Lens Mounting with Elastomeric Bonds

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Abstract

In this paper, a precision method of lens mounting using elastomeric bonding is described. First a brief introduction in element centering and mounting is provided, in which some of the advantages of using elastomeric bonding in a high performance lens system are discussed. Then an overview is given which describes how an assembly is built using an optical centering device and bonded with an elastomer. The paper concludes with a case study of a projection lens system that was built using elastomeric bonding to maintain performance over a large temperature range.

Introduction

In bonding a lens to a cell there are only two fundamental considerations that must be met. First, it must be held tightly and accurately so that it its position is stable and it will not shift during environmental conditions such as shock, vibration, or thermal shifts. Secondly, it must be held so that it will not break, and so that the stresses on the components will not introduce any distortions or deformations.

Thermal changes will cause both the glass and the metal to expand. If the Coefficient of Thermal Expansion (CTE) of the metal and the glass differ, additional stress will be put on the components during extreme temperature changes. This may cause the lens position to shift, cause a bond line in a doublet to fail, or cause the lens to crack or break. The best way to minimize this problem is to either use materials that have very low CTE's, or match the CTE of the glass and mechanical housing. However, sometimes neither of these options are available.

Shock and vibration are other environmental conditions that must be considered when choosing a mounting scheme for a lens. To survive over shock and vibration, a standard retaining ring usually requires very high torque so that the retaining rings will not loosen. A high torque usually means high contact stresses in the lens. As with thermal expansion, this may cause the lens to shift or break.

When a lens must survive a large degree of shock and vibration as well as maintain performance over a wide temperature range, a preferred mounting scheme is to use an elastomer material such as a room temperature vulcanizing (RTV) silicon rubber. The advantage of cementing a lens into a cell is that it will hold the glass securely, but it serves as a compliant material that will protect the lens against extreme shock and vibration as well as null out the effects of the expansion of the materials over temperature.

After a brief discussion on the basics of optical centering and mounting, this paper will provide an overview of the method of using an elastomeric bonding process for mounting a lens.

Methods of Centering Lens Elements.

Sources of Centering Errors

An optical centering error occurs when the optical axis of a lens differs from the mechanical axis. The optical axis is defined by the line connecting the two centers of curvatures of the spherical surfaces, and the mechanical axis is defined buy the ground edge of the lens. An optical centering error in lens system can be due to wedge or decenter in the lens element itself, or due to a wedge or decenter of the lens element as it sits in the housing. These effects can be seen in the figure below which shows the cases of a lens with decenter (6.3b), a tilted element as it would sit in the housing (6.3c), and surface tilt within an element also known as lens wedge (6.3d).

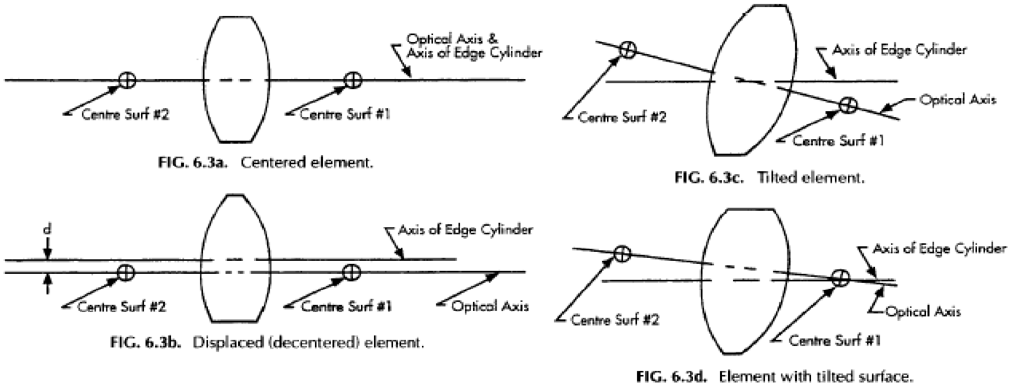


FIG. 6.3a. Centered element.

FIG. 6.3b. Displaced (decentered) element.

FIG. 6.3c. Tilted element.

FIG. 6.3d. Element with tilted surface.

Figure 1: Lens Tilts and Decenters (ISO 10110)

Drop-in Lens Assemblies

There are several methods that are frequently used during assembly to center elements in their barrels or lens cells. The specific centering method the designer chooses to utilize will be determined by the optical tolerances of the system being built and the environmental conditions it must withstand. In the simplest case of low precision systems with tolerances that are sufficiently liberal, the lenses can be simply dropped into their barrels without any adjustments. For assembling multi-elements, the individual lenses can be inserted one at a time, separated by spacers, and secured by a retaining ring or snap ring. An example of a single lens assembly can be seen in Figure 2 below.

