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# HIGH PERFORMANCE LENS MOUNTING

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on behalf of
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## Abstract

For many years the lens designer has been faced with the realization that the limiting criteria in lens performance could not always be attributed to his capabilities in theoretical design, but more to his ability to take into account the limitations imposed by the mechanical design and the skills and facilities available in manufacture.

Modern high performance optical systems do not permit the lens designer the freedom of traditional designs in terms of tolerances and capacity to over design, to compensate for the subsequent loss of performance due to manufacturing techniques.

The development of a method of lens element mounting more suited to the requirements of high performance lens systems, is described and analysed.

## Introduction

For many years the lens designer has been faced with the realisation that the limiting criteria in lens performance cannot always be attributed to his capabilities in theoretical design but more to his ability to take into account the limitations imposed by the mechanical design and the facilities and skills available in manufacture. This problem has been overcome traditionally by over-designing the optical system to allow for the inevitable and predictable performance reduction introduced by the mechanical design and manufacture. In the manufacture of optical systems where such processes do not materially affect the economics of the optical components involved, it is still probably the most acceptable solution.
The problems occur both technically and economically in the high technology systems of recent years, which typically vary from tradition in demanding high resolution, large 'f' number, non-transmitting in visual wavelengths and wide environmental specifications.
Traditional lens system construction methods are not appropriate for the needs noted above, for example;

(a) High resolution: it is probably not economically or technically practicable to over-design the optical system to allow for the subsequent loss of performance.

(b) Large 'f' numbers: in addition to the problems as in (a), traditional design is not suitable for the large meniscus lenses generally associated with such designs.

(c) Non-transmitting in visual wavelengths: the present day requirement is for infra-red optics manufactured in germanium or similar IR transmitting material. The systems normally demand the maximum energy collection related to a high resolution resulting in a design of high aperture and very accurate optical element location.

(d) Wide environmental specifications: traditional designs suffer problems of differential expansion, relative movement unit to unit and permanent damage. Modern aerial survey lenses, IR systems and most government field applications demand optical systems which will not only survive but operate under such conditions.

To overcome traditional mounting problems, an analysis was carried out to determine the elemental requirement of lens mounting and to develop an adequate solution. The development of this procedure was initially applied to an existing production lens system to determine its effectiveness for both technical achievement and economic performance, and later on both an aerial survey and an infra-red objective lens.

## Lens Mounting Analysis.

### Design Requirements.

(a) To locate the lenses in the designed position within the tolerances specified.

(b) To maintain the lenses in the designed position whilst being subjected to environmental requirement in vibration, thermal change, humidity, etc.

(c) To maintain optical and mechanical performance during all environmental tests.

### Manufacturing Requirements.

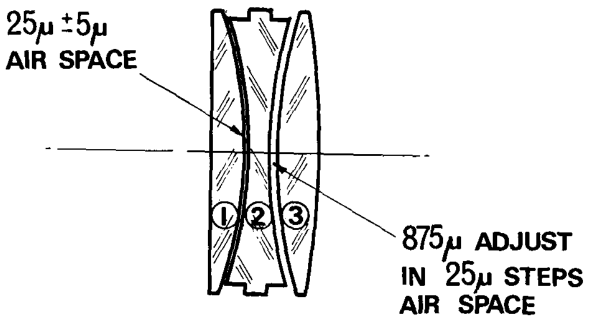
(a) The mounting must allow lenses to be easily adjusted relative to each other for centring and separation.

(b) The lens mountings must be such that differential expansion, vibration and thermal change do not become transmitted to the lens element in the form of stress, sufficient to impede the performance or physically damage the system.

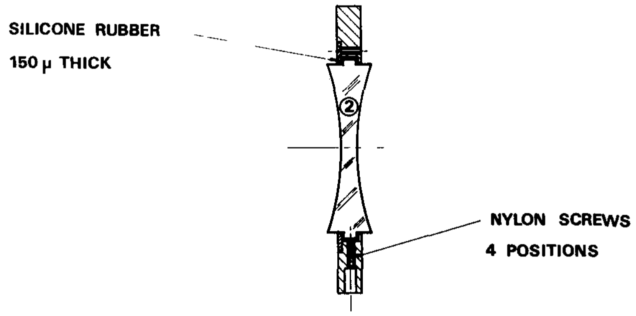
(c) Materials used should not be adversely affected by environmental exposure and should be compatible for interface use.

