§29. Development of an ICRF Wave Measurement System

Ejiri, A., Takase, Y., Tsujii, N. (Frontier Sci., Univ. Tokyo),
Tokuzawa, T., Kasahara, H., Saito, K.

ICRF heating is a main tool for steady state operation in present fusion devices. Although the deposition profile is calculated by various codes, their quantitative accuracies are affected by many practical factors. In the case of LHD, three dimensional magnetic field configuration is one of the difficult factors to take into account in codes. In such a situation, internal wave field measurement and comparison between the measured data and the code results are quite important. In order to measure the RF wave strength inside plasma, we have dveloped a microwave reflectometer, by which RF induced density fluctuation $\delta n_e/n_e$ is obtained, and the RF field can be estimated assuming appropriate wave properties (e.g. radial wavenumber).

A two channel O-mode microwave reflectometer (with probing frequencies of 28.8 and 30.1 GHz) has been installed at port 3.5U of LHD and various quantitative features of the RF (ICRF) wave were obtained [1]. Signals from the two channels provide density oscillations $\delta n_e/n_e$ at two spatial points. Thus, the phase relationship between them provides information on the RF wave structure. For example, when the wave is traveling inward along the minor radius, the phase difference between them is finite. When the RF absorption is weak the wave is reflected by the cutoff and/or by the vacuum vessel, and a standing wave structure can be formed. In such a case the phase difference becomes zero or $\pm\pi$.

Figure 1 shows the time evolutions of the measured density fluctuations and some plasma parameters. The plasma is generated by ECH and sustained by ICRF power. The cutoff positions are located near the edge. The typical $\delta n_e/n_e$ is the order of 10^{-4}. Figure 1 (d) shows the phase (difference) between the two $\delta n_e/n_e$s calculated by a cross spectrum analysis.

About 200 discharges with ICRF heating were analysed. The cutoff radii in the analysed data are located in the range $r_{\mathrm{cutoff}} = 0.7 - 1$ m, because the signal becomes very weak outside this range. The six ICRF straps were operated as three antenna units at three toroidal locations P3.5, P4.5 and P7.5. The average distance between the two cutoff radii was 26 mm for this data set. The amplitude $\delta n_e/n_e$ for the two channels are similar, and no dependence of their amplitude ratio on plasma parameters was found. Figure 2 shows the histogram of the phase data selected by a few conditions. The histogram for all the data shows a peak around zero-phase, which implies that the phase fluctuations (and the resultant $\delta n_e/n_e$s) are in-phase on average (the black curve in Fig. 2 (a)). When we restrict the data to those with a large spatial separation, the peak position moves toward the negative region. This negative phase implies that the ICRF wave propagates from the outer region toward the plasma center. Figure 2(b) shows the histogram of the data set where only the antenna unit at P4.5 or that at P7.5 is operated. The number of data is not large for this data set, and we plotted several different histograms to see the stability of structure. The distribution seems to have a peak at $\pm\pi$, in addition to the peak at 0. This in-phase and out of phase double peak structure is a characteristics of a standing wave structure, which appears when the wave absorption is weak and the wave is confined in a region where propagation is allowed. Since the antenna units P4.5 and P7.5 are located far away from the measurement points, it is reasonable that only a poor absorption component reached the measurement points and forms a standing wave structure.

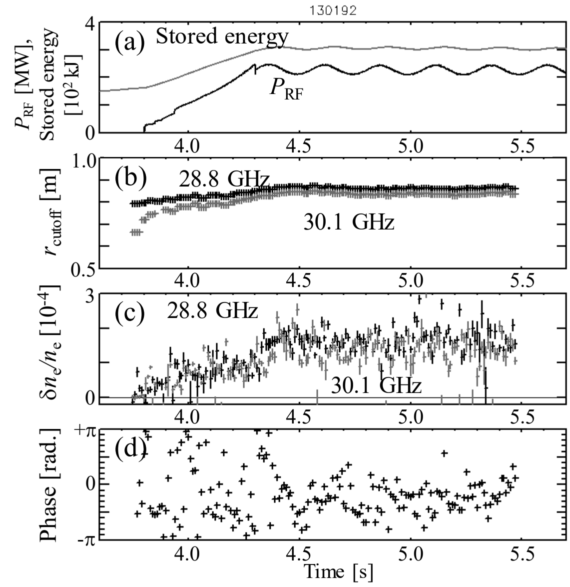

Fig. 1 Time evolutions of net ICRF power (black) and stored energy (grey) (a), minor radii of the cutoff layers r_{cutoff} (b), rms density fluctuation level $\delta n_e/n_e$ (c), and the phase difference between the two density fluctuations (d). Black and grey symbols in figures (b) and (c) represent data for the two microwave frequencies: 28.8 GHz and 30.1 GHz, respectively.

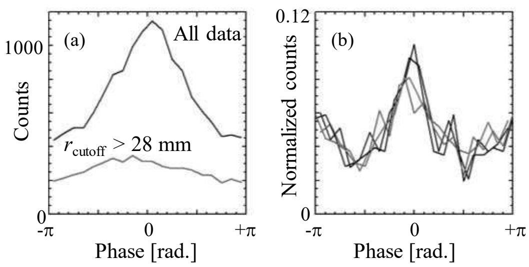

Fig. 2 Histogram of the phase for all the data (figure (a) black curve), and the data set where the distance between the two r_{cutoff}s is larger than the average (=26 mm) (figure (a) grey curve). Figure (b) shows the histograms (black curves) of the data set where only the antenna unit at P4.5 or that at P7.5 is operated. Grey curves are the histograms for the data set where the number of data is doubled by splitting the analysis time window into two time windows. Two curves with the same colour are histograms with shifted binning.

1) A. Ejiri, et al., JINST **10**, C12020 (2015).