Mounting of Optical Components
Mounting of lenses

Jim Burge
Professor, Optical Sciences and Astronomy
University of Arizona
Tucson, AZ 85721
jburge@optics.arizona.edu

Design approach for lens mounts

- Lenses are axisymmetric, usually with spherical surfaces
- Key drivers for design are centration and spacing tolerances
- Metal barrels can be machined so they are highly symmetric

1. Place one lens spherical surface onto a true surface on the barrel. This gives excellent accuracy at low cost.
2. Remaining degree of freedom is centration.

- Control by size of bore, lens, and tight tolerance, clamped or potted in place
  - direct centering error
  - lens wedge

- Lens barrel is critical for control of stray light
  - Balance with optical design to maintain clear aperture, but limit strays
  - Blacken edges of lenses that are illuminated or are viewed
  - Cut threads on inside surfaces, blacken for good rejection
  - Avoid specular reflections into the sensor, even from blackened surfaces
  - Add baffle tube in front of lenses

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Mount lenses using the optical surface

- Using Surface Contact can help to accurately locate the optic correctly

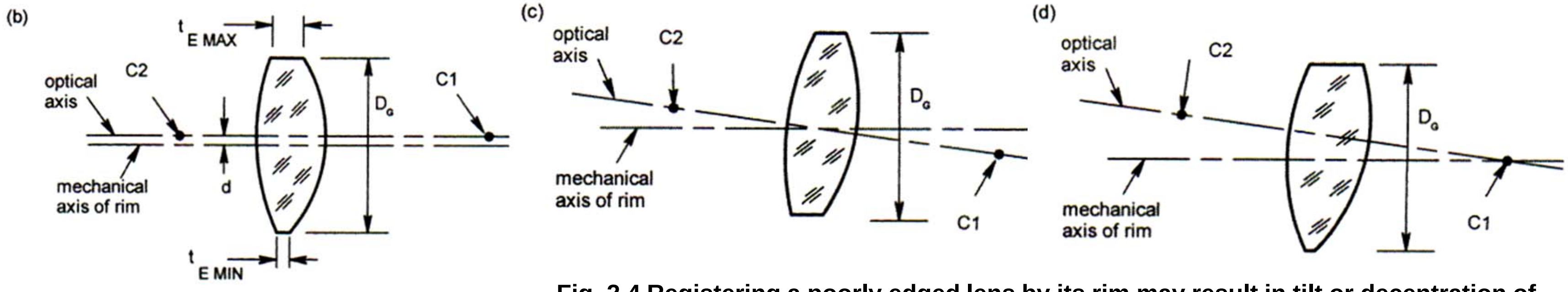

Fig. 2.4 Registering a poorly edged lens by its rim may result in tilt or decentration of the optical axis (b) decenter (c) tilt (d) tilt and decenter

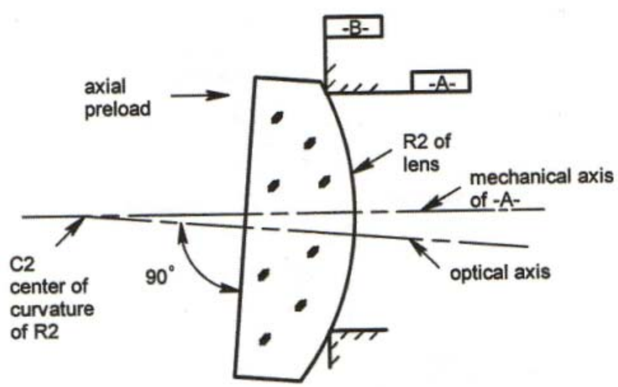

Figure 2.14 Concept for a surface contact lens mounting.

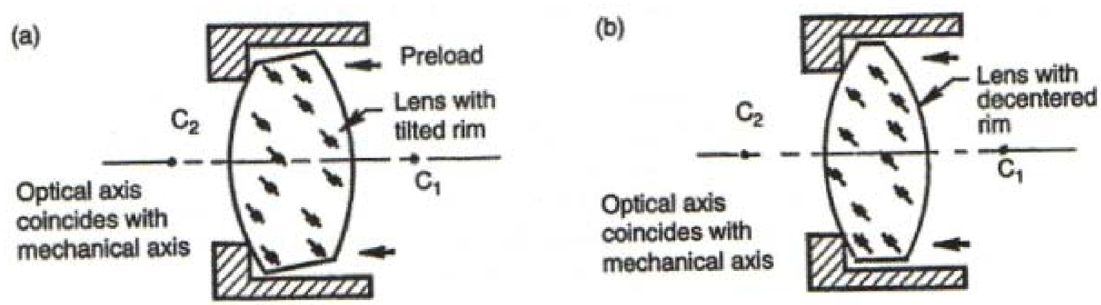

Figure 2.15 Accurate lens edging is not required with a surface contact interface.

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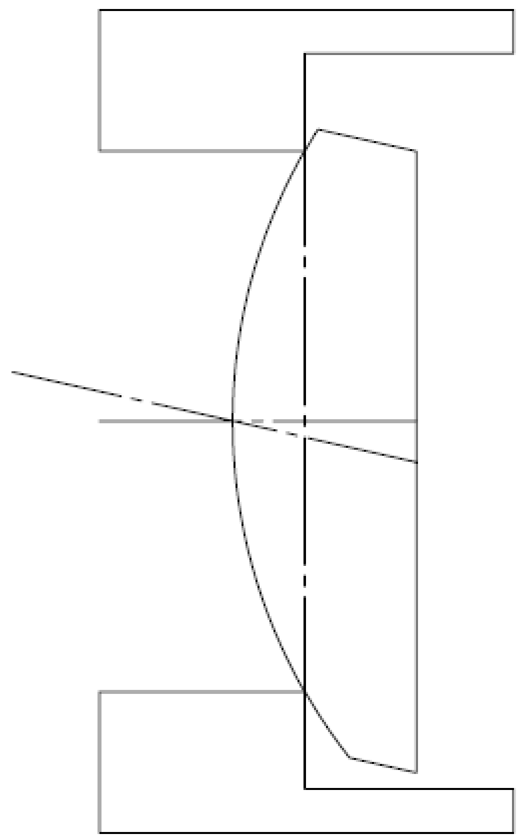
Lens mounts: align the *optical* surfaces

- **Mechanical surface can be in the wrong place with no negative consequences**



Preload for lens mounts

- **Locating the Lens with an axial preload can help to hold a lens in place against maximum acceleration as well.**

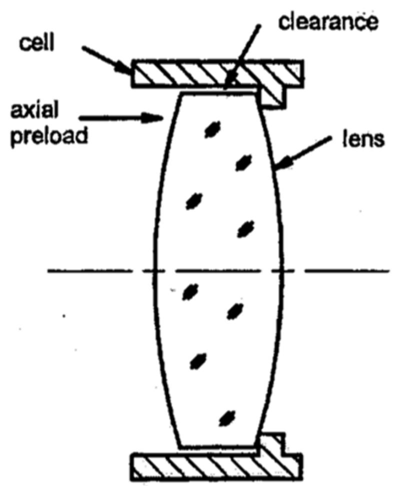


Figure 2.12

- **This preload can be estimated as:**

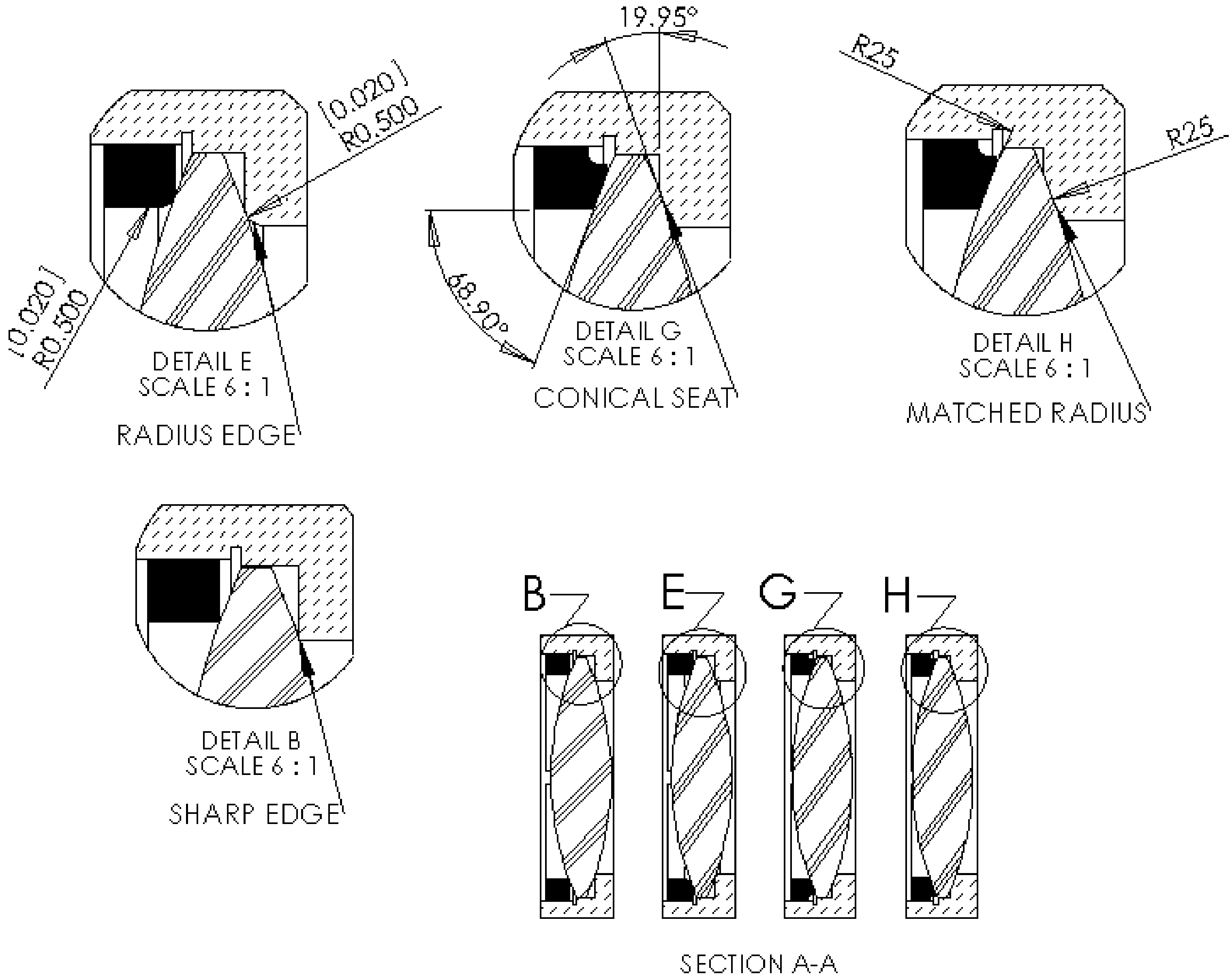
$$P_A = W a_G \qquad (3.1)$$

where a_G is the acceleration factor (times gravity)

- **Typically, acceleration levels of 3 to 15 times gravity occur during handling and shipping of optical instruments. Military environments may impose acceleration a_G of 500 or even 12,000.**

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Lens seats


19.95°
R25
R25
(0.020)
R0.500
(0.020)
R0.500
68.90°
DETAIL E
SCALE 6 : 1
RADIUS EDGE
DETAIL G
SCALE 6 : 1
CONICAL SEAT
DETAIL H
SCALE 6 : 1
MATCHED RADIUS
DETAIL B
SCALE 6 : 1
SHARP EDGE
B
E
G
H
SECTION A-A

Lens interfaces: the sharp corner

- **Basic Type of Lens Seats:**
  - Sharp Corner (R ~ 0.002" or 50 µm)
  - Toroidal Lens Seat
  - Conical or Tangential Seat
  - Spherical Lens Seat
  - Flat Lens Seat
- **Sharp Corner Interfaces for Concave and Convex Surfaces**

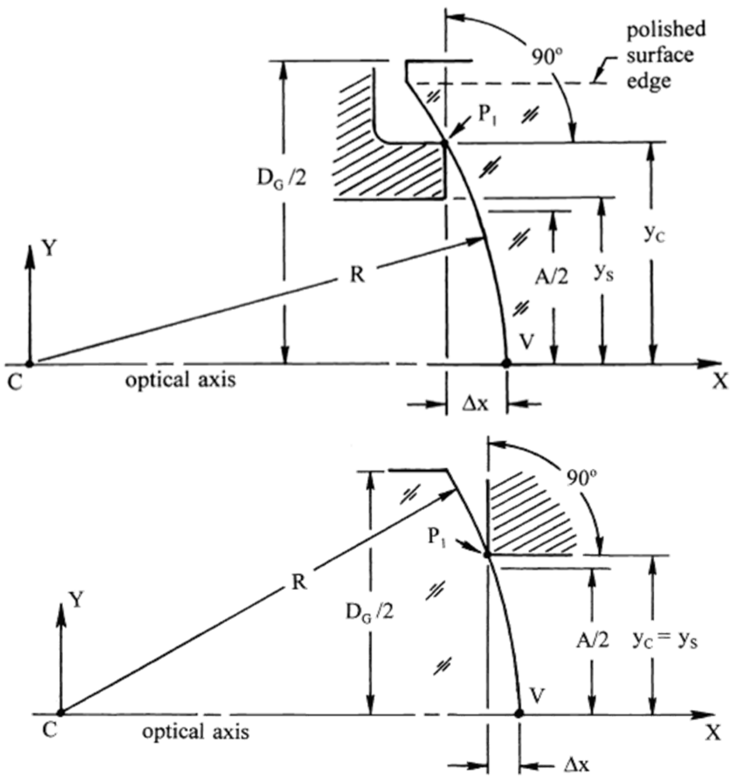


Figure 3.26

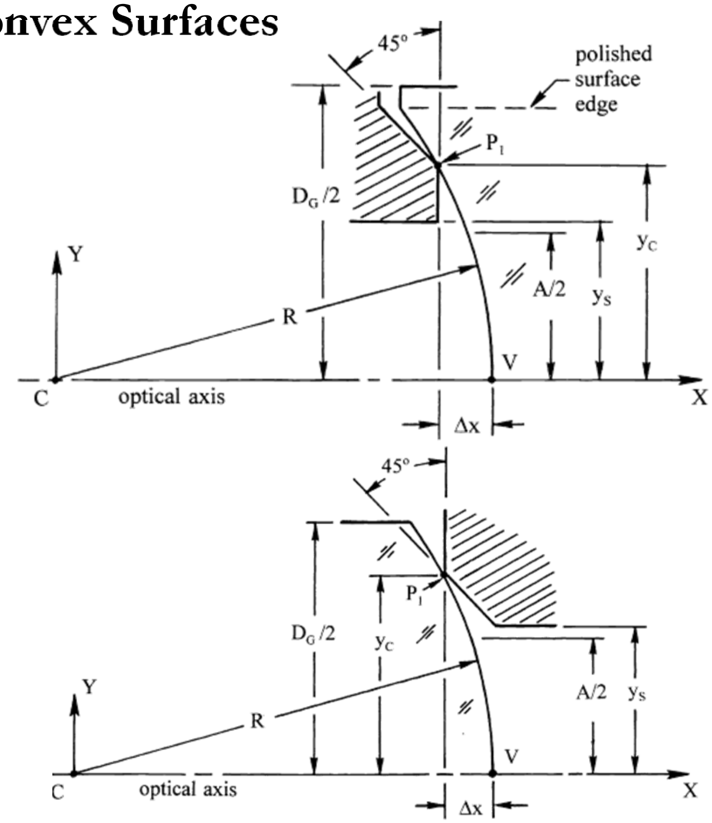


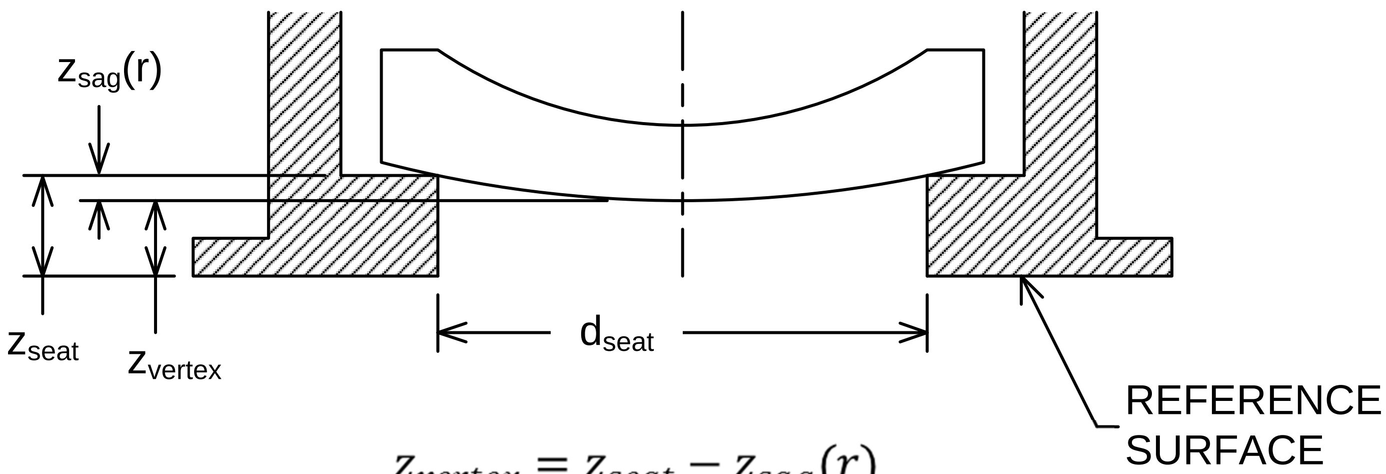
Figure 3.27

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Issues with the sharp corner

