Lens Mounting – A Systematic Approach

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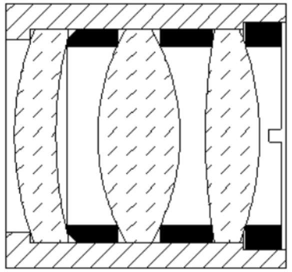
OPTI 521 Tutorial

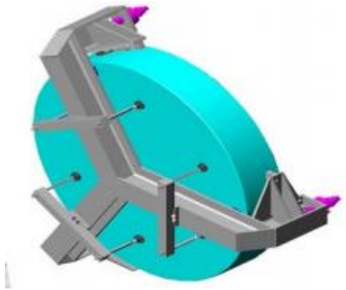
Introduction

- Lens mounting is an age old problem.
- Multiple design solutions have been accepted throughout the optical community.

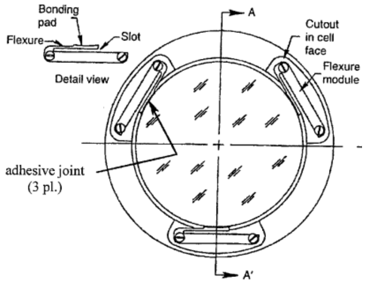
Barrel Assemblies



Wiffle Trees



Flexures



- A solution that best fits the system requirements should be chosen.
    - Keep in mind, complexity adds cost, while simplicity sacrifices performance.
    - How do we make these known designs work?
- *This tutorial will first define a generic design process that can be applied to opto-mechanics*
- *The process will then be used to provide key design considerations and calculations for a **lens clamped in a barrel with a threaded retaining ring**.*

Design Guide

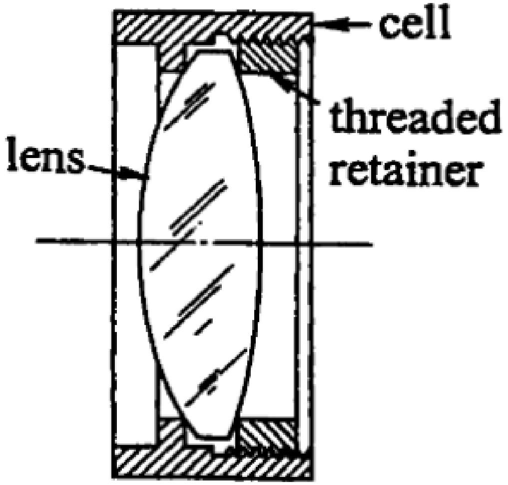
- Who is the end customer?
- Have all key design deliverables been agreed upon? If so, have they been clearly stated and defined?
- What is the cost budget?
- Use a Systematic Approach

1. Define the requirements
   a. Positional Accuracy (Decenter, Tilt, Spacings)
   b. Preload/Shock loading Survival
   c. Vibration Stability
   d. Temperature Survival and stability
   e. Volume Claims
   f. Know the operational environment
2. Down-select Concept
3. Verify Design Parameters
   a) Hand Calculations
   b) Additional Analysis if necessary
4. Check all Degrees of freedom
5. Identify key parameters in the design and know the impact they change.
6. Check for self-weight deflections.

CP1XY

Apply the guide!