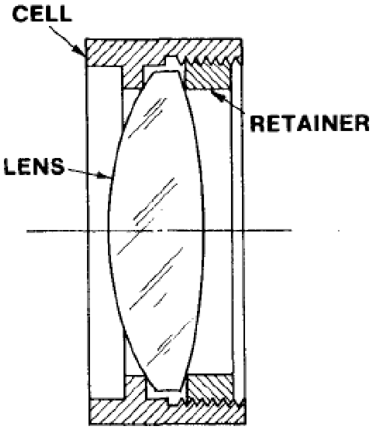


Figure 2: Lens mounted with Retainer Ring (Yoder, 2006)

This method is by far the least expensive method in both assembly hours as well as cost. The inner bore of the lens barrel will need to be larger than the outer diameter of the optics by some margin so the lenses will fit into the barrel without difficulty. A rule of thumb suggested by Vukobratovich is that the gap should not be much tighter than 25um to 50um. Too tight of a bore tolerance may cause the lenses to get stuck during assembly, which may cause a residual element tilt due to the fact that the lens will be wedged in the bore instead of being properly seated against the controlled mechanical surfaces.

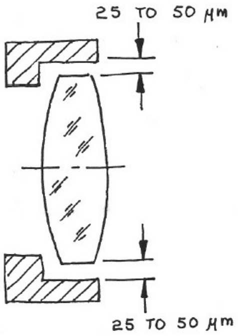


Figure 3: Recommended Gap Spacing (Vukobratovich, 2003)

The main drawback of such a design is in the contact forces at the interface of the glass and metal. This causes stresses in the lens, which may not be problematic at ambient temperatures, but can become significantly worse over thermal shifts. Additionally, because of the high contact stresses, this type of design is not optimal for surviving shock and vibration loads. The figure below illustrates the high contact stress due to a flat retaining ring securing a singlet lens.

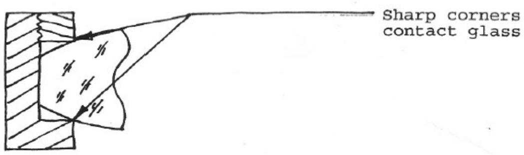


Figure 4: Retainer Contact Stress Example (Vukobratovich, 2003)

In lenses which must survive extreme levels of shock and vibration, as well as perform over wide temperature ranges, other mounting configurations are preferred.

Mechanical shimming

In a higher performance lens system with tighter tolerances, a drop-in lens assembly may not be sufficient to meet the performance requirements, and some type of active centration is necessary. One such technique is to use shims, which can be metal or made of a compliant material such as Mylar or Teflon. In performing a mechanical shimming operation, the assembler centers each lens element by aligning to the mechanical axis as defined by the edges of the lens.

To perform a shimming operation, the lens is first pushed all the way to one side of the bore and the largest shim possible will be fit into the gap. Once the correct size is found, that number is halved and the shims are cut to size and placed into the gap between the lens and the cell. A preferred method is to use three shims spaced 120 degrees apart. As indicated in figure 5 below, once the shimming is performed, the RTV can be injected into holes drilled in the housing.

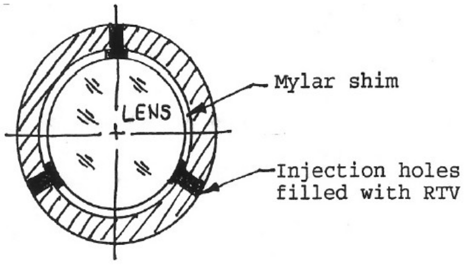


Figure 5: Shimming a lens element (Vukobratovich, 2003)

It is important to keep in mind that an operation using shims centers a lens using its edges (the mechanical axis). Therefore, if the lens wedge and decenter tolerances are not tightly controlled on the element drawing, the mechanical axis may not coincide well with the optical axis.

