Characteristic of a Repetitively Injected Spheromak in a Vertical Guide-Field

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Amplified poloidal flux of spheromak has been observed in the repetitive discharge (50 kHz) of magnetized coaxial plasma gun (MCPG). In this experiment, ejected spheromak is confined within magnetic mirror configuration, and generated flux and emission has been measured. In the case of repetitive discharge, increased poloidal flux and its decay time compared to quasi-DC discharge has been observed. Also increased emission light and its decay time has been observed. These results indicates increasing of energy confinement time. In addition, global stabilization of behavior of spheromaks when it is transporting in discharge tube has been observed in repetitive discharge case.

Keywords: magnetized coaxial plasma gun, spheromak, repetitive injection, magnetic helicity, vertical guide field

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1. Inroduction

A spheromak generated by a magnetized coaxial plasma gun (MCPG) is envisioned as a fuel and magnetic helicity injector for a fusion reactor. Generally, a gun-spheromak is injected through a metallic drift chamber, which serves as a flux conserver, and into a target torus confined within a metal chamber. However, electrical insulation between a magnetized coaxial plasma gun (MCPG) and target chamber potentially has advantages for advanced application of the MCPG, e.g., current drive and control of dynamo activity. Then the behavior of spheromaks has been studied in a drift chamber made of dielectric material with a vertical (parallel to the injection axis) magnetic field which forms a radial pressure balance on the spheromaks. In the case of repetitive discharge, higher efficiency of magnetic flux generation has been observed in the case of repetitive formation of the spheromak compared to the quasi-DC discharge. However, difference of the drift motion encumbers detailed study on the generation efficiency and its mechanisms. Therefore, in this work, the efficiency of helicity generation has also been studied with a mirror confinement field.

2. Experimental Set-Up

Figure 1 shows a typical schematic diagram of experimental set-up. The device consists of drift tube, vertical-field coil and MCPG. In the present study, a Pyrex glass tube is employed as a drift tube and a mirror confinement field is applied as shown in Fig. 1. The mirror coil generates 0.06 T of magnetic field and the guide coil generates

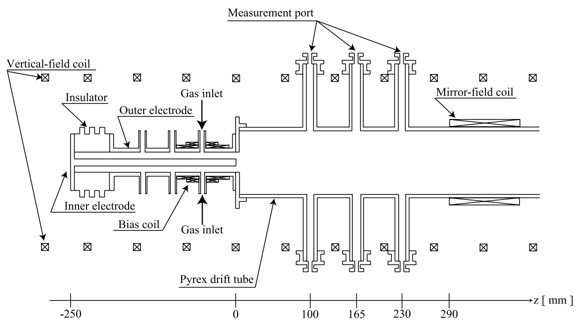

Fig. 1 Typical schematic diagram of experimental set up.

0.01 T of vertical magnetic field. Multi-channel optical diagnostics for the spatial profile of line emission and internal magnetic probes are arranged on the drift tube. A multi-channel optical diagnostic is consisted of a collimator and a photomultiplier tube with band pass filters. HeI and HeII line spectra have been observed by these band pass filters (HeII: 656 ± 5 nm and HeI: 470 ± 5 nm).

3. Discharge Circuit and Waveform

As a discharge circuit, we have employed transformer-coupled circuits. The schemaic of this circuit is shown in Fig. 2. The circuit has three switches. The discharge waveforms shown in Fig. 3 are formed by changing the sequence of switches. Here, gun-current is measured by Rogowski coil on the secondary circuit; i.e., it indicates the amount of current conducted along the plasma discharge. Also, gun-voltage is measured as the difference between the electric potentials of inner and outer electrodes. Fig. 4 shows a magnetic field line when a spheromak is ejected

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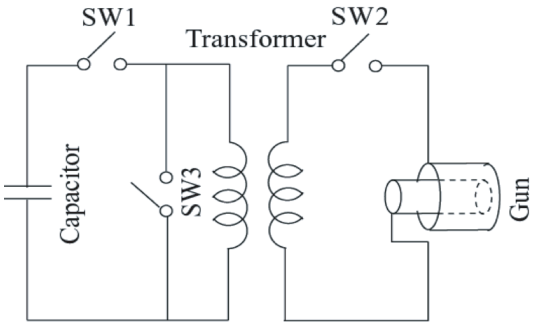

Fig. 2 Transformer-coupled discharge circuits.

