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Compact torus injection into the HIST spherical torus plasmas

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I. Introduction

The three-dimensional interaction of the compact torus (CT) plasmoid with spherical torus (ST) plasmas has been studied experimentally to understand magnetic reconnection, helicity current drive [1], particle fuelling [2] and two-fluid effect of high-beta torus plasmas [3]. The dynamics of the CT as it transverses the ST could be determined by the tilting motion, magnetic reconnection, excitation of waves, and expansion/contraction due to the external toroidal field B_T. Figure 1 illustrates that helicity transfer to the low-q ST plasmas by repetitive CT injection: (a) initial relaxed state, (b) CT injection after the resistive decay of the plasma current, (c) after merging, the relaxation with reconnection, yielding the original state. Alfvén waves excited during the relaxation will equilibrate toroidally the twisted magnetic field lines that results in the current drive. This study contributes on the further understandings of such a complex mechanism of CT particle fuelling and helicity transfer process.

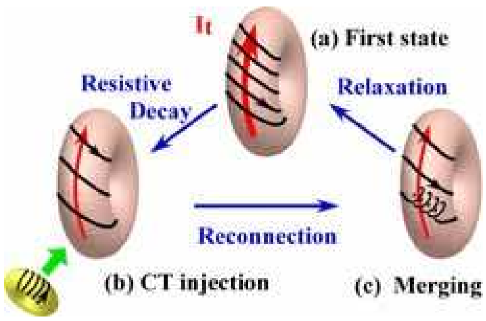

Figure 1. Helicity transfer process by the repetitive CT injection

II. Experimental setup

The CT plasma flow is produced by a single stage MCPG. The MCPG is 1.0 m long, with inner and outer electrode diameters 0.06 m and 0.14 m, respectively. The single stage CT injector was installed on the midplane of the HIST vacuum chamber as shown in Fig.2. The injector is operated with capacitor banks (30 kJ, 10 kV). The peak gun current $I_{g.max}$ is about 60 kA and its half cycle is 150 μs. The typical plasma parameters of this CT injector are as followed; plasma speed V_{ct} < 50 km/s, electron density $n_e < 5\times10^{21}$ m^{-3} and magnetic field B_p < 0.2 T. The polarity of the CT magnetic helicity is reversed by changing the direction of a bias field. Total helicity K_{CT} generated by the injector can be estimated by $K_{CT} = 2\int V_g \Psi_b dt$. Here, V_g is the gun voltage and Ψ_b is the bias flux. When the K_{CT} having the same or revered polarity as that of the ST plasmas is injected, it is so called the co-helicity injection (Co-HI) and the counter-helicity injection (Counter-HI), respectively. The HIST (R/a = 0.5 m/0.24 m) [1] was operated for the CT injection with TF coil current I_{tf} = 30 – 90 kAturns and a peak plasma current of about 150 kA.

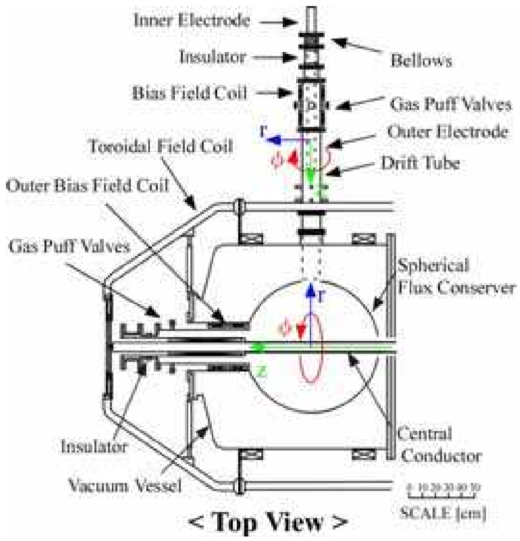

Figure 2. Schematic drawing of the HIST devise and the CT injector.

III. Experimental results

Figure 3 shows the comparison of the change in the toroidal current I_t between co-HI and counter-HI. When we reverse the polarity of the bias flux, the direction of change in the toroidal current is reversed. the increases in I_t observed in the case of the co-HI, suggesting that the magnetic helicity K is conserved during the injection.

Figure 4 shows that the contours of the outer surface poloidal magnetic field profile and the radial profile of the magnetic field in the both cases of the co-HI and the counter-HI. The fluctuation excited by the injected CT appears in the – z region in the both cases. For the radial distribution of MHD activities observed in the co-HI case, the large fluctuations can be seen around the outer edge region. In the other hand, for the counter-HI case, the fluctuation extends up to the radial position of R= 0.15m which indicates that the CT propagates deeply to the core region. In this case, we speculate

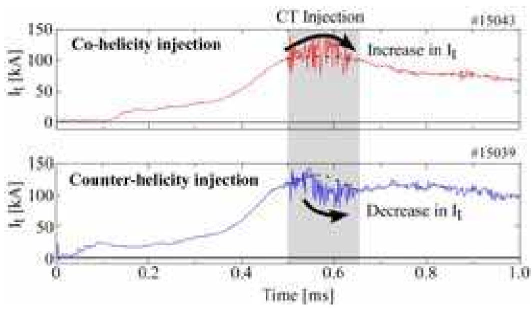

Figure 3. The time evolution of the toroidal plasma current It when the CT is injected.

that there are no anti-parallel magnetic field lines between the leading part of the CT and the ST toroidal field so that magnetic reconnection does not occur.

