Some Thoughts on Lens Mounting

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Abstract

The mounting of lenses is a major consideration in the manufacture of lenses. The design of the mount, the material used and the manufacturing methods can all significantly affect the performance, cost and profit margin in lens making.

Various methods of mounting will be described and some ideas for improvement will be presented. The suggested improvements are based on the observation that the optical shop is a hostile environment for precision instruments and machines. The grinding materials and liquids are ruinous to precision tools. The one process in lens making that is unique to lens making is the degree of concentration on polishing spherical surfaces. To optimize the manufacturing process one should consider reducing precision requirements as much as possible in all the steps except for the polishing. This thinking leads to looking at new methods of assembly which can be done in clean room conditions.

Modern epoxy cements, inch worms, interferometers, and minicomputer control units can be used in assembly to short cut the need for precision lens shaping and tight mounting tolerances.

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The standard way to mount lenses is in a barrel.[1] The lenses are centered and edged and mounted in the barrel with spacers, using the edges of the lenses and the barrel to define a single optical axis. In principle this means that the system is completely overconstrained. To achieve precision alignment of the lenses, all the lens diameters must match the inside diameter of the barrel. The same is true of the spacers. They must all have the correct diameters to fit the barrel and must also have no wedge. The lens barrel and the spacers must be round and the inside diameter of the barrel straight.

The above requirement of precision for the barrel, lens, and spacer parts makes it extremely difficult to make precision lenses. Residual decentering is probably the most important single cause of image degradation. To make a precision lens it is necessary to place tight tolerances (±2 /μm) on all the operations in both the optical shop and the machine shop. The optical shop's primary task should be on the developing and polishing of spherical surfaces in a piece of glass of the correct thickness. These are the properties of the lens that form the images. These are the techniques which only the optical shop can do. With modest tolerances on the blank diameters the lenses can be prepared with minimum wedge. The centering and edging step comes after the polishing and is a step which requires high precision. The optical shop is asked to meet tolerances which are incompatible with the environment of the optical shop. Precision is expected of a machine using a grinding wheel bearing against a lens which is held on with wax, surrounded with coolant, chips of glass and bits of grinding fragments. Even more troublesome is that the optical man is asked to accurately center the lens on the cupped tool without adequate sensing tools which might be damaged in such an environment.

OF-108 received April 20, 1976; revised July 1, 1976.

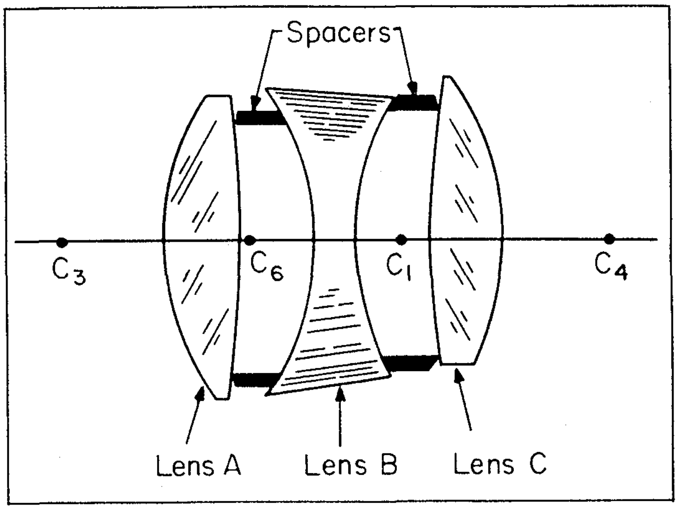

Fig. 1. A triplet lens which is perfectly centered while neither the lenses nor the spacers are centered.

The problems in lens making suggest the need for looking for new approaches. Figure 1 shows a perfectly centered lens. Note the following:

1. The lenses all have wedge.
2. The spacers have wedge.
3. The perfectly centered lens has a minimum overall length.
4. The spacers do not have to be round if airspace thicknesses are measured.
5. The ideal surface cut for the spacers is spherical to match the contacting glass surface of the lenses. If they are not made spherical they can be made cone shaped at an angle to assure contact at either the inside diameter or the outside diameter of the spacer ring. See Figure 2. Method 2a is preferred from the standpoint of keeping the most obtuse edge on the spacer in order to increase the resistance to burrs and nicks in the edge.

