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Opto-Mechanical Designs for Two Special-Purpose Objective Lens Assemblies

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Abstract

Key features of the opto-mechanical designs for two high performance objective lens assemblies of similar focal lengths and relative apertures, but significantly different configurations and applications are discussed The first lens is a 25.4 cm EFL, f/1 5 catadioptric lens designed for a ±2.8 degree field and intended for use with a detector array in a spaceborne star mapper The second example is a 22.8 cm EFL, f/1.5 refractor covering a ±10 degree field intended for distant target observation in an airborne low light level visual periscope and featuring an integral laser channel for target designation and ranging. The logic behind critical materials choices and the techniques applied in mounting the optics in their mechanical surrounds are described

Introduction

The mechanical aspects of optical instrument design are not frequently described in the literature even though they are, in most applications, vital to the ultimate success of the instrument. This is especially true for high performance equipment intended for military, aerospace or other high technology applications.

In this paper, we describe key features of the opto-mechanical designs for two objective lens assemblies which fall into this general category. They have similar focal lengths and relative apertures, but significantly different configurations and applications. We will concentrate on the mechanical design and constructional details; the optical design aspects of each have been described elsewhere

Design No. 1 - Catadioptric Star Field Sensor Objective

A catadioptric lens developed for use as a spaceborne star sensor in a spacecraft attitude monitoring role (see Ref. 1), is shown in Fig. 1. This was a prototype design having a focal length of 25.4 cm, a relative aperture of f/1.5, a field of view of ±2.8 degrees and a silicon charge transfer device array as a detector. The overall axial length of the assembly was ~50 cm while its diameter was ~20 cm.

From the optical schematic of Fig. 2, the lens can be recognized as a derivative of the Cassegrain form with the secondary mirror located directly on the inner surface of the second large aperture refracting element. The focal plane was located approximately 3.6 cm beyond the last vertex of the second field lens This was a convenient distance for interfacing with the thermoelectrically cooled detector array. As reported in Ref. 2, one aspheric was used to provide essentially constant (i.e , balanced) image quality at all points in the field of view.

The mechanical configuration of this lens is illustrated by Fig. 3. The optics were all supported at their rims. The main cell was made in two parts to facilitate assembly. All metal parts were Invar to minimize thermal expansion problems.

The two larger lenses in this assembly were provided with precision annular flats aligned at manufacture to their optical axes defined by the spherical surfaces within a maximum optical wedge of 5 arc-seconds. These flats interfaced with shoulders in the housing; the lenses were held in place by spring clamps. Centering of these elements was adjusted at assembly by means of radially-directed set screws (not shown) passing through the housing wall and bearing against the rims of the lenses. An elastomer (RTV-60) was injected through multiple access holes into the interfaces between the lenses and the housing. After curing, the set screws were removed and the then vacant holes were sealed with additional elastomer.

The rear surface of the meniscus-shaped, front-surface primary mirror was referenced against spherically ground seats in the rear cell and retained with spring clamps that pressed against an annular flat outside the mirror's clear aperture The mirror was also secured with RTV-60 after alignment.

The air spaced doublet field lenses were assembled into a cell and secured with a single threaded retaining ring. Figure 4 shows the general configuration of the resulting subassembly. The surfaces and dimensions identified by letters were all controlled by custom machining operations at assembly to conform to a specific set of lenses. With one exception, (the annular flat on the concave surface of Lens No. 1), the opto-mechanical interfaces were directly on the spherical lens surfaces to facilitate centering of those elements

In this type of mounting, each optical element is radially positioned by the inside diameter (ID) of the mating cell or housing. The outside diameter (OD) of each element must be precision ground to a high degree of roundness and measured The ID of the mating part is then machined to fit that specific element. The axial positions of the various elements are established by properly locating the machined seats while cutting the IDs Since this machining process is traditionally done on a lathe or similar machine tool spindle, it has come to be known as a "lathe assembly" (see Ref. 3)

In a high performance lens assembled in this manner, nominal diametrical clearance between the OD of the element and the ID of the metal part may be as small as 5 micrometers. The adequacy of a design in regard to radial loading of the lens due to shrinkage of the cell at low temperature may be evaluated by calculating the "hoop stress" (Ref. 3).

This subassembly was centered and squared to the system optical axis at assembly. Axial spacing was determined by a custom ground spacer located between the cell flange and the rear housing. Once aligned and properly spaced, the subassembly was pinned in place.

The detector subassembly, including the focal plane array, heat sink, thermoelectric cooler, and electronics, was supported from the main lens assembly by three flexure blades. One of these is indicated in Fig. 3. This kept the detector array centered in spite of temperature changes. Axial location of the array was fixed by custom-ground spacers at each flexure attachment point.