Time-frequency analysis shows that the fluctuation induced in the co-HI case has the maximum spectral amplitude at around 300 – 400 kHz as shown in Fig. 4. This frequency is thought to be attributed to the magnetic reconnection. The CT magnetic field lines experience fast reconnection processes near the outer edge region. As the reconnection time scale $\tau_{rec.}=(\tau_A\tau_R)^{1/2}$ is estimated to be ~ 3.4 μs by Sweet-Parker model on the assumption that the maximum reconnection width l is 0.17 m, where τ_A is Alfvén time and τ_R is the resistive diffusion time of the CT plasmas, the outer poloidal field lines of the CT may reconnect with the toroidal field instantly after the CT injects in the peripheral region. Continuous reconnection may produce the fluctuations with the frequency $f_{rec.}$ ~ 300 kHz that estimated by $1/\tau_{rec}$. This value agrees roughly with the observation.

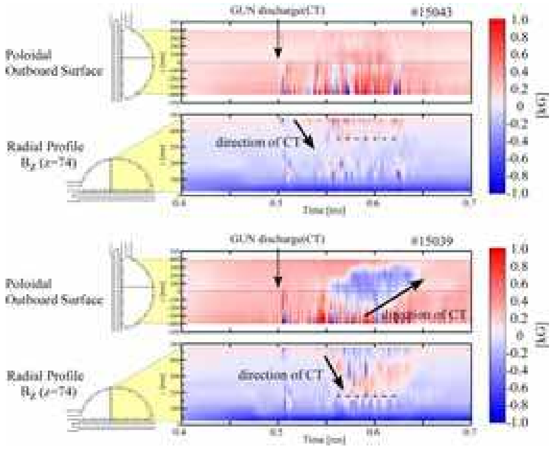

Figure 4. Time evolution of magnetic field profiles measured by using the outer surface magnetic probe and the internal magnetic probe.

Figure 4 shows the comparison of the electron density measured at R= 0.25 m in the both injection cases. As compared to the co-HI case, the counter-HI shows that the density in the core starts to increase after the delay of about 80 μs from the injection time. The higher density increment rate and the longer delay time in the case of the counter-HI may be associated with the deeper penetration without reconnection.

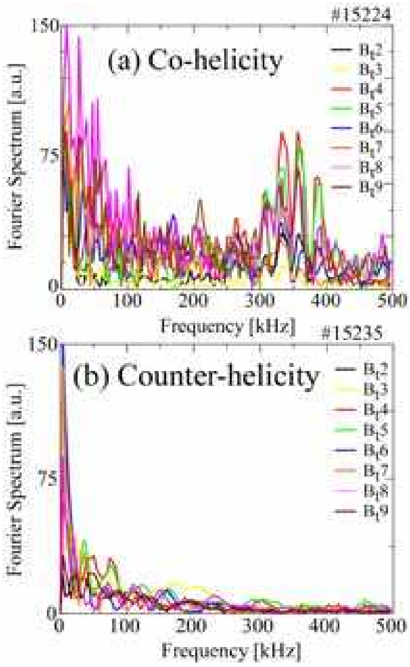

Figure 5. The time-frequency spectrum of the observed magnetic fluctuations is analyzed by FFT.

At the same time, we have observed the other MHD fluctuation propagating in the toroidal direction with the lower frequency of 50 – 100 kHz which changes as varying the strength of the toroidal magnetic field (TF). The estimation of Alfvén frequency f_A indicates the excitation of Alfvén wave by CT injection. Figure 6 shows the time evolution of the electron density measured by means of a double electrostatic probe. As compared to the co-HI, the counter-HI has the larger increment of density by CT injection and also the delay time between the injection time and the density rising time is longer. This result also suggests that for the counter-HI, the CT does not reconnect with the ST fields leading to the deep penetration.

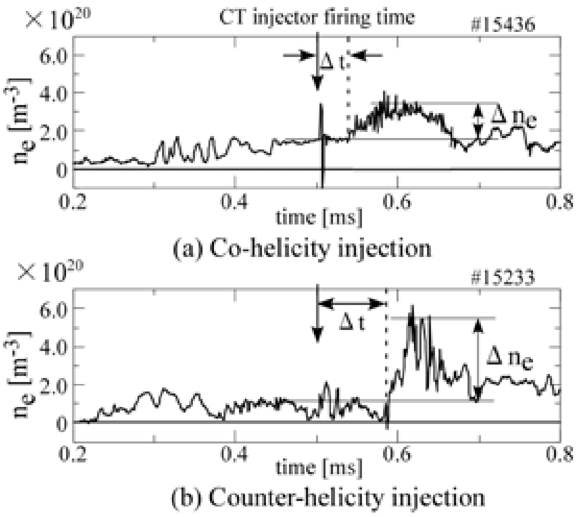

Figure 6. The electron density is measured at R=0.225 m . The density increment

IV. Conclusions

We have examined how the sign of helicity (Co-HI and Counter-HI) of the injected CT influences on the ST plasmas. The dynamics of the CT plasma flow were identified to be significantly different between the both injection cases. As for the counter-HI case, the CT could penetrate deeply into the core region because of no magnetic reconnection. In the other hand, in the case of the co-HI, the reconnection occurs immediately after CT arriving at a periphery region and then particle and helcitiy transfer in the toroidal direction accompanied by Alfvén wave.

References

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[2] M. Nagata, et al.: Nucl. Fusion 45, 1056 (2005).
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