A 3 element collimating lens was used for the development programme, its specification being:

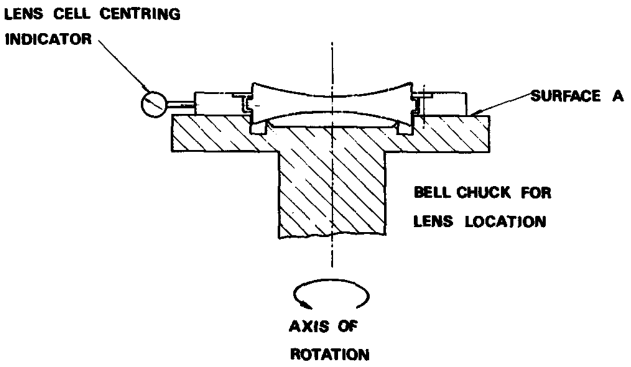
3 elements
air spaced
focal length 1m
f/12



From the drawing it can be seen that the collimator is a classic 3 element design consisting of two crown lenses and one dense flint negative lens. Also shown on the drawing are the separations between the elements, one being fixed at 25 microns ± 5 microns, whilst the other being 875 microns nominal, adjustable in 25 micron steps.
The cell design was developed around the principle that the edging of the optical elements was not to play any part in the location of one lens to another and that the lens optical centre was to be referenced to a mechanical datum for element build-up. Therefore, the negative element, lens number 2, was taken as the datum to which the two crown lenses, lens numbers 1 and 3, were to be referenced. To reproduce the optical axis into a mechanical datum, a stainless steel rig was made having a step with a captive plate, the outside of the lens being ground to form a tongue.



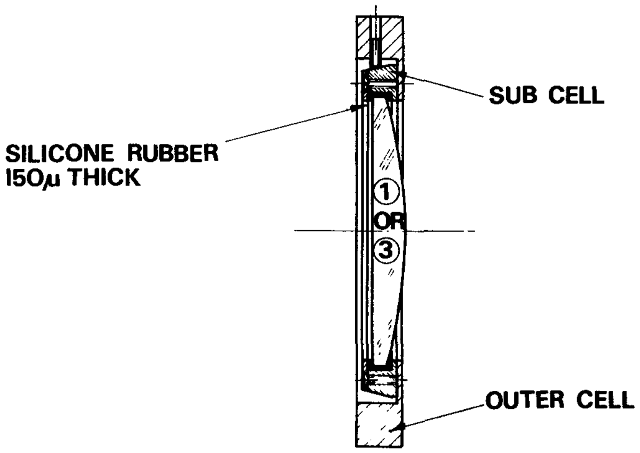
From the drawing it can be seen that the tongue locates with clearance into the groove formed in the cell. The lens is centred in the cell with the aid of nylon screws and the gap filled with a silicone rubber.
The skill comes in determining the thickness of silicone rubber to be used; as well as being an adhesive it is a stress barrier, but it must not be so resilient as to allow the lens to move out of location due to its own weight, or move sufficiently to cause damage, or remain out of adjustment due to 'G' effects during transport or use. Therefore, the thickness of silicone rubber potting is calculated from the stiffness of the silicone rubber, the weight of the optical element, the centring accuracy required, the centring or axial movement which can be tolerated without mechanical contact, the environmental conditions the lens will have to undergo, and the stress insulation required. All factors which have to be weighted relative to their importance, and a compromise determined. In the case of our prototype lens the gaps chosen were 150 microns using a soft silicone rubber. The remaining problem is to centre the optical axis of the optical element with the mechanical outside diameters of the lens cell.



A special chuck was mounted on to a precision spindle. The chuck consists of a flat face (A) on to which the datum side of the lens cell is fixed. The spindle is then rotated and the lens cell centred with the aid of a precision indicator to within 2 microns total indicator reading, and the lens cell locking screws tightened. At this point the lens cell outside datum diameter is accurately determined in relation to the precision spindle axis. In addition to the lens cell mounting face, the chuck includes a classical bell chuck, turned after the chuck was fitted to the spindle and therefore concentric and true to the spindle axis. The lens element is loaded into the lens cell. Four nylon screws working through the wall of the cell are adjusted to centre the lens in the cell, by eye.

