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Plasma Behaviors in the Open Field Region of Reversed-Field Theta-Pinch

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RESEARCH REPORT

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Further communication about this report is to be sent to the Research Information Center, Nagoya Universtiy, Nagoya 464, JAPAN

Abstract

A characteristic begavior of the plasma in an open field region of reversed field theta pinch has been studied with the guide field (GF) which extends the field line along the axial direction. The experimental result suggests that the rotaional instability may be induced in FRC after the plasma touches the wall at the ends fo the open field.

It has been known that the field reversed configuration (FRC) produced by a linear theta pinch is stable for many Alfvén transit times and is mainly annihilated by the rotational instability. In the previous experiment$^{1)}$ it was shown that the onset time of the rotational instability could be delayed by the guide fields (GF) which extend from both ends of the main discharge field to far ends of 2.7 m off each end. In this letter we describe the characteristic behaviors of the plasma in GF the understanding of which may suggest the mechanism of the rotational instability.

The experiment was performed on the STP-L device$^{1)}$ with a main coil of a 1.5 m length and a 12 cm diameter. The main discharge field rises from -0.6 kG to +3 kG in 0.2 μs and subsequently reaches the maximum value of 10 kG in 2.4 μs. At this time the field is crowbarred and decays with an L/R time of about 30 μs. The main discharge is fired when the expanding fronts of D_2 working gas injected by two puffs at a center of the main coil reach the coil ends. Therefore, it may be expected that a plasma escaping from the confinement region expands into a vacuum along the GF up to the ends of the apparatus. Under these conditions, the FRC is formed by the plasma with the following typical parameters: $T_i \sim 350$ eV, $T_e \sim 100$ eV, $\bar{n}_e \sim 5 \times 10^{15}$ cm^{-3} and $\langle\beta\rangle \sim 1$. In present experiment we use a streak camera and a side-on CO_2 laser interferometry to observe the characteristic plasma behaviors in the GF.

It is shown in Fig.1 that the plasma in the GF experiences three different characteristic phases I, II and III which are headed by τ_f, τ_s and τ_d. In phase I the plasma is propagated along the GF. The streak photograph in Fig.1 shows the most notable feature in the phase I that the expanding plasma along the GF splits in two filament-like plasmas rotating about the axis in the direction of electron diamagnetic current. This rotational direction is confirmed by stereoscopic streak photographs viewing from the different two directions having the azimuthal angle of 45°. In phase II, two pieces of the plasma turn into one uniform plasma. After the integrated line density drops at the time of τ_d, which may be caused by the shift of the plasma column, the plasma is annihilated in phase III.

For the filament-like plasmas in phase I we measured the rotational velocity ω and radius r_p from numbers of streak photographs, as shown in Fig.2. It is seen from Fig.2 that the rotational velocity is a function of time but independent of the axial position and the field strength of GF. The time history of the quantity $r_p^2\omega$ shown in Fig.2 suggests that the angular momentum for one particle of the filament-like plasmas is roughly constant. From these results it may be said that the filament-like plasmas in phase I consist of a pair of straight plasma bars rotating about z axis. This is also confirmed by the streak photographs taking the axial plasma propagation in the GF section.

Figure 3 shows the t-z diagram on which three characteristic phases I, II and III are displayed. In the same figure a streak photograph observed near at the midplane of main coil is also shown. As can be seen from this streak photograph, the plasma in the main coil region forms a double structure which consists of the FRC and its surrounding "halo" plasma. It is noted in Fig.3 that the filament-like deformation of the plasma in phase I is generated at the entrance region to the GF and is also propagated back to the halo plasma in the main coil region from about 4 μs. This deformation disappears as soon as the expanding plasma reaches the end of GF. Although the plasma in GF which is stable as a whole in the phase II is terminated at τ_d by the shifting of the plasma column, the FRC in the main coil region is not directly annihilated by the shifting but by the small rotational instability taking place at the time τ_r as shown in Fig. 3. In this case, it roughly takes 13 μs from the τ_s until the plasma is terminated at the τ_r of 27 μs. For the experiment with the GF shortened to the half length, as shown in Fig.3 by the black triangles related with the dotted lines, the τ_s becomes 11 μs. In this case τ_r becomes 24 μs so that the time difference, $\tau_r - \tau_s$, becomes 13 μs which is equal to the one for the case of the full length of GF. These results are also valid for the case without GF,[1] i.e., the FRC is terminated at 17 μs after the start of spinning-up at 4 μs which may correspond to the τ_s. In a series of these experiments under the same FRC plasma parameters, it is noted that the observed time difference of 13 μs is in good agreement with the stable time of strongly viscous plasma predicted by Steinhauer[2] who claims the importance of the endshorting of E_r for the FRC rotation.

