§6. Shafranov Shift Measurements Using a Soft X-ray CCD Camera in Internal Diffusion Barrier Discharges in LHD

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Recently an operational regime with an internal diffusion barrier (IDB) has been found and extensively studied in LHD experiments to explore the highest density and/or stored energy.[1] Magnetic axis tends to be largely shifted outward (Shafranov shift) in this regime because of strongly peaked pressure profiles. Though the Shafranov shift can roughly be determined from electron temperature and density profiles measured by Thomson scattering diagnostic, more precise measurements and systematic analyses of the Shafranov shift would be helpful for the physics studies on the IDB.

Since soft X-ray emissivity can be generally considered as a flux surface function, physical quantities relevant to flux surface shape can be derived from the numerical analyses of the two-dimensional soft X-ray images. In LHD, an imaging system using a soft X-ray CCD camera and beryllium filters has been installed to a tangential viewport. This system has routinely been utilized for the derivation of the magnetic axis shift.[2] In this study, Shafranov shifts in high density discharges with IDB formation are calculated from the soft X-ray images in this way.

The tangential soft X-ray imaging system consists of a CCD camera, a pneumatic mechanical shutter, a pinhole disk and a filter disk to control incoming light intensity.[3] The CCD camera has recently been updated to the one with better spatial and temporal resolution (Andor Technology, DO435-BV) of frame transfer type. Accordingly we have reconstructed the equilibrium database for the fitting. In the fitting procedure, we have loaded fitting data of line-averaged signals for several pre-calculated equilibria with changing average beta value. Assuming that the emissivity profile could be expressed by Fourier-Bessel series expansion, least squares method is applied to determine the Fourier coefficients for all equilibria by comparing with the measured (line-integrated) soft X-ray profile. Finally the magnetic axis shift is determined as a local minimum of the error against the average beta.

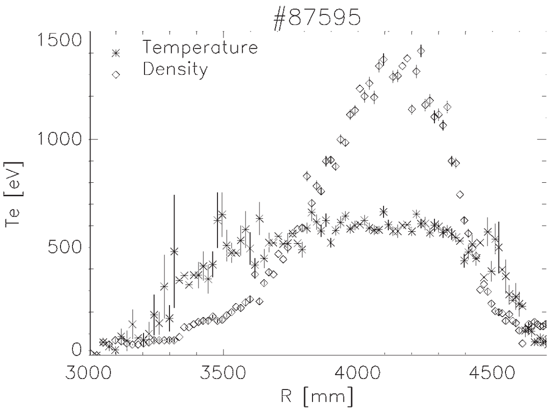

Fig. 1: Electron temperature and density profiles in a discharge with IDB.

An example of the electron density and temperature profiles for an IDB discharge is shown in Fig. 1. The measured and best-fitted contours of soft x-ray emissivity profile for this discharge and another non-IDB discharge are shown in Fig. 2 together with the magnetic axis positions derived from the fitting procedure. The magnetic axis in the plasma with IDB is largely shifted from the position in vacuum (3.85 m) due to the peaked pressure profile.

Systematic analyses of the Shafranov shift for high density plasmas are now underway. The dependences of the Shafranov shift on average beta value, pressure profile, and magnetic field configuration in IDB discharges will be summarized and compared with those in discharges without IDB in the near future. In addition, the results will be compared with those derived from the Thomson scattering diagnostic to discuss the reliability of the present analyses.

1) Sakamoto, R. et al.: Plasma Fusion Res. **2** (2007) 047.

2) Liang, Y. et al.: Plasma Phys. Control. Fusion **44** (2002) 1383.

3) Suzuki, C., Ida, K., Kobuchi, T., and Yoshinuma, M.: Rev. Sci. Instrum. **79** (2008) 10E929.

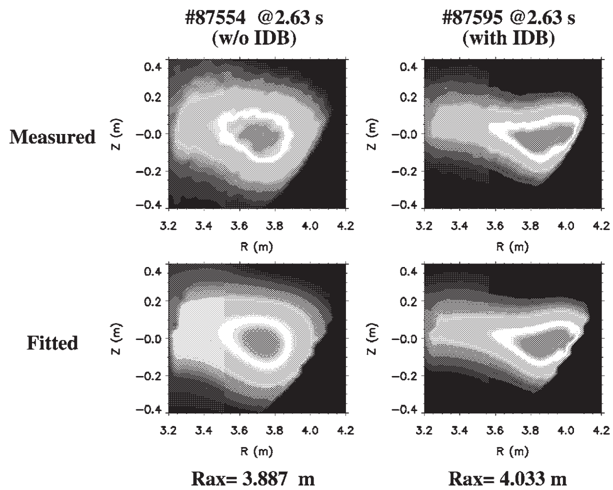

Fig. 2: The measured and best-fitted contours of soft x-ray emissivity profile in the same discharge as Fig. 1 and a discharge without IDB. The magnetic axis positions derived from the fitting are also shown.