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TITLE: CURRENT RESULTS FROM THE LOS ALAMOS CTX SPHEROMAK

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Abstract

Continued discharge cleaning, improved vacuum practices, and optimized plasma formation operation have resulted in the CTX experiment achieving 1-ms plasma lifetimes with average temperatures of 20–40 eV. The major advance in operation has been the use of 5–20 mTorr H_2 gas fill. A multipoint Thomson scattering diagnostic with 12 radial positions yields radial profiles of temperature and densities, an example of which is shown. Local β's can be determined from the measured pressure profile, and average values are typically 15–20%. In clean, long-lived discharges the density decreases at a more rapid rate than the magnetic field, until it reaches a value around 2–4 × 10^{13} cm^{-3} where it remains constant. This is in contrast to the colder, radiation-dominated behavior, and is taken as evidence that the plasma β is a limit to current operation in CTX.

CURRENT RESULTS FROM THE LOS ALAMOS CTX SPHEROMAK

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INTRODUCTION

Continued discharge cleaning, improved vacuum practices, and optimized plasma formation operation have resulted in the Los Alamos CTX spheromak experiment achieving 1 millisecond plasma lifetimes with average temperatures of 20-40 eV. Several methods have been used to augment the cleanup of the plasma, resulting in significant reductions in the impurity radiation power loss. The major advance in operation has been the use of a constant, uniform background of 5-20 mTorr of H_2 filling the vacuum tank, flux conserver, and plasma source. This fill operation directly reduces the impurities generated in the plasma source, allows operation of the source at parameters resulting in fewer impurities, and provides a neutral particle source to maintain the density for long lifetimes. In this paper we present data on the improved operation of CTX.

NEW DIAGNOSTICS

Essential to the increased understanding of the CTX spheromak has been the addition of several new plasma diagnostics. Foremost has been a multipoint Thomson scattering system with 12-radial positions, giving radial profiles of temperature and density on a single shot. Spectroscopic measurements have been augmented by the use of a 1-m vacuum ultraviolet spectrometer for observing the power radiated in resonance transitions of low-Z impurity ions. Also, a quartz UV spectrometer has been used to view the inter-electrode region of the source.

METHODS FOR IMPURITY REDUCTION

We have continued a program of discharge cleaning the electrodes and the vacuum system after any opening to the atmosphere. Continued use of a 0.1-0.2 Hz repetitive operation of the source at low (1.5-2.5 kV) voltage results after several nights (10^4-10^5 pulses) in significant decreases in carbon and nitrogen radiation, as well as oxygen achieving higher charge states and approaching burnthrough. During the pulse discharge cleaning we now use an rf glow discharge which is seen to be at least as effective in cleaning as a dc glow, but with far less sputtering of metal surfaces in the vacuum system.

In order to prevent arcs across the insulator of the source electrodes as the voltage reverses we now crowbar the main capacitor gaps. This has prevented the arcs from releasing aluminum and oxygen after each shot that would contaminate the electrodes for the next shot.

When using the dc glow for discharge cleaning the copper flux conserver sputtered badly, coating optical surfaces in the vacuum system. To reduce sputtering the flux conserver was nickel-plated by electroplating it in a solution of $NiSO_3NH_2$ and boric acid. However, after considerable use it was recognized that this coating was an important source of impurities in the system. The replacement of the Ni-plated flux conserver with an oxygen-free-copper one resulted in significant improvement of the discharge.

We have been heating the flux conserver to over 200^0C during discharge cleaning but as yet cannot ascribe directly any improvement to this effort. The installation of hydrogen-furnace-baked tungsten-sprayed electrodes coincided with the removal of the Ni-plated flux conserver, and again no direct improvement can be asserted.

