J. Plasma Fusion Res. SERIES, Vol. 6 (2004) 492–495

Compact Torus Plasma Injector in High Repetition Rate Operation

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(Received: 9 December 2003 / Accepted: 24 February 2004)

Abstract

Compact torus plasma injection with high repetition rate has been experimented. Using the same polarity oscillating current as a power source, a magnetized coaxial gun could generate a series of compact torus plasma with the same helicity sign in a high repetition rate. A series of generated compact torus plasmas was injected into a drift tube. The second generated compact torus plasma interacted with the decayed first one. Accumulation effect was observed though the experiments were conducted in the drift tube. The repetition frequency of the compact torus plasma was increased from 50 KHz to 70 KHz. The ratio of accumulation effect increased remarkably by increasing the repetition frequency.

Keywords:

compact torus, spherical torus, high repetition rate CT injector, coaxial helicity injector, fueling, current drive, sustainment

1. Introduction

It is promising that injection of compact torus (CT) plasma (CT plasma also includes spherical tokamak) is a useful way for starting up an initial plasma, for putting on fuel particle and for sustaining of main tokamak plasma and spherical tokamak plasma. A CT plasma can be injected deeply and fueled particle the interior of main tokamak. Comparing with the other sustainment methods the CT plasma injection supplies many torus plasma components of main tokamak plasma. The CT plasma itself has all plasma parameters and components of main tokamak plasma.

For effective fueling and sustainment, single pulsed injection of small CT plasma is not sufficient in many cases [1]. Therefore high repetition rate CT injector is required.

We have experimented on the CT plasma injection with high repetition rate and studied effect of an increasing repetition rate. The CT plasma was generated by a small magnetized coaxial gun (be also called as Coaxial Helicity Injector: CHI). Using same polarity oscillating current as a power source, the magnetized coaxial gun can generate a series of the CT plasmas with high repetition rate.

A series of the generated CT plasmas was injected into a drift tube. A metal (SUS) made drift tube was used for measurement of magnetic field structure of the injected CT plasmas. A transparent drift tube that was made of pyrex glass was used for an observation of cross sectional view of the plasma in the drift tube by a fast-gated image intensifier (FGII) camera.

The first plasma that was generated by the first current pulse of gun moved into the tube. According to the decreasing of the first gun current, the injected first plasma decayed. The second gun current pulse generated the next CT plasma. The second CT plasma moved into the tube and interacted with the former decayed CT plasma.

Therefore we observed the accumulation effect by the interaction between the second plasma and the first one, though the experiments were conducted in the drift tube.

2. Estimate of helicity injection

It is possible that repetitive CT injection can sustain helicity, particle and many other components of torus plasma. We tested a simple model of repetitive helicity injection. In the repetitive CT injection case, we estimated the helicity from the following next helicity balance equation [2]

$$\frac{\mathrm{d}H}{\mathrm{d}t} = -\frac{H}{\tau_H} + f 2V_g\,\phi_g$$

where H is the helicity of the CT plasma in the drift tube. The second term of the RHS consists of voltage pulse V_g that is repetitively supplied to the magnetized gun and magnetized flux ϕ_g threaded electrodes. A function f includes frequency or repetition rate. The helicity in the drift tube decays with time constant τ_H. When the CT plasma is resistive, the helicity decay time can be estimated by the magnetic energy decay time. For simplicity, it is assumed that the injected CT plasma relaxes faster than the helicity decay time.

