Review of paper
"Non-image-forming optical components"
by P. R. Yoder Jr.

Proc. of SPIE Vol. 0531, Geometrical Optics,
ed. Fischer, Price, Smith (Jan 1985)

Karlton Crabtree
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Introduction:

This is a summary of an older paper by Yoder discussing the first order optics and opto-mechanics for non-image forming optical components. The paper is conveniently divided by element type, and this summary also follows that form. The order of presentation is plane parallel elements (windows, filters, and reticles), flat mirrors, prisms, beamsplitters, and scanners.

Windows, Filters, and Reticles:

The first category of optical components is plane parallel plates, specifically windows, spectral filters, and reticles. Windows are the simplest category, mechanically speaking. The author lists numerous considerations when selecting the optical and mechanical properties of a window (Table 1).

Table 2. Parameters of Importance in Optical Window Design

- o Transmission throughout applicable spectral range
- o Dimensions
  - \- Optical aperture (instantaneous and total)
  - \- Diameter or width and height
  - \- Thickness
  - \- Wedge angle (incl. orientation)
  - \- Special shape and/or bevel requirements
- o Optical properties
  - \- Transmitted wavefront quality requirements (or surface flatness/irregularity and index homogeneity)
  - \- Transmitted wavefront relative aperture (f/no)
  - \- Surface and bulk scatter characteristics
  - \- Coating requirements (reflectance, thermal emissivity, electrical)
  - \- Bubbles, inclusions and striae
  - \- Polarization characteristics
- o Environment
  - \- Temperature extremes and exposure profiles (storage and operational)
  - \- Pressure (incl. ram air and turbulence effects)
  - \- Pressure differential to be supported (magnitude and sign)
  - \- Exposure to humidity, rain erosion and particular matter
  - \- Radiation (thermal, cosmic, nuclear)
  - \- Vibration (amplitude and frequency power spectral density)
  - \- Shock (amplitude and duration)
- o Mounting configuration
  - \- Orientation relative to optical beam and windstream
  - \- Mechanical stresses induced (operation and storage)
  - \- Thermal properties of materials
  - \- Heat transfer mechanisms and paths
  - \- Mechanical interface (i.e., hole pattern, sealing)

Table 1: List of important parameters in optical windows design (from Yoder)

To first order, a window causes image displacement along the axis (defocus) if not tilted, and also causes displacement perpendicular to the axis if tilted. Some of the important parameters include the pressure differential which will be applied across the window, the glass quality needed (high if near an image plane), and the tolerable wavefront errors due to the window. The author discusses three examples, only one of which is considered here. This is the case of a multi-aperture windows for an airborne electro-optical sensor. The primary component is manufactured from ZnS, and the refractive index inhomogeneity issues are compensated by selectively polishing portions of the window to make them thinner, resulting in a constant optical path length through the window (for small numerical aperture beam). For this element, the window was bonded to the frame by an elastomeric adhesive.

For optical filters, all the above considerations apply, with additional constraints to ensure the expected spectral transmission. These constraints depend on the type of spectral filter. Some spectral filters are absorptive, in which case the absorption is determined from the filter thickness. These are sensitive to angle only in that a tilt changes the effective thickness, and hence the transmission.

Interference filters can be strongly dependent on angle of incidence. Yoder states that in practice, interference filters with a FWHM > 30 nm usually have acceptance angles up to 5°. Temperature dependence can also be significant. Neutral density filters can be made from two polarizers whose relative orientation can be changed. These naturally need additional control in rotation about the propagation axis.

Reticles are usually placed at intermediate image points, and usually scribed onto a thin glass disc. This makes the requirements for inclusion, bubbles, etc in the glass much tighter, since any such errors will directly appear. The features on the reticle are generally sized to appear to subtend about 0.5 mrad for lines and 6 to 10 mrad for alphanumeric characters. It is quite common to illuminate a scribed reticle from the side, where only the scribed areas allow the light to escape, creating a nicely illuminated reticle. Some applications, such as heads-up-displays require the reticle pattern to be projected onto a screen, in which case the reticle pattern will be a transmissive pattern in an otherwise opaque plate.

Flat Fold Mirrors:

Usually fold mirrors are made from a low-expansion glass then coated on one side with something like silver or aluminum or a dielectric stack to provide high reflectivity. At the time this paper was written, it was apparently common to determine the size of a fold mirror by actually looking at the beam size when it reached that point in the optical system. Yoder suggests that it is preferable to have a lens designer use specialized ray-tracing software to determine the optimum size of the beam. Given the easy availability of high performance computers and ray tracing software today, not performing the ray trace seems a spectacularly poor idea. It is also, traditionally speaking, a rule of thumb to set the thickness of a fold mirror to $1/5^{th}$ or $1/10^{th}$ the largest face dimension. When mounting such a mirror, many factors must be considered, including

- magnitude, location, orientation of the steady state forces
- transient forces
- size, flatness, of the mirror
- rigidity and long-term stability required
- needed adjustments
- package size, weight, and configuration constraints
- cost

Yoder discusses spring loaded clamps, and notes that shock can transmit from the metal directly into the glass is this type of mounting. For high shock environments, this can cause the glass substrate to shatter.

