Switching of Compact Toroid Traveling Direction in Forked Drift Tubes by Applying External Magnetic Fields

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As a new approach for vertical compact toroid (CT) injection, we have proposed a magnetically control method of CT transport for the purpose of injecting a CT vertically in any radial direction by a single CT injector. We have successfully demonstrated switching of the CT traveling direction in a forked drift tube by the application of an external magnetic field.

Keywords:
Compact Toroid (CT), CT injection, refueling, forked drift tube

The compact toroid (CT) injection method has been proposed as an advanced technology for refueling in fusion reactors [1]. Experimental demonstration of the technique has thus far been conducted in tokamaks using "horizontal" CT injection [2,3]. However, adverse effects of toroidal fields on the horizontal CT injection were reported [4]. In order to avoid these effects, we proposed "vertical" CT injection with a curved drift tube to change the direction of CT propagation, and have experimentally demonstrated efficacy of CT transport using the curved drift tube [5]. Furthermore, we recently proposed vertical CT injection with forked drift tubes so that the CT can be vertically injected in any radial position in the target plasma, as shown in Fig. 1. The radial injection port can be flexibly switched shot-by-shot by applying an external magnetic field (the kick magnetic field), which acts as a magnetic wall to obstruct one exit in the forked drift tube, guiding the CT to another exit. To study this unique control method of CT propagation, experimental switching of the CT traveling direction in the forked drift tube was conducted using the HIT-CTI2 [5] at the University of Hyogo.

The experimental set-up of the forked drift tube, the kick field coils and diagnostics are shown in Fig. 2. We observed a CT propagating at each port – P1T, P3 and P4 – along the drift tube using multi-channel magnetic probe arrays, which were inserted transversely into the CT plasma. Double electrostatic probes are set at the P1B and P5T ports to measure the electron density of the CT. Visible spectroscopic measurements were performed at the P2 and P5S ports.

Figure 3(a) and (b) show the electron density (P1B) and the spectral line intensity of CIII (P2), and the time evolution of the magnetic field B_z at the center channel (P1T) measured before the forked drift tube, respectively. The radial profiles of B_z and B_x at 65.5 μs shown in Fig. 3(c) correspond to the

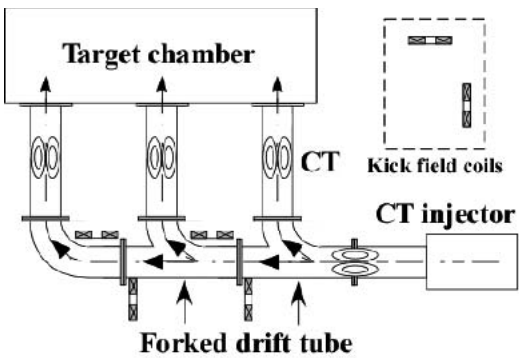

Fig. 1 Conceptual drawing of CT injection in multiple positions with a forked drift tube. The position is switched by applying a "kick magnetic field".

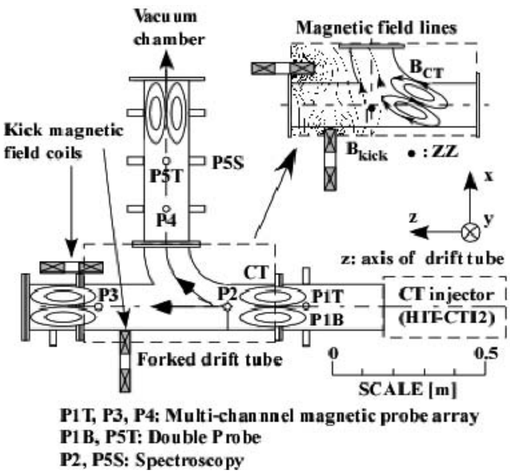

Fig. 2 Schematic of a forked drift tube and kick magnetic field coils, and the kick magnetic field and CT poloidal field (B_{kick} and B_{CT}) to lead a CT into the curved drift tube. B_{kick} is applied 1905 μs before CT firing, and then is maintained at about 0.5 kG at ZZ during CT transport.

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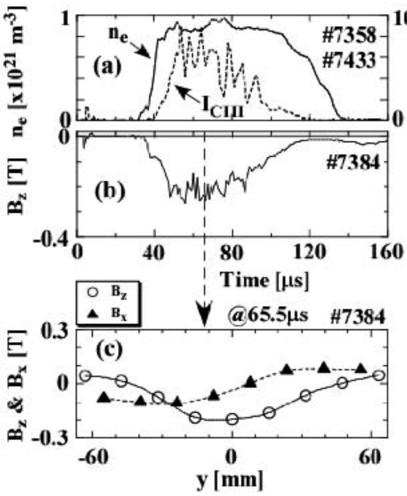

Fig. 3 Typical characteristics of an initial CT plasma before the forked drift tube region. (a) Time evolution of the electron density and the carbon ion line of CIII, (b) B_z at the center channel, and (c) Typical profile of B_z and B_x.

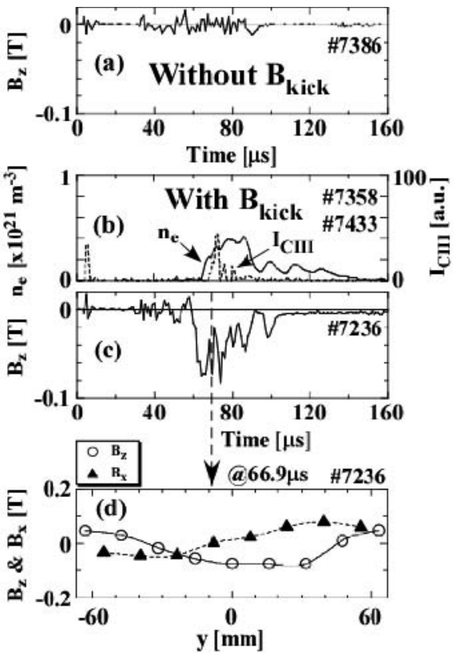

Fig. 4 (a)(c) the B_z signals in the downstream section of the forked drift tube without and with B_{kick}. (b) Time evolution of the electron density and CIII, and (d) typical profile of B_z and B_x with B_{kick}.

poloidal and toroidal magnetic field profiles of CT plasmas, respectively. When the kick magnetic field was not applied, we did not observe the B_z signal at P4, as shown in Fig. 4(a), since the CT plasma travels straight in the drift tube. When the kick field was applied to the fork region, the CT turned a 90° bend and reached the P4 port in the downstream section, as shown in Fig. 4(b) and (c). The strength of the magnetic field and the electron density of the CT decreased at the upstream ports owing to resistive decay. The intensity of CIII significantly decreased after propagating into the kick field region. This may indicate an impurity filtering effect by the external field. The magnetic field profile at 66.9 μs in Fig. 4(d) is similar to that at the upstream port P1T. Thus, the kick magnetic field allows the CT to turn the bend without destroying the spheromak configuration in the forked drift tube. However, we found that if the kick magnetic field lines are anti-parallel to the poloidal field lines of the CT, the CT cannot turn a bend to pass through the fork region owing to magnetic reconnection between the oppositely-directed field lines.

In summary, we have successfully demonstrated switching of the CT traveling direction in the forked drift tube by applying the kick magnetic field. The results allow for the injection of CTs vertically in any radial direction in the target tokamak plasmas using a CT injector, leading to a new approach to flexible CT injection.

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