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# FRCHX Magnetized Target Fusion HEDLP Experiments IC

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We are testing the first liner implosions of high pressure field-reversed configuration (FRC) plasmas as a physics demonstration of magnetized target fusion (MTF)*. Integrated hardware on the new Field Reversed Compression and Heating Experiment (FRCHX) at the Air Force Research Laboratory Shiva Star facility, will form initial FRC's at 3 Tesla magnetic field, with high-beta ($\beta \sim 0.9$, $T = \langle T_e + T_i \rangle \geq$ 300 eV, $n_e \approx 5\times10^{16}$ cm$^{-3}$) plasma pressures of 20-30 atmospheres, and translate and capture them into an aluminum liner, and then compress them to kilovolt temperatures, forming a high energy density laboratory plasma (HEDLP). Magnetics design and 2-1/2 dimensional MHD fluid (MACH2) simulations for the translated plasma and time-dependent magnetic geometries have been done, construction is nearly finished, and first 4.7 MJ implosion tests are expected in Spring 2008. Modeling shows that FRC's should be formed after the liner implosion begins, to match plasma lifetime, and the liner compression timescales (~10 and 20 usec, respectively). Details of the hardware, diagnostics, and pre-compression plasma formation and trapping experiments, both from LANL and AFRL, will be presented.

At the simplest level, the experimental design of a translating FRC experiment and its interface to the MTF compression follows from an adiabatic physics model. It invokes general equilibrium and few dynamic assumptions, by presuming that the FRC plasma evolves through a sequence of isentropic magnetohydrodynamic (MHD) equilibria. This thermodynamic approach only accounts for initial and final states and omits dynamics, although a loss factor can be included. In addition, we have modeled the liner and plasma dynamics, using MACH2. For prolate FRC's, elongated equilibria are a reasonable description, and this property enables one to extract two dimensional information from a one dimensional calculation. We consider adiabatic compressions of the idealized cylindrical FRC that can occur either via changes in wall compression or flux compression. A variety of cases have been considered, with radial compression ratios of 10-15*x*. There is a design trade-off between sufficient time for a robust formation process and maximum translation speed to reduce the plasma lifetime requirements. Translation speeds approach the upstream ion acoustic speed, which is ~ 20cm/usec.

| | rs (mm) | E | $l$s/2 (m) | Volume (m^3) | Ti (keV) | n (m^-3) | P (bar) | B (Tesla) | Beta | DD neutrons |
|---|---|---|---|---|---|---|---|---|---|---|
| initial-1 | 28 | 6.5 | 0.18 | 9.0-04 | 0.20 | 3.5E+22 | 22 | 2.6 | 0.83 | |
| final-1 | 2.8 | 26 | 0.072 | 3.6E-06 | 4.8 | 5.3E+24 | 8.10E+04 | 160 | 0.83 | 3.4E+12 |
| initial-2 | 28 | 6.5 | 0.18 | 8.7E-04 | 0.26 | 1.3E+23 | 83 | 5 | 0.84 | |
| final-2 | 1.9 | 33 | 0.062 | 1.3E-06 | 9.1 | 5.2E+25 | 1.50E+06 | 680 | 0.84 | 9.2E+14 |

Table 1. Two design cases are shown above, 40% losses assumed, 0.3 usec dwell time, elongation E=6.5, 2.4-D compression. Case 1: low field, 10x convergence. Case 2: higher field, with 15x convergence.

