*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-4.103 (2005)*

Initial results of helicity and flow injection on TPE-RX reversed-field pinch

T. Asai[1], M. Nagata[2], H. Koguchi[3], S. Kiyama[3], Y. Hirano[3], Y. Yagi[3], and H. Sakakita[3]

[1] *College of Science and Technology, Nihon University, Tokyo, Japan*

[2] *Graduate School of Engineering, University of Hyogo, Himeji, Japan*

[3] *National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan*

I. Introduction

A reversed-field pinch (RFP) attracts attention as a candidate for a simple and economical fusion reactor core. However, it is still necessary to improve the methods of confinement, fueling and sustainment. In the RFP plasma, the poloidal current is sustained through the dynamo activity. The dynamo activity is the consequence of tearing instabilities which degrade the energy confinement. Therefore, the external poloidal current drive is a longstanding problem in the RFP research to improve energy confinement. The pulse poloidal current drive (PPCD) [1] is an efficient means of solving this problem, but not in the steady-state. We have proposed a method in which a magnetized plasma flow (MPF) with a large amount of a magnetic helicity contents is injected into the edge region to drive the poloidal current non-inductively. Also, this possible non-coaxial helicity injection current drive has been tested as an assist of RFP start-up. In the spherical tokamak (ST) experiments,

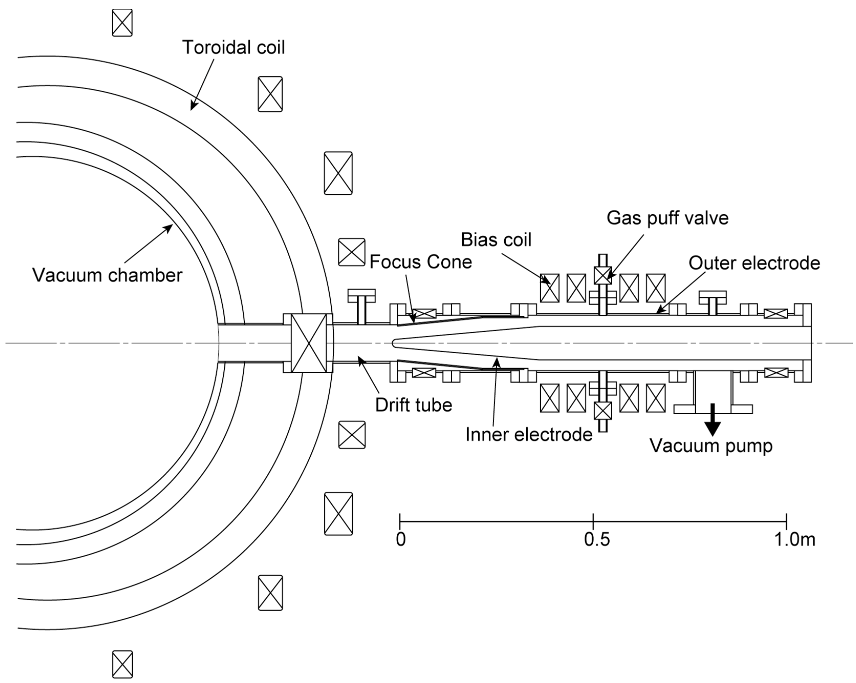

Fig. 1 Schematic view of a poloidal cross section (toroidal angle $\phi = 225°$) of TPE-RX device and a helicity injector.

various methods of non-inductive start-up and sustainment have been studied *e.g.* coaxial-helicity injection (CHI), neutral beam injection (NBI) and wave heatings[2]. Especially, for the conventional RFP with high aspect ratio, establishment of this technique can be a substitution for the CHI in a ST. Those initial experiments of MPF injection have been performed on the toroidal pinch experiment TPE-RX RFP which is one of the world's largest RFP devices [3], in order to demonstrate fueling, helicity injection and non-inductive start-up on a RFP.

