

Tutorial: Mounting Optical Lens
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1- Introduction

An assembly of lens is hold usually in a lens barrel. Each lens is fixed in this barrel by a mounting structure. An example of a lens barrel is shown in Figure 1. The following criteria should be met by a lens mount:

- 1– It should define the position of the lenses to the required accuracy.
- 2– Does not deform or change the optical properties of the optics by stress
- 3 – Provides the required adjustments for the optics
- 4 – Protects the optics from the maximum predicted shock to the device
- 5 – Protect the optics in presence of environmental extremes such as extreme cold and heat or moisture. The device might not be operational in these extreme situations.
- 6 – Maintain its function upon operational environmental variations. The most common environment effects are temperature and vibrations.

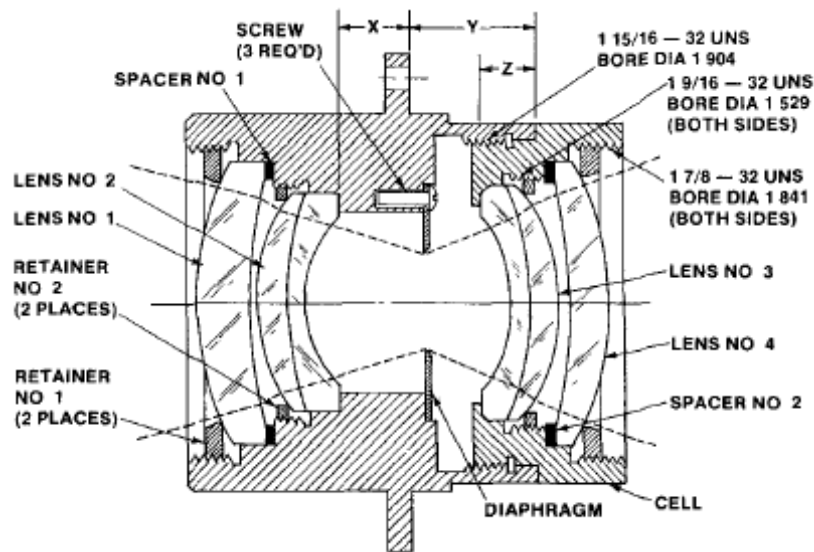


Figure 1: a lens barrel assembly¹

The position of the optics is defined by a fixed mechanical structure and a retainer pushes the optics to this reference point. Figure 2: Lens hold in the cell illustrates a lens hold in a cell. In this article, different methods of mounting the lens are presented. In each case, thermal properties and resistance to shock and vibration of the mount is discussed.

¹ Figure 6 of reference 1

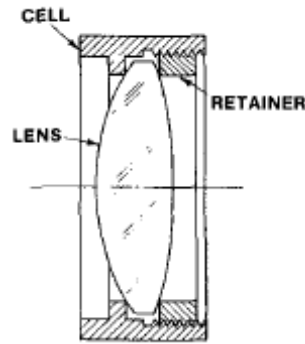


Figure 2: Lens hold in the cell²

2- Mounting the Lens

2-1- Mounting with Reference to the Mechanical Axis

In loose tolerance or less expensive systems, the position of the lens may be defined by its mechanical axis. Mechanical axis is defined by the mechanical edges of the lens. The major issue here is of course misalignment of optical axis of the lenses in the system. The other problem occurs when the lens has appreciable edge thickness. In this case, lenses might tip and their edges might crack. To avoid the latter problem either the edge of the lens is made in a circular format or a relief should be made in the cell. The former case is shown in Figure 3 and the latter case in Figure 4.

