Mounting of Optical Components

Windows, filters, and prisms

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Mounting of windows, domes, and filters

- Optical and mechanical issues with windows
- Example designs for window mounts
- Domes
- Filters, issues and examples

Windows: protect the inside from the outside

- **Choose a material that holds up to the outside environment**
- **Fused silica is a good strong glass**
- **Sapphire provides extra strength, but beware of birefringence**
- **In many cases, plan to use a low cost sacrificial window. Replace as needed**
- **Coatings are frequently more fragile than the window.**

Windows and filters

- **Windows usually are plane parallel plates of glass, fused silica, crystalline material, or plastic used to isolate the interior of an instrument from the outside environment.**
- **Deep meniscus-shaped windows are called shells or domes**
- **Optomechanical properties of concern include**
  - **Safety (strength from rupture)**
  - **homogeneity**
  - **wedge angle**
  - **surface figure**
  - **sealing provisions**
  - **bowing due to pressure differential**
  - **temperature gradients**
  - **impact and erosion resistance**
  - **loss of strength due to surface defects.**
- **Optical filters may be considered special windows made of material with selective specular transmission characteristics or coated for selective transmission vs wavelength.**

Optical issues for mounting windows

- Optical transmission vs. wavelength (materials and coatings)
- Transmitted wavefront irregularity
  - The transmitted wavefront for a window is very weekly coupled to distortion in the window.
  - Wavefront error is driven by surface form errors and refractive index inhomogeneity

$$\Delta W = \sqrt{\left(\Delta S_1 (n-1)\right)^2 + \left(\Delta S_2 (n-1)\right)^2 + \left(\Delta n \cdot t\right)^2}$$

Where ΔS_1, ΔS_2 = rms surface irregularity from each side of the window
Δn = rms refractive index inhomogeneity
t = window thickness

- Stress causes birefringence in most materials. Determine retardance as:

$$\Delta W_P = \frac{K \cdot t \cdot \sigma}{\lambda}$$

ΔW_P is wavefront retardance between principal polarizations in waves
K is stress-optic coefficient of the glass, typically ~-2 to 4 x 10^{-12} Pa^{-1}
σ is the difference between maximum and minimum principal stress in the glass
t is thickness of the optic, or of the stressed region
λ is wavelength of the light

Rule of thumb: birefringence of 1 nm/cm for 5 psi stress (assume K = 3E-12 Pa^{-1})

Stress optic coefficient for optical materials

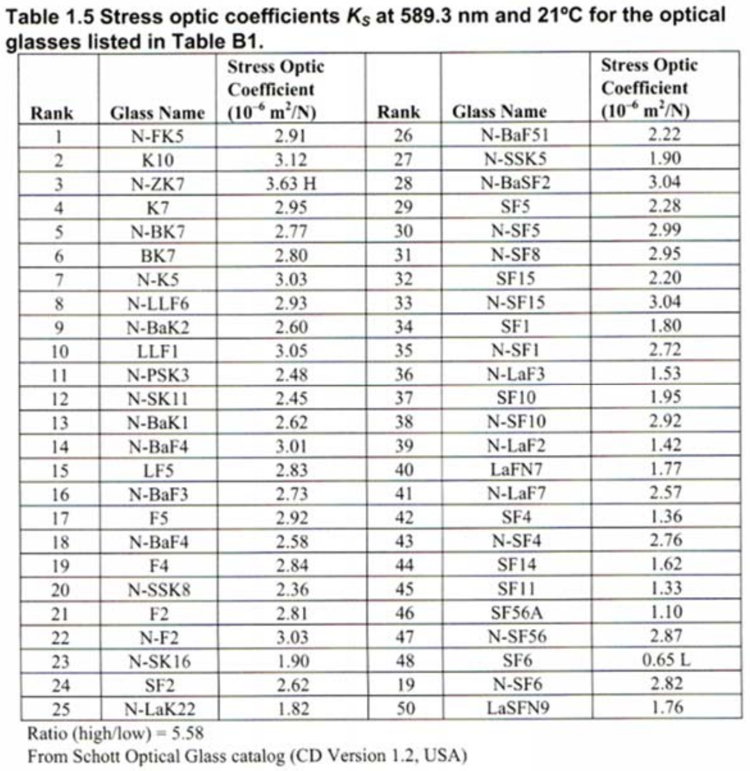


Table 1.5 Stress optic coefficients K_S at 589.3 nm and 21°C for the optical glasses listed in Table B1.

