Diamond-turning applications to multimirror systems

Mark Craig Gerchman

Pneumo Precision, Incorporated
Precision Park, Keene, New Hampshire 03431

Abstract

Diamond-turning applications for the opto-mechanical assembly of multimirror systems are given. These applications are categorized into three construction types: one-piece (monolithic) systems; assemblies using radial location surfaces; and assemblies employing non-radial location surfaces. A cross-sectional schematic is used to illustrate each application. The construction types are analyzed with regard to ease of manufacture, ability to hold assembly tolerances and limitations.

Introduction

One means for producing catoptric optical systems is diamond-turning. This technique is selected for a variety of reasons. It is chosen primarily because it produces aspheric surfaces with relative ease. Another reason is its ability to incorporate integral mounting surfaces in metal mirror substrates.

This paper will describe how these integral mounting surfaces can be used in the construction of various multimirror systems. The multimirror systems discussed are centered optical systems. All optical surfaces share a common axis and are generated rotationally. All components, spacers and housings have geometries that allow direct diamond machining. The constructions do not provide for relative component adjustments at assembly.

All catoptric systems have unique optical and opto-mechanical considerations.[1] As the specifications of diamond machined optical components and their manufacturing considerations are specialized[2], not all of the assembly techniques presented here are appropriate for some applications. However, all of the techniques reviewed here have been successfully produced and are now functioning in their respective applications. These applications include extremes in thermal environments (eg. cryogentic and high energy application requiring cooling) and vibrational environments (eg. pyrotechnic shock and launch conditions). The determination of suitability of a fabrication technique for a particular application is the responsibility of the system designer.

This description of diamond-turned assembly techniques begins with simple two-mirror systems and progresses to multimirror applications. For each application a cross-sectional schematic will be used for demonstration. These techniques are reviewed with regard to ease of manufacture, ability to hold assembly tolerances and limitations.

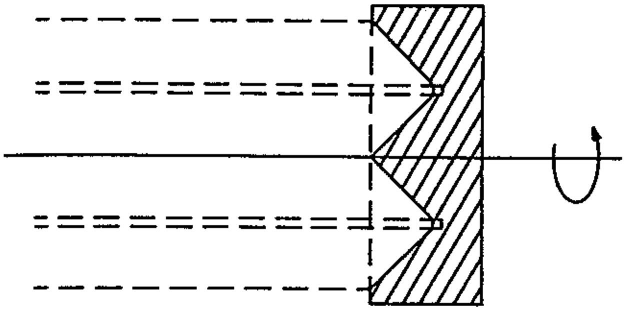
One-Piece(Monolithic)Systems

One-piece systems are unique to diamond-turning. They represent an assembly construction form that does not exist in conventional optics. By diamond-turning all surfaces of a multimirror system on a single component, the need for component assembly can be eliminated and system integration time reduced. In addition, the optical tolerances of relative component despace, tilt and decenter can be held to typically less than 0.25 um (0.00001 inch) when the diamond-turning can be performed without repositioning the cutting tool.

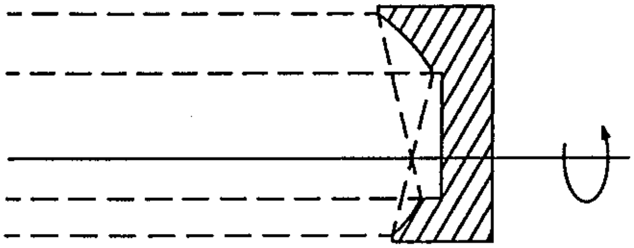
These systems are not without their limitations. Figure #1 represents a monolithic waxicon, one of the simplest multimirror systems. A waxicon is so named because it is formed by a nested pair of axicon surfaces whose cross-sectional profile forms the letter "W". Although relatively easy to diamond-turn, it is difficult to post-polish or evaporatively thin-film coat. All monolithic waxicons require a small undercut at the junction of the two optical surfaces for tool clearance.

Figure #2 shows a more complicated monolithic assembly. This schematic diagrams an opposed set of confocal 90 degree off-axis parabolic mirrors operating as a beamexpander. In addition to the obvious assembly advantage, this off-axis assembly can be machined in pairs. This is done by doglegging the support for the two mirror surfaces around the rotational axes. Two systems can thus be machined simultaneously in this yin-yang arrangement.

The types of optical designs that can be produced by this monolithic technique are restricted. In figure #2, the beamexpander is working at a magnification that permits the two surfaces to be revolved such that the diamond tool does not strike the secondary while the primary is being machined. This can not always be achieved. Usually image forming systems produced this way are forward folding in design. Optical systems that have their focus reflected back towards the primary are generally fabricated in multiple component assemblies.



