Staged Z-pinich Target for Fusion

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Presented at:
ARPA-E Annual Alpha Meeting
August 9-11, 2016
Seattle, WA

ARPA-E, DE-AR0000569
**Z-pincho**

**Driver Parameters:**

- $I = 0.1 - 10'$s MA, $V = 0.05 - 5$ MV
- $t_{1/4} = 0.1 - 10'$s $\mu$s, $P = 10^{-3} - 100'$s TW
Staged Z-pincho (SZP)

- Axial magnetic field, $B_z$
- High atomic # liner, Kr
- Low atomic # target, DT
- Stable-target implosion
- Magneto-inertial compression
- Fusion-product containment
- Target ignition
- Existing driver systems

SZP - UC Irvine (~1993-1998)

Kr $\to D^+$, $B_z = 0.01$ T
5 ns, Laser Schlieren Image

Unstable liner
Stable target
Outline

• Staged Z-pinchn Overview

• Status

• Next steps
Pressure \((r, t)\)

- Shock breakout, \(~90\) ns
- Target compressed, \(~166\) ns
- Target recompressed, \(~174\) ns
Zebra (UNR)

2 TW, 1 MA, 100 ns, 1.9 Ω
SZP Layout

Pre-ionizers

Annular Liner/Target Injector

Anode

Cathode

Bz Helmholtz coils
Peak Current
~ 850 kA

Simulated Load Current

Upstream Current

X-ray pulse,
$Y_{K\alpha} \sim 50J$

Simulated X-ray pulse

X-ray pulse,
< 1 keV

Measured Load Current

Simulated Load Current
Shot 4328: $v_r$, $n_i$, $T_e$

Optical Streak

Courtesy: Eric Dutra
NSTech

$V_r \sim 35 - 40 \text{ cm/\mu s}$

Filtered X-ray spectra - 1 μm Ni

$B_{z0} = 10^{-2} \text{ T}$

$B_{zf} = 50 \text{ T}$

$n_{0_{\text{Ar}}} = 5 \times 10^{17} \text{ cm}^{-3}$

$n_{\text{f}_{\text{Ar}}} \sim 5 \times 10^{18} \text{ cm}^{-3}$

$n_{\text{f}_{\text{Ar}}} < 2 \times 10^{20} \text{ cm}^{-3}$

$r_0 = 12 \text{ mm}$

$\Delta r_0 = 5 \text{ mm}$

$r_f \sim 0.6 \text{ mm}$

$C = r_0/r_f = 20$

$T_{fe} \sim 500 \text{ eV}$

$Y_{K\alpha} \sim 50 \text{ J}$
Next Steps

• Fall campaign - 12-30 September 2016
  • Improved liner/target injectors
    • nozzle refinements
    • target-plasma density
  • Laser diagnostics
  • Gated-optical imaging

• Optimal target density (from simulations):
  • $n_{0\text{, target}} \sim 5 \times 10^{17}/\text{cm}^3$, $Y_{\text{Neutron}} \sim 10^{12}$
  • $n_{\text{target}} \sim 50 \times \text{Spring campaign}$
?’s
Zebra Experiments

• 17 shots: 28 April 2016 – 6 May 2016
  • ½ time hardware/diagnostics, ½ time shots
  • 9 shots, liner only, w/ & w/o B_z field
  • 4 shots, liner + gas-jet target, w/ B_z field
  • 4 shots, liner + plasma-jet target, w/ B_z field
Standard electrical probes: V-dot, B-dot, etc.

X-ray:
- Fast XRD/PCD, < 10keV detectors
- Curved KAP crystal spectrometer (film, time-integrated)
- X-ray pinhole camera imaging (film, time-integrated)
- Hard x-ray (> 50keV) scintillator detectors (n-TOF)

Optical:
- Visible emission streak imaging
- Fast 2-image transmission imaging (Ekspla 1064/532/266nm)

Neutron:
- Ag, Y – activation yield detectors, calibrated
- 4 fast neutron time-of-flight (TOF) scintillation detectors
$n_i$, $J_z$, and $B_\theta$

**Peak Compression**
- Unstable liner
- Flux compression
- Current reversal
- Shock front
- Stable target
Characterization of the Liner - Target Injector (Test-Stand Results)

Ar liner @ 3 Bar, D₂ target @ 20 Bar
Plasma Gun - 3 kV, 3 kA, 15 μs

Target delay - 180 us

Target delay - 300 us
• R = 1 cm, n ~ $10^{17}$ cm$^{-3}$, $\rho$ ~ 0.01 kg/m$^3$, 50 kPa Ar
• MACH Number ~ 7, for Ne, Ar, Kr
On-axis valve injects D$_2$

HV pulse accelerates plasma into the AK gap

Plasma enhances ionization and defines the initial target

Results shown at left: 4 $\mu$s & $z = 0$ cm
Annular-Liner Injector – n(t, z = 6mm)

Gas exits ~200 us, linear increase ~220 us, asymptotic flow ~ 450 us
Annular-Liner Injector – \( n(r, z = 6\text{mm}) \)

- The gas jet is imaged 300 us after valve firing (linear regime)
- Flow is well-collimated axially with a radius, \( R = 1 \text{ cm} \)
- The density is suitable for the experiments
- Gas density present on axis
Annular-Liner Injector, \( n(r, t, z = 6\text{mm}) \)

- Gas evolves on-axis during the linear-flow regime
- Due to gas flow interaction with boundaries, late in time
- Appropriate timing will reduce its effect
Target Jet Injector LID

Jet with known dynamics
HV pulse ionizes/accelerates
Plasma is highly reproducible
Pre-ionization level <10%
$\Delta t_{\text{jitter}} \sim 1 \mu s$,
$V_z \sim 1-2 \text{ cm/}\mu s$,
$\tau_{\text{lifetime}} \sim 20 \mu s$
Refractive indices opposite sign for the gas & plasma
Target Jet Injector – Visible Light

- Plasma exits in ~5us
- Lifetime is ~20 us