Rank	Glass Name	Stress Optic Coefficient (10^{-6} m^2/N)	Rank	Glass Name	Stress Optic Coefficient (10^{-6} m^2/N)
1	N-FK5	2.91	26	N-BaF51	2.22
2	K10	3.12	27	N-SSK5	1.90
3	N-ZK7	3.63 H	28	N-BaSF2	3.04
4	K7	2.95	29	SF5	2.28
5	N-BK7	2.77	30	N-SF5	2.99
6	BK7	2.80	31	N-SF8	2.95
7	N-K5	3.03	32	SF15	2.20
8	N-LLF6	2.93	33	N-SF15	3.04
9	N-BaK2	2.60	34	SF1	1.80
10	LLF1	3.05	35	N-SF1	2.72
11	N-PSK3	2.48	36	N-LaF3	1.53
12	N-SK11	2.45	37	SF10	1.95
13	N-BaK1	2.62	38	N-SF10	2.92
14	N-BaF4	3.01	39	N-LaF2	1.42
15	LF5	2.83	40	LaFN7	1.77
16	N-BaF3	2.73	41	N-LaF7	2.57
17	F5	2.92	42	SF4	1.36
18	N-BaF4	2.58	43	N-SF4	2.76
19	F4	2.84	44	SF14	1.62
20	N-SSK8	2.36	45	SF11	1.33
21	F2	2.81	46	SF56A	1.10
22	N-F2	3.03	47	N-SF56	2.87
23	N-SK16	1.90	48	SF6	0.65 L
24	SF2	2.62	19	N-SF6	2.82
25	N-LaK22	1.82	50	LaSFN9	1.76

Ratio (high/low) = 5.58
From Schott Optical Glass catalog (CD Version 1.2, USA)

Mechanical issues for mounting windows

- Provide seal
  - Pot window in place using elastomer
  - Solder window in place for vacuum
  - Use O-rings
- Choose material and thickness to limit stress to < 25% of glass strength (Safety Factor > 4)

$$\sigma_{\max} \cong \frac{1}{4}\left(\frac{D}{t_w}\right)^2 \Delta P$$

Where:

$\sigma_{\max}$ is maximum glass stress in the center of the window on the low pressure side

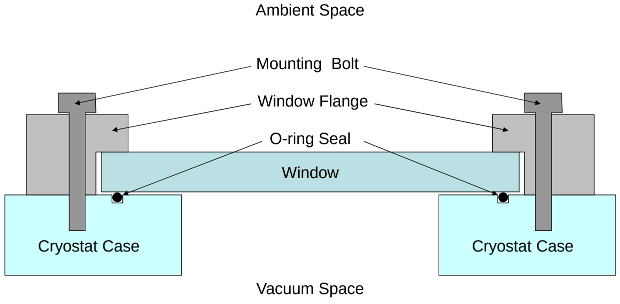
t_w = the window thickness

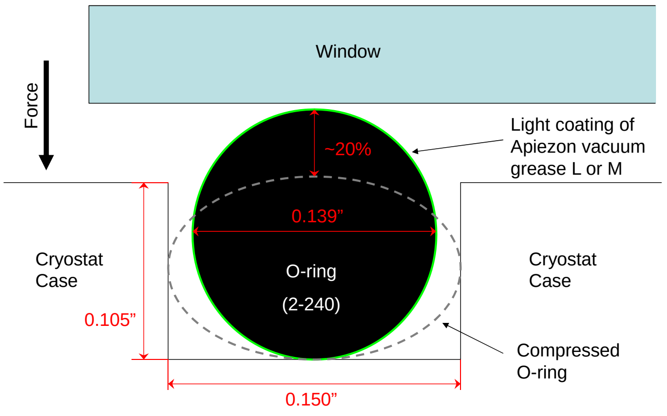
D = the window diameter (D/t_w is the aspect ratio)

ΔP = the pressure differential across the window

- In many cases, it will cost very little to increase the window thickness much beyond that needed. This provides margin for unexpected mishaps.

