21PB-074 Development of 3D tomography for radiation measurement using IRVB measurement in LHD

LHD における IR イメージングボロメータ計測を用いた輻射分布 3 次元トモグラフィー開発

Ryuichi Sano[1,4], Byron J. Peterson[2], Masahiro Kobayashi[2], Masaru Teranishi[3], Naofumi Iwama[2], Kiyofumi Mukai[2], Shwetang N. Pandya[1]

佐野竜一, Byron J. Peterson, 小林政弘, 寺西大, 岩間尚文, 向井清史, Shwetang N. Pandya

[1]*SOKENDAI, Department of Fusion Science, 322-6, Oroshi, Toki-shi, Gifu, 509-5292, Japan*

[1]総研大核融合科学専攻 〒509-5292 岐阜県土岐市下石町322-6

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

[2]核融合科学研究所 〒509-5292 岐阜県土岐市下石町322-6

[3] *Hiroshima Institute of Technology, 2-1-1, Miyake, Hiroshima, Hiroshima, 731-5193, Japan*

[3]広島工業大学 〒731-5193 広島市佐伯区三宅2-1-1

[4]*JSPS Fellow*

[4]学術振興会 特別研究員

Radiation measurement from a fusion plasma is important for controlling the plasma. To understand the radiation which has a 3D structure, a 3D measurement is required. A large 3D tomographic inversion system for the 3D measurement in LHD has been designed. The tomographic system has been examined with the Tikhonov-Phillips regularization using a Laplacian matrix as a differential operator. Reconstructed radiation profiles show the characteristics of the original profile in numerical tests. These results indicate the system has a possibility for 3D radiation measurement. Reconstruction from experimental data will also be presented in the conference.

1. Introduction

The power balance between the incident power and the lost power is important for controlling a fusion plasma. Radiation which is emitted from impurities such as carbon, is one of the major paths of power loss from fusion plasmas. Therefore, measurement of the radiation distribution is important. Several parameters of a plasma such as the electron temperature may be able to be handled with the one dimensional assumption of being constant on a magnetic surface and therefore a one dimensional measurement may be effective. However, the radiation mainly emanate from outside of the LCFS such as from the ergodic edge region which has the completely three-dimensional (3D) structure. Locally enhanced radiation is also important to understand plasma phenomena which are related to radiation such as radiation collapse. If the radiation at the starting point of the phenomena is understood, control of the phenomena may become easy. Therefore the development of 3D measurements is required. Tomography is a major analysis method to identify local physical parameters using line integrated data in fusion science [1]. The 3D radiation measurement which is an inversion from two-dimensional (2D) measurement data has been already carried out in tokamak devices such as HL-2A [2] with an axisymmetric assumption. The assumption reduces the 3D inversion problem to a 2D inversion problem. However, the assumption is not suitable to handle plasmas in helical devices such as LHD. Therefore the 3D radiation measurement in LHD has to be carried out as a 3D inversion problem. The 3D measurement in LHD is planned using InfraRed imaging Video Bolometers (IRVBs)[3] which are measurement instruments for radiation. The IRVB provides sight integrated radiation as a 2D image. The IRVBs have a characteristics of a large number of channels. The characteristics are suitable for the tomographic inversion. Currently, four IRVBs have been installed in LHD with a total of 3,196 channels

In this study, a large 3D tomographic inversion system for the 3D measurement in LHD is designed. The large tomographic system is numerically examined with the Tikhonov-Phillips regularization, which is the standard solver of inverse problems.

2. Tomography system for 3D inversion

When tomographic inversion is performed from measured data, the solution space and the observation space should be defined. In the 3D tomography measurement in LHD, the solution space consists of the plasma-voxels defined in the LHD plasma, and the observation space is composed of the IRVB channels (3,196ch). The LHD plasma is divided into 936,000 plasma-voxels with the approximate shape of 5-centimeter cubes in $(r, z, \emptyset)$ cylindrical coordinate. The number of voxels is decreased to 16,174 with a helical periodicity assumption and a mask excluding voxels where no plasma is expected.

Observation and solution spaces are correlated by a geometry matrix which is calculated as a projection matrix from each plasma-voxel to each IRVB pixel. The geometry matrix corresponds to the field of view (FoV) of the IRVB [4]. The tomography system is composed by these three part.

3. Inversion technique

A series expansion of the Tikonov-Phillips regularization with the GCV criterion [5] [6] has been employed as the inversion technique for the 3D measurement in LHD. With the method, radiation profiles on plasma-voxels are given with the geometry matrix H as

$$\hat{\mathbf{S}} = \sum_{j=1}^{M} w_j \frac{\langle \mathbf{u}_j \cdot \mathbf{P} \rangle}{\sigma_j} C^{-1} \mathbf{v}_j \qquad (1)$$

$$w_j = \frac{1}{1 + \gamma M \sigma_j^{-2}}, \qquad (2)$$

where $\mathbf{P}$ is the measured data, $\hat{\mathbf{S}}$ is the reconstructed radiation profile, σ_j is the singular value of H, $\mathbf{v_j}$ and $\mathbf{u_j}$ are the column vectors of the right and left singular matrix of HC^{-1}, respectively, M is the total number of IRVB channels, γ is a regularization factor with minimum GCV and C^{-1} is an inverse matrix of the Laplacian matrix which is calculated with the consideration of the masked voxels and the periodicity assumption.

4. Reconstruction from given radiation profiles(Numerical test)

Several numerical tests of the inversion have been carried out using simple model profiles such as uniform radiation and a physical model profile which is calculated theoretically with the EMC3-EIRENE code in LHD[7]. The corresponding four IRVB images were calculated with their FoV and the given radiation profile, and each image was corrupted additively with normal random numbers, whose standard deviation was 10 % of the mean of the projection values. These noise magnitudes were chosen in considering the largest noise that was observed in the experiment without plasma.

Figure 1 show the given and reconstructed profiles. Reconstructed results show the characteristics of the original profiles. Especially, reconstructed profiles from soft profiles such as the uniform radiation show high reproducibility of the original profile. The behaver indicates this inversion technique is useful for the 3D measurement with the tomography system. Especially the inversion technique is effective for the soft profiles. Reconstruction from experimental data will also be presented in the conference.

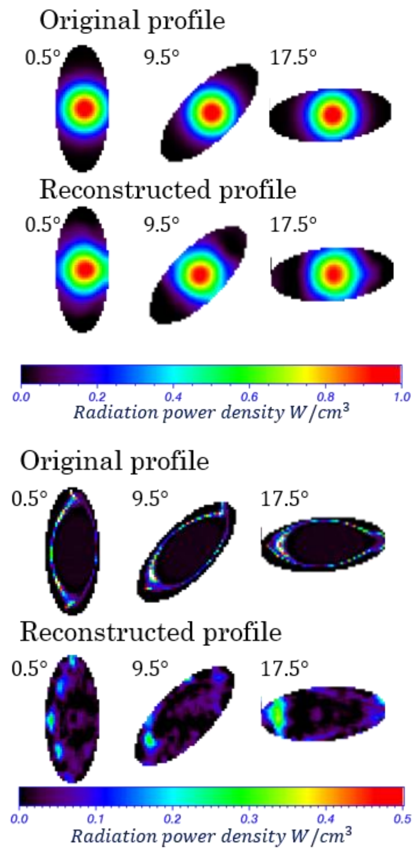

Figure 1 Reconstructed profiles at 0.5°, 9.5° and 17.5° proidal cross section from core radiation profile (upper) and physically simulated profile (lower).

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