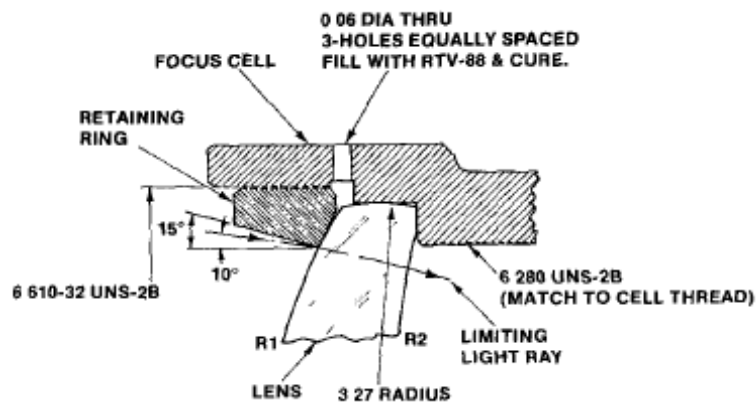


Figure 3: Details view of a lens with spherical rim³

² Figure 5 of reference 1

³ Figure 7 of reference 1

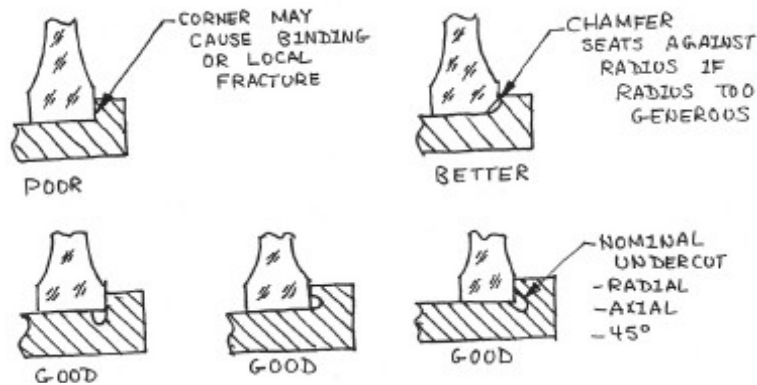


Figure 4: Putting a relief in the cell to avoid jamming⁴

2-2- Mounting with Reference to the Optical Axis

The optical surfaces of the lens determine its optical axis. There are three well known methods to seat the lens on its optical surfaces: obtuse angle, tangent and spherical contact. All three types are shown in Figure 5. In terms of ease of production and precision, ranking order of the three designs is 1- obtuse angle, 2- tangent and 3- spherical. In terms of tolerance to stresses the order is the reverse. The obtuse angle edge sharpness can vary. We will discuss this in more detail in the stress section.

All the structures in Figure 5 are shown for convex surfaces. The mount shapes for four configurations of mechanical interface to optical surfaces are shown in Figure 6. The tangent structure can not be used with concave surfaces.

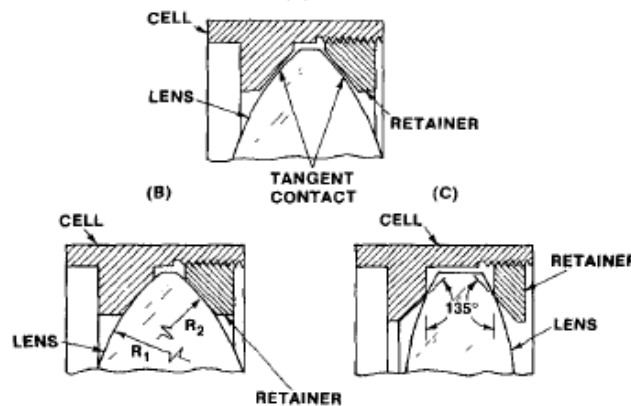


Figure 5: Mounting lens on its optical surfaces⁵

⁴ Figure from reference 2 page 197

⁵ Figure 8 of reference 1

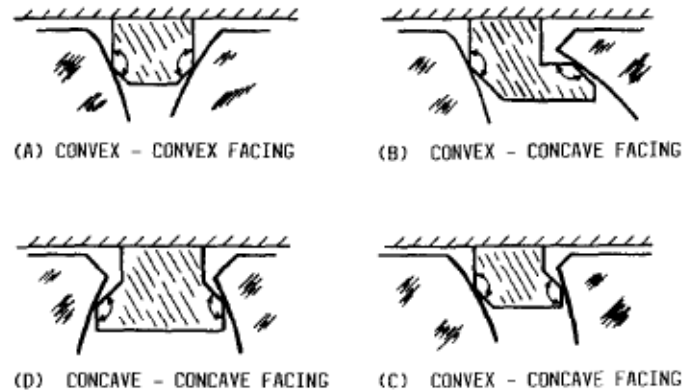


Figure 6: Four configuration of mechanical interfaces on spherical lens surfaces.⁶