Another common technique is adhesive attachment, typically by bonding the back surface of the mirror to a structural plate. Yoder points out that when performing this type of bonding, it is important to follow the proper procedure for the particular adhesive used. Another technique mentioned is to mount the mirror between multiple flexure mountings, which allow one to control how the mirror moves under thermal expansion.

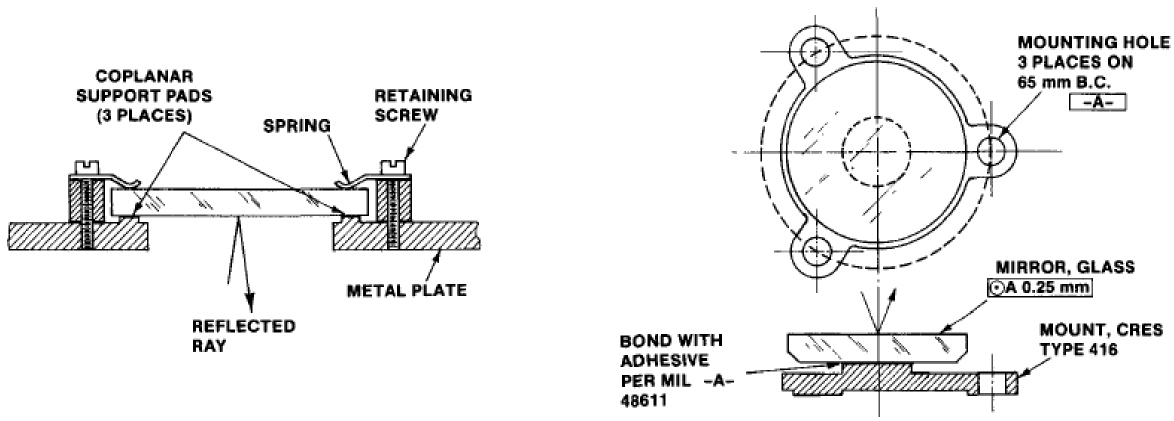

Figure 1: Common Methods for mounting a flat fold mirror (taken from Yoder)

Prisms:

Yoder points out that in geometric optics, prisms can be modeled as a plane parallel plat whose thickness is derived from the tunnel diagram. Yoder suggests mounting with non-kinematic spring-loaded clamps. The primary mounting difficulties are that many prism surfaces are optical in nature, and cannot be touched. Therefor, any prism mounting must contact only the non-optical surfaces. The details for this vary for different prism types, but most prisms have designated surfaces for mounting.

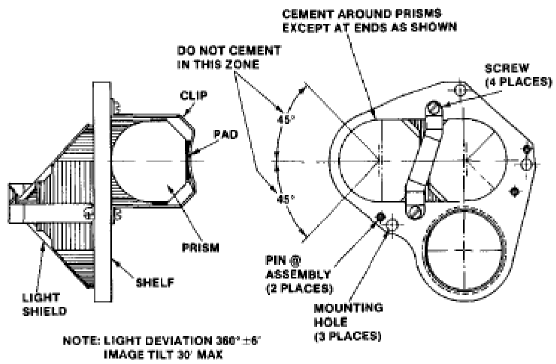

Figure 14 - A mechanically clamped Porro prism subassembly of the type commonly used to erect the image in binoculars and telescopes.

Figure 2: Example of Porro Prism Mounting (From Yoder)

Beamsplitters:

Beamsplitters usually come in two variations, plane-parallel plates, and cube beamsplitters. Plate beamsplitters can usually be held like a window. A cube beamsplitter is much like a prism, and must be held at the designated surfaces.

Scanners:

Optical systems in which a beam must be scanned in either a rotational, oscillatory, linear, or raster scan motions are quite common. The most common types are nodding mirrors, rotating polygon mirrors, and rotating prisms, though other arrangements are also possible.

A rotating prism scans over a cone shaped volume – this is sometimes referred to as a conical scan system. This can also be implemented by rotating a tilted mirror. Nodding mirrors produce a back-and-forth line scan motion. A polygon mirror sweeps unidirectionally across a line as one segment rotates past, then there is a short pause as the vertex is in the beam path, then the next face begins the scan again. This can suffer from non-uniform scanning if all the faces are not tilted exactly the same. Some clever designers in the past have deliberately altered the tilt of every other polygon face, to create the correct pattern for interlaced scanning.

Mechanically, a designer must consider that large forces can occur in scanners, and use proper materials for both the scanner and mount. Rotating polygon mirrors can, in some installations, run at tens of thousands of revolutions per minute. This can cause a system made from a soft material to significantly distort, or cause a brittle system to explode. Nodding mirrors must reverse direction quite rapidly – in some systems, bumpers are placed for the mirror to collide with in order to remove energy. Obviously the mirror and mounting must be both stiff enough to prevent distortion, strong enough to handle the abuse, and rugged enough to last over time. An example of the last problem, not reported by Yoder, LANDSAT systems are reported to have lost scan pattern alignment over a period of a few years as the bumpers got worn down. (Storey, J. "LANDSAT-5 Bumper Mode Geometric Correction", IEEE Transactions on Geoscience and Remote Sensing, VOL. 42, NO. 12, Dec. 2004)

Conclusion:

In this paper Yoder presents a list of optical requirements and problems related to non-image forming components in optical systems. Yoder also presents basic information on mechanical properties and mountings required for these components. In total, this paper represents a reasonable introduction to this type of component for opto-mechanical engineers.