First Observation of Plasma Motion in GAMMA 10 Using a Fast Camera

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Visible imaging measurement using a fast camera in conjunction with a gas puff was demonstrated in the GAMMA 10 tandem mirror. In order to image plasma behavior on the periphery, a hydrogen gas puff in the bottom of the vacuum chamber near the GAMMA 10 central-cell was used. Without the gas puff the light emission was not sufficiently bright, and SN ratio is not good. By using the gas puff, the light emission could be clearly observed, and a 5 - 6 kHz vibration of the plasma column was confirmed. This motion is most likely plasma rotation due to the electron drift wave and $E_r \times B$ drift. These results show that the fast camera used in conjunction with a gas puff is a promising candidate for the measurement of peripheral plasma behavior even in low-density mirror plasmas.

Keywords: gas puff imaging, plasma rotation, turbulence, mirror plasma, GAMMA 10

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Rapid progress has recently been made in the performance of ultra-high speed (fast) cameras and their application to plasma diagnostics. Gas Puff Imaging (GPI) is one effective method to visualize the turbulence in peripheral plasma, called “blob” or “filament” in the STs [1] and tokamaks [2]. In this technique, the quantity of the gas puff was carefully determined not to generate the undesirable turbulence of the gas puff itself. A movable limiter has been used to study peripheral plasma behavior and plasma-wall interaction in a helical device [3]. The studies of peripheral plasma turbulence using the fast camera have involved mainly toroidal plasmas. In a linear device, plasma turbulence was recently imaged using a visible fast camera [4]. In this paper, a technique for imaging peripheral plasma behavior using a fast camera in the largest linear device, the GAMMA 10 tandem mirror, is demonstrated.

In the GAMMA 10 tandem mirror, the central-cell gas puff has been used to improve density control and confinement time [5]. In the present experiment, the gas puff in the central-cell was used to visualize the plasma periphery and it was expected that plasma turbulence would be observed. Figure 1 shows the schematic of the GAMMA 10 central-cell and the location of the fast camera. The gas puff was located at the bottom port near the central-cell mid-plane. In this experiment, the plasma discharge started 50 ms after the main trigger, and ended at 250 ms. The gas puff (pulse width 3 ms) began at 190 ms, but was delayed a few ms due to the small conductance of the tube. The ECH pulse was applied for a duration of 180 - 208 ms.

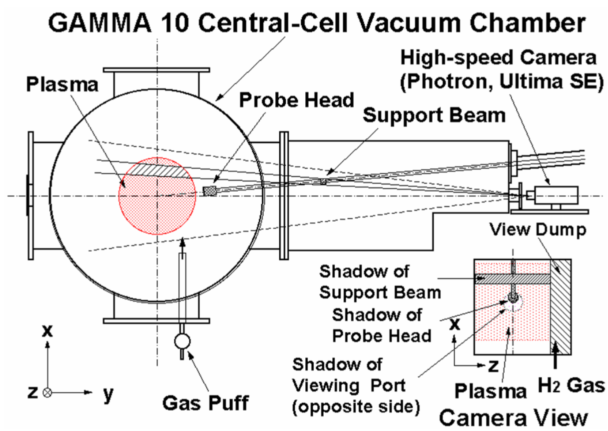

Fig. 1 Cross-section of GAMMA 10 and camera location.

Figure 2 shows the images of the fast camera during the gas puff at 40500 frames per second and at a resolution of 64 × 64 pixels (#194844). A typical field of view is illustrated in the bottom right of Fig. 1. The right side in each image is limited by the view dump. Without the gas puff the plasma is dark; however, the plasma column was clearly observed during the gas puff.

It was observed that the plasma column moved up and down for a period of about 100 - 200 ms. In particular, dur-

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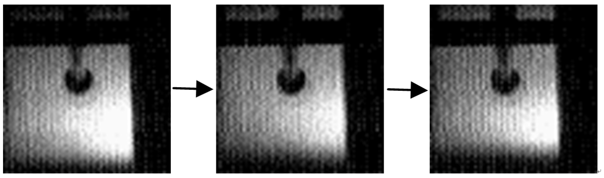

Fig. 2 Video output image during gas puff imaging. (The time difference between each frame is about 50 µs.)