Start Simple



Scale complexity

Design Guide Applied – Simple Lens Barrel

The Mount

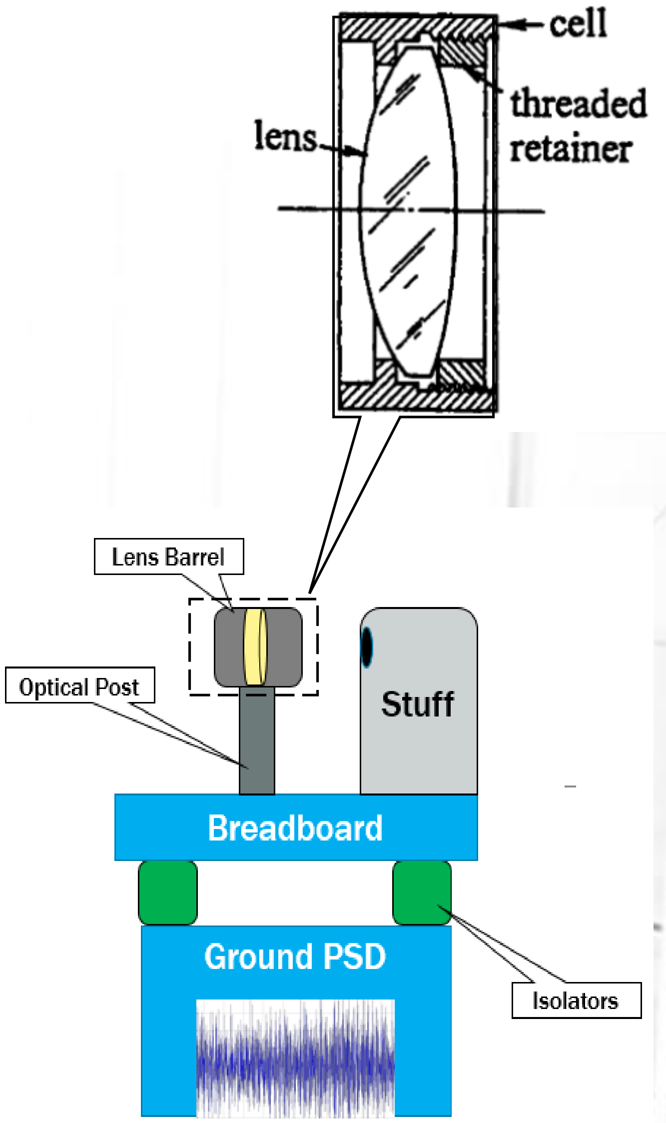
- Design a barrel to mount a single plano-convex lens.
- Barrel will be mounted on a round, solid post.
- The post will then be attached to a floating optical table that is located in a low traffic cleanroom.
- Exercise the design guide to ensure all key performance parameters are known.

Note

- The design concept chosen is a simple case where hand calculations can be used to make first order approximations of performance.
- A more complex design architecture may be needed if performance requirements are stringent or environmental conditions are harsh.

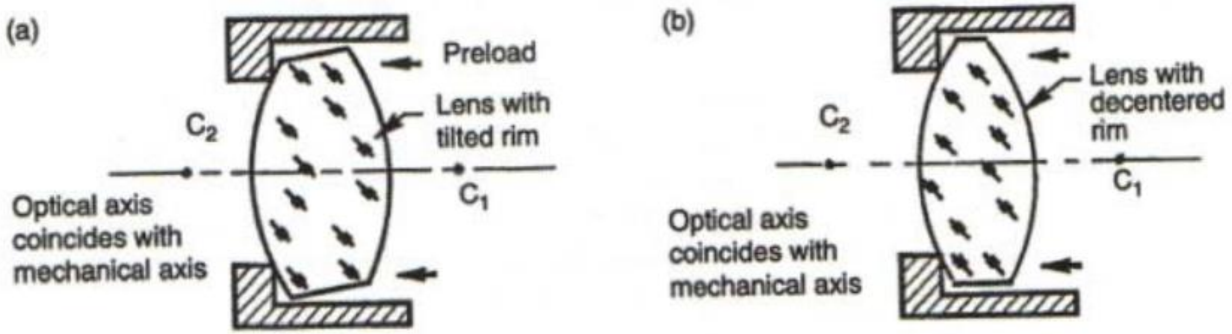
Details

- Use a threaded ring to hold the lens in place
- Assume sharp corner contact at the barrel to lens interface



1a. Positional Accuracy

- When the curved lens surface contacts the sharp edge of the barrel seat, the lens optical axis self-aligns with the barrel axis.