The entire opto-mechanical assembly was interfaced to the external space platform structure through flexures. The system was designed to hold focus constant within 5 micrometers and to maintain boresight stability to <0.1 arc-second over a wide range of temperatures. This was required in order to ensure proper optical function in the intended operational environment. Laboratory tests confirmed the complete success of the opto-mechanical design in regard to these critical factors.

Design No. 2 - Refracting Dual-Channel Periscope Objective

This lens assembly was designed as the objective of a low light level visual periscope used in a military observation aircraft. The system also functioned in target designation and ranging modes with a pulsed Nd:YAG laser beam transmitted coaxially through the objective and the gimballed beam pointing mirror.

The objective, shown schematically in Fig 5, had a focal length of 22.8 cm, a relative aperture of f/1.5, and covered a ±10 degree field of view. It was designed to image distant tagrets on the 80 mm diameter photocathode of an image intensifier tube. The output of this intensifier was viewed through relay and eyepiece optics by the operator. Focusing on targets as near as about 50 m was accomplished by moving the first element axially.

The optical characteristics and performance of both channels of this objective were discussed in Ref. 4 The lens form was derived from the Double-Gauss photographic objective, but offers improved imagery over more conventional designs in the 0.50 to 0 90 micrometer spectral region used by the image tube. The prism served the triple purposes of folding the light path by 90 degrees allowing the laser beam to be injected through a central "piggy-back" prism and serving as a thick, meniscus-shaped lens near the focal plane to reduce field curvature.

The opto-mechanical assembly, shown in Fig. 6, was approximately 29 cm long and 17 cm in diameter at its largest point. The infinity focal plane was located about 1.4 cm beyond the exit aperture to prevent high voltage arc-over from the image intensifier to the metallic lens housing. The assembly was mounted to the periscope on three ears protruding from the housing near the assembly's center of gravity. Custom ground spacers attached to these ears parfocalized the assembly so it was interchangeable with similar units. The centering interface for the objective relative to the periscope axis was at a precision-machined radial interface adjacent to these mounting ears.

The front housing of the lens was made of 6061-T6 aluminum while the rear portion of that housing was made of 2024-T4 aluminum. The two-part construction facilitated assembly of the folding prism. Both housings were stress relieved and thermally stabilized at appropriate points during the machining process. Impregnated castings were not used to prevent optical surface contamination problems due to vaporization of the impregnation compounds by laser light reflected or scattered within the assembly

To hold each lens and retainer securely in place, a RTV compound was injected into radially directed holes equally spaced around the cell or housing walls to fill the voids between glass and adjacent metal parts. Silicone rubber Type RTV-88 cured at elevated temperature was chosen for this particular application because of its exceptional sealing properties and resistance to vaporization upon irradiation by the laser beam.

Two individually rotatable optical wedges in the 7 mm diameter collimated unexpanded input laser beam were used manually to boresight that beam to a reticle pattern in the visual periscope prior to a mission. The worm gear and control knob of one wedge may be seen at the right of Fig 6. As shown in Fig. 5, a single element negative lens diverged the beam as it entered the small prism cemented to an unaluminized central area on the fold prism hypotenuse This beam refracted through the various lens elements of the assembly and emerged from the entrance aperture of the objective as a nominally collimated beam of 7 cm diameter.

The portions of the prism and lens apertures intercepted by the laser beam were antireflection coated for the 1.06 micrometer laser wavelength to minimize back reflections and light loss. Particular care was exercised during the optical design of this lens to place all focused reflected (or ghost) laser beam images in airspaces wherever possible. The design shown here has consistently withstood, for extended periods of time, input laser beam energy of typically 100 to 150 millijoules per pulse at 10 pulses per second. A design feature contributing significantly to this operational capability was to enclose the beam path between the prism and diverging lens with a stainless steel bellows (see Fig 7) to prevent reflected and scattered light from reaching the inner surfaces of the housing.

Conventional optical cements were found not to be satisfactory in regions where the laser beam was concentrated A two component silicone elastomer, Sylgard XR-63-489, was successfully used in the present design

To prevent problems with moisture inside the lens assembly, it was sealed and evacuated, then backfilled, purged, and pressurized with dry nitrogen.

The front cell, containing a single meniscus-shaped lens element, was threaded onto the main lens housing so it could be rotated through ring and pinion gears by a reversible external motor (not shown) to focus the lens on nearby objects. The interface between this lens and its cell is shown schematically in Fig 8. The threaded retaining ring made line contact at its inner edge with the convex lens surface R1, while an annular flat on concave surface R2 rests solidly against a shoulder in the cell. The lens was Schott SK15 glass, while all metal parts were thermally stabilized 6061-T6 aluminum.

