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First results from the Columbia Non-neutral Torus

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Introduction

The Columbia Non-neutral Torus (CNT) is a stellarator of unique design, dedicated to the study of non-neutral and electron-positron plasmas confined on magnetic surfaces. Such plasmas have unique properties and have not been studied experimentally before. The equilibrium for a low density pure electron plasma confined on magnetic surfaces has been investigated theoretically and numerically in some detail [1, 2, 3, 4]. Theory predicts the existence of stable equilibria with long confinement times. Most recently, a three-dimensional equilibrium code has been written, and equilibria in the CNT geometry have been calculated [5]. At moderately small Debye lengths, the electron density can vary significantly along a magnetic field line, both toroidally and poloidally, even when the plasma is surrounded by a perfect conductor shaped to conform to the last closed flux surface.

CNT is a two-period, ultralow aspect ratio stellarator whose magnetic field is created from only four circular coils, two internal, interlocked (IL) coils, and two external poloidal field (PF) coils [6]. CNT operation started in November 2004. Here, we briefly report on the first results from CNT, field line mapping, and initial pure electron plasma experiments.

Field line mapping results

Magnetic field line mapping results show that a large volume of good magnetic surfaces is present in CNT. These results are in good agreement with numerically calculated magnetic surfaces and show that CNT has an aspect ratio $A \leq 1.9$, the lowest aspect ratio stellarator constructed to date [7]. The best results were obtained at the highest magnetic fields, B=0.1 Tesla. A significant, but smaller volume of good magnetic surfaces was seen even at B=0.003 T. Details of the field line mapping are given at this conference by Sarasola et al [8].

First experiments with non-neutral plasmas

Experimental setup

Non-neutral plasmas have been created in CNT by injection of electrons from a multifilament electron emitter. The emitter consists of four thoriated tungsten filaments mounted on a hollow ceramic rod, spaced approximately 8 cm apart so they contact different magnetic surfaces. The filaments can be operated independently in several ways. Heated, negatively biased filaments act as sources of electrons, filling up the magnetic surfaces. Unbiased, heated filament terminated to ground through 1 GΩ resistors act as emitting floating probes, whose potentials are close to that of the plasma, except when the plasma density is negligible. Filaments shorted directly to ground act as large local sinks for electrons. Using the four filaments in a variety of configurations, a number of experiments have been conducted. We report on some of the results obtained so far.

Estimates of confinement time and electron inventory

The first experiments in CNT focused on confirming that the plasma volume could be filled with a significant number of electrons. The data were taken over several seconds, so a steady state had established between the electron emission and the electron losses. The plasma potential was measured at three different radial locations, confirming that indeed a negative space charge filled the magnetic surfaces. Extrapolation of these measurements was used to estimate the electrostatic potential difference between the magnetic axis and the last closed flux surface. This difference, $\Delta\Phi$, can be used to estimate the total electron inventory. A simple circular cylindrical estimate, assuming constant electron density and a cylinder length of $2\pi R$ yields a total electron inventory N of $N = 8\pi^2\varepsilon_0 R(\Delta\Phi)/e$. For a particular experiment with a neutral pressure of 5×10^{-9} Torr, B=0.05 T, a bias of -150 V was applied to the innermost emitting filament, yielding roughly $\Delta\Phi \approx 80$ V and $N \approx 1\times10^{11}$ electrons according to this estimate. A more sophisticated estimate was performed using the CNT 3-D equilibrium code [5]. This yielded $N \approx 1.3\times10^{11}$ electrons. For this experiment, the steady state emission current was 1.5 μA, that is, 10^{13} electrons per second, and hence the confinement time was approximately 10 milliseconds. The electron inventory and confinement time estimates presented here are believed accurate to within a factor of two. As more detailed diagnostic information becomes available, the uncertainty in these estimates will be greatly reduced.