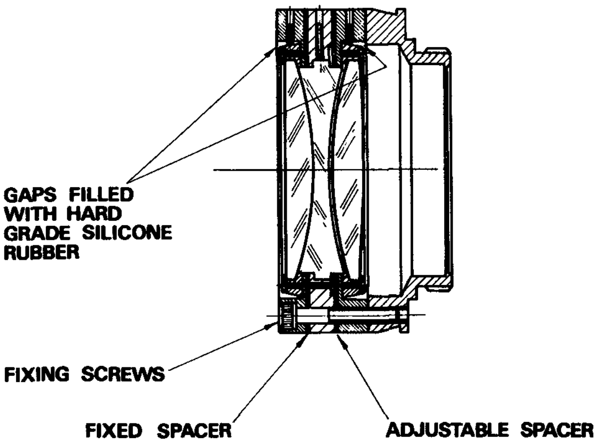
The final centring is achieved by rotating the spindle under a lens centring gauge or an auto-collimation system. Upon completion of centring, the gap between the lens and the cell is filled with silicone rubber and allowed to cure. The nylon screws are removed following curing, leaving a lens potted to a metal cell, concentric with the periphery and square to the datum face. On this particular lens the centring accuracy achieved is in the order of 2 microns total run out. The accuracy varies, being dependent upon the curve of the lenses being centred, when a surface reflection or auto-collimation method of centring is being used. Conversely, the accuracy of centring is of greater importance for lenses with steeper curves so in fact the system "works the correct way". At this point a lens has been potted into a cell with all of the optical datums reproduced into the metal cell.

At the development stage of this lens cell design, it was considered that it would be difficult to achieve the required image quality by treating the two crown lenses in an exactly similar manner and relying only on the mechanical outside diameters of the cell to achieve relative centring, one lens to another. The doubts were not in the ability of the mechanical cells to be manufactured correctly or the ability to relate them one to another, but to allow small adjustments one to another to 'balance' and optimise the small figure variations in each optical element, to achieve the best performance.



The drawing shows the adjustment provided in the crown lenses (Nos. 1 and 3) both lenses having a similarly designed cell. The processes used for assembly of the centre flint, lens number 2 are repeated to the point where the lenses are potted into their respective sub-cells, the optical axis being concentric to the outside diameter of the sub-cell. The location of the sub-cells into the outer-cell is again achieved using a precision spindle with a suitable chuck, on to which the outer-cell is located and centred with respect to its outside edge. The inner-cell, complete with optical element is loaded, and the centring screws adjusted to centre the optical axis with respect to the outside diameter of the outer cell. The potting between the inner and outer-cells is not carried out at this stage.

The lens assembly has now progressed to the point where all lenses have been located into cells having a common outside diameter, and a location face square to the optical axis, and at a known dimension from an optical surface datum.



Assembly of the three elements one to another is carried out in a precision 'V' block, taking advantage of the cell outside diameters. A spacer is manufactured to fit between lens cells 1 and 2 to provide a fixed separation of 25 microns. In a similar manner, an adjustable spacer is provided to fit between lens-cells 2 and 3 to provide separation of 875 microns variable in 25 micron steps.

The sandwich of lens cells and spacers is carefully assembled together and locked, using screws through the three lens cells. A tool-threaded cell is attached to one end, allowing the lens assembly to be located on an optical bench for assessment of optical performance.

It has been found in practice that separation adjustment between lenses 2 and 3 is necessary.

In traditional cell design this was a difficult task and was therefore not optimised to the same degree as can be achieved with this design.

The small centring adjustment provided for the crown lenses 1 and 3 has never been used and has been eliminated in later designs, without introducing problems.

Following adjustment, and acceptable performance being achieved, the gap between the inner and outer cells of lenses 1 and 3 is potted with silicone rubber of a harder grade than that used for direct lens mounting.

In addition the clearance around the screws holding the sandwich together is also filled with silicone rubber.

A housing is provided to screen the adjustments and to provide a thread and face location at either end of the lens cell for user mounting.

## Design Analysis.

### Advantages (manufacture)

(a) In concept the design is analytical rather than analogue, i.e. providing the optical elements are in specification each operation during the assembly is fully understood, measurable, and can be related to the end performance.

(b) All variables can be measured.

(c) A specific sequence of operations can be defined in assembly to achieve the end result. If errors are found, known paths of correction are available.