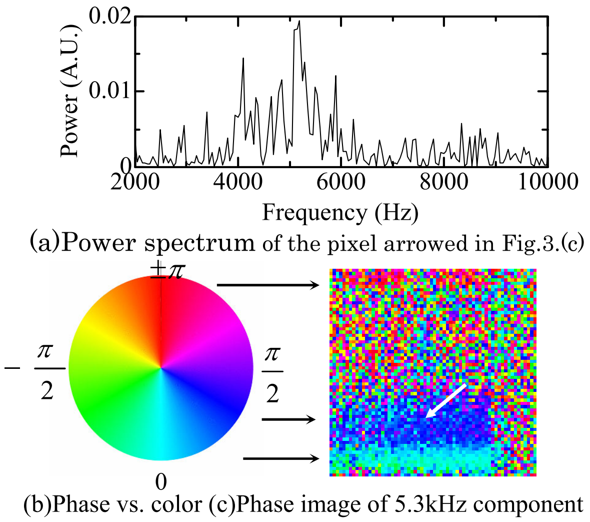

Fig. 3 Typical result of Fourier analysis.

ing the gas puff this plasma motion was clearly seen due to the strong emission shown in Fig. 2. Using an image enhancement technique, it seemed that the diameter of the plasma column measured by the fast camera did not change during this motion. Therefore, this motion must be plasma rotation and/or up-down vibration. Fast Fourier Transform time analysis was applied to the each pixel dataset of the images for a duration of 180 - 200 ms.

Figure 3 (a) shows the power spectrum of the position shown in Fig. 3 (c). The main frequency of this motion is approximately 5 - 6 kHz. Two-dimensional phase images are obtained using the phases of the same frequency Fourier components at each pixel data set. The absolute value of the phase is arbitrary. The one pixel at the lower plasma edge is chosen as the zero phase point. In Fig. 3 (b), the color sample for the phase value is shown, while the phase image of the 5.3 kHz Fourier component is shown in Fig. 3 (c). The phases are almost the same in the horizontal direction in the top and bottom regions; in particular the colors of the bottom region are very clear due to the strong emission by the gas puff. The phase of the top region is almost π radian and that in the bottom is 0 radian. At the middle region, the phase colors of pink and yellow are seen to mix. This might be caused by the low SN ratio of the signal and the integrated effect along the line of sight. Near the top region the integrated effect helps us to see a red phase color, because the phase of the edge region does not differ significantly. The phase color changes to blue (~1 radian) with turning toward the upper direction from the bottom in Fig. 3 (c). Therefore, the phase difference from the top to the bottom is nearly π radian. If this motion is a rigid vibration, the phase color should be the same. Thus, the motion is indicated to be rotation. A comparison of the profile of the phase color in Fig. 3 (b) to that of Fig. 3 (c) suggests that the mode of this rotation is most likely $m = 1$ and that the direction of rotation is clockwise in the cross-sectional view shown in Fig. 1 because of the phase delay. Visible light measurements [6] from the other ports have also shown the plasma motion of the 5 - 6 kHz components simultaneously. Other diagnostic results have suggested that the rotation mechanism involves the combination of the electron drift wave and $E_r \times B$ drift [7].

In conclusion, gas puff imaging was demonstrated successfully in the GAMMA 10, allowing the observation of a plasma column rotation of 5 - 6 kHz in the central-cell. The results show that the fast camera is the primary candidate for peripheral plasma measurement even in low electron density plasma. This study was undertaken in Bi-Directional Collaboration between Hiroshima University and Tsukuba University. The authors gratefully acknowledge the support of the National Institute for Fusion Science.

[1] R. Maqueda *et al.*, Rev. Sci. Instrum. **74**, 2020 (2003).
[2] S. Zweben *et al.*, Plasma Phys. **9**, 1981 (2002).
[3] N. Nishino *et al.*, J. Plasma Fusion Res. **80**, 175 (2004).
[4] N. Ohno *et al.*, J. Plasma Fusion Res. **80**, 275 (2004).
[5] Y. Nakashima *et al.*, J. Plasma Fusion Res. **75**, 1211 (1999).
[6] H. Higaki *el al.*, Rev. Sci. Instrum. **75**, 4085 (2004).
[7] A. Mase *et al.*, Phys. Rev. Lett. **64**, 2281 (1990).