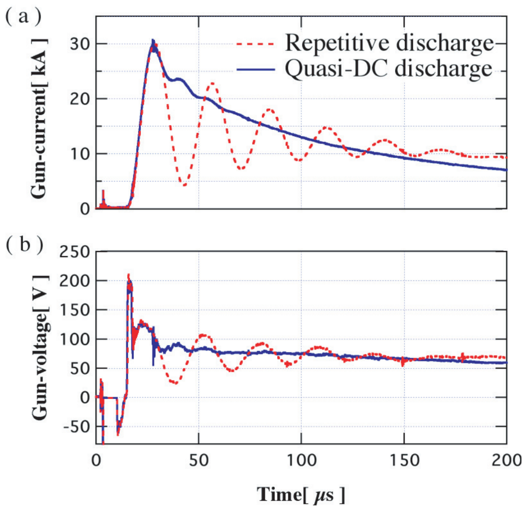

Fig. 3 Typical waveform of (a) gun current and (b) gun discharge voltage on the MCPG.

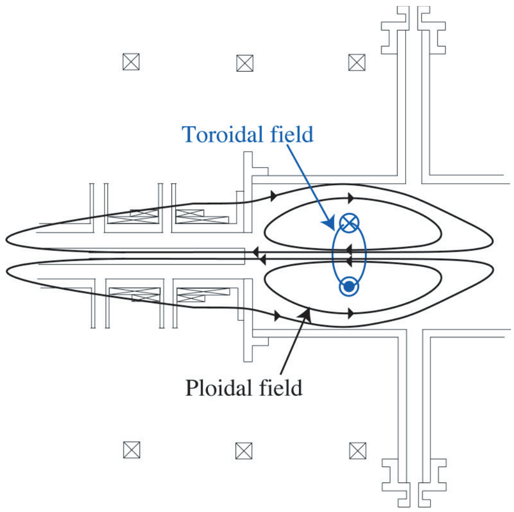

Fig. 4 Ejected spheromak from MCPG.

from MCPG. Then a part of discharge current pass through a magnetic field line. Therefore, it indicates poloidal loop voltage. The transformer makes a half-wave rectifier circuit. Then multiple discharge pulses, which can generate spheromaks with same sign of helicity, can be formed in the secondary circuit. Switch 3 acts as a crow-bar and diversion switch which can form quasi-DC and single-pulse discharges.

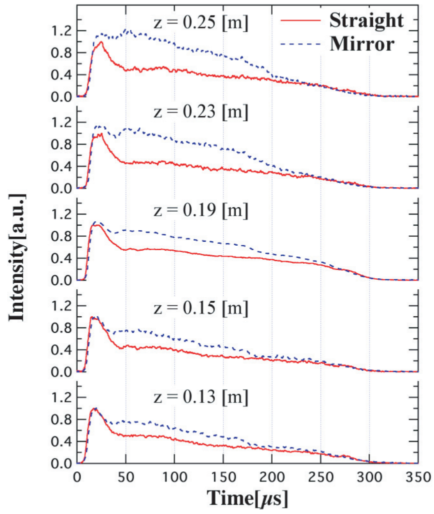

Fig. 5 Time evolution of HeII spectrum at each z-position with straight and mirror field.

4. Magnetic Mirror Configuration

Initially, the effect of a mirror field has been evaluated with quasi-DC injection. Internal magnetic field and intensity of the HeII spectrum have been measured in the case with mirror and with straight field (without mirror field). Figure 5 draws a time evolution of the HeII spectrum at each position along the z-axis. In the case with the mirror field, the decay rate of the HeII spectrum is approximately 50% less than in the case without the mirror field (straight field). This result indicates that the selected spheromak is confined and stays within the measurement region due to the mirror field. Also the increment and prolonged decay time of toroidal and poloidal magnetic field shown in an internal magnetic field measurement reinforce the confined spheromak within the vertical mirror field.