- Tilt and decenter tolerances are controlled by careful characterization of the barrel diameter.
- Choose theta (θ), and calculate the tolerance zone of the bore diameter

$$d_{max} = 2 * R_{Lens} * \sin\left(\theta + sin^{-1}\left(\frac{d_{lens}}{2*R_{lens}}\right)\right)$$

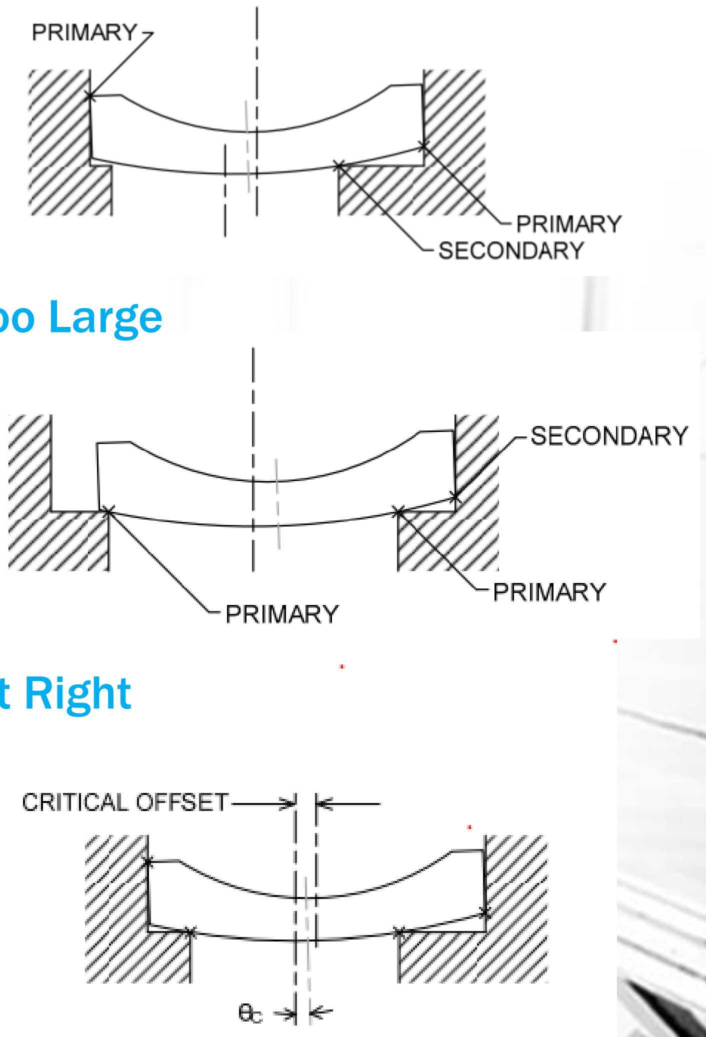
$$d_{min} = \sqrt{d_{lens}^2 + t_{edge}^2} * \cos\left(sin^{-1}\left(\frac{t_{edge}}{d_{lens}}\right) - \theta\right)$$

$$\Delta y = \theta * R_{Lens}$$

Too Small

Too Large

Just Right



1b. Preload/Shock Survival

- *To constrain the optic along the z axis (6th DOF), a preload is applied* to the flat side of the optic using a threaded retaining ring.
- Assuming a 1G load, the minimum preload to maintain stability is equal to the weight of the optic.

$$P = mg$$

**Where m is the mass, g is gravity*

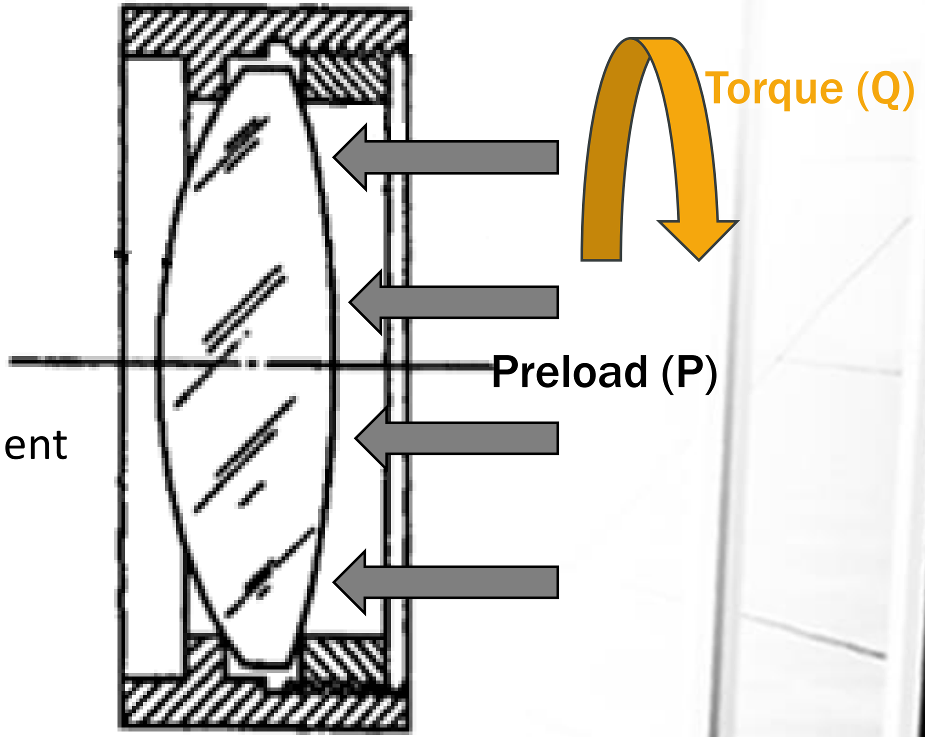
- If we apply a shock load requirement, G, the required preload