Emission current scalings

As one would naively expect, the emission current is observed to increase with bias voltage. In some cases, the increase is linear, which implies that the confinement time is independent of bias voltage. In other cases, such as that shown in Figure 1, the emission current increases somewhat faster than linearly with bias voltage, indicating a confinement degradation at higher bias voltages. At this point, it is not clear why the scaling is sometimes linear, sometimes not, and this is the subject of current investigation. One may speculate that confinement degradation

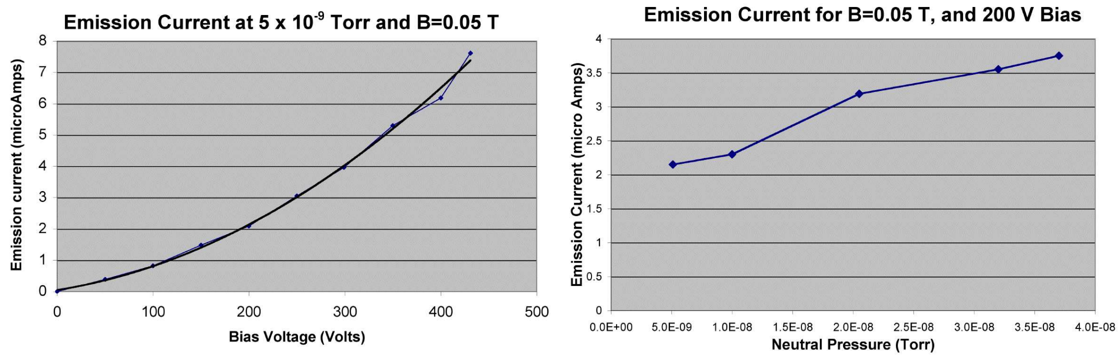

Figure 1: Left: Electron emission rate versus bias for B=0.05 Tesla and a neutral pressure of 5×10^{-9} Torr. Right: Electron emission rate versus neutral pressure for B=0.05 Tesla and a bias of 200 Volts

at high bias voltages is due to ion contamination. A measurement of the ion content can be made by measuring the (ion saturation) current to a strongly negatively biased non-emitting probe tip. Such measurements are planned for the near future.

At a given magnetic field strength and a given emitter bias voltage, the emission current was observed to increase with increasing neutral pressure, as shown in Figure 1. This implies a decreased confinement time with increased neutral pressure, as one would expect. If the confinement time is set by diffusion due to the increased electron-neutral collision rate, then one would expect a simple proportionality between neutral pressure and emission current. However, the relationship appears to be approximately off-set linear in the neutral pressure range explored here, which implies that there are other transport processes involved.

At fixed neutral pressure and emitter bias voltage, the emission current decreases with increasing magnetic field strength. Confinement may be limited by the presence of the emitter rod, which provides an electrostatic perturbation that allows electrons to flow radially due to ExB drifts. If this is the dominant loss mechanism, then confinement should improve linearly with B.

Discussion and conclusion

The first data from CNT confirm that an ultralow aspect ratio (A$\leq$ 1.9) stellarator with high quality magnetic surfaces has been created. The magnetic surfaces have been filled with 10^{11} electrons, and confinement times of 10 msec have been observed. This confirms that a fluid equilibrium exists. If electrons were to ∇B drift directly out of the plasma, or if the ExB drift direction were across the magnetic surfaces, then confinement would be on the order of 50-500 μsec at best. Although the confinement time is long compared to those time scales, it is still orders of magnitude shorter than what is predicted from theory [1]. This is likely due to the perturbing presence of the emitter rod and the exposed metal on its outside . The confinement time is observed to increase with decreasing neutral pressure and increasing magnetic field strength. There is some evidence of ion accumulation at high neutral pressures, but this has yet to be quantified by a direct measurement of the ion content. Experiments in the near future will focus on a detailed characterization of the plasma equilibrium, and optimization of the number of Debye lengths, and will also attempt to establish the main mechanism of cross-field electron transport.

Acknowledgments

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