# High-speed Imaging of Edge Plasma in the GAMMA 10 Tandem Mirror

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*The dependence of the resonance position of the central-ECH (c-ECH) on plasma behavior was investigated using a fast camera. When the resonance positions were higher, low frequency fluctuation of ~6kHz was observed and at the same time the diamagnetic signal decreased. Also, the same frequency fluctuation was observed in the potential signal by Au beam probe. On the other hand this low frequency fluctuation was not appeared when the resonance position was seemed to be on the axis of the plasma. These results indicate that the convective ExB drift instabilities may be induced due to the off-axis heating by c-ECH*

## I. INTRODUCTION

Edge plasma study is one of the important issues to realize good energy/particle confinement plasmas and to decrease the plasma-surface interaction. In GAMMA 10 tandem mirror edge plasma behavior has been studying by fast cameras [1-5], and the measurement results have recently shed much new light on the plasma behavior. In this paper the relationship between ECH for central-cell plasma heating and plasma behavior was investigated.

## II. EXPERIMENTAL SETUP

The location of the fast camera and the central-cell plasma are shown in Fig.1. The camera views the central-cell plasma from the horizontal port.

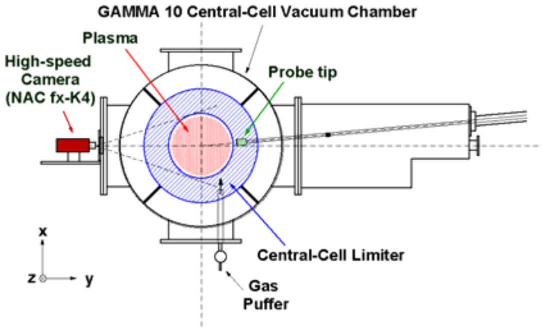

Fig. 1 Cross-section of GAMMA 10 central-cell
The fast camera was installed in the horizontal port.

Figure2 shows the fast camera image and the field of view from the same horizontal port.

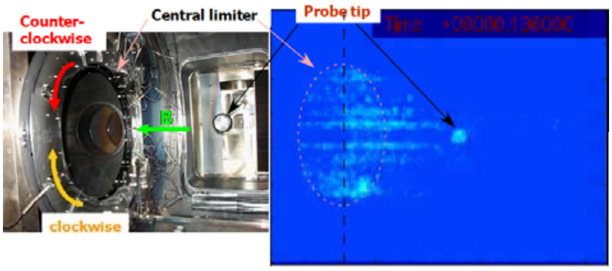

Fig.2 Field of view and camera image
Left: Photograph by normal CCD camera from the central-cell horizontal port
Right: Fast camera image from the same horizontal port.

In the image the magnetic field direction is left shown in Fig.2 (left). The counter-clockwise is the ExB drift (Er>0) and/or ion diamagnetic drift direction, and the clockwise is the electric diamagnetic drift direction. In these experimental series the resonance position of the central ECH (c-ECH) was changed by a moving cylindrical mirror in front of the wave-guide in the vacuum vessel. It should be desired the resonance position is on the axis of the central-cell plasma. The vertical mirror position d of 0mm should be corresponding to the resonance position of the machine axis of the vacuum vessel. The mirror position d of -9mm is to be the lower resonance position from the machine axis, and d of +10mm is to be the higher resonance position from the machine axis. Figure 3 shows these alignments in the vacuum vessel.

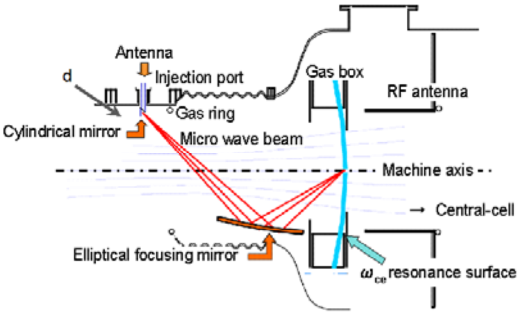

Fig.3 c-ECH system in this experiment

It is noted that the resonance position of the central-cell plasma should be decided by the experimental results due to the error of the mechanical alignment.

