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

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The x-ray imaging system with soft x-ray back-illumination CCD detector sensitive to the energy range of 1keV to 10keV has been applied to measure magnetic axis in LHD [1, 2]. Although the time resolution determined by mechanical shutter is poor (0.25s), the system has good spatial resolution (1024x512 pixels in image area). By choosing appropriate combinations of size of pinholes and thickness of Be filters, the x-ray image can be measured for the plasmas in the wide range of electron temperature and density. Since the total x-ray emission is considered to be constant on the magnetic-flux surface, the x-ray image represents the magnetic-flux surface.

The inversion of integrated x-ray intensity along the line of sight to the local x-ray emission is not possible, without the equilibrium calculation based on the measured pressure profile, because the inversion needs the shape of magnetic flux surface. The x-ray emission are integrated by using the database of magnetic flux surface which has been calculated for various pressure profiles in LHD, using the three-dimensional free boundary equilibrium code VMEC. The major radius of magnetic axis, R_{ax}, is derived by choosing the magnetic flux surface from databases, which is consistent with the two-dimensional x-ray profile measured [3].

Figure 1 shows the Shafranov shift measured with soft x-ray CCD camera as a function of averaged-beta $<\beta_{dia}>$ measured with diamagnetic loop. The accuracy determining the major radius of magnetic axis depends on the radial profile of soft x-ray intensity, and is typically few mm and 10mm for the plasma with peaked and flat profile of soft x-ray intensity, respectively. The measured Shafranov shift increases linearly as the averaged beta $<\beta_{dia}>$ is increased up to 2.6%. The Shafranov shift calculated with VMEC code for different plasma pressure profiles of $\alpha 1$=2, 8 and $\alpha 2$=2, 8, where the plasma pressure profile is simplified as $P=P_0(1-\rho^{\alpha 1})(1-\rho^{\alpha 2})$. Here ρ is normalized averaged minor radius. For the high beta discharge with low magnetic field of 0.5T, the Shafranov shift increases up to 28cm (47% of minor radius), and approaching to the calculation with more flat profile as indicated in the magnetic flux surface in Fig. 1.

Figure 2 shows the Shafranov shift measured with a soft x-ray CCD camera as a function of averaged beta for R_{ax}^{v}=3.5m and 3.75m in LHD. The electron densities in these discharges are larger than $2\times10^{-19}m^{-3}$. The Shafranov shifts measured with soft x-ray CCD camera show that the shift of magnetic axis in the plasma with R_{ax}^{v} =3.75m is larger than those measured in plasmas with R_{ax}^{v}=3.5m in a range of $<\beta_{dia}>$ <1.5%. The Shafranov shift measured with CCD camera agrees with that calculated using VMEC code with reasonable pressure profile both for the plasmas with R_{ax}^{v}=3.5m and 3.75m.

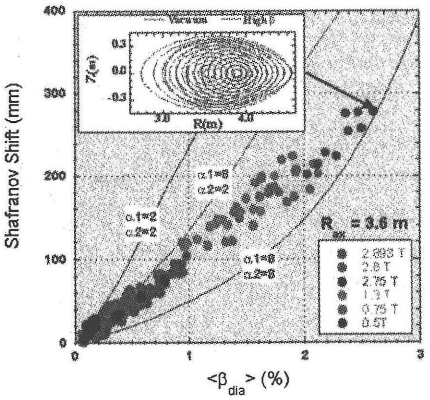

Fig. 1 The Shafranov shift as a function of the averaged-β $<\beta_{dia}>$ for the plasmas with R_{ax}^{v}=3.6m. The horizontal elongated magnetic flux surfaces are plotted for high β plasma and vacuum condition, respectively.

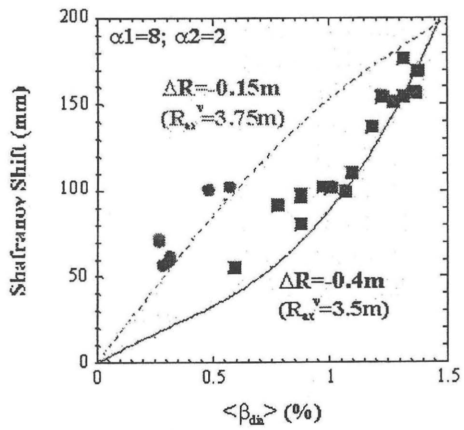

Fig. 2 The Shafranov shift measured with soft x-ray CCD camera as a function of $<\beta_{dia}>$ for the plasmas with R_{ax}^{v}= 3.75m (circle) and R_{ax}^{v}= 3.5m (square), respectively.

References

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