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Gemini Multi Object Spectrograph Optomechanical Design

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ABSTRACT

The Gemini 8 - meter telescopes under construction on Mauna Kea, Hawaii and Cerro Pachon, Chile will each be equipped with a high performance multi object spectrograph. Design and construction of the Gemini Multi Object Spectrograph (GMOS) is carried out by a team of scientists and engineers from both Canada and UK and involves the mounting of some relatively large optical elements. The elements range in size from 136mm to 300mm in diameter and are fabricated from a variety of glasses with quite different thermal and mechanical properties. Each GMOS unit will contain 10 different lens groups with each group varying in complexity from 1 to 4 elements.

A novel mounting scheme was devised for each group utilizing elastomers, subcells with matching coefficients of thermal expansion (CTE), and optical couplants. The resulting groups achieve both radial and axial athermalization, in a relatively simple mechanical configuration. The groups are also easily disassembled and reassembled (e.g. for coating the outer surfaces) without requiring realignment.

The initial assembly actually corrects for any discrepancies between the optical axis and the mechanical axis of the lenses, and results in a lens group with common optical axis. The group is contained in an outer aluminum structure that can easily be mounted / adjusted within a barrel-type assembly. The structure also has fixtures to allow for the expansion or contraction of the optical couplant. The assembly was designed to athermalize at temperatures between -40 and +35 degrees Celsius. Several elastomers were studied extensively and their physical properties characterized. FEA was used extensively to confirm the results of the initial analysis.

KEY WORDS: Elastomers, Optomechanical design, Optical instrumentation, Telescopes, Lens mounting.

1. INTRODUCTION

In each of the two GMOS instruments there are two lens barrels, not including Atmospheric Dispersion Compensators (ADCs). Each of these barrels in turn contains 3 lens groups for a total of 28 glass elements per instrument. The instrument is a cassegrain instrument, and will be utilized in a variety of orientations.

In mounting the lenses of GMOS, a method of constraining these lenses accurately to their prescribed location with the necessary tight tolerance is required. This method must also ensure that the lenses are not being overly stressed and that thermal effects will not degrade the performance of the system. Due to the large size of some of the lenses in question, the task of mounting them is no longer trivial. If not supported correctly, the weight of the lens alone is enough to create image degrading stresses.

Several methods of radially constraining such lenses were studied - including methods that provide support from several hard points, support by a uniform pressure (i.e. metal bands or straps), support through variable pressure (i.e. o-rings or mercury tubes), and support by applying variable tension/pressure (i.e. elastomeric potting). It was found that the elastomeric mounting technique is 5 times superior to the uniform/variable pressure methods and 10 times better than 3 point mounting techniques, with respect to deflections at the surface[1]. The elastomeric mounting technique also has several other advantages to consider:

- Simplicity.
- Accurate element alignment during assembly.
- Athermalization (glass remains strain free over a range of temperature).
- Overall stiffness of assembly.
- Sealing of lens edge to subcell.
- Elimination of the need for additional mechanical contact points on the lens surface.

Based on these considerations, it was decided to elastomerically mount each lens into a ring of material with a coefficient of thermal expansion similar to that of the lens. It is possible to choose the elastomer and thickness of elastomer film in such a way that the lens will be under no radial stress during a temperature change. It is also possible to arrange these lenses and corresponding cells in such a way that any variations in temperature will not effect the axial separation of the lenses. This will have a profound effect on the choice of couplants as cavitation will not be a major issue to deal with.