## III. RESULTS AND DISCUSSION

Dependence of the plasma parameter on the resonance position during c-, p-, b-ECH (28GHz, 100kW, 200kW, 150kW, respectively) was examined in these experimental series. It was found plasma behavior was changed with the resonance position. In particular the diamagnetic signal (DMcc), which indicates the confinement energy, was quite changeable. Figure 4 shows the time trace of the diamagnetic signal, the line-average electron density and the streak image along the black dashed line in Fig.2 (right) at various mirror positions. When the mirror position d is -9mm (upper figures in Fig.4), the DMcc increased with time. However, when d is larger than -5mm (only the results of 0mm and 10mm are shown in the middle and lower figures of Fig.4, respectively ), the DMcc began to decrease during c-, p-, b-ECH, even though the line-average electron density was not so changed. See Fig.4 (right), the decrease of the DMcc was coincidence with the strong light emission of the lower part of the central limiter in the images. This time there is no optical filters, thus the light emission should be mainly Hα emission due to the electron collision with hydrogen atom. Therefore, the light emission is nearly proportional to the electron density [4]. From camera images the apparent plasma rotation and/or vertical motion were seen during this strong emission period near the central limiter.

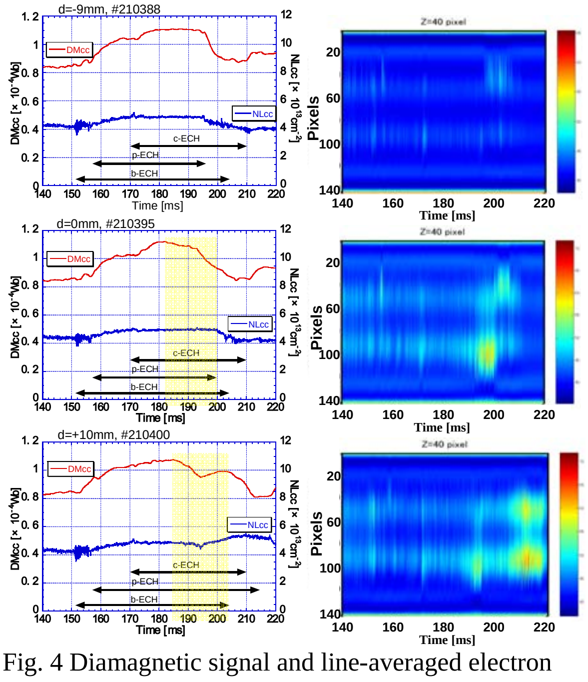

Fig. 4 Diamagnetic signal and line-averaged electron density (left) and streak images from the fast camera.

Usually the light emission near the limiter indicates the recycling at the limiter and this recycling restricts the confinement energy of GAMMA 10 plasmas. The apparent plasma rotation, when the DMcc decreased, was counter-clockwise (=ExB drift and/or ion diamagnetic drift) and it was also found at many GAMMA 10 plasmas. These experimental results show plasma behavior depend on the resonance position. To investigate these phenomena the power spectra are examined. Figure 5 (left) shows the power spectra of the pixel data in the image. The pixel of the lower part of the limiter, which is bright position in Fig.4 (right) was selected. Also, the power spectra of the space potential of the central-cell plasma by Au beam probe [6] were shown in Fig.5 left. Both data are calculated using time-dependent FFT.