$$P = G * mg$$

- Now calculate the torque to set the retainer at the preload requirement

$$Q = \frac{P}{D_T(.577\mu_M + .577\mu_G)}$$

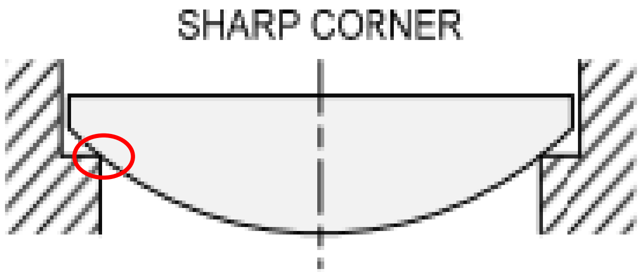
$$Q = \frac{5P}{D_T} \quad (Approximate)$$



**Where D_T is the major thread diameter, μ_M is the coefficient of friction for the retainer, and μ_G is the coefficient of friction for the glass.*

**Equation 6b was given as an approximation due to the high variability in coefficients of friction.*

1b. Preload/Shock Survival (cont)

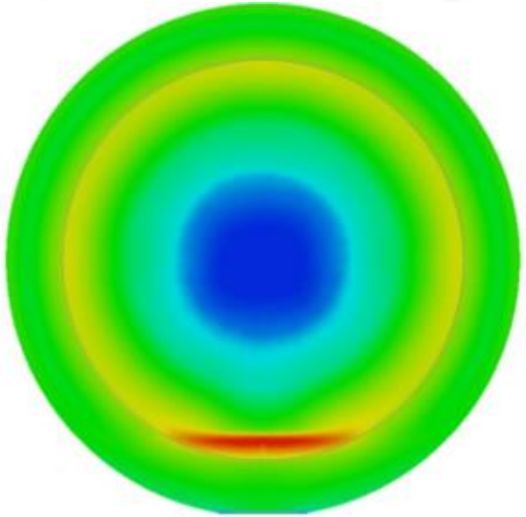


- Assume a stress concentration at the sharp corner contact with a corner radius of .05mm
- Calculate the maximum stress induced by the preload.

$$\sigma_A = .4\sqrt{\frac{P * E}{2\pi * D_i * R}}$$

Where E is the Young's modulus of the barrel, R is the machined radius of the sharp edge, and Di is the inner barrel radius.

- Weibull statistics can then be used to determine if the glass with fracture



Material	Weibull Modulus (m)	Characteristic Strength (MPa)	Probability of failure
N-BK7	30.4	70.6	0
F2	25.0	57.1	0
SF6	21.9	57.3	0
Silicon	4.5	346.5	2.2×10^{-8}
Germanium	3.4	119.8	6.1×10^{-5}
ZnSe	6.0	54.9	3.9×10^{-6}
Sapphire	4.0	485	4.1×10^{-8}
Calcium Fluoride	3.0	5.0	0.93
Zerodur	5.3	293.8	2.5×10^{-9}
Corning ULE	4.5	40.4	3.75×10^{-4}

$$P_f = 1 - \exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right]$$

$P_f =$ Probability of failure
$\sigma =$ Applied stress
$\sigma_0 =$ Characteristic strength (stress at which 63.2% of samples fail)
$m =$ Weibull modulus (indicator of the scatter of the distribution of the data)