2. OVERVIEW

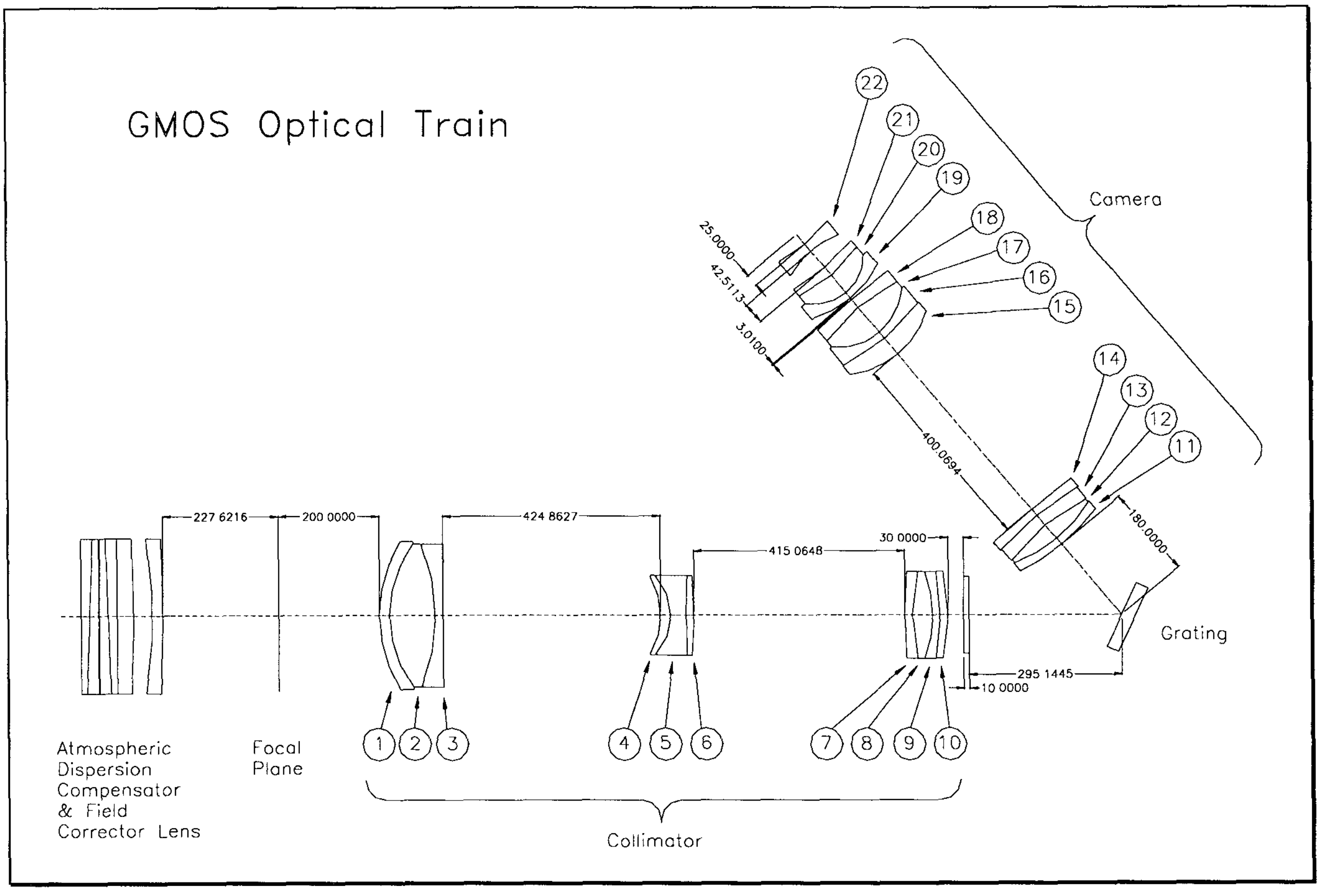

Figure #1 : GMOS Optical Train

The general layout of all of the glass elements in GMOS is shown in Fig.#1 (all dimensions are in mm). Only the mounting of the collimator and camera optics are considered in this paper; however, the same techniques are to be utilized in the mounting of the elements of the ADC. The coefficients of thermal expansion (CTE) of the lenses are given in Table #1 as well as the different types of glass used.

