Tungsten Powder as an accelerator target & In-Beam Testing

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Davenne: Limitations of target technologies

Maintaining the target temperature and stress levels within safe limits is the main engineering design driver.

So designs become increasingly elaborate as energy and power deposited in the target are increased.
Candidate target technologies for a Neutrino Factory

1. Mercury
   + already exist, e.g. SNS
   - toxic!
   - reacts violently with beam

2. Moving Solid Tungsten Bars
   + studies on dynamic stress and strain-rate effects published
   - Reliability in harsh environment?
   - High static stress levels require much larger beam sigma than baseline beam parameters

3. Tungsten Powder
   + Pneumatic conveyance of powder demonstrated
   - wear of parts and powder
   - Containment

Mercury Jet in the MERIT experiment before (left) and after (right) a proton beam interaction, Kirk et al.

lifetime testing of tungsten wires in response to dynamic thermal loading, Skoro et al.

Pneumatically conveyed dense-phase tungsten powder jet, Caretta et al.
Tungsten Powder Test Programme in PASI-WP3 + ASTEC

- Offline testing
  - Pneumatic conveying (dense-phase and lean-phase)
  - Containment / erosion
  - Heat transfer and cooling of powder

Dense-phase delivery

Lean-phase lift

Drag not what expected but at least it lifts!
HiRadMat Beam Parameters:

A high-intensity beam pulse from SPS of proton or ion beams is directed to the HiRadMat facility in a time-sharing mode, using the existing fast extraction channel to LHC. The SPS allows accelerating beams with some $10^{13}$ protons per pulse to a momentum of 440 GeV/c. Details of the primary beam parameters and focusing capabilities are summarised below:

**Beam Energy** 440 GeV  
**Pulse Energy** up to 3.4 MJ  
**Bunch intensity** $3.0 \cdot 10^9$ to $1.7 \cdot 10^{11}$ protons  
**Number of bunches** 1 to 288  
**Maximum pulse intensity** $4.9 \cdot 10^{13}$ protons  
**Bunch length** 11.24 cm  
**Bunch spacing** 25, 50, 75 or 150 ns  
**Pulse length** 7.2 µs  
**Beam size at target** variable around 1 mm$^2$
In beam test rig

- Tungsten powder sample in an open trough configuration
- Helium environment
- Two layers of containment with optical windows to view the sample
- Remote diagnostics via LDV and high-speed camera
HiradMat Installation and Remote diagnostics
HiRadMat: Run 7

Intensity: 8.40E+10 PoT
HiRadMat: Run 8

Intensity: 1.75E+11 PoT
HiRadMat: Run 9

Intensity: $1.85 \times 10^{11}$ PoT
HiRadMat: Run 21

Intensity: 2.94E+11 PoT
Prompt energy deposition/radiation (FLUKA® Monte Carlo Code)

Maximum Energy Deposition: 4.5 GeV/cm³/primary

6 mm

Observation window
Lift height correlates with deposited energy.

Shot #8, 1.75e11 protons
Note: nice uniform lift

Shot #9, 1.85e11 protons
Note: filaments!

Trough photographed after the experiment.
Note: powder disruption
Davenne: CFD predictions/post fits

Beam heating

Test Results from Shot #8, 1.75e11 protons, beam sigma 0.75

CFD simulation of Shot #8, assuming 1 micron particle size
(n.b. no lift with 25 micron particles at this intensity)
Speculating (stumbling in the dark!)

1. **EXTERNAL STRESS**

   A kick from the trough?
   Trough resonance perhaps too slow &
   Trough does not appear moving in the HSV

2. **GAS LIFT**

   Lift proportional to Energy deposition
   CFD says yes but the energy/diameter is rather different.
   Drag model is incorrect for W or
   is it a different phenomenon?

3. **THERMAL STRESS PROPAGATION**

   Lift proportional to Energy deposition
   Too slow and too late compared with propagation through a solid.
   Peak ~40J/g (similar to MERIT) but
   100 times lower velocities 0.5m/s.
   Is this due to attenuation through the powder?
No reliable beam stamp: the gitter

i.e. no measurement of stress wave propagation time!
LDV: the problems *Part 2*

High frequency high amplitude noise?!

Yet not in all the runs?!
LDV: the problems *Part 3*

Doom: watch out for the drift!

High vibration velocities before beam impact
LDV: the good bits

Having taken all the bad data away (technically defined as data massaging!!)

- the amplitude of vibration appears proportional to PoT
- Vibration amplitude is higher in the inner trough than on the outer trough
- There is a 1kHz resonant frequency peak (expected from trough resonance)
Loveridge: ANSYS predictions

**Spectrum analysis of surface velocity**

- **run8 holder**: Green line
- **run9 dummy**: Red line
- **ANSYS**: Blue line

- **LDV data, filtered and offset corrected**
  - **<Shot #8, 1.75e11 protons, inner trough>**
  - **<Shot #9, 1.85e11 protons, outer trough>**

  **Velocity** ≈ 1 m/s

- **ANSYS simulation of secondary heat induced vibrations**
  - **Velocity** ≈ 0.1 m/s

**ANSYS vs LDV are “apart” by one order or magnitude**
Lessons learnt and stuff left to do

**HiRadMat mark 2** (after CERN shutdown)

1. Powder mono-size distribution
2. More samples (prevent interference between measurements)
3. Full length view of the sample
4. Repeat test in He and vacuum (separate Aerodynamic Lift vs momentum transfer)
5. LDV

   • calibrate signal in situ
   • use flat mirrors
   • Establish beam gitter
   • Watch out for windows interference

**Other general powder work**

1. Continue generic powder conveying study
2. Calorimetric heat transfer
3. Evaluate effect of magnetic field