1c. Vibrational Analysis

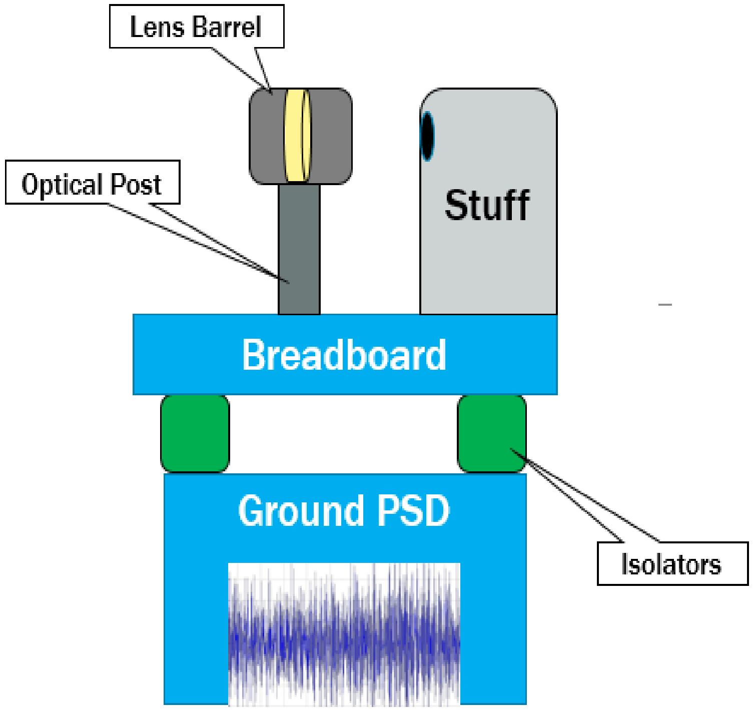
- Determine the motion of an object relative to “stuff” in the presence of a PSD (10E-8 for quiet lab)
- The assembly is mounted to an isolator system with a resonant frequency (ω).
- Rule of thumb-Assembled structures optimized for rigidity have a Critical Damping Ratio (Cr) of 2% and Q factor of 25.
- Our lens barrel assembly has mass (m) mounted and is mounted on the end of post with length (L). Calculate its deflection and stiffness.

$$I = \frac{\pi D^4}{64}\ in^4 \qquad \delta = \frac{FL^3}{3EI}\ in \qquad k_t = \frac{F}{\delta}\ \frac{lb}{in}$$

**I is the moment of inertia of the post, δ is the deflection of the post due to the weight of the Lens barrel assembly (mg), E is Young’s Modulus of post, and k is the total stiffness*

- Calculate the resonant frequency in both rad/s and Hz

$$\omega_n = \sqrt{\frac{g}{\delta}} \qquad f_n = \frac{\omega_n}{2\pi}$$



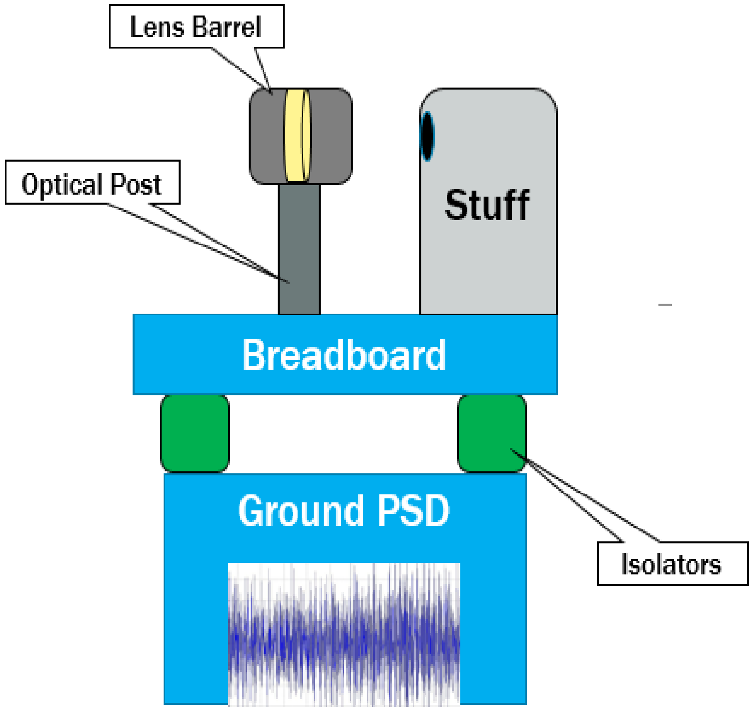
1c. Vibrational Analysis (cont)