- Provides highest accuracy, and is easy to verify
- Potentially large contact stresses
  - For most applications, these will not cause any risk
- Sharp corners are susceptible to damage or to burrs
  - Standard practice of "breaking corners" will result in loss of accuracy

- "Sharp" corner with radius > 0.002" can be considered as toroidal seat



$$z_{vertex} = z_{seat} - z_{sag}(r)$$

$$z_{vertex} = z_{seat} - R_{lens} + \sqrt{R_{lens}^2 - \left(\frac{d_{seat}}{2}\right)^2}$$

Tensile stress, caused by contact stress

- **The deformation due to point loading on a glass surface causes a localized *tensile* stress at the surface, a small distance from the load. The peak tensile stress σ_T is estimated as**

$$\sigma_T = \frac{(1-2\upsilon)}{3}\sigma_C$$

σ_C is the peak compressive stress from the concentrated load

ν is Poisson's ratio for the glass

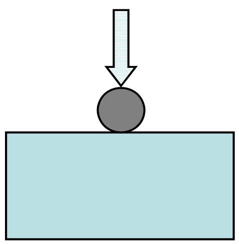
- **This stress field is small, and shallow**
- **This can be a concern for point loads, which can cause a conical fracture in the glass**
- **The effect for line loads does not drive most designs**
- **Verified by testing at UA. Unable to detect decreased strength, even after loading with >50,000 psi**

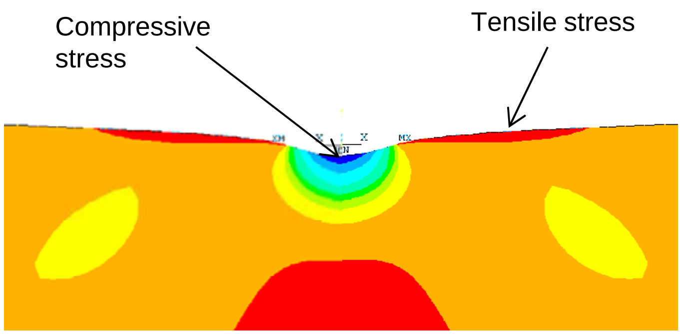
<u>Finite element model of cylinder on flat</u>

R = 2", 9 lb/in load
with <0.0001" elements

3800 psi maximum compressive stress

350 psi maximum tensile stress
0.015" from the load
<0.001" deep

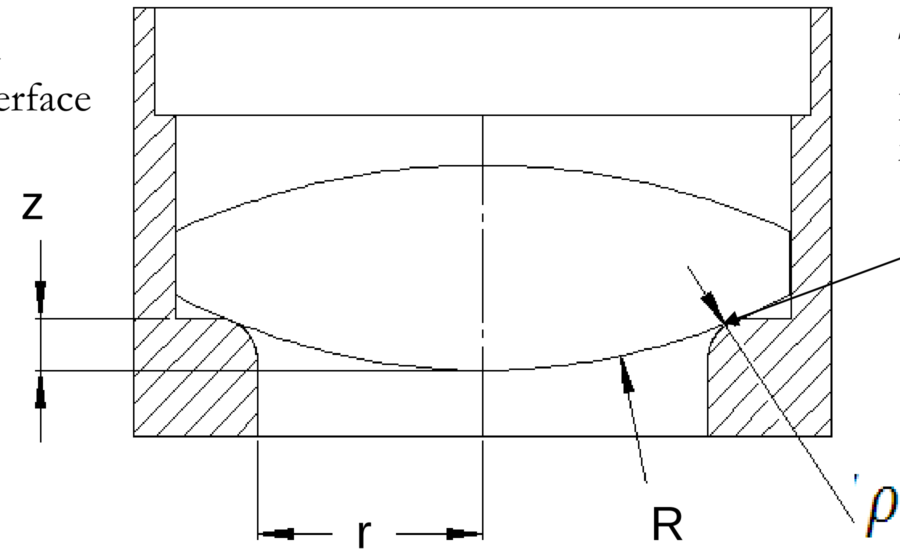




Geometry for toroidal seats for lens mounts

Position of lens vertex defined by toroidal interface

Toroidal interface, radius ρ position defined by intersection of flat and cylindrical surfaces



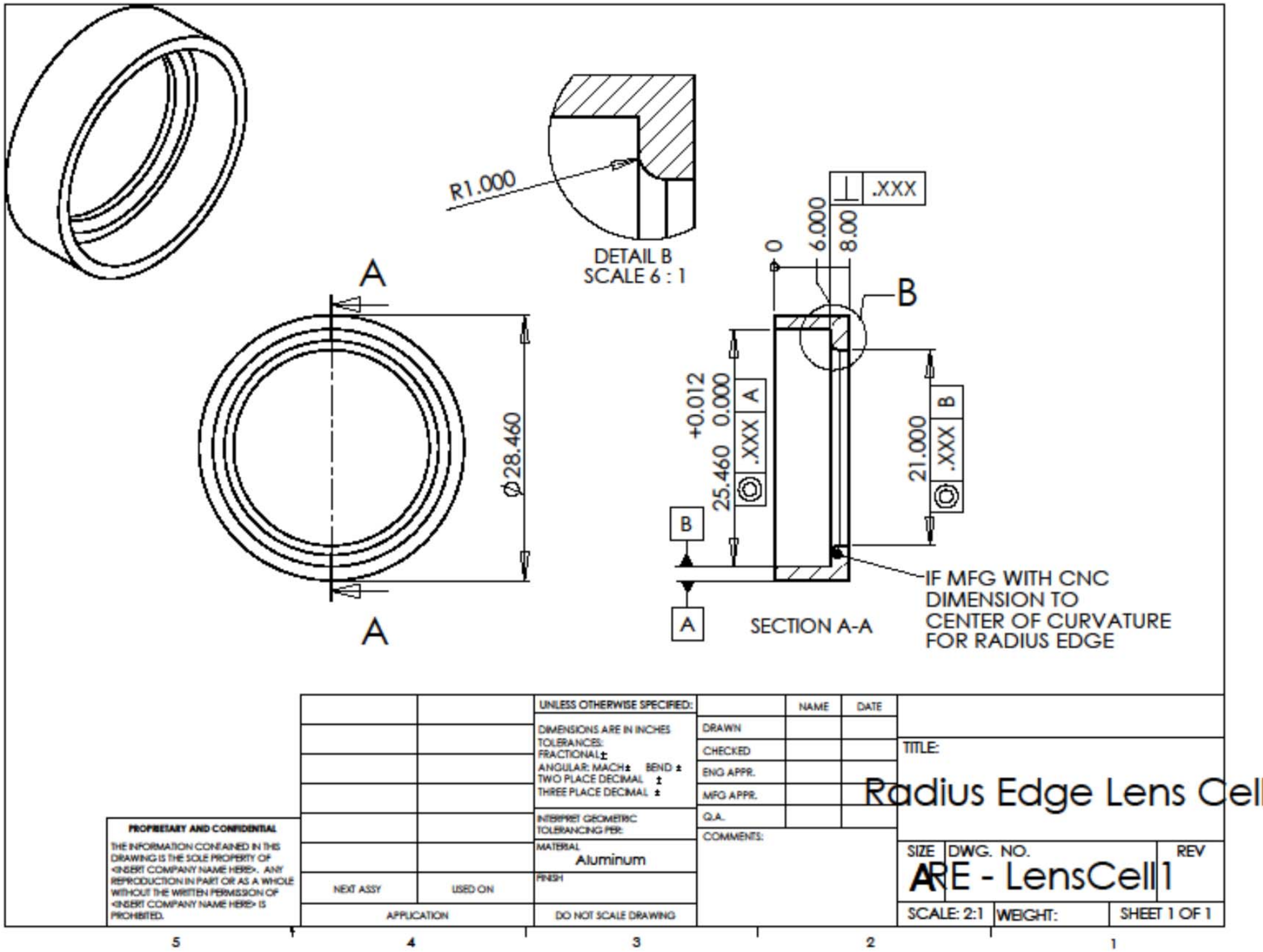
$$z = R + \rho - \sqrt{(R+\rho)^2 - (r+\rho)^2}$$

If sharp corner is defined, but actual radius of ρ is obtained, axial shift of lens, with respect to ideal, is

$$\Delta z \cong \frac{r}{R}\rho$$

Typical value for ρ is 0.05 mm or 0.002”

Specifying toroidal interface



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Conical interface, or tangent contact

- **Reduce contact stress using conical interface**
  - **Note that this works only for convex surfaces**
- **It is harder to hold the lens spacing tolerances with conical seats**

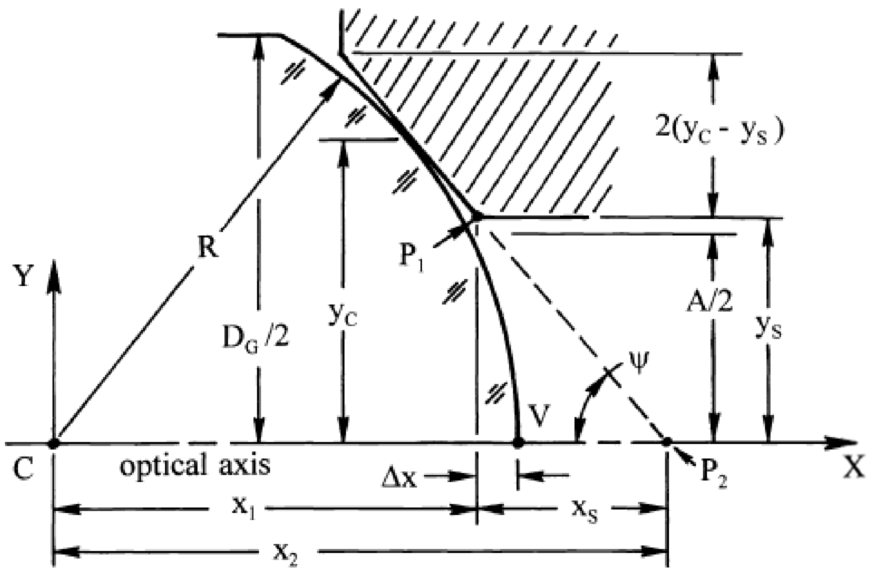
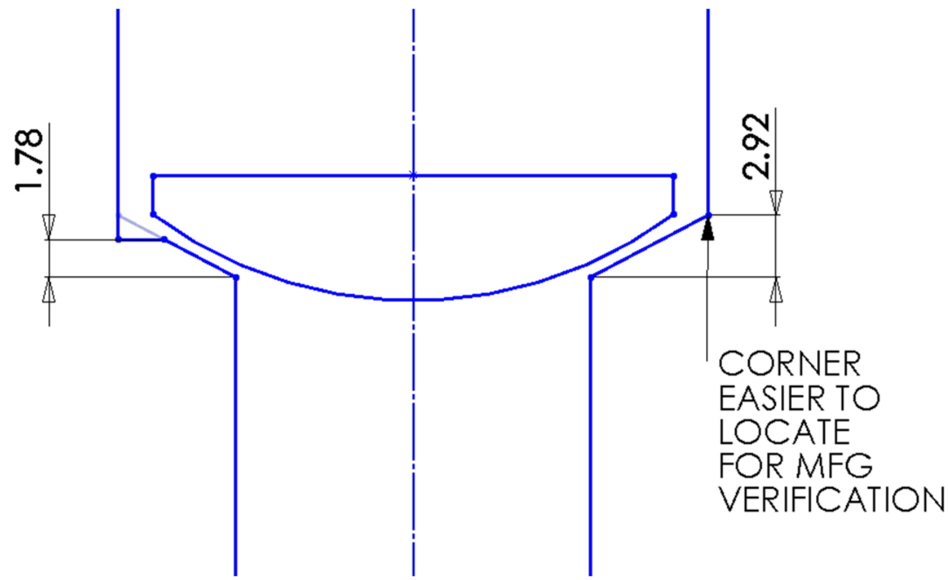


Fig 3.28 - Schematic of a tangential interface on a convex spherical surface.



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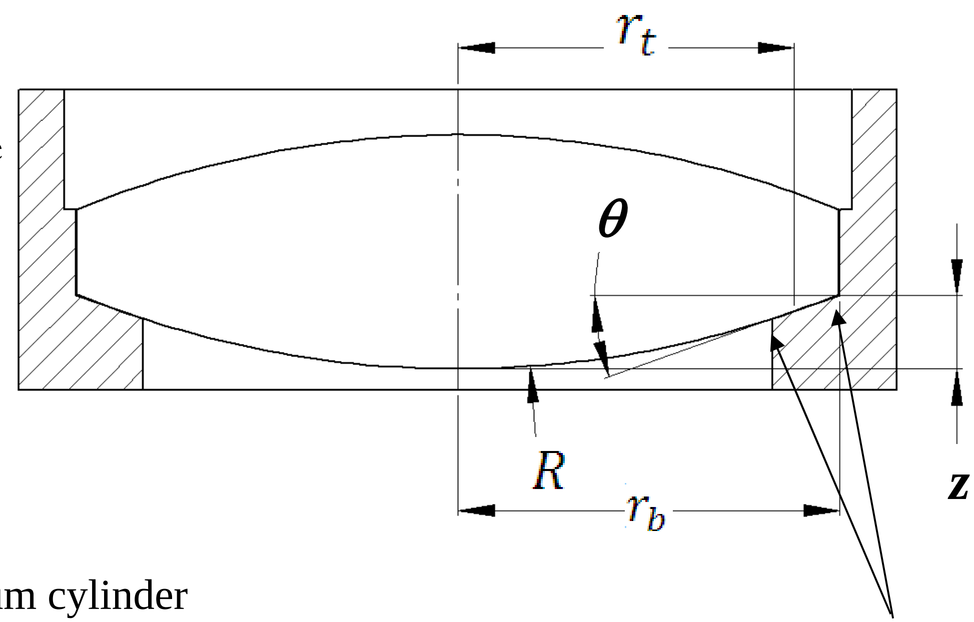
Geometry for conical interface, or tangent contact

