21PB-087

Responses of FRC plasma to a magnetized plasmoid injection
磁化プラズモイド入射によるFRCプラズマの応答

[1]Hirotomo Itagaki, [2]Tomohiko Asai, [3]Michiaki Inomoto and [2]Tsutomu Takahashi
[1]板垣宏知, [2]浅井朋彦, [3]井通暁, [2]高橋努

[1]Advanced Industrial Science and Technology
1-1-1, Umezono, Tsukuba, Ibaraki 305-8568, Japan
産業技術総合研究所 〒305-8568 つくば市梅園１－１－１
[2]College of Science and Technology, Nihon University
1-8-14, Kanda-Surugadai, Chiyoda, Tokyo 101-8308, Japan
日本大学理工学部 〒101-8308 千代田区神田駿河代１－８－１４
[3]Graduate School of Frontier Science, The University of Tokyo
5-1-5, Kashiwanoha, Kashiwa, Chiba 277-8561, Japan
東京大学大学院新領域創成科学研究科 〒277-8561 柏市柏の葉５－１－５

A FRC has favorable features such as extremely high beta, natural diverter, linear device geometry and without central structure. However, lifetime of the FRC has been severely restricted by the rotational instability generally appeared in dynamically formed FRC and has been known as most destructive instability for the FRC. In this study, magnetized plasmoid injection into FRC by double-sided magnetized coaxial plasma gun has been conducted on the Nihon University Compact Torus Experiment (NUCTE), aiming to mitigate spin-up of a FRC. The injected plasmoid has spheromak like configuration and travels axially to merge with the pre-existing FRC. Suppression of toroidal spin-up and mitigation of rotational instability were achieved by the double-sided plasmoid injection without degradation of the plasma performance

1. Introduction

A FRC has been a potential candidate as advanced fusion reactor core plasma since the FRC has favorable technological futures: extremely high beta, natural diverter, linear device geometry and elimination of central structure [1]. Although the FRC has these attractive features, problems have still remained. One of critical issues is to suppress toroidal spin-up since the rotational instability, which is most destructive instability for dynamically formed FRC and is an interchange-like mode driven by the centrifugal effect in rotating plasmas, severely restricts a lifetime of FRC [2].

In this study, plasmoid injection into FRC by double-sided magnetized coaxial plasma gun (MCPG) has been conducted on the Nihon University Compact Torus Experiment (NUCTE) [3], aiming to suppress the rotational instability.

2. Experimental set-up

This experiment has been performed on NUCTE-III which is θ-pinch-based FRC device. The NUCTE-III consists of a quartz discharge tube with 2 m in length and 256 mm in I.D., a one turn theta-pinch coil with 32 elements and two MCPGs on both ends as shown in fig.1. The diagnostic for measuring typical plasma parameters consists of a flux loops with set of magnetic probes to determine an axial profile of the separatrix radius r_s, He-Ne interferometer to measure line-integrated electron density $\int n_e dl$ and ion Doppler spectrometer to determine an ion toroidal flow speed and ion temperature. Besides 60 optical diagnostic systems consists of collimator, grass optical fiber tube and photo multi-plier tube with a band pass filter ($\lambda = 550 \pm 5$ nm) were mounted on the quartz discharge tube for Bremsstrahlung measurement.

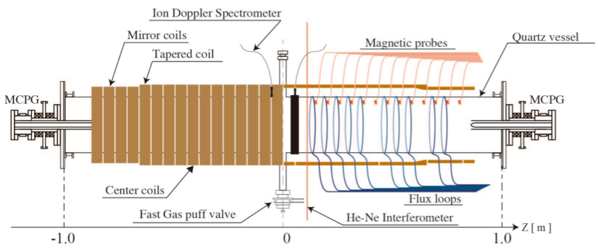

Fig.1. A schematic view of NUCTE –III with two MCPGs

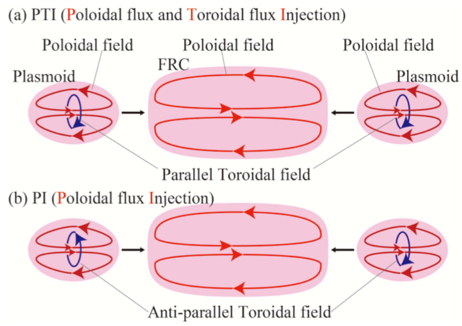

Fig.2. The conditions of double-sided plasmoid injection of (a) PTI and (b) PI

3. Conditions of the plasmoid injection

The injected magnetized plasmoid travels axially with velocity up to 50 km/s and merges with pre-existing FRC. In addition to the plasma thermal energy, the plasmoid with spheromak-like configuration provides poloidal and toroidal magnetic fluxes to the FRC. In this double-sided plasmoid injection experiment, two injection modes were available as illustrated in fig.2; One is the poloidal and toroidal fluxes injection (PTI) in which two MCPGs produce plasmoids with parallel toroidal flux, and the other is the poloidal flux injection (PI) in which the MCPGs produce plasmoids with anti-parallel toroidal flux to be cancelled out after injection.