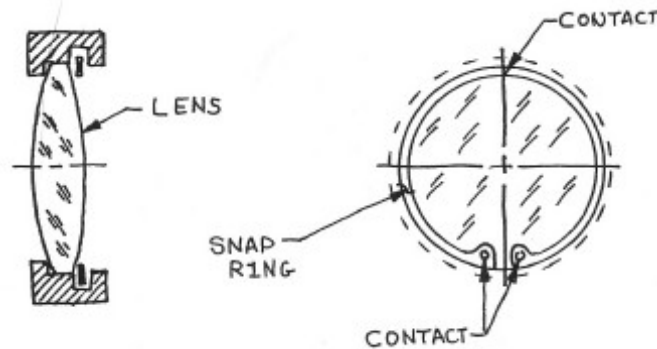
3- Retainer

In this article retainer is any structure which provides the spring force to press the optics to the reference mount. In this section different retainer types are presented. The next sections would explain the stress and thermal issues of the most common types of retainers.

3-1 Snap Ring

Snap ring is a flexible ring which is bent and slid in a groove by the lens. This structure is shown in Figure 7. Some snap rings have two contact holes. These contact holes alleviate gripping and tightening them. However, most snap rings used to hold optical devices, do not have these contacts. Therefore, taking them out of the groove is very difficult.

Figure 7: Snap Ring⁷



3-2 Shim Mount

Shimming is used to reduce the radial distance

between the lens and the mount. Shims help to isolate the lens from vibration and thermal expansion. Effect of shim is somewhat similar to flexures. Brass shims are easier to insert but are not very compliant. Mylar and Teflon shims are very compliant. A shim mount is shown in Figure 8.

⁶ Figure 9 of reference 1

⁷ Figure from Reference 2, page 198

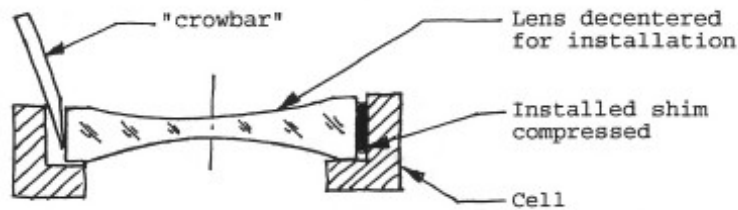


Figure 8: Shim mount⁸

As shown in Figure 9 the shims can be inserted in three 120° segments. The radial gap between the optics and the cell ranges from 0.08 to 0.13mm. This technique is usually combined with RTV potting (discussed later). The resulting mount is very resistive to vibration.

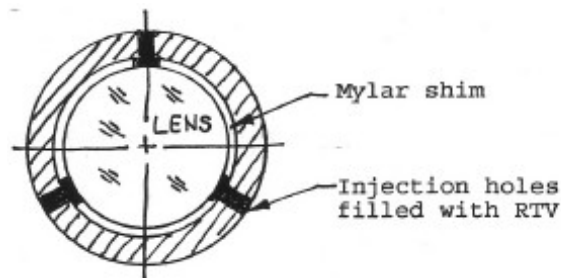


Figure 9: Shims in three 120° segments⁹

3-3- Flexure Retainer

Flexures are passive mechanical structures which isolate an optical element from the mechanical and thermal effects of the structural support. A flexure mount has the following advantages over kinematic or semi-kinematic design

- 1- Free of slick-slip and friction effects of semi-kinematic design
- 2- Have less hysteresis than rolling or sliding contacts
- 3- More robust to adverse environment effects such as extreme temperatures, vacuum, and abrasive dust
- 4- Needs very little maintenance if any

A flexure mount is shown in Figure 10. The three tangent bars hold the lens. If the three bars have equal compliance, the mirror would maintain its centeration upon temperature change. Also the tangent bars operate as shock absorbers.