Position of lens vertex defined by conical interface



$\boldsymbol{\theta}$ = cone angle

$\boldsymbol{r_b}$ = radius of barrel datum cylinder

$\boldsymbol{r_t}$ = contact radius of cone and spherical surface

$\boldsymbol{z}$ = position of lens vertex with respect to intersection of conical seat and barrel datum cylinder

$$\sin\theta = \frac{r_t}{R}$$

$$z = R\left(1 - \frac{1}{\cos\theta}\right) + r_b \tan\theta$$

Choose OD for mechanical clearance of lens in barrel

Choose ID for optical clear aperture

GD&T for conical lens seat

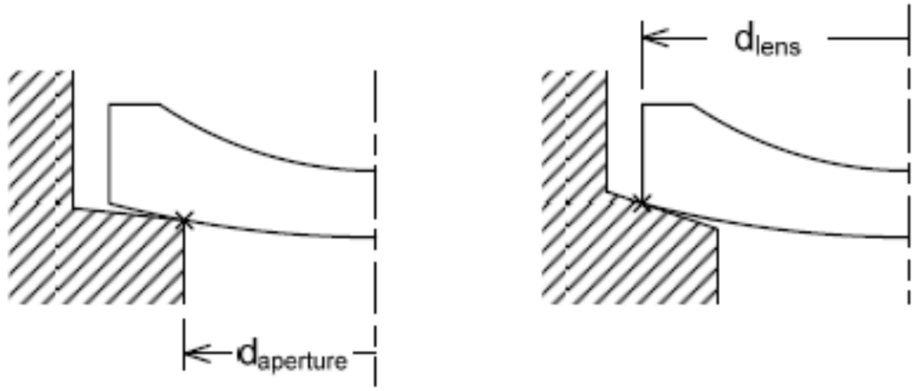
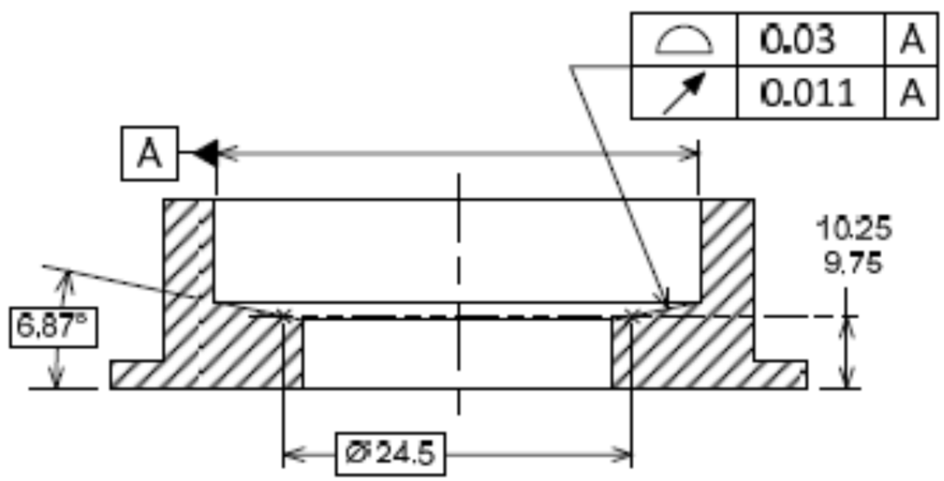


Figure 14. Situation that can occur if the seat diameter is either less than the aperture diameter (left) or greater than the lens diameter (right)

$$\theta_{min} = \sin^{-1}\left(\frac{d_{aperture}}{2R_{lens}}\right)$$

$$\theta_{max} = \sin^{-1}\left(\frac{d_{lens}}{2R_{lens}}\right)$$



Spherical Seats

- Very benign, nominally zero stress concentration
- Difficult to manufacture and measure accurately.
    - Possible, but costs will be driven significantly by these interface types.
    - Seldom justified

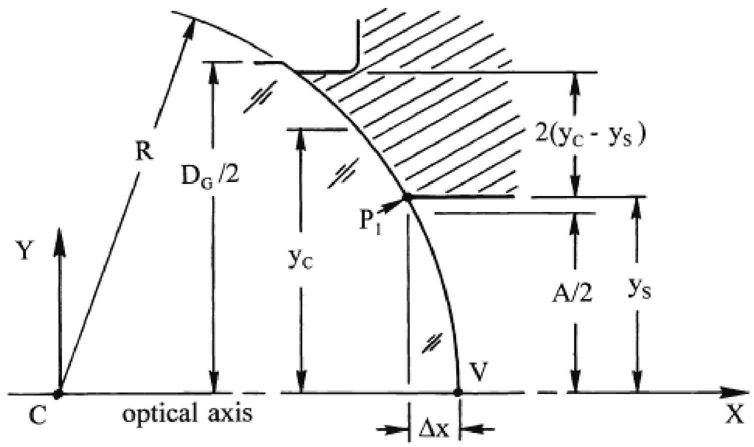


Figure 3.31

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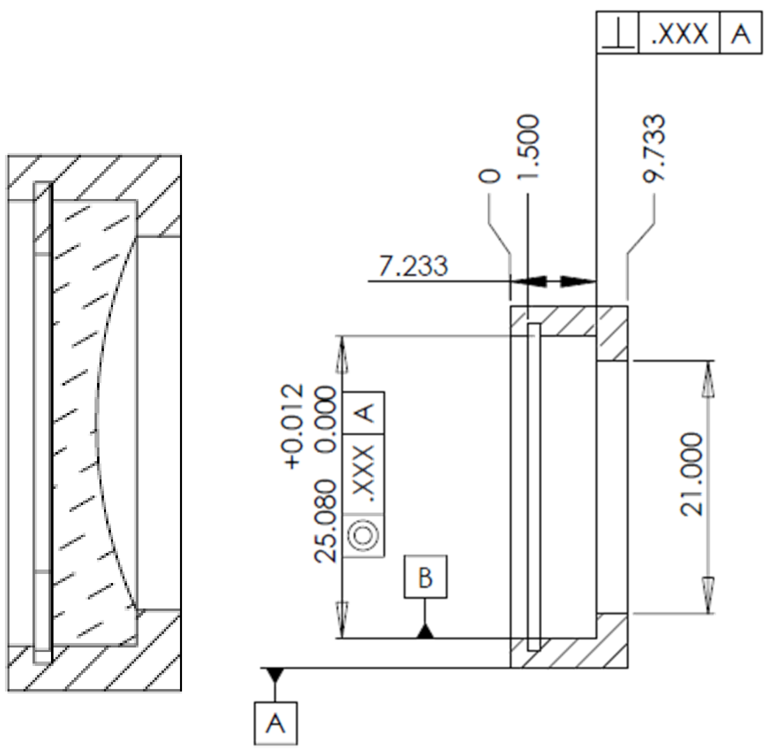
Using mechanical surfaces for mounting interfaces

- Edge Flat Seat and Various surfaces can be used for a lens mounting purposes.
  - Any mounting surfaces should be treated as precisely defined and oriented surfaces
  - Uncertainty in cutting the mounting surface will directly affect lens position accuracy



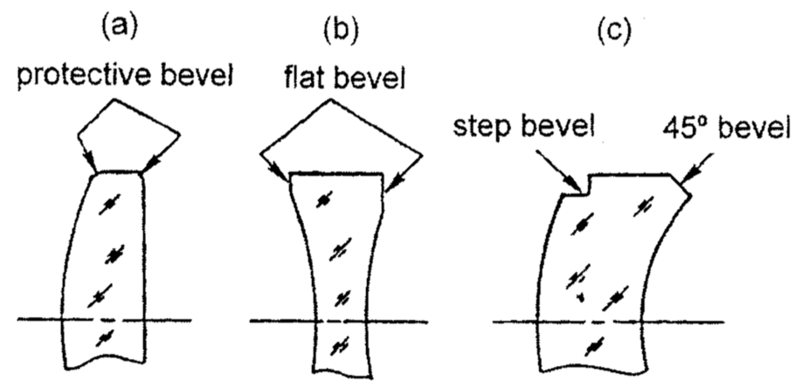


Figure 3.32

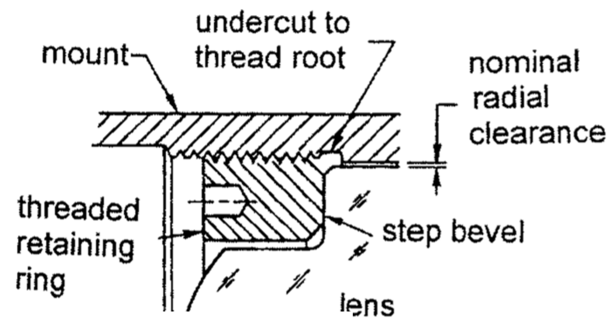


Figure 3.33

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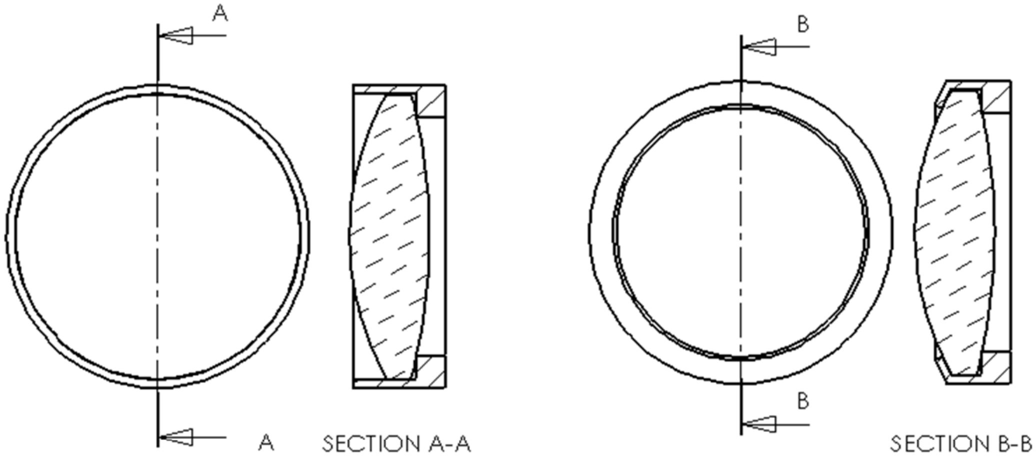
Retainers

- The features in the lens barrels should define the lens position
- The retainers maintain a preload to hold the lens in place
- Types of retainers:
    - Burnished Edge
    - Flexure
    - Snap Ring
    - Threaded Retainer
    - Press Fit or Interference Fit Retainer
    - Elastomeric Retainer

Lens retainer with burnished edge

- The metal of the lens cell is either rolled or bent into the appropriate shape to hold the lens in place.
- Preloads and springs may be used as well
- Low cost for production



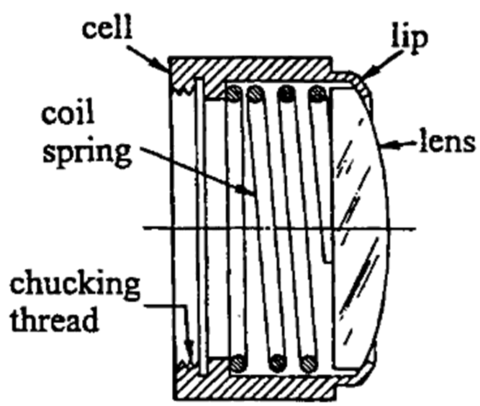


Figure 3.39

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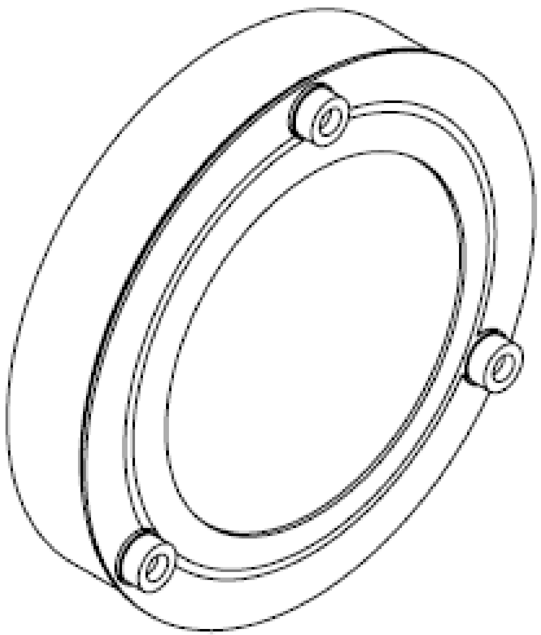
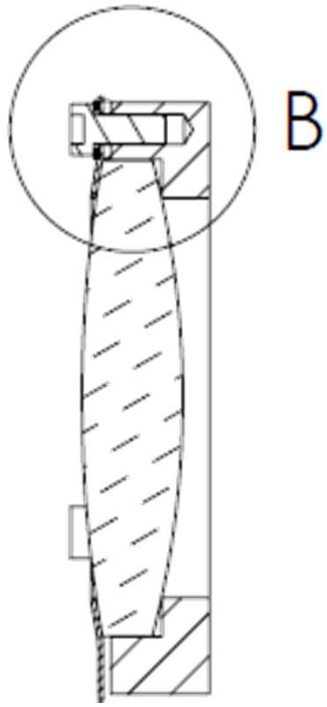
Lens retainer with flexure ring

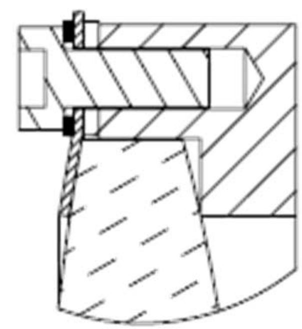
For larger lenses compliant spacers can be used under the mounting screws to help to distribute force more evenly around the optic being mounted

Provides good control of compliant preload

Increase part count and cost







DETAIL B

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Lens retainer with snap ring

- Low cost, simple design
- Common practice uses a ring with circular cross section. Once in place, virtually impossible to get out

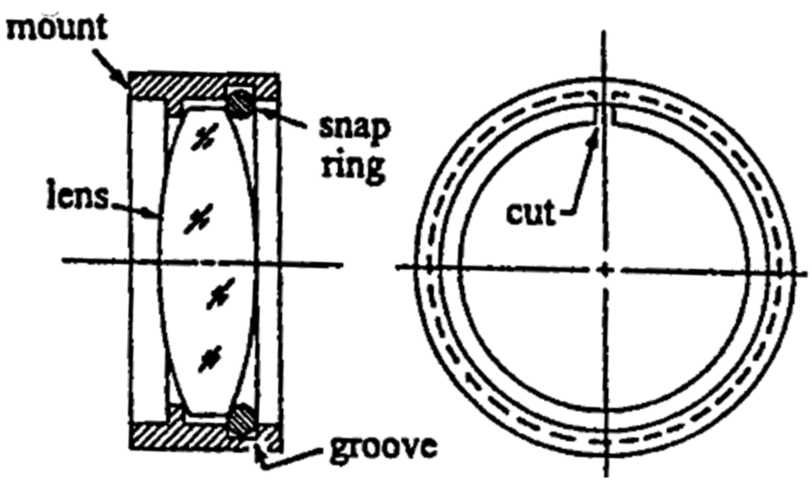
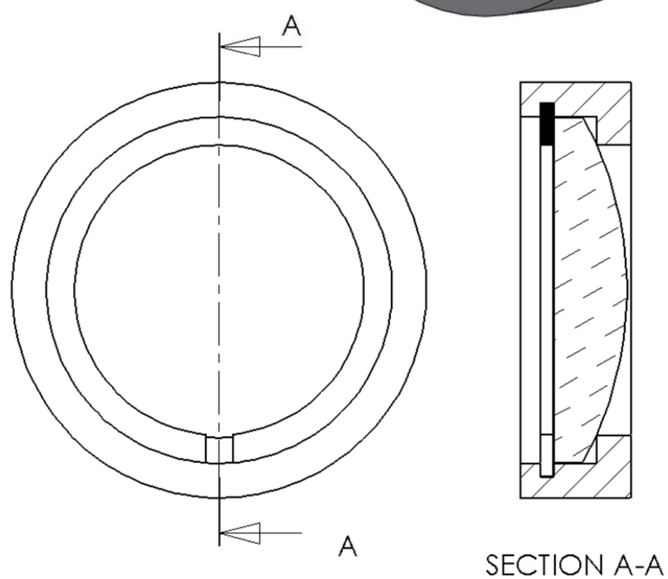


Figure 3.10



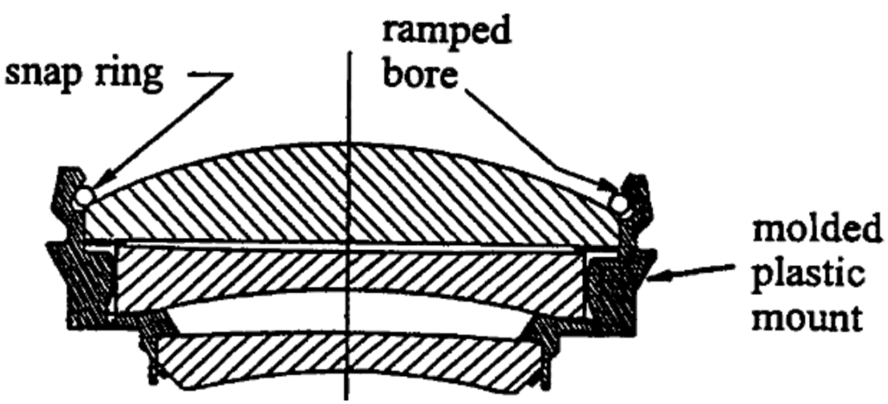


Figure 3.15

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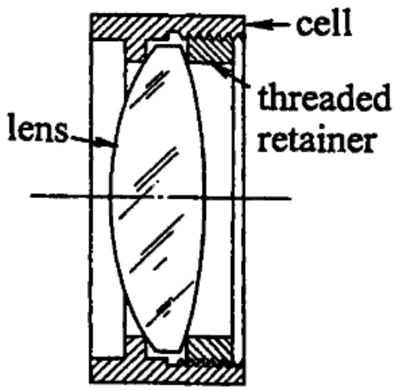
Lens retainer using threaded ring