4. Experimental results

Table 1 shows the typical parameters of target FRC and injected plasmoid.

Table I. Typical parameters of FRC and plasmoid

	$E_{thermal}$ (J)	$E_{magnetic}$ (J)	Total inventory ($\times 10^{19}$)
FRC	2600	1800	2
Plasmoid	3 + 3	230 (PTI) / 120 (PI)	0.09

Table II. Mitigation effects of the plasmoid injection the rotational instability

	τ_{onset} (μs)	$T_{rotation}$(μs)	τ_{growth}(μs)
w/o Injection	25	15	0.7
PTI	32	21	1.7
PI	33	23	2.5

Since the total energy of magnetized plasmoids of 240 J was only 5 % of FRC total energy, injected energy by plasmoids could be neglected compared to the energy loss of a target FRC.

Table II summarizes the results of plasmoid injection on the elliptic deformation. Both injection cases showed mitigation of the instability, and the PI case showed more effective suppression; delayed onset time τ_{onset} from 25 to 35 μs, prolonged rotation period $T_{rotation}$ by 7 μs (145 % extension) and prolonged growth time τ_{growth} by 1.7 μs (300 % extension).

The mitigation on the rotational mode is possibly provided by the decrease in plasma rotation speed, or slowing down of the FRC's spontaneous spin-up. Experimental results also showed suppression of FRC's spin-up in injection cases. Figure 3 shows time evolution of toroidal angular velocity observed at the separatrix of FRCs (r~5cm). Spin-up of the FRCs with injection of plasmoids stopped to rise after 23 μs from the initiation of MCPG discharge although spin-up of no-injection case kept accelerating in the whole time. Flow velocity inside

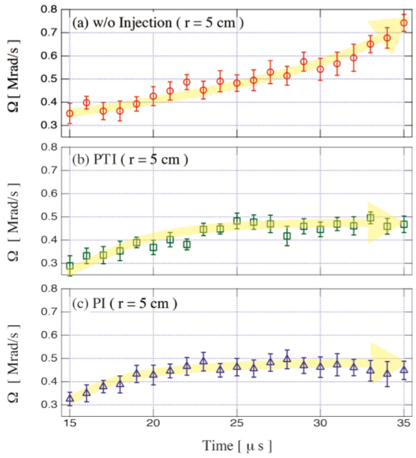

Fig.3. Time evolutions of angular velocity of the cases with and without injection case

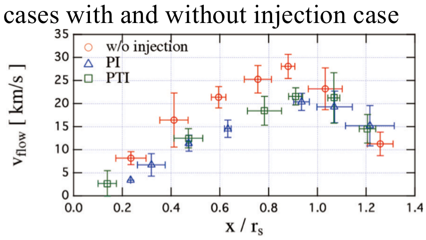

Fig.4. Radial profiles of flow velocity at t = 25 μs.

the separatrix has also been decreased as shown in fig.4. This indicates the plasmoid injection reduces a toroidal torque causing a spin-up, and then spontaneous rotation could be mitigated. Since an elliptic deformation is caused by centrifugal force by plasma rotation [2], this mitigation effect of FRC's spontaneous-rotation is considered to delay the onset time of elliptic deformation and to prolong the growth time.

5. Summary

We have demonstrated the double-sided plasmoid injection to control the rotational instability. In both injection cases we have achieved reduced angular velocity and suppressing effects of elliptic deformation. Therefore proposed method successfully mitigates the FRC's spontaneous rotation and following elliptic deformation.

Acknowledgments

This work was partly supported by NIFS collaboration NIFS14KNWP004, Grand-Aid for Scientific Research (KAKENHI) 22686085 and Nihon University *N.* Research Project.

References

[1] H. Momota, O. Motojima, M. Okamoto, S. Sudo, Y. Tomita, S. Yamaguchi, A. Iiyoshi, M. Onozuka, M. Ohnishi and C. Uenosono: Fus. Technol. **21**(1992) 2307.

[2] M. Tuszewski: Nucl. Fusion **28** (1988) 2033.

[3] T. Asai, S. Akagawa, K. Akimoto, N. Tada, Ts. Takahashi and H. Tazawa: Plasma and Fusion Res. **2**(2011) 2402151.