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In-situ calibration system for foil detector of infrared imaging video bolometer in Large Helical Device

LHDにおけるIRイメージングボロメータ用薄膜検出器のその場較正システム

Kiyofumi Mukai[1], Byron J. Peterson[1], Shwetang N. Pandya[2] and Ryuichi Sano[3]

向井清史[1]， Byron J. Peterson[1]， Shwetang N. Pandya[2]， 佐野竜一[3]

[1]*National Institute for Fusion Science, 322-6 Oroshi-cho, Toki-shi, Gifu 509-5292, Japan*

[1]核融合科学研究所 〒509-5292　岐阜県土岐市下石町322-6

[2] *Institute for Plasma Research, Bhat, Gandhinagar 382 428, India*

[3]*Graduate University for Advanced Studies, 322-6 Oroshi-cho, Toki-shi, Gifu 509-5292, Japan*

[3]総合研究大学院大学 〒509-5292　岐阜県土岐市下石町322-6

The InfraRed imaging Video Bolometer (IRVB) is a useful diagnostic from the viewpoint of multi-dimensional radiation measurement. The IRVB has a combination structure of a pinhole camera and an IR camera. A two-dimensional heat diffusion equation should be solved on a platinum foil detector to obtain the radiation profile from the temperature profile measured with the IR camera. Then, the calibration of the heat characteristics of the foil is essential. For the application of the measurement to the neutron environment in the Large Helical Device, the characteristics must be evaluated by in-situ calibrations. Therefore, in this study, an in-situ calibration system was designed.

1. Introduction

Plasma radiation measurement is a critical issue to investigate plasma detachment and radiation collapse phenomena in plasma fusion studies. Since the radiation mainly occurs in the plasma edge region especially outside the last closed flux surface where one cannot assume the uniformity of the radiation on plasma flux surfaces, multi-dimensional measurement is required. The IRVB is a powerful diagnostic [1-4] since a large number of channels is needed for the multi-dimensional measurement. In the Large Helical Device (LHD), four IRVBs have been installed with different Fields of View (FoVs, tangential, semi-tangential, vertical from top, and vertical from bottom) to measure the three-dimensional radiation profile using a tomography technique. When the IRVB measurement is applied to the plasma experiments using deuterium gas which are planned for LHD, its foil detector will be exposed to the neutron irradiation. Since the heat characteristics of the foil are essential parts of the measurement, the effect of the neutron irradiation on the foil characteristics should be investigated. Therefore, an in-situ calibration system is required to improve the IRVB measurement in the neutron environment. In this study, a calibration system was designed for the IRVB.

2. Schematic of the IRVB Measurement

Figure 1 shows the schematic of one of the four IRVBs. The IRVB mainly consists of a pinhole camera section and an IR camera section. The plasma radiation profile is projected through a 4 mm square aperture in the pinhole camera onto a 9 × 7 cm platinum foil detector with a thickness of 2.5 μm. The foil is blackened on both sides by carbon to increase the emissivity. The radiation profile is observed as a two-dimensional temperature distribution through a diffusion process. Then, this distribution is observed through a CaF_2 vacuum window from the back side by an IR camera as an IR image. The IR camera, FLIR/ SC7600 is installed inside a magnetic shield of soft iron with a thickness of 6 mm.

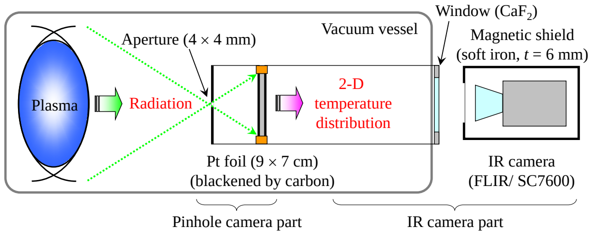

Fig.1. Schematic of IRVB

3. Two-Dimensional Heat Diffusion Equation

To obtain the plasma radiation, P_{rad}, from the temperature distribution on the foil, T, the two-dimensional heat diffusion equation shown in Equation (1) should be solved.

$$-\frac{P_{rad}}{kt_f l^2} + \frac{\varepsilon\sigma_{S-B}(T^4 - T_0^4)}{kt_f} + \frac{1}{\kappa}\frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}, \qquad (1)$$

Here, l^2 is foil pixel area, σ_{S-B} is the Stefan-Boltzmann coefficient and T_0 is background temperature. Then, the foil thickness, t_f, emissivity, ε, and thermal diffusivity, κ, must be evaluated for each bolometer pixel on the foil. For the thermal conductivity, k, the typical value of platinum is assumed since its variation can be included to the variation of t_f in Equation (1) by considering it as an effective value. These three parameters can be calibrated by laser irradiation of each bolometer pixel instead of the plasma radiation [5, 6].