- Easy design, easy to make
- Allows easy assembly and disassembly

Figure 3.17



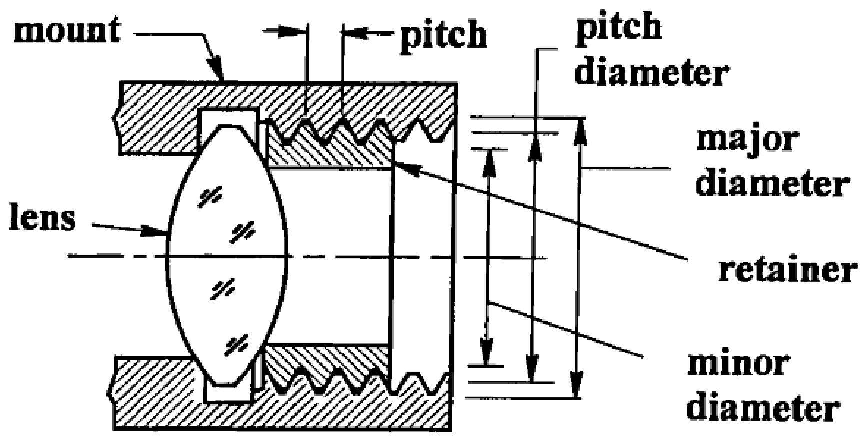
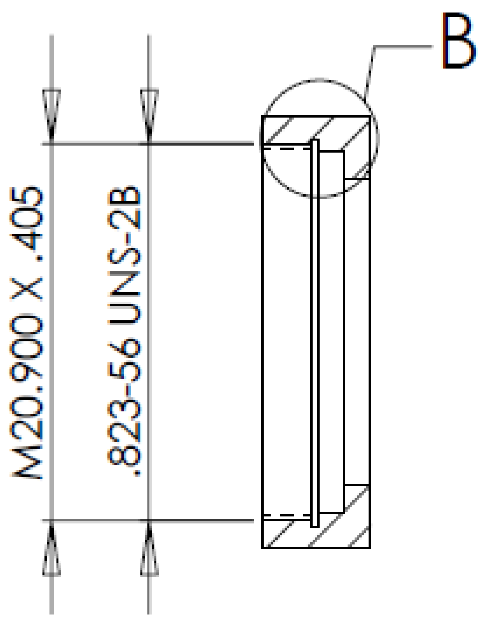
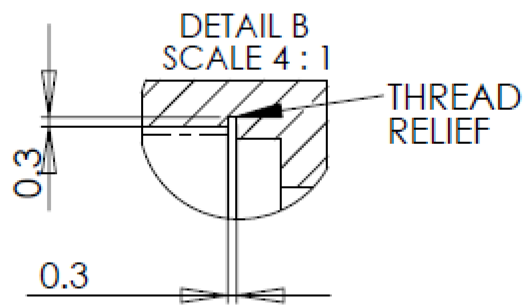
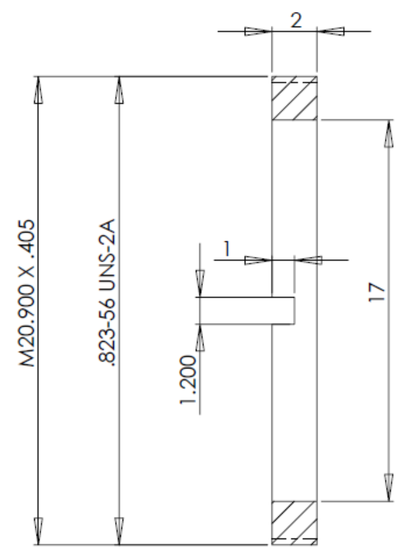


Figure 3.19







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Torque setting for retaining rings

- **The most common method for precision mounting of a lens uses the threaded retaining ring.**

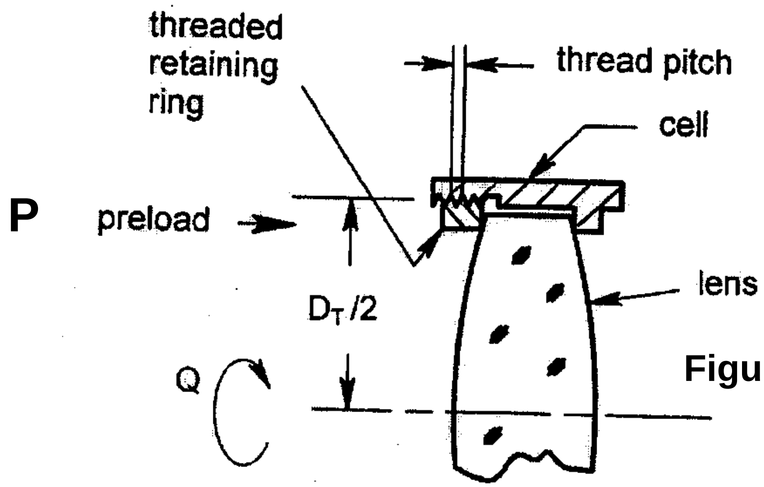

Figure 3.18

- **Eq. 3.34 (derived in Appendix C of the text) relates preload to torque applied to the ring.**

$$P = \frac{Q}{D_T\left(0.577\,\mu_M + 0.500\,\mu_G\right)} \qquad (3.34)$$

This is an approximation, primarily because we do not know the values for μ_M and μ_G. Common practice assumes

$$P = \frac{5Q}{D_T} \qquad (3.34a)$$

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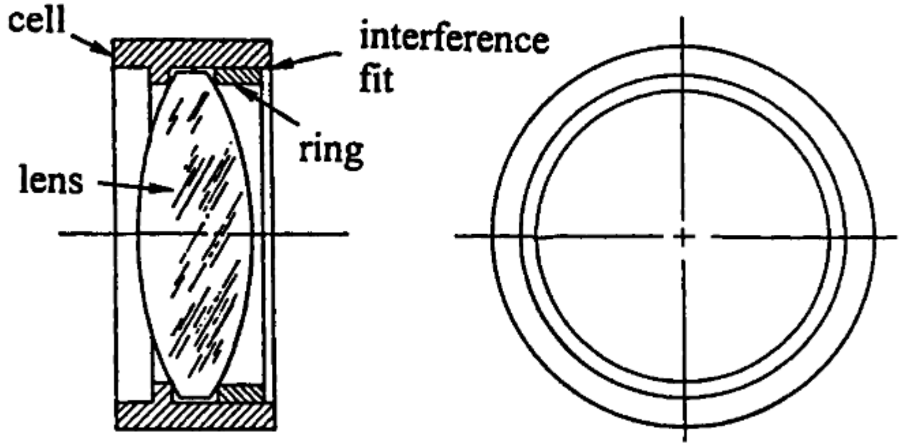
Lens retainer ring pressed in

- Easy design, low cost production
- Difficult to control preload
- Difficult or impossible to disassemble



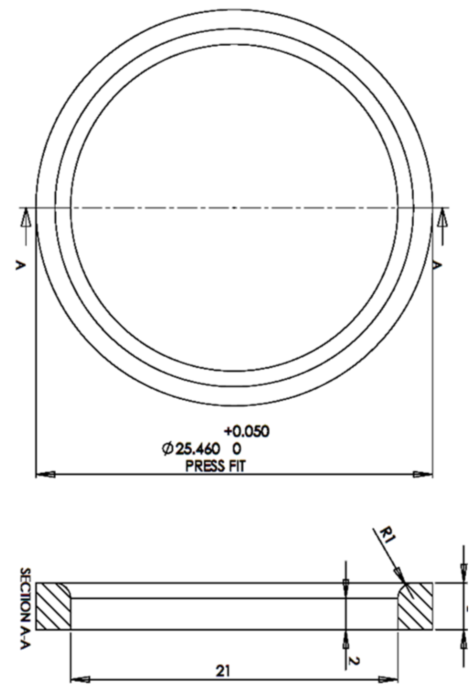


Fig. 3.16 A lens constraint design with a continuous ring pressed in place with en interference fit. (Adapted from Yoder.[1])

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Pot the lens in place

- Need to provide holes to inject adhesive
- Control adhesive flow during assembly. Don't get it on the optical surface

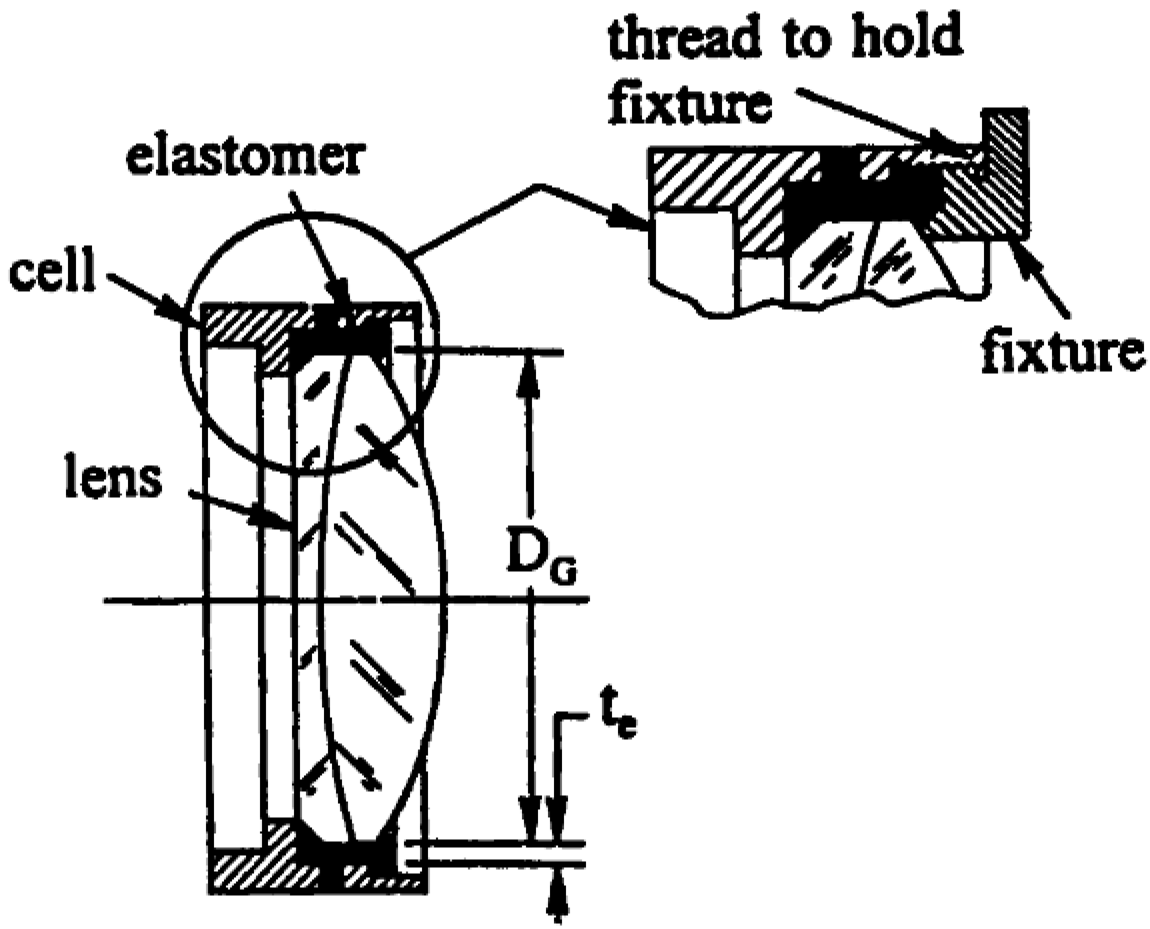

Figure 3.36

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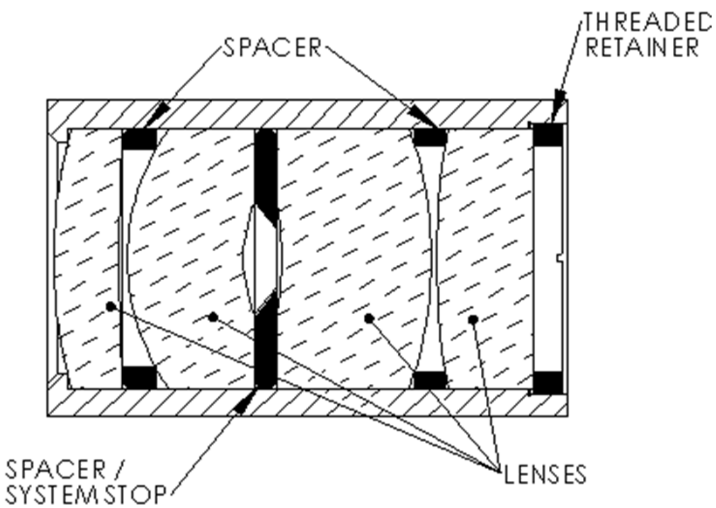
System assemblies : Barrels

- Barrels are usually aluminum, easy to machine
  - Stainless steel (416) gives better CTE match, can go to thinner sections
- Simplest barrel is a straight bore. All lenses are the same size. Low cost, high accuracy
- More complex barrels are needed for most optical designs
- Set machining tolerances to allow simple assembly.
- Maintain 0.001" radial clearance for assembly
  - This will also limit interference from thermal effects
- Readily achieve accuracy of 50 µm. Work harder and get to 25 µm
- For higher accuracy with this type of design
  - Provide centration adjustment based on rotation measurement, then pot lens
  - Provide spacing adjustment using shims



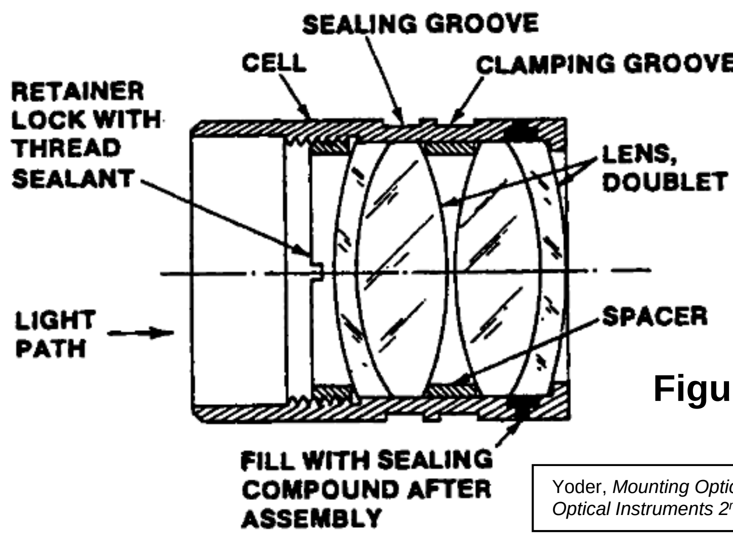


Figure 4.10

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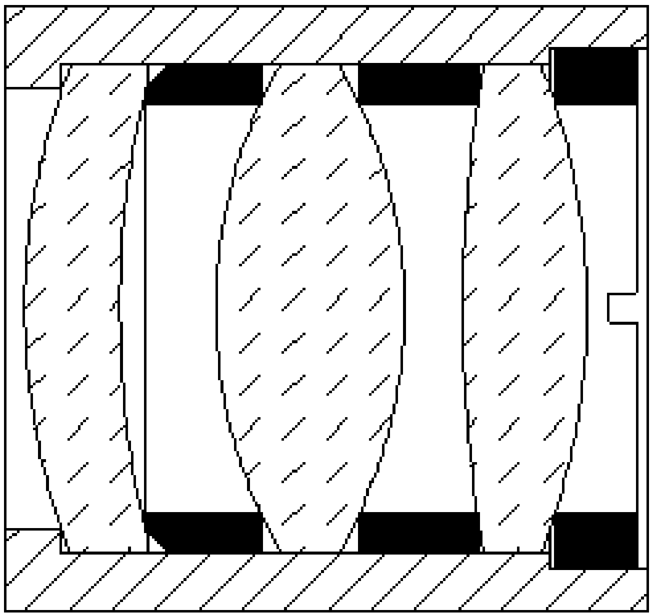
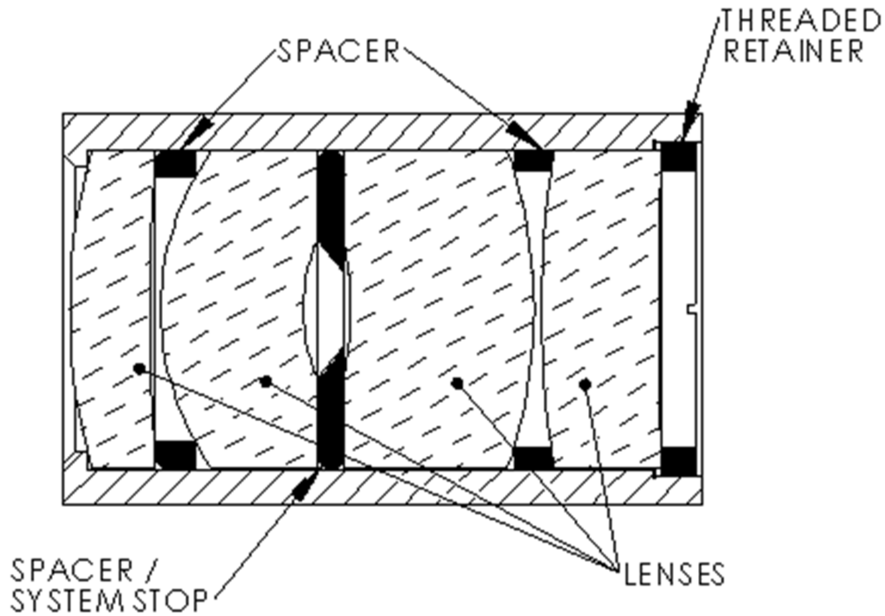
Easiest lens barrel

