High density FRC: new results

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Innovative Confinement Concepts workshop
Austin, Texas
13-16 Feb 2006
abstract

A high plasma pressure Field Reversed Configuration at Los Alamos

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We describe the experimental program and goals of FRX-L, which is a high density and pressure Field Reversed Configuration (FRC) experiment at Los Alamos National Laboratory. The purpose of FRX-L is provide a robust plasma target for Magnetized Target Fusion (MTF), which could be a low cost path to fusion, in a regime that is intermediate between magnetic and inertial fusion energy. One recent result is the achievement of high plasma pressure (>20-30 atmospheres) and density (> 6e16cm^-3). The resultant short Coulomb mean free path coexists with a large Lundquist number which is usually taken to signal a collisionless regime. We show that the anomalous increase of resistivity over the Spitzer value gets smaller as density increases. This FRC plasma regime has never been investigated with spatially resolved diagnostics, such as density profiles that can be unfolded with our multi chord interferometer. The key technology advance that makes the previous results possible is the successful operation of a much improved crowbar switch for the main bank current. Other recent program progress includes installation of a passive mirror onto the existing theta coil to improve the axial centering of the FRC, and the second generation design for the impending translation and implosion experiment.

supported by DOE OFES contract W-7405-ENG-36
Outline

• FRX-L description
• Engineering progress towards MTF
• High pressure shots in Mbar range
• FRC can explore microphysics
  – anomalous resistivity
  – Scale collisionality, Lundquist number
• Student programs
Magneto-Inertial fusion

- Pulsed, high pressure approaches to fusion
- Inertial + magnetic confinement
- Magnetic field plays essential role
- **Magnetized Target Fusion - MTF example**
  - Field reversed configuration (FRC) in a beer can
  - Solid liner
  - Magnetized target
MTF: high risk high payoff route to fusion

- Pulsed, high pressure approach to fusion
- Inertial + magnetic confinement
- Magnetic field plays essential role
FRXŁ Field Reversed eXperiment – Liner
geometry & model of FRC

- Excluded flux radius $r_s \approx 3\text{cm}$ at last closed flux surface
- Field null radius $R \approx 2\text{cm}$, separatrix length $z_s \approx 30\text{cm}$
- $J \cdot B \approx 0$, i.e. not a Taylor relaxed equilibrium

(r, θ, z) coordinate system
MTF results: Integrated design - liner on plasma

2004 TAPERED TALL LINER
ri = 4.89 cm, t = 1.1 mm, 30cm tall

- LANL≈ $1.4M + AFRL≈$0.7M
- FRC formation in conical theta coil
- Tapered deformable compression liner, tested 2004-5
- translation v≈12cm/µsec
- Integration of LANL front end with AFRL Shiva-Star implosion
- FY 2007 schedule for liner on plasma shots
FRC $\theta$ pinch sketch
Theory: Simulation of formation, translation, bounce

- MOQUI 2D finite element MHD code simulation
  - Force balance, resistivity, Hall effects
  - R. Milroy (U. Washington), J. Park LANL
Reduce crowbar modulation ⇒ double FRX-L parameters

- Lifetime $\tau_{\Phi} \approx 10 \, \mu$sec
- Density $n \approx 2 \times 10^{22} \, m^{-3}$
- Temperature $T_e + T_i \approx 250 \, eV$
- Maintain peak $n,T$ ⇒ double!

First (non-optimized, 40kV) new CB test vs 70kV shot

Los Alamos

Intrator ICC 2006feb13-16
LA-UR-06-0743
FRX-L high plasma pressure shots

- Large plasma pressure $\approx 2$-3 MPa
- Lifetime will be increased in the near future.
Add passive bolt on mirror coils to center FRC

Mirror & force down to $R=2.5$ cm

No mirror force for $R<5.5$ cm
FRC: Basic plasma science

The FRC is an elongated, self-organized compact toroid state that has toroidal plasma current and poloidal magnetic field.

- large beta
  - high plasma pressure / B field coils
  - Compare to $B_{\text{poloidal}}$ in tokamaks
- vanishing rotational transform, magnetic shear, toroidal field, helicity
- FRC $J \cdot B \approx 0 \Rightarrow$ extreme magnetic configuration
- Anomalous resistivity
  - to ohmically heat formation FRC
  - FRXL can scan collisionality & Lundquist number
Density profiles => resistivity at O-point

- Interferometer array has 8 channels
- Tomographic inversion yields density profiles
- Gradients in $\beta$
  - $\nabla \times B \approx \frac{\partial B}{\partial r}$
- $\Rightarrow$ estimates of resistivity
Time evolution of anomalous resistivity

Resistivity anomaly evolves more like Lundquist number than Coulomb collisionality.

Reduce $T_e$ to magnify Coulomb collisionality.
FRX-L: highly collisional FRC

- Coulomb collisionality
- \( \lambda_{ii} = \lambda_{ee} \)
- Lundquist number
- Dimensionless density parameter compares several experiments
Resistivity does not depend on coulomb collisions

size/mean free path vs density

\[ \lambda_{ei} \approx \lambda_{ii} \approx \frac{T^2}{n} \]

Anomalous resistivity \( \eta^* J^2 \) ohmically heats FRC
Discussion

• Asymptotic $S \approx 200$ at $\eta^*/\eta_\perp \approx 1$

• $S = r_s v_A / (\eta_\perp / \mu_0)$
  – Where $r_s \approx 1$-3 cm

• If microphysics occurs at $S$(effective) $\approx 1$

• $\Rightarrow$ effective “micro physics” length scale
  – $L^* = r_s / 200 \approx 0.01$ cm
  – But $r_{Gi}$ (edge), $c / \omega_{pi}$ (O-point) $\approx 0.1$ cm!?
  – Micro-physics $L^*$ between ion, electron skin depth
Attract & recruit the next generation

- Plasma physics summer school in P-24
Summary

• FRX-L has a high pressure target plasma for MTF
  – Lifetime still needs improvement
• Engineering for MTF is on track
• Physics exploration of anomalous resistivity
  – FRXL can scale Coulomb vs MHD collisionality
• Student programs