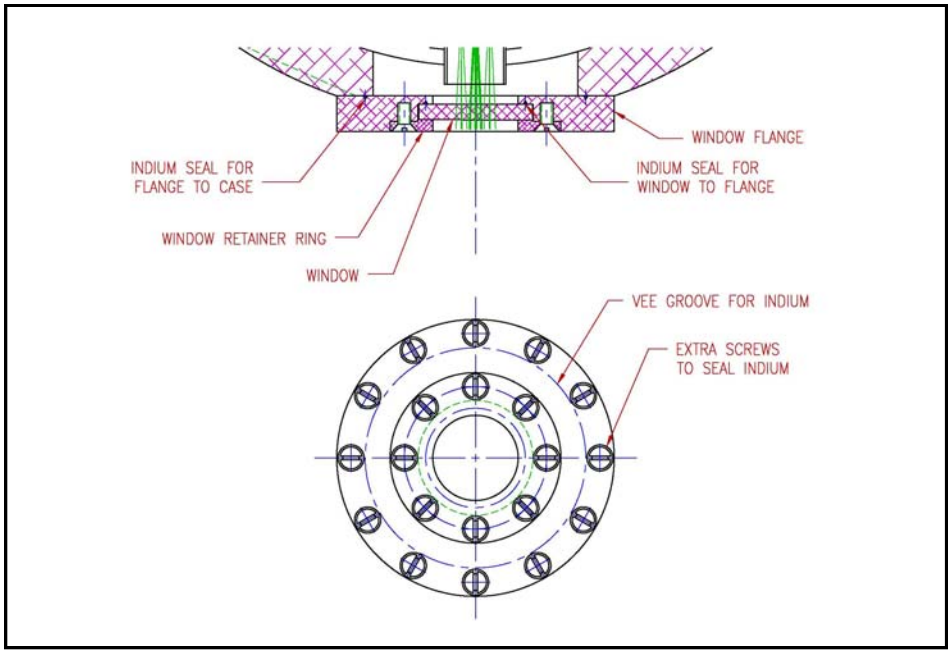
Mounting vacuum widows using O-rings





Indium seal for cryogenics

- **Indium has good cold-flaw characteristics, maintains seal at low temperature (elastomers become hard)**
- **Use indium wire, multiple wraps or make casting of indium gasket**



Plano windows, potted in place

- **Use elastomer for support and seal**
- **Use mechanical support to take the loads**
- **Some good elastomers:**
  - **RTV-566 from MG Chemicals**
  - **SikaFlex from Sika**
  - **QC-6093 from Dow Corning**
  - **EC-801 polysulfide from 3M was used for these:**

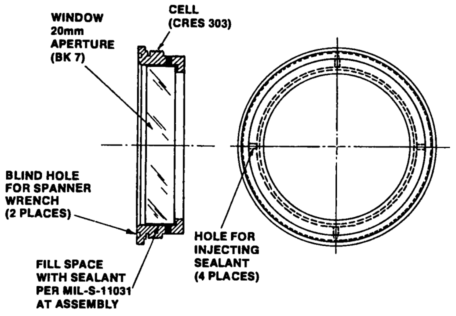


Fig. 5.1 Window subassembly with an elastomerically sealed-in-place glass optic. (From Yodar.[1])

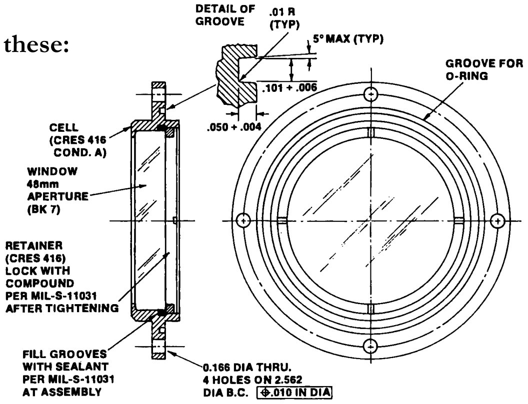


Fig. 5.2 Glass window constrained by a threaded retaining ring and sealed with elastomer. Dimensions are in inches. (From Yoder.[2])

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

Distortions of optical windows

- **Roark (1975) gave the following equation for Δ*x*, the deflection at the center of a circular window under a pressure differential:**

$$\Delta x = 0.0117\left(1-\nu^{2}\right)\frac{\Delta P\, D^{4}}{E_{G}t_{W}{}^{3}} \qquad \text{Eq. (5.4)}$$

- **According to Vukobratovich (1992), the transmitted wavefront OPD produced by a rim-mounted window of Young's modulus E_G and refractive index *n* when deflected by a pressure differential would be given by this equation reported by Sparks and Cottis (1973):**

