EFFECT OF ELECTRON CYCLOTRON WAVE POLARIZATION ON PLASMA HEATING AND PERIPHERAL ION LOSS IN GAMMA 10 ECRH

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In the GAMMA 10 central ECRH experiments, the electron heating estimated from the soft X-ray (SX) measurement was observed with any X-mode ratio. As increasing X-mode ratio from 0% to 100%, the SX power signal increased from about 2 times to about 3 times. And the Diamagnetic signal at the central cell (DMCC) increase is the maximum (+5%) with 100% X-mode. That is, 100% X-mode is the appropriate injecting polarization as expected. The DMCC decrease was observed except with 100% X-mode though electron heating was observed. And as decreasing X-mode ratio, the peak intensity of SX radial profile shifted from the center to the South and the asymmetric electron heating was observed. And as decreasing X-mode ratio, the peripheral ion loss seems to increase.

I. INTRODUCTION

Electron Cycrotron Resonance Heating (ECRH) is one of the major heating schemes for fusion plasma heating. In GAMMA 10, the central cell ECRH has been used for the reduction of electron drag of the high temperature ions. Until now, the GAMMA 10 experiment results indicated that increasing X-mode ratio by using the polarizers brought the appropriate electron heating on central ECRH[1]. That is, X-mode 100% is the appropriate injecting polarization in central ECRH.

In the GAMMA 10 central ECRH experiment on 2009, the SX power signal, which corresponds to the scale of electron heating, increased with any X-mode ratio. But the DMCC, which is proportional to the stored energy of plasma, decreased except with 100% X-mode. Plasma sometimes broke down with decreasing X-mode ratio. The purpose of this paper is to investigate the cause of these deterioration of plasma. In addition, we reviewed to confirm 100% X-mode is the appropriate injecting polarization on the steerable horizontal mirror.

The Sec. II describes the appropriate polarization in GAMMA 10 central cell. The Sec. III gives the experimental results in the GAMMA 10. Sec. IV is the discussion of the peripheral ion loss. Finally, conclusion in Sec. V

II. THE APPROPRIATE POLARIZATION IN GAMMA 10

In the central cell ECRH, high power microwave from 28 GHz 500kW gyrotron is transmitted by corrugated waveguide and controlled by the miter bend polarizers and injected to plasma through two mirrors. The two polarizers are Twister Polarizer and Circular Polarizer and can control X-mode ratio of injecting polarization.

The miter bend polarizers, Twister Polarizer and Circular Polarizer, are installed into the transmission system of the central ECRH as shown in Fig. 1. The Twister Polarizer can control mainly the tilted angle α and the Circular Polarizer can control mainly the ellipse angle β of elliptical polarization. These miter bend polarizers can control arbitrary polarization theoretically.

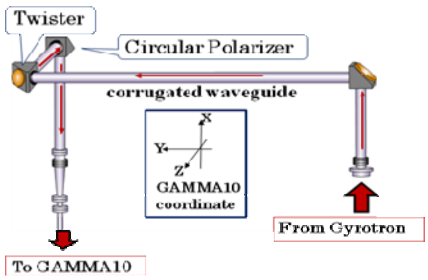

Fig. 1. The schematic diagram of the transmission system in the central ECRH

We calculated X-mode ratio from the dispersion relation. The X-mode ratio (Rx) is given as follow,

$$Rx = \frac{1+\tan^2\theta + |\sigma_x|^{-2}}{(1+\tan^2\theta)|1+\eta|^2 + |\sigma_x^{-1}+\eta\sigma_o^{-1}|^2} \quad (1)$$

$$\left(\begin{array}{l} \eta = -\dfrac{P-\sigma_x^{-1}}{P-\sigma_o^{-1}}, P = -\dfrac{\sin\alpha\tan\beta + i\cos\alpha}{\sin\alpha\cos\theta + i\cos\alpha\tan\beta\cos\theta} \\ \sigma_o = -\dfrac{1}{2}\left\{B\sin^2\theta + \sqrt{(B)^2\sin^4\theta + 4\cos^2\theta}\right\} \\ \sigma_x = -\dfrac{1}{2}\left\{B\sin^2\theta - \sqrt{(B)^2\sin^4\theta + 4\cos^2\theta}\right\} \end{array} \right)$$

where θ is the angle of injecting to plasma, and B=Ωe/ω (Ωe is the electron cyclotron frequency and ω is the injecting wave frequency) is the normalized magnetic field at the vacuum-plasma boundary [2]. In the GAMMA 10 central ECRH, θ=35°and B=2 at the vacuum-plasma boundary of the microwave injection path. In using these parameter, equation gives the relation of X-mode ratio and α, β as shown in Fig.2.