Lenses of Equal Diameter With Axial Position Defined by Spacers





- Precise bore is low cost operation
- Assembly is easy
- Rely on tolerances of lenses for centration
- Rely on tolerance of spacers for tilt, axial spacing

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Spacers

- Separate lenses with individual spacers
- Spacers must be centered also
- Spacer stack : beware of tolerance stack

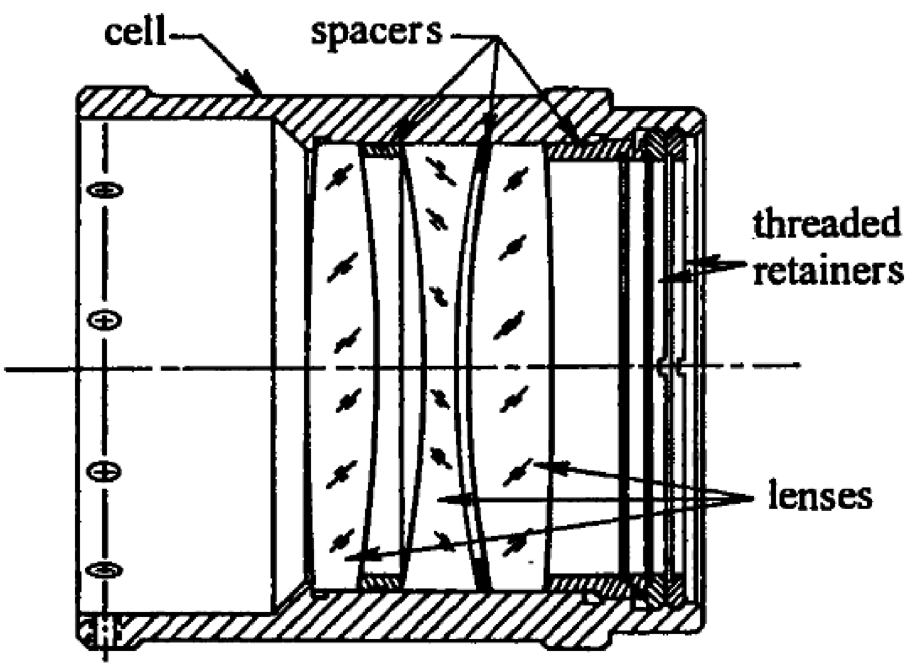

Figure 4.7

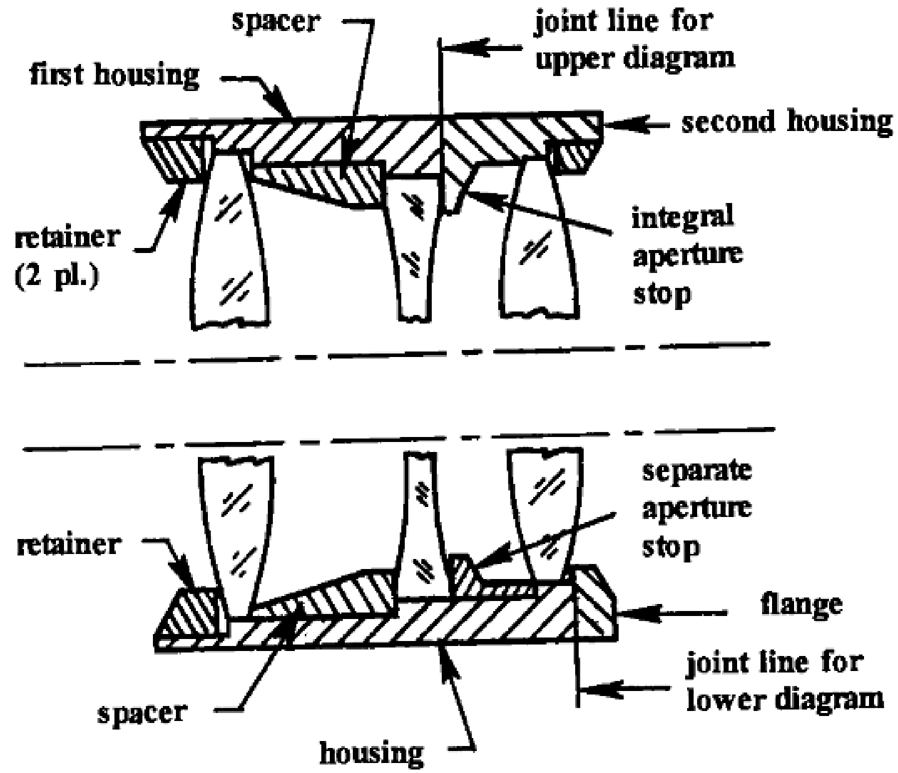

Figure 4.39

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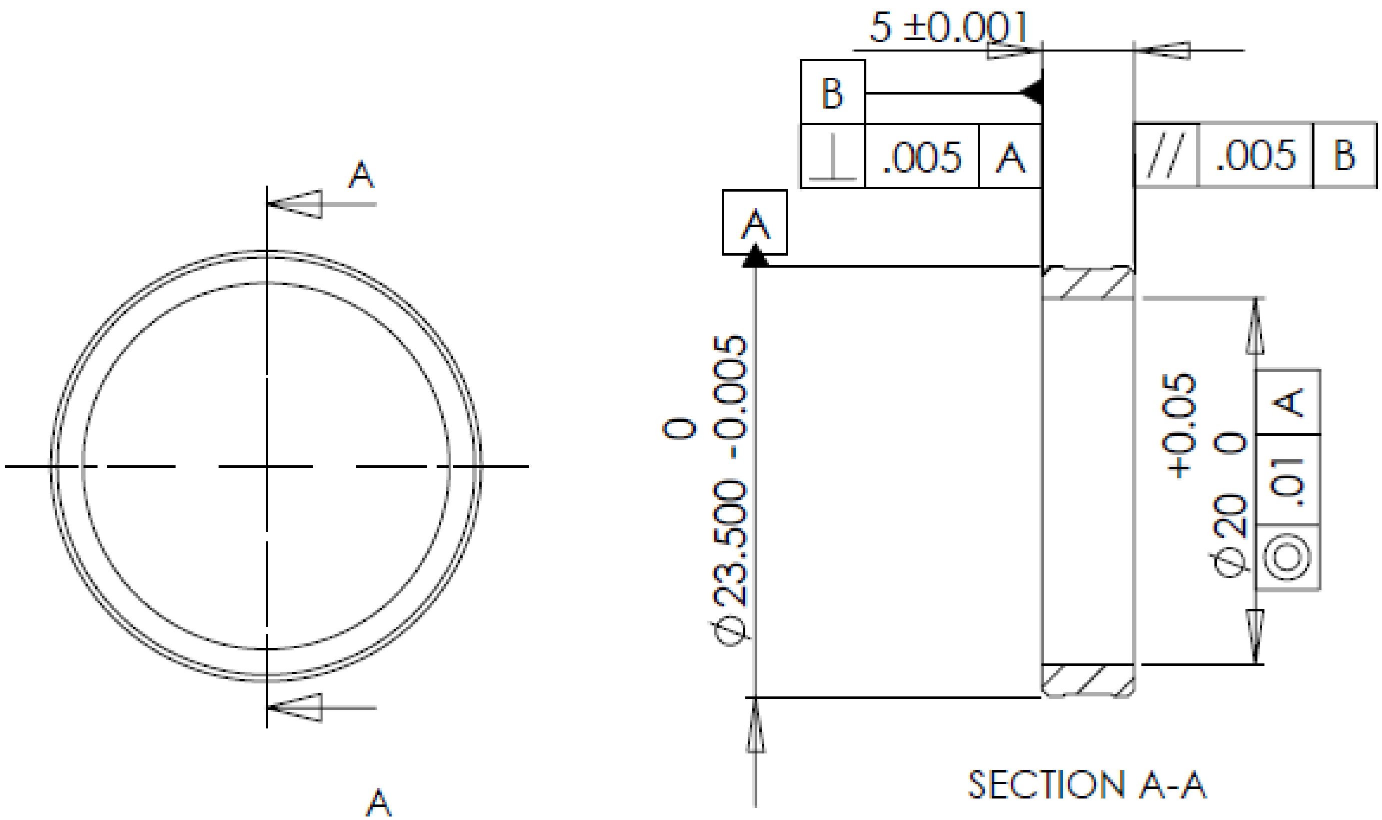
Precision spacer design



"Lathe" assembly

- Achieve high precision by customizing each barrel for the as-built lens elements
- Creates situation where parts are not interchangeable

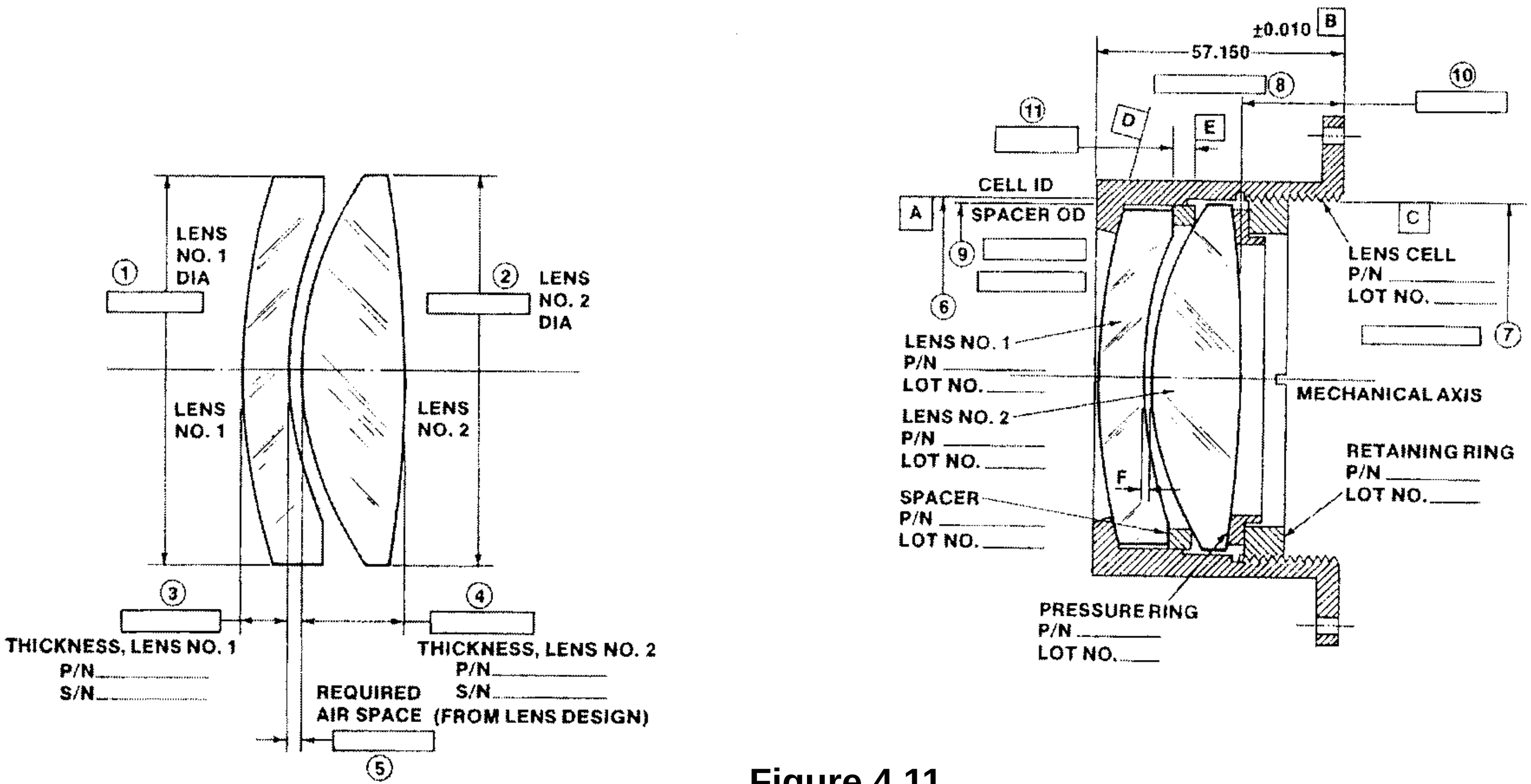


Figure 4.11

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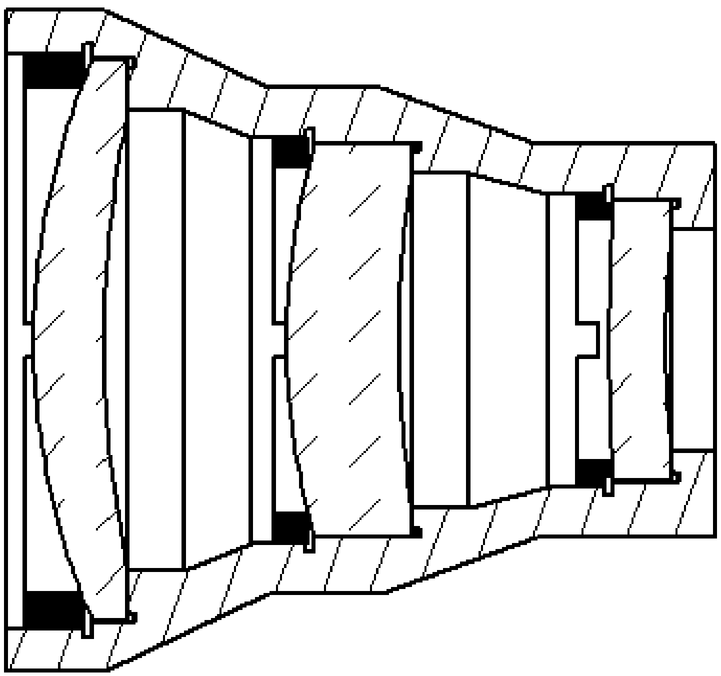
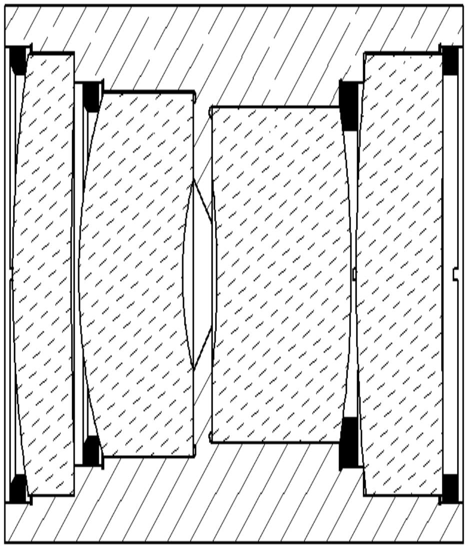
Lenses With Varied Diameters

- No spacers needed
- Lens positions defined by barrel machining
- Each lens needs retainer or adhesive





