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RECONNECTION DURING THE IMPLOSION PHASE OF FIELD REVERSED CONFIGURATIONS

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Magnetic field topology changes in Field Reversed Configurations (FRC's) are essential for the formation and containment of the plasma. A significant part of the FRC research program relies upon the idea that a newly formed plasma, formed on open field lines will quickly change field topology before the rapid parallel electron thermal conduction depletes the plasma energy.

We have simulated the implosion dynamics of FRC formation using an axisymmetric hybrid model consisting of kinetic ions and finite resistivity fluid electrons. The LASL FRC experiments are well described by our model, which assumes quasineutrality, zero electron inertia, and no electromagnetic radiation.

The simulation parameters during the initial stage of the implosion are similar to those of FRX-B. The simulation procedure assumes a homogeneous fully ionized plasma imbedded in a 1.5 kG uniform reversed bias field. At $t = 0$, an V_θ of 45 kV is applied at the wall. Five distinct stages of dynamical evolution can be identified. They are: (1) The initial early implosion process, wherein the ions are driven inward at twice the magnetic piston velocity ($v_{ion} \sim 4 \times 10^7$ cm/sec). (2) The ions are reflected from the reversed bias field, during which time axial perturbations of the reversed bias field lines occur. During this stage, a significant amount of localized toroidal magnetic field (B_θ) is produced, however there is no net toroidal flux. (3) Nonlinear bouncing of the ions between the two regions of antiparallel fields follows, with the bias field line perturbations focusing the secondary reflected ions into the positive bias region, thereby causing clumping of ions localized near the field wall. Concurrently during this stage, small scale island structures develop. (4) Nonlinear coalescence of the small scale islands into larger islands rapidly follows. Also during this stage, the B_θ field is annihilated. (5) After coalescence, a quasistationary equilibrium stage occurs, wherein no significant dynamical processes take place.

Since the implosion process is highly dynamical and very complicated, a detailed analytical description of the process is out of the question. However there are several aspects of the process which can be explained qualitatively with quantitative estimates of the time scales involved. Perhaps the most intriguing aspect of the implosion, is the very rapid development of field line perturbations in the reversed bias region. Equilibrium-stability studies have ruled out the two most commonly used explanations, the mirror mode instability driven by highly anisotropic ion pressure and tearing mode instability driven by magnetic energy relaxation. Stability studies of these modes were performed using the Hybrid code itself and a Vlasov-fluid linear stability code. The results are in agreement, these modes grow on a time scale which is an order of magnitude too slow for explaining the observations. What we do feel is the correct explanation is a kinetic ion, fluid electron version of the Kruskal-Schwarzschild (K-S) instability driven by ion acceleration in a region where the density gradient is favorable for instability. The region in which this explanation could apply is exactly where the bias field line perturbations are initially observed. The magnitude of ion acceleration can be estimated by considering the reflection of the ions off the reverse bias, this gives $a \approx v_i^2/r_L \approx 3.2 \times 10^{14} \frac{cm}{sec^2}$. The formula for the growth rate of the K-S mode gives an estimate of the relevant time scale; this is $\gamma^2 = ka - k^2V_A^2$. The stabilizing term $-k^2V_A^2$ has sufficient strength to localize the instability to the vicinity of the field null. Simulation values substituted into this formula give $\gamma^{-1} \approx 37ns$, a result which is more than adequate to explain the observations.

Another observation which requires explanation is the rapid small scale island formation. This process is probably a nonlinear consequence of the K-S mode for the following reason. Distortions in the reverse bias field where the K-S mode is unstable tend to focus the reflected ion beam into localized regions in the positive bias side of the magnetic null. (See Fig. 1) The ions then undergo a secondary reflection, the result of which is to distort the positive bias field lines such that the ions are more sharply focused into clumps near the magnetic null. (See Fig. 2) Since ion density clumping must necessarily involve magnetic islands to maintain the localization of the ions, this seems to be a reasonable explanation. If this picture is correct, an estimate of the time scale to form fully developed islands is obtained by calculating the ion

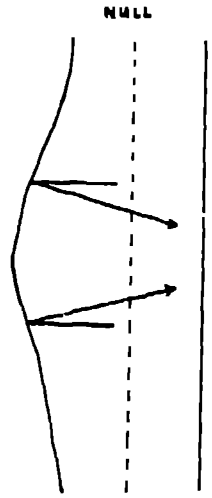

Figure 1

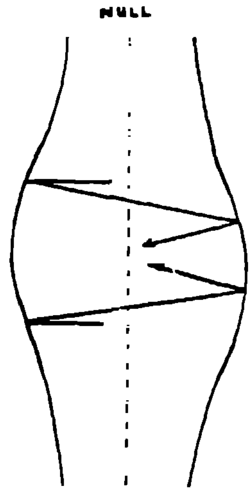

Figure 2

bounce time between the regions of maximum magnetic field line perturbation. The time scale for island formation should then be about a couple of bounce times. The bounce time is calculated to be about 50ns and the island formation time is between 100 and 150ns. Figure 3 shows the contours of poloidal flux from simulations after 150ns -- clearly showing the existence of small scale magnetic islands at the field null by this time.

