Solid Target Studies for NF

Rob Edgecock
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On behalf of:

J.Back, R.Bennett, S.Gray, A.McFarland, P.Loveridge & G.Skoro

Tungsten wire at 2000K
Reminder

• **Solid means**
  - tungsten bars, each ~2x20cm
  - 150-200 bars
  - changed between beam pulses
  - cooled radiatively or possibly by helium/water

• **Why?**
  - lots of experience world-wide & safer
  - already have a license at RAL

• **Issues for solids:**
  - shock – original show-stopper
  - radiation damage
  - target change

• **Focus has been on shock - but now moving on**
Shock

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

Aims: measure lifetime validate LSDyna model understand W behaviour

More than sufficient lifetime demonstrated:
  > 10 years for 2cm diameter target
  > 20 years for 3cm diameter target

Better at lower temperature!

60kV, 8kA PSU, 100ns rise time
Laser Doppler Vibrometer

• Used to measure wire surface velocity & CF LS-Dyna

  Longitudinal and radial measurements possible

  Wire

  Laser beam

• Longitudinal
  ▪ Bigger oscillations: ~µm; lower frequency: ~20kHz
  ▪ But.....temperature variation along wire
  ▪ Wire fixed at one end, constrained at other
  ▪ Oscillations more difficult to understand

• Radial
  ▪ Smaller oscillations: 50-100nm; higher frequency: ~12MHz
  ▪ But......fixed temperature
  ▪ Easier to model
Longitudinal oscillations vs LSDyna

Frequency analysis
Radial oscillations vs LSDyna

Radial oscillations: frequency analysis vs LSDyna
Concern: low strength from static measurements at high temp

'Fit' - will be used later for comparison

J.W. Davis, ITER Material Properties Handbook, 1997, Volume AM01-2111, Number 2, Page 1-7, Figure 2
If we know the Poisson's ratio $\mu$, density $\rho$, root of corresponding Bessel function $\zeta$, wire radius $r$ and measure the frequency $f$ as a function of temperature then:

$$E = \frac{(2\pi f)^2 r^2 \rho}{\zeta^2} \left( 1 - \mu^2 \right) \left( 1 + \mu \right) \left( 1 - 2\mu \right) \left( 1 - \mu \right)$$

$$\mu = 0.279 + 1.0893 \times 10^{-5} \cdot T[C]$$
Tungsten Young’s Modulus

Encouraging, but not tensile strength
Tensile Strength of Tantalum

<table>
<thead>
<tr>
<th>Strain Rate</th>
<th>T = 2100 C</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mHz</td>
<td>40 MPa</td>
<td></td>
</tr>
<tr>
<td>10 Hz</td>
<td></td>
<td></td>
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<tr>
<td>5 kHz</td>
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<tr>
<td>Extrapolated?</td>
<td></td>
<td></td>
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</tbody>
</table>

- Stress; wire remains straight

Graph showing tensile strength at different strain rates.
Tensile Strength of Tantalum

Graph showing the tensile strength of tantalum as a function of temperature. The graph compares the tensile strength of tantalum wires of different diameters and under different stress conditions. The temperature is plotted on the x-axis, ranging from 0 to 2600 °C, and the tensile strength is plotted on the y-axis, ranging from 0 to 600 MPa. The graph includes lines for Ta; 0.5 mm wire; Stress; straight, Ta; 0.5 mm wire; Stress; bent, Ta; 0.8 mm wire; Stress; straight, and Ta; 0.8 mm wire; Stress; bent.
Tensile Strength of Tungsten
Tensile Strength of Tungsten

The graph illustrates the tensile strength of tungsten as a function of temperature. The strength is measured in MPa (MegaPascal) and the temperature in °C (Celsius degrees).

Key observations include:
- Different lines and markers represent various conditions and sources of tungsten.
- The strength decreases significantly as the temperature increases.
- Specific conditions, such as power levels and pulse counts, are indicated for each data point.
Shock Conclusions

• We have demonstrated:
  ▪ LS-Dyna model we are using is correct
  ▪ Tungsten is strong enough at high temperature
  ▪ It has a more than sufficient lifetime

• What still needs to be done:
  ▪ Use beams to confirm bulk samples
  ▪ Measure with LDV to cf LSDyna
  ▪ Most likely: use Ilias’s facility at CERN
  ▪ Measure strength after irradiation......
Radiation Damage

Tungsten

FLUENCE, n/cm² (E > 0.1 MeV)
- 0.5 × 10²² AT 371 °C
- 0.9 × 10²² AT 382 °C

Bauer, G.E., W. Lehmann, and F. Stelzer:
"Some Remarks Concerning the Use of a Blanketing W-Target in a High-Power Spallation Neutron Source."

NB Static measurements.
Radiation Damage
Target Change

• Targets must be changed between beam pulses, i.e. 50Hz

• Must:
  ▪ have minimal impact on pion production
  ▪ have minimal effect on shielding
  ▪ be reliable
  ▪ allow the replacement of individual targets remotely
  ▪ not be damaged by heat or radiation
  ▪ be based as much as possible on existing technology

• Various options studied by a small group:
  
  Roger Bennett
  Dave Bellenger
  David Jenkins
  Leslie Jones
Target Change

- Focus until recently: target wheel
- Helmholtz coil looks difficult due to forces

Diagram with numerical values and dimensions.
All tungsten.
Manufacture discussed
with Plansee.
Visit to factory soon.

Proposed lubricant (coating):
$WS_2$
Demonstrated to work to
~1300°C in vacuum.
Target Change

DRIVE WHEEL
PLANETARY DRIVE MOTOR
IL3750
500 TARGETS A/C 75 SPACING 3750 CHAIN
GUIDE
TENSIONER
Target Change

~12% more pions
**Target Change**

- Early days
- Work planned to verify:

  1. Thermal Calculations on Chain/Target Design.  
     Goran
  2. Thermal Shock Calculations on Chain/Target Design.  
     Goran
  3. Yield Calculations and Optimisation.  
     John
     David
     Consult with Reynolds Chain, Plansee.
  5. Calculate Strength of Helmholtz Insert.  
     David
     David
  7. Chain/Helmholtz Insert Design Stress Analysis.  
     David
     Adrian?
     Roger
    John
 11. Radiation studies  
    All
 12. Remote Handling, Replacement, Servicing.  
    David
    Roger/?
 14. Target Station Design.  
    David
Conclusions

• **Shock:**
  - We’ve done this to death!
  - Don’t believe it is a problem
  - Tests with beams to come

• **Radiation damage:**
  - Lots of local experience exists
  - Needs to be applied to our case
  - But existing data are encouraging

• **Target change:**
  - New scheme under study
  - Looks encouraging, but more studies required