Lens	Material	CTE (x10^{-6} /°C)
1	BSL7Y	6.8
2	CaFl	18.85
3	BAL15Y	7.6
4	S-BSL7	7.2
5	CaFl	18.85
6	PBL1Y	8.4
7	BAL15Y	7.6
8	CaFl	18.85
9	BALF5	8.1
10	PBL1Y	8.4
11	BAL15Y	7.6

Lens	Material	CTE (x10^{-6} /°C)
12	SFPL53	14.2
13	SLAL7	6.7
14	SILICA	0.55
15	SILICA	0.55
16	BAL15Y	7.6
17	CaFl	18.85
18	BAK4	7.0
19	BAL15Y	7.6
20	CaFl	18.85
21	F5	8.0
22	SILICA	0.55

Table #1: Lens Properties.

A cross section of a finished lens group assembly (first lens set of collimator) can be seen in Fig #2. Each individual lens is elastomerically mounted inside of a subcell of a material with a similar CTE. The subcell itself can be fabricated from a single material or can exist as a composite of two materials bonded with a structural adhesive.

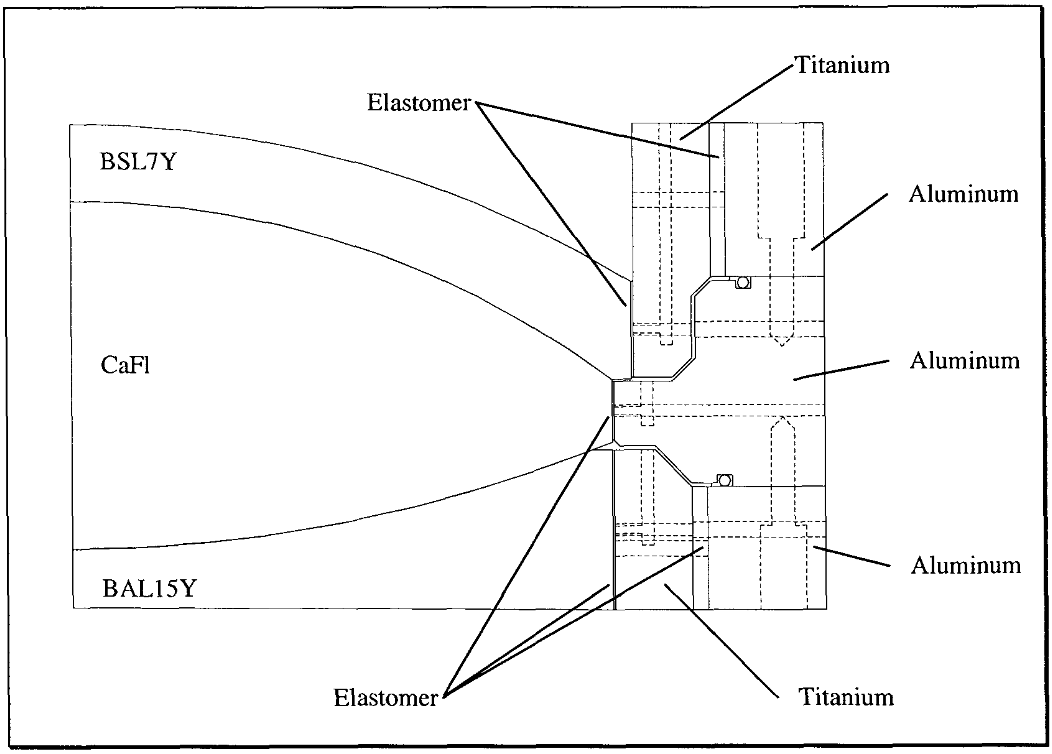

Figure #2: First lens set of collimator

The subcells are attached to each other with a series of bolts around the circumference as well as 4 pins. The holes for the pins are bored after the lenses are adhered into their correct position. These pins are fashioned in such a way that they may not be removed without first moving the subcells apart along the axis of the pins. This is accomplished with the disassembly bolts located immediately beside the pins and will ensure that the lenses will not contact each other during any disassembly.