As these early small scale islands are followed in time, they grow in amplitude and ultimately coalesce until saturation and equilibration reveal a series of quiescent compact tori. As seen in Fig. 4, the final state is a sequence of current rings with $L_z \approx 15$ cm and cross sectional radius of ≈ 2.5 cm at $R = 5$ cm. A significant feature is the existence of an internal separatrix that could conceivably enhance MHD stability over the more simply connected magnetic geometry that had previously been supposed.

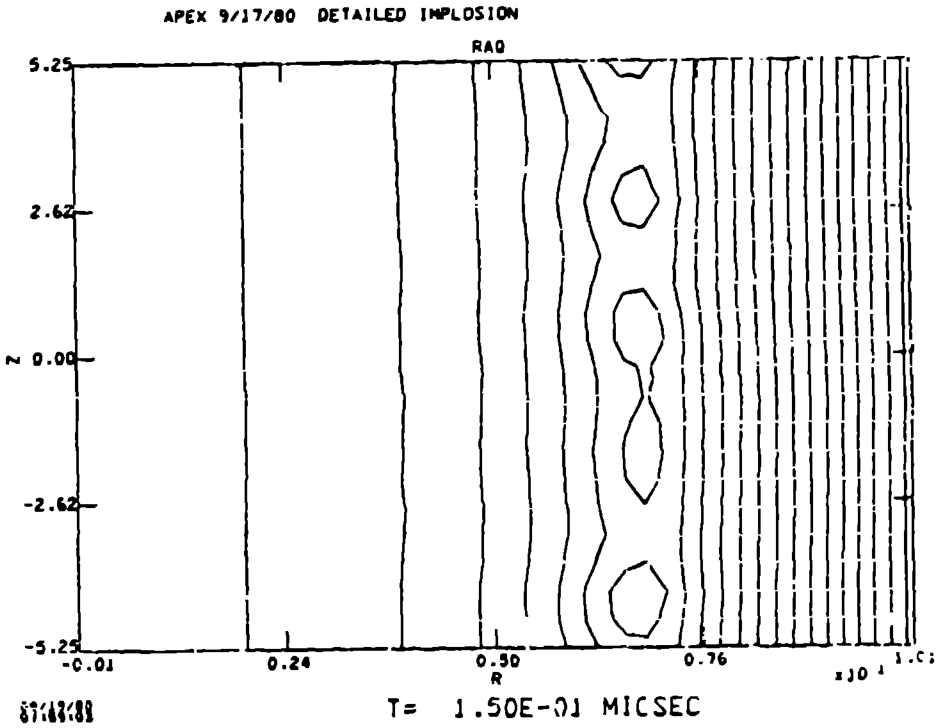

Figure 3

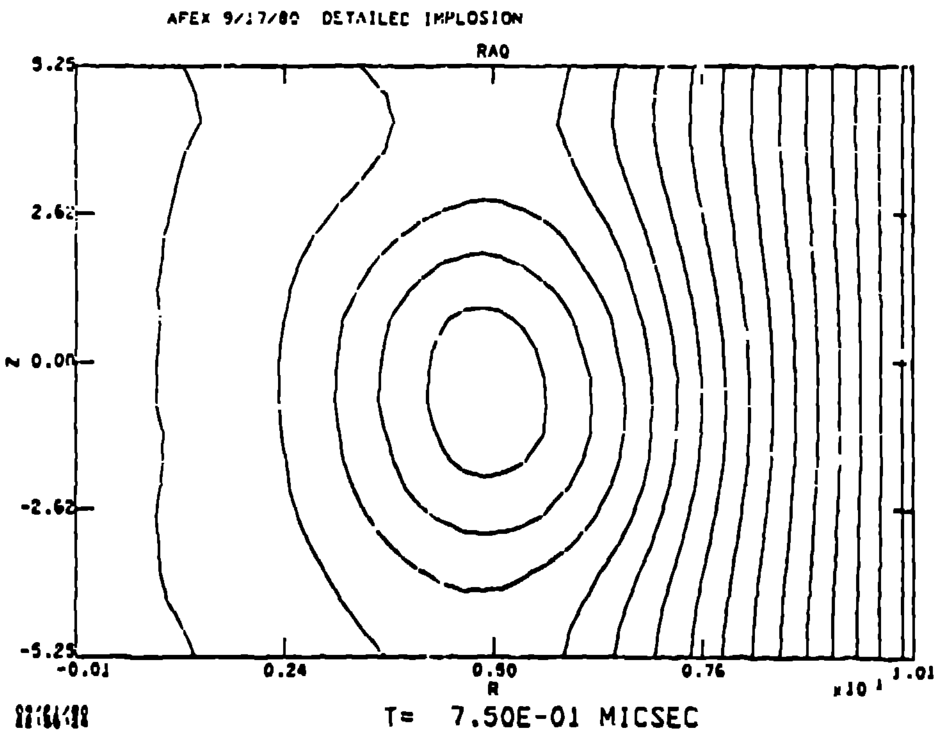

Figure 4