§18. Toroidal Flow Velocity Fluctuation Measurements based on Development in Ultra-fast Charge Exchange Recombination Spectroscopy

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The characteristics of intrinsic rotation have been investigated in LHD. A theoretical study has predicted that Reynolds force in the toroidal (parallel) direction due to the turbulence transport is a candidate for the internal torque of the intrinsic rotation. To reveal the driving mechanism experimentally, the measurement of the velocity field fluctuation is required to estimate the Reynolds stress in toroidal direction. However, the sampling speed of the flow velocity measurement by the conventional technique of charge exchange spectroscopy (CXRS) has not been enough to observe the flow velocity fluctuation. In this study, we develop ultra-fast CXRS for measurement of the toroidal flow velocity fluctuation.

As shown in Fig. 1, The ultra-fast CXRS system consists of high-dispersion camera lens monochromator with Echelle grating, image optics (lens and optical fiber) and fast avalanche photodiode (APD) camera (Fusion Instruments, APDCAM). The fast APD camera has 8 × 4 APD array with each element of 1.6 × 1.6 mm^2. Since the dispersion of the camera lens monochromator is about 3-10 times higher than that of the conventional one used in CXRS, the APD camera is used to measure the CXR emission spectrum with high time resolution. The ADC equipped in the APD camera has sampling frequency up to 2MHz. The cut-off frequency of APD camera is set to be 220kHz.

In this FY, we have carried out installation of the imaging optics and performance test, as follows. First, the imaging optics were designed and constructed. The imaging optics for the APD camera consists of an image fiber and a set of relay lens. The control and data acquisition system for the APD camera were set up. Second, the control software developed for the LHD BES system was applied to the Heliotron J system. The frequency response of the APD camera was measured using a LED (λ_{CWL}=655 nm) with a high frequency driver circuit. The cut-off frequency was confirmed to be 220kHz as designed. As shown in Fig. 2, the characteristics of the frequency response is almost the same as APD used in Heliotron J (Scientex, M-100, f_c = 200kHz). Finally, the response to small amplitude of fluctuation was measured. The ratio of the 50 kHz fluctuation component of the LED current δi_d to that of DC component $\langle i_d \rangle$ changed from 10% to 0.1% to obtain required number of ensemble average. In the case of $\delta i_d/\langle i_d \rangle$ of 10% and 1%, the fluctuation component can be identified using one and 10 ensembles, respectively, while, in the case of $\delta i_d/\langle i_d \rangle$ = 0.1%, 200 ensemble average is required at least to identify the component (see Fig. 3).

1) S. Kobayashi, et al., 20th ISHW Oct/5-9/2015, Greifswald, Germany, S3-O2.
2) S. Kobayashi, K. Ida, et al., 15th H-Mode WS, Oct/19-21/2015, IPP Garching, Topic 5: M5.
3) S. Kobayashi et al., 32th JSPF annual meeting, Nov/24-27/2015, Nagoya, 26aA05 (Invited).
4) X. X. Lu, S. Kobayashi, et al., 32th JSPF annual meeting, Nov/24-27/2015, Nagoya, 24pD17P.

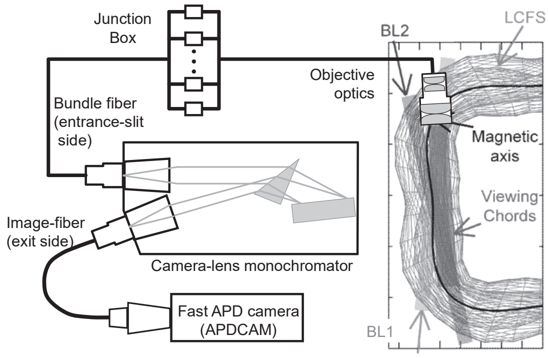

Fig. 1. Schematic illustration of ultra-fast CXRS system. The objective optics for the Heliotron J CXRS has wavenumber less than 0.7 in the radial direction using 16 sightlines.

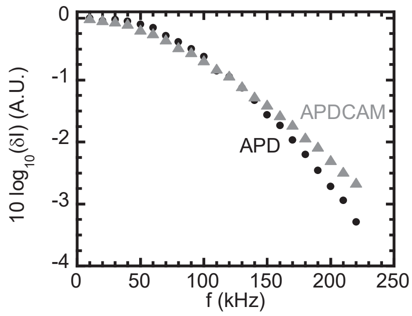

Fig. 2. Frequency response of APD camera (APDCAM) using LED and comparison to APD used in Heliotron J. The LED has center wavelength λ_{CWL} of 655 nm and bandwidth $\Delta\lambda_{CWL}$ of 20nm.

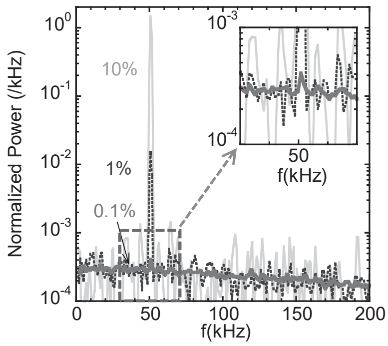

Fig. 3. Power spectrum of APD camera output. The fluctuation component of LED current to that of the DC one ($\delta i_d/\langle i_d \rangle$) changes from 10% to 0.1%. In the case of $\delta i_d/\langle i_d \rangle$ = 0.1%, the required number of ensemble average is 200 at least.