(d) Adjustments during manufacture are possible without inter-reaction with other variables.

(e) It is possible to adjust the lens or to strip, clean and reassemble without losing adjustment.

(f) The design, although complex in component parts, is economic in the variable areas of assembly and specification achievement, when used for high performance systems.

### Disadvantages (manufacture)

(a) The design is costly in manufactured components and should be used only for high performance optical systems.

(b) Different skills are employed Whereas traditional cell design uses precision turning, non-ferrous materials, and few close tolerances, most of the accuracy being achieved by each-to-each manufacture the design in question employs ferrous materials, extensive use of grinding, and components made to close tolerances with absolute dimensions.
The lens centring and adjustment tends to be 'mechanical' rather than craft Skills have to be acquired in preparing material and surfaces for silicone rubber potting, in addition to the handling of the materials.

## Technical Achievement.

(a) The design allows a higher degree of optical performance to be achieved predictably, without over-designing the theoretical optical system.

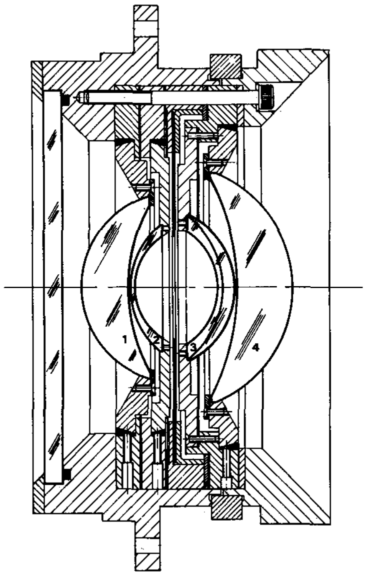
(b) The design has high resistance to environmental damage

(c) The design has long term stability.

(d) The lens system can be serviced without having to 'refind' the performance.

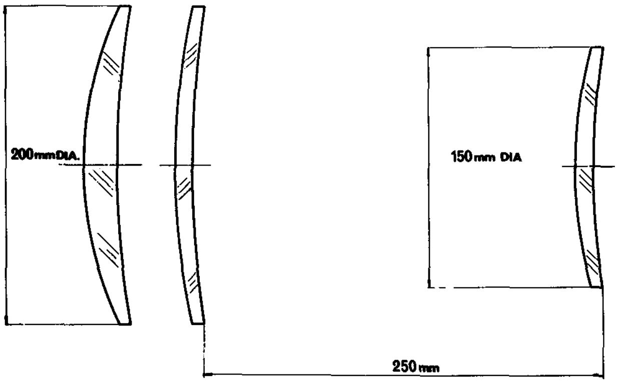
Another example of the advantages of this lens mounting system is illustrated by a particular aerial survey lens which has given good service for over ten years, but could not stand the vibration which it occasionally met in service. Under vibration, some lenses had been known to trepan themselves from their mountings and, with the combination of delicate lenses and small clearances, damage was extensive.

The original lens cells were manufactured from brass, having a differential expansion in the order of double that of the lenses; this resulted in high stress being transmitted to the optics during thermal changes. Therefore, the aerial survey lens had very good optical performance, but it objected to aircraft vibration and the normal operational thermal changes. In fact an ideal candidate for re-mounting.



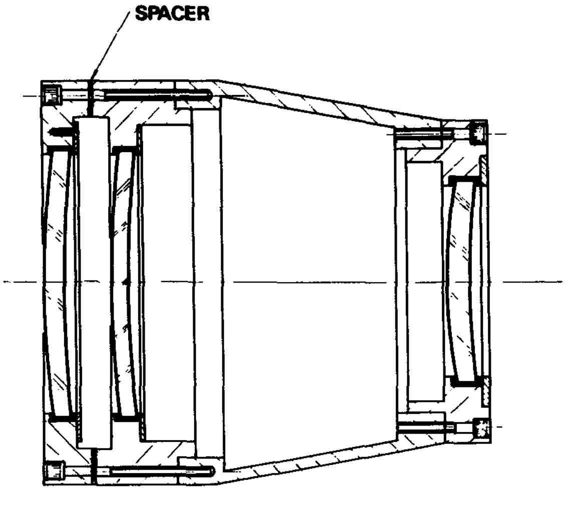
As can be seen from the drawing, the optical design is typical of aerial survey, being symmetrical and employing deep meniscus elements.
A check on the optical design suggested that the deep meniscus combination lens No. 3 should be treated as the master lens to which lens No. 4 should be adjusted. Lenses 1 and 2 should then be assembled relative to the lens combination 3 and 4.
The lens cell design can be seen to be a direct adaptation of the earlier collimator concept. To achieve the recommended assembly procedure lens 3 is potted via a separation joint to an outside cell, lens 4 is then potted into an inner cell which is assembled to lens 3 in the common outer cell, thus satisfying the assembly recommendations.
Lenses 1 and 2 are potted into inner cells and then into outers as previously described. Therefore, the assembly procedure is to centre lens 3 to the common outer cell, and fit and centre lens 4.
As before, make-up spacers and using a precision 'V' block assemble lenses 2 and 1 to the combined 3 and 4 outer cell. Complications are introduced because of the iris diaphragm mechanism but in concept it is the same design as the earlier collimator concept.
The lens withstands and will operate at, all of the service environmental requirements and has therefore been successful from the point of view of cell design.

