§5. Measurement of Shafranov Shift with Soft X-ray CCD Camera

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The tangential soft x-ray image has been measured using soft x-ray CCD camera in imaging mode with good spatial resolution in the Compact Helical System (CHS) [1]. Since the total emission of x-ray is considered to be constant on magnetic flux surface, the shape of magnetic flux can be reconstructed from the soft x-ray image. The magnetic axis moves outward due to the vertical field created by the asymmetric toroidal current (Pfirsch-Schlüter current) produced by the plasma pressure gradient in a finite-beta toroidal plasma, which is well known as a Shafranov shift. The measurement of Shafranov shift due to the Pfirsch-Schlüter currents in toroidal magnetic confined plasma is important to study equilibrium beta-limit and effect of magnetic shear on plasma confinement.

The Shafranov shift of the plasma magnetic axis is derived from the best fit of the intensity contour of soft x-ray emission calculated using equilibrium code with various pressure profiles to that measured with soft x-ray CCD camera. It is found that the measured Shafranov shifts are larger than that expected from diamagnetic measurements in NBI heated low-density plasma, because of a significant fraction of beam component tangentially injected [2]. The Shafranov shift (Δ_{CCD}) measured with CCD camera is corresponding to the total pressure p including thermal pressure and parallel (p^b_{para}) and perpendicular (p^b_{perp}) beam pressure. The Shafranov shift can be derived from stored energy measured with diamagnetic loop (Δ_{Diamag}). However, isotropic pressure profile (i.e. $p^b_{para}=p^b_{perp}$) should be assumed to calculate the Shafranov shift from the stored energy, because the diamagnetic loop detects only perpendicular pressure. Therefore, anisotropy of plasma pressure can be evaluated from the difference of the Shafranov shift measured with CCD camera.

Figure 1 shows the Shafranov shifts measured using x-ray CCD camera with electron density scan. The pressure anisotropy is found to be increased as the electron density is decreased from $4\mathrm{x}10^{19}\mathrm{m}^{-3}$ to $0.5\mathrm{x}10^{19}\mathrm{m}^{-3}$ in the NBI heated plasma. The large anisotropy is consistent with the fact that the slowing down time (~0.1s) of neutral beam is longer than energy confinement time (~1ms) at low electron density plasma in CHS. Therefore, the pressure anisotropy disappears for ECH plasma even at the low electron density (n_e~$0.5\mathrm{x}10^{19}\mathrm{m}^{-3}$) or high density NBI plasma (n_e~$4.0\mathrm{x}10^{19}\mathrm{m}^{-3}$).

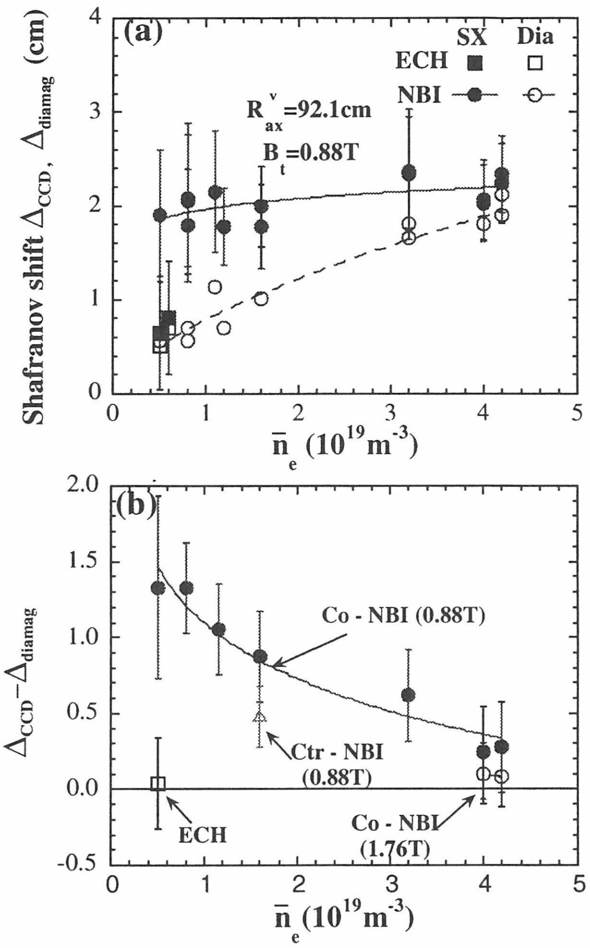

Fig. 1 (a) Shafranov shift measured by using soft x-ray CCD camera and expected from VMEC code with β measured with diamagnetic loop as a function of line averaged n_e for plasma heated by ECH and co-injected NBI, respectively; B_t=0.88T, R_{ax}^{V}=0.921m. (b) The Shafranov shift due to plasma pressure anisotropy as function of line averaged n_e for plasmas heated by ECH (B_t=0.88T), co-injected NBI (B_t =0.88T and 1.76T) and counter-injected NBI (B_t =0.88T), respectively.

References

[1] Liang, Y., Ida, K., et al. : Proc. of the 2nd IAEA TCM on Steady State Operation of Magnetic Fusion Devices – Plasma Control and Plasma Facing Component, Fukuoka, Japan, 25-29th Oct. 1999, Vol. III, pp. 736-751.

[2] Liang, Y., Ida, K., et al. : Plasma Phys. Control. Fusion (To be submitted).