We also have performed integrated MHD simulations of FRC and liner for experimental design using MACH2. Simulation movies can be viewed on the web, at http://wsx.lanl.gov/mach2.htm. We use the Chodura resistivity initially, and switch to classical resistivity after the FRC is formed. Liner portions of the simulation have already been benchmarked against experiments. The simulation is particularly useful to guide the design of mirror fields in the capture region, which are dynamically compressed even as the FRC first arrives in the liner. We see loss of particles on each bounce as the FRC settles down in the liner region, and also observe that if the liner is too short axially, some of the translating plasma is expelled upon entry. These simulations use a quasi-Lagrangian grid in the liner and an adaptive quasi-Eulerian grid in the rest of the problem so that the radial and axial resolutions in the FRC are both roughly three times smaller than the respective average cell sizes of 1 mm and 2 mm. The requirement to model high field, low density regions limits the time step so that hundreds of thousands of time steps are necessary; thus complete simulations through compression take a few days on two 3 GHz 64-bit processors with gigabit Ethernet communications. The elliptic vacuum field problem limits efficient parallelization, so that though the two-processor run is 40% faster than a single processor run, a four-processor run is only 8% faster than the two.

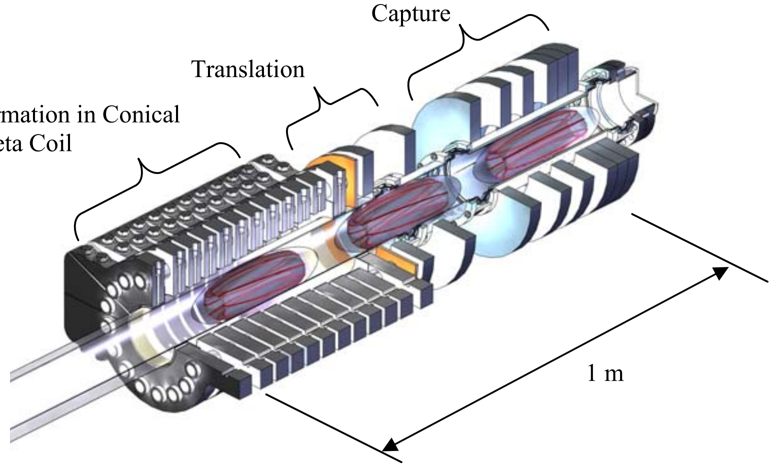


Figure 1: FRCHX at AFRL and FRX-L at Los Alamos use an identical conical theta coil set to form a translating FRC, and guide and capture it in a liner compression region. The Shiva Star capacitor bank will couple ~1.5 MJ into the kinetic energy of the aluminum liner, which collapses cylindrically at ~ 5km/sec. Initially, expected neutron yields are in the range of > $10^{12}$ DD neutrons per shot, at a density of ~ $5 \times 10^{18}$ $cm^{-3}$, and temperature of ~ 5 keV.

FRCHX uses three independent capacitor banks in the FRC formation process: a Bias bank, consisting of two 10 kV, 2.5mF bank modules, a Preionization bank, consisting of a single 100-kV, 2.1 μF capacitor, and a Main bank, which is essentially a Shiva Star bank module (144 μF, 60 kV). Though independently charged and triggered, these three banks all drive the same single-turn Theta coil. Two additional banks driving Cusp coils at each end of the Theta coil are used to aid with magnetic reconnection during the final stages of the formation process. Each of these Cusp banks consist of three 10-kV, 500 μF capacitors. The theta coil cone angle is variable between 0º and 6º, and initial tests will use 4º. As the FRC exits from the Theta and Upper Cusp coils, a Guide field set up by three multi-turn coils allows the FRC radius to expand to 3-4 cm. The FRC then passes through a minor magnetic mirror and an 8 cm diameter aperture in the lower liner electrode to enter the solid liner region. A magnetic mirror at the upper end of the liner stops the FRC's forward motion, and since part of its kinetic energy is converted into internal thermal energy in this process, it lacks the momentum needed to exit the liner region again through the minor mirror. Guide and Mirror coils are connected electrically in series and are driven by a single 10-kV, 12 mF capacitor bank. Nondestructive testing of systems and plasma formation/capture are underway, and imploding plasma/liner tests at a shot rate of 3-5 per year are beginning in Spring 2008.

*K. F. Schoenberg, R. E. Siemon, et al., http://wsx.lanl.gov/Proposals/mtf_pop_proposal.pdf , " Magnetized Target Fusion: A Proof of Principle Proposal" LA-UR- 98-2413