Two-color temperature diagnostic in Z-pinch dynamic hohlraum

Qiang Yi, Faxin Chen, Jianlun Yang, Rongkun Xu, Zeping Xu

Institute of Nuclear Physics and Chemistry, China Academy of Engineering Physics,
Mianyang, 621900, China

Introduction

Z-pinch dynamic hohlraum (DH) is one of the most promising approaches to generate high energy density X-ray to be applied in inertial confinement fusion, radiation physics and opacity measurements. The quality of the hohlraum radiation field can be characterized by radiation temperature. Brightness temperature provides an integration of the radiation power spectrum over a whole photon energy range, while color temperature is a characteristic quantity of the spectrum shape, which can give the spectrum intensities at different photon energies, providing more insights about the blackbody radiation filed. This paper will be focused on some theoretical and design considerations about the color temperature measurement.

This work was designed for the upcoming experiments on the Julong-1 facility in China with a peak current of about 8 MA and a rise time of about 70 ns. The color temperature of the DH will be measured by two-color method, where the ratio of the fluxes of the power spectrum integrated in two different energy bands is used to infer the temperature.

Experimental setup

One beamline configuration of the experiment can be seen in Fig. 1. The dynamic hohlraum is regarded as a blackbody radiation source. An aperture is used to limit the field of view. Multilayer mirror is chosen as the reflective optics element to reflect soft X rays to a scintillator plate, where X rays are absorbed and visible lights are emitted, which will be finally detected by the photomultiplier. A few beamlines need to be planned for X rays at some different wavelengths. The material combination, $d$-spacing, thickness ratio of the absorption layer to $d$-spacing, bilayers and incidence angle of the multilayer mirrors will be elaborately selected and optimized using IMD software [1, 2].

![Fig. 1 Schematic of one beamline of the color temperature measurement system.](image-url)
Spectral power and detector dynamic ranges

The absolute spectral power of the DH radiations is calculated from the Planck formula expressed as follows [3],

\[ I_p(E_v, T_r) = \frac{2e^4 \kappa^2}{h^3 c^2} \left[ e^{(E_v/T_r)} - 1 \right]^{-1} \left[ \text{w/m}^2/\text{Sr/ eV} \right] \quad (1) \]

Fig. 2 has shown the calculation result of the spectral power at radiation temperature, \( T_r \), of 50 eV, 100 eV, 150 eV and 200 eV. The two shadow bands have shown the flux at different central wavelengths. In order to display the dynamic range of the power needing to be measured, the relative spectral power at photon energy of 1000 eV, 1150 eV, 1250 eV and 1350 eV have also been shown in Fig. 3. It can be seen that absolute flux in a band can be changed by \( \sim 10^6-10^7 \), while the flux ratio has only changed no more than 10. So the dynamic range of the detectors has to be considered as an important influence factor during the measurement.

\[ S = \frac{dR}{dT_r} \quad (2) \]

Fig. 2 (a) Absolute Plankian spectral power at four radiation temperatures; (b) Relative spectral power at four photon energies

Energy bands selection and sensitivity

The energy bands selection is one of the most important questions during the spectrometer design, as the flux ratio may be sensitive to different radiation temperature ranges which are actually unknown. To overcome this difficulty, four energy bands are selected to form six kinds of combinations with each one fit for a temperature range, finally realizing a full cover of the possible temperature scope. Every combination is firstly selected by the maximum flux ratio sensitivity as shown in Fig. 3, which is defined as the derivative of the flux ratio to temperature, i.e.,

\[ S = \frac{dR}{dT_r} \quad (2) \]
The analytic expression of sensitivity determined at wavelength $x$ and $y$ can be calculated as

$$ S = \frac{y^4 e^{y/T_r} e^{(x/T_r-1)} x^2}{T_r^2 x^4 (e^{y/T_r-1})^2} - \frac{y^3 e^{x/T_r}}{T_r^2 x^2 (e^{y/T_r-1})^2} $$

During this calculation, the photon energy range is selected as 1000 eV-2550 eV. According to the principle of maximum sensitivity, 1000/1150 eV is selected as the best couple for $T_r$ =100 eV, 1000/1250 eV is selected as the best couple for $T_r$ =150 eV and 1000/1350 eV is selected as the best couple for $T_r$=200 eV. In order to select the optimal energy band after a compromise with the dynamic range of the detector system, the sensitivity results of the six energy band combinations are displayed in Fig. 3.

**Uncertainty theorem and analysis**

The derivation of $T_r$ is mainly dependent on the flux ratio. A ratio curve of flux centered at 1000 eV and 1150 eV versus $T_r$ is calculated and shown as the black line in Fig. 4. As an uncertainty of 10% is accepted in the measurement of flux ratio, so lower ratio curve of 0.9 fold and a higher ratio curve of 1.1 fold of the truth value have also been depicted in this figure as a comparison. It can be seen if the flux ratio deviates from the truth value, the $T_r$ determined would be also deviating from the right value. In detail, when the measured flux ratio is lower than the truth value, as we don’t know this fact and we still derive $T_r$ from the black line, then we’ll obtain a lower temperature of $T_{r1}$. In turn, when the measured flux ratio is higher than the truth value, as we still don’t know this fact and we’ll still derive $T_r$ from the black line, then we’ll obtain a higher temperature of $T_{r2}$. So we can define the uncertainty as $R = \frac{T_{r1}-T_r}{T_r}$. 

![Fig. 3 Sensitivity of the flux ratio to radiation temperatures](image-url)
Fig. 4 The uncertainty origin of color temperature

According to this theorem, the absolute uncertainty of $T_r$ calculated using energy band of 1000/1500 eV is shown in Fig. 5(a) and the relative result is shown in Fig. 5(b). It can be found that the uncertainty of $T_r$ would not exceed 15% under an assumption of the measured flux ratio not more than 10%. It was also found that the change of the energy bandwidth would not affect the relative uncertainty of $T_r$ evidently.

Fig. 5 Absolute uncertainty (a), and relative uncertainty (b) of $T_r$.

Conclusions

Four energy points and six energy band combinations are selected according to the maximum sensitivity and proper dynamic range of detectors to determine color temperature of Z-pinch DH. An uncertainty of $T_r$ lower than 15% would achieved under an assumption of the measured flux ratio less than 10%.

Acknowledgement

This work is supported by the National Natural Science Foundation of China (11135007).

References