II. Experimental Discription

The MPF is generated by a magnetized-coaxial plasma gun (MCPG) which is mounted radially on the mid-plane of the TPE-RX. Figure 1 shows a schematic view of the MCPG and a poloidal section (toroidal angle ϕ = 225°) of the TPE-RX. The injector has a formation capacitor bank of 367mF with a maximum charging voltage of 800V. A set of bias field coils driven by a dc power supply with 16.8V and 300A generates the bias flux up to 9mWb. Two fast solenoid-valves are mounted on the middle of the outer electrode for deuterium gas-puffing. A maximum gun current of 40-60kA generates a MPF with approximately 17km/s of flow velocity and 3-5 ms duration time. The polarity of the magnetic helicity can be reversed by changing the direction of a bias field. Total helicity K_{inj} generated by the gun helicity source can be estimated by $K_{inj} = 2\int V_g \Psi_b dt$ [4]. Here, V_g is the gun voltage and Ψ_b is the bias flux. In the present experiments, the maximum helicity is approximately 2.5mWb^2.

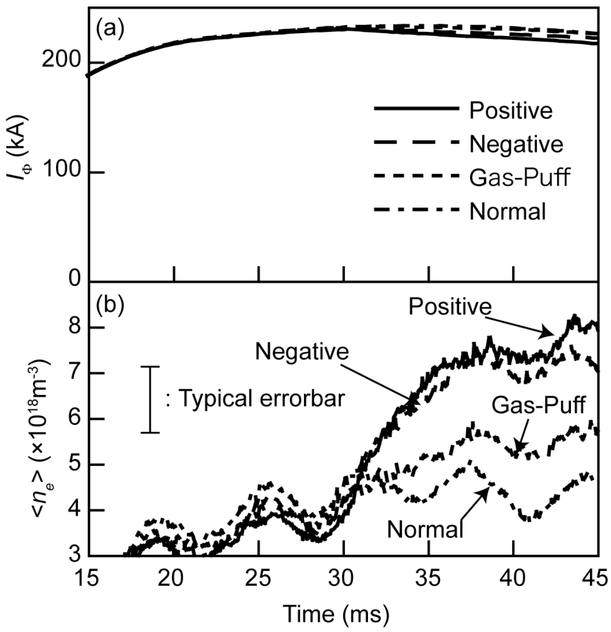

Fig. 2 Time evolution of (a) plasma current I_Φ and (b) line averaged electron density $<n_e>$ measured at ϕ=135.

III. Helicity injection experiment

Fueling and helicity injection effects of the MPF have been studied. The experiments were performed with a flattop plasma current I_Φ of 230 kA and line-averaged electron density $<n_e>$ of 5_10^{18} m^{-3}. The operating condition was chosen to avoid a saw-tooth crash, which would hinder observation of the response of the RFP to plasma flow injection. In this experiment, the trigger time of MCPG was fixed at t = 30 ms from the start of I_Φ.

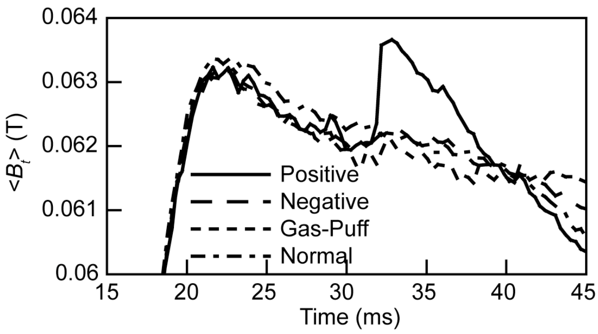

Fig. 3 Time evolution of volume averaged toroidal magnetic field.

Typical time evolutions of I_Φ and $<n_e>$ are shown in Fig.2. The curve in Fig.2(b) shows the twofold increase in $<n_e>$; from 4_10^{18} to 8_10^{18}m^{-3} with ~5 ms rise time. The particle content increased by ΔN_{RFP} (= Δn_g _ V_p) ~ 2.8_10^{19} and the particle inventory of the plasma flow was N_{inj} ~ 3.8_10^{19}. Therefore, the fueling efficiency ε = $\Delta N_{RFP}/N_{inj}$ was roughly 74% [4]. This increase rate was approximately twice as fast as that in the case of singly- operated gas-puffing on MCPG (dashed line). Note that the impurity line intensities of Mo II and Fe I (at ϕ = 225°) did not show any apparent increase of influx rate during the injection.