- Calculate the resonant frequency of the isolators (w).
- Next calculate the transmissibility of the isolation system

$$T = \frac{isolated\ motion}{base\ motion} = \frac{x}{u} = \sqrt{\frac{1 + \left(2\frac{\omega}{\omega_n}C_R\right)^2}{\left(1 - \frac{\omega^2}{\omega_n^2}\right)^2 + \left(2\frac{\omega}{\omega_n}C_R\right)^2}}$$

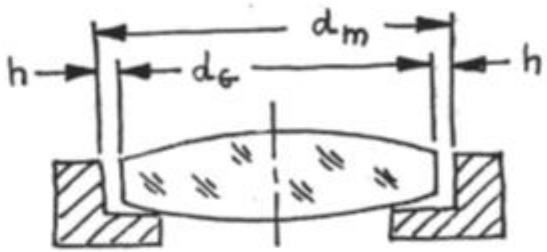
- Finally calculate the rms motion of the lens barrel mount using miles equation

$$\delta_{rms} = g \cdot T(f_n)\sqrt{\left(\frac{1}{32\pi^3}\right)\left(\frac{Q}{f_n^3}\right) \cdot PSD_{BASE}}$$



1d. Thermal

- Consider a barrel material with higher CTE than the lens material.
- Subject the assembly to a large negative temperature swing. If the barrel diameter is sized too small, it could potentially “squeeze” the optic to failure
- Calculate the lens clearance (h) needed to avoid contact after a negative temperature swing (ΔT)



**D_G is the diameter of the optic, α_m is the CTE of the metal, and α_G is the CTE of the glass.*

- The quantity “h” can be added to the inner barrel diameter to ensure survival of the lens.

Additional Rules:

<u>Degree of Freedom Check</u>

- The most important degree of freedom is the radial constraint for the optic. The barrel diameter must be toleranced carefully in order to control the centration and tilt errors of the lens.

<u>Self weight Deflection</u>

- Typically, most lenses under 75mm do not deflect much due to there self weight.

- Analysis needed the optical thickness is less than 1/7th the diameter (large aspect ratio)

- All lenses over 75mm should be checked for self deflection

$$\delta_{V\max} = C_{SP}\left(\frac{\rho g}{E}\right)\frac{r^4}{h^2}\left(1-\upsilon^2\right)$$

$\delta_{V\max}$ is maximum displacement
(rms shape change is ~0.25*$\delta_{V\max}$)
C_{SP} is constant, depending on configuration
ρg is weight density of the mirror material
E is Young's modulus for mirror
ν is Poisson ratio for mirror material
r is half of the mirror diameter
h is mirror thickness

Support Constraint	C_{sp}	FORD*
Ring at 68% (of diameter)	0.028	11
6 points equispaced at 68.1%	0.041	8
Edge clamped	0.187	1.5
3 points, equal spaced at 64.5%	0.316	-
3 points, equal spaced at 66.7%	0.323	~1
3 points, equal spaced at 70.7%	0.359	0.9
Edge simply supported	0.828	1/3
"Central support" (mushroom or stalk mount) (r = radius of stalk)	1.206	1/4
3 points equispaced at edge	1.356	1/4

*Factor of Reduced Deflection compared to the 3-pt support

Questions?

References

1. Application of geometric dimensioning & tolerancing for sharp corner and tangent contact lens seats. C. L. Hopkins, J. H. Burge College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA
2. OPTI521 Class Notes