In present experiment we have observed two notable behaviors of the plasma affected by the GF, i.e., the rotational behavior of the escaping plasma from the FRC and the stable time ($\tau_r - \tau_s$) to be independent of the length of GF. From these observations we may obtain the folloiwng conclusion for the mechanisms of the rotational instability in the FRC. Although the first behavior may be consistent with the preferential loss mechanism[3)] for the FRC rotation, the latter may suggest that the instability are caused by the plasma spin-up closely related to the endshorting mechanism.

References

1) Y. Aso, Ch. Wu, S. Himeno and K. Hirano: Nucl. Fusion 22 (1982) 843.
2) L. C. Steinhauer: Phys. Fluids 24 (1981) 328.
3) A. S. Kaye: J. Plasma Phys. 11 Part 1 (1974) 77.

Figure Captions

Fig.1 Three characteristic phases of the expanding plasma from FRC into GF. Streak photograph and integrated line density are measured at $z = 48$ cm and 83 cm, respectively.

Fig.2 Time history of the rotational velocity ω and radius r_p of the filament-like plasmas in phase I.

Fig.3 At t-z diagram for three characteristic phases I, II and III and a streak photograph near at the midplane of main coil, where the data indicated by "I" and "S" are determined from the integrated line density and the streak photographs, respectively.

