Accelerated Taylor State Plumes in SSX

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Our goal

- **Twisted Taylor state** → A magnetic plasma object exhibiting minimum energy state
- First observed in SSX lab (Gray *et al.*, PRL, 2013)
- **Our goal** is to *accelerate* a Taylor state to high velocity, then stagnate and *compress* the object into a suitable MIF target
Overview of talk

- System description
- Un-accelerated SSX plasma
  - Injected into glass tube with different liners
  - Baseline velocity, density and temperature
- Accelerated SSX plasma
  - Velocity predictions
  - Experimental progress
- Summary
System schematic

Spheromak Source

Flux conservor

B dot probes

Stagnation flux conservor

(Temperature/Density/Magnetics Diagnostics)

Glass Tube

Theta pinch coil

Timing Module

(a) Stuffing field applied by external coil, gas is puffed in
(b) Bank circuit switched on, gas is ionized
(c) JxB forces push plasma to the right, stuffing field bulges
(d) Field lines reconnect, spheromak structure is formed
Un-accelerated Plasma
Current set-up

Spheromak Source

Flux conservers

B dot probes

Glass Tube 1 meter

HeNe Laser Interferometry

Expansion Chamber (Temperature/Magnetics Diagnostics)

×4

×8

×4
Velocity Measurements
$\dot{B}$ probes installed on glass

- Single turn wire loops
- Separated by 10 cm each
Time of Flight measurements

Time travelled by the structure at different locations

B-dot1

B-dot2

B-dot3

B-dot4
Plume velocity with glass
Resistive flux conserver

- SS309 foil, thickness ~ 50 \( \mu m \)
- Magnetic soak time ~ 3 \( \mu s \)
Plume velocity with resistive liner
Mesh flux conserver

- Bronze mesh, thickness $\sim 450 \mu m$, transparency $\sim 42\%$
- Magnetic soak time $\sim 245 \mu s$
Plume velocity with mesh conserver
Density & Temperature measurements
Interferometer chord, different chords of IDS and two magnetic probes also shown in the expansion chamber
Density of Taylor plume

Ave. Density $[cm^{-3}]$ vs. Time $[\mu s]$

071216 Ave. Shot 44-57

24 August 2016
16-channel trans-impedance amplifier circuit
Line shape from glass

\[ t = 93.0 \mu s \]

\[ \Delta v = 0.9 \pm 0.6 \text{ km/s} \]

\[ kT = 10.1 \pm 1.4 \text{ eV} \]
Plasma production

Glass Side Source

Flux conserver

B dot probes

Glass Tube
1 meter

HeNe Laser Interferometry

Expansion Chamber
(Temperature/Magnetics Diagnostics)

Expansion Side Source
Ion temperature of expansion side plasma

080216 Shot 7

Ion Temp [eV] vs Time [us]
Line shape of expansion side plasma

\[ t = 60.0 \, \mu s \]

\[ \Delta v = 9.9 \pm 0.3 \, \text{km/s} \]

\[ kT = 27.9 \pm 1.1 \, \text{eV} \]
Un-accelerated Taylor state

- Density $\approx 10^{15} \text{ cm}^{-3}$
- Volume $\sim 15$ liters
- Velocity $\sim 30 \text{ km/s}$
- Mass $\approx 25 \mu g$
- Kinetic energy $\sim 10 \text{ Joules}$
Overview of talk

- System description
- Un-accelerated SSX plasma
  - Injected into glass tube with different liners
  - Baseline velocity, density and temperature $v = 30 \text{ km/s}$, $n \approx 10^{15} \text{ cm}^{-3}$, $T_i = 30 \text{ eV}$
- Accelerated SSX plasma
  - Velocity predictions
  - Experimental progress
- Summary

24 August 2016
Accelerated Plasma
Acceleration with single theta pinch coil
## Acceleration system capabilities

\[ C \approx 1.3 \ \mu F \ \text{(@100} \ kV) \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply output voltage</td>
<td>40 \ kV</td>
</tr>
<tr>
<td>Energy stored, ( E_C )</td>
<td>1 \ kJ</td>
</tr>
<tr>
<td>Acceleration to velocity, ( v_{acc} )</td>
<td>290 \ km/s</td>
</tr>
<tr>
<td>@25% efficiency, ( v_{acc} )</td>
<td>145 \ km/s</td>
</tr>
</tbody>
</table>
Multiple parallel coaxial cable connections to reduce inductance, $L \approx 1 \mu H$

$$\tau_{1/4} \propto \sqrt{LC} \cong 1 \mu sec$$
Progress

• Theta pinch coil & stagnation flux conserver are ready to be installed.

• Assembling the different parts of the Capacitor charging and discharging circuit i.e., Bochkov switches, Ross relay, diodes, resistors, and capacitors and timing modules etc. (Ian Allfrey & Travis Valentine (TAE) are helping us with their useful suggestions)
Ultimate goal

Four theta pinch coils will be triggered separately & sequentially to accelerate plasma to velocities over $200 \, km/s$ and to achieve compressional density over $10^{16} \, cm^{-3}$.
Summary

• Taylor state characterized in new glass extension with a variety of liners, ready for stagnation experiments

• Theta pinch coil and accelerator test stand (1 \( \mu F \) @ 20 \( kV \)) nearly ready using TAE components
Thank you