19PA-027

Studies of Magnetohydrodynamics Equilibrium and Stability by Using Soft X-ray CT in High Density Plasmas of Heliotron J
ヘリオトロンJの高密度プラズマにおける軟X線CTを用いたMHD平衡ならびに安定性の研究

Kosuke Nishikawa 1), Satoshi Yamamoto 2), Tohru Mizuuchi 2), Kazunobu Nagasaki 2), et al.

西川 幸佑1), 山本 聡2), 水内 亨2), 長崎 百伸2), 岡田 浩之2), 南 貴司2),
門 信一郎2), 小林 進二2), 大島 慎介2), 中村 祐司1), 木島 滋2), 釼持 尚輝1),
大谷 芳明1), 中山 裕介1), 木谷 壮志1), 村上 弘一郎1), 洪 重遠1), 神野 洋介1),
塚崎 僚1), 原田 伴誉1), 桐本 充晃1), 鈴木 文子1), 程 崧明1), 呂 湘潯1),
安枝 樹生1), 元嶋 誠1), 小田 大輔1), 中野 裕一郎1), 松田 啓嗣1),佐野 史道2)

1) Graduate School of Energy Science, Kyoto University, Uji, Kyoto, 611-0011, Japan
2) Institute of Advanced Energy, Kyoto University, Uji, Kyoto, 611-0011, Japan
1) 京都大学 エネルギー科学研究科 〒611-0011 京都府宇治市五ヶ庄
2) 京都大学 エネルギー理工学研究所 〒611-0011 京都府宇治市五ヶ庄

Three Soft X-ray(SX) detector systems are installed into Heliotron J for tomographic analyses of Magnetohydrodynamics(MHD) phenomenon. The main purpose of the study is to analyze the MHD equilibrium and stability by using SX Computer Tomography (SXCT) plasma image reconstruction. We observed MHD instabilities and modification of MHD equilibrium, so called Shafranov shift, but two SX detector systems were not used for CT but for measurement of MHD instabilities. In this paper, we report the improvement of the SX detector systems, the measurement result, and reconstruction plasma image.

1. Introduction

MHD phenomena often degrade the performance of plasma confinement in fusion plasmas. It is necessary to clarify the behavior of pressure-driven MHD phenomena in high density corresponding to high beta plasmas because such MHD instabilities give rise to movement of plasma and stochastization of magnetic surfaces. We analyzed the MHD phenomena by using Soft X-ray measurement consisting of two diode arrays with 20 sight-lines each. As a result, MHD instabilities such as interchange mode and fast-ion-driven MHD instabilities and modification of MHD equilibrium so called Shafranov shift at plasma core region were observed [1].

Two-dimensional image of SX local emission estimated by computer tomography CT is a powerful method to know the behavior of MHD equilibrium and instability. The arrangement and the number of sight-lines were not optimized for SXCT in previous system with 40 sight-lines. We optimized SX measurements due to the increase in the number of sight-lines and rearrangement of sight-lines in order to increase the accuracy of reconstruction of SX by SXCT.

In this paper, we report the improvement and experimental result of SXCT in Heliotron J.

2. Soft X-ray Measurements and Their Optimization

Bremsstrahlung is emitted from electrons in high temperature plasmas in the range of SX. The SX measurement is an effective method to measure the behavior of MHD equilibrium and instability. Our SX measurement uses a pinhole type camera which consists of a AXUV-20EL Si diode linear array with 20 channels, thin Al filter with 5 μm thickness corresponding to the cut-off energy of 0.75 keV.

Figures 1 (a) and (b) show the arrangement of previous and new SX measurements, respectively. In the previous SX measurement, there is a lack of measurable region in the magnetic surfaces because we focused on the measurement of radial profile of MHD instabilities at plasma core region with high spatial resolution, as shown in Fig. 1 (a). In order to increase the accuracy of SXCT, we optimized the arrangement of sight lines and increased the number of sight lines by installing a new SX diode array and then the number of sight lines is increased from 40 to 60 in order to cover the whole plasma confinement region, as shown in Fig. 1 (b).

We apply a Thikhonov-Phillips regularization method with the minimum generalized cross validation (GCV) value to the SXCT for both optimization of SXCT and analysis of experimental data. The Thikhonov-Phillips regularization is the most commonly used method against the ill-posted data which has noise and lack of sight lines. It is also known as the constrained linear inversion method [2,3].

