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A Synopsis of Paul R. Yoder's *Lens Mounting Techniques*

Paul R. Yoder presented the paper *Lens Mounting Techniques,*[1] which appeared in a 1983 SPIE proceedings titled Optical Systems Engineering III. Yoder is a preeminent figure in the optomechanical arena and is well known for his book titled Opto-Mechanical Systems Design.[2] This book is commonly considered as quintessential for the bookshelf of any optomechanical engineer. Also in Yoder's repertoire of publications is his newer book Mounting Optics in Optical Systems[3]. Yoder's introduced the first edition of Opto-Mechanical Systems Design in 1986, three years after *Lens Mounting Techniques* was published. The paper is therefore a precursor to the general lens mounting topics covered in his first book. Yoder begins his paper by discussing three fundamental lens mounting techniques that are discussed in further detail in Chapter 4 of his first book. Yoder follows these mounting techniques in his paper by an analysis of axial stresses in glass-to-metal interfaces, then a description of stress under various operating conditions, and finally with a section on multiple element mounting configurations. The topics covered in Yoder's paper are essential for an optomechanical engineering in understanding the underlying lens mounting techniques used in optical systems with ½ in. to 10 in. diameter optics, and the stresses associated with mounting contact and thermal variations.

The three lens mounting techniques that Yoder describes are burnishing a lens into its cell, using an elastomer layer on the outer diameter of the lens, and using a retainer ring to hold the lens into the lens cell. For a quick reference of each of these techniques and their advantages refer to Table 1. The burnishing method is accomplished by cutting a beveled edge into the lens. The lens is then inserted into the lens barrel and then burnished or "crimped" onto the beveled edge of the lens. This technique is primarily used with small lens such as microscope objectives, endoscopes, or short focal-length lens[a]. An alternative technique to this method is to replace the burnished edge by a coil ring or a snap ring. This technique is generally in systems subject to high shock values.

The elastomer layer technique requires that the lens barrel be cut to a diameter larger than the lens diameter. The lens is inserted into the barrel and a later of vulcanizing elastomer is inserted around the edge of the lens. The lens is first positioned with aid of shims followed by the insertion the elastomer with a hypodermic syringe. After the elastomer is injected, it is set by curing. The required thickness of the elastomer layer t_E according to Bayer (1981) [4] is given by

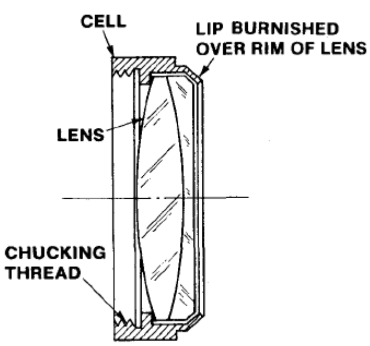
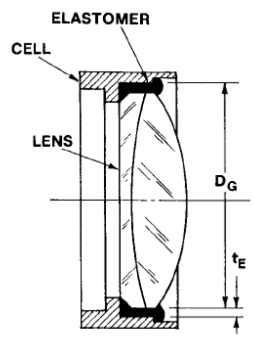
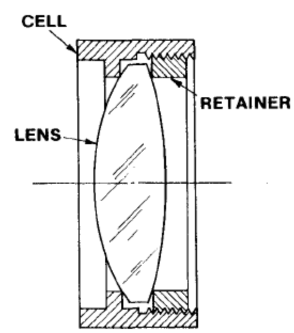
[a] Described in page 179 of Opto-Mechanical Systems Design

$$t_E = \frac{D_G(\alpha_M - \alpha_G)}{2(\alpha_E - \alpha_M)}, \qquad (1)$$

where D_G is the lens diameter, α_M is the CTE of the metal lens barrel, α_E is the CTE of the elastomer, and α_G is the CTE of the glass. A typical elastomer thickness value is on the order of t_E = 0.1 in.

The common method for mounting individual lenses is to use a threaded retaining ring. The lens barrel is manufactured to be compatible with the thread pattern compatible of the retaining ring. The lens is simply inserted into the lens barrel followed by the retaining ring. The retaining ring is placed flush against the lens. This technique provides a method that easily allows the lens to be inserted and removed from the system. The square retaining ring is the most easily manufactured, but other tangential and spherical retaining ring configurations are also used.

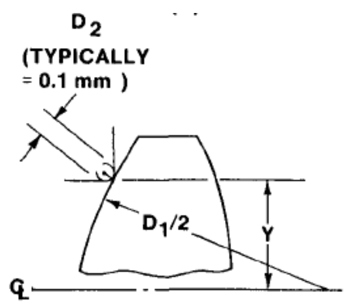
Table 1: Summary of Lens Mounting Techniques and Their Advantages

Burnishing	**Elastomer Layer**	**Retaining Ring**
		
Description: Lens barrel is deformed to the beveled edge of the lens.	**Description:** The outer diameter of the lens has a layer of elastomer inserted to secure it to the lens barrel.	**Description:** Threaded retaining ring inserted firmly against the lens in lens barrel.
Advantages: - Inexpensive - Firm mounting technique - Can be modified for a high shock situations	**Advantages:** - Elastomer is elastic leaving the lens unstressed - Inexpensive - Simple	**Advantages:** - Firm mounting technique - Easy to assemble and disassemble - Compensates for axial thickness variations - Adding o-ring creates environmental seal
Disadvantages: - Can induce strain on the lens - Can induce tilt into the lens	**Disadvantages:** - Decentration under shock/vibration	**Disadvantages:** - Can induce axial stress - If lens has a flat edge bevel, then a tight tolerance is required
Notes: - Technique is considered permanent. - Used for low precision (<30 arcmin of wedge).	**Notes:** Typical RTV compounds are - Dow Corning RTV732 - Dow Corning RTV93-500 - GE RTV8112	**Notes:** - Retainer ring can be square, tangent, or spherical.