A unique design feature of the lens mountings used throughout this objective assembly may be seen in this figure as well as at elements 6 and 7 in Fig 7 In order to facilitate insertion of the lenses into housings with inside diameters custom machined only a few micrometers larger than the lenses' outside diameters, the lens rims were fine ground spherical instead of cylindrical during edging. If then the lens was tipped slightly at assembly, it would still slide freely instead of jamming before it was properly seated. Although this required some additional optical fabrication effort and increased tooling costs slightly, it has been found to be worthwhile in preventing damage to fragile lens elements at final assembly when they have received maximum value-added This "value" factor included, in addition to the material and fabrication costs, the cost of recomputing the optical design for specific glass melts and adjustment of the airspaces for measured element axial thicknesses as necessary to obtain maximum optical performance from the completed assembly

Conclusion

In this paper, we have described the salient mechanical features of two special purpose optical assemblies. It is hoped that the information provided here will be of value to the designers of similar high performance optical devices.

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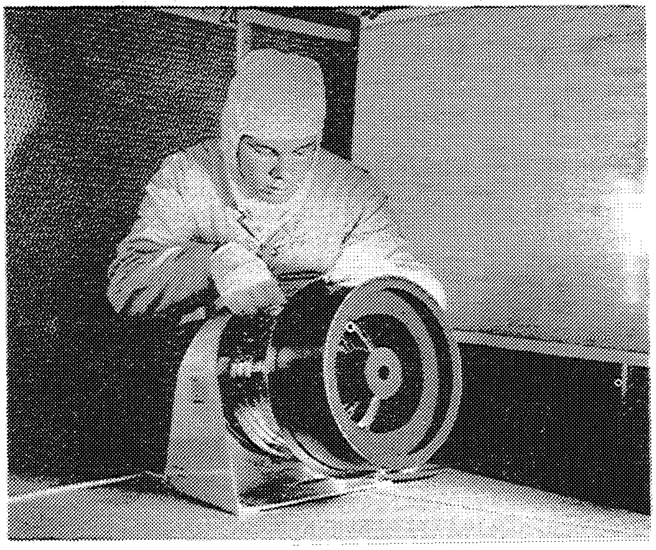

Figure 1 Prototype of a spacecraft attitude star sensor comprising a 25.4 cm focal length, f/1.5 catadioptric objective and a cooled silicon charge coupled device array.

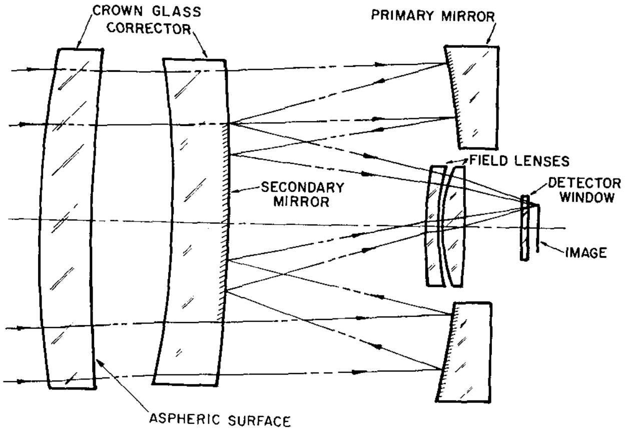

Figure 2 Optical schematic of the Cassegrain type catadioptric lens system used in the lens shown in Fig 1.

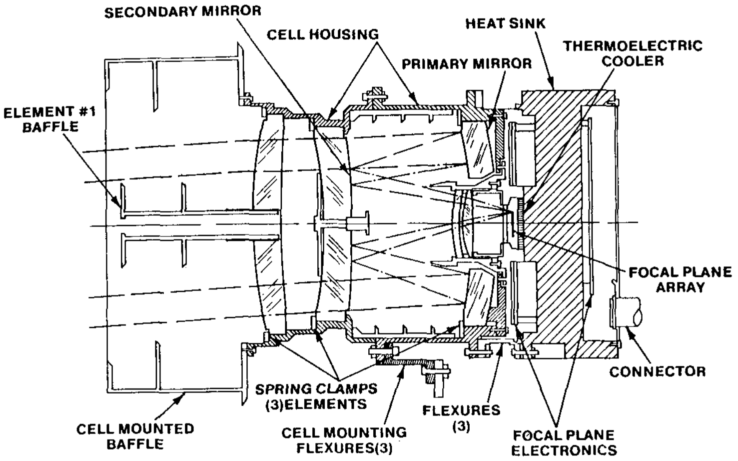

Figure 3. Opto-mechanical schematic of the star sensor objective system From Ref 1

