Consistency of radiometric temperature measurement with a local realization of the ITS-90 from 1700 °C to 2900 °C

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Abstract. We measured temperatures of a blackbody with a filter radiometer to confirm the consistency of radiometric temperature measurement with the local realization of the ITS-90 at KRISS from 1700 °C to 2900 °C. The resulting temperature differences are within a range from 1 °C to 2 °C, which is less than the measurement uncertainty as well as our calibration and measurement capability of luminous intensity that is 0.5 % (k = 2) at 2900 °C.

I. Introduction

Since high temperature blackbodies were used as the spectral radiance and irradiance sources for spectro-radiometer calibration, several NMIs compared filter radiometer measurements with the international temperature scale ITS-90 using blackbodies [1-3]. Measurement of the thermodynamic temperature of blackbodies with a filter radiometer enables us to confirm its consistency with the ITS-90 and to establish a detector-based irradiance scale [4]. Although the filter radiometry requires more advanced realization technique, it can reduce errors caused by the extrapolation of the ITS-90 above 1084.62 °C. Furthermore, if the ITS-90 and the filter radiometry are realized simultaneously within one laboratory, a high level of confidence in the radiometric scale as well as in the ITS-90 can be achieved by periodic comparison [2].

In this paper, we present the comparison results of the ITS-90 with radiometric temperature measurements at a high temperature blackbody from 1700 °C to 2900 °C. The difference between the two measurement methods is discussed considering the major uncertainty components of the radiometric temperature measurement and the ITS-90 realization in KRISS.

II. Experimental setup

The experimental setup consists of a high temperature blackbody, a filter radiometer, and the KRISS reference pyrometer, as shown Fig.1. A graphite tube with an inner diameter of 36 mm and a length of 280 mm acts as a heating element in the blackbody (Thermogage). The aperture of the graphite tube is limited by a blackbody aperture with a diameter of 6 mm. The radiometer and the pyrometer are installed on a linear translation stage. The filter radiometer is a photometer supplied by LMT with a temperature controller. An external precision aperture is installed to define the active area size of the radiometer. The size of the precision aperture is measured by the laser spot scanning method [5] with a relative uncertainty of $8{\cdot}10^{-5}$. The distance between the radiometer aperture and the blackbody aperture is fixed to 1 m. The distance of the pyrometer from the blackbody is adjusted so that the pyrometer has the same field of view as the radiometer.

The pyrometer has two spectral bands determined by interference filters with a bandwidth of 10 nm at a peak wavelength of 650 nm and 850 nm, respectively. With the 650-nm filter, an additional band suppression filter (CVI KG5) is used to reject the possible leakage light at longer wavelengths [6]. At both spectral bands, the pyrometer is scaled in reference to a copper point blackbody according to the definition of the ITS-90.

The absolute spectral responsivity of the radiometer is measured from 360 nm to 825 nm by the Spectral Responsivity Comparator (SRC) at KRISS. A trap detector (QED-200, Grasby Optronics) and a pyroelectric detector used as a transfer standard in the SRC are calibrated against the KRISS absolute cryogenic radiometer. The relative standard uncertainty of the radiometer is 0.3 % in terms of the illuminance responsivity.

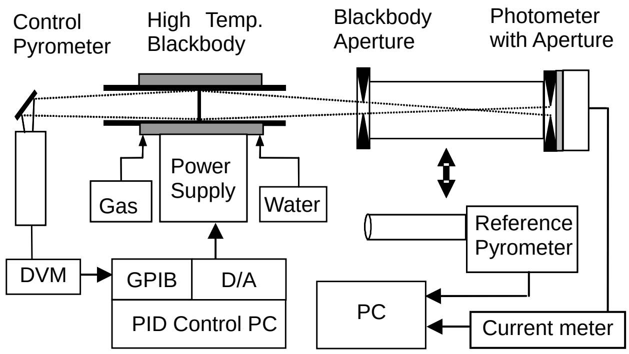

Figure 1. Schematic diagram of experimental setup for comparison between the detector-based radiometric temperature measurement and the source-based ITS-90.

III. Results

Temperature measurement is performed at each temperature setting after confirming stabilization of the blackbody with the reference pyrometer. The pyrometric temperature at each setting is determined by taking an equally weighted average of temperatures obtained with the two spectral bands.

Temperatures measured by the filter radiometer are calculated from the simplified equation [3]

$$I_D = G\,\varepsilon \int_0^{\infty} S(\lambda)\,L(\lambda,T)\,d\lambda$$

, where the photocurrent I_D is given by an integral of the blackbody radiance $L(\lambda,T)$ multiplied with the absolute spectral responsivity of the radiometer $S(\lambda)$. The geometric factor G is given by the aperture areas and the distance between the apertures. The blackbody emissivity ε is assumed to be unity.

