PRad Vacuum Tank Window Design

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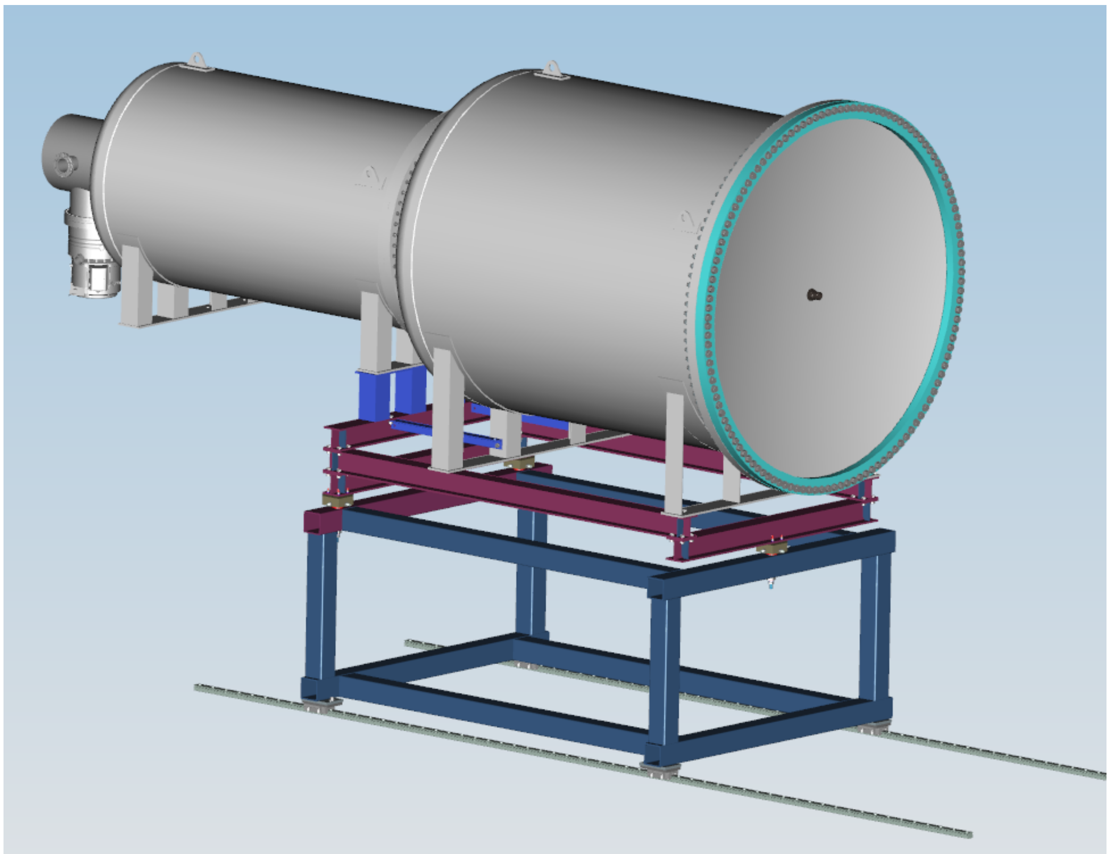

Figure 1: PRad Vacuum Tank and Window on Stand

Description

The PRad experiment requires a vacuum tank from the target to the detectors. At the end of the vacuum tank, a thin window is installed to maintain the vacuum and allow the particles to pass through to the detectors. The experiment requires that a beam pipe is attached to the center of the window which goes all the way to the beam dump.

The PRad window is made of 2024-T3 aluminum with a thickness of 0.063 inches. The window is 66 inches in diameter and has a 1.75 inch hole in the center for an adapter to the beam pipe.

Background

During the design phase of this project, the rough size of the window needed was 72” in diameter. It turns out the Hall C already had a vessel with a 66” aluminum window that had already been formed, tested, and installed on a chamber for their Heavy Gas Cerenkov (HGC) detector. Therefore, the PRad window was made the same size, with the same bolt pattern so the Hall C tooling and forming experience could be used. The differences between the HGC and the PRad windows are: the HGC window is 0.040” thick, where the PRad is 0.063” thick, and the PRad window has a center hole for the beam pipe. The material thickness of the PRad window was increased because the 0.040” thickness material was no longer available in this size.

