Plasma Formation and the Correlation with Current Loss in Post-Hole Convolutes

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Outline

• Introduce Z-Pinches, the Z-Machine, and post-hole convolutes
• Diagnostic setup
• Example spectrum and basic analysis
• Experimental measurements
  – Axial plasma location
  – Plasma density as a function of load
  – Propagation of plasma across A-K gap
  – Plasma density as a function of location
• Summary and conclusions
Magnetically-driven z-pincho implosions are a very rich field of study

• Wire array or gas puff x-ray sources
  – Intense x-ray sources
    • up to 2 MJ x-rays as 200 eV Planckian
    • up to 80 – 300 kJ in K-shell radiation (several keV)
  – Applications to laboratory astrophysics

• Magnetically-driven cylindrical liners
  – Inertial fusion
  – Dynamic materials
  – Growth of the Magneto-Rayleigh-Taylor instability
Magnetically driven implosions are efficient, powerful, x-ray sources from 0.1 to 10 keV

Power scales as current squared
20% current loss => 36% power reduction
The Z-Machine is the world’s most powerful pulsed power driver, capable of delivering 25 MA with a 100 ns risetime [1]
Up to 20% of the peak current is lost between the stack and the load\textsuperscript{[2]}

Blue = Anode
Red = Cathode

MITL B-dots

Load B-dots
High-power post-hole convolutes have complex geometries and high electric and magnetic fields which produce interesting plasma[3]
The Z-Machine uses a 12 fold azimuthal symmetry double post-hole convolute\cite{4}.

Wire-Array Z-Pinch Load

Anode

Cathode

Anode

Cathode

Anode

Posts

30 cm

DPHC designed by Bill Stygar et al. It is the standard used for all 2200+ shots on Z.
Post-Hole convolute simulations show that current loss can be explained by plasma formation in the convolute\cite{5}.

Simulations by Dave Rose et al.
The experimental probe replaces one of the inner B-dots and views just downstream of the convolute.

**Streaked Visible Spectroscopy system**
- 2 Å spectral resolution
- 2 ns temporal resolution
- Fiber optically coupled

**Convolute Plasma Emission Diagnostic**
- replaces one inner MITL B-dot
- “on-post”
- Limiting aperture provides coarse spatial resolution
Stark broadening of the H-alpha absorption feature was used to determine the plasma density.

H-alpha absorption feature: 6563 Å

Timing fiducial
LiF dopant was used in the convolute to constrain the axial location of the continuum emitter[3]
The experimental data indicate that the observed continuum emitter is located between the two dopant locations\cite{5}.

Simulations agree with experimental measurements to first order.
The plasma density as a function of time was investigated for two different load geometries.

Z2172 – High initial L, Low L-dot
Z2082 – Low initial L, High L-dot
The energy transferred through the convolute affects the plasma forming in the region.

This data indicates a closure velocity of 10-20 cm/µs.
Experiments were conducted to directly measure the velocity of the continuum emitter\textsuperscript{[3]}

Experimental setup:
- Identical loads
- Identical diagnostic settings
- Different field of view
Emission source travels from cathode to anode at up to 40 cm/µs
The plasma closure velocity was estimated based on plasma density measurements at several locations in the convolute.
The plasma density inferred from the cathode view was greater than the gap view for all times.

The inferred gap closure velocity is \(~ 20 \text{ cm/\mu s}\).
Summary

• Li absorption features observed
  – Observed continuum emitter located in convolute
  – Set loose bounds on axial position

• Inferred plasma densities up to $10^{18}$ cm$^{-3}$

• Plasma density dependent on load impedance history

• Plasma crosses A-K gap from cathode to anode
  – Apparent closure velocity is 10s of cm/µs
Conclusions

• Post-hole convolutes are a critical component of high current pulsed power driver designs
• The losses in convolutes for certain loads have increased significantly as the power throughput of the convolute increased
• The plasma conditions/dynamics in the convolute are key to understanding the losses
• Experimental data are needed to confirm simulation results
• These experiments provide a basis to begin a study of the complex physics taking place in the convolute
References


