§26. Experiments on Helical Nonneutral Plasmas Confined on Magnetic Surfaces of Heliotron J

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Studies on nonneutral plasmas have been conducted on various machines such as the Paul trap, Penning trap, and toroidal devices. Recently, experimental studies on toroidal nonneutral plasmas confined on helical magnetic surfaces (HMS) have been initiated[1, 2]. Contrary to toroidal neutral plasmas, both space potential ϕ_s and electron density n_e of toroidal nonneutral one are non-constant on helical magnetic surfaces. This phenomenon can be approximately explained by the theory[3] that shows in nonneutral plasmas, parallel electrostatic force balances with the parallel pressure gradient force. This actually calls for variations of ϕ_s and n_e along magnetic field lines on closed magnetic surfaces. However, variations of ϕ_s and n_e are so far observed only on the HMS, not along magnetic field lines except for the magnetic axis[2]. In order to compare the observed variations with the theory, measurements of those plasma parameters along magnetic field lines are thus called for.

The experiments are now being performed on Heliotron J at Kyoto University under this research collaboration program. Before performing those, we estimated[4] the variations of ϕ_s and n_e along helical B-lines of Heliotron J, which was based on a simple scaling used in Ref (3). In this report, we show that on the magnetic axis, variatios of ϕ_s and n_e are about 7 V and 2×10^7 m^{-3} for the case of $B \sim 0.3$ kG. Other accessible B-lines and the estimated variations of ϕ_s and n_e on them are also presented.

In a preliminary experiment, apparent differences in ϕ_s have been observed on each magnetic surface of Heliotron J. Since the B-field strength is also varied on each of them, we can thus relate the difference in ϕ_s with the B-field strength. From the data showing the relationship between the potential variation $d\phi_s$ and the B-field strength, we assume

$$d\phi_s \propto (\Psi^{1/2})^2, \tag{1}$$

$$dB \propto \Psi^{1/2}. \tag{2}$$

Thus, the value of $d\phi_s$ can be written as

$$d\phi_s \propto (dB)^2. \tag{3}$$

From the experimental data, we obtain

$$d\phi_s \approx -242(\Psi^{1/2})^2 + 28.5, \tag{4}$$

and

$$dB \approx 5.7 \times 10^{-3}\Psi^{1/2}. \tag{5}$$

Therefore, the relationship between $d\phi_s$ and dB is represented as

$$d\phi_s \approx -75.8 \times 10^5 (dB)^2 + 28.5. \tag{6}$$

Assuming that the Eq. (6) holds also along B-field lines, we calculate variations of both ϕ_s and n_e. For the case of B-field line at $\Psi^{1/2} = 0$ (on the magnetic axis), the difference in $|B|$ between the 11.5 and 6.5 cross-sections is about $\delta B \sim -1.67 \times 10^{-3}$ T. The obtained negative value of δB means that the value of $|B|$ at the 11.5 cross-section is larger than that at the 6.5 cross-section. Thus, the value of $\delta\phi_s$ can be calculated to be ~ 7.4 V. On the other hand, for the case of B-field line at $\Psi^{1/2} \sim 0.25$, two values of δB are existed. When $\delta B \approx -2.19 \times 10^{-3}$ T is applied, $\delta\phi_s$ is about -7.80 V. If $\delta B \approx -5.63 \times 10^{-4}$ T is used, $\delta\phi_s \sim 26.1$ V is obtained.

Secondly, regarding the n_e variation, we consider the fluid force balance equation for a low density pure electron plasmas. The variation of n_e along a B-field line is expressed as

$$\frac{\delta n_e}{n_e} \approx \left(\frac{a}{\lambda_D}\right)^2 \frac{\delta\phi_s}{\phi_s}. \tag{7}$$

Here, a is the typical scale length so that we regard it as the averaged minor radius of Heliotron J. Also, $\lambda_D = \sqrt{\epsilon_0 \kappa T_e / n_e e^2}$ shows the Debye length. Substituting the value of $\delta\phi_s$ for Eq. (7), the value of δn_e is estimated to be $\sim -2.22 \times 10^7$ m^{-3} for the B-field line at $\Psi^{1/2} = 0$ (on the magnetic axis). For the case of B-field line at $\Psi^{1/2} \sim 0.25$ (off the magnetic axis), δn_e is about $1.61. \times 10^8$ m^{-3} at the 6.5 cross section, while -5.38×10^8 m^{-3} at the 10.5 cross section.

As understood from above results, the estimated δn_e is much smaller than n_e, which calls for better resolution for measurements in the series of Heliotron J experiments. Another important thing to perform the experiments would be to either increase n_e or decrease T_e. This is because λ_D is the key parameter to decide the variation of n_e along B-field lines. In fact, smaller λ_D gives rise to larger δn_e. Since T_e is probably affected by V_{acc} strongly, experiments using smaller V_{acc} should be required. In fact, if T_e becomes 1/10 times smaller, dn_e would then become 10 times larger. This will be tested soon in the next series of experiments.

1) H. Himura *et al.*, Phys. Plasmas (2007) vol.14, pp.022507.

2) M. Hahm *et al.*, Phys. Plasmas (2008) vol.15, pp.020701.

3) T. S. Pedersen and A. H. Boozer, Phys. Rev. Lett. (2002) vol.88, pp.205002.

4) D. Sugimoto, K. Nakamura, H. Himura, S. Masamune, A. Sanpei, H. Okada, S. Kobayashi, S. Yamamoto, T. Mizuuchi, F. Sano, *presented at the 17th International Toki Conference* (2008).