BACKGROUND FILL OPERATION

The coaxial source has been operated in the presence of a static background of hydrogen filling the source, flux conserver and vacuum tank. This mode of operation has directly reduced the impurity production in the source compared to operation at the same voltages and bias fields injecting into a low-base-pressure vacuum. Even more importantly it has broadened the range of operating parameters to lower voltages and higher poloidal fields, further reducing the impurities in the spheromak.[1] In this mode the plasma has higher initial temperatures and slower magnetic-field-energy decay rates τ_{B^2}. Figure 1 shows the magnetic field and density for one of our best shots obtained with the fill operation. The lifetime is 1 ms, with τ_{B^2} exceeding 400 μs. The poloidal field on axis has bumps during its decay. Further analysis reveals that after the separated spheromak has

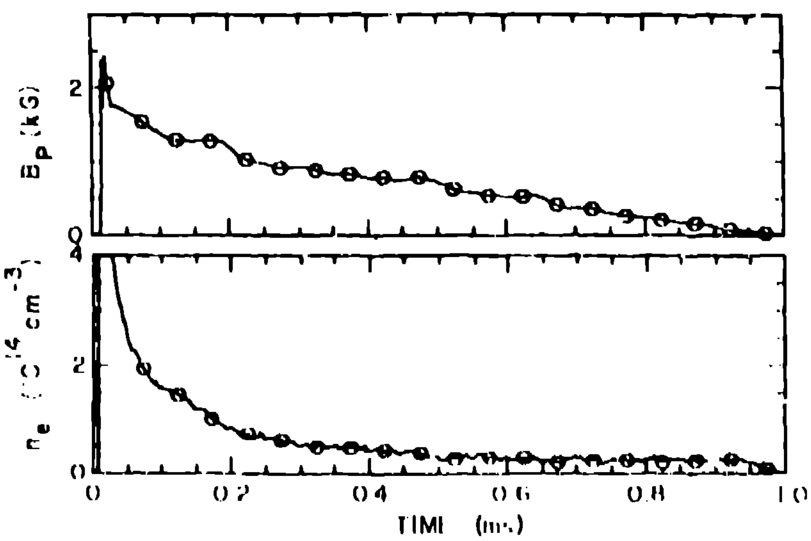

Fig. 1.
Poloidal magnetic field and line-integrated density versus time for H_2 fill operation.

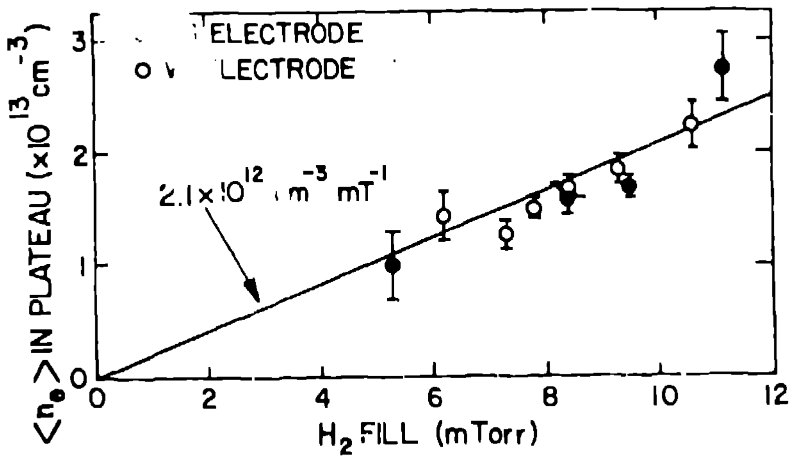

Fig. 2.

Mean electron density during the "plateau" versus the fill pressure of hydrogen. Too little gas does not protect the electrodes and results in dirty, short-lived shots. Too much gas also causes too much radiation and faster B-field decays. The optimum pressure is typically 7–9 mTorr for our experiment.

formed, these bumps in the axial component of the field are accompanied by a rotation of a helical kink-like structure of the transverse components in the center of the plasma. This fluctuation quickly saturates and does not adversely affect the stability of the plasma; rather, it seems to always accompany the longest lived discharges.

The density shows an initial spike that precedes the observation of magnetic field in the spheromak, possibly due to an ionizing shock from the source. Further, the density decreases at a more rapid rate than the magnetic field, until it reaches a value around $2\text{–}4\times10^{13}\,cm^{-3}$ where it remains constant. This differs from the results observed under vacuum-operation conditions where the magnetic field decays smoothly, and the density decays at about the same rate.[2] The level of the constant density "plateau" is linearly proportional to the fill pressure in the tank (Fig. 2). Changing vacuum surfaces can have a noticeable effect of the optimum amount of fill for operation.