We observed an increase of the toroidal flux, which exhibited a clear dependence on the polarity of the injected magnetic helicity. Figure 3 shows time evolutions of the volume averaged toroidal magnetic field. In the case of positive (the same sign as the target RFP) helicity injection, the field increased by approximately 2.4%. On the other hand, almost no change was observed either in the negative-polarity or gas-puff cases. At the toroidal position where the injector is mounted, the cross-sectional average toroidal field increases by approximately 10%, which propagates toroidally in the opposite direction of I_Φ. These results indicate the possibility of an edge dynamo electric field induced by positive helicity injection and a self-generation of the toroidal flux. During the injection phase, the increment of volume integrated helicity is 1.72mWb^2. Here, the amount of helicity is roughly estimated by integrating over the relation $dK/dt = \Phi V_\Phi - \Psi V_\theta$ (Φ: toroidal flux, V_Φ: toroidal voltage, Ψ: poloidal flux and V_θ: poloidal voltage)[5]. Generated helicity by MCPG was approximately 2.5mWb^2, therefore the efficiency of helicity injection is 69%.

IV. Start-up Assist

Application of the MPF injection for the RFP start-up has been tried. The magnetized plasma is initially injected into vacuum vessel by the MCPG instead of gas-fill operation used in the case of usual RFP start-up. The MCPG is triggered 2ms before the start of plasma current. Figure 4 shows the time evolution of line averaged electron density in the case of normal start-up and MCPG assisted. In the case with MCPG, density pump-out was not observed and relatively constant density evolution followed. This indicates the MCPG initiation reduced the gas density limit for the breakdown and lowered the neutral particle inflow caused by recycling process in the flattop phase. Effect of injected helicity (magnetic energy) on the relaxed RFP configurations will be studied in the following experiments.

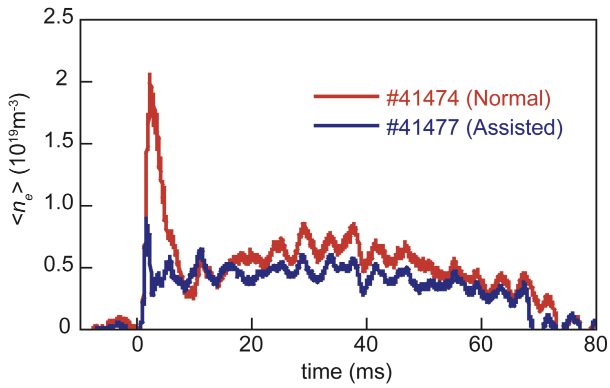

Fig.4 Time evolution of line-averaged electron density $<n_e>$.

V. Summary

In summary, the MPF injection experiments have been started successfully on TPE-RX RFP. The fueling effect of plasma flow injection has been clearly shown. Also, an increase in the toroidal flux due to the MPF injection and its dependence on the helicity polarity have been observed. Furthermore, the effect of plasma flow injection on RFP start-up was also demonstrated. Further investigation on the mechanism of the poloidal current drive and flow effect is underway, and shall be reported elsewhere.

The first author acknowledges useful discussion with T. Takahashi (Nihon University). This work is supported by Grants-in-Aid for Scientific Research and the Budget for Nuclear Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan and Grants-in-Aid for Specially Promoted Research, College of Science and Technology, Nihon University.

References

[1] S.Sarff, N. E. Lanier, S. C. Prager *et al.*, Phys. Rev. Lett. **78**, 62 (1997).

[2] for example, S. M. Kaye, M. G. Bell, R. E. Bell *et al.*, Phys. Plasmas **8**, 1977 (2001).

[3] Y.Yagi, S. Sekine, H. Sakakita *et al.*, Fusion Eng. Design **45**, 409 (1999).

[4] N. Fukumoto,Y. Inoo, M. Nomura *et al.* Nuclear Fusion **44**, 982 (2004).

[5] J. W. Johnston, Plasma Phys **23**, 187 (1980).