Simulation of High-Power Mercury Jet Targets for Neutrino Factory and Muon Collider

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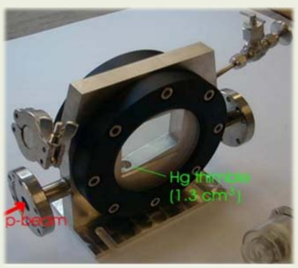
Introduction

- Liquid mercury jet interacting with proton pulses in 15-20T magnetic field is a key element of high-power target systems
- Proof-of-principles targetry experiment MERIT was conducted at CERN in 2007
- Previous numerical studies
  - FronTier MHD code with free surface support
  - Simulation of cavitation by forming tracked-surface cavitation bubbles in rarefaction waves
  - Difficulties to resolve small scales associated with distances between bubbles
  - Simulations demonstrated distortion of the mercury jet entering nonuniform magnetic fields
  - Surface instabilities, cavitation, and fragmemtation of the mercury jet after interaction with proton pulses
  - Stabilizing effect of the longitudinal magnetic field

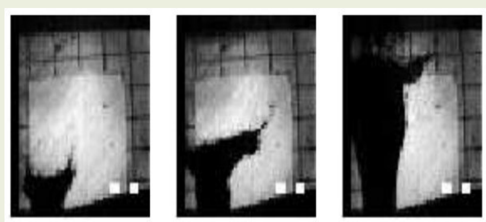
Current numerical approach

- New series of simulations have been performed using smoothed particle hydrodynamics (SPH)
- SPH is a Lagrangian particle method in which particles replace Lagrangian cells
- SPH eliminates the mesh distortion problem in complex flows – the major difficulty of the traditional Largangian method
- Parallel SPH code has been developed
  - Advanced numerical algorithms, parallelization for traditional supercomputers and GPU's
  - Contains physics models pertinent to the mercury target problem
  - Cavitation modeling by turning off particle interaction in strong rarefaction waves
  - Cavities can form on inter-particle size scales
- Present work focuses of pure hydro processes. MHD studies are in progress

Validation: Mercury thimble experiments

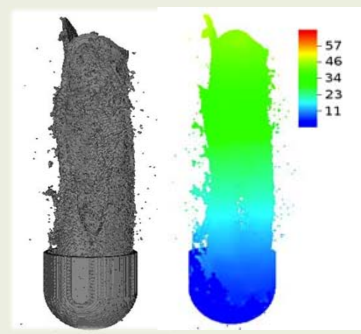


The volume of the thimble in a stainless steel bar is 1.3 cm^3. It consists from bottom to top a half sphere (r = 6 mm), and a vertical cylinder (r = h = 6 mm).



Digital image of mercury splash at time (from left to right) 0.88, 0.125, and 0.7 ms after proton impact of 3.7 10^{12} protons at energy 24 GeV.

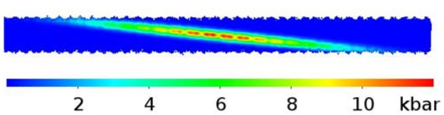
- Simulation results are in good agreement with experimental measurements of velocities of the mercury splash



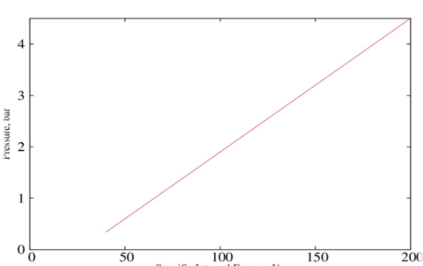
(a) Mecury surface (b) z-velocity, m/s

Simulation of the thimble experiement. Shape (left) and vertical velocity (right) of the mercury splash column at time 0.85 ms.

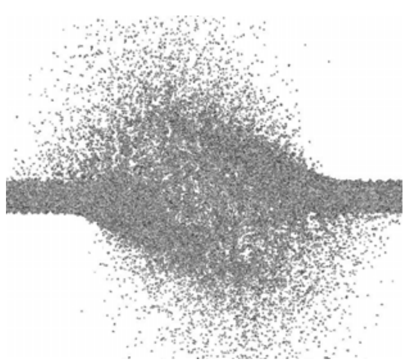
Mercury targets for neutrino factory and muon collider



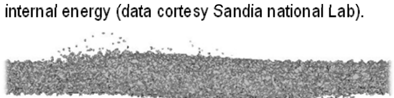
Initial pressure distribution in cross-section of the mercury jet due to neutrino factory beam energy deposition.



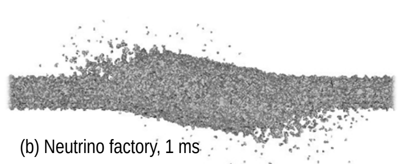
Isochoric increase of mercury pressure with increase of internal energy (data cortesy Sandia national Lab).



(c) Muon collider, 0.35 ms

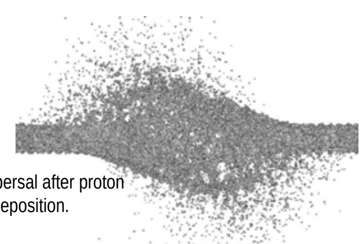


(a) Neutrino factory, 0.35 ms



(b) Neutrino factory, 1 ms

- 4 MW beam of 8 GeV protons is delivered in 150 bunches/s for the neutrino factory and in 15 bunches/s for the muon collider
- 20.8 teraproton bunches arrive at the neutrino factory target with the 6.67 ms. In the case of the muon collider, 208 teraproton bunches arrive with the time interval of 66.7 ms
- The velocity of the neutrino factory target splash is in the range of 15 - 35 m/s. These velocities are in the same range as ones observed in MERIT experiments
- Using the muon collider proton beam parameters, the dispersal of the gallium jet was similar to that of the mercury jet. This observation is consistent with a simple energy balance law
- For the case of the neutrino factory proton beam, the jet expansion velocities were lower compared to the mercury jet and the gallium jet exhibited little distortion at 1 ms



Gallium jet dispersal after proton beam energy deposition.

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