At the beginning the injection term is given. The flux ϕ_g is constant and the gun voltage V_g is applied as repetitive pulse. The gun voltage pulses with two different repetition

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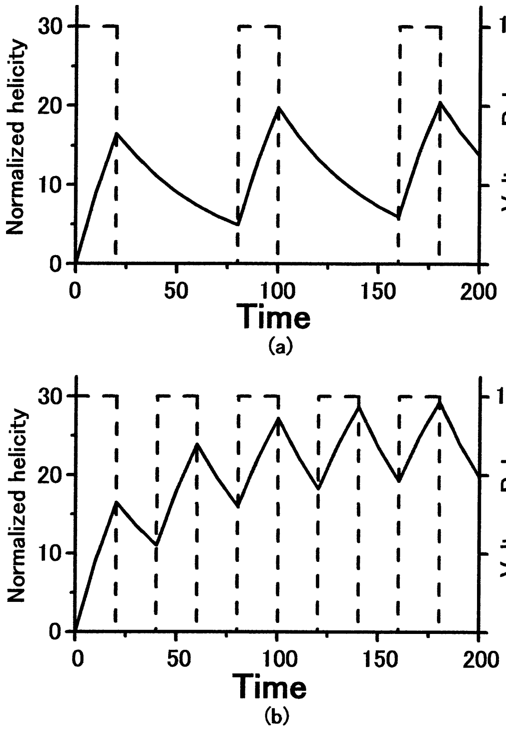

Fig. 1 A model of accumulation effect by increasing repetition frequency.

rates are shown as broken line (square pulses) in Fig. 1 (a), (b). The decay time constants τ_H are estimated by resistive diffusion time of the magnetic field and are assumed as the same in both calculations. The numerical solutions of resulting normalized helicity are plotted as solid line (sawtooth like pulse) in Fig. 1(a), (b). If we select the proper repetition rate the normalized helicity is accumulated and finally sustained continuously.

3. Experimental apparatus

The schematic drawing of experimental device is shown in Fig. 2. The magnetized coaxial gun ① generates and injects CT plasmas into the drift tube in high repetition rate. The diameters of inner, outer electrode and these lengths are 2 cm, 4 cm and 20 cm respectively. Fast acting valve ② supplies He gas from this port. Drift tube ③ is set on in front of the magnetized plasma gun. In this experiment drift tube of pyrex glass is used mainly for the observation of whole plasma by FGII camera. The diameter and the length of the drift tube are 10 cm and 100 cm respectively. An external solenoid coil ④ generates axial magnetic guide field on the drift tube. The center conductor ⑤ is set on the axis of pyrex drift tube all the way long.

One of the discharge circuits to generate repetitive current pulses with the same polarity is shown in Fig. 3 (a). The capacitance and the magnetized coaxial gun are connected with a transformer. Both primary circuit and secondary circuit have start switch .The primary circuit of the transformer is switched on and when the current of the circuit reaches the peak value the secondary circuit is switched on. In order to study the accumulation effect the capacitor of the gun was decreased to 4.4 μF. Figure 3 (b) shows two current waveforms that flow into the magnetized coaxial gun. The solid line is the waveform in 8.8 μF capacitor and the frequency is f = 50 KHz. The broken line is the waveform in 4.4 μF and the frequency is f = 70 KHz. The doted line is the waveform that the switches of primary and secondary circuit are turned on simultaneously. This case allows alternative polarity current and then the helicity of each generated CT plasma changes the sigh alternatively.

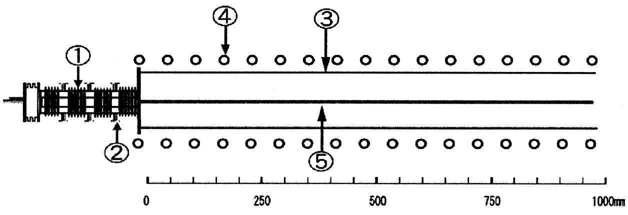

Fig. 2 Setup of pyrex drift tube experiment.