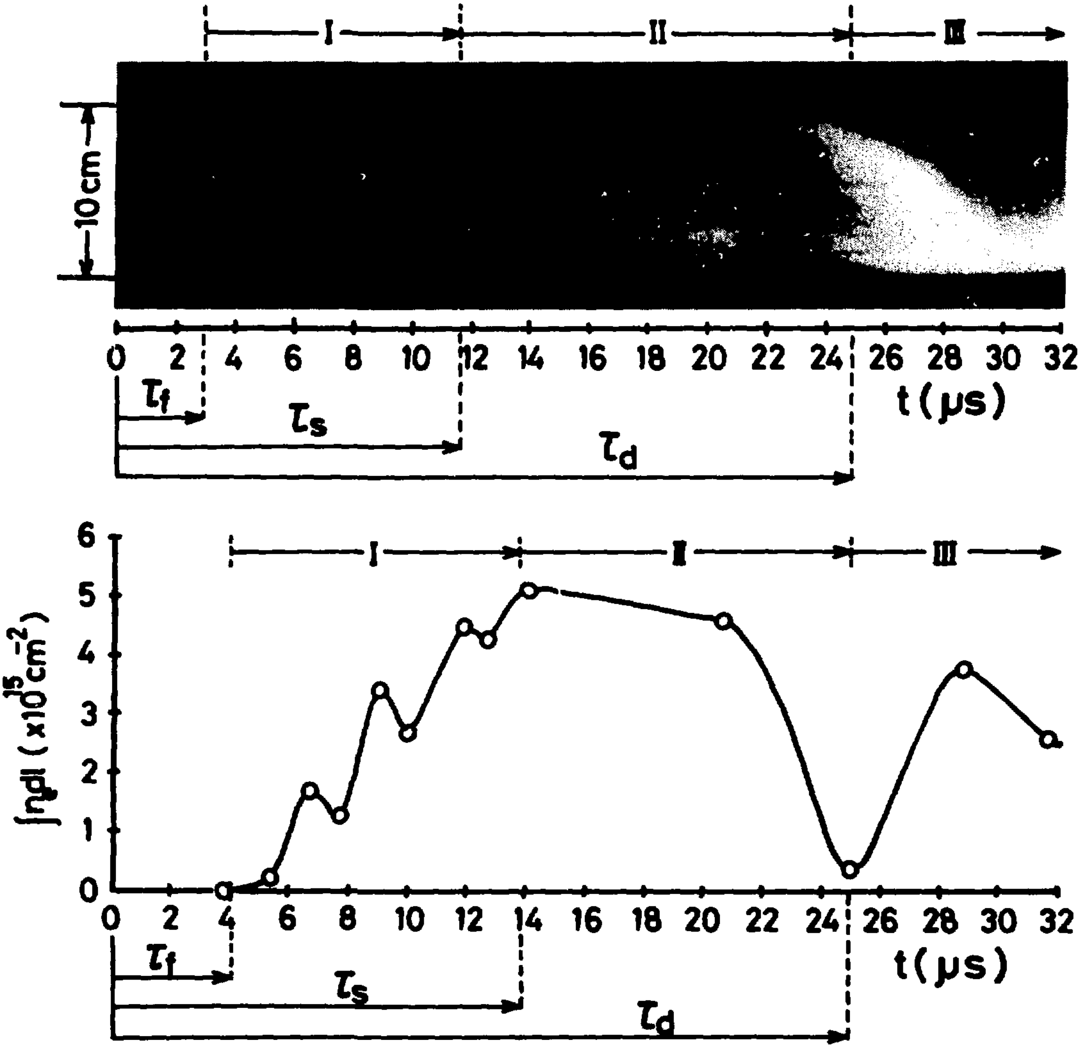
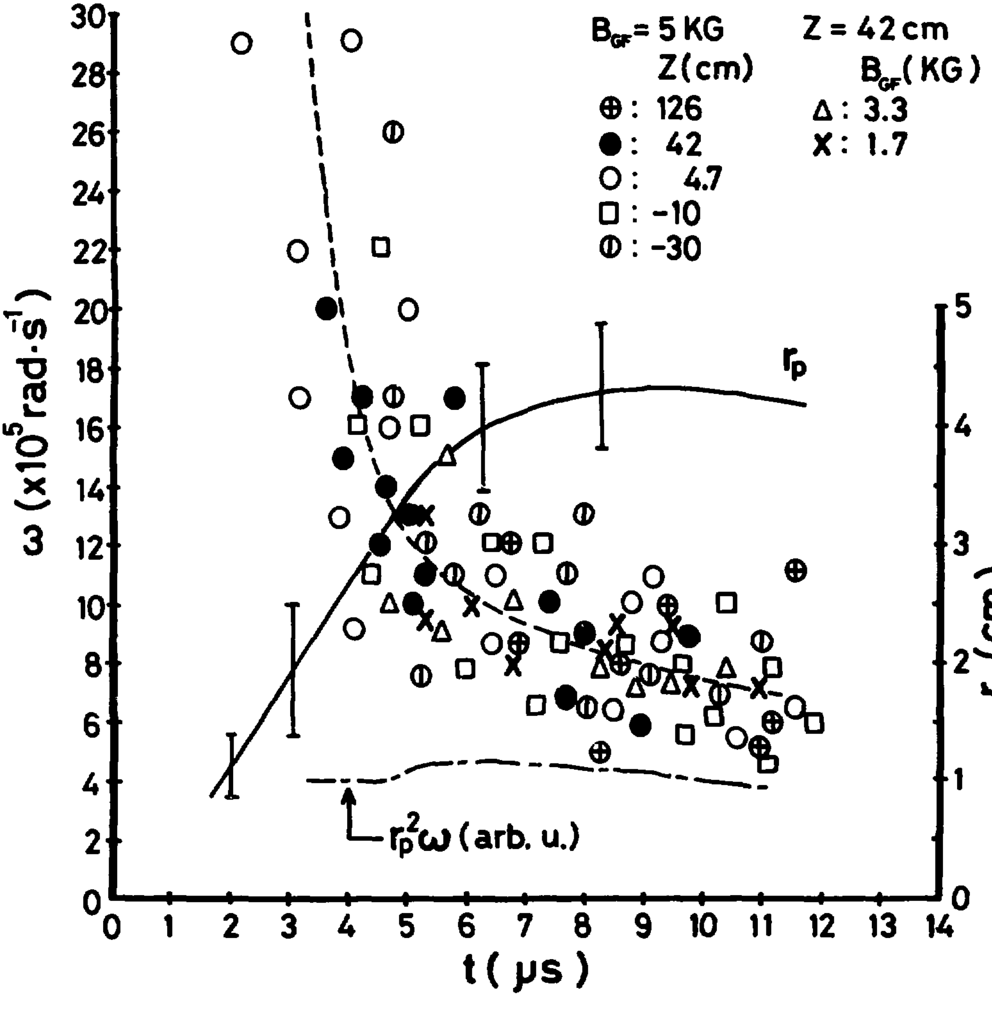