HGC Window Forming

The HGC window was formed at 45 psi and a second window was tested to 60 psi without failure.

Window Forming Requirements

The ES&H manual, chapter 6151, part 7 gives direction on designing formed vacuum windows. The PRad window is a Category 1 window, the volume of the tank is larger than 35 ft^3 and the tank is not attached to a credible pressure source that can exceed 15 psig and is protected from pressurization exceeding 15 psig through engineering controls.

The only credible pressure source connected to the vacuum tanks is a temporary source of nitrogen used to backfill the tank. The nitrogen source is limited to 1 psi by a relief valve.

7.2 Design Requirements for Category 1, or 2 Vacuum Windows

7.2.1 General
The design of any thin vacuum window shall consider the following:

- Material compatibility
- Life cycle and fatigue
- Effects from radiation or corrosion
- Possible accidental damage from puncture etc
- Magnitude of deformation
- Crack and tear propagation

Design calculations (see 7.2.2) or proof test (see 7.2.3) shall be performed to ensure that the stresses in the thin window are acceptable

7.2.2 Stress and Deformation Calculations

The stress in the window shall be determined after all fabrication steps have been completed (i.e. hydro-forming). The calculated stress in the window shall be less than the allowable stress. The allowable stress in tension for any thin vacuum window shall be the lesser of

$S_a = 0.5\ S_{ut}$ (allowable stress is ½ ultimate tensile)

$S_a = 0.9\ S_y$ (allowable stress is 9/10 yield)

7.3 Documentation

Documentation for thin windows (design calculations, material certifications, test data, etc.) shall be maintained by the Responsible Vacuum Engineer. A Vacuum System folder within the Pressure Systems webpage is available for documentation storage.

7.4 Formed Windows

Windows that are shaped by hydro-forming or some other process can often be safely made from much thinner material than a corresponding flat window of the same diameter. Typically, a thin flat disc of Aluminum is hydro-formed into a predetermined spherical shape. A typical hydroforming pressure is two to three times the usual operating pressure (14.7 psi). This pressure is necessary to yield the material into the desired shape and has the benefit of an inherent overpressure test. Many hydro-formed windows exist at Jefferson Lab - typically made from Al 2024 Alclad which is available in a half soft state and has a large elongation and a moderately high yield and ultimate strength. It is recommended that only 30% of the available elongation be used so that adequate reserve remains in the window to provide safety against foreign object penetration. The thin window stock or precut blanks shall be carefully inspected prior to use to ensure that there are no defects, deep scratches or wrinkles that could easily compromise the strength of these thin materials.

Window Material and Properties

Material	2024-T3 Aluminum
Yield Stress (psi)	39200
Tensile Stress (psi)	58700
Elongation at Break (%)	12

Allowable Stress

Sa = 0.5 Sut (allowable stress is ½ ultimate tensile) = 0.5 * 58700 = 29350 psi
Sa = 0.9 Sy (allowable stress is 9/10 yield) = 0.9 * 39200 = 35280 psi

The allowable stress is the lower of the two, which is 29350 psi.

Recommended Maximum Elongation

The recommended maximum elongation is 30% of elongation at break. 30 % of 12 % elongation is 4 %.

Therefore, the maximum recommended elongation of the window is 4%.

Design Calculations for PRad Window

The design calculations are included in the attached spreadsheet and are summarized in the following table.

Forming pressure (psi)	35
Window bow at operation pressure (in)	2.7
Stress at operation pressure (psi)	24650
Elongation at operating pressure (%)	0.7

Therefore, the window meets the stress and elongation requirements of Chapter 6151, Part 7.2 of the ES&H manual for Category 1 windows.