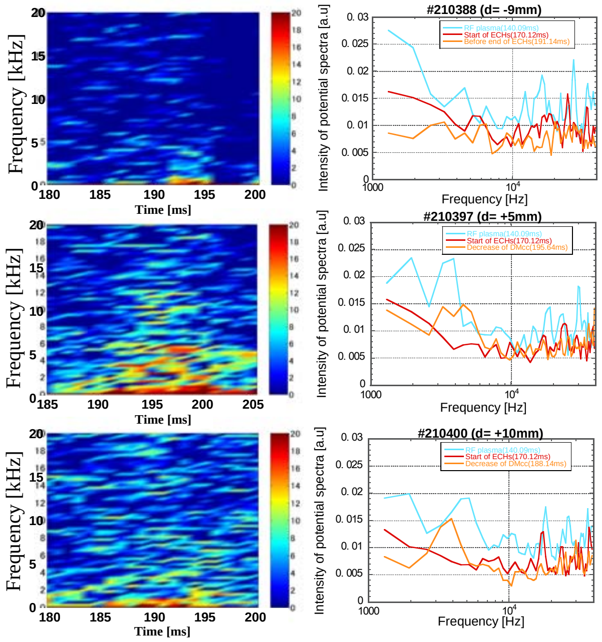

Fig.5 Power spectra of the pixel data in the image and the space potential
Left: the pixel data in the lower part of the limiter
Right: the potential signal from Au beam probe

In the upper left figure of d=-9mm there is no typical frequency peak and no clear features in the power spectra. However, in the middle left and the lower left figures, which are d=0mm and d=+10mm, respectively, there are some low frequency peak in the power spectra. In the upper right figure the fluctuation of the space potential was suppressed by ECHs at the almost every frequency. Also the middle right and lower right figures the fluctuation of the space potential was suppressed by ECHs at high (>10kHz) frequency region. On the other hand at the lower frequency region of <10kHz the fluctuation arose when the DMcc decreased. This low frequency fluctuation, especially of ~6kHz, was seen in the image as apparent plasma rotation and/or vertical motion mentioned above, and this apparent motion probably induce the recycling near the limiter. The fluctuation of the space potential may indicate a kind of the drift instabilities. Therefore, the suppression of these low frequency fluctuations should be the key issue to maintain the DMcc.

Consideration of the coincidence of the peak frequency of plasma behavior and the space potential, the low frequency of the light emission indicates real plasma behavior. The positive space potential during ECHs and the ExB (Er>0) rotation direction support this interpretation.

The reason of these phenomena is the off-axis heating of c-ECH in the central-cell plasma. On the axis of the central-cell plasma the density and temperature should be higher than the other region; that means the pressure should be higher on the axis. When the heating position (=the resonance position) is very close to the axis of the central-cell plasma and if the plasma would rotate due to ExB, there may be no convective loss and the plasma does not interact the limiter. However, when the heating position is far from the axis of the central-cell plasma and if the plasma would rotate, the motion of this plasma should induce the convective loss. Also, the plasma may rotate around the off-axis of the plasma and thus plasma may interact with the limiter. Above interpretation will not conflict with the kind of the drift instability though the resonance position with a wide range of the variation should be needed.

Thus, we may conclude the on-axis heating is very important for realizing good confinement plasma in GAMMA 10 tandem mirror to suppress the convective ExB drift and the recycling at the limiter. In the future we have to measure the multi-points space potential measurements and electron density/temperature profile measurement to confirm above interpretation. They should be planned in time.

Anyway the fast camera is very useful and powerful tool for visualizing plasma behavior even though the light emission has some ambiguity.

## IV. CONCLUSIONS

Dependence of plasma behavior in GAMMA 10 central-cell on the c-ECH resonance position was investigated using mainly fast camera. The relationship between the diamagnetic signal and the light emission in the images showed that plasma behavior and the recycling, which mainly occurred at the central limiter, were the key issues to get good confinement plasma. Also, the recycling increased with the potential fluctuation by Au beam probe signal. It suggested that the drift instabilities occurred when the c-ECH resonance did not meet the plasma center.

Above experimental facts may indicate that the important thing to get good confinement plasma is that the resonance position meets the plasma center not to increase the drift instabilities.

## ACKNOWLEDGMENTS

The authors thank to the GAMMA 10 supporting group for their excellent arrangement of the experiments. This work is performed with the support and under the auspices of the Bi-directional collaboration research program (NIFS09KUGM033) between Hiroshima Univ. and Plasma research center, Univ. of Tsukuba. One of authors (N.N) acknowledges S. Nishino for continues encouragement.

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