I
II
III
10cm
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
t(μs)
τ_f
τ_s
τ_d
$\int n_e dl$ ($\times 10^{15}$ cm^{-2})
0
1
2
3
4
5
6

Fig. 1



B_{GF} = 5 KG
Z(cm)
⊕ : 126
● : 42
○ : 4.7
□ : -10
⦶ : -30
Z = 42 cm
B_{GF} (KG)
△ : 3.3
X : 1.7
r_p
$r_p^2\omega$ (arb. u.)
ω (x10^5 rad·s^{-1})
r_p (cm)
t (μs)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

Fig-2

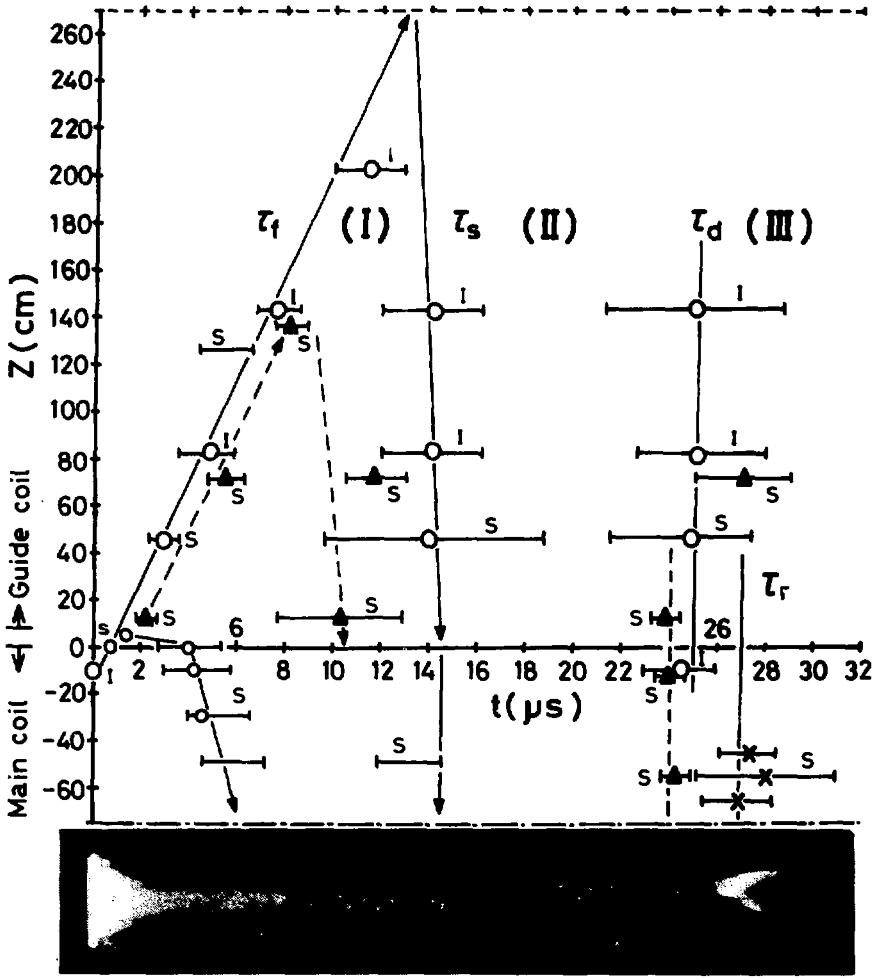

Z (cm)
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
Main coil ← | → Guide coil
t (μs)
2
6
8
10
12
14
16
18
20
22
26
28
30
32
τ_f (I)
τ_s (II)
τ_d (III)
τ_r
I
S

Fig-3