FAR-TECH’s Numerical Simulation Efforts for Plasma Jet Merging *

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Work is being performed by
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Adiabatically imploding spherical shell created by perfectly merging of plasma jets may create hot dense matter (HDM) and warm dense matter (WDM)

Hydrogen Phase Space

Temperature (eV)
Density (g/cm³)

Stagnation of H-plasma jets $M_0 = 20$

With lower $M_0$

Initial plasma jets

HDM

radiatively heated foils

$s - T$ track for sun

spherical compressions

WDM

planar shocks

planetary cores

CM
Main code: LSP[1] is a good physics code benchmarked for many problems including high density plasmas.

- Use first principles – PIC (Particle-In-Cell)
- PIC codes are most accurate but most time consuming
- Switch on GradP to capture fluid nature while speed up (Hybrid PIC code)
- Multiple processing

Two plasma jet merge head-on collision simulation model

Plasma (H): \( V_x = 10 \text{ km/s}; \ n_i = 10^{17} \text{ cm}^{-3}; \ T_i = 0.25 \text{eV}; \ M_0 > 1 \)

Background Neutrals (H): \( n_n = 10^{13} \text{ cm}^{-3}; \ T_n = 0.025 \text{eV} \)

Computational domain (10cm X 6cm X 6cm)
Two plasma jets of $M_0 \sim 1.6$, head-on collision, produced shocks by LSP ($T_i = T_e = 0.25\text{eV}$)
At present, in LSP, plasma jets are created by ionization from neutral beams resulting in two neutral jets & two plasma jets.
Two plasma jets in vacuum, at 30°
$V_0 = 1000 \text{ km/s}$, $n_i = 10^{11} \text{ cm}^{-3}$, $n_n = 10^{14} \text{ cm}^{-3}$, merge to one

Neutrals (green dots)

Ions (blue dots)

Ion density profile

Computational domain (60cmX40cmX45cm)
with vacuum inside and open faces
Plasma ion density plots at various cross sections along jet propagation (x) at t=11.5 ns
Two plasma jets merge into one

Maximum ion density

t=11.5ns

Beam front formation

Beam focusing zone

ion density profile

x (cm)

max $n_i$

$n_i$ (ions/cm$^3$)
Plasma jets merge ($V_0=1000\text{km/s}$, $n_i\sim 10^{11}\text{cm}^{-3}$)
Neutral jets diverge ($V_0=1000\text{km/s}$, $n_n\sim 10^{14}\text{cm}^{-3}$)

Density plots at 11.5 ns
Two plasma jets merge at 11.2° \((n_i \sim 3 \times 10^{17} \text{cm}^{-3}, V_0 = 100 \text{km/s}, M_0 \sim 1.5)\) in background neutrals shows turbulence.

Unlike neutral jets, plasma jets suddenly develop turbulence (~270 ns) and collapse (~275 ns).

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**Background neutrals:**
300k, 1 mTorr, 3.22 \(10^{13} \text{ cm}^{-3}\)

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**Density**

\(t = 270 \text{ ns.}\)

**Velocity**

\(t = 275 \text{ ns.}\)
HyperV capillary plasma jets merging experiment (2006-2007)†

† F. Douglas Witherspoon, Andrew Case, Michael W. Phillips “Dense Hypervelocity Plasma Jets”, APS DPP 2006 Poster
Three plasma jets merging (H) at 5.6° $n_i \approx 10^{17}\text{cm}^{-3}$, $V_0 = 100\text{km/s}$, $M_0 \approx 5$

H-neutral background: 300k, 1 mTorr, $3.22 \times 10^{13}\text{cm}^{-3}$
Five H-plasma jet merging at 5.6°, ($n_i \sim 3 \times 10^{17} \text{cm}^{-3}$, $V_0 = 100 \text{km/s}$, $M_0 \sim 5$) shows some instability in liner formation. - preliminary results

H-neutral background: 300k, 1 mTorr, $3.22 \times 10^{13} \text{ cm}^{-3}$
Summary

- Preliminary simulations are performed for plasma accelerators and merging of high density and mach number plasma jets with parameters:
  
  \[ n \approx 10^{13}-10^{17} \text{ cm}^{-3}; \quad T \approx 0.01-10 \text{ eV}; \quad V \approx 10-1000 \text{ km/s}; \]
  
  Merging angles (for 2, 3, 4, 64 jets)

- Plasma jets merge together, while gas jets disperse as they collide.

- Plasma jet front liner instability was observed but still preliminary.

- Ongoing work:
  - HyperV experiment simulation and interpretation
  - Theoretical understanding of the implosion, liner formation, and their stability
Speedup of LSP runs are necessary for high-density, high Mach number plasma jet simulations for HEDP, MTF, astrophysics and other applications.

- LSP (3D PIC) is well benchmarked, for high density plasmas, Radiation module is being implemented.

- Full 3D LSP runs take unrealistically long computation time
  - For full kinetic, use of MPI is necessary
  - Scalability up to ~100 processors is necessary
  - EMHD (fluid electron) should solve the computer time problem.

- Essential to be aided by simple codes and analytic estimates.
  - For accelerators by 1D slug model[2], 2D membrane model[3].

Plasma jet accelerator simulation

Backward plasma flow, re-strike formation

Magnetic piston
The END
Stay Tuned!