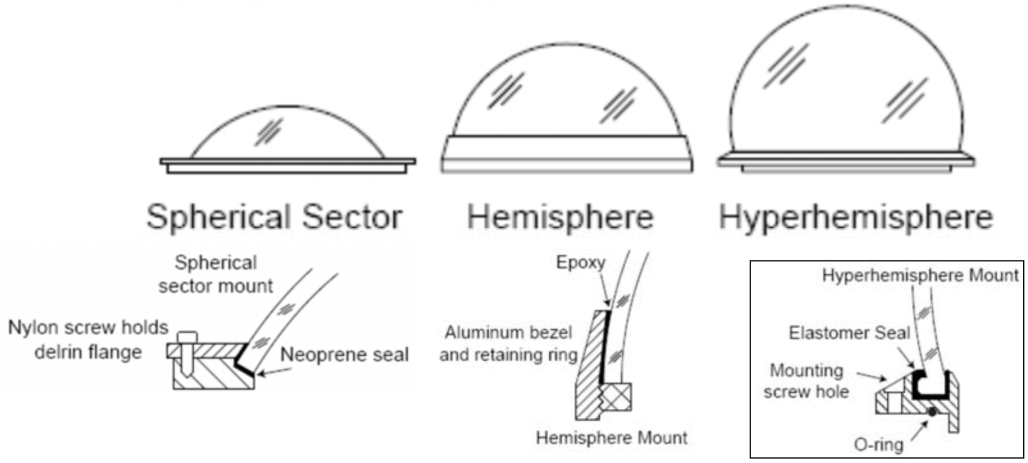
$$OPD = 0.00889(n-1)\frac{\Delta P^{2} D^{6}}{E_{G}{}^{2} t_{W}{}^{5}} \qquad \text{Eq. (5.3)}$$

D is window diameter
n is window refractive index
ΔP is pressure differential across window
E_G is Young's modulus for the glass
t_w is window thickness
ν is Poisson ratio for glass

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

Dome windows

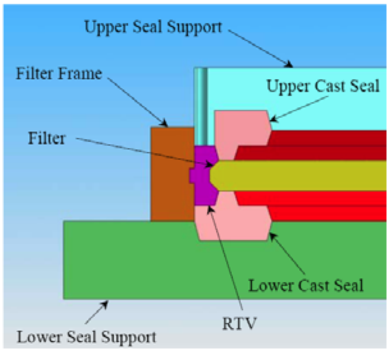
- **Typical mounting geometries include elastomeric mounting to a flange or directly to the system, clamping and sealing with o-ring or elastomer, and brazing the optic to the housing.**

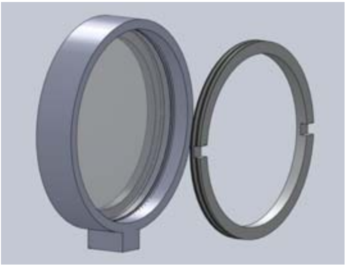


- **Beware of special issues with domes under pressure. References in the text.**

Filters

- Filters typically have the easiest mounting requirements
  - Small distortions of the filters do not affect transmitted wavefront
  - No need for sealing
  - Position requirements are not important
- Pot the filter into a bezel (PanStarrs 50 cm diameter filters)
- Clamp the filter using retaining ring or equivalent
- Spring loaded holder (Edmund Optics example)





Mounting of prisms

- Prisms are stiff, not very susceptible to mounting distortion
- They can be heavy, which requires strong bonds and springs
- Angular positions are usually critical, but positions (displacements) are usually not important

- Chapter 6 in the text shows how to design and apply 30 types of prisms and prism systems
- Chapter 7 (and this section) deal with ways to mount prisms by:
  - Mechanical Clamping
    - Kinematic
    - Non-kinematic
  - Adhesive bonding
    - Supports the optic in a relatively stress-free condition
    - May be single or double-sided
    - A few prisms supported in elastomer ring
  - With flexures

Semi-kinematic constraints

- Datum interfaces define prism position
- Preload force must be applied
- Determine contact stresses to evaluate stress and survivability

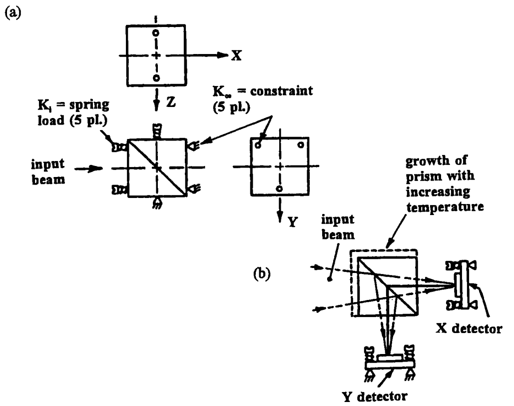


Fig. 7.2 (a) Three views of a semikinematic mount for a cube-shaped beamsplitter prism. (b) Sschematic of a typical optical function showing the effect of temperature rise. (Adapted from Lipshutz.[1])

