to improve the uniformity. Experimental investigation of influence of possible modification to the uniformity and, therefore, the temperature distribution in the HTBB elements is quite difficult (or in some cases impossible) due to high operating temperatures.

This paper presents a computer simulation of thermal processes in HTBB, which takes into account the furnace geometry and the physical properties of the materials used. The model allows computing the temperature distribution in the HTBB (along the radiating cavity walls, heat shield, and other parts) for two cases: the stationary case (when the HTBB temperature is stable – the usual blackbody regime) and the dynamic case (when the temperature is increasing or decreasing). The latter is applied to simulate the melting and freezing processes of HTFPs.

SIMULATION OF HTBB

HTBB has a cylindrical heater formed by a stack of graphite rings, which is heated by electrical current passing through the rings. The heater and a surrounding heat shield, made of graphite and carbon felt, are assembled horizontally in a stainless-steel water-cooled cylindrical housing. The space between the furnace construction elements is filled with argon gas.

The model of HTBB is purely axis-symmetrical. Although it ignores gravity effects, it still captures the most important features of the process.

The finite element method (FEM) [3] is used to solve numerically the stationary equations for electric heating and heat transfer, thus computing the temperature field in the HTBB model. The model takes into account electrical resistivity, thermal conductivity and specific heat capacity of the materials used depending on temperature. Heat radiation is taken into account as a boundary condition for all furnace surfaces. The emissivity of graphite is taken equal to 0.85, wavelength independently.

Fig.1 shows the cross-section of the HTBB model with computed temperature distribution (presented in colours) in the stationary case at the cavity temperature of 3000 K.

The simulation is being applied to improve HTBB, namely to find a way of such modification of HTBB design and the parameters of the heater and heat shield materials, which allows improving the temperature uniformity of the blackbody radiating cavity and, thus, increasing the emissivity and/or more accurate determining of the emissivity uncertainty.

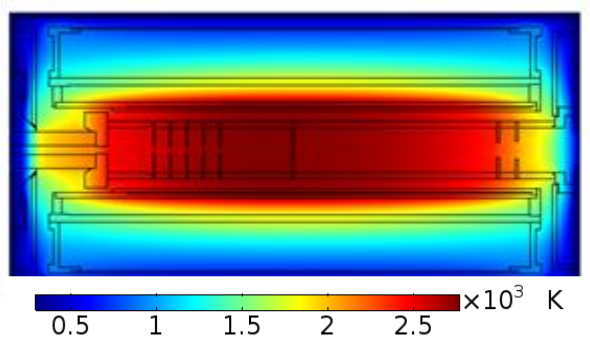

Figure 1. Computed temperature distribution in HTBB.

SIMULATION OF HTFP

When simulating the HTFP transition experiment the model includes only the heater and the HTFP cell itself excluding other parts of the furnace. The temperature distribution along the heater outer surface (see above) is treated as a boundary condition. To simulate a melting plateau the heater temperature is slowly increased by certain step, linearly in time.

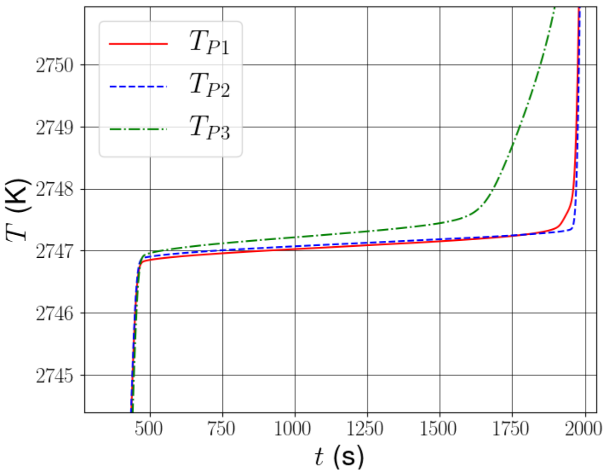

Figure 2. Melting plateaus of Re-C cell in point P1, P2 and P3 shown in Fig.3.

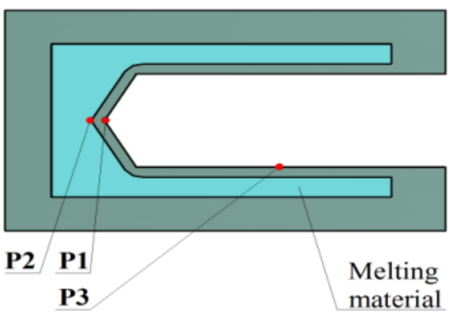

Figure 3. Diagram of HTFP cell

Phase transition is simulated as an additional specific heat of the melting material in a narrow temperature range around the melting point. The value of the range is varied around 1 K in different simulations. Difference in specific volume of solid and liquid phases is neglected, assuming equal densities at the melting point.

Fig. 2 presents melting plateaus computed for a Re-C cell in the points P1, P2 and P3 shown in Fig.3. The difference between the points P2 and P1 is the “temperature drop”, and the difference between P3 and P1 indicates the temperature gradient along the cavity wall. The shape of computed the curves and the temperature differences depends on uniformity of the temperature field around HTFP. Therefore, varying the temperature profile or the position of the cell in the furnace, one can investigate their influence on the cell characteristics.

The simulation is being used as an instrument to investigate the temperature drop effect in HTFP cells and the temperature gradient along the cell cavity, and for optimising the thermal conditions for the cells.

CONCLUSION

A model of a high-temperature blackbody (HTBB) based on finite element method (FEM) has been developed for simulating thermal processes and temperature distribution in HTBB and HTFPs. This simulation instrument is being applied for further improvement of HTBB uniformity and, therefore, more accurate determination of the emissivity. Another application is investigation of HTFP cells conditions and characteristics, in particular better evaluation of the temperature drop correction and its uncertainty.

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