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Mounting and Alignment Technique for an Eccentric Pupil Collimator

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ABSTRACT

Structural stability of mounts and housings is critical to the success of high performance optical designs. Often, however, stability is at odds with the multiple degrees of freedom required on the mounts for accurate alignment. Here we describe the technique used to accommodate these two factors for an eccentric pupil collimator.

1. INTRODUCTION

Positional tolerances on reflective optical systems are generally very tight if image quality is to be preserved. This demands two things from the support structure: means by which the optical surfaces can be initially adjusted to be within the tolerances, and long-term stability in order to maintain these tolerances. These two requirements can often be in conflict with one another – the more degrees of freedom the system has, the less stable it is likely to be. Potential problems in this area can be minimized through the development of an efficient mounting and alignment technique early on in the design process. Such a technique was developed and implemented at the Center for Applied Optics for an eccentric pupil collimator. The method, based on precision machining and diamond turning technology, yielded an easily aligned system with good long-term stability.

2. OPTICAL SYSTEM

The goal of this effort was to design, build, and demonstrate a compact infrared collimator for use in a field-based FLIR test set. The optical specifications were based on the tests to be performed, and it was determined that an unobscured design was required to achieve the proper wavefront quality. Mechanically the system had to fit within a modified electronics rack with the beam emerging at a comfortable working height. It was also desired to keep all optical surfaces vertical to avoid dust collection and to have the source at or above the optical axis to minimize thermal gradients. These design specifications are summarized in Table 1.

OPTICAL	MECHANICAL
Focal Length = 40±.5'	Width = 22'
Entrance Pupil = >7.9' (unobstructed)	Depth = 29' - 40'
Field of View = 3 degrees (full field)	Height = 40' - 42'
Geometric Spot Size	Beam Centerline Height
= ≤0.1 mrad @ ≤0.5 degrees	= 36±2'
= ≤3.0 mrad @ 0.5to3.0 degrees	Thermal Source at or above centerline of system
Spectral Range = 3-14 um	
IR Transmittance = ≥0.80	
Baffles as neccessary	

Table 1. Design Specifications for the Infrared Collimator.

As a result, an off-axis Cassegrainian-type system was developed as illustrated in Fig. 1. The 8.0 inch diameter section of the parabolic primary is centered 7 inches above the axis. The hyperbolic secondary is 5.75 inches in diameter and contains higher order aspheric deformations in order to correct the system in this eccentric pupil configuration. It is diffraction-limited at 10.6 microns within the central 0.5 degree cone with rms spot sizes of less than 1 mrad across the rest of the 3 degree field. The overall length is less than 10 inches allowing the entire collimator (optical system, target wheel, and source) to fit straight in the rack front-to-back without being folded. Thus, the design achieved all of the optical and mechanical specifications. A tolerance analysis was performed to maintain image quality within the limits stated in Table 1. The tolerances on mirror positions were found to be on the order of an arc minute for tip and tilt and a thousandth of an inch for decenter and spacing. The exact values are listed in Table 2.

	PRIMARY	SECONDARY
Vertical Tilt	0.5 arc min	2.4 arc min
Horizontal Tilt	1.6 arc min	7.5 arc min
Vertical Decenter	0.0027'	0.0027'
Horizontal Decenter	0.0009'	0.0009'
Spacing	0.0013'	0.0181'

Table 2. Positional Tolerances for the Infrared Collimator.