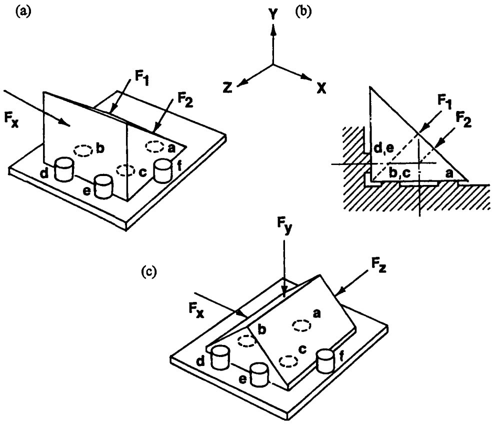


Fig. 7.3 Schematics of semikinematic mounts for (a) and (b) a right-angle prism referenced to one refracting face, and (c) a Porro prism referenced to its hypotenuse face. (Adapted from Durie.[2])

Spring interface details

Potential problems with flat spring interfaces

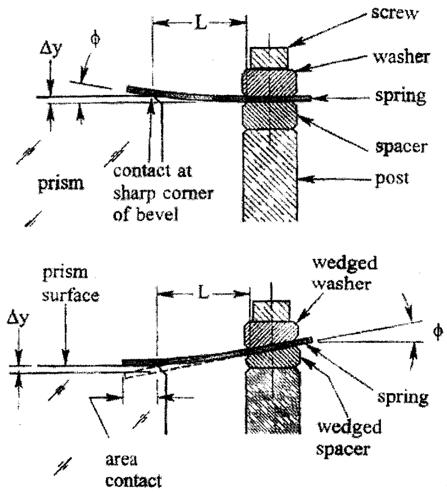


Fig. 7.7

Better solution with curved pad (spherical or cylindrical)

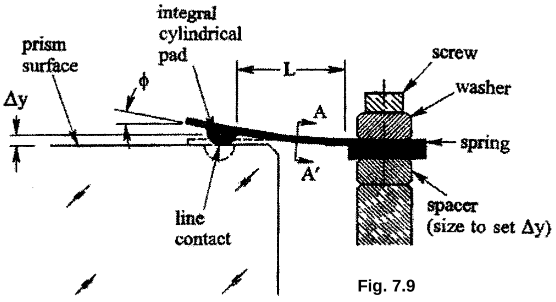
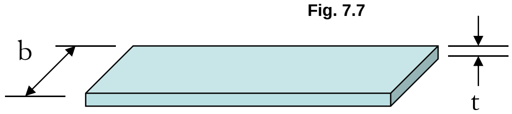


Fig. 7.9



Spring constant K = F/Δy

$$K = \frac{Ebt^3}{4L^3}$$

b, t are spring width, thickness

E is Young's modulus of spring

Alternate preload spring

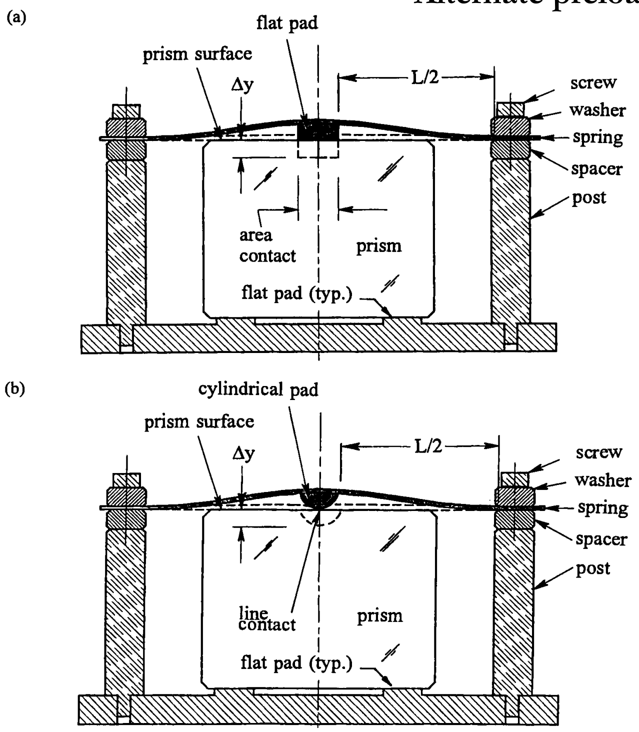


Fig. 7.10 **Straddling spring constraints for a prism. (a) With a flat pad, (b) with a cylindrical pad.**