5. Effects of Repetitive Injection

The effect of repetitive injection on spheromak generation has been experimentally studied in this magnetic mirror configuration and compared to the quasi-DC operation case. A time evolution of HeII line spectrum measured by collimator with photomultiplier tube at $z = 0.19$ m is shown in Fig. 6. In the quasi-DC injection case, the HeII spectrum is monotonically decreased. However, in the repetitive injection case, increasing (t = 30-70 μs) and maintained ($t < 400$ μs) phases can be seen.

Toroidal and poloidal magnetic fields have also been measured by an internal magnetic probe array installed at the second port of the drift tube ($z = 0.165$ m). Time evolution of center poloidal field and toroidal field measured

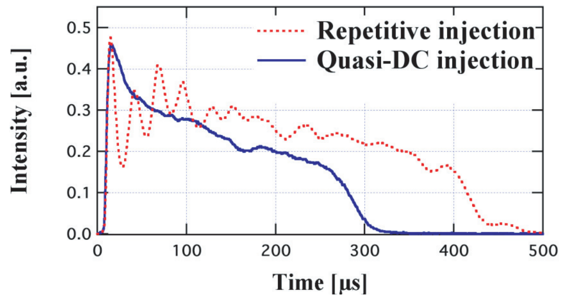

Fig. 6 Time evolution of helium ion (HeII) spectrum intensity.

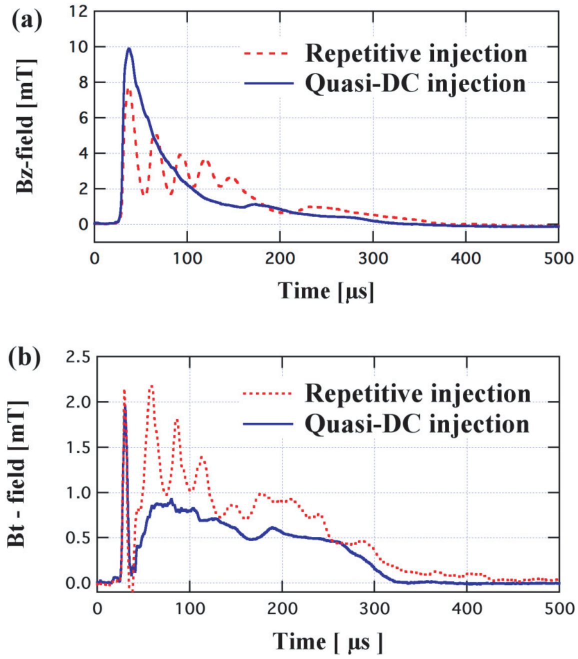

Fig. 7 Time development of (a) poloidal (vertical) and (b) toroidal magnetic field density observed by the internal probe array.

by a quarter of the discharge tube at $r = 0.025$ m are indicated in Fig. 7. Then r is defined as distance from center of device axis. At the pulse-peak of edge poloidal field in the repetitive discharge case is increased as compared to the quasi-DC injection case after the second discharge pulse. Toroidal field in repetitive injection is also increased as compared to quasi-DC injection. This increase of magnetic field in repetitive injection is potentially caused by the higher efficiency of magnetic heicity generation in repetitive operation; e.g., higher efficiency of inductive drive of toroidal current.

A higher increment has also been observed in toroidal field. Of significant difference from poloidal magnetic field is the lower decay rate of field density, especially after 4 major ejected pulsed spheromaks. Similar phenomenon has also been measured in the helium ion spectrum (Fig. 6). This may indicate increased flux and energy confinement in the spheromak generated by repetitive discharge of the MCPG.

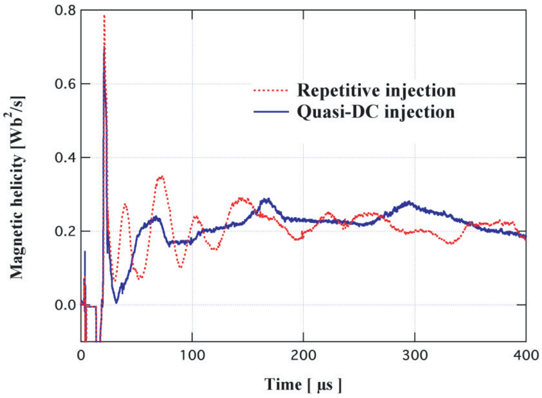

Fig. 8 Time derivative of helicity injected from MCPG.