Lenses as shown in Figure 1 can be assembled in stable mounts if one abandons the concept of using the barrel's inside diameter as the reference axis for alignment of the lenses. It is possible with a collimator, particularly with a laser collimator, to use the lenses themselves to indicate the straightness of the optical axis. This is based on the concept that light from a point source on the optical axis of a lens reflects images from each of

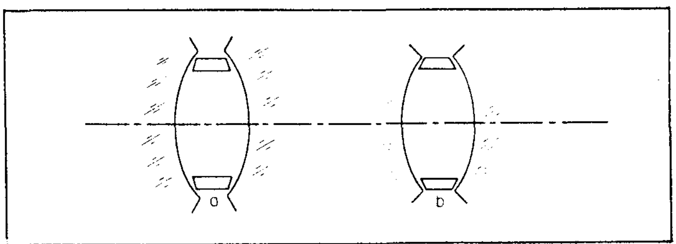

Fig. 2. Type of face cuts on spacers.

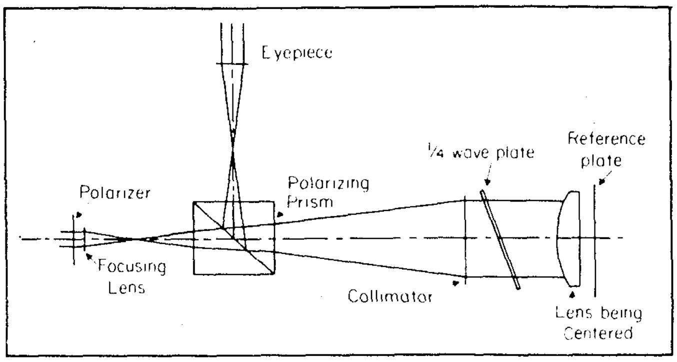

Fig. 3. Optical system for aligning optical systems.

the surfaces, and every image is centered on a straight line, when the lens is truly centered. The return images focus on the straight line at distances ranging from plus infinity to minus infinity. In order to focus on these images it is necessary to move the collimator or the eyepiece over a considerable range. Any movement of the collimator or the eyepiece may upset the original requirement that the collimated beam must enter the lens parallel to the axis. If necessary these lenses could be made to move in a constant straight line. Fortunately the laser provides a way to make this unnecessary. The optical system for a laser collimator for use in the assembly of lenses is shown in Figure 3.[2] The laser has to be focused on the spatial filter (pin hole). The spatial filter, the prism and the nodal points of the objective determine the reference axis to which the alignment of lenses are to be assembled. The laser light should be introduced from underneath the reference surface, with the use of a turning mirror. It is necessary for this axis to maintain stability during a lens assembly.

The lens may be assembled as shown in Figure 4.

1. The laser optical axis should be aligned perpendicular to the reference optical surface. This is accomplished by adjusting the returning mirror and noting when the light passes back through the pin hole. This can be observed optically or by noting the effect on the light output with a photo detector.

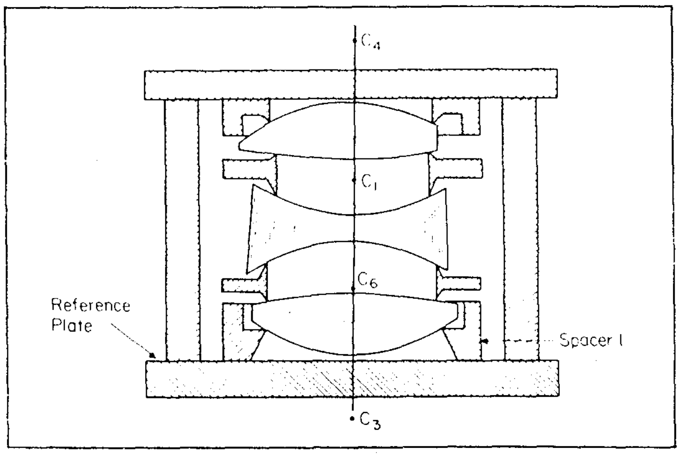

Fig. 4. A schematic of a lens mounting system.