- Adjust preload based on maximum acceleration. Keep the contact points in contact.
- Stiffness of spring K

$$K = \frac{16Ebt^3}{L^3}$$

Semi-kinematic mount

- Example of a semi-kinematic mount for a penta prism

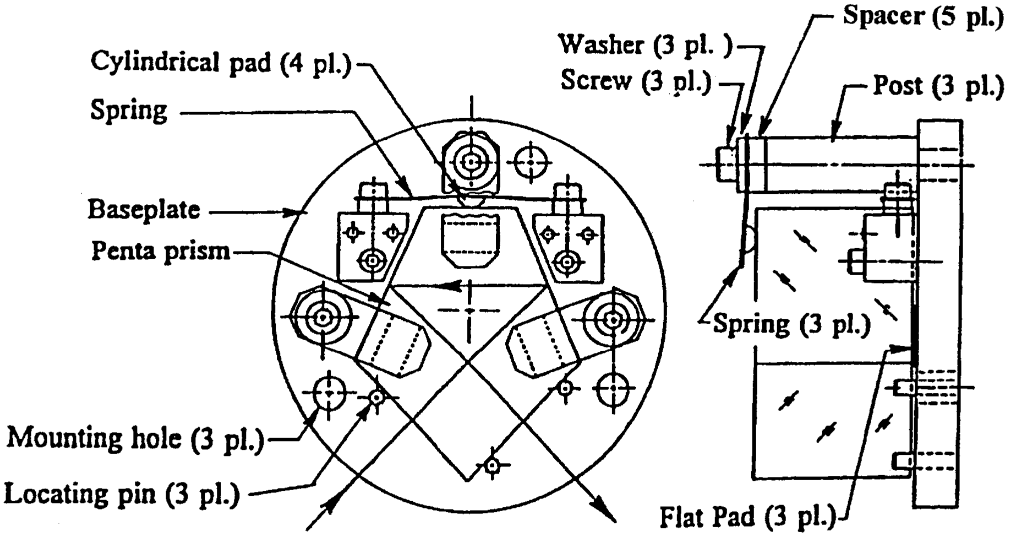
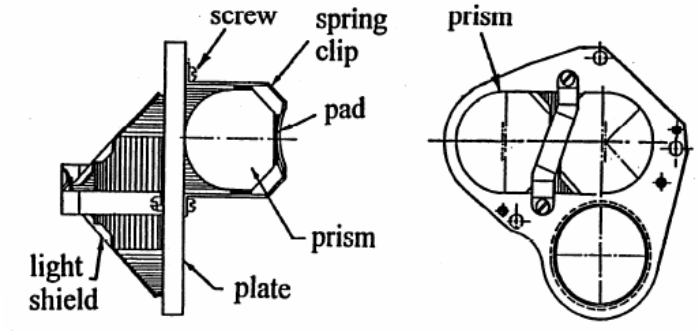


Figure 7.6

Porro prism mount with spring clip

- **Prisms can be clamped to a mount with springs – as shown in this example from a typical military binocular. The same design is frequently used in commercial binoculars and telescopes.**
- **The interface is non-kinematic since the prism contacts a narrow shelf machined into the aluminum plate. The springs typically are phosphor bronze or stainless steel.**
- **Note the thin sheet metal light shields. (No contact in aperture)**



See photo, Fig. 7.14 (pg. 271) in text

Bonded joints for prisms

- Many prisms are bonded to their mounts with adhesive such as epoxy. The area **"Q"** of the bond and the strength **"J"** of the joint must be large enough to hold the prism's weight **"W"** under acceleration **"a_G"** with a safety factor **"f_S"**.

$$Q_{MIN} = \frac{W a_G f_S}{J}, \qquad (7.9)$$

- For a typical epoxy, J $\cong$ 2500 lb/in.^{2} (1.72x10^7 N/m^2)

- We recommend $2 < f_S < 5$ to allow for possible non-optimum bonding procedures such as:
  - inadequate cleaning of surfaces
  - overage adhesive
  - incorrect bond thickness and/or dimensions
  - inadequate cure time and/or temperature

- The strengths of sealant materials such as room temperature vulcanizing (RTV) elastomers are not as great as those of epoxies. Typically, J_{RTV} = 500 lb./in.^{2} (3.44×10^6 N/m^2). These softer materials are not widely used as adhesives for bonding optics.