The subcells themselves are formed in such a way that a "channel" for optical couplant exists around the circumference of the lens. The interface between adjacent subcells is sealed with a single o-ring.

Centering of the lenses within its corresponding subcell is accomplished with 4 set screws located on the outer circumference of the assembly. Two of the screws are "hard tipped" and two of them are "spring tipped" to prevent stressing of the glass elements. Once the lens is located properly (described in assembly procedure later), it is adhered into place.

Similar set screws are provided for centering of rings of different materials within the same subcell (i.e. for fabrication of composite rings). These screws however are located on the inner circumference of the subcell. After the concentric rings are adhered to each other, these holes are filled with an inert epoxy elastomer.

3. ADHESIVES

A large number of adhesives were found with a large variety of properties; however, very few of these had all of the required properties documented. As a result, several of the more promising products were chosen and are being purchased for testing. Confirmation of all of the pertinent mechanical , and chemical properties, would be best accomplished by extensively testing the final candidate.

An elastomer with a very low viscosity would be preferred and most of the data published is for room temperature. Viscosity at 10°C (see section on environmental conditions) would be a useful result. If an elastomer is used with a relatively low Young's Modulus, the stresses in the glass will be reduced. This however comes at the price of larger element deflections. The coefficient of thermal expansion will have a significant impact on the athermalization calculations. It is desired to document the CTE for a variety of temperatures and geometries.

An adhesive that was used for all of our initial calculations was Norland 65. This adhesive was one of only a few for which we had data on both the CTE and the Young's Modulus. Norland also claims that this elastomer is used extensively in the mounting of optics, or for glass to metal interfaces.

Some of the other Adhesives considered are shown in Table #2.

Name	**Manufacturer**
NOA 65	Norland Products
NOA 72	Norland Products
Milbond	Summers Laboratories
Epo-Tek 301-2	Epoxy Technology Inc.
UV10FL	Master Bond Inc.
System 151	Master Bond Inc.

Table #2: Adhesives

4. ENVIRONMENTAL CONDITIONS

It has been assumed that the lenses, assembled into their subcells, must be able to withstand temperatures in the range of -30 °C to +45 °C. The lens group itself is assumed to be stress free at whatever temperature the assembly of the group took place at. The stress must then be calculated at the extreme temperatures (i.e. for a lens/subcell assembled at 20 C, stresses would have to be calculated for a $\Delta T = -50°C$ and $\Delta T = +25°C$).

In a preliminary calculation, it was determined that a ΔT= -50°C produced stresses of magnitude approximately 20% higher than the case of ΔT= -40°C. From this calculation it was concluded that assembly and curing of the lenses at 10°C (as opposed to 20°C) would be preferred. It was also concluded that assembly at this temperature would not be a problem with respect to equipment, and the relative comfort of the assembly technician.

All calculations from this point on assumed a ΔT= -40°C and ΔT= +35°C based on a T_o = 10°C.

5. CALCULATIONS:

(Gaps Between Lenses)

The coefficients of thermal expansion of the glasses were then examined in order to determine a suitable material for the subcell. It was found that we could roughly match all of the lenses using four materials - aluminum, titanium, INVAR, and copper.

Using a "worst case scenario" the gaps for each lens interface was calculated. In this calculations, the lenses and their corresponding subcells dimensions were all calculated at the extreme temperatures of the environmental conditions. Note that in some cases this meant that subcells and glasses were at different temperatures (i.e. lens at -40°C and subcell at +35°C). The gaps calculated were assumed to be larger than the worst case and have automatically incorporated a "safety factor".

(Radial Athermalization)

A calculation was then performed to determine the thickness of elastomer layer required between the glass and it's corresponding subcell. This calculation was based on the CTEs of the glass, elastomer, and subcell as well as the diameter of the glass. A linear equation (found in many standard optomechanical texts and technical papers[2,3]) was initially used but was found to give poor results when checked with a finite element model. A new modified equation was developed from first principles and was found to give much better results.

