Fermilab

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Title: Prime Focus C5 Cell Analysis and Assembly Procedure

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Abstract Summary: The C5 lens is the optical window for the prime focus camera vessel. The C5 lens is mounted in a cell to provide alignment features and to minimize stresses from the mount. Mounting stresses are provided for an operating temperature range of -5C to 27C.

Applicable Codes:
Brookhaven: GUIDE FOR GLASS AND PLASTIC WINDOW DESIGN FOR PRESSURE VESSELS

Introduction

Taken from the Opto-mechanical section of the Optics PDR:
The C5 lens is the last element in the corrector, and also serves as the window to the focal plane assembly vacuum vessel. The baseline concept for mounting C5 is to support it athermally and quasi-kinematically in a cell. The cell will support the lens axially on an o-ring that provides one of the seals between the lens and the vacuum vessel. The o-ring groove will be designed such that ~90% of the vacuum load is carried through compression of the o-ring, and the remaining pressure load is carried on a plastic-lined lip between the lens and cell. When the vessel is evacuated, the lens will compress the o-ring until it comes to rest on the lip. The vacuum load is sufficient to prevent the lens from moving radially under most conditions, but athermal spacers, located evenly around the circumference of the lens (3 to 6 places), will define the radial position of the lens in the cell without over-constraining it. Additional retainers will be provided to retain the lens in its cell when the vacuum vessel is at atmospheric pressure.

The window is mounted in the cell such that it is not significantly stressed due to clamping, or thermal stressed over an operating temperature range of -5C to 27C. Stress analysis is provided, along with an assembly procedure for the cell. Figures 1 and 2 illustrate the C5 cell.

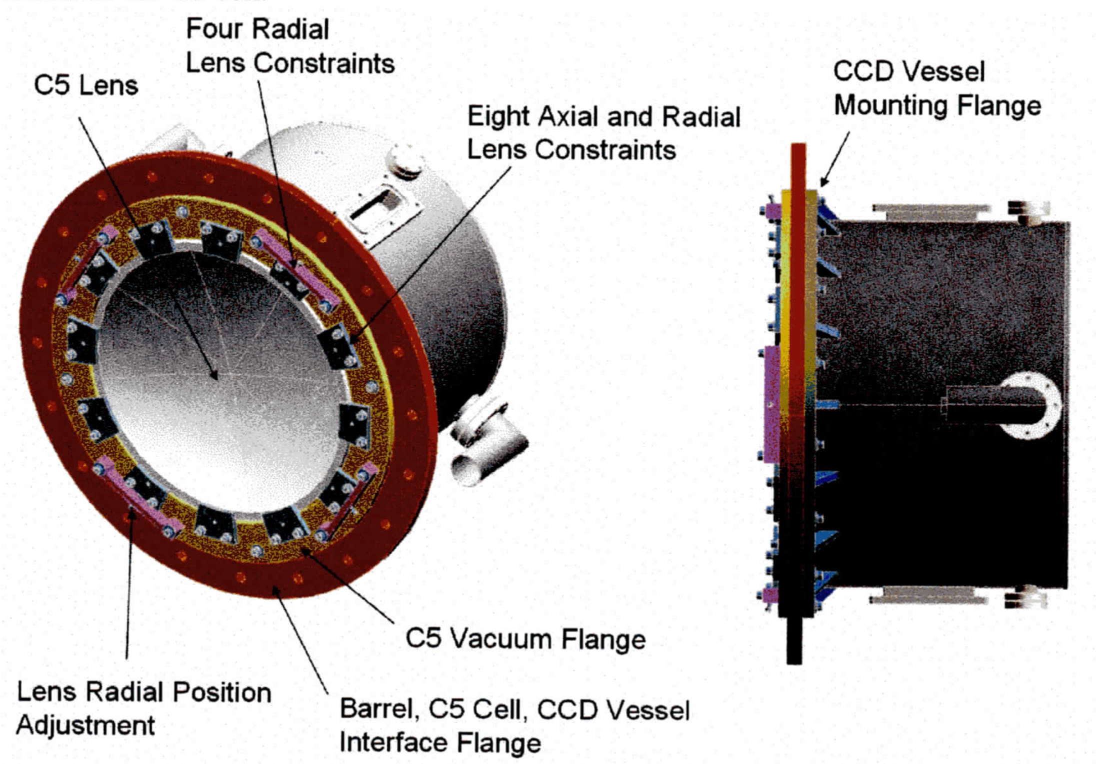

Figure 1. The C5 cell mounted to the prime focus camera vessel.