From Yoder (1988)

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Bonding prism to plate

- Choose bond area for necessary strength
- Adhesive shear must accommodate thermal mismatch

● **This Porro prism is cantilevered from a nominally vertical interface**

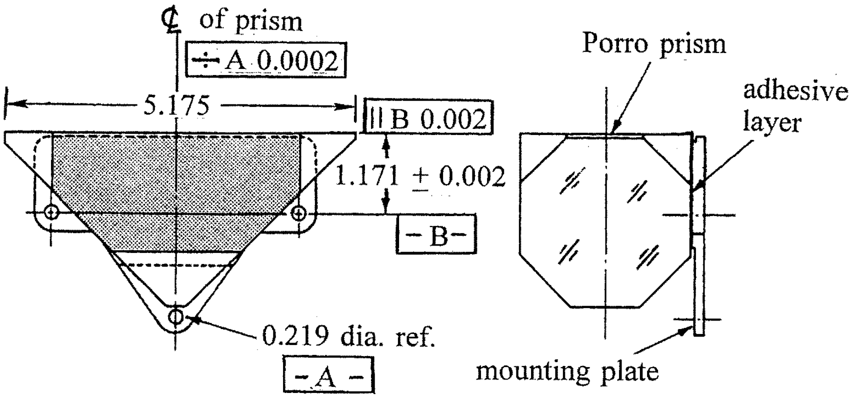

Figure 7.22 Mounting configuration for a Porro prism bonded on one side in cantilevered fashion. Dimensions are in inches. The bonding area is shown shaded.

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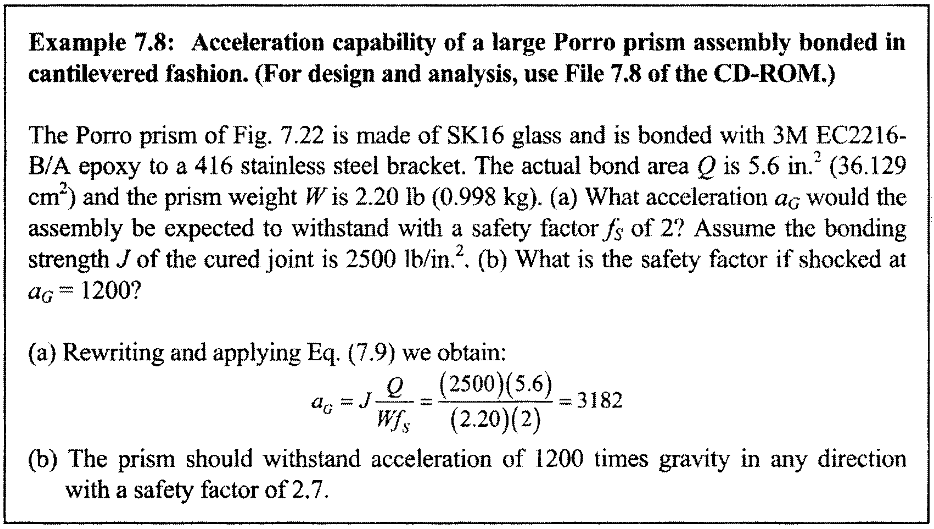
Example for strength calculation

- Example for Porro prism bonded using 3M 2216 epoxy



Example 7.8: Acceleration capability of a large Porro prism assembly bonded in cantilevered fashion. (For design and analysis, use File 7.8 of the CD-ROM.)

The Porro prism of Fig. 7.22 is made of SK16 glass and is bonded with 3M EC2216-B/A epoxy to a 416 stainless steel bracket. The actual bond area Q is 5.6 in.^{2} (36.129 cm^2) and the prism weight W is 2.20 lb (0.998 kg). (a) What acceleration a_G would the assembly be expected to withstand with a safety factor f_S of 2? Assume the bonding strength J of the cured joint is 2500 lb/in.^{2}. (b) What is the safety factor if shocked at $a_G = 1200$?

(a) Rewriting and applying Eq. (7.9) we obtain:

$$a_G = J\frac{Q}{Wf_S} = \frac{(2500)(5.6)}{(2.20)(2)} = 3182$$

(b) The prism should withstand acceleration of 1200 times gravity in any direction with a safety factor of 2.7.