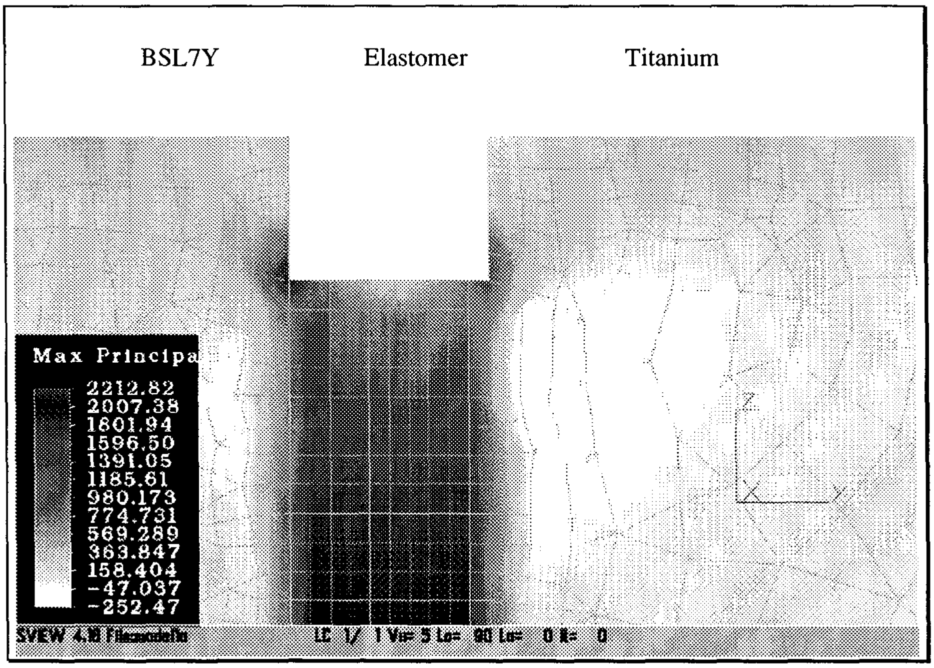

Figure #2: Finite element model of lens / elastomer / subcell interface

A finite element model of the lens, elastomer, and subcell was then constructed using ALGOR (shown in Figure #2) and the maximum principal stresses were examined in the glass for a temperature change of - 40 °C as well as +35°C. The numbers shown for stress in Figure #2 are in kPa. Rule of thumb[2] numbers used in industry for maximum glass stress are 350 MPa in compression and 35 Mpa in tension. Birefringence caused by stress can occur as low as 3.5 Mpa . We chose to restrict all stresses to less than 5 Mpa at the extreme temperatures given ; hence, for the general life of the glass, stresses will be well below this already conservative limit. The finite element model helps to show that most if the stress build-up is actually in the elastomer as expected.

After the lens/elastomer/subcell model was checked at the temperature extremes, the dimensions of the subcell were altered by ±50μm and this new model checked for excessive stress. This calculation was used to determine the sensitivity of the assembly to the tolerances that the shop would produce the subcell rings. The 50 μm tolerance imposed no stresses that exceeded our limits.

The finite element model was then used to determine if there would be any stresses induced if the lens and the cell were at different temperatures. Although the assembly should never be shocked so badly as to produce this large a gradient, a 5°C temperature differential was placed on the lens and outer subcell. The results still remained below our 5Mpa limit.

(Axial Athermalization)

During the design of the individual subcells it was found that in some cases a subcell made up of two materials was necessary in order to achieve athermalization both radially and axially. The two materials were attached to each other using a structural adhesive and the same "adhesive gap" calculation was used to determine the thickness of adhesive layer required. In such cases a calculation was also performed to determine the location of the glue interface (axially) such that over the range of temperatures, the spacing between the faces of two adjacent lenses (at the center of the field) would remain constant. This would minimize the movement of couplant in the gap during temperature cycling and help to prevent any cavitation from occurring.

