Title: PROGRESS WITH DEVELOPING A TARGET FOR
MAGNETIZED TARGET FUSION

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PROGRESS WITH DEVELOPING A TARGET FOR MAGNETIZED TARGET FUSION

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ABSTRACT

Magnetized Target Fusion (MTF) is an approach to fusion where a preheated and magnetized plasma is adiabatically compressed to fusion conditions.^{1,2} Successful MTF requires a suitable initial target plasma with an embedded magnetic field of at least 5 T in a **closed-field-line** topology, a density of roughly 10^{18} cm^{-3} , a temperature of at least 50 eV, and must be free of impurities which would raise radiation losses. Target plasma generation experiments are underway at Los Alamos National Laboratory using the Colt facility; a 0.25 MJ, 2–3 μs rise-time capacitor bank. The goal of these experiments is to demonstrate plasma conditions meeting the minimum requirements for a MTF initial target plasma. In the first experiments, a Z-pinch is produced in a 2 cm radius by 2 cm high conducting wall using a static gas-fill of hydrogen or deuterium gas in the range of 0.5 to 2 torr. Thus far, the diagnostics include an array of 12 B-dot probes, framing camera, gated OMA visible spectrometer, time-resolved monochromator, filtered silicon photodiodes, neutron yield, and plasma-density interferometer. These diagnostics show that a plasma is produced in the containment region that lasts roughly 10 to 20 μs with a maximum plasma density exceeding 10^{18} cm^{-3} . The experimental design and data are presented.

INTRODUCTION

Magnetized Target Fusion (MTF) is an approach to fusion where a preheated and magnetized plasma is adiabatically compressed to fusion conditions.^{1,2} Compared to traditional inertial confinement fusion (ICF), the magnetic field substantially reduces electron thermal conduction losses, and lower initial density (of order 10^{18} cm^{-3}) reduces radiation losses. This allows larger targets (cm scale) to be imploded at much reduced speed ($\sim 1 \text{ cm}/\mu\text{s}$). Successful MTF requires a suitable initial target plasma with an embedded magnetic field of at least 5 T in a **closed-field-line** topology, a density of roughly 10^{18} cm^{-3} , a temperature of at least 50 eV, and must be free of impurities which would raise radiation losses. The required compression ratio needed to reach fusion conditions is directly dependent on the initial plasma temperature, and thus, an initial temperature of 100–300 eV would be desirable. Target plasma generation experiments are underway at Los Alamos National Laboratory using the Colt facility; a 0.25 MJ, 2–3 μs rise-time capacitor bank. The goal of these

experiments is to demonstrate plasma conditions meeting the minimum requirements for a MTF initial target plasma. In the first experiments, a Z-pinch is produced in a 2 cm radius by 2 cm high conducting wall using a static gas-fill of hydrogen or deuterium gas in the range of 0.5 to 2 torr. Follow-on experiments will use a frozen deuterium fiber along the axis³ (without a gas-fill). Further along, experiments exploring spheromak geometry may be pursued. Thus far, the diagnostics include an array of 12 B-dot probes, framing camera, gated OMA visible spectrometer, time-resolved monochromator, filtered silicon photodiodes, neutron yield, and plasma-density interferometer. In the static gas-fill mode of operation, only $\approx 20\%$ to 45% of the drive current ($0.8 \text{ MA} \leq I_{\text{drive}} \leq 1.9 \text{ MA}$) is delivered to the plasma-containment region, with the remaining current staying in the power-feed region. The optical diagnostics show that the plasma produced in the containment region lasts roughly 10 to 20 μs , the B-dot probes show a broad current-profile in the containment region, and the interferometer shows that the maximum plasma-density exceeds 10^{18} cm^{-3} .

EXPERIMENTAL DESIGN

The Los Alamos MTF target-plasma generator is designed around a z-pinch initiated from a cryogenic deuterium fiber and driven by the Colt capacitor bank; a Shiva two-stage Marx module containing 24 6- μF capacitors with a maximum charge voltage of 60 kV Marxed to 120 kV and 36 μF capacitance. The system inductance to the vacuum insulator is roughly 60-65 nH.

The size of the cylindrical plasma containment region is 2 cm radius by 2 cm high, and is based on two dimensional magneto-hydro-dynamic simulations. These calculations show that the fiber z-pinch rapidly expands due to instability driven heating and turbulence, and fills the containment region in several hundred nanoseconds. As the unstable plasma comes in contact with the conducting metal wall of the containment region, images currents in the conducting wall begin stabilizing the plasma. After roughly a microsecond, the plasma attains a fairly quiescent state with smooth profiles from the geometric axis to the wall. The simulations indicate this plasma could heat up to 350 eV density-averaged temperature by 2 μs with a peak current of 1.8 MA flowing through the plasma. These conditions would satisfy the requirements for a MTF target plasma.

