CALIBRATION OF STANDARD LAMPS IN COLOR TEMPERATURE

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Abstract: Calibration of standard lamps in Color Temperature with uncertainty in the 20 K range can be performed conveniently with commercially available diode array spectrophotometers. The calculation methods are compared for both, the distribution temperature and the correlated color temperature. Experimental results for a Fel lamps and tungsten filament lamps are presented. The spectral distribution can be modeled considering bulb transmittance, tungsten emissivity and the thermodynamical filament temperature

Key words: color temperature, distribution temperature, correlated color temperature

1. INTRODUCTION

Tungsten filament lamps, as well as tungsten-halogen lamps, are widely used as transfer standards for "color temperature", as an alternative to black body artifacts, which are difficult in handling and are also rather costly to operate. Filament lamps under controlled current operation are reliable over long storage times and, therefore, are widely used for calibration purposes of photometers and colorimeters.

The calibration of standard lamps in color temperature (CT) is accomplished by essentially by two methods, both relying on spectral measurements, that is, the relative power distribution (SPD) of the lamp has to be measured. Once the SPD is known, two different evaluation procedures allow for determination of the "color temperature". One method leads to the concept of correlated color temperature-(CCT)- [1,2], T_{CCT} and the other to the concept of the distribution temperature-(DT)-[3], T_{DT}. Strictly speaking, T_{CCT} and T_{DT} will take the same value, only in the case, of the lamp exhibiting a SPD of an ideal Planckian radiator. However, for SPDs deviating not too far from that of a Planckian distribution, slightly different values are expected for T_{CCT} and T_{DT}. The difference between T_{CCT} and T_{DT} will depend on the individual SPD of the lamp under consideration. The SPD is measured with a diode array spectroradiometer for two kind of standard lamps, a tungsten filament lamp of the Osram Wi41G type and a Sylvania tungsten halogen Fel lamp. The color temperature for both methods has been evaluated and is compared.

2. Experimental

When a filament lamp is operated at controlled constant current, the tungsten filament reaches a steady state temperature T_{fil}, typically in the 2000 to 3000K range. Thus, the spectral power distribution function (SPD) of the radiation emitted by the tungsten filament is that of a grey emitter. The SPD for given T_f will be proportional to $\varepsilon(\lambda,T_{fil})*S_{bb}(\lambda,T_{fil})$, where $\varepsilon(\lambda,T_{fil})$ stands for the emissivity of the tungsten filament and $S_{bb}(\lambda,T_{fil})$ is the spectral distribution of the black body radiation, as given by Planck´s law, and for the purpose of color temperature calculations is considered in the spectral range from 380nm to 780 nm.

Furthermore, the SPD of the filament may be altered in transmission through the glass envelope of the bulb. The spectral transmittance will depend on the glass type of the bulb and on the presence of a blackening tungsten film internal to the bulb. New tungsten filament standard lamps undergo, in general, an aging period of about 100 hours before calibration. For tungsten-halogen lamps, such as Fel lamps, however, this blackening effect is absent, since the evaporated tungsten in these lamps is readily removed from the hot wall due to the reactive halogen-tungsten cycle, thus, leaving the quartz envelope clean.

Spectral transmittance measurements, conducted by this laboratory, through five previously aged WixxG lamps, not being powered, have shown remarkable different spectral transmittances, thus revealing that the SPDF of these filament lamps will not the same as by the filament alone. Thus the SPDF of a WiG lamp can be modeled according to:

$$S_n(\lambda) = \kappa * \tau(\lambda) * \varepsilon(\lambda,T_f) * S_{bb}(\lambda,T_f), \qquad (1)$$

where, $\tau(\lambda)$ stands for the experimentally determined spectral transmittance through one glass wall of the bulb and κ is a normalizing constant, such that at λ=560 nm $S_n(560) = 100$. The emissivity of tungsten $\varepsilon(\lambda,T_f)$ can be calculated with an analytical expression [4] based on the experimental data from De Vos [5].

Once $S_n(\lambda)$ is determined experimentally, T_{CCT} and T_{DT} are calculated, in order to determine the "Color Temperature" of the lamp, which of course, are found to be

quite different from T_{fil}. For the tungsten filament lamps we use the model equation (1) to find the T_f value in order to reproduce the experimentally measured power distribution $S_n(\lambda)$.
In figure1 is shown the ratio of the measured SPD and the the Planckian-SPD at 2856 K of a Wi41G lamp. The lamp`s current was adjusted such that T_{CCT} was 2856 K. Calculated T_{DT} was found to be 2852.