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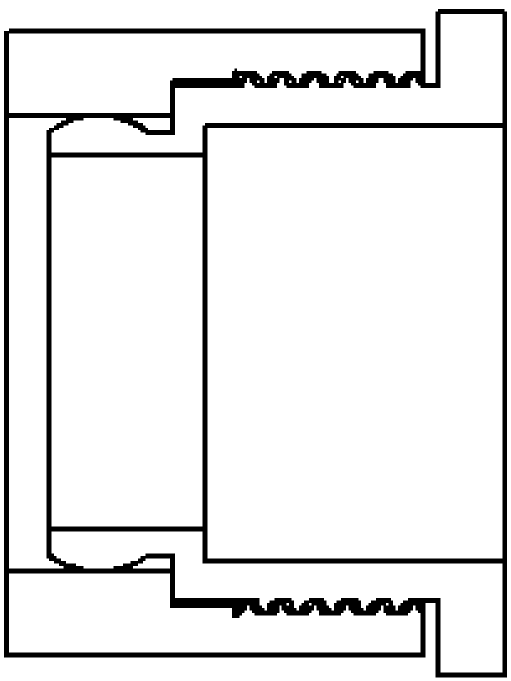
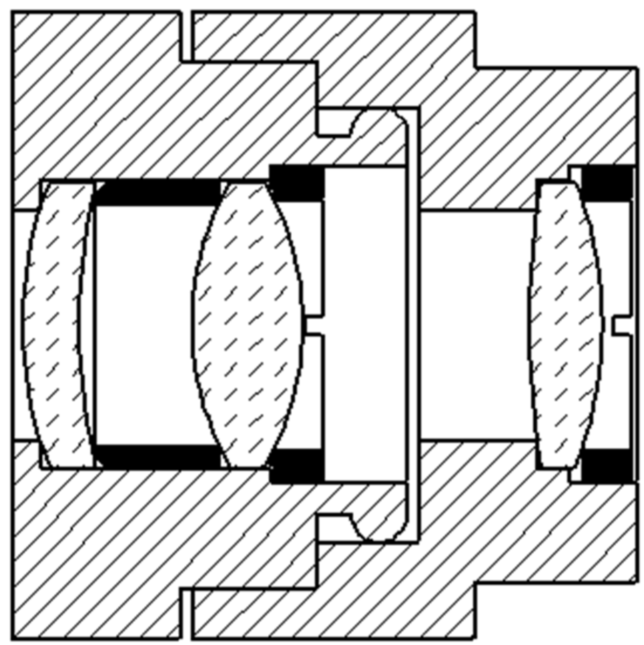
Two Part Lens Barrel

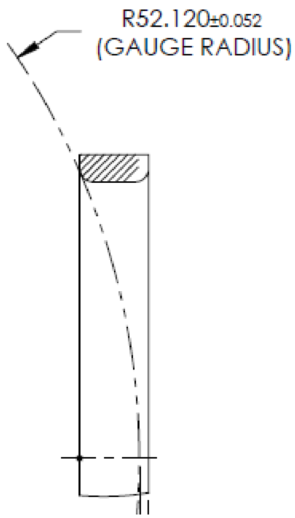
- **The centration is defined by the toroidal interface**
  - **Allows tight fit (+/-0.002 mm), yet allows assembly**
- **The axial position and tilt are defined with the plane surfaces**

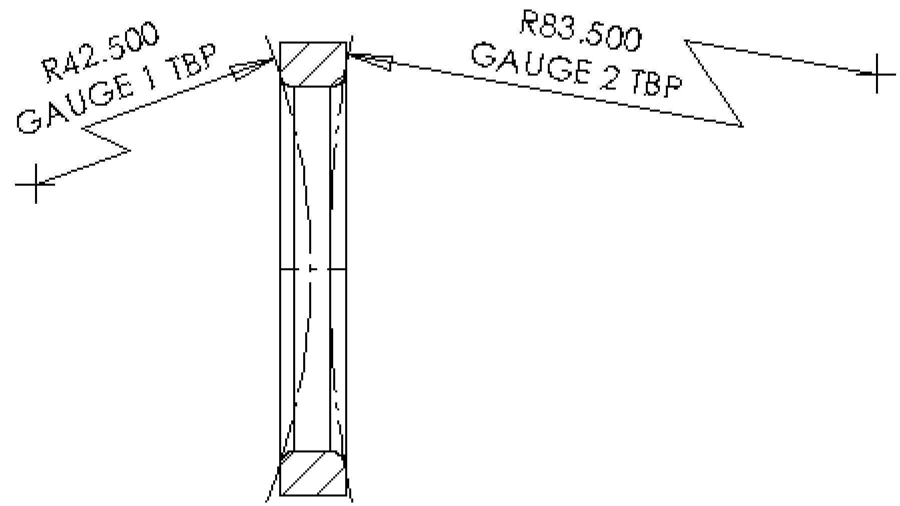




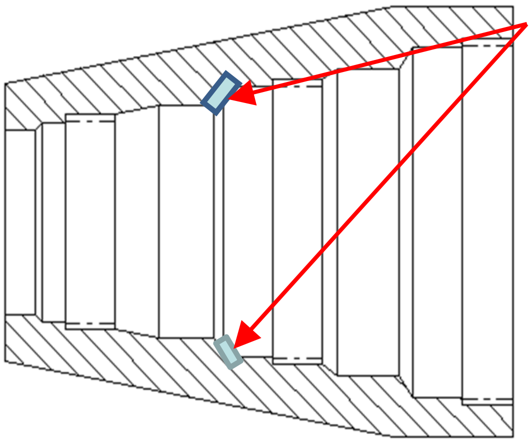
Use of gauges for lens barrels

- The use of a gauge to verify your manufactured parts can improve accuracy
- Sacrificial Lenses or Gauges Manufactured to the specified radius or shape can be used



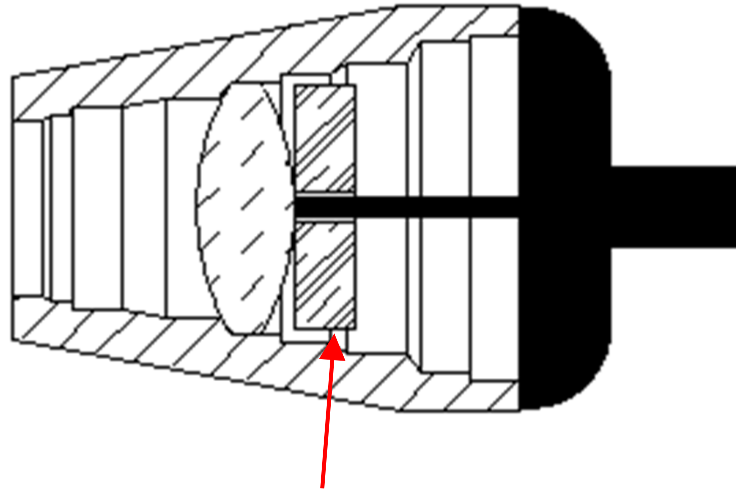


Manufacturing using a gauge

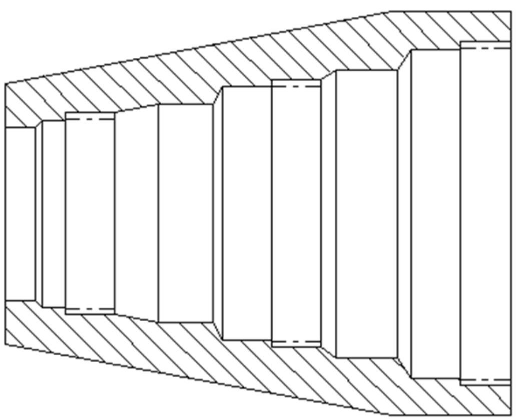


1. Initial Cut
Leave Material

2. Insert Gauge
Measure Position with
Depth Mic or CMM

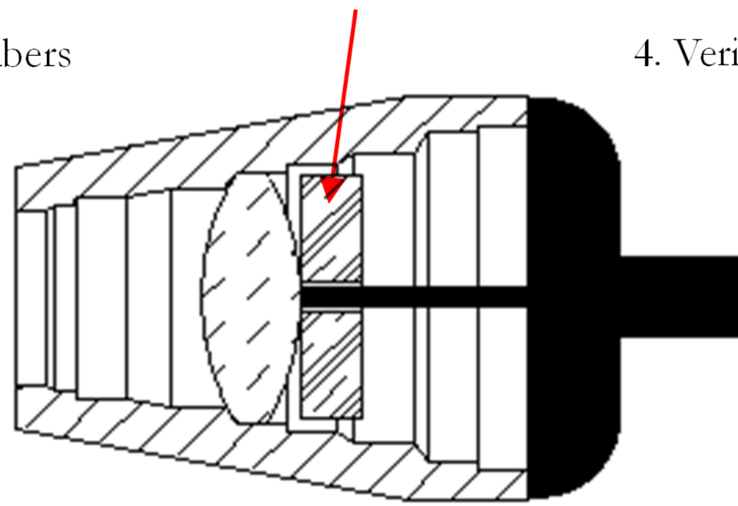


Teflon Centering Plug



3. Final Cut
By The Numbers

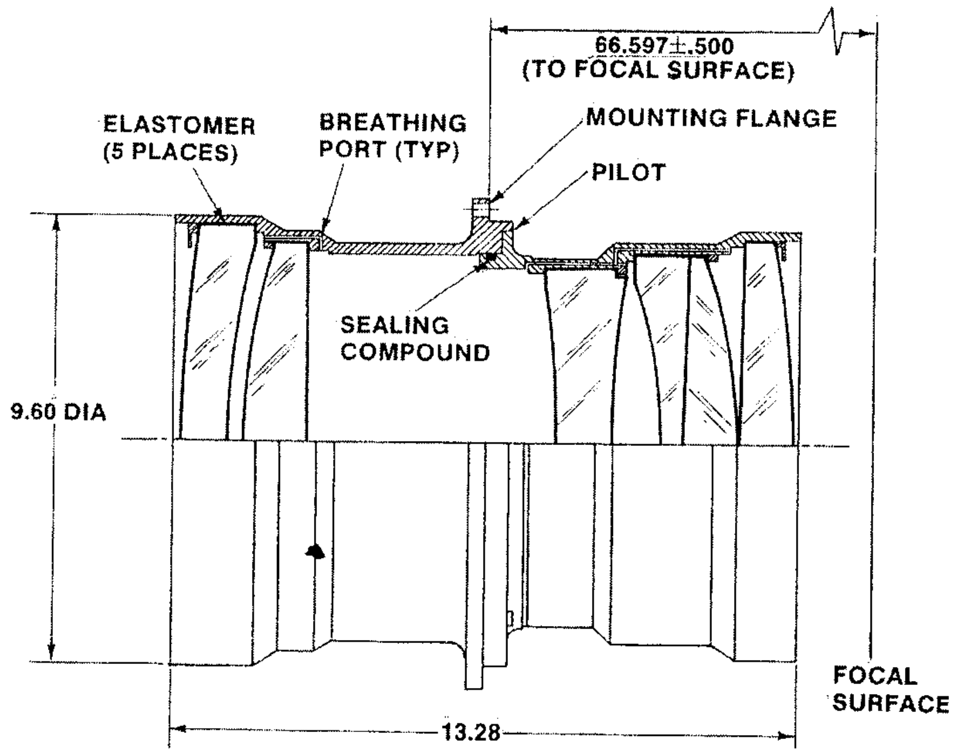
4. Verify Cut



Alignment of individual elements

- Achieve tighter tolerances by adjusting lens centration, rather than relying on machining tolerances
- Spin up lens system on air bearing, adjust lens centration and pot lenses in place

- **Another high performance aerial camera objective lens was designed to have elastomerically mounted lenses. Its EFL was 66 in. (1.67 m) and its relative aperture was f/8. Dimensions are inches.**



From Bayar (1981)

Figure 4.13

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

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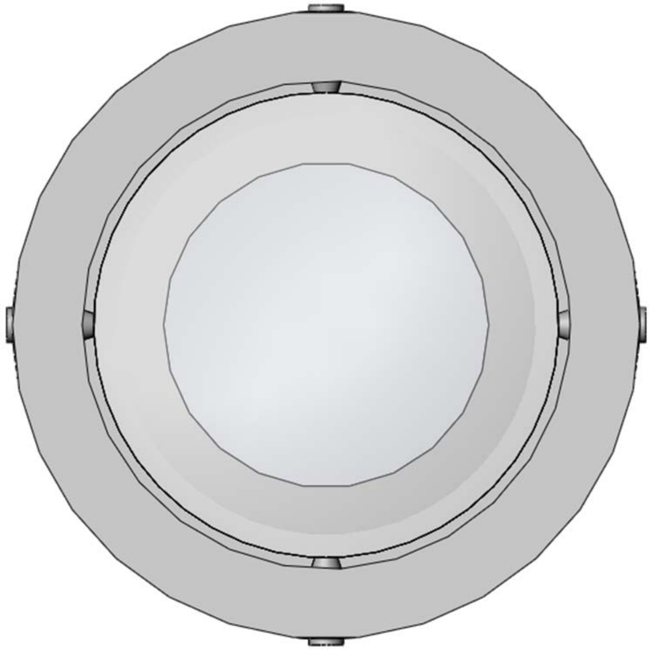
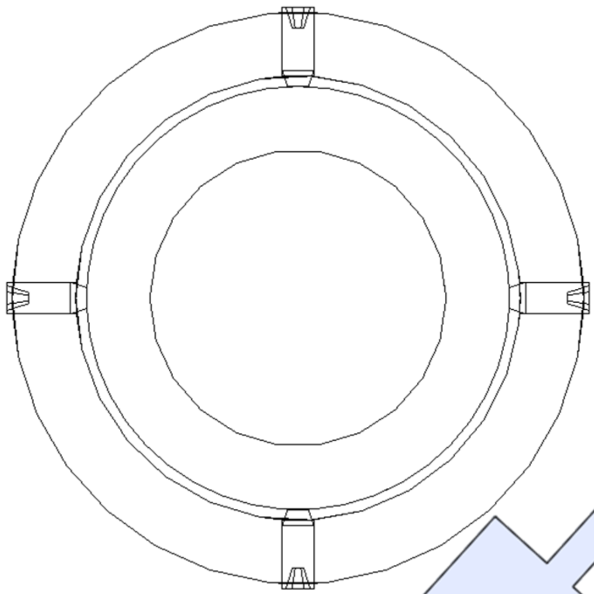
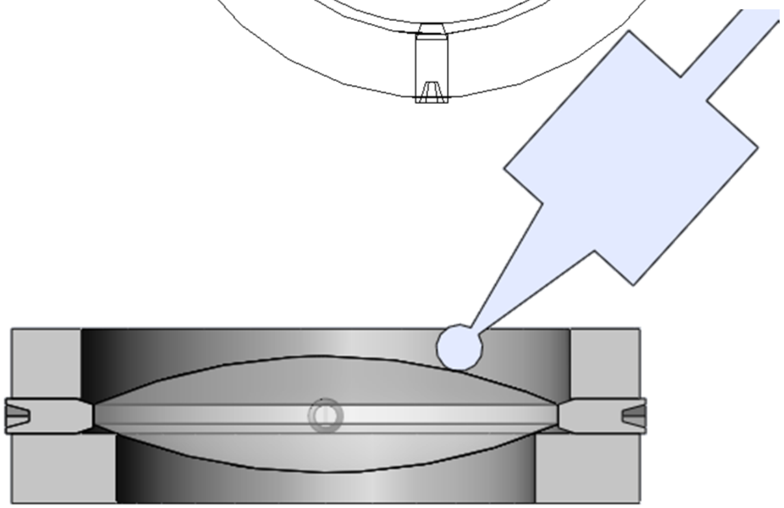
Alignment of elements

- Alignment with Push Screws
- Use mechanical or optical measurement of wobble as the barrel is rotated
- Once aligned, pot the element in place

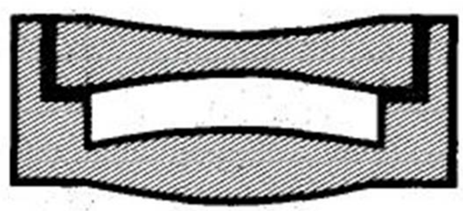


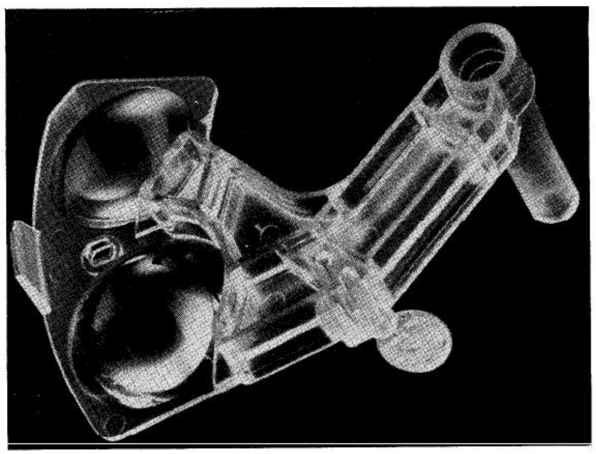




Plastic lenses

- Optical quality of plastic is inferior to glass
  - Dispersion
  - Stress birefringence
  - Hardness, climatic resistance
  - Stability (thermal, moisture)
- But plastic has important advantages
  - Plastic lenses are manufactured in large quantities by injection molding
    - Cost is $2-20k for tooling, then << $1 per part
  - Lightweight, half the density of glass
  - Ability to create complex shapes
    - Aspheric optical surfaces
    - Diffractive surfaces
    - Incorporate mounting features in the optic itself
    - More complex optical systems