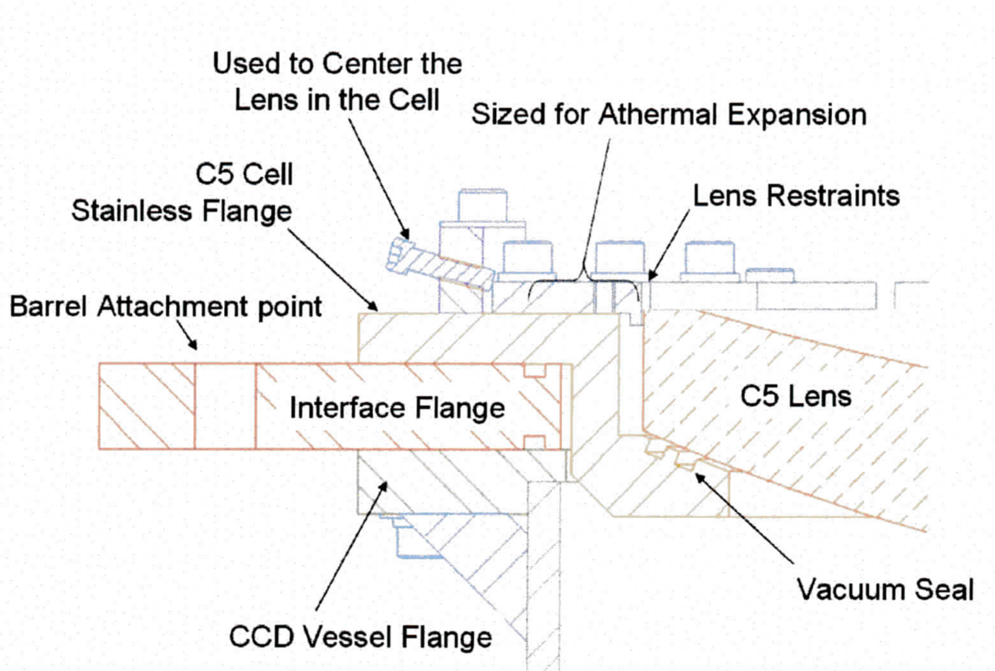

Figure 2. Cross section view of the C5 cell.

Design:

Allowable Material Stress:
Due to possible stress concentrations and the brittleness of the material, the maximum allowable stress is a factor of 10 times less than the yield strength of the material. The window is constructed of Corning Fused Silica with a manufacturing allowable tensile stress of 50 MPa (7250 psi), a Young's modulus of 72 GPa (10.5e6 psi), and a Poisson's ratio of 0.16. Reducing the yield strength by a factor of 10, for safety, gives a maximum allowable stress of 5 MPa (725 psi). For long term applications, the Brookhaven document further reduces the maximum allowable stress to 4.6 MPa (680 psi).

*Ref. H0607_Fused_Silica_Industrial_Grade_ProductSheet.pdf

Minimizing Radial Stresses due to temperature changes:
Athermal spacers are placed between the lens and the stainless steel cell flange to minimize radial stresses over an operating temperature range of -5 C to 27 C. The spacers are sized to expand thermally at a rate equal to the difference of the expansion between the lens and the stainless steel cell.

For a given temperature change:

$\alpha_{spacer} * L_{spacer} = (\alpha_{cell} * Radius_{cell}) - (\alpha_{lens} * Radius_{lens})$

With the constraint that spacer fits in between the cell and the lens:

$L_{spacer} = Radius_{cell} - Radius_{lens}$

Where:
$\alpha_{lens} = 0.57e\text{-}6$ microns / meter deg C for fused silica
$Radius_{lens} = 0.5 * 0.542$ M = 0.271 Meters
$\alpha_{cell} = 17$ microns / meter deg C for stainless steel

And the other values are variables.
Limiting α_{spacer} to the range of plastics with larger CTEs like HDPE with 143e-6 microns / meter deg C allows solving for the spacer thickness.