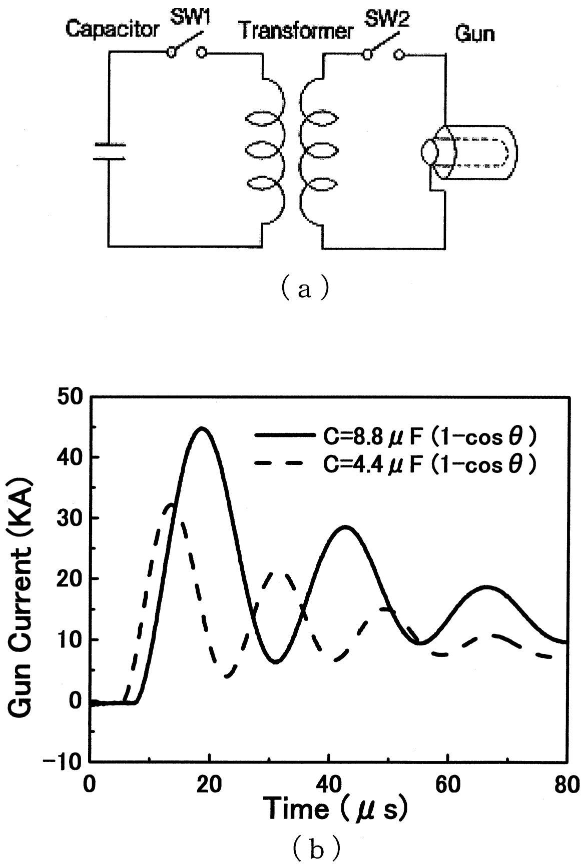

Fig. 3 Discharge circuits (a) and gun currents (b).

A CCD camera with fast-gated image intensifier was used to take a side view of CT plasma in the pyrex drift tube.

Two band-pass filters were prepared for the spectroscopic observation. Central wavelength of one filter was 468.6 nm for the first ionized He ion line. Another one was 587.6 nm for the excited neutral He atom. We took two pictures for each filter in same conditions from different shots. Intensity ratio for each pixel of the two pictures transform into a distribution of plasma temperature by means of line pair method.

4. Experimental results

The first experiments were carried out by using 8.8 μF capacitor. Magnetic flux loops lapped around on the pyrex drift tube measured the flux change in the guide field. The flux change was measured at four positions on the drift tube. Figure 4 shows a contour map of the flux change on axial distance-time (z-t) plane. Axis of abscissas is the time from the start of current in the primary of the gun circuit. Axis of ordinates is the axial distance from the gun muzzle. The values of flux change are shown on the contour in unite of $\times 10^{-5}$ Wb. Three or more blobs of the CT plasma are ejected from the magnetized coaxial gun. The period and the frequency of repetition are 24 μs and 50 KHz respectively. These values are correlated with the period and the frequency of the gun current pulse. The typical drift speed is 40 Km/s.

Accumulation effect is estimated by the ration of peak flux change for the numerical order of injected CT plasma to the peak flux change for the first one. Figure 5 shows the flux change ratio for the different external guide fields.

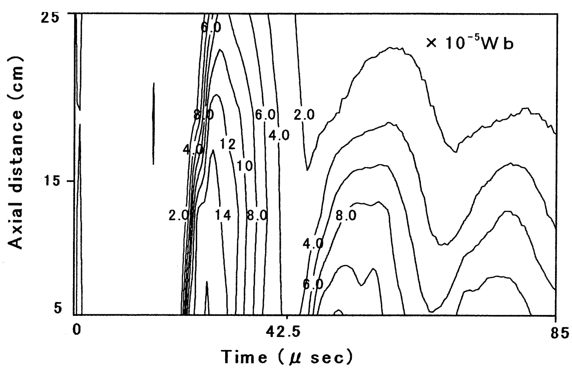

Fig. 4 Contour map of flux change on *Z-t* plane. Repetition frequency 50 KHz.

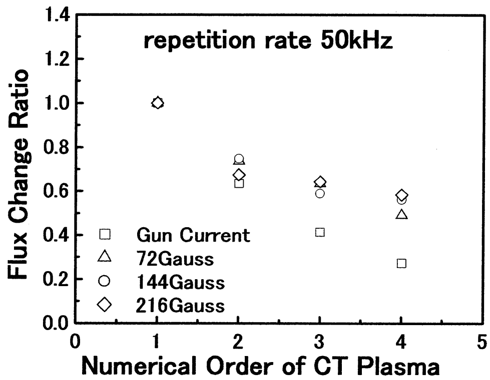

Fig. 5 Flux change ratio in 50 KHz repletion frequency.