Thermal issue with bonding prisms

- Thermal mismatch between the glass and metal must be accommodated by the adhesive. Usually the compliance of metal interface and the prism is negligible
  - <u>High temperatures</u>,
    Adhesive loses strength, but also the shear modulus drops so the stresses are relaxed
  - <u>Low temperatures</u>,
    Usually the limiting case because the shear modulus increases dramatically

- Mechanisms for stress
  - Differential expansion between the glass and metal over bong thickness gives shear strain, stress
  - Constrained adhesive “wants” to contract in all directions, but can only contract in z, except for edges which bulge in.
  - This combination can give a high shear stress at the outer edge of the bond
    - This gets worse when the adhesive has a fillet
    - This is mitigated by using several smaller bonds, rather than one large bond. Rule of thumb, maintain aspect (maximum dimension/thickness) < 100.
    - These issues are complex, and may require finite element modeling.
- For cryogenic temperatures, avoid bonding. If you must, then rely on careful models and test data.

Two-sided bonded mounts

- Increase reliability and allow the use of smaller bonds by bonding from both sides, reducing the stress in the adhesive

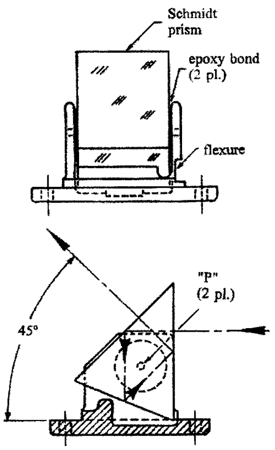


Figure 7.24 Shmidt prism bonded on both sides to a U-shaped mount. (From Willey.)

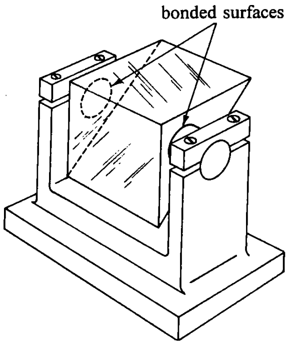


Figure 7.23

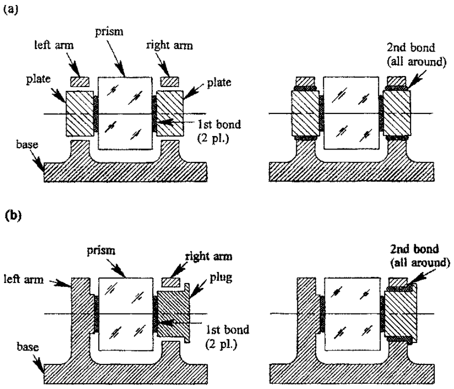


Figure 7.25 Two concepts for double-sided bonding of a prism to a U-shaped mount [(a) Adapted from Beckmann.]

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

Use of flexures

- Large prisms and large temperature ranges require the use of flexures that allow thermal expansion without causing high stresses

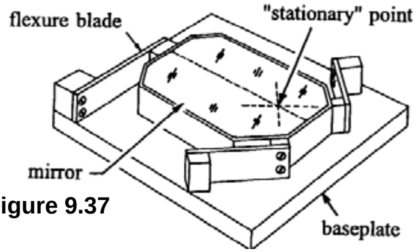


Figure 9.37

- **Schematic of a very successful flexure mounting for a large (6 in. wide) Zerodur prism subassembly. It is bonded to 3 flexures attached to an aluminum structure.**

Concept

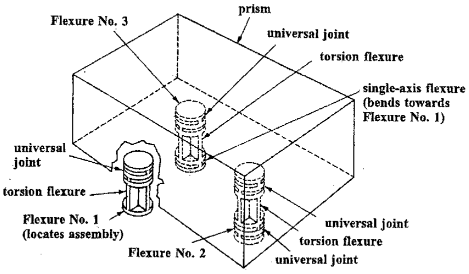


Figure 7.30

Design

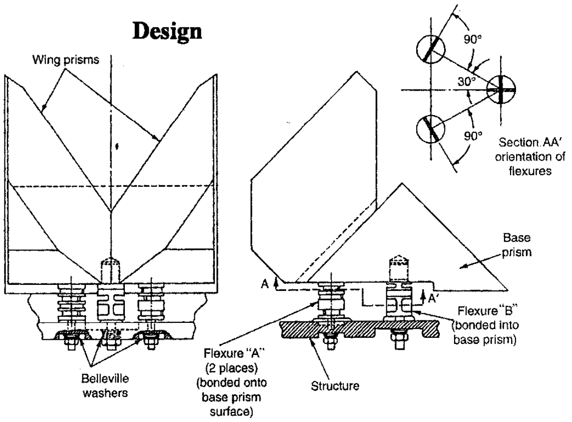


Figure 7.31

- **The flexures are separated by ~4 in. This dimension changes by 0.002 in. over a 40 °F temperature range. The flexures bend to "S" shape to prevent stressing the glass or the bonds.**

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