Figure 2 shows the temperature difference between the local ITS-90 realized by the pyrometer and the filter radiometric measurement in a temperature range from 1700 °C to 2900 °C. The differences lie in a range from 1 °C to 2 °C. Even if the ITS-90 is smaller that the radiometric measurement, the differences are less than the comparison uncertainty (k = 2) denoted by the error bars in Fig. 2. Furthermore, the comparison shows that the relative difference of the radiometer and the ITS-90 at 2900 °C in terms of the illuminance responsivity is less than 0.5 %, which is declared in our calibration and measurement capability (CMC) of the luminous intensity.

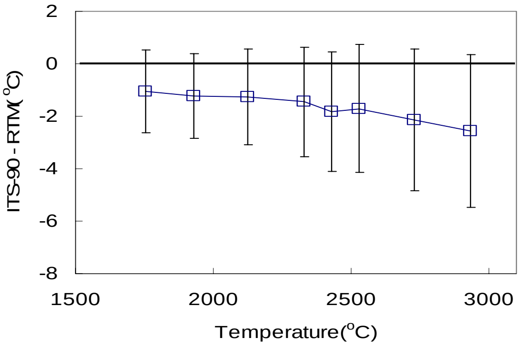

Figure 2. Temperature difference between the ITS-90 and the radiometric temperature measurement (RTM) at different temperatures.

Table 1. Uncertainty budget of comparison of the ITS-90 and the radiometric temperature measurement at 2700 °C.

Sources	Components	Uncertainty (°C; k=2)
the ITS-90	Temperature scale	0.68
Radiometric temperature measurement	Spectral responsivity	1.07
	Infrared leakage	0.17
	Distance	0.35
	Blackbody aperture	0.05
	Radiometer aperture	0.04
	Signal measurement	0.02
Comparison using blackbody	Stability	0.1
	Uniformity	0.15
Combined uncertainty (k=2)		2.1

To understand the difference and draw out ideas to improve the consistency, the comparison uncertainty at 2700 °C is evaluated as shown in Table 1, where the uncertainty from the ITS-90 realization, the radiometric temperature measurement, and the comparison process using the blackbody are considered. The uncertainty of the ITS-90 is estimated by the local realization of the ITS-90 and the measurement deviation of the two spectral bands of the pyrometer. Taking the uncertainty components such as the cooper fixed point blackbody, and the spectral characteristics, non-linearity of the pyrometer into account according to the standard method described in the reference [7], we estimated the ITS-90 realization uncertainty. The expanded uncertainty (k=1) increases from 0.1 °C at the copper fixed point to 0.7 °C at 3000 °C.

The uncertainty of the ITS-90 is smaller than that of the radiometric temperature measurement, in which the spectral responsivity uncertainty is the dominant uncertainty component. Although the temperature differences shown in Fig. 2 are within the error bars, the uncertainty evaluation seems to be somehow optimistic. A systematic error might be mainly related to our lower assignment in scaling the spectral responsivity and the illuminance responsivity, which is observed also in the key comparisons such as CCPR-K.2.b [8] and CCPR-K3.b.2 [9]. Additionally, since the silicon-based photometer can response up to 1100 nm and the spectral emission of the blackbody is more dominant in the infrared, the calibration range of the radiometer spectral responsivity needs to be extended. The uncertainty of the infrared leakage in Table 1 is estimated by assuming a uniform leakage in the order of 10^{-6} from 825 nm to 1100 nm. The infrared leakage uncertainty become more significant as the temperature deceases, resulting in 0.5 °C at 1700 °C. We expect that an improvement in the spectral responsivity measurement of the radiometer can resolve the systematic error below 2600 °C. Above 2600 °C, however, we address the pyrometer linearity as an important correction factor to be considered, which has been only measured below the irradiance level corresponding to 2600 °C.

IV. Conclusion

Consistency of radiometric temperature measurements with the local realization of the ITS-90 at KRISS is confirmed by comparing the blackbody temperatures measured with a reference pyrometer and a filter radiometer in a range from 1700 °C to 2900 °C. The differences are within 2 °C, which is less than the measurement uncertainty as well as our calibration and measurement capability of luminous intensity that is 0.5 %. More accurate calibration of the spectral responsivity of the radiometer in the IR range up to 1100 nm is expected to resolve the systematic error below 2600 °C. Above 2600 °C, it is necessary to check nonlinearity of the pyrometer.

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