LH2 Absorber Window R & D Program

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MUTAC Review
LBL
April 26, 2005
Review
- Window design and test history
- FNAL test requirements

Current program
- FEA (finite element analysis)
- MICE cooling channel windows
- New window tests – and improvements
- Comments
Absorbers, Vacuum and RF windows

- Forced-Flow Absorber with external cooling loop
- And secondary window

KEK Convection Absorber at MTA

MICE Convection Absorber in AFC module (and containment)

MICE 201 MHz RF (Be window)
Window design independent of particular cooling channel configuration

Cooling and safety issues are in the window profile

Originally...

500 to 120 µm reduction

Modified torispherical FNAL, Cummings

Tapered torispherical Black, Cummings

“Bellows” Lau, Black

“Thinned Bellows” Lau, Black, Yang

Interface/integration engineering issues are in the flange design
ASME vessel design definitions:
- Design by Rule:
  - Based on maximum Stress Theory
  - Standard shapes, equations
- Design by Analysis  Must do destructive tests!
  - Based on maximum Shear Stress
  - Use FEA to determine MAWP for non-standard windows

1. Want windows confirmed as safe
2. Different radii of curvature on either side of window
3. Machined sides possibly not concentric
4. What is the critical measurement?

If not at the center, where?
FNAL Requirements:

Vacuum

1. **Burst** test 5 vacuum windows at room temp. to demonstrate a burst pressure of at least 75 psid for all samples. (pressure exerted on interior side of vacuum volume).

2. **Non-destructive** tests at room temperature:
   a. External pressure to 25 psid to demonstrate no failures: no creeping, yielding, elastic collapse/buckling or rupture
   b. Other absorber vacuum jacket testing to ensure its integrity

Absorber

1. Room temp test: pressurize to burst ~ 4 X MAWP (25 psi at FNAL)
2. Cryo test:
   a) pressure to below elastic limit to confirm consistency with FEA results
   b) pressure to burst (cryo temp – LN2) ~ 5 X MAWP
      from ASME: UG 101 II.C.3.b.(i)
Mucool manufacture and measuring procedures deemed safe

RAL window pressure test requirements (Absorber and Vacuum)

<table>
<thead>
<tr>
<th>Test Pressure</th>
<th>Test temperature</th>
<th># of tests required</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>96 psi (4 x design P)</td>
<td>@ 293K</td>
<td>3</td>
<td>Test to rupture. Windows to subject to thermal cycling before the test</td>
</tr>
<tr>
<td>&gt; 96 psi (5 X design P)</td>
<td>@ 77K</td>
<td>1 or 2</td>
<td>Test to rupture. If shrapnel is evident, one further test will be needed. The additional test will have the safety mesh fitted to verify that shrapnel doesn’t reach the safety window.</td>
</tr>
</tbody>
</table>

25 psi Room temp 1 Test for buckling (external)

Design Pressure = 24 psid MAWP FNAL = 25 psid - Effectively, the same for MICE and MuCool
The current window design has a double curvature to ensure that the thinnest part is membrane stress dominate.

The current window FEA analyses show that the shape scales can use same analysis for different diameters of same profile!

<table>
<thead>
<tr>
<th>Window Type</th>
<th>MICE Req. Burst Pressure</th>
<th>FEA calc. Burst Pressure</th>
<th>MICE Req. Buckling Pressure</th>
<th>FEA calc. Buckling Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorber (30 cm diam)</td>
<td>96 psid</td>
<td>105 psid</td>
<td>25 psid</td>
<td>26 psid</td>
</tr>
<tr>
<td>Safety (32 cm diam)</td>
<td>96 psid</td>
<td>105 psid</td>
<td>25 psid</td>
<td>26 psid</td>
</tr>
</tbody>
</table>

Step loading the window with internal pressure until ultimate tensile stress is reached – numerical definition of rupture.

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The same FEA was applied to all the window shapes that were developed subsequently...

Behavior of window under an incremental **internal** pressure until burst

Behavior of Window under incremental **external** load...