Figure 2 shows the estimated radiation profile “phantom” image by taking into account, reconstructed local emission for previous systems with 40 sight lines, reconstructed local emission for new systems with 60 sigh-lines, and 1-D profile of phantom, previous and new SX measurement as a function of pixel for the error estimation. We assume the electron temperature and density of $n_{\mathrm{e}}(\rho) = 1\mathrm{x}10^{19}(1-\rho^2)$ [m^{-3}] and $T_{\mathrm{e}}(\rho) = 1\mathrm{x}10^{3}(1-\rho^8)$ [eV]. Result of the previous SX measurements has up-down asymmetry although estimated phantom has up-down symmetry because the previous system has a lack of sight line shown in Fig. 1. We can reduce the error which is defined by the root mean square of residual value between phantom and reconstructed data, from 10.60 % to 7.81 %. Therefore, we designed new SX measurement based on this optimization.

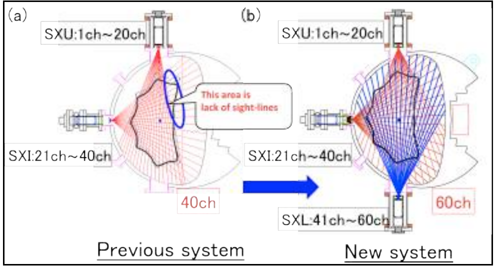

Fig. 1, Arrangement of sight lines of (a) previous and (b) new ‘optimized’ SX measurement.

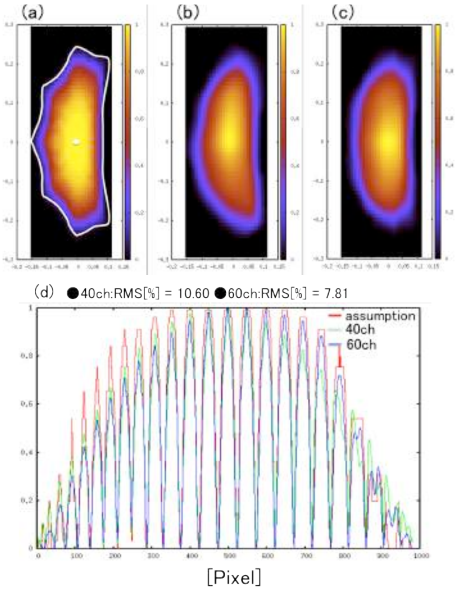

Fig. 2, Optimization of SX measurement. (a) phantom,(b) and (c) reconstructed SX emission by Thikhonov-Phillips regularization for previous and new SX measurement, (d) 1-D profile for phantom and reconstructed data with residual error.

3. Method of the SXCT

We apply Thikhonov-Phillips regularization to experimental SX data, shown in Figs. 3 (b)~(d). Figure 3 (a) shows the reconstructed experimental data at t=270 ms of the plasma corresponding to Figs. 3 (b)~(d). We have successfully reconstructed experimental data of SX by using the new SX measurements. That’s not only reconstructed the plasma core region, but the region around. According to the above results prove that increase the accuracy of reconstruction of SX by SXCT in Heliotron J.

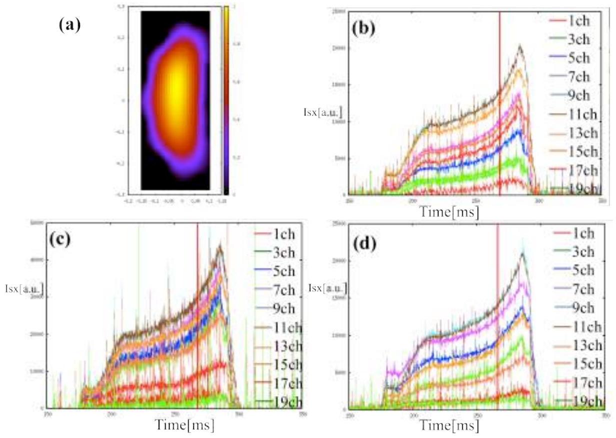

Fig. 3, (a) reconstructed image of SX signal in experiment,t = 270ms. (b) ~ (d) time evolution of upper, inner and lower SX measurement signal.

Acknowledgments

This work is performed with the support and under the auspices of Collaboration Program of the Laboratory for Complex Energy Processes, Institute of Advanced Energy, Kyoto University, National Institute for Fussion Science (NIFS) Collaborative Research Program (NIFS10KUHK030, NIFS09KUHL, and NIFS10KUHL033).

References

[1] 諏訪勝重:ヘリオトロンJ における軟X線揺動検出器を用いた電磁流体力学的(MHD)不安定性の空間構造に関する研究 2011,2.

[2] 岩間尚文，大舘暁：プラズマ計測のためのトモグラフィ解析法：J. Plasma Fusion Res. **Vol.82**,No.7 2006, 399-409.

[3] 寺崎奈緒美，岩間尚文，細田陽介：Tikhonov-Phillips 正則化とGCVによる疎データCT 像再構成 —プラズマ画像への応用—：電子情報通信学会論文誌 1998/1 Vol.J81-D-II No.1.