THOMSON SCATTERING AND B PROFILES

Figure 3 shows radial density (normalized to interferometric density measurement) and temperature profiles measured on a single shot with multipoint Thomson scattering. This shot is typical of fill operation, and has a τ_B of 410±100 μs. On almost all shots the density is peaked at the 28 cm position, near the expected location of the magnetic axis.[3] The temperature has a decrease or "hollowing" at the peak density. In spheromaks which are known to be very dirty (achieved by poisoning the fill gas with up to 6% argon impurity) the temperature is flat and low (≤15 eV) with a dip at the peak density. On cleaner shots the peak temperature can

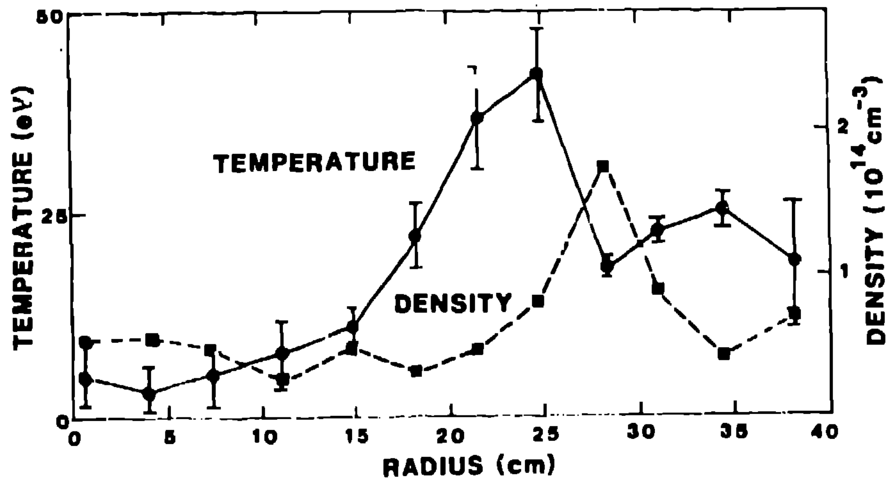

Fig. 3.
Thomson scattering temperatures (circles) and density (squares) measured on a single shot 198 μs after source injection.

be over 50 eV, and it almost always has a pronounced hollow profile. This would be expected if impurity radiation were dominating the local energy balance near the magnetic axis, for the radiation increases greatly with higher density and can tend to locally cool the plasma.

Assuming a model for the magnetic field which minimizes the magnetic energy at constant helicity,[3] and normalizing the magnitude to the single point measurement on the geometric axis, local β's can be determined from the measured pressure profile. The ion density and temperature are assumed to equal the electron values. Figure 4 shows the value of β determined from the data of Fig. 3. Values of β from 10% to 30% have been observed in the clean fill operation, with an average value of typically 15±8%. For the data of Fig. 4, an energy confinement time can be estimated by assuming all the magnetic energy decay is going into input heating power. Then $\tau_E \simeq 3/2 \langle\beta\rangle \tau_{B^2} \approx 62 \pm 24$ μs where the average plasma pressure normalized to the average B-field squared is about 10±3%.

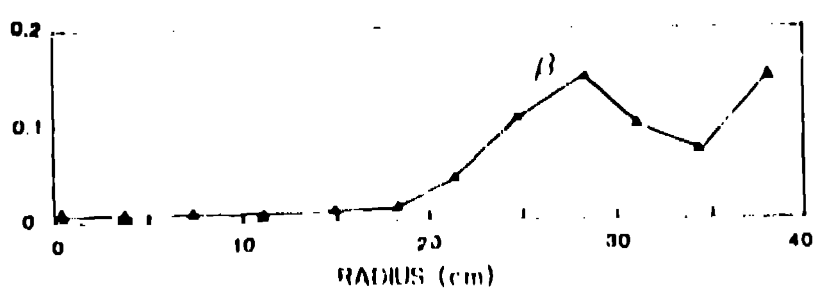

Fig. 4.
The local β obtained from the measured plasma pressure (Fig. 3) with ion density and temperature assumed equal to the electron values, and the calculated magnetic field (Ref. 3).

Finally we note that the dramatic difference in plasma behavior between the colder, radiation-dominated discharges and the hotter, fast-density decay shots provides evidence that the plasma β is a limit to the current operation of CTX.[4]

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