6. Discussion

Magnetic helicity [1] generated by the MCPG can be estimated as

$$\mathrm{d}K_{\mathrm{inj}}/\mathrm{d}t = 2V_{\mathrm{g}}\Psi_{\mathrm{g}}. \quad (1)$$

the time derivative of magnetic helicity injected from MCPG to spheromak is defined as the product of gun-voltage V_{g} between electrodes and magnetic flux Ψ_{g} supplied by a bias solenoid coil [2,3].

The time evolution of $\mathrm{d}K_{\mathrm{inj}}/\mathrm{d}t$ is shown in Fig. 8. In the repetitive discharge case, higher fluctuation level has been observed during 0 to 400 µs because of the fluctuating discharge pulse. However these waves indicate that the amount of magnetic helicity generated at the MCPG does not have significant difference between the cases of repetitive and quasi-DC discharge as expected from the time evolutions of gun voltage and flux. This is consistent with the measurements of magnetic field and HeII spectrum (Figs. 6 and 7). Namely, the intensity of the helium ion spectrum and magnetic fields have almost the same value just after major injection of the spheromak even with what.

However, significantly different decay rates of these parameters follow after injection. This shows the improved plasma confinement feature of the spheromak. In the case of repetitive discharge, collision between an ejected spheromak is occurred. Then it seems that there are a possibility of magnetic reconnection event. Increased plasma temperature, therefore less resistance due to thermalization by the dissipation of magnetic energy through the magnetic reconnection events [5], can be a possible mechanism of these observed phenomena.

Global movement of the spheromak has also been observed. The measurement (Fig. 9) shows less displacement and movement have been seen in the case with repetitive operation. Direct relation of this phenomenon to the difference of the discharge feature has not been identified yet. However, this is also a possible cause of prolonged decay time of magnetic field and emission.

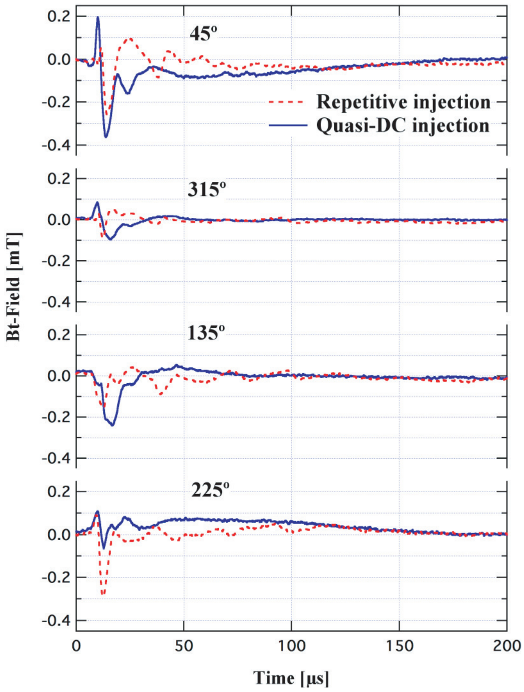

Fig. 9 Time history of toroidal field measured in the poloidal cross section at $z = 165$ mm.

7. Summary

In the repetitive injection case, an increased intensity of HeII line spectrum has been observed in the time with spheromak injection from the MCPG (30-75μs). Prolonged decay time has also been observed after the injection phase. This indicates improved an confinement property with repetitive injection. This is corroborated by the prolonged decay time of toroidal and poloidal magnetic field density in the case of repetitive injection.

These phenomena have been observed while the amount of magnetic helicity generated at the MCPG does not have significant difference in repetitive and quasi-DC discharges. Reduced global displacement and movement have also been observed in the case with repetitive operation. This is also a possible mechanism of improved confinement. To study the mechanism of stabilized grobal motion, detailed observation has been continued and the results will be presented elsewhere.

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