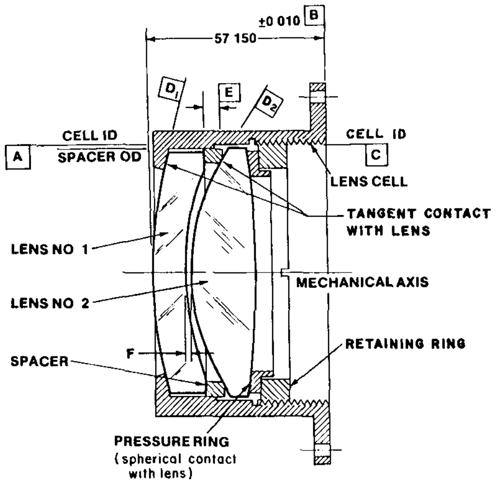

Figure 4 Configuration of the field lens subassembly from the star sensor objective

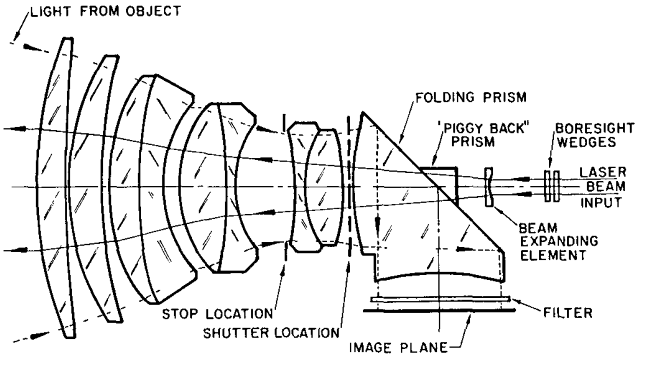

Figure 5 Optical schematic of the dual-channel objective lens. From Ref 4.

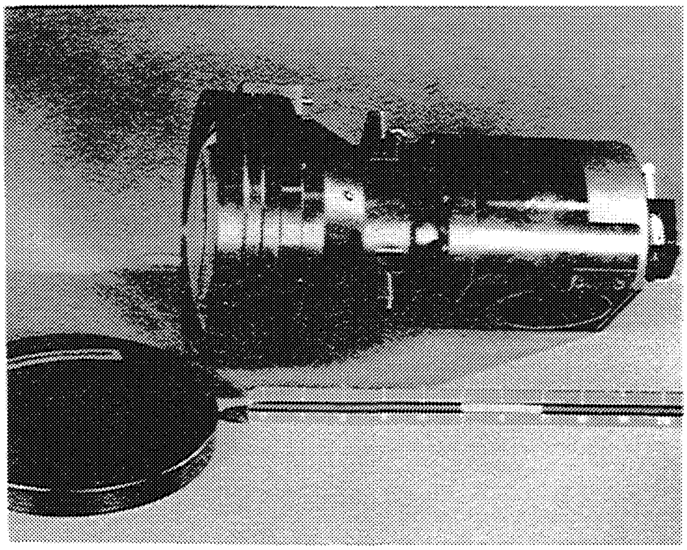

Figure 6. External view of the dual-channel objective lens assembly. The scale is calibrated in inches From Ref. 4.

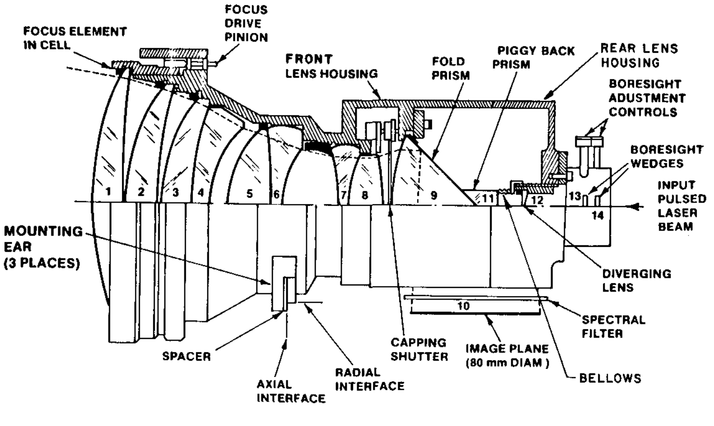

Figure 7. Partial section view of the dual-channel objective assembly. From Ref 5.

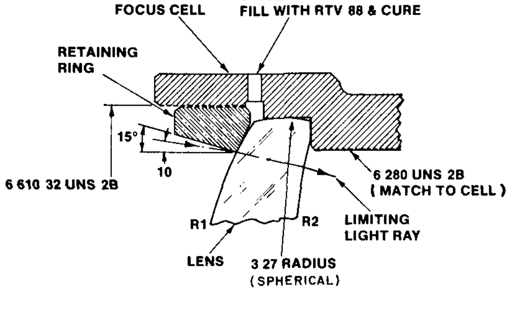

Figure 8. Detail view of the glass-to-metal interface for the front focussing element of the dual-channel objective assembly Dimensions are inches. From Ref. 5