4. In-Situ Calibration System for the IRVB Foil Detector in LHD

4.1 *Requirement for In-Situ Calibration System*

The calibration of the heat characteristics of the foil detector is one of the most essential issues for the IRVB measurement. However, the foil will be exposed to a neutron environment in the deuterium experiment. Since the characteristics may be affected by neutron irradiation, the heat characteristics should be calibrated using an in-situ calibration system [7].

Requirements for the in-situ calibration system are as follows: (i) A periscope system must be applied to avoid the damage to the IR camera detector from direct irradiation of X-rays, neutrons, and gammas from the plasma. (ii) Since the plasma side is covered with the aperture plate in the plasma experiment, a visible laser should be injected from the camera side of the foil. (iii) The irradiation points of the laser can be scanned on the whole area of the foil with the size of 90 × 70 mm (diagonal is 114 mm) through the vacuum window with the effective diameter ϕ = 100 mm. (iv) The irradiation points can be controlled with sufficiently high accuracy compared with the bolometer pixel size, 2.5 mm × 2.5 mm. (v) A removable system is favorable to avoid damage to components from the neutron irradiation during plasma experiments.

4.2 *Schematic of calibration system*

Figure 2 shows the schematic of the in-situ calibration system. A visible laser is injected to the foil detector after checking the power and beam profile. A hot mirror (Edmund Optics/ 45° 101 × 127) is applied to transmit the laser light and to reflect the IR signal from the foil as a mirror of the periscope system. It has high transmittance (> 85%) for visible light and high reflectance (> 95%) for IR signal. It can be used to satisfy requirements (i) and (ii) since the incidence angle is 45°. Two motorized goniometers (SIGMAKOKI/ GOHTM-40A60, GOHTM-40A75) are used as a biaxial goniometer with a mirror to scan the laser irradiation position. Here, the distance from the mirror with the biaxial goniometer to the foil detector is assumed to be 1000 mm considering the distance of 600 mm from the IR camera to the foil in the current setting (Figure 1) and the unfixed thickness of the neutron shield. In this case, 90 mm and 70 mm of the foil size correspond to ±2.6° and ±2.0°, respectively. These angles are in the range of the travel angles of the goniometers ±5° and ±4°. Moreover, the length corresponding to the diagonal of the foil at the vacuum window is 39.6 mm. It is shorter than the effective diameter of the window described in the requirement (iii). Then, the irradiation points can be scanned over the whole foil area through the vacuum window. These goniometers can be controlled using LabVIEW software with a positional repeatability of ±0.004°. This repeatability is equal to the resolution of ±0.07 mm and sufficiently smaller than the size of the bolometer pixel as shown in the requirement (iv). Therefore, this system can scan the irradiation points with sufficient accuracy. Requirement (v) can be satisfied since this system is simple and the position of the installation can be reproduced using knock pins.

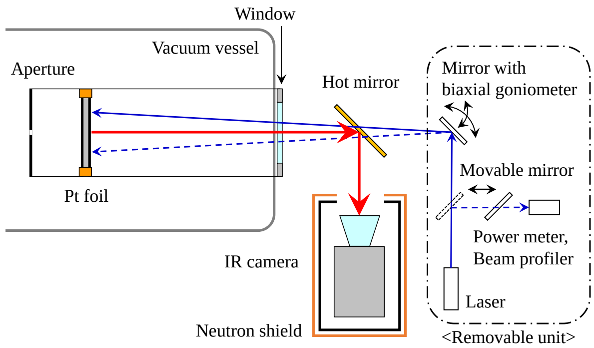

Fig.2. Schematic of in-situ calibration system for IRVB.

Acknowledgements

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