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Groups of lenses

- Tolerances are always tighter for element within a group. Group-to-group alignment requirements are looser. Watch for this

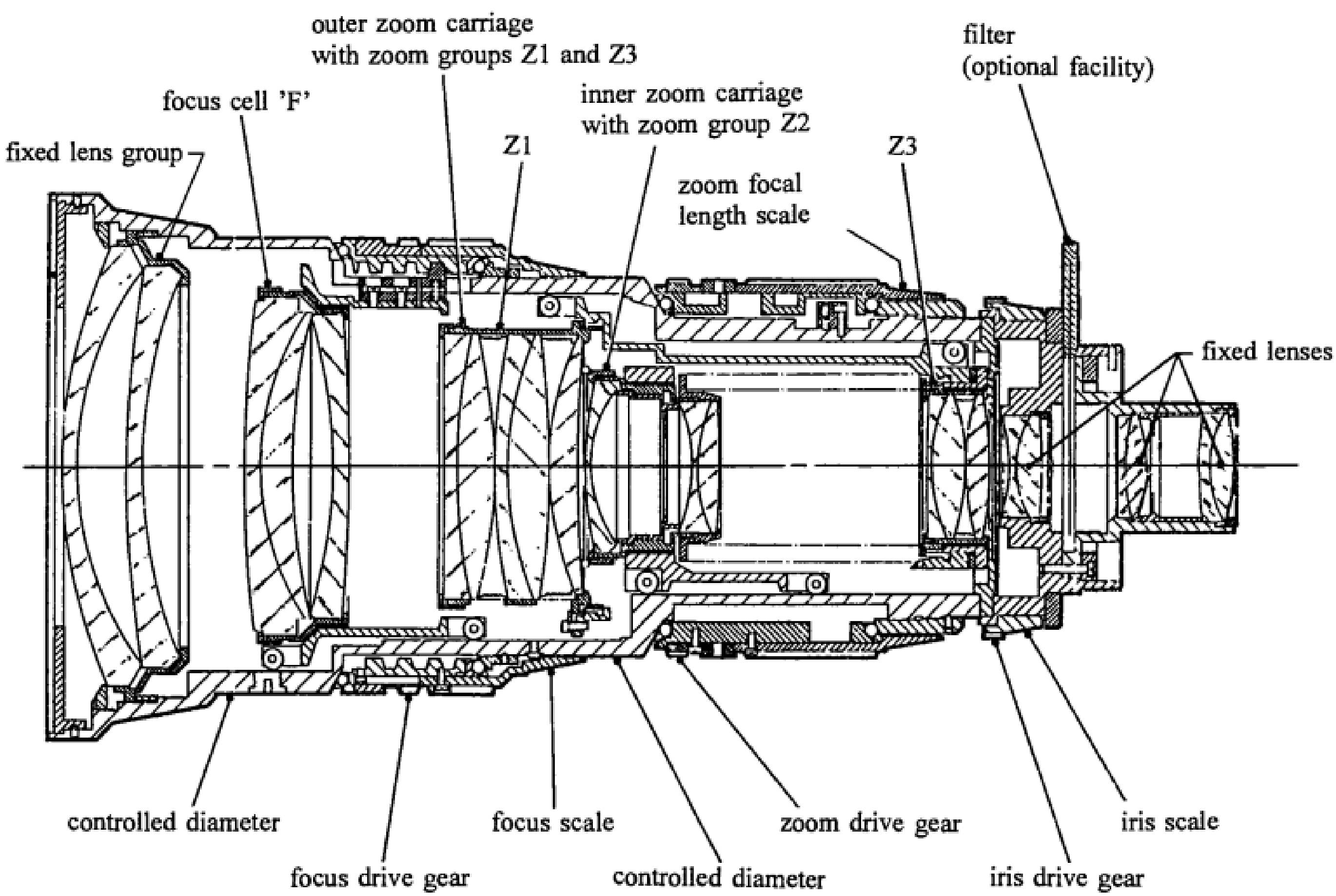
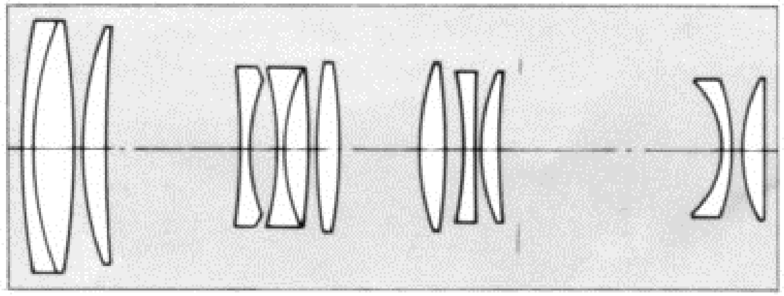
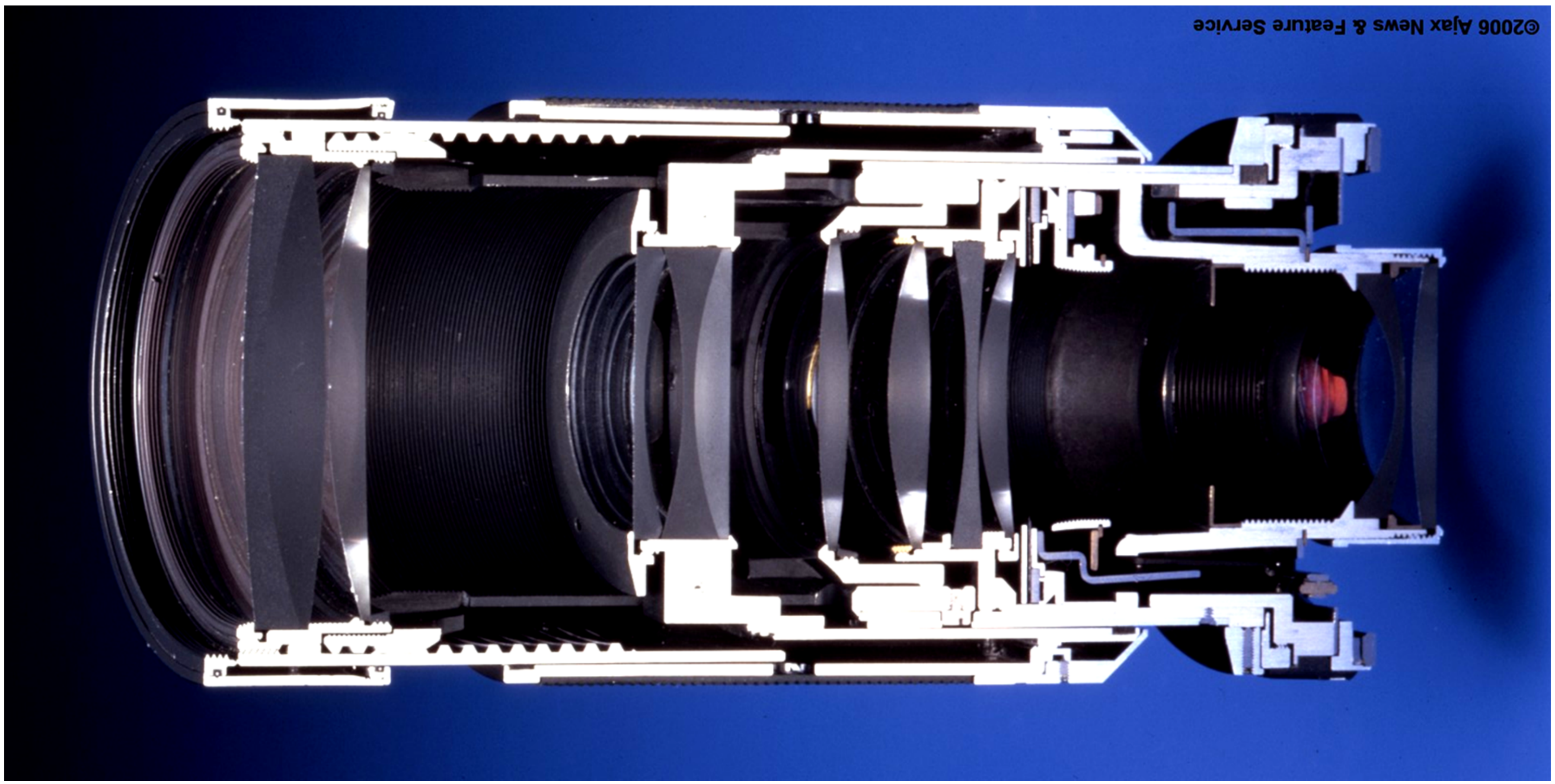


Fig. 4.37 Sectional view of a 20- to 100-mm (0.787- to 3.937-in.) focal length, f/2.8 zoom lens assembly. (From Ashton.[26])

From Yoder Mounting Optics in Optical Instruments 1st Edition
See Figure 4.52 in Yoder's 2nd Edition on pg 173 for more.

Example lens mount showing groups





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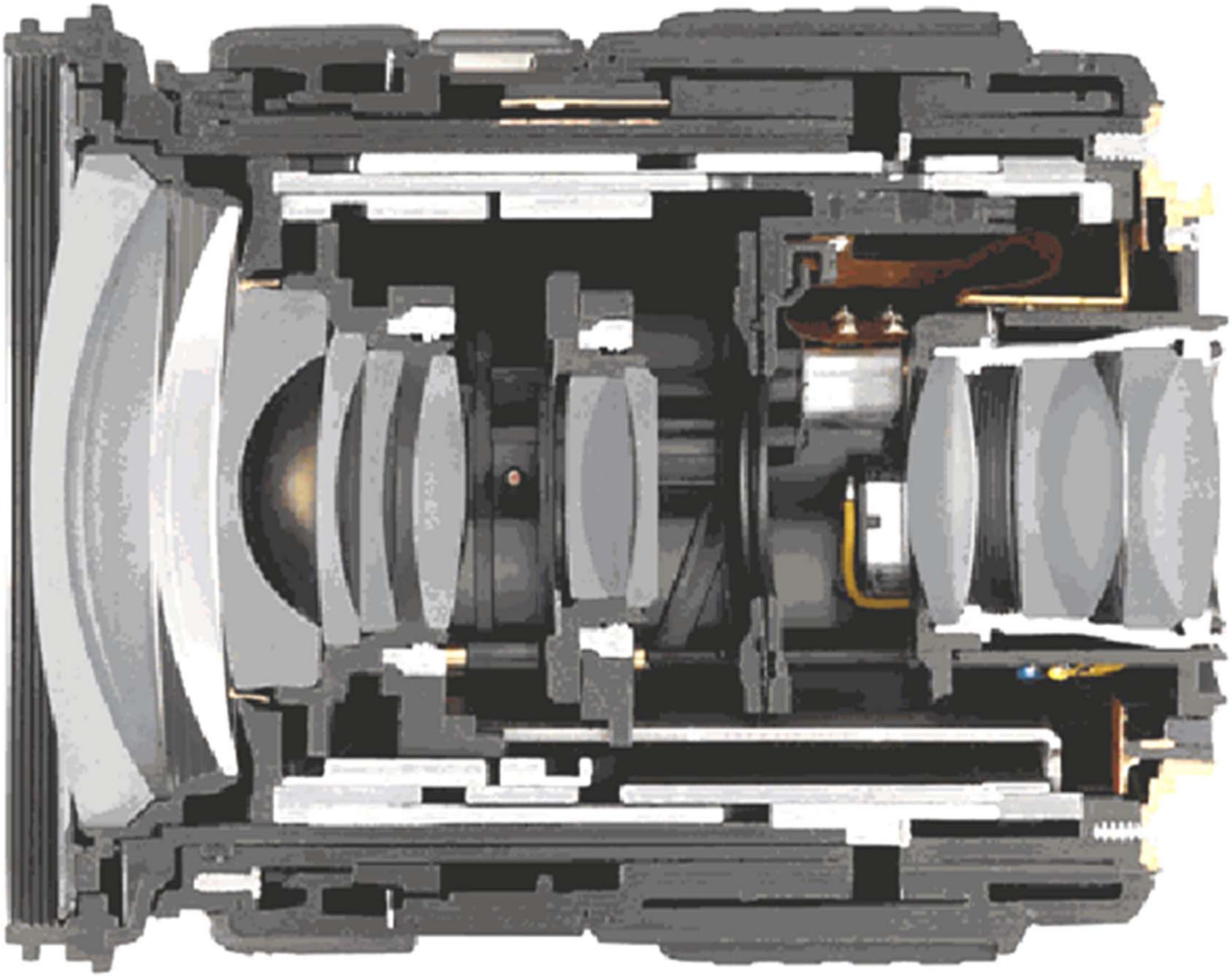
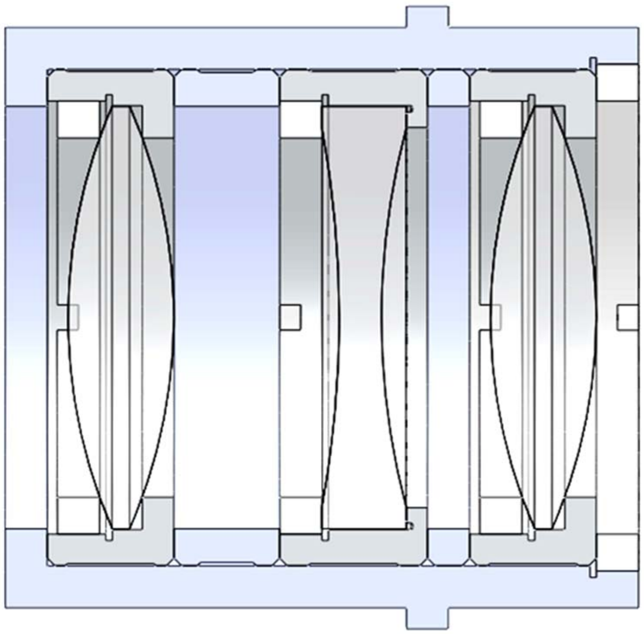
Multi-element lens in groups



http://www.kenrockwell.com

For higher precision, use subcells, stack up like poker chips

- Align lenses in subcell
  - Move lens to match mechanical datum, then pot
  - Pot lens in cell, spin up about optical axis, make final cut on mechanical surfaces
- Datum surfaces on subcells can be controlled to microns
- Barrel bore and shim spacers can be controlled to micron levels
- Subcells are stacked up in barrel like poker chips