The specific geometry of the z-pinch electrodes and initial position of the cryogenic fiber prior to current-flow are shown in Figure 1. Also shown in the figure are the positions of the 12 B-dot probes used to diagnose the current-flow pattern at the outer electrode. Optical viewing access is through 10 rectangular holes 4.8 mm high by 8 mm wide centered on the midplane of the containment region. These holes are the spaces between 10 bushing/spacers places on the 10 bolts which attach the lower portion of the containment region to the upper portion. Experiments have been performed with both bare 304 stainless steel electrodes and with 304 SS electrodes coated with 0.25 mm thick tantalum. There appears to be modest improvement with

Figure 1: This figure shows a cross-sectional view of the Los Alamos MTF target-plasma generator, including the primary parallel-plate power-feed, region of conversion to coaxial-feed, electrical insulators, inner and outer coaxial electrodes. Also shown are the locations of the B-dot probes, and the position of the cryogenic deuterium fiber before the start of current flow. Not shown is the cryostat used to produce the cryogenic deuterium fiber, which is above the power-feed. The dimensions of the plasma containment region are 2 cm radius by 2 cm high. The electrodes are made of 304 stainless steel and the vacuum insulator is made of nylon.

the tantalum coating, but the details of this improvement are not yet elucidated.

RESULTS

The experiments performed to date have not used the cryogenic deuterium fiber. Instead, a static gas fill of either hydrogen or deuterium in the range of 0.5 to 2 torr has been used. In this case, the initial break-down is near the vacuum insulator, and the current moves down the power-flow channel towards the plasma containment region. This phase of the discharge is not unlike the run-down phase of a dense plasma focus discharge. After 1.5 to 2.5 μ s, depending on the fill pressure and charge voltage, current and plasma fills the containment region, however only roughly 20% to 45% of the total drive current gets into the containment region. The remaining current remains in the power-flow channel distributed between B-4 and B-6 in Figure 1. After the peak in the drive current, the power-flow channel crowbars between B-5 and B-6; current above that position rings with the drive current, while current

below that point decays towards zero without reversal. Typical B-dot probe data are shown in Figure 2. After 100 to 200 discharges, there is considerable melting and damage to the electrodes from B-6 downward and throughout the containment region.

Figure 2: Magnetic probe data from a discharge with 0.5 torr hydrogen static fill and an erected bank voltage of 40 kV. The first plot shows, in order of decreasing magnitude, the drive current, and data from probes B-1, B-4, B-6, and B-8. The second plot shows data from probes B-10, B-11, and B-12.

Two single-pass laser interferometers have been fielded with the beam-path following a diameter through the midplane of the plasma containment region. The first interferometer used a 1300 nm wavelength laser, but did not give useful data during the interesting part of the discharge. It appears that the scene-beam is deflected out of interference almost immediately as plasma arrives at the laser path. Interference appears to return roughly 15 μ s later, and inferred plasma density drops from roughly $2.5 \times 10^{18} \text{ cm}^{-3}$ to zero with an e-folding time of roughly 7 μ s. A second interferometer was fielded using a wavelength of 442 nm, which gave useful data at the beginning of the discharge, but also lost interference after a microsecond of density rise. Typical data from this interferometer is shown in Figure 3. The curves have been truncated at the time where interference is lost.

Optical spectroscopic data has been obtained from a gated OMA spectrometer and a time-resolved monochromator, as shown in Figure 4. The visible spectrum is broad and smooth. There appears to be an absence of line emission, except for 2 or 3 lines at early time. The line at just under 470 nm is not identified yet.

An array of seven filtered silicon photodiodes has been fielded. These diodes have fairly flat response throughout the visible up to several keV photons. The diode filters are, in order of decreasing expected signal strength: diode #7: no filter; diode #3: $322 \mu\text{g/cm}^2$ of parylene-n; diode #1: $66,000 \mu\text{g/cm}^2$ polystyrene; diode #4: $323 \mu\text{g/cm}^2$ of kimfol plus $10 \mu\text{g/cm}^2$ aluminum; diode #5: $452 \mu\text{g/cm}^2$ Ni; diode #6: $1,143 \mu\text{g/cm}^2$ Ti; diode #2: $1,028 \mu\text{g/cm}^2$ aluminum. No signal was observed from diodes #6 or #2. The data from diode #3 is almost identical to the data from diode #1. The data are shown in Figure 5.

Figure 3: Plasma density data from the 442-nm HeCd laser interferometer. The analysis assumes a constant path-length of 4-cm. The four upper curves are from four discharges with 0.98 torr of hydrogen and an erected bank voltage of 56 kV, while the two lower curves are from two discharges at 0.5 torr and 40 kV.

Figure 4: Optical spectroscopic data from discharges with an erected bank voltage of 40 kV. The first plot shows data from a gated OMA visible spectrometer with a 330 ns gate-width. The times are, in order of decreasing signal magnitude, 3.76 μ s, 7.10 μ s, 3.08 μ s, 2.78 μ s. These discharges had 1 torr of hydrogen fill. The second plot shows data from a visible/near-UV monochrometer, and a photodiode monitoring total visible emission (top curve). The wavelengths are 375 nm for the middle curve, and 500 nm for the lowest curve. These discharges had 0.5 torr of hydrogen fill.

Figure 5: Silicon photodiode data. The first plot shows the signal from an unfiltered diode for five discharges ranging in erected bank voltage from 40 kV (lowest curve at 10 μ s) to 80 kV (highest curve at 10 μ s). The fill pressure of hydrogen was scaled as the square of the bank voltage from 0.5 torr to 2 torr. The second plot shows unfiltered and filtered photodiode data for a discharge with 1.36 torr of hydrogen and an erected bank voltage of 66 kV. In order of decreasing peak signal magnitude (as plotted with the stated multipliers) is diode #7, #5 (multiplied by 25), #1, and #4 (multiplied by 50). There is good shot-to-shot reproducibility for the diode signals except for diode #5, which has varied from zero signal to over twice that shown in this plot for discharges where all other diagnostics show little shot-to-shot differences.

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