Clamping Load of Window Flange

The clamping load required to hold the window was determined by calculating the linear load along the edge of the window and bolt preload required with the friction between the aluminum window and steel flanges. The factor of safety against the window sliding at the clamping surfaces was calculated for similar windows, which were found to be in the range of 4.5-6.2. The window flange bolt torque is set at 210 ft-lbs for the ¾-10 grade 5 bolts, resulting in a factor of safety of 4.2. These calculations are based on the linear load during window forming; therefore, the factor of safety is higher under the operating vacuum.

Beam Line Adapter

The experiment requires that a beam tube is attached to the window. Windows with holes are not specifically addressed in the ES&H manual, but have been successfully used at JLab. Hall B has used a beam tube adapter for a Polarized Target experiment (dwg 66850-C-02743), and Hall C has a beam tube adapter for a Target Chamber Window (dwg 67153-56029).

The PRad window uses the Polarized Target design to attach the beam tube to the window. To ensure that the beam tube adapter was safe to use on the vacuum tank, a hydrostatic test was completed.

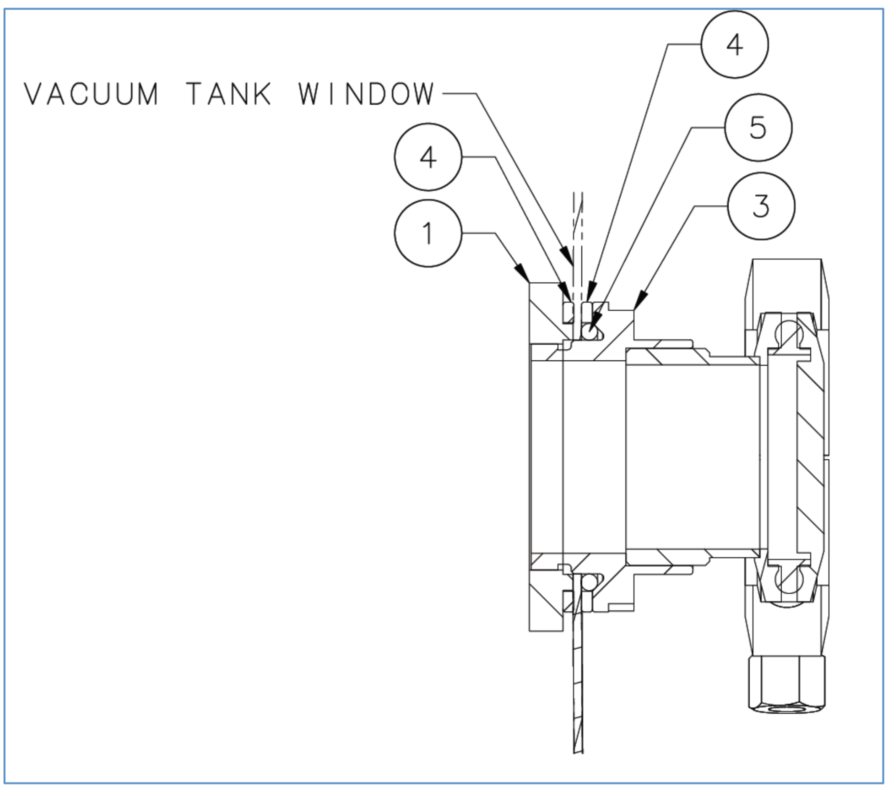

Figure 2: PRad Beam Tube Adapter

To complete the hydrostatic test, the beam tube adapter was attached to the window and a blank was installed in place of the beam tube. The window was attached to the forming fixture and hydrostatic ally tested to 30 psi with no leaks present.

<u>Window Protection</u>

A window cover has been fabricated from 1/8” thick aluminum to protect the window from damage due to something falling into the window. This cover will be attached to the window at all times except when the experiment is running.

The window will be installed or removed only when there is no vacuum in the tank. This will remove the stored energy in the tank so people can work near the window.

<u>Personnel Protection</u>

The PRad experiment is set up on level 1 of the Hall B spaceframe. This area will be roped off whenever the tank is under vacuum and safety glasses and hearing protection will be required to enter level 1.