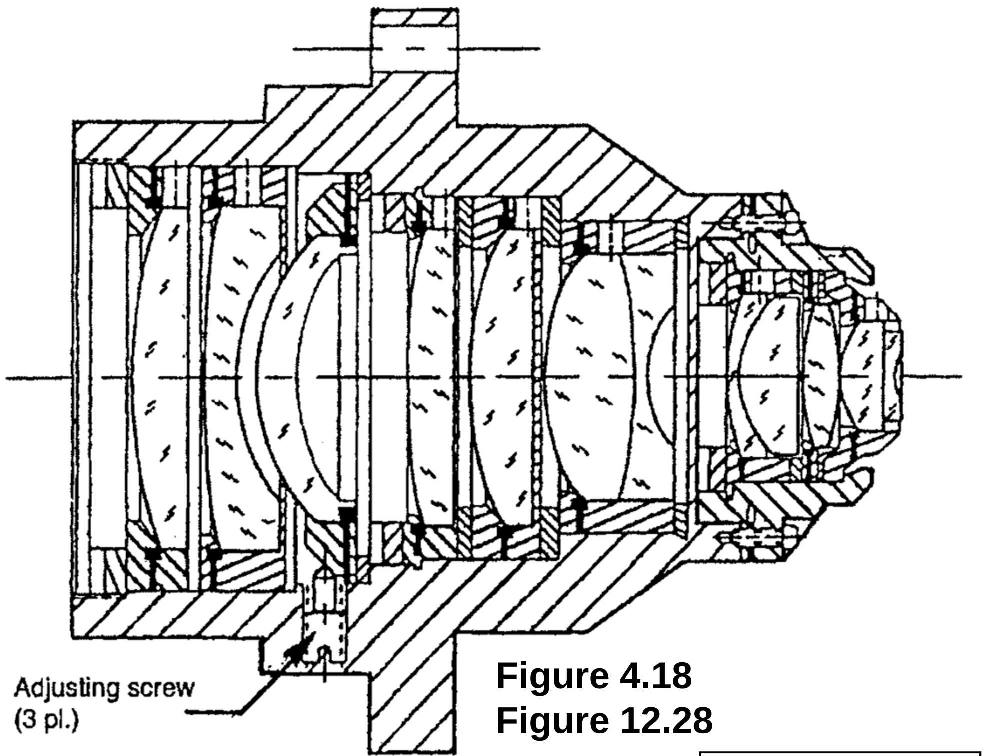


Figure 4.18
Figure 12.28

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

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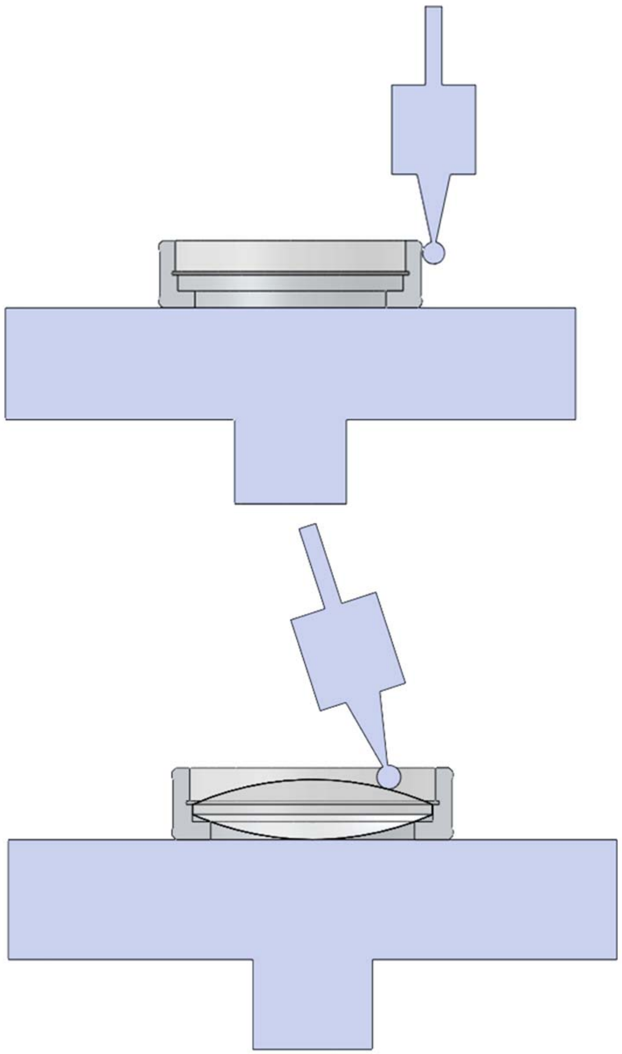
Alignment of lens into subcell



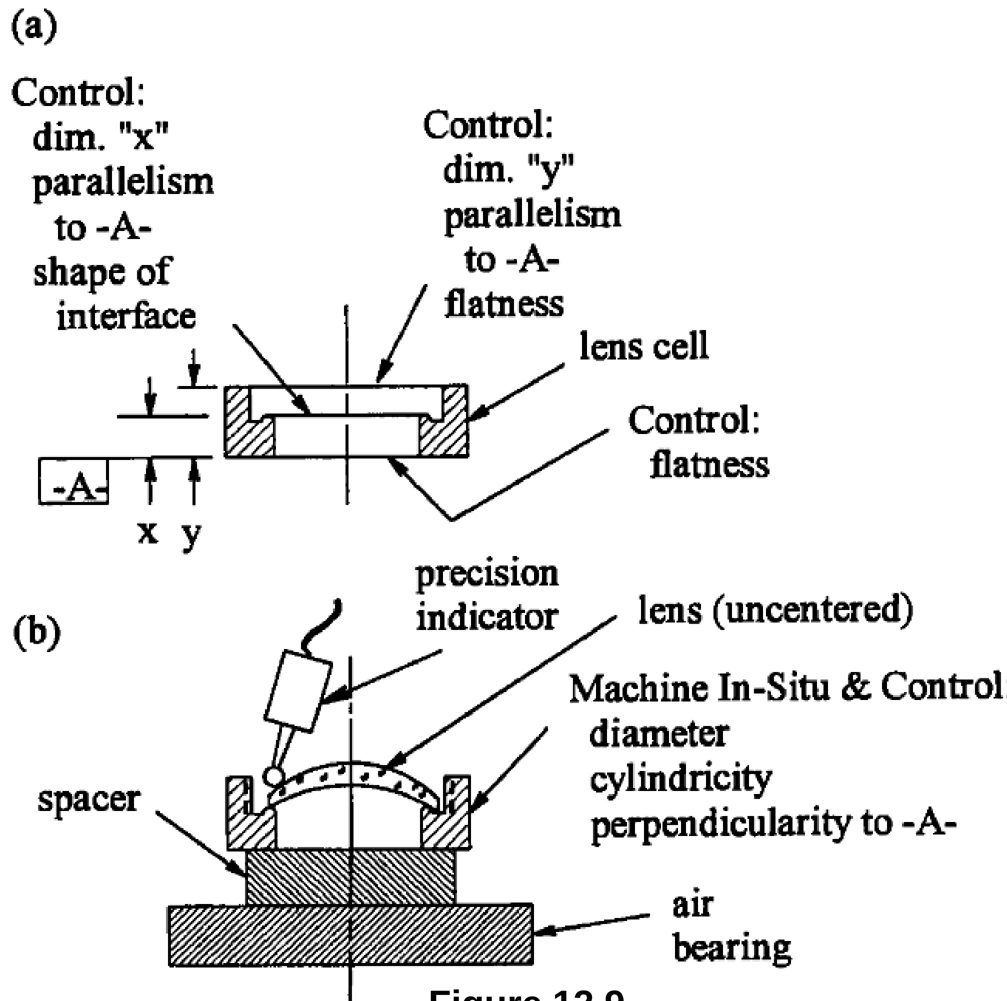


Figure 12.9

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Fine spacing adjustment using shims

- Alignment use of Shims

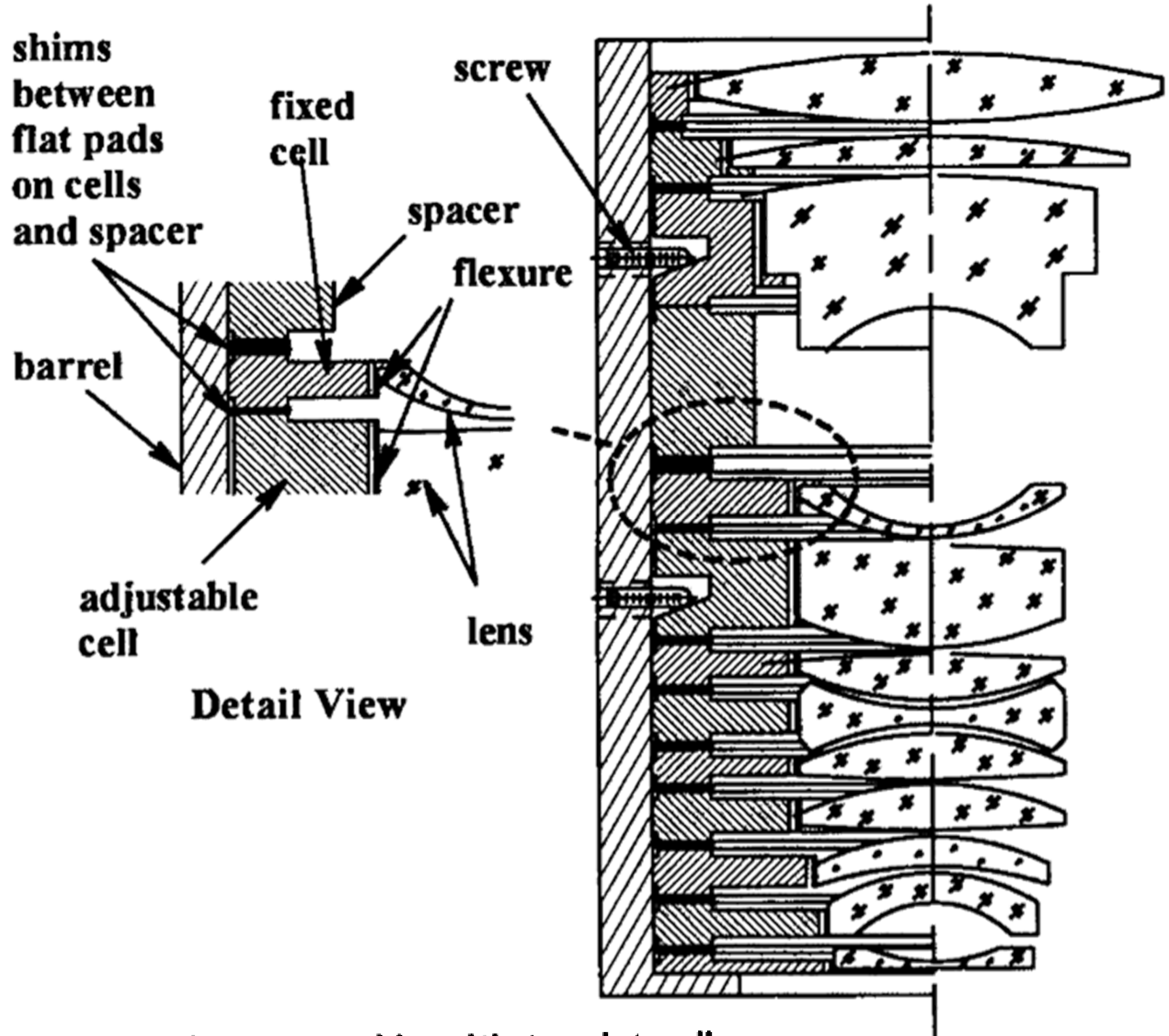


Fig. 12.29 Schematic partial section view of a lens assembly with two laterally adjustable cells. The lenses are assembled and aligned in their cells and the cells machined precisely to fit the barrel ID.

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Precision microscope objectives

- Alignment accuracy of 5 μm is typical, using precision subcells

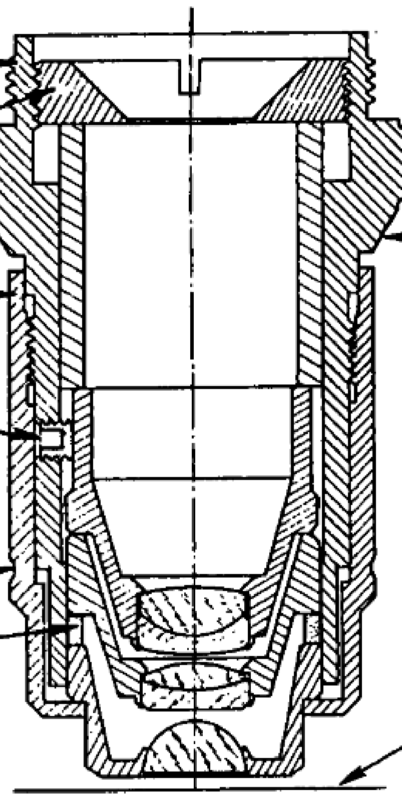


Fig. 12.18 Construction of a typical microscope objective. (Adapted from Benford.[7])

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Recap: Lens mounting methods

In order of increasing precision, complexity, and cost

- Straight barrel : All lenses same diameter
  - Simple low cost bore. Use spacers and retaining ring.
  - Easy assembly, can be automated
  - Precision is limited mostly be the precision of the elements, including stack up of errors
- Stepped barrel : Accommodate lenses with varying sizes
  - More complex machining. Use sharp contact for highest accuracy.
  - Easy assembly, can be automated
  - Precision is limited by the machining. 50 µm is common, 10 µm is possible.
- Add centration adjustment to elements using rotation + optical measurement
  - Labor intensive assembly
  - Achieve 10 µm easily, 1 µm is possible
- Spacing adjustment with shims
  - Choose custom spacer based n measurement
  - Labor intensive assembly
  - Achieve 25 µm easily, 5 µm is possible
- Spacing compensation using *as-built* data
  - Labor intensive assembly
  - Achieve 25 µm easily, 5 µm is possible
- Mount elements in sub-cell, stack up for assembly
  - Very labor intensive, expensive
  - Achieve 10 µm easily, <1 µm is possible

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Thermal stress for bonded lenses

- Achieve low stress mount by controlling the bond dimension
- As temperature increase, metal expands more then glass, opening up the gap.
- Use adhesive with high CTE that expands with the correct proportion to fill the gap in a stress-free state

● **The elastomeric ring mounting constrains the lens without preload. It is nearly "stress free."**

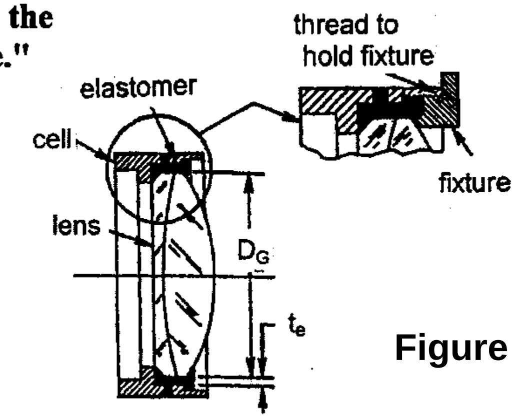


Figure 3.36

● **The annular thickness t_e is important. Here are two equations used to define it:**

- **Bayar (1981)**

$$t_{e\,\text{Bayar}} = \left(\frac{D_G}{2}\right)\frac{(\alpha_M - \alpha_G)}{(\alpha_e - \alpha_M)} \tag{3.59}$$

Herbert (2006) recommended use of α_e* here instead of the bulk CTE for the elastomer

where:

$$a_e^* = \frac{\alpha_e(1+\nu_e)}{(1-\nu_e)}. \tag{3.60}$$

- **Meunch [per Vukobratovich (2000)]**

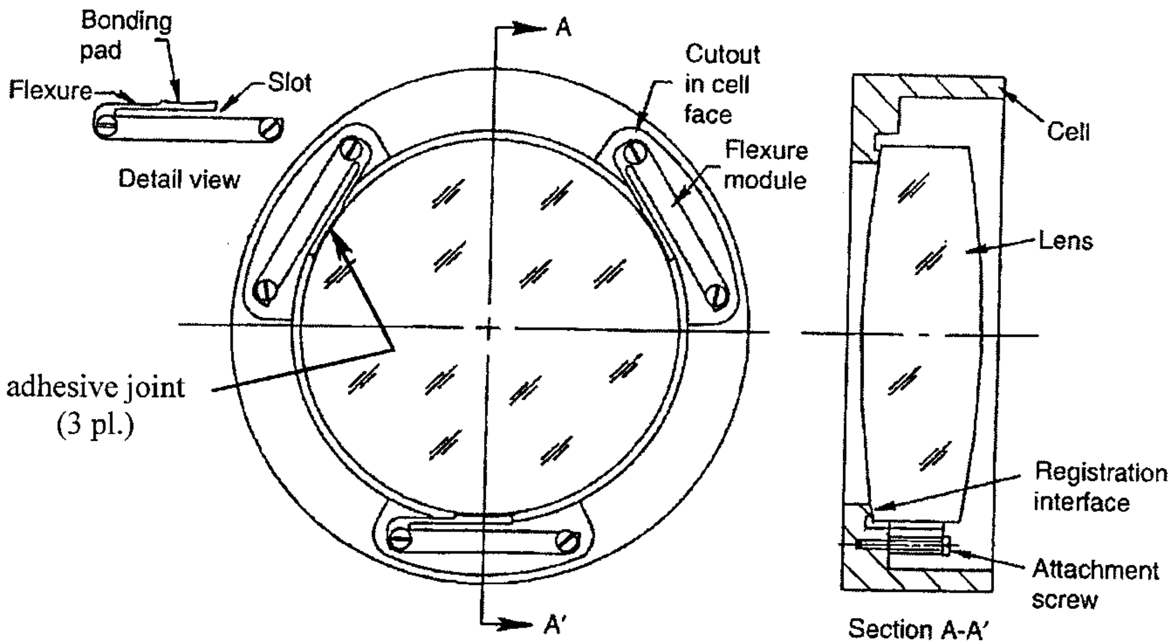
$$t_{e\text{Muench}} = \left(\frac{D_G}{2}\right)\frac{(1-\nu_e)(\alpha_M - \alpha_G)}{\left[\alpha_e - \alpha_M - (\nu_e)(\alpha_G - \alpha_e)\right]} \tag{3.61}$$

41

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*

Provide thermal isolation using radial flexures

- **Lenses can be mounted on three or more radially-acting flexures to accommodate dimensional changes due to temperature changes. This example uses separate flexures attached and pinned to the cell.**



From Ahmad and Huse (1990) **Figure 3.43**

Yoder, *Mounting Optics In Optical Instruments 2nd Ed.*