(Displacements)

Using the gap of elastomer that we have calculated it is now possible to determine the displacement of the lens axially and radially in its various orientations. It was found that the displacements[3,4] were well below the tolerances specified by the optical design. The ramifications of this are such that we may look at an adhesive with a slightly lower Young's Modulus thus reducing the stresses in the glass even further.

6. ASSEMBLY PROCEEDURE:

The assembly procedure for the first two subcells of the first lens group is as follows (see Figure #3):

Assembly of subcell #1:

- The two elements of the first cell are placed on the rotating table and the set screws through the inner of the two rings are inserted.
- The set screws are adjusted until the two rings are concentric (outer surface of inner ring to be concentric with inner surface of outer ring).
- The structural adhesive is added and allowed to cure.
- The set screws used to center the two rings with respect to each other are removed and the holes are filled with structural adhesive.
- Any set screw hole from the outer circumference to the lens are redrilled to remove any glue and the set screws are inserted.

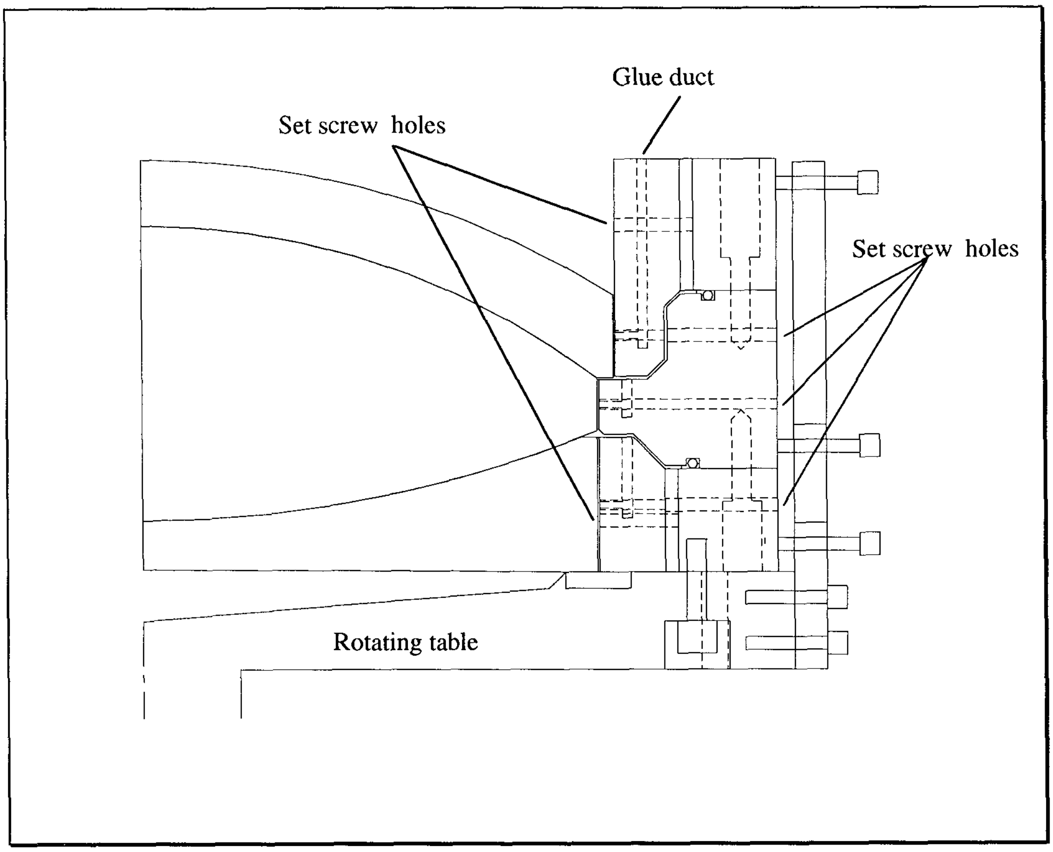

Figure #3: Rotating assembly table for lens groups.