3. MOUNTING AND ALIGNMENT

There were two major difficulties to be faced in aligning this system: (i) the off-axis primary did not contain its own vertex and (ii) both surfaces were aspheric. Precision machining and the diamond turning process were used together to overcome these problems. Along with each mirror, an alignment flat was fabricated. To begin, guide pins were placed in the blanks to within 0.0001 inch position accuracy using a jig bore. In this way, each mirror and its corresponding flat could be located in the same place (on the diamond turning machine and subsequently on the mount) with a high degree of precision. The primary alignment fixture was made large enough to include the axis of rotation where a small (0.001 inch) cone-shaped tip was left corresponding to the primary vertex location as shown in Fig. 2. Both sides were diamond turned to within a few arc seconds parallelism while the back surface of the mirror was machined to within 10 arc seconds perpendicularity to the axis of rotation (optical axis). A small flat was machined at the top of the primary for accurate thickness measurements. The secondary mirror and its alignment fixture were similarly fabricated. Since the secondary was rotationally symmetric, only one centered guide pin was required. The alignment problem was thus reduced to positioning the two flats perpendicular to and centered on a line with the correct spacing. A housing was then designed with the minimum amount of adjustments necessary to accomplish this task (see Figs. 3 and 11). Rather than aligning the primary to an externally fixed optical axis, it was decided to align the system axis to the primary mirror optical axis as described below. This allowed the rather large primary to be rigidly mounted to the housing backplate resulting in much greater stability. The smaller secondary required a 5 degree-of-freedom mount. A flange on the mount was held between the housing frontplate and a collar bolted to the plate. With the collar slightly loose, the mount could be adjusted laterally with nylon-tipped allen screws that pushed against the flange. The collar could then be tightened to hold the desired position. Angular adjustment was accomplished by rotating two wedged rings located just behind the mounting surface with respect to one another. Locking screws could then be tightened from the rear of the mount to hold this position. In both of these cases the locking screws needed to be loosened only a very small amount in order to make adjustments. This caused a minimum amount of change between unlocked and locked positions. Finally, a fine-pitch screw located along the axis of the mount was used for longitudinal positioning. This was held in place with a locking nut. The source assembly was also placed on 5 degree-of-freedom positioner. Lastly, a removable alignment window (described below) located at the collimator aperture required tip and tilt adjustment. This was accomplished with three adjustment pins (threaded at one end with locking nuts) that were held against three standoffs on the housing frontplate. The housing, mirrors, and mounts were all made of aluminum.

With the method and required apparatus already in place, the alignment of the collimator was accomplished easily in a short amount of time (about a day). To begin, the housing, with mounts installed, was firmly secured to an optical table. The primary alignment flat was mounted in the housing with the vertex tip facing the rear (Fig. 4). An alignment telescope/autocollimator held in a 4 degree-of-freedom mount was secured to the table about 1.5 meters behind the housing. In autocollimation, the telescope was adjusted to be perpendicular to the flat. Next, it was focused onto the surface of the flat and adjusted laterally to be centered on the vertex tip. This process was iterated until angular errors were below 15 arc seconds and lateral errors were below 0.00025 inch. The optical axis of the telescope was thus aligned to that of the primary. The primary flat was then removed and the secondary flat installed (Fig. 5). Using the mechanisms described above, this flat was adjusted to be perpendicular to and centered on the optical axis (alignment telescope remained fixed). The primary flat was then reinstalled and a 200X traveling microscope focused on the surface (Fig. 6). The primary flat was removed again and a precision gauge block adjusted to a length determined by the primary thickness, the secondary thickness, the secondary flat thickness, the primary sag, and the desired vertex spacing of 5 inches. The gauge block was then placed in the housing flush against the secondary flat (Fig. 7) and the mount adjusted longitudinally until the end of the block was in sharp focus when viewed through the microscope. The angular and lateral position of the secondary was then rechecked and adjusted as necessary. This process was iterated until errors were equal to or below those for the primary as stated above. It should be noted that the microscope could be located out of the line-of-sight of the telescope during this procedure. Once well within tolerance, the mount was locked in place and the position rechecked. This required a few iterations to insure accurate alignment along with very tight locking for long-term stability.

An alignment window was required to provide the initial (one-time) source alignment and subsequent UUT alignment. This window was aligned to the collimator in the following manner. With the primary flat in place, the alignment telescope was moved to the front of the collimator and approximately centered in the aperture (Fig. 8). In autocollimation, the telescope was adjusted to be normal to the flat. The alignment window was then mounted to the housing faceplate (not shown in Fig. 8) and adjusted to be parallel with the primary flat. The adjustment pins were then locked. At this point, the actual mirrors were installed along with the source assembly (Fig. 9). The alignment target shown in Fig. 9 was selected and illuminated by a visible source. While viewing through the alignment telescope (still focused at infinity), the source was adjusted until the center pinhole was in best focus and centered on the reticle. Next, the source was adjusted angularly until the four outer pinholes were equally in focus. This was iterated as appropriate and the source assembly locked into place. The telescope and alignment window were then removed completing the alignment process (Fig. 10). Subsequently, UUTs could be boresighted to the collimator using the alignment window which, when mounted against the standoffs, provides an optical surface perpendicular to the collimator optical axis.