MONOLITHIC WAXICON BEAMEXPANDER
FIGURE 1



OPPOSED 90° PARABOLIC BEAMEXPANDER
FIGURE 2

Systems With Radial Location Surfaces

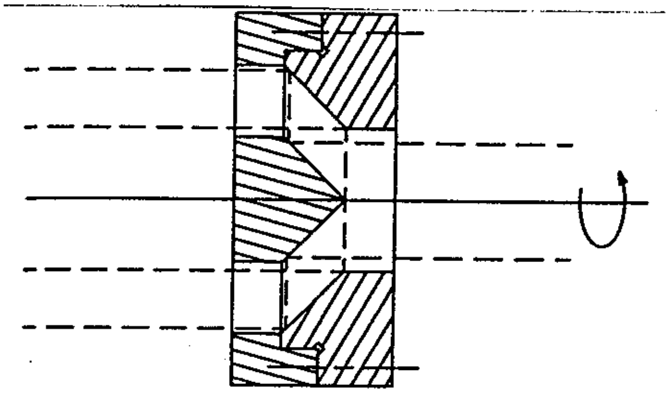
An assembly of multiple components can be designed by taking advantage of their common rotational axis. Restrictive decenter tolerances can be held by designing components with radial location surfaces. For surfaces with diameters of less than four inches, diametrical tolerances are typically 2.0 um (0.00008 inch). The associated decenter tolerance results from the clearance required for mating the location surfaces. A guide for determining this clearance is the ANSI standard for Preferred Limits And Fits For Cylindrical Parts.[3] Locational clearance fits (LC1) are generally the most appropriate. Transition, interference and shrink fits are not used because of stress, galling and re-assembly considerations.

Flange mounting surfaces control tilt and despace tolerances. The mounting face should be on the same side as the mirror surface so they can be machined in the same operation. Because surface finish is not as important on the mounting surface, always machine to establish a mounting dimension after a suitable optical surface is obtained.

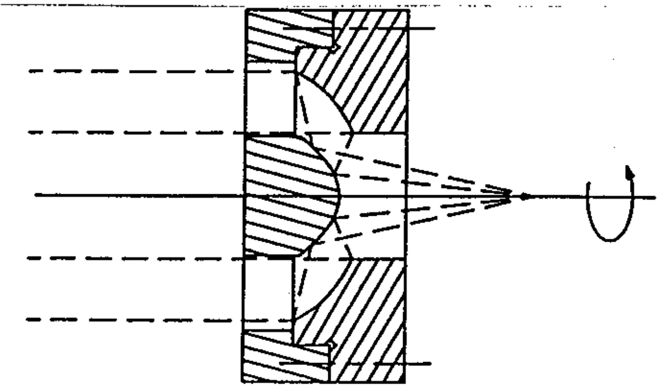
Figures #3 and #4, although for different applications, demonstrate the same principal of construction. Figure #3 displays a reflaxicon beamexpander. Figure #4 shows a fast Cassegrain telescope with a 90 degree parabolic primary. Their construction has the primary mirror component being nested into the secondary's ID flange and bolted together through the shoulder. The secondary mirror surfaces are supported by integral spiders to their outer mounting surfaces. Applications that permit this simple two piece construction have short axial dimensions.

When the application calls for greater axial separation between components, separate housings are employed. Figure #5 displays a typical example of a Cassegrain system in which the assembly is constructed from three parts. As in the previous two examples, the secondary optical surface is supported on an integral spider to its outer mounting surfaces. A barrel housing is now used in place of the direct component-to-component mounting. Here the overall length of the housing is used to space and control tilt between the components and the same form of ID/OD mounting is used to control the decentration. For ease of manufacture the housing is generally fabricated first. Its overall length then measured accurately. The components are then fabricated. On one component the spacing between the theoretical optical surface vertex and its flange mounting face is adjusted to account for the measured value of the housing length to preserve vertex-to-vertex spacing.

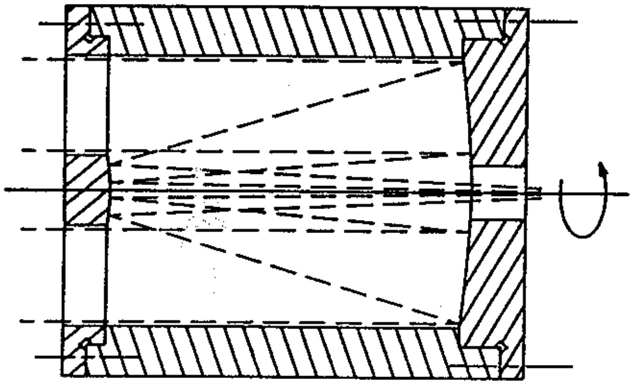
Sometimes more components are included in the assembly. Figure #6 demonstrates how a straight bore tube can be used with a precision spacer to achieve a slightly different system design. For this Schwarschild microscope objective the mirror reference location surfaces are separated by a precision spacer. The decentration of the components is controlled by their fit to the straight bore of the housing. The components are held in place by the use of two retaining rings. As with the slow Cassegrain housing it is common practice to fabricate the spacer first so that axial adjustments can be made with component flanges.