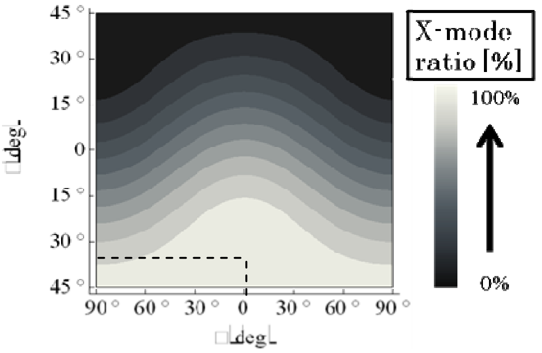

Fig.2. The relation of X-mode ratio and the tilted angle α, the ellipse angle β in GAMMA 10 central cell. The dotted line is the line of α=0° and β=-34°.

If the direct output from the gyrotron was injected (α=0°,β=0°), X-mode ratio is about 69%. From Fig.2, it is found that one of the combination of (α,β) is (0°,-34°) for 100% X-mode. X-mode fits R-mode (Right-handed polarization) on the EC resonance. Since the density of the plasma and the temperature of the electron are low in GAMMA 10, the absorption of O-mode is quite low. That is, X-mode injection is required for the efficient heating, which requires the cyclotron wave from the strong magnetic field.

III. EXPERIMENT RESULTS OF THE X-MODE RATIO DEPENDENCE

The steerable horizontal mirror is installed into GAMMA 10 central ECRH on 2009 experiments[3]. On the optimal position, the polarization experiment was carried out with 100%, 75%, 50%, 25%, 0% X-mode ratio by using the polarizers. The central ECRH power was 100 kW at the gyrotron. On Fig.3 and Fig.4, "$\Delta k/k_0$" is the changing ratio of "k" to "k_0", where "k" is the value on 170ms (during central ECRH) and "k_0" is the value on 150ms (before central ECRH). "k" is SX on Fig.3(a), the line density at central cell(NLCC) on Fig.3(b) and DMCC on Fig.4.

Fig. 3(a) shows the X-mode dependence of $\Delta SX/SX_0$, and Fig. 3(b) shows the X-mode dependence of $\Delta NLCC/NLCC_0$. From Fig.3, the SX signal during ECRH increased compared with that before ECRH, which indicates the electron heating. And SX power signal increased from about 2 times to about 3 times with X-mode ratio from 0% to 100% though NLCC changed a little in any polarization. This result means that X-mode 100% is appropriate polarization as expected.

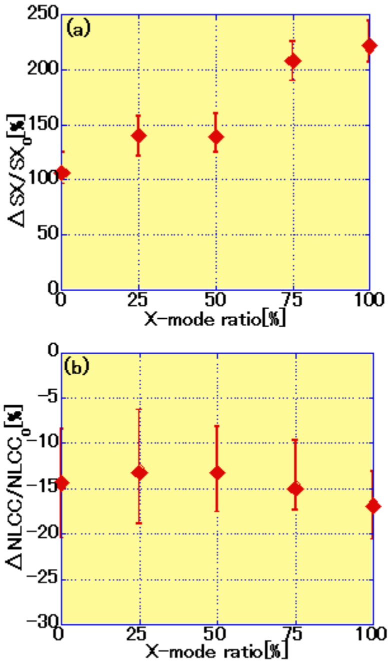

Fig. 3The X-mode dependence of (a)the SX changing ratio and (b)the NLCC changing ratio.

Fig. 4 shows the X-mode dependence of $\Delta DMCC/DMCC_0$. From Fig. 4, the DMCC increased nearly +5% on X-mode 100%. And as X-mode ratio decreased, the changing ratio of DMCC decreased from nearly +5% to nearly -23%. This result means that the DMCC decreased except with X-mode 100% though electron heating was observed with any X-mode ratio. This indicates the ion loss driven with decreasing X-mode ratio.