⁸ Figure from Reference 2, page 206

⁹ Figure from Reference 2, page 207

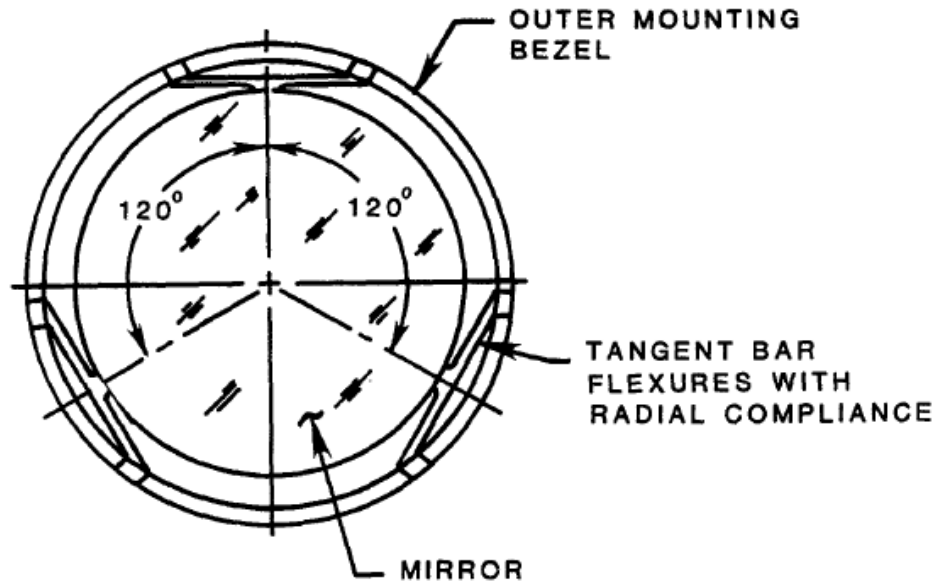


Figure 10: A flexure mount: 3 tangent bars holding a lens¹⁰

3-4- Threaded Retainer Ring

This is the most popular type of retainer. Threaded retainers can have any of the structures of Figure 5. Figure 2 shows a lens held by a threaded retainer. The height of the retainer and the cell mount should be the same. Otherwise a torque would be applied to the lens which would cause additional stress. The situation is shown in Figure 11.

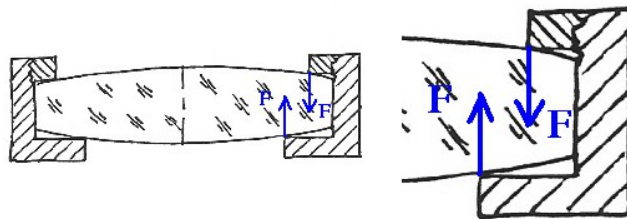
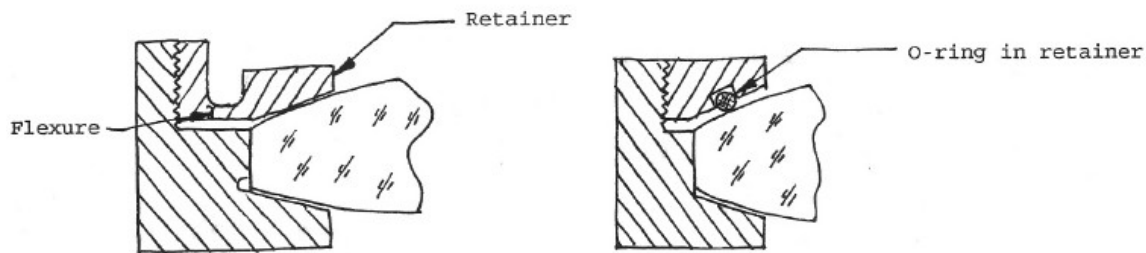


Figure 11: Stress as a result of misaligned forces¹¹

The major problem with this type of retainer is stress at the contact. A nylon retainer could reduce contact stress. An O-ring could be inserted in the retainer to avoid metal-glass contact. Another way to reduce stress is to combine a threaded retainer with a flexure one. Figure 12 illustrates these retainers.



¹⁰ Figure 11 of reference 3

¹¹ Figure from reference 2, page 213 with modifications

Figure 12: Special types of Threaded Retainers¹²

Retainers also tend to tilt the optics. Threaded pieces are generally not precise. Therefore, they should only apply the spring force to the seat and not change the position. One key factor is that threaded retainers should have loose fit. Sometimes an intermediate non-rotating ring is first inserted to hold the lens in position.

4- Stress Issues in Mounting Optics

Stress in glass is caused by several factors. The mount needs to hold the optics in its place. This force causes an initial stress. Shocks can cause much greater stress. Temperature change is also a major cause of stress which is discussed in the next section. Pressure variation might be of concern in special systems as well.