4. CONCLUSIONS

Figure 11 shows the completed prototype collimator (minus the side and face plates). During the alignment phase, a 6 inch drop test was performed with the flats installed in the locked mounts. Two such tests failed to move the system out of tolerance. Since that time (fall of 1988) the collimator's performance has remained within specifications as determined with resolution targets.

By the straightforward application of precision machining and diamond turning, a technique was developed resulting in an easily alignable system with good long-term stability. We are currently in the process of applying this method to an all-reflective four-element zoom telescope which will be reported in the near future.

5. ACKNOWLEDGEMENTS

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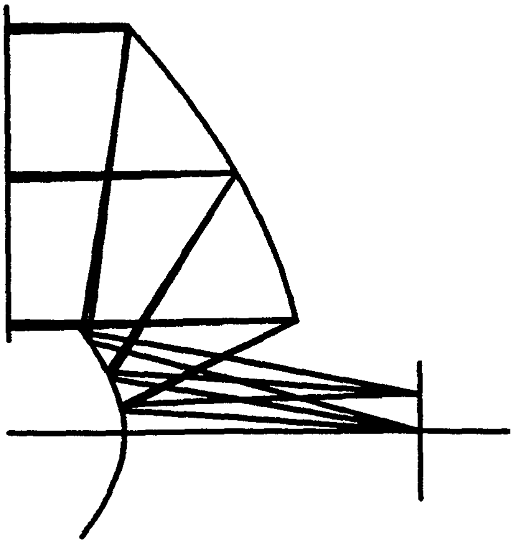

Figure 1. Side View of the Infrared Collimator.