$\alpha_{spacer} * L_{spacer} = \alpha_{cell} * (L_{spacer} + Radius_{lens}) - (\alpha_{lens} * Radius_{lens})$
$\alpha_{spacer} * L_{spacer} = \alpha_{cell} * L_{spacer} + \alpha_{cell} * Radius_{lens} - (\alpha_{lens} * Radius_{lens})$
$L_{spacer} = (\alpha_{cell} * Radius_{lens} - (\alpha_{lens} * Radius_{lens})) / (\alpha_{spacer} - \alpha_{cell})$
$L_{spacer} = 17 e\text{-}6 * 0.271 - (0.6e\text{-}6 * 0.271) / (143e\text{-}6 - 0.6e\text{-}6)$
$L_{spacer} = 0.0312$ Meters (1.229 inches)

Substituting to find the inside radius of the cell, or where the spacer is mounted to the cell:
$L_{spacer} = Radius_{cell} - Radius_{lens}$
0.0312 Meters = $Radius_{cell}$ - 0.271 Meters
$Radius_{cell} = 0.302$ meters (11.898 inches)

The cell is designed with a 1.229 inch thick HDPE spacer between the lens and the stainless steel cell. The mounting location for the HDPE has a radius of 0.302 meters

The radial spacers both center the lens in the mount, and significantly reduce thermal stresses in the radial direction over a large range of operating temperatures. The lens needs a radial restraint to keep it on center with vacuum turned on and off.

Axial Clamping Stresses due to the mount:

The plastic external retainers provide an axial restraint to keep the window in the cell. The exterior retainer partially compresses the window against the o-rings. O-rings make the vacuum seal. Once vacuum is applied, the o-rings compress fully and the lens rests against the stainless steel flange. A mylar pad is placed between the two o-ring grooves so that there is no direct lens to steel contact.

Edge stresses due to the mount:

Vacuum is applied to the lens. To spread out the load around the edge of the lens, double o-rings are used. The inner o-ring carries about 45% of the load and provides the vacuum seal. The second o-ring carries another 45% of the load. The pad between o-rings is lined with a 50 microns (0.002 inch) thick mylar ring. The remaining 10% of the load is carried by the pad between o-rings. The total deflection of the lens is less than 40 microns (Reference DES Document 312, Thermal Analysis of C4-C5 Lenses) so the spacer also ensures that the lens never makes direct contact with the stainless steel flange.

The vacuum load is = 101kPa * π * (0.517 m/2)^2 = 6749 N

The surface area on the two o-rings are 2* π * 0.517 m * 0.0046 m =
= 0.0149 m^2

Line load assuming 90% of the vacuum load is applied at the o-rings
= 0.9 * 6749 N / 0.0149 m^2 = 0.4 MPa

The surface area on the mylar pad is 2* π * 0.517 m /2 * 0.0046 inch =
= 0.0075 m^2

Line load assuming 10% is applied at the mylar pad
= 0.1 * 6749 N / 0.0075m^2 = 90 kPa

Cell Flange Deflections:

The cell flange under vacuum loading slightly distorts. The magnitude of the distortion is calculated using an FEA. The cell flange is constrained in motion at the interface ring, and vacuum load is applied in the region of the two o-rings where the lens makes contact with the cell. The lens pulls towards the focal plate by approximately 5 microns. The results are shown in Figure 3.

