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Phase imaging method for density measurement and simulation analysis in the plug region of GAMMA10
位相イメージング法を用いたGAMMA10プラグ部での密度計測及びシミュレーション解析

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The phase imaging interferometer is set to measure electron density distribution at plug region in GAMMA10. We measure the phase difference between the microwave passing through the plasma and the reference wave by use of the phase imaging interferometer. We derive the electron density by Abel transform technique. We try to decide plasma density distribution by using the finite difference time domain simulations. Moreover, we construct the asymmetry Abel transform in case of the asymmetric plasma distribution, and check the validity of it.

1. Introduction

GAMMA10 is the largest tandem mirror device utilizing a plasma confinement by not only magnetic mirrors but also electrostatic potentials. It consists of the central, anchor, and plug/barrier mirror cells. We show the schematic diagram of the phase imaging device in Fig. 1. The phase imaging interferometer system [1] is set horizontally to measure upper half of the plasma in the plug cell. The phase imaging method is the method to measure the phase difference between the microwave passing through the plasma and the reference microwave which depends on the line integrated electron density. We can obtain two-dimensional (2D) line integrated electron density distributions by using the 2D detector. A 2D plasma density distribution is useful to understand the mechanisms of plasma confinement or fluctuation measurements.

We use Abel transform technique to the line integrated electron density distribution in order to derive the electron density radial distributions. In previous measurements, we used Abel transform in the assumption of axisymmetric distribution of plasma density. However, the plasma profile is not always axisymmetry. Then, using Abel transform method for nonaxisymmetric plasma may have large error in the calculated electron density. Therefore, we try to calculate the electron density by the use of asymmetry Abel transform [2,3] which is assumed asymmetric distribution of plasma density and to improve the accuracy of obtained electron density. In order to calculate the asymmetric density distribution by the measured radial electron line integrated density distribution, we use finite difference time domain (FDTD) method [4]. In this paper, we focus on establishment of this method.

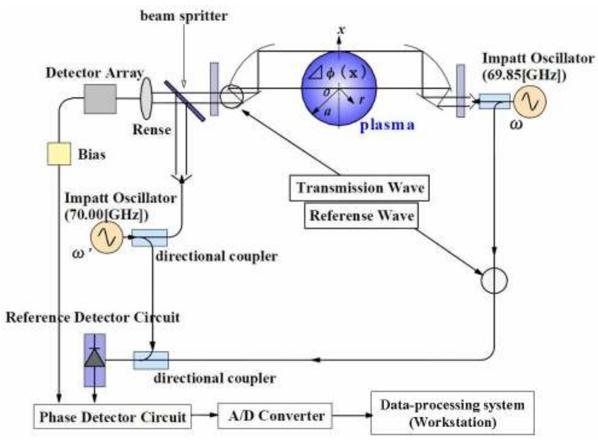

Fig.1. The schematic diagram of the phase imaging device

2. Phase imaging method

The incident microwave (69.85 [GHz]) is divided by a directional coupler. One wave is transmitted wave which goes through the plasma and changes the phase. The other wave is reference wave which remains initial phase. This device detects the phase difference $\Delta\varphi(x)$ between those two waves. The incident wave is extended into a sheet beam by a plane mirror and a parabolic mirror, and it is irradiated to the upper half of the plasma cross section. After that, the wave is concentrated into the detector array by mirrors and lenses at receiver side. On the other hand, the reference wave is transmitted through waveguides and it is incorporated into the phase detector circuit with the transmitted wave. We take heterodyne that is added oscillator of 70.00 GHz at receiver side in order to gain sufficient power of the phase difference.

3. FDTD simulations

3.1 *Simulation method*

We try to decide the plasma distribution by use of FDTD method. The details are as follows; we decide a plasma density distribution in the analysis area, and compare the phase difference obtained by the simulation and the phase difference obtained by the experiment. If phase difference is in agreement, the profile of plasma will be used for Abel transform. If it is not in agreement, we set another plasma density distribution, and simulate again.

3.2 *Simulation model*

Analysis area is 2D space (x,y). The frequency of incident wave is 69.85 GHz. In Fig. 1, the incident wave reflects at plane mirror and parabolic mirror (radius of curvature is 796.7433 mm) and reaches the plasma. Moreover, it reaches the detector with mirrors and lenses. We set parameters such as distances and angles to match experimental device. The asymmetric plasma contour distribution profile is described from the following equation.

$$\left(x-\gamma\left(\mathrm{r}_{\max}-\mathrm{r}\right)\right)^2+y^2=\mathrm{r}^2 \tag{1}$$

Where γ is the deviation of density, r_{max} is maximum radius of the plasma.

4. Asymmetric Abel transform

We derived the equation of the Abel transform which is described for asymmetric plasma distribution such as equation (1), and checked the validity of it. In order to check the validity, we assume density, and compare it and the density which is found from Abel transform of the discrete observed value which is obtained from the assumed density. The discrete observed value of equation (1) is described as the following equation,

$$I(x)=2\int_0^{\sqrt{r_{\max}^2-x^2}}\varepsilon(r)dy \quad . \tag{2}$$

Here $\varepsilon(r)$ is the density of plasma. We replace the integrant of equation (2) with r. When it is $x>\gamma r_{max}$,

$$I(x)=2\int_{r_0}^{r_{\max}}\varepsilon(r)\frac{\left(1-\gamma^2\right)r-\gamma\left(x-\gamma r_{\max}\right)}{\sqrt{r^2-\left(x-\gamma\left(r_{\max}-r\right)\right)^2}}dr \quad , \tag{3}$$

where $r_0=(x-\gamma r_{max})/(1-\gamma)$. We assume that the density is $\varepsilon(r)=exp(-(r/30)^2)$, equation (3) of $\gamma=0.3$ is shown in Fig. 2. In this Fig. 2, the left side from peak is derived from symmetricity.

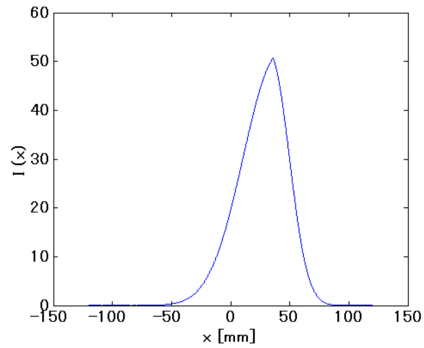

Fig.2. The discrete observed value of $\gamma=0.3$

The assumed density, for example $x=37.365$, is $\varepsilon(x)=0.995$. The Abel transformed density $E(x)$ which is found from the discrete observed value of $x=37.365$ is $E(x)=0.995$.

Therefore, we checked the validity of the asymmetry Abel transform which is described by asymmetric plasma distribution such as equation (1).

5. Summary

Improving the analytical accuracy by the inductive technique is the purpose of this study. We construct the simulation model of phase imaging device by using FDTD method, and derive the phase difference of asymmetric plasma distribution such as equation (1). This simulation enables to decide γ which is the deviation of density. Moreover, we derived the equation of the Abel transform which is described for asymmetric plasma distribution such as equation (1), and checked the validity of it.

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