§5. CO_2 Laser Imaging Interferometer in LHD

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A heterodyne interferometer is a promising technique to measure the electron density of high temperature plasma because the measurements are based on phase, so it is insensitive to change of laser intensity or detector sensitivity. An interferometer measures the line integrated electron density, so, Abel inversion is necessary to obtain the radial density profile. In order to reconstruct radial profile with good accuracy, it is necessary to have multi channel measurements covering the whole plasma cross section. In LHD, we installed a multi channel imaging interferometer [1]. Compared with a conventional interferometer using discrete multi beams, in an imaging interferometer, it is easy to have many channels using a multi channel detector array combined with a slab beam. We use of 10.6 μm CO_2 laser for density measurements. A sufficiently powerful (~8W) and stable laser source is available, and multi channel detector arrays with excellent sensitivity are also available. These can offer good signal to noise ratio for the beating signal for heterodyne detection. However, the phase shift due to mechanical vibration is not negligible, so, we subtract the phase shift due to vibration using a co-axial 1.06 μm YAG laser HI.

Recently improved central particle confinement has been achieved in pellet injected discharges in the high density regime (>$10^{20}$$m^{-3}$) of LHD [2]. It is strongly required to measure the density profile to understand high density transport physics and plasma control in such a high density region is also required. However, the existing 13 channel 118.9 μm far infrared laser interferometer suffers from fringe jumping at such a high density and many chords fail to measure correctly. This is caused by the reduction of the heterodyne beating signal amplitude when the mixing efficiency gets worse due to the beam bending due to strong density gradient. With the use of a short wavelength CO_2 laser, the fringe jumps due to loss of signal are almost completely avoided, since refraction effects are negligible.

Figure 3 is temporal evolution of line density measured by the CO_2 HI with vibration compensation. The line density was successfully measure without fringe jumping. The phase shift was calculated by digital demodulation technique from the digitally sampled heterodyne beating signal [3]. Abel inversion to obtain radial density profile was done by using linear least square fitting with regularization of the density gradient. These techniques are well established for tomography reconstruction [4]. The flux surfaces for the reconstruction procedure were determined as follows. A set of 18 different equilibria were calculated for different beta and pressure profiles with volume averaged beta from 0% up to 1.2 % with about 0.1% step. The electron temperature (T_e) profiles help to determine the appropriate equilibrium flux surface. The most appropriate flux surface is selected in order to match T_e profile on flux surface coordinate ($T_e(\rho)$) from inside and from outside of magnetic axis.

Figure 2 (a) and (b) show an example of the result of flux surface selection showing that both inner and outer $T_e(\rho)$ closely match each other. Figures 2 (c) and (d) show comparisons of the reconstructed density profile and the electron density profile measure by Thomson scattering. The absolute value of Thomson scattering was determined from the co-axial microwave interferometer [1]. The discrepancies between density profiles from CO_2 interferometer and Thomson scattering is observed as shown in Fig. 2 (b) and (c). The possible reason of these discrepancies are due to the selection of inappropriate flux surface or due to the saturation of Thomson scattering detection or imperfect of the beam alignment.

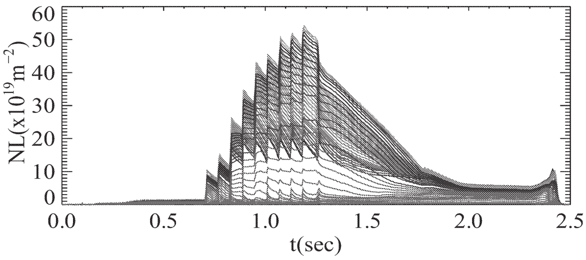

Fig. 1 Example of line density measurements. Mechanical vibration was compensated by YAG laser interferometer

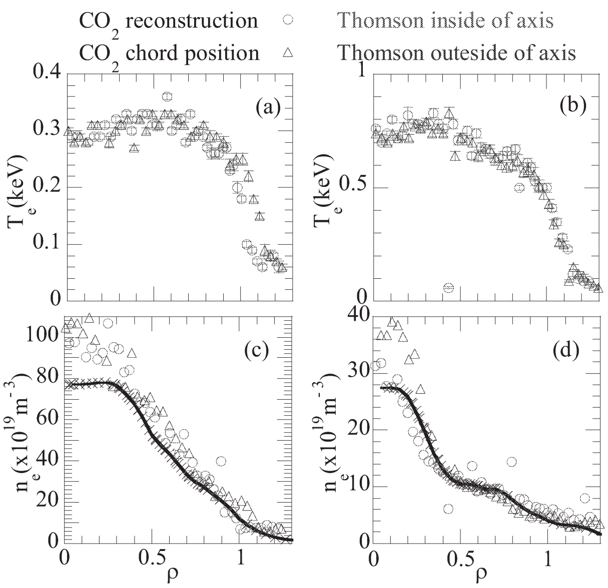

Fig.2 Measured profiles ((a),(c) t= 1.2 sec) and (b),(d) t= 1.7 sec) of the discharge of Fig.1 (a) (b) Temperature profile from Thomson scattering(c), (d) Comparison of profile by CO_2 HI Thomson scattering.

References
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