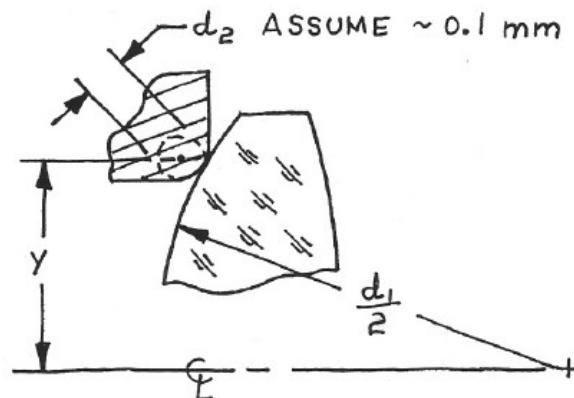
The stress is problematic for two reasons. First it can make the glass to break or chip. This usually happens at relatively high stresses. Glass is resistant to tensile stress of 1 ksi for permanent load and about 4 ksi for short term loads. However, glass in optomechanical devices is usually under compressive stress rather than tensile. Most glasses have about 50 ksi compressive strength.

Sometimes compressive stress in one part of a glass might cause tensile stress in other parts and produce small cracks. To make sure that these cracks do not occur, the maximum compressive stress should not be more than a sixth of the maximum compressive strength of the glass. However, usually these cracks are ignorable.

A much more delicate effect of stress on glass is birefringence. This is usually caused by smaller stress of about 500 psi [1]. However, birefringence is mostly a concern in polarization sensitive applications.

4-1 Axial Stress

A contact between lens and mount is shown in Figure 13. The sharper the edge, the less would be its radius. The stress of the mount on the lens is given by equation 1¹³.



¹² From reference 2, page 214 and 215

¹³ From reference 2, page 216

Figure 13: Contact point of a mount and a lens¹⁴

$$\sigma_A = 0.798 \left[\frac{\frac{F(d_1 + d_2)}{2\pi y d_1 d_2}}{\left(\frac{1 - \nu_G^2}{E_G} \right) + \left(\frac{1 - \nu_m^2}{E_m} \right)} \right]^{\frac{1}{2}} \quad \text{Equation 1}$$

F	Is the retainer preload
d ₁	Is twice the lens radius
d ₂	Is twice the corner radius
ν _G	Is Poisson's ratio for the lens
ν _m	Is Poisson's ratio for the retainer
E _G	Is the modulus of elasticity for the lens
E _m	Is the modulus of elasticity for the retainer
y	Is the height of line contact on the lens

For tangential contact, d₁ << d₂ and for sharp edge mounts d₂ << d₁. However, the radius of the edge can be assigned to tailor the stress of the mount. For most material used in mounts ν < 0.3 and therefore, 1-ν² ≈ 1. Also if E_G ≈ E_m as it is for Aluminum and glass, then equation 1 reduces to

5- Temperature Effect

Materials expansion/contraction as a result of temperature change depends on their coefficient of thermal expansion (CTE). Variation of CTE in different material in a mount causes stress or looseness. The CTE of many common glass materials is summarized in Table 1 and the mechanical properties of common metals used in opto-mechanics is included in . As we can see the CTE of most glasses varies between 4.5-9.2 ppm/°C but for metals the range is 10 to 25 ppm/°F. The CTE of BK7 and Aluminum which are most commonly used in optical devices are 7.1 and 23.6 respectively. We investigate the stress resulting as a result of temperature changes in the next sections.

Table 1: Opto-mechanical properties of common glass materials¹⁵

¹⁴ From reference 2, page 216

¹⁵ Table 3 of reference 1

Glass Code	Schott Type	dn _e /dT		Thermal Expansion Coefficient		Modulus of Elasticity		Poisson's Ratio	Density	
		(X10 ⁻⁶ °C)	per °F)	(ppm per °C)	°F)	(10 ¹⁰ N/m ²)	(10 ⁶ lb/in ²)		(g/cm ³)	(lb/in ³)
487704	FK5	-1.3	-0.7	9.2	5.1	6.2	9.0	0.205	2.45	0.085
501564	K10	4.2	2.3	6.5	3.6	6.6	9.6	0.192	2.52	0.088
511604	K7	1.7	0.9	8.4	4.7	6.9	10.0	0.218	2.35	0.088
517642	BK7	3.0	1.7	7.1	3.9	8.1	11.7	0.208	2.51	0.088
603380	F5	4.9	2.7	8.0	4.4	5.8	8.4	0.220	3.47	0.121
613443	KzFSN4	5.6	3.1	4.5	2.5	6.0	8.7	0.276	3.20	0.112
617366	F4	4.0	2.2	8.3	4.6	5.5	8.0	0.225	3.58	0.125
689495	LaFN23	0.9	0.5	8.1	4.5	8.2	11.9	0.284	4.20	0.146
740282	SF3	8.2	4.6	8.4	4.7	5.6	8.1	0.239	4.64	0.162
785258	SF11	13.0	7.2	6.1	3.4	6.6	9.6	0.237	4.74	0.165
808408	LaSF3	6.7	3.7	5.5	3.0	12.1	17.5	0.289	4.21	0.147