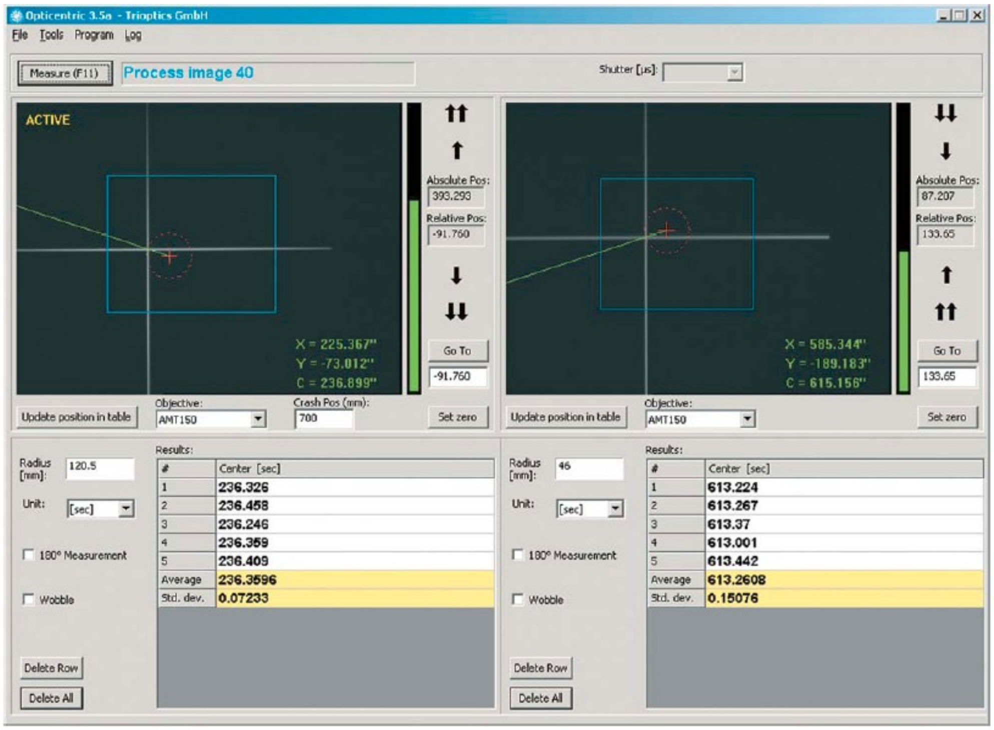
Optical Centering Device

A common way to center elements in a precision lens system is to use an optical centering apparatus. This type of device consists an autocollimator, a motorized precision air bearing rotation table with stepper motor control, a CCD camera with frame grabber, and analysis software that displays the centering data on a PC. The rotation table typically has adjustment capabilities for both centration and tip-tilt. An example of an optical centration machine made by a German company called TriOptics can be seen in Figure 6. The tip-tilt table for this particular apparatus has a sensitivity of +/-1 arcsec, and the translation sensitivity is +/-1μm.

Figure 6: Optical Centering Machine (www.trioptics.com)

The optical centering machine works by projecting a reticle through an autocollimator and looking at either the reflection off of a spherical surface or the deviation in boresight when operating in transmission mode. The system under test is then rotated on a precision air bearing table. When the surface or lens element is centered, the image of the reticle will not move during rotation. However, if decenter or wedge exists, the image of the crosshairs will precess in a circle about a center point. The lenses can be either measured in transmission mode or in reflection mode. In transmission mode, the light source is placed underneath the lens and projects a crosshair up through the lens, where in reflection mode the reticle is projected through a beam splitter at the top of the system near the CCD image plane and gets reflected back up to the image plane.

In older system, this precession was observed by eye. However, more modern versions have a CCD focal plane array and include software that directly calculates the decenter of the lens from the radius of the precession circle. The decenter is then output to the screen and can be read out in units of microradians or microns. A screen shot showing the capabilities of the TriOptics software can be seen in Figure 7.



Process image 40

X = 225.367"
Y = -73.012"
C = 236.899"

Absolute Pos: 393.293
Relative Pos: -91.760
Go To: -91.760
Objective: AMT150
Crash Pos (mm): 700
Radius [mm]: 120.5
Unit: [sec]

Results:

#	Center [sec]
1	236.326
2	236.458
3	236.246
4	236.359
5	236.409
Average	236.3596
Std. dev.	0.07233

X = 585.344"
Y = -189.183"
C = 615.156"

Absolute Pos: 87.207
Relative Pos: 133.65
Go To: 133.65
Objective: AMT150
Radius [mm]: 46
Unit: [sec]

Results:

#	Center [sec]
1	613.224
2	613.267
3	613.37
4	613.001
5	613.442
Average	613.2608
Std. dev.	0.15076

Figure 7: TriOptics OptiCentric Software (www.trioptics.com)

Precision Centering with Elastomeric Mounting

If the specifications and tolerances on the lens system dictate a build that requires an elastomeric build with centration occurring on an optical centering machine, several features must be designed into the components before hand. In the lens housings and/or cells, accurate datum surfaces must be specified that can be used as reference surfaces from which to define the optical axis.

These mechanical surfaces will define the optical axis and tip/tilt of the assembly, which will then be used as a reference to center the optics. As an example, if the concentricity and circularity of the lens barrel is called out to a tight tolerance, the bore of the lens barrel may be used to determine the center of the optical axis. To find this center, the assembly is first mounted to the rotation table, then the optical axis is established by using an indicator that is placed on the bore of the lens barrel. When spun about its axis on a rotary air bearing table, the centration adjustment can be tweaked until the total indicator runout (TIR) is nulled out as accurately as possible.