The final example is high 'f' number Infra-red objective lens.



From the drawing , it can be seen that the design consists of 3 elements.
The front two air-spaced, but positioned close together, the third being at some 250 mm separation.
Two of the elements are germanium, the third being Irtran 5. The front and second elements are 200 mm diameter whilst the third is 150 mm diameter. The requirements are such that a trade off between transmission and image quality had to be made, therefore neither the ideal image quality or transmission can be achieved. With this in mind the cell design was aimed at optimising image quality by geometrically positioning the optical elements to their theoretically true position.

The standard techniques already described were considered adequate for treating each element and its related cell. The problem being the relationship between the two front elements and the third element, separated at some 250 mm.



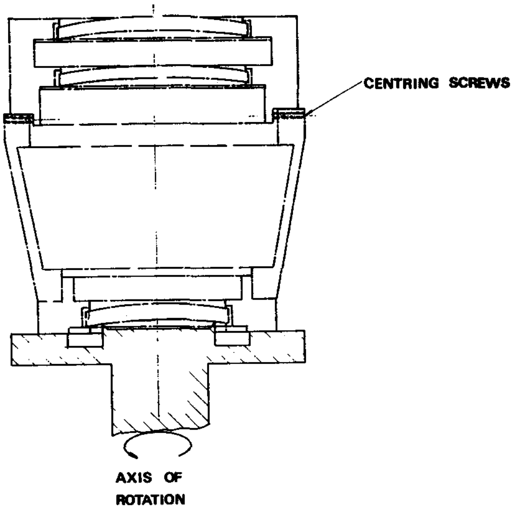
The solution was to treat the two front elements in the conventional way, i.e pot into cells, clamping the cells together using the outside diameter reference.

In addition, at the time of manufacture the second lens cell had a location spigot ground concentric with and the face square to, the outside reference diameter.

The third lens was also potted into a cell concentric with an outside reference diameter. Similarly, this cell had a spigot diameter and face ground concentric and square with the outside reference diameter.

The first and second lens cell assembly was located to the third using a tubular structure. This was manufactured, using the theory that if both the location diameters and faces are machined at the same time, taking all possible care and precautions, the two reference diameters will be as accurate as is practicable. Into each end of the tube assembly the lens cell assemblies are located, using the location spigots already described.

The final accuracy of the system is not known; it works well but not to the ideal requirement which was known not to be possible. With the system being visually opaque and infra-red detection unstable to the degree required, a detailed analysis has not been possible. What is known is that the total centring errors of the front two elements to the outside reference diameters and to each other were better than 2 microns, the same tolerance being achieved with the back element with respect to the location spigot. Measurement of the tube suggested that the spigot diameters were out of round by 4 microns and the eccentricity was lost in that error. From this information it is reasonable to predict the total centring error present from the first lens to the last was better than 5 microns. Should a better quality be required, the errors attributable to the separation tube can be reduced by introducing more tooling, and assembly in the following order:-



(a) Centre the back lens cell on to the precision spindle, centre the back lens into the cell and pot.

(b) Assemble tube on to location spigot of back lens cell.

(c) Provide front lens location spigot with clearance and centring adjustment.

(d) Assemble front lens assembly on to tube using centring machine; centre assembly.

Building the lens assembly on the centring spindle in this manner should produce the optimum in mechanical assembly.