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**Observations of Separatrix Motion during the
Formation of a Field-Reversed Configuration**

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OBSERVATIONS OF SEPARATRIX MOTION DURING THE FORMATION OF A FIELD-REVERSED CONFIGURATION

by

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ABSTRACT

An axial array of B_z probes is used to monitor the formation and initial motion of the x-point of the separatrix in a field-reversed configuration. The x-point is observed to form near the outside edge of the main coil at approximately $3.0 \mu s$ after main field initiation and then move rapidly toward the center of the coil.

In the formation of a field-reversed configuration (FRC), oppositely directed magnetic field lines must connect at the end of a theta-pinch coil around a hot plasma.¹ "Reconnection" of these field lines is complete when the negative bias flux, trapped in the plasma, is completely connected to an equal external positive flux generated by the rising main field. Additional positive flux constitutes open field lines separated from the reconnected, closed field lines by a separatrix. Upon complete reconnection an x-point of the separatrix appears on-axis in the reconnection region at the end of the coil. In the present work, internal probes were used to study the appearance and motion of the x-point in order to characterize the reconnection phase of FRC formation. Numerical studies are also being pursued to examine this phase of FRC formation.^{2,3}

The FRC's in this study were produced by the FRX-B field-reversed theta-pinch device. FRX-B has a main coil 1-m long with a 25-cm I.D. At each end of the coil a 10% mirror field is produced on-axis through shaping of the main coil. The vacuum vessel is a 20 cm I.D. quartz tube. The present experiments use a fill gas of D_2 at 29 mtorr. A more complete description of the apparatus is found in reference 1.

Preionization of the plasma is accomplished in the presence of a -3 kG bias field by an rf burst at approximately 70 MHz followed by a ringing theta-pinch discharge at approximately 500 kHz. The combined bias plus

ringing theta-pinch field has a maximum value of approximately -500 gauss. The main field has a risetime of 2.5 μ s to a maximum value of approximately +12 kG.

The axial array of B_z probes consisted of five probes spaced at 4 cm intervals. They were inserted into an 8 mm o.d. quartz jacket and moved with the jacket as an assembly. When the probe assembly was fully inserted into the vacuum endcross, the innermost probe was 12 cm inside the coil. With the probes fully withdrawn into the endcross (approximately 30 cm outside the coil), FRC's with 40 μ s stable periods and 80 μ s lifetimes were produced, where time is referenced to the initiation of the main field. The stable period refers to the time before onset of the $n = 2$ rotational instability. When the probe array was closer than about 20 cm to the outside edge of the coil, the FRC was affected by the presence of the probes. At this position, excluded flux and CV measurements indicated an FRC lifetime of 10-20 μ s with no rotational instability observed. Examination of excluded flux and CV signals during the first 5 μ s indicated similar plasma behavior to when the probes were completely withdrawn. Hence, the probes are assumed to not seriously perturb the plasma during the first 5 μ s of the FRC formation period. Studies of the separatrix motion were limited to this early formation period.

Figure 1 presents shot-averaged B_z data vs z at 3.0 μ s, which indicates the appearance of an x-point. The sign of the main field corresponds to positive signal excursions while the reverse bias field corresponds to negative excursions. The magnetic field is displayed in arbitrary units. Figure 1 indicates a probable separatrix profile inferred from the averaged field values. Figures 2a and 2b show plots of B_z vs z at various times for the seven representative shots averaged in Figure 1. On several shots, a noise spike due to crowbar triggers appeared at approximately 2.6 μ s. The fields were smoothly connected across this 200 to 400 ns noise period. This smoothed data sometimes extended into the first few frames in Figures 2a and 2b. Figure 2a presents shots with the probe assembly fully inserted, whereas Fig. 2b presents shots with the innermost probe 2 cm inside the coil. The position of the coil is indicated at the top of the figures. Separatrix formation is seen to occur most frequently between 3.0 and 3.2 μ s. A few shots had later formation at about 3.6 μ s as indicated by the dotted line in Fig. 2a. For reference, FKR theory,⁴ as simplified by Eberhagen and

Fig. 1
The average of the data in Fig. 2 is presented at $t = 3.0 \mu s$. A probable separatrix corresponding to this average data is shown schematically as a dashed line. Several field lines are also indicated (solid lines).

Grossmann,⁵ gives a tearing time of 3.3 and 4.7 μs for an end region plasma temperature of 5 and 10 eV, respectively (with the field null at $r = 4$ cm and a current sheath thickness of 2 cm). Although these end-region temperatures are reasonable estimates by conventional theta-pinch scaling, this agreement of tearing times must be regarded as fortuitous due to the dynamic nature of

Fig. 2a

Fig. 2b

Fig. 2

B_z on-axis is plotted vs z for times near the formation of the x-point. Figure 2a displays data taken with the innermost B_z probe at -12 cm. Whereas, Fig. 2b displays data taken with the innermost B_z probe at -2 cm. The coil location is indicated at the top of the figures.

the plasma during this period of time. The x-point initially moves inward at 20-40 cm/ μ s, slowing to roughly 5 cm/ μ s about 600 ns after formation.

In summary, the averaged data in Figure 1 indicates the separatrix x-point forms at 3.0 μ s within about 1 cm of the outside coil edge. The early 20-40 cm/ μ s motion of the x-point is only visible on individual data sets and is masked by averaging over shot-to-shot variations. The averaged x-point moves inward at a relatively constant velocity of 8 cm/ μ s until the last probe station, 12 cm inside the coil, is passed at 4.6 μ s.

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