Table 2: Mechanical Properties of Common Metals¹⁶

Metal	Thermal Expansion Coefficient		Modulus of Elasticity		Poisson's Ratio	Density	
	(ppm per °C)	°F)	(10 ¹⁰ N/m ²)	(10 ⁶ lb/in ²)		(g/cm ³)	(lb/in ³)
6061 Aluminum	23.6	13.1	6.90	10.0	0.33	2.71	0.098
I-70 Beryllium	11.2	6.4	30.4	44	0.025	1.85	0.067
Titanium	8.8	4.9	11.7	17	0.30	4.43	0.16
Magnesium	25	14	4.5	6.5	0.35	1.77	0.064
C3600 Brass	20.5	11.4	9.6	14.0	0.34	8.50	0.307
A16 Stainless Steel	9.9	5.5	20	29	-	7.75	0.28
36 Invar	1.3	0.75	14.8	21.4	-	8.03	0.29

Since the Coefficient of thermal expansion of optical material and mounts are usually different the

5-1- Radial Stress

Radial stress is an issue when the lens flat edge is in contact with the mount. If the device is tight to the barrel, the stress on lens as a result of temperature drop is

$$S_R = \frac{(a_M - a_G) dT}{(1/E_G) + (D_G/2E_M t_C)} \quad \text{Equation 2}^{17}$$

S_R is the radial stress

a_M is the metal CTE

a_G is the glass CTE

dT is the temperature change

E_M is the metal modulus of elasticity

E_G is the metal modulus of elasticity

¹⁶ Table 4 of reference 1

¹⁷ Equation 1 of reference 1

Tutorial: Mounting Optical Lens

D_G is the lens diameter

t_c is the metal wall thickness

For typical values of $\alpha_M=13.1\text{ppm}/^\circ\text{F}$, $\alpha_G=3.9\text{ppm}/^\circ\text{F}$, $dT= -50\text{ }^\circ\text{F}$, $E_M= 10\text{e-}6\text{ lb/in}^2$, $E_G=11.7\text{e-}6\text{ lb/in}^2$, $D_G=2\text{ inch}$ and $t_c= 0.0625\text{ inch}$, stress would be 272 which is far less than the compressive stress of the glass. It is also about a factor of 2 less than birefringence criteria of the glass.

The relative diameter change of glass to the mount can be calculated from

$$\Delta R = \Delta \alpha R \Delta T$$

For the same parameters of above except $dT = +50/^\circ\text{F}$, ΔR would be $47\mu\text{inch}$. This value is less than $12.5\mu\text{m}$ which is about the radial clearance of a typical small lens.

5-2- Axial Stress

For a sharp edge retainer the maximum axial stress as a result of temperature change can be obtained from the following equation:

$$\sigma_A = \frac{(\alpha_m - \alpha_G) E_m E_G \Delta T}{E_m + E_G} \quad \text{Equation 3}^{18}$$

For the same typical values used in section 4-1 the maximum axial stress would be 2.48ksi more than the birefringence limit but still much less than compressive strength of the glass.

6- Elastomeric Mounting of Lenses

Elastomers are widely used to attach optics to cells. The elastomer should be inert. Room temperature vulcanizing (RTV) silicon rubber polymer is a common material used as elastomer. Characteristics of some common RTVs is summarized in Table 3.

When elastomer is used, the radial spacing between glass and metal would be larger. Typical values are between 0.01 to 0.02 inches (0.25 to 0.5mm). Figure 14 shows an elastomeric bond. The elastomer is injected through several holes along the rim of the lens. Since, it is difficult to take apart elastomer from lens, it is important to make sure that the lens is centered before applying the elastomer.