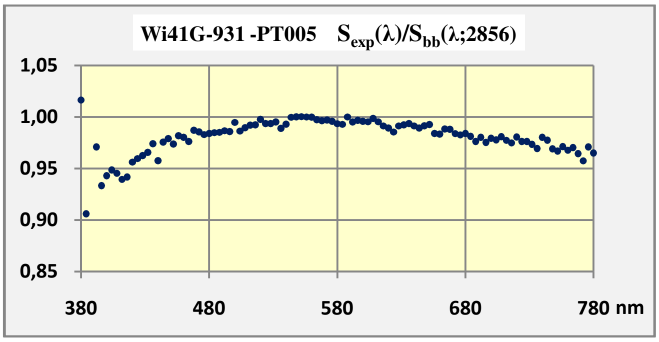

Fig.1 Experimental SPD showing the deviation from perfect Planckian Radiator at 2856 K: T_{CCT} = 2856K; T_{DT} = 2852 K

Figure 2 shows the expected SPDF of the same lamp, taking into account the measured spectral transmittance of the glass envelope and the tungsten emissivity. The calculated T_{CCT} = 2856 K and T_{DT} = 2855 K, when the filament temperature is chosen to be at 2800 K.

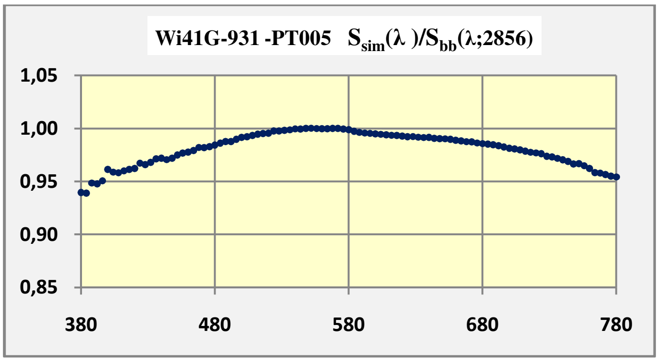

Fig.2 Simulated SPD for filament temperature at 2800K, yielding an effective T_{CCT} of 2856 K.

Tungsten halogen lamps of the Fel type present a closer spectral approximation towards a Planckian distribution. In order to show this a Fel lamp was chosen, which was calibrated at Nist in color temperature for 2856 K. Once again the ratio of the spectra of the Fel lamp and the black body are plotted versus wavelength as shown in Fig 3. This demonstrates that the SPD of Fel lamp is a better approximation to a black-body radiation.

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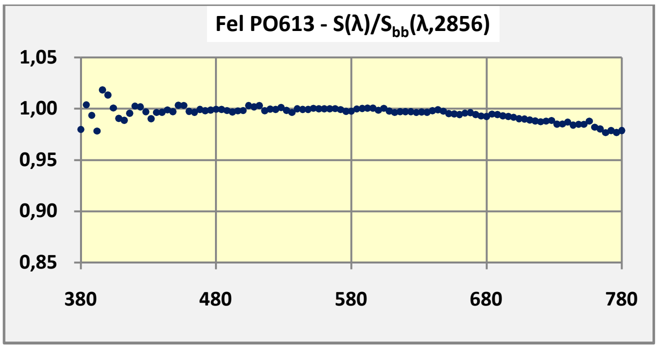

Fig.3 Experimental SPD of Fel PO613 lamp shows close agreement with a Planckian Radiator at 2856 K.

Results and Discussion

In the table below, we summarize our results for two standard lamps, a calibrated Fel lamp purchased from Nist and a Wi41G-931 recalibrated at PTB.

Artifact	Certificate [K]	T_{DT} [K]	T_{CCT} [K]
Fel-PO613	2856 ± 8	2849 ± 19	2848 ± 19
Wi41G-931	2856 ± 7,2	2832 ± 19	2839 ± 19

Although our values are in fairly good agreement with both of the certified values, our result for the Wi41G stimulated further investigation. It was found, by analyzing the SPDs from this and other four similar lamps of the Wi41G type, that their SPDs deviate consistently in the lower part, λ<440 nm, and also in the higher part of the spectrum, λ>680 nm, from a blackbody distribution. For the midrange of the spectrum, however, a good fitting with a 2856K Planckian distribution is found. According to the calibration certificate for the Wi41G lamp, PTB uses the red-blue substitution method with a 2856K transfer standard lamp. Therefore, it is not surprising that our values of T_{DT} and T_{CCT} show larger deviation for Wi41G, than for the Fel-PO613. From the previous discussion of the blackening effect and spectral simulation one can conclude that Fel lamps produce a better Planckian distribution than Wi41G.

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