Solid Target Studies in the UK

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On behalf of:

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Introduction to Solid Targets

• Why solid?
  ▪ lots and lots of experience
  ▪ both liquid targets: looking at solids again

• Candidate materials – strong at high temperature
  ▪ tantalum
  ▪ tungsten

• Issues:
  ▪ shock
  ▪ radiation damage
  ▪ temperature rise........changing target, target station, etc

• Possibilities:
  ▪ a number (150-500) of ~2x20cm bars
  ▪ particle jet
• ISIS:
  ▪ used tantalum for > 10 years, tungsten ~5 years
  ▪ targets changed after ~12dpa
  ▪ ~2-5 years at NF, depending on # of targets
  ▪ no signs of swelling or embrittlement
  ▪ Ta examined in detail; W still to be done

• Still to be done
  ▪ tensile strength after irradiation
  ▪ will be done by Nick Simos at BNL
Shock

- Solid show-stopper: one of main reasons for liquids
- Impossible to lifetime test with proton beam, so

60kV, 8kA PSU, 100ns rise time

0.5mm diameter wire
<table>
<thead>
<tr>
<th>Material</th>
<th>Current (A)</th>
<th>ΔT (K)</th>
<th>Max. T (K)</th>
<th>Pulses to failure</th>
<th>Eq. power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tantalum</td>
<td>3000</td>
<td>60</td>
<td>1800</td>
<td>0.2x10^6</td>
<td></td>
</tr>
<tr>
<td>Tungsten</td>
<td>5560</td>
<td>130</td>
<td>1900</td>
<td>4.2x10^6</td>
<td>2.7/5.0</td>
</tr>
<tr>
<td>Connector failed</td>
<td>5840</td>
<td>140</td>
<td>2050</td>
<td>&gt;9.0x10^6</td>
<td>3.0/5.4</td>
</tr>
<tr>
<td></td>
<td>7000</td>
<td>190</td>
<td>2000</td>
<td>1.3x10^6</td>
<td>4.3/7.8</td>
</tr>
<tr>
<td>Cable #6 failed</td>
<td>6200</td>
<td>160</td>
<td>2000</td>
<td>10.1x10^6</td>
<td>3.3/6.1</td>
</tr>
<tr>
<td></td>
<td>8000</td>
<td>255</td>
<td>1830</td>
<td>2.7x10^6</td>
<td>6.1/&gt;13</td>
</tr>
<tr>
<td></td>
<td>7440</td>
<td>230</td>
<td>1830</td>
<td>0.5x10^6</td>
<td>5.2/11.4</td>
</tr>
<tr>
<td></td>
<td>6520</td>
<td>180</td>
<td>1940</td>
<td>26.4x10^6</td>
<td>4.1/8.7</td>
</tr>
<tr>
<td></td>
<td>4720</td>
<td>77</td>
<td>1840</td>
<td>&gt;54.4x10^6</td>
<td>2.1/4.5</td>
</tr>
<tr>
<td></td>
<td>6480</td>
<td>~600</td>
<td>&gt;80.8x10^6</td>
<td></td>
<td>4.0/8.6</td>
</tr>
</tbody>
</table>

For 200 targets:
- 10.6 years in 2cm
- >22 years in 3cm
- better at lower temperature
• VISAR

  ▪ Velocity Interferometry System for Any Reflector
  ▪ Surface displacements ~100nm; velocity ~1m/s
  ▪ Two main problems:
    Noise!
    Moving target
  ▪ Signals now being seen – new delay line required

• Protons

  ▪ Two possibilities: ISIS, ISOLDE
  ▪ Crucial measurement: VISAR
Temperature Rise

• $\Delta T \sim 100\text{K}/\text{pulse}; \sim 5000\text{K}/\text{second}$

• Must change target between pulses:
  - 150-500 targets, swapped between pulses
  - particle jet

• Two (and a bit) methods investigated

Chain:
- Speed: $\sim 5\text{m/s}$
- Eddy currents: ok
- Forces: ok
- B-field: ok

Problems:
- moving parts high radiation
- meshing with chains

The target bars are connected by links - like a bicycle chain. Possibly made of carbon reinforced ceramic or carbon/carbon.
Temperature Rise

- **Wheels**

  - Spoked wheel
  - Moving parts out of radiation
  - Structurally ok
  - Radiation shielding
  - Forces on coils
Main problem: radial and hoop stress exceed Cu tensile strength noted as problem in study 2
~7kt bending force: “very difficult”

Possible solutions: pulsed NC magnets
smaller B-field (B² effect)
spokeless wheel......
**Spokeless Wheel**

- **Outer diameter:** 5m
- **Speed at rim:** 5m/s
- **Revolution time:** 3.14s
- **Target spacing:** 100mm
- **# of targets:** 157

Slot through solenoid: “possible”

Shielding easier

Cooling possible

**Issues:**

- Eddy currents
- Structural support
- Target mounting
- Radiation damage to support
- Drive system
- Tritium in water

Bruce King et al., 2001

*RAI 1957 - 2007*
Particle Jet

Advantages

• Solid
  - Shock waves constrained within material - no splashing, jets or cavitation as for liquids
  - Material is already broken
  - Reduced chemistry problems compared with the liquid

• Fragmented
  - a near hydrostatic stress field develops in the particles so high pulsed energies can be absorbed before material damage
  - Better for eddy currents?
  - Favourable (activated) material disposal through verification

• Moving/flowing
  - Replenishable
  - Favourable heat transfer
  - Decoupled cooling
  - Metamorphic (can be shaped to convenience)

• Engineering considerations:
  - Could offer favourable conditions for beam windows?
  - It is a mature technology with ready solutions for most issues
  - Few moving parts away from the beam!
Particle Jet

Issues

• Is W fluidisable and does it flow?
• What density can be achieved?
• Effects of magnetic field
• Effects of electric charge:
  ▪ frictional electrostatic charge
  ▪ beam charge
• Elastic stress waves and thermal expansion
• Erosion and ware of rig and W particles
• Storage and disposal of radioactive powder

First tests at Gericke Ltd
Particle Jet

- **W** powder, $<250\mu m$ particle size
- 3.9bar driving pressure
- Is fluidisable
- Does flow
- Density $\sim 29\%$ v/v
New Test Rig at RAL

Study, in particular: long term erosion and wear density
heat transfer
optimum rig arrangement
Conclusions

• Solid:
  ▪ Shock: looks OK, but VISAR & protons needed
  ▪ Radiation damage: looks OK, but detail needed
  ▪ Spokeless target wheel: early days!
  ▪ NB: most information known or calculable
    no large R&D projects required

• Particle jet:
  ▪ Looks interesting
  ▪ Much work required, but this is starting
  ▪ Use of radioactive powder needs careful study