Mounting of optical element in subcell #1·

- A single arm is attached to the rotating table (constructed in such a way that the arm will be used to hold the lens in place while measurements are taken on the outer circumference).
- The first lens is placed on the table and centered using the edge as a reference surface. The arm is used to hold the lens in place
- The subcell ring is placed over the lens and is centered also to the table axis using the set screws from the cell to the lens (actually moving the cell relative to the lens and table).
- The gap is now properly established between the lens and the subcell.
- The single armature used to restrain the lens is now removed and the lens cell is fixed into position via the set screws from the outside of the table to the outer surface of the subcell.
- The gauge in moved to the upper surface of the lens (near the outer circumference) and the lens is centered by making adjustment to the set screws (from table to outer circumference) and the mounting screws.
- Adhesive is added and allowed to set.
- Set screws are removed and the holes are filled with structural adhesive.

Mounting of optical element in subcell #2:

- The rotating table is modified so that set screws can be used on the second cells outer surface.
- Shims of appropriate thickness are placed at several locations around the outer edge of the lens.
- The second lens is placed on the first lens (on the shims) and the single arm is replaced on the table.

- The lens is centered using a dial gauge on it's outer circumference. Once this is accomplished, it is restrained using the single arm.
- The second subcell is moved into place and centered with respect to the lens by use of the set screws from the lens to the cell.
- Once the gap between the lens and the cell has been established, the armature is removed and set screws from the edge of the table to the outer circumference of the subcell are installed.
- The dial gauge is moved to the top surface of the lens and set screws to the outer surface of the subcell are adjusted until the lens is located correctly.
- Once the lens is located correctly and it's mounting screws are in place, the lens is adhered into place.
- After the adhesive has set, the pin holes are redrilled and pins are inserted.

(The above procedure is repeated for subsequent lenses and subcells.)

Introduction of couplant to interface

- Once the lens group is completely assembled, it is placed on edge for the addition of couplant.
- A tube to a reservoir is attached to the bottom port and the top port is left open for venting purposes.
- The couplant level is slowly enough to allow all air to escape (i.e. prevents bubbles from becoming trapped).
- Once the fluid reaches the top vent, it is sealed and the assembly turned over. Now the tube attached to the reservoir (at top at this point) can be removed and sealed.

7. COUPLANTS

It was decided that Cargille 3421 laser liquid would be utilized as the optical couplant; however, tests are still under way to determine it's compatibility with the glasses, elastomers, and subcells.

Optically, the fluid has excellent properties and mechanically, initial indications are all good. A small amount of the fluid was easily "wicked" into a 50 μm gap between two cover glasses and it is hypothesized that lens subcells will not have to be disassembled for the addition of the couplant. Also initial chemical tests on subcell materials are positive and we anxiously await the arrival of glass samples for testing.

Any expansion / contraction of the optical couplant is accommodated by four bellows type structures located around the circumference of the subcells. These structures will also serve as ports for which the couplant will be "bled" into the gap. The subcell groups have been designed in such a way that if it is placed on it's edge, then couplant could be bled from a port at the bottom of the group and vented through a port in the top without trapping any air.

8. PACKAGING

The dimensions of the subcells were all chosen to allow for a simple mechanical assembly and ease of manufacture (i.e. all of the rings were designed to have "robust" cross-sections). With the exception of one group, none of the subcells were constrained dimensionally.

In the case of the first lens group of the camera - the outer circumference of the subcells was constrained to prevent any interference with the filter wheel. This constrain complicated one of the subcell interfaces slightly; however, the problem was overcome easily with the only consequence being that the first cell would have to be sealed using a flexible RTV elastomer.

What results is an accurately mounted lens group with a robust subcell structure on which hard mounting points can be constructed. In the case if GMOS, a three point mounting scheme from the barrels to the subcells was utilized. The incorporation of machinable shims held in place with both bolts and pins allows the group to be easily aligned and subsequently removed for recoating without any realignment.

9. ACKNOWLEDGMENTS

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