T2K Beam Window Design

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High Power Targets Workshop

Malmö
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# Comparison of neutrino beams

<table>
<thead>
<tr>
<th></th>
<th>EUROnu superbeam (700 kW)</th>
<th>LBNE (2 MW)</th>
<th>T2K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam power</td>
<td>1</td>
<td>0.7</td>
<td>2</td>
</tr>
<tr>
<td>Beam energy</td>
<td>5</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Protons per pulse</td>
<td>1.50e14</td>
<td>5.60e13</td>
<td>1.6e14</td>
</tr>
<tr>
<td>Beam sigma</td>
<td>4</td>
<td>1.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Peak energy dep.</td>
<td>~ 80</td>
<td>~ 200</td>
<td>~ 128</td>
</tr>
<tr>
<td>Pulse length</td>
<td>5</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Frequency</td>
<td>12</td>
<td>1.32</td>
<td>1.32</td>
</tr>
</tbody>
</table>

**NOTE:** Energy deposition is normalised to beryllium.
Main beam window candidate materials

<table>
<thead>
<tr>
<th></th>
<th>Beryllium</th>
<th>Titanium alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1844 kg/m³</td>
<td>4540 kg/m³</td>
</tr>
<tr>
<td>Specific heat capacity</td>
<td>1925 J/kg.K</td>
<td>558 J/kg.K</td>
</tr>
<tr>
<td>CTE</td>
<td>11.5</td>
<td>8.7</td>
</tr>
<tr>
<td>Modulus</td>
<td>303 GPa</td>
<td>113 GPa</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>216 W/m.K</td>
<td>7 W/m.K</td>
</tr>
</tbody>
</table>

Others candidates: AlBeMet, GUM, INVAR…
T2K beam window

- Double-skinned titanium alloy window, cooled by helium gas.
- Installed October 2009.
- Designed for 0.75 MW beam power.
T2K target station

Window

Proton beam

Target

Focusing horns
Position in beamline

Monitor stack

To Target
Double skinned window with helium cooling

Average He velocity ≈ 5 m/s

CFD by M. Fitton (RAL)

Transient temp over first 8 pulses (30 GeV)
Titanium components

Downstream dome

Upstream dome

Downstream plate

Upstream plate
Helium flow grooves

He in

He out
- Test piece 1 distorted due to welding, no. 2 did not.
- In the worst case, the test pieces distorted by up to 1 mm.
- This distortion could create large stresses in the titanium domes.
Solution

50% stitch weld

Continuous circumferential weld
Main components

**Top plate**
- Used for inserting and removing window
- Protects pillow seals and mating flanges
- Provides a connection point for services

**Pillow seals**
- Seal helium vessel and beam line

**Side plates**
- Provide a firm support for the beam window to hold it in position

**Ti-6Al-4V beam window**

NOTE: Model is out of date. Pantograph was not used in final design.
Monitor stack (TRIUMF, Canada)

Target station (KEK, Japan)

Beam window (RAL, UK)

Window inserted and removed remotely with bayonet tool from above. Top plate provides rough guidance until contact with three support bars is initiated to provide accurate final location. Bus bars must withstand ~ 1 tonne resultant pressure load.
Installation and removal

- Installed from above with bayonet tool.
- Operator can stand on top of target station for final alignment and pipe connections once the window is in place.
Installation and removal
Inflatable bellows seals

Picture courtesy of Y. Miyake and S. Makimura (KEK)

Picture courtesy of PSI

Picture courtesy of PSI

KEK Muon Group

Picture courtesy of Y. Miyake and S. Makimura (KEK)
Cross section through seal

Pressure ≈ 3 bar gauge

Vacuum

Pressurised foil diaphragms

Pressure
Seal and mating flange

Seal foils (surface roughness, $Ra = 0.004 \, \mu m$, $Rt = 0.030 \, \mu m$)

Polished flange (surface roughness, $Ra = 0.020 \, \mu m$)
Bellows extension

Plastic deformation of bellows resulted in the natural or ‘free’ length of the seal increasing from 68 mm to 78 mm.

As a result, a vacuum will need to be applied to bellows on installation and removal to reduce the length of the seals.
Upgrade potential?

- 0.75 MW; 3.3x10^{14} PPP; 4.24 mm beam sigma
- ~150 °C temperature jump
- Max stress waves ~ 100-150MPa
- Transient thermal stress ~ 90MPa
- Yield strength of titanium ~ 900 MPa
Summary

• T2K beam window installed in October 2009
• $1.46 \times 10^{20}$ protons so far
• No evidence of damage from earthquake
• One spare window available in the event of failure
Thank you