Looking for the development of the first yield stress

Finding the first sign of buckling development
Flange/window unit machined from aluminum piece (torispherical 30 cm diam)

Backplane for window pressure tests

Backplane with connections, and with window attached
Photogrammetry

1. Contact vs. non-contact measurements (projected light dots)
2. “Several” vs. ~ thousand point measurements (using parallax)
3. Serial vs. parallel measurements (processor inside camera)
4. Can do measurements and performance tests
5. Better fit to spherical cap.
6. Precision measurement of real space points

Photogrammetry is the choice for shape and pressure measurements

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Rupture tests
photogrammetry measurements

1. Leaking appeared at 31 psi
   outright rupture at 44 psi!

2. Burst at ~ 120 psi
3. Burst at ~ 152 psi
4. Bzro test
   “350” µ windows

130 µ window
Performance measurement on **torispherical** windows

- Discrepancies between photogrammetry and FEA predictions are < 5%
- Room temperature and cryogenic tests validated design

Performance measurement on the 21 cm **“bellows”** window

**Tests:**
- Measured at 190 µm .. Designed for 132 µm
- Leaked at seal in first pressure test (design improved)
- Burst at 144 psid.. (predicted burst at 104 psid)

**Corrections:**
- Revised FEA calculations ... and ~144 is predicted
- Optical coatings determined to be major source of measurement error
Vapor deposition:
- Set-up and experts at FNAL
- Safety review completed
- Working to achieve proper TiO2 uniform coating < 2 μm

Alternatives:
- Chemical process for deposition
  - Simpler technology
  - Need to demonstrate on aluminum
- No coatings:
  - Test photogrammetry, other CMM methods can give sufficient results

Cryostat for deposition test
Broken window in deposition test
So far, we have looked at the window safety from a single source of loading only, i.e. the pressure load.

Other possible loads considered, but not rigorously analysed. These include:

- Thermal load caused, possibly, by the uneven temperature distribution of the liquid hydrogen during operation
- Stress from beam deposition – (pizeo-electric instrumentation)
- Thermal cycling – fatigue tests

Still need to study the high stresses at the edge of the new window

Other alloys are still under consideration (i.e., Al Li alloys, Albemet)

Window instrumentation is still planned
- Can be used as a threshold for occlusion or clearance

- Baumer electronics laser distance sensor is one candidate

- Test set-up at NIU:
- New manufacturing of bellows windows (just started)
- Optical coating (thickness control)
  - Vapor deposition
  - Chemical deposition
  - Tests for uncoated
- Upgrades to projector and new camera. Optical table obtained for dedicated destructive tests.
- Plans are maturing for vacuum tests
ICAR funding loss has hurt this program
Do not want “institutional” knowledge to disappear.
Absolutely need to go through a complete testing cycle for the new window, to continue progress.
Have a dedicated window test area at FNAL, and can accommodate all Mucool and MICE window tests.
Takes good advantage of expertise at FNAL
If new window source is established, will expedite tests and certifications.
Can have possible beam test of thin window on LH2
Good program for students
The ASME design code stipulates the following stress limits:

- Primary membrane stress, the lower of $S_m < \frac{2}{3}$ of yield or $\frac{1}{4}$ UTS
- Primary bending stress $S_b = 1.5 S_m$

The MAWP exceeds these limits, but because of the non-standard design, ASME allows certification based on burst tests:

Section UG-101-m-2a suggests that the burst pressure $P_b$ should be

$$P_b = 5 \times P \times \frac{S_t}{S_w}$$

where $P$ is the maximum working pressure and $S_t$ is the minimum tensile stress at test temp and $S_w$ is the minimum tensile stress at working temperature.

The $S$ value for 6061 T6 material is 310 MPa at room temperature and 415 MPa at working temp.

$$P_b = 5 \times 310 \, / \, 415 \times P = 5 \times 0.76 \, P = 4 \times P$$

Hence a burst pressure of 4 times the working pressure when tested at room temperature will meet the requirement of section UG -101 in Div. 1 of ASME VIII.