**Investigation of Magnetic Reconnection and
Relaxation in Spheromak Magnetofluids**

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Michael R. Brown

Swarthmore College
Swarthmore, PA 19081

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Abstract: Construction has been completed and initial experiments performed on a versatile new spheromak facility at Swarthmore College called the Swarthmore Spheromak Experiment (SSX). Establishment of the facility was made possible in part by start-up funds provided by DOE. The facility can incorporate either one or two magnetized plasma guns of different sizes and one or two flux conservers with a flux conserver radius up to 0.3 m. The 0.6 m diameter, 1.2 m long stainless steel vacuum chamber is evacuated with cryo and sorption pumps (purchased with DOE funds) in a effort to reduce wall contamination due to pump oil. Spheromaks are formed and sustained by up to four 10 kV, 50 kJ capacitor modules (originally used on FRX-C and obtained through DOE). Initial experiments have been performed with a single gun and a small copper flux conserver to test the system. Our initial spheromak magnetofluids are characterized by magnetic fields up to 0.5 T, diameter of 0.16 m, lifetimes of about 40 μ s and electron temperature about 10 eV. Large (0.5 m diameter) copper flux conservers are currently being installed in SSX.

Report

During the two year duration of this award, we have constructed a facility called the Swarthmore Spheromak Experiment in the Magnetofluids Laboratory at Swarthmore College and generated our first spheromak plasmas. The spheromaks are generated by high voltage, pulsed, magnetized plasma guns mounted on a 0.6 m diameter, 1.2 m long stainless steel vacuum vessel (see figures 1, 2 and 3). The vessel is evacuated with cryogenic and sorption pumps to clean, high vacuum conditions (10^{-8} torr range). Up to four independent 10 kV, 50 kJ pulsed power modules are available for power sources for the spheromak guns. The power sources were originally used on FRX-C at LANL.

Our initial spheromak magnetofluids are characterized by magnetic fields up to 0.5 T, diameter of 0.16 m, lifetimes of about 40 μ s and electron temperature about 10 eV (see figure 4). These spheromaks have been formed with a single module charged to 5 kV at 6 kJ with discharge current up to 100 kA. We have measured peak magnetic fields over 5 kG in the small spheromak. At the moment, we are studying the magnetic structure of our spheromaks with arrays of magnetic probes and comparing results to theory. Our second set of magnetized plasma guns and large copper vessels are being constructed here at Swarthmore (see figure 5) and we plan to perform spheromak merging experiments during the coming year. Subsequent experiments will incorporate two identical guns facing each other with two flux conservers sharing a back wall. The goal here will be to form and sustain two spheromaks and allow them to communicate through an opening in the back wall. The resulting reconnection boundary layer will be studied with an array of tiny magnetic probes placed in the opening.

Our initial, preliminary results include (1) a study of the spheromak formation threshold and (2) preliminary fits of magnetic probe data to a simple force-free model (see, for example, Taylor, Rev. Mod. Phys., 1986). In figure 6, we plot the peak magnetic field in the spheromak as a 2D function of the magnetic flux and the discharge current in the gun. We expect that if the magnetic flux in the gun is high (low) then high (low) gun current is required to form a spheromak. We corroborate this expectation and find that the formation threshold is consistent with a force-free model:

$$\lambda_{\text{threshold}} = \frac{\mu_0 I_{\text{gun}}}{\Phi_{\text{gun}}} = 43 \text{ m}^{-1} \approx \frac{3.83}{r_{\text{gun}}} = 46 \text{ m}^{-1}$$

where 3.83 is the first zero of the Bessel function J_1 . In figure 7, we plot $B_z(r)$ and $B_{\text{tor}}(r)$ (solid) and compare to the prediction of the force-free Bessel function model for spheromak equilibria (dashed) and find good agreement. Our next step is to reproduce these experiments with the larger flux conservers then proceed with our proposed reconnection experiments. For more details, look at our web page at <http://laser.swarthmore.edu/html/research/SSX/index.html>.

Finances

DOE funds were used to purchase high vacuum pumping capability and vacuum diagnostics for SSX (as originally proposed). This included cryo and sorption pumps, gauges, vacuum coating of electrode structures and high vacuum electrical breaks. Funds were also used to attend two workshops. In addition, this DOE grant starter grant enabled an equipment transfer of pulsed power modules from Los Alamos National Laboratory to Swarthmore. The following table summarizes expenditures from this DOE starter grant.

Table I: Summary of DOE expenditures

CTI cryopump	8500
RJM sorption pump	3900
Televac gauges	2400
CT workshop	500
Ceramaseal breaks	2200
reconnection wrkshop	1700
PTI, tung coating	800
total	20000

Swarthmore Spheromak Experiment Reconnection Boundary Layer and Particle Acceleration

Figure 1: Swarthmore Spheromak Experiment (SSX)

Figure 2: SSX Initial Configuration

Figure 3: SSX (top) and the Magnetofluids Laboratory (bottom)

Figure 4: Typical data from initial configuration: gun current (trace 1), B_z at the top and bottom of the flux conserver (traces 2 and 3), H_α signal (trace 4).

Figure 5: Large copper flux conservers

Spheromak Formation Threshold - Averaged Runs

Kornack Valve, 88 μ F Cap Ignitron Power Supply.

Figure 6: Spheromak Formation Threshold: $B_{\text{aver}}(I_{\text{gun}}, \Phi_{\text{gun}})$, a clear threshold is seen at $\mu_0 I_{\text{gun}} / \Phi_{\text{gun}} = 43 \text{ m}^{-1}$

Figure 7: Fit of $B_z(r)$ and $B_{\text{tor}}(r)$ data (solid) to the force-free model (dashed)