§17. Developments of Frequency Comb Microwave Reflectometer for Interchange Mode Observations in LHD Plasmas

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In the magnetic confinement plasma experimental devices, the suppression of the deterioration of the high plasma confinement performance is one of the important issues. MHD instability, especially low-n interchange instability, is a cause of the deterioration in the LHD. The structure of the fluctuation is key information to know the characteristics of MHD instability. The measurement with a microwave reflectometer has high spatial and temporal resolution on the electron density fluctuation due to MHD instabilities. The reflectometer uses the cut-off phenomena between the launching electromagnetic wave and plasma. When some frequency components of the microwave launch simultaneously, each frequency component reflects back at each corresponding different cut-off position and gives the radial profile. For these reasons, we have developed a multi-channel microwave reflectometer system. In particular, this system uses a frequency comb as a source. Comb generator can output many frequency components simultaneously and it is useful to measure the density fluctuation profile [1]. The previous system consists of Ka-band microwave components, which can measure the electron density range with 1 - 2 x 10^{19} m^{-3} [2]. According to the prior studies in the LHD experiments, the MHD instabilities frequently appear in the relatively higher density range more than 2 x 10^{19} m^{-3}, because the amplitude of the m/n =1/1 MHD fluctuation observed by the magnetics increases with the increase of beta and the decrease of magnetic Reynolds number. Here, m and n are poloidal and toroidal mode number, respectively. Therefore we upgrade the multi-channel reflectometer system in the U-band microwave range for measuring plasma regions at higher density, and we apply it to the neutral beam injected plasma experiments [3].

Figure 1(a) shows the time evolution of the plasma stored energy and the line averaged electron density in the NB-injected discharge with the magnetic field of 1.375T. The heating power of NBI is almost constant from t = 5.3s to 9.3s, and from t = 9.3s to 12.0s. At t = 9.3 s, the line-averaged electron density reached to 3.5×10^{19} m^{-3}, and the volume averaged beta value is around 1%. Figure 1(c) shows the time evolution of the frequency ranges with a high coherence level measured by the magnetic probes. Here m/n=1/1, 2/3, 3/3, 3/4, 4/3 modes are observed, which are considered to be the low-n interchange mode instabilities. Figure 1(b) shows the frequency spectrogram of the signal measured by the microwave reflectometer system of 53.0 GHz. From t = 5.3 s, the corresponding cut-off layer appears. The component around 2 kHz frequency are observed by both the magnetic probes and the microwave reflectometer, which is corresponding to m/n =1/1 mode. The complex signal amplitude of this frequency component in the microwave reflectometer is calculated on each channel. Then, the profile of the amplitude of the radial displacement evaluated from density fluctuation amplitude is plotted in Fig.2. Here, the data points do not use only the U-band system but also the Ka-band system. It is observed that this density fluctuation caused by the interchange mode instability localizes around r_{eff}/a_{99} is 0.97 and its mode width is about 15% of the minor radius, and the maximum amplitude of the radial displacement is 1.2mm, which corresponds to 0.15% of the minor radius, which corresponds to about one-third of the value measured by the Soft X-ray measurement.

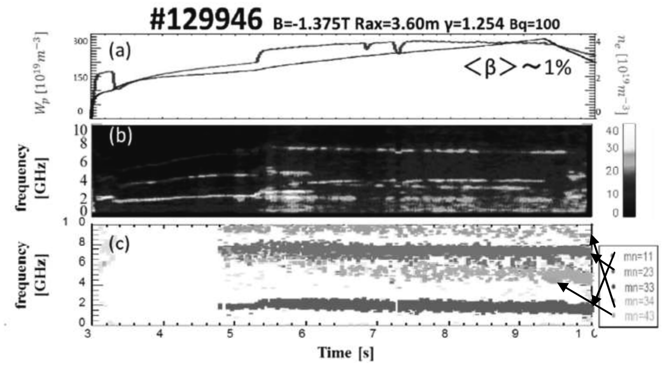

Fig. 1 (a) the time evolution of the plasma stored energy, W_p and the line averaged electron density, n_e. (b) The frequency spectrogram of the signal measured by the microwave reflectometer system of 53.0 GHz. (c) The time evolution of the frequency ranges with a high coherence level measured by the magnetic probes.

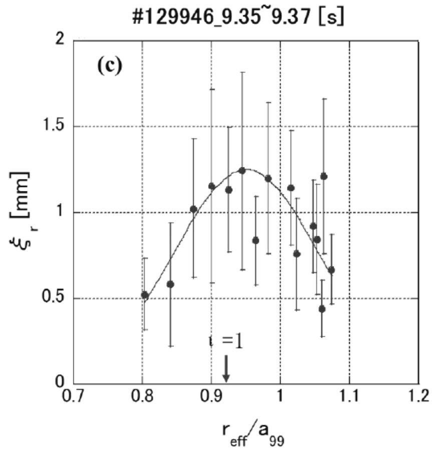

Fig. 2 the profile of the amplitude of the radial displacement, ξ_r, evaluated from density fluctuation amplitude. r_{eff} is a effective minor radius, and a_{99} is a plasma minor radius.

[1] W. A. Peebles et al., Rev. Sci. Instrum. 81 (2010) 10D902.
[2] T. Tokzuawa et al., Plasma and Fusion Research. 9 (2014) 1402149.
[3] R. Soga eta l., J. Instrumentation, 11 (2016) C02009.