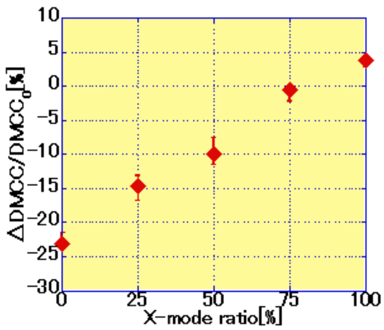

Fig. 4. The X-mode dependence of the DMCC changing ratio and X-mode ratio.

IV. DISCUSSION

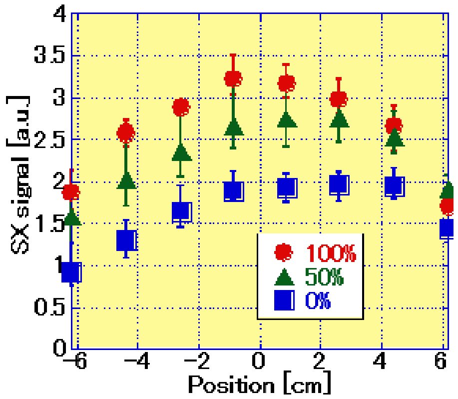

Fig. 5.The X-mode dependence of the SX profile.

Fig. 5 shows the radial profile of the SX power signal on 100%, 50%, 0% X-mode ratio. On the figure, the right is the South and the left is the North. From Fig. 5, as decreasing X-mode ratio, the peak intensity of SX signal shifts from the center to the South. This result means that the asymmetric electron heating occurs in case of low X-mode ratio.

And Fig. 6 shows the ion current measured with Ion Sensitive Probe (ISP). The ISP measures the amount of the high energy charged ion to get over the electron barrier which makes use of the difference of lamor radius between Ion and electron. It was placed at 20.9cm off from plasma axis on GAMMA 10 central cell.

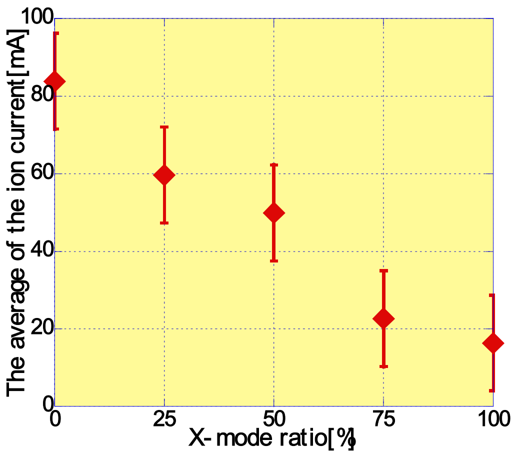

Fig. 6. Dependent of the average of the amount of the ion current on X-mode ratio.

From Fig. 6, the average of the ion current decreased with X-mode ratio increased. The ISP placed at the periphery of plasma. That is, ISP might be able to detect the peripheral ion loss. The average of the ion current might reflect the peripheral ion loss. This result means that the peripheral ion loss increased with decreasing X-mode ratio.

Decrease in the X-mode ratio brings increase in the O-mode ratio. O-mode belongs to the left-handed polarization from the dispersion relation. The left-handed polarization passes the EC resonance, reflects at the inside wall, and absorbed at surround plasma. And asymmetric electron heating occurs. And then the asymmetric electron heating might cause the asymmetric potential profile, the enhanced ion loss breaks out. The asymmetric heating also causes the out gas from the limiter, which brings the CX loss. The deterioration of plasma characteristics might be occurred by these structures.

V. CONCLUSION

In the central ECRH, the electron heating was observed with X-mode ratio from 0% to 100%. The SX power signal increased from about 2 times to about 3 times with X-mode ratio from 0% to 100%. And the DMCC increased 5% on X-mode 100%.That is to say, X-mode 100% is the appropriate injecting polarization as expected.

During central ECRH, the DMCC decreased with decreasing X-mode ratio though electron heating was obtained. And as decreasing X-mode ratio, the peak intensity of SX signal shifts from the center to the South and the asymmetric electron heating was observed. And as decreasing X-mode ratio, the peripheral ion loss measured by ISP increased as well as the DMCC decrease, which indicates the ion confinement degradation. The experiment measuring the potential profile will be needed to see the ion loss mechanism in detail. From these results, it is important to minimize of the O-mode ratio and to decrease the stray microwave.

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