Similarly, if a mechanical datum has been called out on a top or bottom surface of the cell to establish the perpendicularity of that surface with respect to the optical axis, this can be used as a reference to define the tip-tilt of the axis. This is adjusted via the same method of putting an indicator on the reference surface, rotating the table and nulling out the indicator so that the total indicator runout is minimized.

Other features necessary for elastomeric bonding must also be designed in. Several holes must be drilled into the barrel itself for the RTV to be injected via a syringe after it is centered, and it is helpful to have centering screws built in to aid in the centering process. These screws will also serve to push the lens around during centering, and then hold the centered lens in place as the elastomer cures.

Finally, the bore should be undersized so that the elastomer layer will have the optimal thickness to null out the effects of thermal expansion. This optimal thickness can calculated using the diameter of the lens, the CTE's of the two materials, and the CTE of the elastomer. The equation, which can be seen in the figure below, is just the differences of the glass and metal CTE's multiplied by the diameter of the lens, and then divided by twice the difference of the metal and elastomer CTE's, or:

$$t_e := D_G \cdot \frac{(\alpha_m - \alpha_g)}{2 \cdot (\alpha_e - \alpha_m)}$$

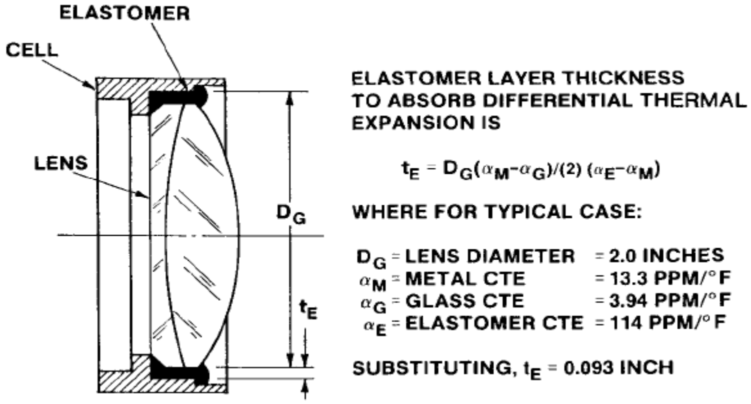


Figure 8: Optimal Elastomer Layer Thickness Equation (Yoder, 2006)

Elastomeric Bonding Example

A prime example of a successful elastomeric lens design is described in the paper "Case Study of Elastomeric Lens Mounts" by Robert E. Fischer. This design had very tight performance requirements over the temperature range of -55 to +95 degrees C. Due to these wide thermal requirements, an elastomeric design was selected with each lens built into individual cells known as poker chips. The material for lens barrel and the cells were made of stainless steel, and the lenses were actively centered and then bonded into their cells with a compliant elastomer. In the final build step, the individual cells were then assembled into the outer housing.

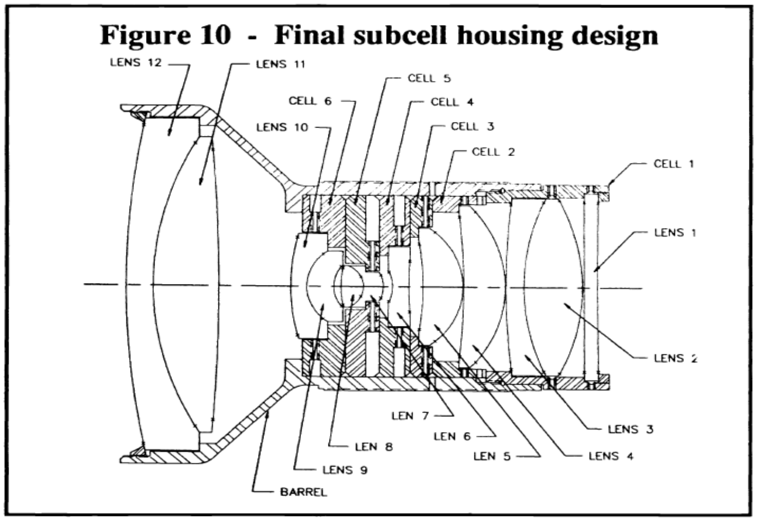


Figure 9: Precision Projection Lens Utilizing Elastomeric Mounting (Fischer, 1991)

The lens reportedly performed excellently and met the performance requirements on all counts. The method was recommended as a superior option for similar high performance lens designs that needed to hold tight performance specifications over a wide thermal ranges.

References

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