Operation of the Magnetic Nozzle Experiment (MNX) with $m = 0$ and 1 helicon antennas

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MNX experimental program

- Study plasma cooling and acceleration during expansion (CM1.013, UP1.014)
- Serve as a testbed for NSTX-MSE diagnostic development (QP1.049)
- Provide plasma source for FRC experiment (KP1.041, QI1.003)
High-density cold-ion helium plasmas are required.
Description of the MNX

• Antenna section: 30-cm long, 4-cm ID Pyrex section with coaxial 3-cm long m = 0 (or 12-cm long m = 1 saddle coil) helicon antenna placed at the center of the Pyrex tube. A tungsten plate is at one end of the Pyrex tube.

• Breach section: 25-cm ID, 45-cm long stainless-steel section. $B_a$ to 6 kG

• Nozzle/expansion section: 1-cm ID magnetic nozzle coil and a separately pumped 60-cm long 15-cm ID Pyrex tube.

• Diagnostics: Langmuir probe, visible spectroscopy, LIF
Magnetic Nozzle Experiment (MNX)

- $T_e$: 7(4) eV  He(Ar)
- $n_i$: 1(5) x 10^{13} /cm$^3$
- Main Coils: to 6 kG
- Nozzle Coil: 2.5 kG
- RF Power: to 1500 W
- Minimum main chamber operating pressure:
  - 2 mTorr Helium
  - 0.3 mTorr Argon
Views of Ar Plasmas in MNX

Ar plasma in the region between the Helmholtz coils

Ar plasma expanding from the nozzle
He recombination in main volume
Why try different antennas?

- Using the saddle coil antenna, attempts to form high-density helium plasmas, above $5 \times 10^{13} \text{ cm}^{-3}$, resulted in:
  - Too low a density
  - Broad-profile
  - Poor RF coupling
  - Melted Pyrex antenna sections

- What was the cause of the low density?
  - Losses to W plate
  - Helicon modes
  - Field strength and profile
  - Available power
  - Plasma “pumping”
Particle losses to W and Mo plates

Currents to Mo, W Plates
Ar, 5.4 mT, I_M = 200 A
360 W forward, m=1 antenna

Currents to Mo, W plates
Ar pressure scan, I_M = 200 A
m=1 antenna, 500 W forward
Axial magnetic field

Modified Helmholtz magnet configuration

To produce maximum expansion near nozzle
Magnetic field uniformity near antenna

![MNX magnetic field graph]

- Field strength (Gauss) vs. Current in main magnets (Amps)
- **Under main magnet**
- **At W plate**
- **At location of helicon antenna**
- **at edge of W plate, with or without Fe**
- **with Fe plug**
- **without Fe plug**
Explore low-field region

Current to Mo Plate
Helium, 26.6mT, $I_m = 62, 75$ A
$m=0$ antenna

<table>
<thead>
<tr>
<th>Current (A)</th>
<th>Power net (W)</th>
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<tbody>
<tr>
<td>62 A</td>
<td></td>
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<tr>
<td>75 A</td>
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Diagram showing the relationship between current and power.
Current vs Power

Current vs Net Power

Target current (Amps)

Forward-reverse Power (W)
Modes of operation

Argon

- Broad Mode
- Blue-core Mode
- Hollow Blue-core Mode

Helium

- Broad Mode
- Blue-core Mode
- m=0 only

m=0 only
Peaked vs hollow profiles in Helium

Transition to peaked promoted by higher B tuning
m = 0

B = 5 kG
p = 24 mT
P_n = 400 W
m = 0
Summary

• Losses to $W \sim 50\%$ effect
• $B$ uniformity not an issue
• Power limit may be a problem
• Ion temperature is higher than desired
• Plasma radius may be too large for available power
**Broadening in Ar Plasma**

- $T_i = 0.5 \text{ eV}$, $T_e = 5 \text{ eV}$,
- $n_e = 1 \times 10^{13} \text{ cm}^{-3}$,
- $B = 1 \text{ kGauss}$,
- $I_o = 3.8 \text{ kW m}^{-2} = (2 \times I_{\text{max}}/ds)$
- $\lambda_o = 6686.1 \, \text{Å}$, $\Delta v_{\text{laser}} = 1 \text{ MHz}$

### Mechanism FWHM Profile type

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>FWHM</th>
<th>Profile type</th>
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<tbody>
<tr>
<td>Natural</td>
<td>$\Delta \lambda_N = 2.33 \times 10^{-4} , \text{Å}$</td>
<td>Lorentzian</td>
</tr>
<tr>
<td>Doppler</td>
<td>$\Delta \lambda_D = 6.31 \times 10^{-2} , \text{Å}$</td>
<td>Gaussian</td>
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<tr>
<td>Stark</td>
<td>$\Delta \lambda_S = 1.16 \times 10^{-5} , \text{Å}$</td>
<td>Lorentzian asymmetric*</td>
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<tr>
<td>Zeeman</td>
<td>$\Delta \lambda_Z = 5.4 \times 10^{-3} , \text{Å}$</td>
<td>Rough Gaussian ($\pi$)</td>
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<tr>
<td>Power</td>
<td>$\Delta \lambda_p = 5.3 \times 10^{-3} , \text{Å}$</td>
<td>Asymmetric ($\sigma$ components)</td>
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<tr>
<td>Power</td>
<td>$\Delta \lambda_p = 1.0 \times 10^{-4} , \text{Å}$</td>
<td>Lorentzian</td>
</tr>
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</table>
Future Plans: Getting to higher density

- Raise power to 5 kW (pulsed)
- Lower RF frequency
- Shrink radius of Pyrex section
- Consider conversion back to LH heating
- Other plans
  - RF compensated Langmuir probes
  - Reorient LIF system to measure axial flow
  - Develop LIF for He (WVU)