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Analysis of Internal Magnetic Field Structure using SXR CT method in Low-Aspect-Ratio RFP RELAX plasmas

軟X線計測及びCT手法の適用による低アスペクト比RFPプラズマの磁気面構造解析

Yosuke Aoki, Akio Sanpei, Go Ishii, Ryota Ueba, Ryosuke Kodera, Tomoyuki Nagano, Masataka Higuchi, Kenta Jikuhara, Haruhiko Himura, Sadao Masamune
青木陽祐, 三瓶明希夫, 石井豪, 上羽涼太, 小寺良典, 長野友幸, 樋口真行, 軸原健太, 比村治彦, 政宗貞男

Kyoto Institute of Technology, Department of Electronics
Goshokaidocho, Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan
京都工芸繊維大学電子システム工学専攻 〒606-8585 京都市左京区松ヶ崎御所海道町

The reversed-field pinch (RFP) is produced in an axisymmetric toroidal vessel, torus machine plasma. It has made recognized clear that spontaneous transition of plasma configuration from axisymmetric to non-axisymmetric (helical) state is common to all RFP machines. In a low-aspect-ratio RFP machine RELAX, the helical RFP state can easily be realized due to its low-A nature. In RELAX, a soft-X ray (SXR) computed tomography (CT) diagnostic system is being installed for detailed study of the transition to and back-transition from helical RFP state. The system description is given, together with discussion about initial results from the SXR CT diagnostic system.

1. Introduction

The reversed-field pinch (RFP) is one of the magnetic confinement systems for high beta plasma. One of the topics is a spontaneous transition of plasma configuration from axisymmetric to non-axisymmetric which is helical structure dubbed quasi-single helicity (QSH) state. In this QSH state, improved confinement has been observed in the helical core, either inside a large magnetic island or helically deformed nested flux surfaces, with increased electron temperature and/or higher density. Formation of electron transport barrier at the boundary between the helical core and axisymmetric surrounding region has also been reported [1]. In the extreme case where helical magnetic axis is formed, the configuration is referred to as the Single Helical Axis (SHAx) state. It is therefore quite important to recognize the mechanism of transition to QSH or SHAx RFP state, and to develop the means to control the transition externally.

RELAX (Reversed-field pinch of Low-Aspect-ratio eXperiment) is an RFP machine with major radius R = 0.5 m and the minor radius a = 0.25 m, and the resultant aspect ratio A = 2 [2]. When the aspect ratio is lowered, the q value on axis increases, while the edge value does not change so much because the field reversal surface (q = 0) is close to the edge. Therefore, if we could avoid the resonance near the core, rather wide space is available in the core region without major resonance; the single island of a core resonant tearing mode can grow without interaction the neighboring islands associated with the tearing modes. This picture has been demonstrated experimentally in RELAX in which transition to QSH takes place at lower current density and lower Lundquist number than in other machines such as RFX-mod and MST [3].

The soft-X ray (SXR) computed tomography (CT) is a powerful tool to identify the thermal structure inside high temperature plasma. When the plasma is in equilibrium, the SXR emissivity contours agree with magnetic flux surfaces because both the electron temperature and density can be regarded as surface quantities (and so is pressure). SXR CT can also play important roles in identifying magnetic structures inside the plasma in combination with magnetic diagnostics. In identifying the thermal structure during QSH in RELAX, we have developed SXR pin-hole camera combined with high-speed camera to observe quasi-periodic appearance of the helically deformed thermal structure [4]. The experimental structure has been shown to agree with equi-pressure surface structures from 3-D nonlinear MHD simulations.

2. SXR measurement & CT

We have used two photodiode arrays at the top and bottom diagnostic ports at the same toroidal location in RELAX. The cross-sectional view of this diagnostic system is shown in Fig.1. We have used 20-channel photodiode array AXUV20EL for 20 chord-integrated SXR emissivity profile at the top and bottom diagnostic ports. A 0.8-μm thick aluminum foil is used as a filter to observe only the SXR emission because the AXUV is sensitive to radiation over a wide range of wavelength including visible light. Since time resolution of the SXR signal is determined by the sampling frequency (typically 1 micro-s), we may be able to trace the time evolution of SXR emissivity profile both at transition to and back-transition from the helical RFP state in RELAX.

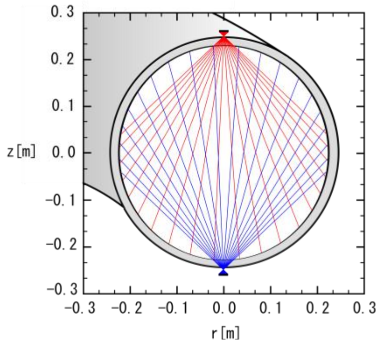

Fig.1. Ploidal cross-section of RELAX with lines of sight of each photodiode

We have developed a CT algorithm to reconstruct the SXR emissivity profile from the measured chord-integrated emissivity profiles. We have used Fourier-Bessel expansion method in the present algorithm [5-6].

3. Results

Time evolution of some of the chord-averaged SXR emissivity signals are shown in Fig.2 with time evolution of the toroidal plasma current I_p. The signal SXR_ch10 is from the central chord at the top port.

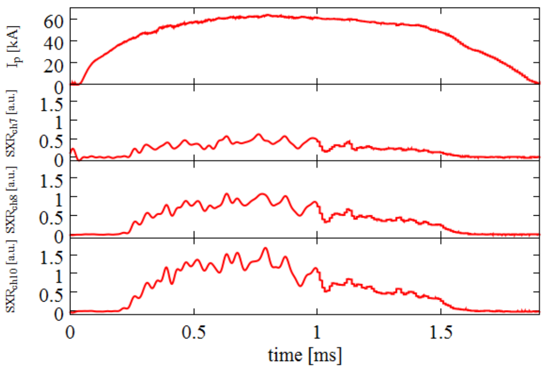

Fig.2. Time evolution of the toroidal plasma current and SXR emission signals.

Figure 3 shows an example of the CT result at t = 0.838 ms for the discharge shown in Fig.2. In this reconstruction process, the Fourier expansion order is 1 and the Bessel function order also 1. In the present algorithm, optimization of the order of the Bessel function is carried out as follows. We calculate the average residual sum of squares S for appropriate orders of the Bessel function, to find the order which minimizes S,

$$S = \frac{1}{N}\sum_{i}^{N}\left(f_i - \hat{f}_i\right)^2 \tag{1}$$

where f_i is the measured chord-integrated SXR emissivity signal for the i-th chord, $\widehat{f_i}$ is the chord-integrated value for the CT result, and N is the number of chords used in the experiment.

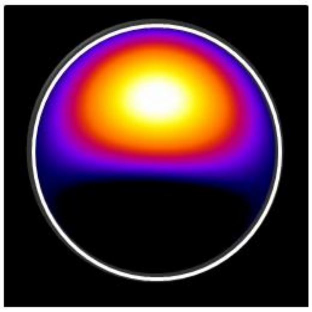

Fig.3. CT reconstructed image

4. Conclusion

A SXR diagnostic system using multi-chord emission measurements combined with CT technique has been developed for detailed analyses of the transition to and back-transition from the helical state in RELAX. Initial results are obtained by using the algorithm to optimize the Bessel function order. Further improvement of the algorithm and/or elaboration of the experimental data are required to increase the reliability of the results.

Acknowledgments

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