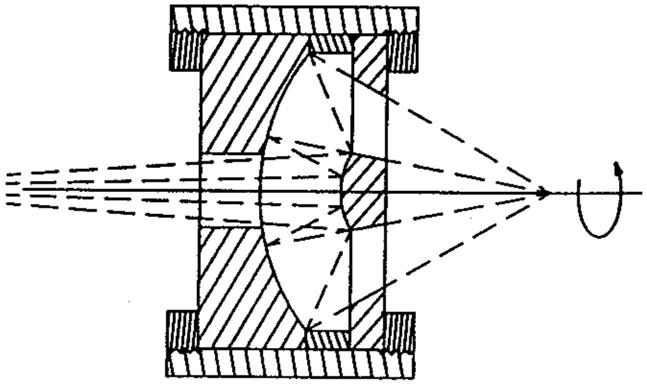
REFLAXICON BEAMEXPANDER
FIGURE 3



FAST CASSEGRAIN TELESCOPE
FIGURE 4



SLOW CASSEGRAIN TELESCOPE
FIGURE 5



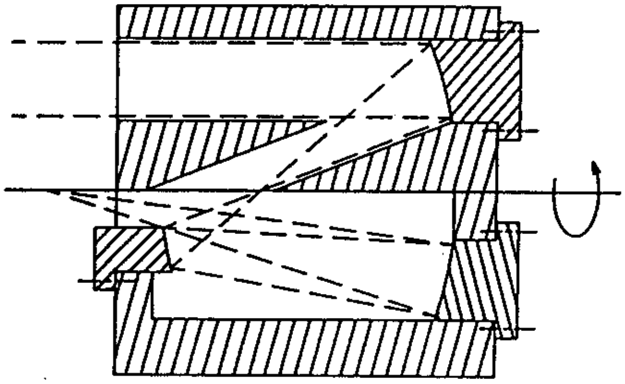
SCHWARZSCHILD MICROSCOPE OBJECTIVE
FIGURE 6

Systems With Non-Radial Location Surfaces

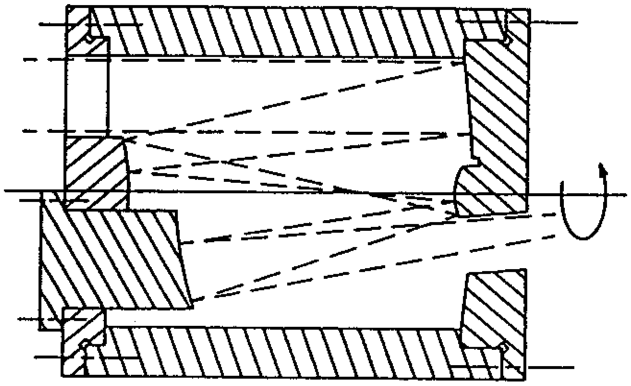
Occasionally space constraints prohibit the use of radial location surfaces. Decenter is then controlled by precise doweling techniques. Tolerances for decentration are typically greater with doweling technique than when using radial location surfaces. The errors are doubled because the component needs to be doweled twice. First to the fixture plate for diamond-turning, typically 5.0 um (0.0002 inch), then the component must be doweled at assembly, another 5.0 um (0.0002 inch). The component is also capable of self-centered rotation (clocking) resulting from the doweling. This effect compounds the error in the optical system.

Figure #7 shows a three-mirror assembly composed of four main components. The three mirrors are inserted into a monolithic housing and doweled to form the assembly. The manufacture of this system involves several steps. First, the housing would have the through hole drilled for the primary mirror. Blind holes would then be drilled for the secondary and tertiary mirrors. The angled hole would be machined for light path clearance between the primary and the secondary. The two mounting faces of the housing would be diamond-turned to yield parallel mounting surfaces. The separation between surfaces would then be measured. Precision dowel holes would be drilled in the mounting faces to permit the pinning of the components at assembly. The components would then be cut and their flange mounting faces machined to adjust for the measured value of the housing's mounting surface separation. Occasionally, these types of off-axis components require mounting flanges to be machined in a different setup. The use of additional setups results in looser axial tolerances.

Figure #8 shows a four-mirror system that combines all of the mounting techniques. The primary and tertiary mirrors are monolithic in structure. The quarternary mirror is inserted into the secondary mirror. These four mirrors are mounted into a holding that employs radial location techniques. This system could also be constructed by other combinations of these assembly techniques.



INSERTED THREE-MIRROR SYSTEM
FIGURE 7



COMBINATION FOUR-MIRROR SYSTEM
FIGURE 8

Conclusion

These examples have shown how various multimirror systems can be constructed. By using diamond-turning, these techniques have the advantage of being able to hold very accurate tolerances. In addition, the problems usually associated with the assembly of multimirror systems are greatly reduced.

References

1. "Annotated bibliography of optomechanical design," O'Shea, Donald C., Optical Engineering, vol. 25, no. 10, pp. 1160-1170 (1986).

2. "Specifications and manufacturing considerations of diamond machined optical components," Gerchman, Mark Craig, in Optical Component. Specifications for Laser-Based Systems and Other Modern Optical Systems, Robert E. Fisher and Warren J. Smith, ed., Proc. SPIE 607, pp. 36-45 (1986).

3. Preferred Limits And Fits For Cylindrical Parts, ANSI B4.1-1967 (R1979), American National Standards Institute.