2. Spacer 1 is then placed on the stage of the reference plate. It should be centered on the reference surface well enough to be assured that the collimated beam will pass through its center. The spacer should be well anchored on the reference plate. This can be done with vacuum if the equipment is properly designed. It may be held down with clamps or with soft wax. Lens number 1 is then placed on the spacer. It should be moved around until the optical axis of the lens and the collimator are parallel. It should be noticed that it is not necessary to have the axis coaxial. One can observe the parallel condition by viewing the interference fringes in the eyepiece. Each surface, the reference surface and the first and second surfaces of the lens, return wavefronts with differing curvature. These three wavefronts form three sets of interference fringes similar to Newton's rings. When three surfaces have a common axis connecting their centers the three interference patterns are concentric. The eyepiece can be focused on the reflected image from one of the surfaces. It will appear as a small spot directly in the center of the ring pattern formed by the other two surfaces. There are cases where the interference fringes have such a large center that it is difficult to accurately center the point image of the third surface. If this happens, a reticle in the eyepiece can be used to help establish the center. There are several other methods to get around this. A large central ring in the interference pattern indicates that two of the surfaces have their centers close together. If this happens one can add a centered lens to the stack to introduce more centers with smaller rings. If the original collimating beam was not sufficiently well set normal to the reference surface, it will not be possible to bring all the images together. The turning mirror then has to be adjusted as well as movement of the lens to bring all the interference rings concentric. Once the lens has been centered on the optical axis of the reference plate, it may be cemented to the cell with an ultraviolet setting cement.

3. Spacer 2 is then placed on the lens number 1. The second lens is placed on the spacer. Spacer 2 is then moved about on the lens 1 until the reflections from surfaces 3 line up with those from the previously aligned surfaces. When this is accomplished, the cell should be cemented to the lens 1. Finally the lens 2 is moved about until surface 4 is centered.

4. Spacer 3 and lens 3 are then placed on top of the stack and assembled in the same manner.

5. Finally the top spacer 4 is put on the lens. It is moved about until the top surface is parallel to the bottom surface. Then the top and bottom spacers should be clamped together to maintain the minimum overall length of a centered system. The barrel that goes around the outside has no need for precision or stability. The stability of the system is built into the spacers and the lenses which really are what is important about the lens.

There are many alternatives to this concept of lens assembly which used the collimator alignment principle. For example, it may be better to mount the lenses one at a time in the spacers and then stack them together two at a time. It has been pointed out that the lens spacers do not have to be round and the lens can be put into a centered condition before the cementing takes place. Clearly a round spacer is preferred, for then the lens will seat evenly and there will be less possibility of distorting the lens when the pressure is put on the stack to maintain the minimum space. Round spacers also make a surer determination of the lens spacing. This method of mounting merely requires less precision. Figure 4 shows a mounting where the spacers actually do not touch. The spacers touch both optical surfaces. An alternate procedure is to mount only one spacer to a lens. The airspace is then maintained by the spacers' contacting each other. Figure 5 shows a cross-section view of such a case. This type of mounting is necessary when the air space is very thin, as in an airspaced telescope doublet. If this procedure is used, the spacers must be made exactly plane parallel. They may be cemented with a groove around the outside. Ability to disassemble is an important consideration, for unless extreme care is taken in measuring all the components before assembly there may be some thickness or surface errors which will degrade the image. If this is so and the lenses are expensive, it may be necessary to disassemble and replace the offending problem.

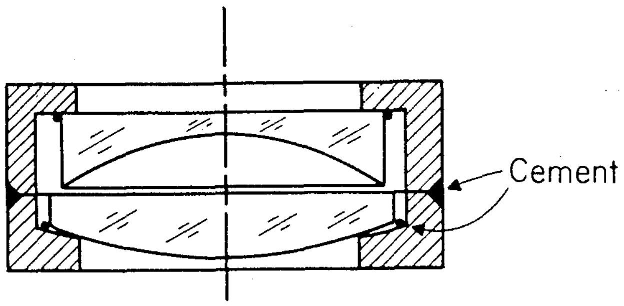

Fig. 5. Mounting with lenses cemented to only one cell. Lens cells must be plane parallel.

The method has been tried out in a few experimental assemblies, and the results indicated promise. The accuracies obtainable for centering appear to be adequate for even the most precision lens types. The experiments showed that lenses could be centered within ±2 μm. The ability to center seems to be limited primarily by the techniques used in positioning the lenses, and the care one takes in observing the concentricity of the moire fringe patterns. A well-designed collimator system and appropriate tooling in the assembly stage are essential to enable one to achieve the inherent capabilities of the system.

Summary

It has been shown that in principle lenses can be assembled with near-perfect centering without precision on all the dimensions of the parts. The emphasis is placed on the precision of the spherical surfaces and the thickness of the lenses, and spacers. The method places emphasis on the assembly procedure. It requires good instrumentation and operator skill in the clean surround of the assembly room.

References

1. Modern Optical Engineering, Warren Smith, McGraw-Hill (1966), p. 429.
2. U.S. Patent 3,507,597, E. M. Brockway et al., Lens Axial Alignment Method and Apparatus.