The Potential of Fluidised Powder Target Technology in High Power Accelerator Facilities

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Motivations: what are the limits for solid targets? E.g. T2K Graphite target for 750 kW operation?

Pion production target installed inside magnetic horn for 'conventional' neutrino beam ($\nu_\mu \rightarrow \nu_e$ oscillations)

First Beam: 23rd April 2009

Phase I: 30 GeV, 750 kW beam

5 year roadmap: 1.66 MW
Ultimate: 3-4 MW

Target options?
Powers and power densities in a few target systems using proton accelerator drivers

<table>
<thead>
<tr>
<th>Material</th>
<th>Proton beam energy</th>
<th>Power in target kW</th>
<th>Peak power density J/cc/pulse</th>
<th>Pulse length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphite, 30-50 GeV</td>
<td>30</td>
<td>30</td>
<td>344</td>
<td>5x10^{-6} s</td>
</tr>
<tr>
<td>Hg jet or tungsten, 5-15 GeV</td>
<td>1000</td>
<td>1000</td>
<td>300</td>
<td>Few x10^{-9} s</td>
</tr>
<tr>
<td>Contained Liquid Hg, 1 GeV</td>
<td>1400</td>
<td>1400</td>
<td>10</td>
<td>10^{-6} s</td>
</tr>
<tr>
<td>Ni, ++, 120 GeV</td>
<td>200</td>
<td>200</td>
<td>25000</td>
<td>5x10^{-9} s</td>
</tr>
</tbody>
</table>
Broken graphite targets / samples from existing accelerator facilities
Target technology progression:

SOLIDS
- Monolithic
- Segmented Pebble bed
- Moving

Increasing power

LIQUIDS
- Contained liquids
- Open jets

Challenges:
- Power dissipation, Radiation damage, Shock waves/thermal stress
- Power limits, Low density
- Cooling, Lubrication/tribology, Reliability
- Shock waves, Cavitation, Corrosion, Radiochemistry
- Splashing, radiochemistry, corrosion

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Mercury jet target is ‘already broken’ - Neutrino Factory / Muon Collider baseline

... pulsed beam ‘splash’ mitigated by solenoidal magnetic field (ref. MERIT experiment talk by Kirk MacDonald)

Some issues remain e.g. interaction of jet with mercury pool

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Liquid metal jets with magnetic horns? Probably not...

No magnetic field inside a magnetic horn, so no damping of splashes

Cavitation Damage
Erosion from SNS/JSNS research

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Is there a ‘missing link’ target technology?
Flowing powder targets: some potential advantages

- **Shock waves**
  - Material is already broken - intrinsically damage proof
  - No cavitation, splashing or jets as for liquids
  - High power densities can be absorbed without material damage
  - Shock waves constrained within material grains, c.f. sand bags used to absorb impact of bullets

- **Heat transfer**
  - High heat transfer both within bulk material and with pipe walls - so the bed can dissipate high energy densities, high total power, and multiple beam pulses

- **Quasi-liquid**
  - Target material continually reformed
  - Can be pumped away, cooled externally & re-circulated
  - Material easily replenished

- **Other**
  - Can exclude moving parts from beam interaction area
  - Low eddy currents i.e. low interaction with NF solenoid field
  - Fluidised beds/jets are a mature technology
  - Most issues of concern can be tested off-line i.e. cheaply!

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Pion+muon production for 50% W powder vs 100% Hg

Dotted line is Hg jet yield for 10 GeV beam using Study II optimum tilt, beam & target radii

MARS calculation for variable length 50% density W
r_{beam} = 0.5 cm
by John Back, Warwick University

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Schematic layouts of flowing powder targets for neutrino facilities

Superbeam target - contained within pipe

- Helium
- Powder hopper
- Magnetic horn
- Beam window
- Beam

Neutrino factory target - open jet configuration used in test rig on day 1 (for MERIT comparison)

- (1) pressurised powder hopper
- (2) discharge nozzle
- (3) recirculating helium to form coaxial flow around jet
- (4) proton beam entry window
- (5) open jet interaction region
- (6) receiver
- (7) pion capture solenoid
- (8) beam exit window
- (9) powder exit for recirculation
- (10) return line for powder to hopper
- (11) driver gas line

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Powder test rig: open jet configuration

1: Powder drop
2: Pressurise and eject powder
3: Open jet
4: Powder lands in receiver
5: Vacuum recirculation

High level hopper
Pressure pot

18 kW Roots blower for vacuum recirculation
Overview of Powder Test Rig operation

• Powder recirculated in “Batch” mode
  - Rig contains ~130 kg Tungsten Powder
  - Discharge pipe ~20 mm diameter x 1 m long
  - Particle size < 250 microns

• Fully automated control system
  - Valve open/close sequence
  - Blower on/off
  - Blower Frequency
  - Data Logging
  - Hard-wired safety interlocks
GUI for Powder plant Control System
First data runs in March 2009

- 31 injection cycles - 3000 kg powder re-circulated
  - Driving pressure range 2 - 5 bar
- Best quality jet obtained for 2 bar driving pressure
  - Jet Velocity = 3.7 m/s
  - Stable Jet
  - Constant pressure in hopper throughout ejection
  - Constant velocity (top/bottom and over time)
  - Constant dimensions (with distance from nozzle and time)
- Jet material fraction = 42% $\pm$ 5% ~ bulk powder density at rest

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Driving pressure = 2 bar
Jet velocity = 3.7 m/s
Material fraction ~ 42%
CW operation: schematic circuit outline

(1) powder discharge nozzle
(2) gas return line forming coaxial flow
(3) target jet,
(4) receiver hopper
(5) suction nozzle for gas lift
(6) gas lift receiver vessel with filter
(7) powder heat exchanger
(8) and (9) pressurised powder hoppers
(10) Roots blower
(11) gas heat exchanger
(12) compressor
(13) gas reservoir
Flowing powder target: future work

- Optimise gas lift system
- Carry out long term erosion tests and study mitigation
- Investigate low-flow limit
- Study heat transfer between pipe wall and powder
- Demonstrate shock waves are not a problem
  - Possibility to use test facility for shock wave experiment on a powder sample in helium environment?
- Demonstrate magnetic fields/eddy currents are not a problem
  - Use of high field solenoid?
- Investigate active powder handling issues (cf mercury?)
Flowing powder target: interim conclusions

- **Flowability of tungsten powder**
  - Excellent flow characteristics within pipes
  - Can form coherent, stable, dense open jet
  - Density fraction of 42% ± 5% achieved ~ static bulk powder density

- **Recirculation**
  - Gas lift works for tungsten powder (though so far 10 x slower than discharge rate)

- **Both contained and open powder jets are feasible**