Elastomer thickness could be designed to compensate thermal expansion of the metal and glass. This is because the CTE of RTVs are much higher than both metal and glass. This is a difficult technique and is only used when the lens is going to face extreme temperatures. The relation for the thickness of the RTV to have an athermal design is:

¹⁸ Reference 2, page 218

Tutorial: Mounting Optical Lens

$$t_E = \frac{D_G (a_M - a_G)}{2(a_E - a_M)}$$

Since RTVs are not very stiff they might allow small motion of the optics. Therefore, some motion of the optics might occur during shock or vibration.

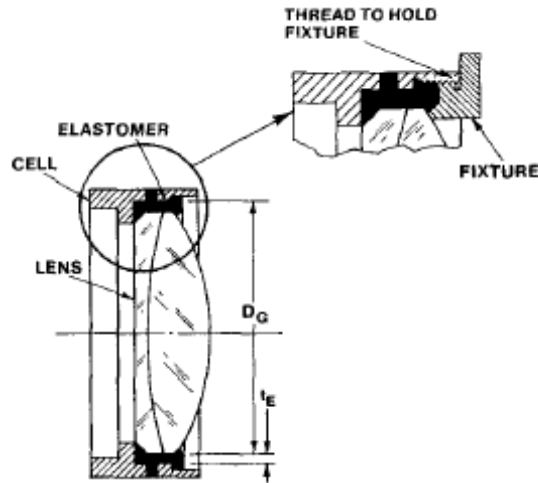


Figure 14: Elastomeric mounting of lens¹⁹

Table 3: Characteristics of common RTVs²⁰

Material	Source	Generic Type	Viscosity (cps)	Cured Hardness (Shore B)	Shear (S) or Tensile (T) Strength (10 ⁶ N/m ²)	(lb/in ²)	Thermal Expansion Coefficient (ppm per °C)	°F
EC-2216 A/B	3M Corp.	2-part epoxy	paste	60-75	17 (S)	2500 (S)	-	-
(A) Gray								
(B) Clear			9500		14 (S)	2000 (S)	183	102
Devcon A	Devcon Corp.	2-part epoxy	320,000	85	17 (TS)	2440 (TS)	25	14
Devcon B			45,000	85	17 (TS)	2500 (TS)	25	14
Devcon F			300,000	85	17 (TS)	2460 (TS)	45	25
Devcon F-2			45,000	70	17 (TS)	2460 (TS)	45	25
Epon 828	Shell Chemical Co.	epoxy	7000	70	31-48 (TS)	4500-7000 (TS)	90	50
R9-2039/H2-3561	Dexter Corp.	2-part epoxy	600	75-80	34 (TS)	4900 (TS)	54	30
Eccobond 285	Emerson & Cuming Co.	2-part epoxy	-	-	14 (S)	2100 (S)	27	15

Source: Manufacturer's data.

7- Stacked Cell Lens Mounting

In this design, individual lenses are mounted on separate cells. Then all the cells are mounted in housing. Each lens should be concentric and coaxial with its cell. This design

¹⁹ Figure 10 of reference 1

²⁰ Table 5 of reference 1

Tutorial: Mounting Optical Lens

can be very precise and is used in precision applications. Figure 15 shows a stacked-cell lens mount.

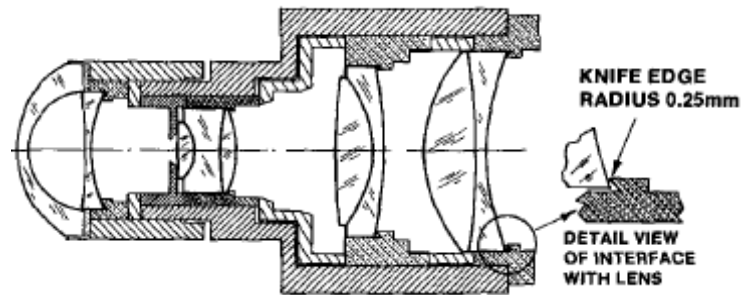


Figure 15: Stacked-cell lens mount

8- Conclusions

Several techniques for mounting lenses were reviewed. Depending on the required alignment and environmental situations, a particular design is preferred to the others.

References

- [1] Yoder P. R., Proc. of SPIE, Vol 0959, P 2, Jan 1988
- [2] Vukobratovich D., Vukobratovich S., Introduction to Opto-mechanical Design, Ratheon Systems Co., Defence Systems Segment.
- [3] Vukobratovich D, Richard R M, Flexure Mounts For High Resolution Optical Elements, Proc of SPIE Vol. 0959, Jan 1988