§42-9 Development of Plasma Diagnostics based on Doppler-free Spectroscopy

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In the LHD experiments, the particle balance in the plasma edge region is important for the study of the high-performance confinement. Since the magnetic field strength and direction vary with the position and are known in the LHD plasma, the Zeeman-splitting of spectral lines carries the information of the position of excitation, which is almost the same as that of ionization. This information is helpful for investigating the particle balance in LHD. In the case of hydrogen plasma, however, the structure of Zeeman-splitting is masked by the Doppler broadening. For that reason, we developed a system of "Doppler-free" saturation spectroscopy at the Balmer-alpha line of atomic hydrogen. In our previous study, it was confirmed that the LHD plasma was optically thin for the Balmer-alpha line of atomic hydrogen for conventional absorption spectroscopy and we developed a combination method of saturation spectroscopy and frequency modulated spectroscopy to enhance the sensitivity of absorption. However, it was also confirmed that the wavelength dependency of the transmission characteristics of the optical paths degrade the signal to noise ratio of the detected signals of the frequency modulated absorption spectroscopy. In this year, we tried to apply the frequency modulated absorption spectroscopy to the LHD plasma with single mode optical fibers and collimation optical systems.

Single-mode polarization-maintaining optical fibers were installed between the instrumentation room and 7.5-U/L ports of LHD. Fiber couplers (TOPTICA FiberDock) were installed on these ports and each optical axis was carefully aligned on the same chord. Each beam waist position was adjusted at the midpoint of the optical path in the LHD vessel. The light source was a tunable cw diode laser (NewFocus Vortex II), which is able to scan the whole range of the Balmer-alpha line of atomic hydrogen without mode-hopping. The output laser light was coupled to the optical fiber at the instrumentation room, and was transmitted to 7.5-U port. The laser beam passed through the LHD plasma along the long axis in the poloidal cross section and was led to a wide area photo diode (ThorLabs PDA100A) by a beam sampler placed between the window and the fiber coupler at 7.5-L port. The frequency of the laser was scanned in 100 GHz width around the Balmer-alpha line of atomic hydrogen with a 10 Hz triangle waveform and a frequency modulation of 18 GHz deviation by a 1 kHz sinusoidal waveform was superposed. The second harmonic component of the modulated signal (2f signal) was detected using a lock-in amplifier (Stanford Research System SR830).

By using the single-mode optical fiber, laser beam profile reached to the detector did not vary with the laser wavelength sweep. As a result, the 2f signal amplitude without absorption by plasma was reduced. Figure 1 shows the obtained 2f signals at the discharge #125989. The abscissa is corresponding to the frequency sweep with a triangle waveform. The laser frequency was increased linearly from t = 0 ms to 50 ms and was decreased from 50 ms to 100 ms. At this discharge, the plasma was generated at T = 3.5 s and a disruption was occurred at T = 3.8 s but low temperature plasma was kept until T = 4.8 s. The 2f signals at T = 3.0 s, before the plasma generation, and at T = 5.0 s, after the discharge, are almost same. On the other hand, at T = 4.0 s, in the case of exist the plasma, the 2f signal shows significant difference to the signals without plasma. Figure 2 shows the 2f spectra obtained by subtracting the 2f signal at T = 5.0 s. At T = 4.0 s, the 2f spectrum shows the absorption of the Balmer-alpha line with 2000 – 3000 K Doppler broadening. To detect the Lamb dips by the combination of the saturation spectroscopy and the frequency modulated spectroscopy, an intense pump beam from 7.5-L port is required.

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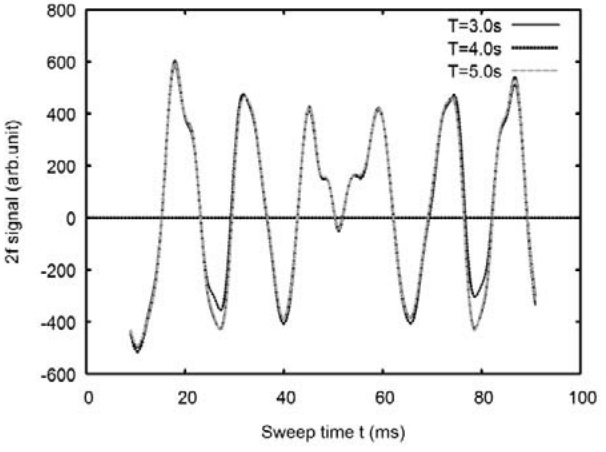

Fig. 1. 2f signals at the discharge # 125989.

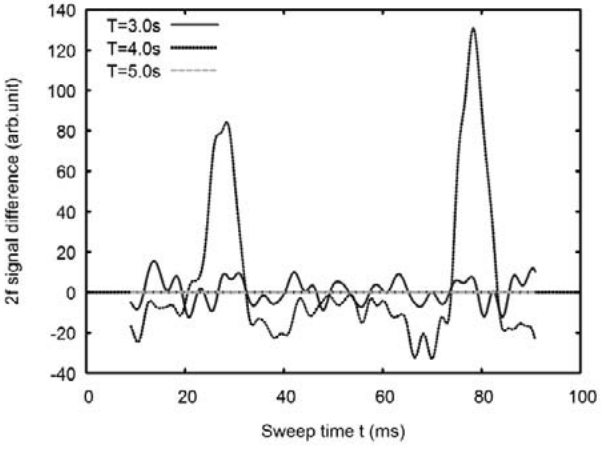

Fig. 2. 2f spectra of #125989. (Difference to T = 5.0 s)