Fig. 6 Temperature distribution in the drift tube.

The ratio of flux change for the second CT plasma to the first CT plasma is typically 0.7. This figure also shows the ratio of the peak gun current normalized by the first current. The gun current ratio of the second pulse to the first one is 0.6. A slight accumulation effect was observed in this repetition rate.

We observed a series of injections of luminous CT plasmas. The side view of CT plasmas looked like a convex parabolic. The shapes for each CT plasma were similar to the solutions analyzed by P.M. Bellan [3] even though the experimental conditions are more complicated and the analysis is not strictly applicable in this experiment.

Figure 6 shows a temperature distribution in the drift tube. The contrast of the picture is changed from the original for printing. The highest temperature of the luminous parts is around 10 eV.

Plasma density was not measured in this experiment, however, averaged density from the former measurement by He-Ne laser interferometer showed 1.5×10^{20} m^{-3} at peak density.

Figure 7 shows a contour map of the flux change on axial distance-time (z-t) plane. Four or more blobs of the CT plasma were ejected from the magnetized coaxial gun. The period of repetition becomes 18 μs (f = 70 KHz) which correlate with the period of the gun current pulse. The flux change ratio is shown in Figure 8. The ratio of flux change for the second CT plasma to the first CT plasma is 1.0~1.1.

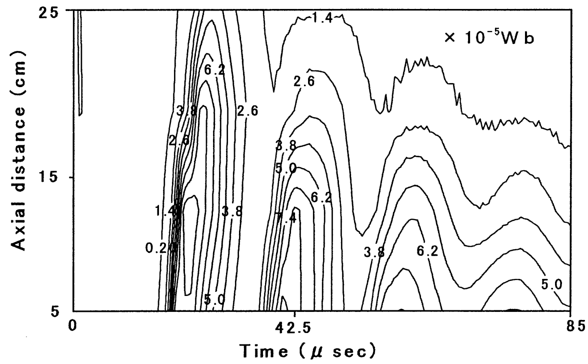

Fig. 7 Contour map of flux change on *Z-t* plane. Repetition frequency 70 KHz.

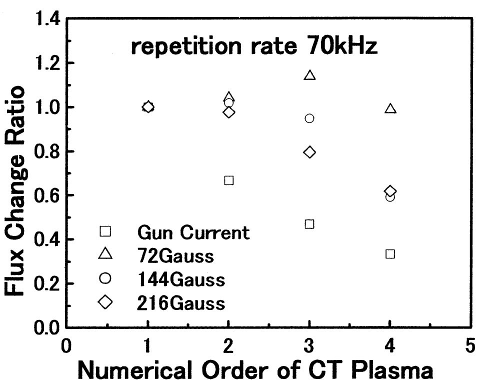

Fig. 8 Flux change ratio in 70 KHz repetition frequency.

The gun current ratio of the second pulse to the first one is almost the same as 0.6. Increasing the repetition frequency from 50 KHz to 70 KHz, accumulation effect increased from 0.7 to 1.0~1.1.

5. Summary

Increasing 1.4 times the repetition rate, the ratio of flux change raised from 0.7 to 1.0~1.8. The ratio of the second gun current to the first current was both same. The accumulation effect was increased remarkably.

References

[1] T. Ogawa *et al.*, Nucl. Fusion **39**, 1911 (1999).

[2] C.W. Barns *et al.*, Phys. Fluids **29**, 3415 (1986).

[3] S. Shimamura *et al.*, J Plasma Fusion Res. **l3**, 494 (2000).

[4] P.M. Bellan, *Spheromaks* (Imperial College Press, 2000) p.162.