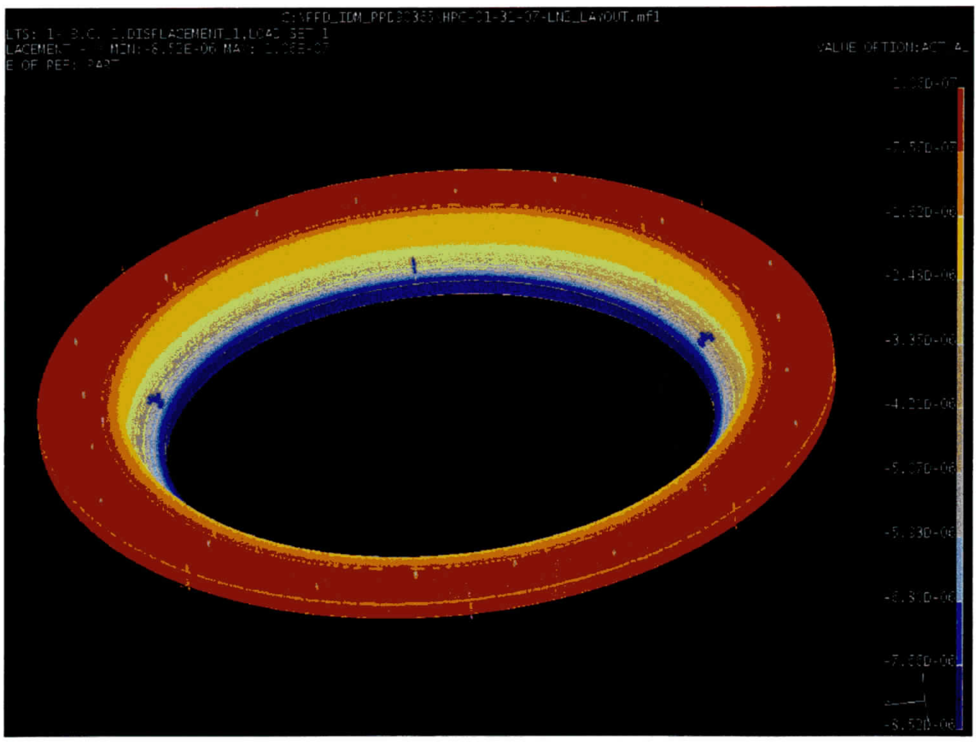

Figure 3. C5 Flange FEA results, deflection in the axial direction.

Cell Assembly Procedure:

This assembly procedure is to be used as a guideline for assembling the lens into its cell. The cell acts as some level of protection for the lens.

All components are to be cleaned for vacuum prior to assembly.
Gloves are worn at all times.

1) The cell flange is placed flat on a table with the window sealing surface pointing up.
2) A 50 micron (0.002 inch) mylar ring is placed on the cell flange between the two o-ring grooves. The purpose is to prevent glass to metal contact. Point contacts on the glass could cause regions of high stress which could lead to failure.
3) Insert the proper size o-ring into the o-ring grooves. Do not use any lubricants on the o-ring. The outer o-ring does not have to be continuous.
4) By hand, place the window in the cell on the o-ring. Center the window in the flange by eye.
5) Mount the plastic radial thermal spacers to the cell. Allow the radial spacer to just touch the outer diameter of the lens.
6) Using gages, ensure the lens is centered in the C5 cell mounting flange within 100 microns (0.004 inch).
7) Mount the remaining plastic restraints to the cell. The radial lip touches the outer diameter of the lens, and the axial lip keeps the lens in contact with the cell. A temporary spacer is needed against the axial lip while the o-rings are removed for alignment.
8) Alignment of the C5 cell with respect to the interface flange and barrel can take place.
9) Once alignment is complete, the cell is removed from the interface flange and the o-rings replaced in their grooves.
    a. Remove cell from barrel
    b. Remove only the axial restraints from the cell
    c. Remove the lens
    d. Put o-rings in their grooves, do not use a lubricant
    e. Replace the lens in the cell
    f. Remount the axial restraints to the cell
    g. Remount the cell to the barrel

Optical Alignment Notes:

Optical alignment is performed by positioning the cell with respect to the interface flange while vacuum is not applied to the lens. To perform the alignment, the vacuum o-ring seal is removed from the assembly so that the lens can be seated against the stainless steel mounting flange. The radial spacers are not removed from the cell when replacing the o-rings which keep the lens centered before and after removing the o-rings.