After describing these three general techniques, Yoder provides a description to determine the correct seat, spacer, or retaining ring based on axial stress. This configuration is chosen based on the worst possible axial stress due to retainer ring tightness or thermally induced contractions. Yoder uses a calculation presented by Delgado and Hallinan (1975)[5] to calculate axial stress S_A due to ring contact

$$S_A = 0.798 \sqrt{\frac{P(D_1+D_2)/(D_1 D_2)}{\left(\frac{1-v_G^2}{E_G}\right)+\left(\frac{1-v_M^2}{E_M}\right)}} \quad (2)$$

where P is load per unit length of line contact, D_1 is the lens diameter, D_2 is the corner diameter of the retainer ring, v_G is the Poisson's ratio for glass, v_M is the Poission's ratio for metal, E_G is the glass modulus of elasticity, and E_M is the metal modulus of elasticity. The retaining ring diameter placed against the lens can be easily seen in the following figure:



For a BK7 lens, a typical axial stress value from an aluminum retaining ring with edge diameter of 0.004 in and load per unit length of 0.3 lb/in is on the order of 20,000 psi. The maximum safe compressive load for glass is on the order of 50,000 psi. Yoder also includes an equation also introduced by Bayer (1981), which looks at the axial stress due to thermal variation given by

$$S_{A'} = \frac{(\alpha_M - \alpha_G)(E_M E_G \Delta T)}{E_M + E_G} \quad (3)$$

In a worst case scenario, if ΔT is equal to 150°F then the axial stress would be on the order of 7500 psi. The axial stresses due to the retaining ring force and thermal changes give a factor of safety of around two. The obvious solution to reduce the contact stress from the retaining ring while maintaining the same contact force is to increase the surface area of the glass and retaining ring interface.

The next topic Yoder discusses is the hoop stress induced on the outer diameter of the lens at the barrel interface. Typically the clearance for a lens in a barrel is on the order of 0.0005 in. The hoop stress is induced by thermal variations. Yoder provides a worst case scenario calculation showing that the hoop stress for an aluminum glass interface is 1000 psi for a ΔT equal to 150°F. This stress can thus be considered negligible.

The temperature ranges that Yoder uses in his thermal variation calculations are much greater than most typical operating temperatures. It is qualitatively assumed that the optical performance variations due to temperature changes will outweigh the birefringent variation due to thermal induced stress. Birefringence however is a factor to consider in optical systems that are intrinsically polarization dependent including laser interferometers and polarimeters. These optical systems generally need to be contained in a thermally controlled environment to reduce the effect of stress induced birefringence.

In the final section of Yoder's paper, he provides examples of multiple element mounting configurations. The first example includes a military eyepiece that contains two achromatic doublets. The doublets are separated by a spacer with a thickness that yields the appropriate airspace between the doublets. The key figures of merit from the example are the 10 arc second wedge tolerances in the lens and the 0.003 in diametrical clearance for the lenses and spacers in the barrel. In the next example, Yoder describes a lathe assembly technique that can be used for high tolerance lens assemblies corresponding to a tight 0.0002 in diametrical lens to barrel clearance. This lathe assembly process is one that creates the lens housing after the lens has been manufactured. It is accomplished by first measuring the outer diameter of the lens. The inner diameter of the housing is then machined with a 15 arcmin perpendicularly to the optical axis and with a 7 to 12 μm diametrical clearance of the measured lens diameter. The remaining spacer dimensions and lens contact surfaces are machined to appropriate tolerances with respect to the measured dimensions of the lens.

A general understanding of these lens mounting techniques is critical for any optical engineer because specifying edge thicknesses is crucial to interfacing optical elements with the mechanical parts holding them. Understanding the present stresses, shock values, working environment, optical performance requirement, and manufacturing capabilities determine which lens mounting technique is suitable for any particular optical system. These lens mounting techniques can range from applications to microscope objectives to tightly toleranced lithography systems. The axial stress equations Yoder provides are necessary for any optomechanical engineer to determine the stress due to mounting ring contact and thermal variations. It is however generally understood will in most cases fall below the compressive strength of glass. For additional resources on these topics, an optomechanical engineering should reference Bayer (1981), Delgado and Hallinan (1975), and of course any of Yoder's books.

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[1]Yoder Jr., P.R. "Lens Mounting Techniques," Proc. of SPIE Vol. 0389, Optical Systems Engineering III, ed. William H. Taylor (Jan 1983).

[2] Yoder Jr. P.R. Opto-Mechanical Systems Design. New York: Marcel Dekker, Inc. 2005

[3]Yoder Jr. P.R. Mounting Optics in Optical Systems. Bellingham: SPIE. 2008

[4] Bayar, M., "Lens Barrel Opto-Mechanical Design Principles", Opt. Eng. 20, 181 (1981).

[5] Delgado, R.F. and Hallinan, M., “Mounting of Lens Elements:, Opt. Eng. 14, S-11 (1975).