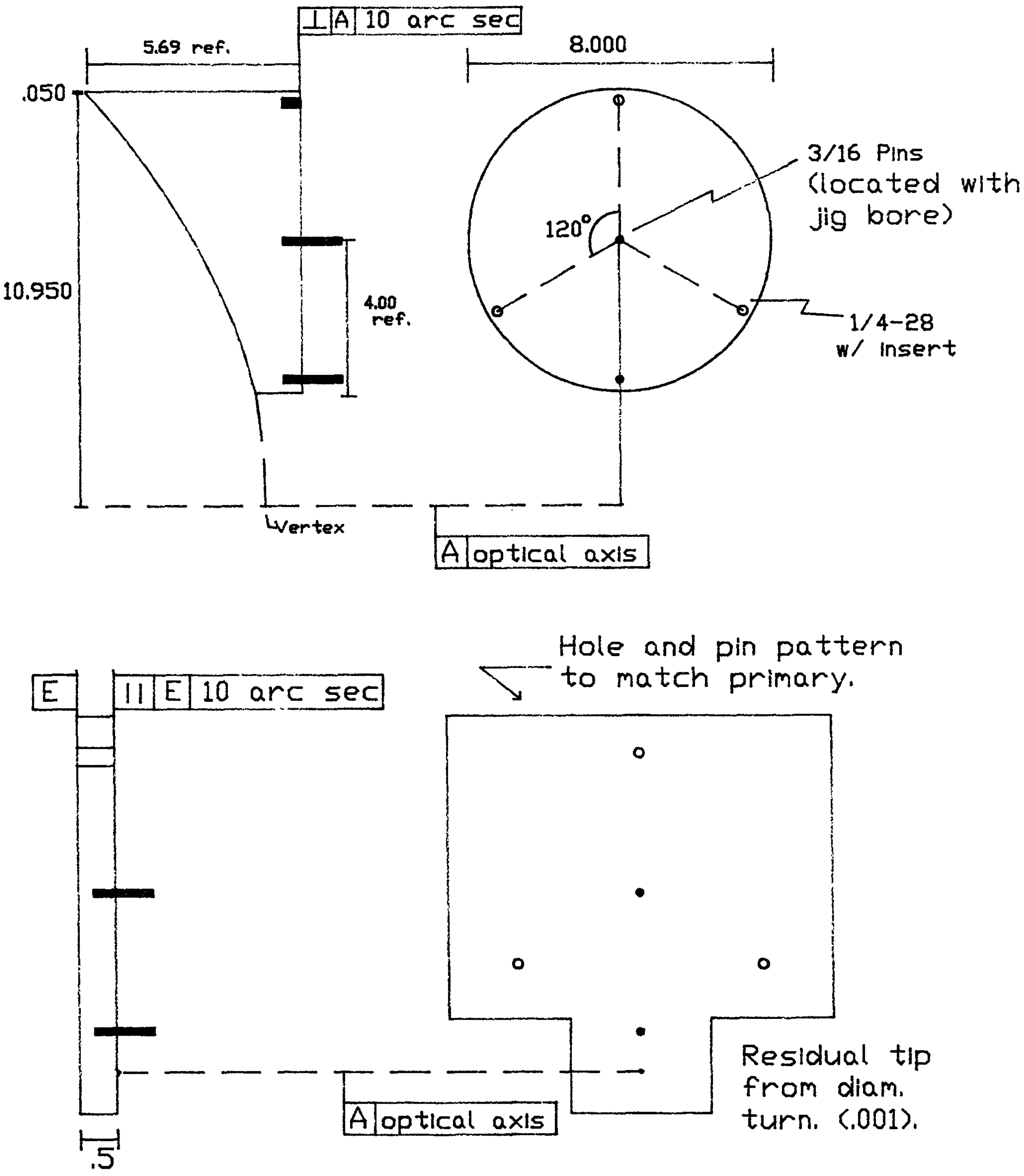

Figure 2. Primary Mirror and Alignment Flat.

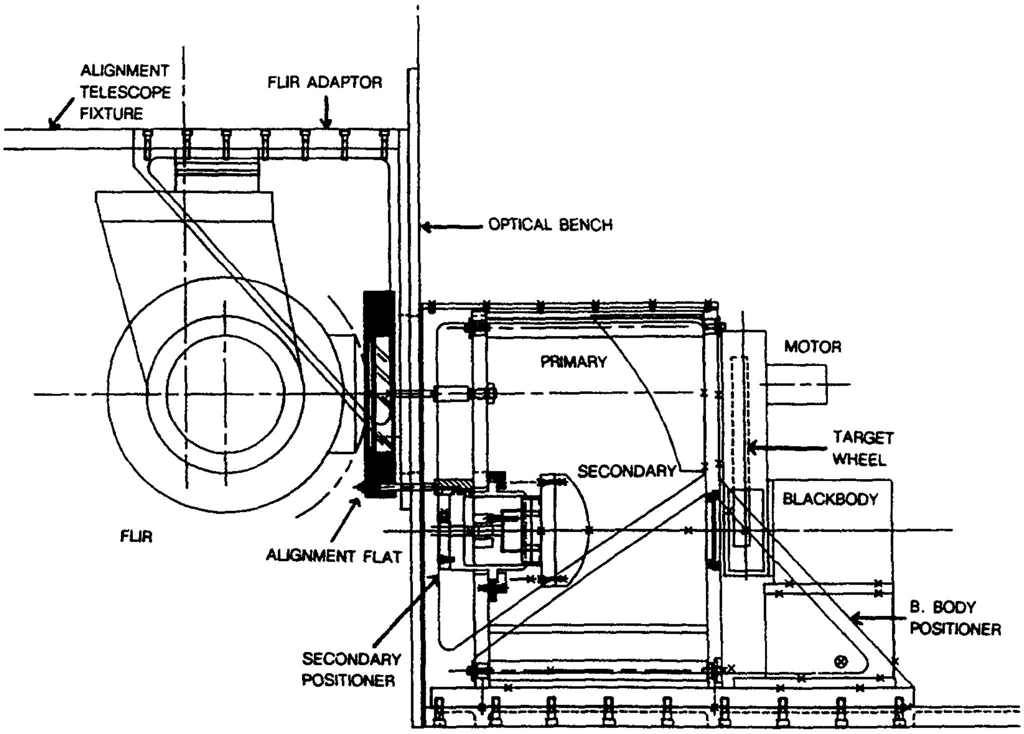

Figure 3. Infrared Collimator Layout.

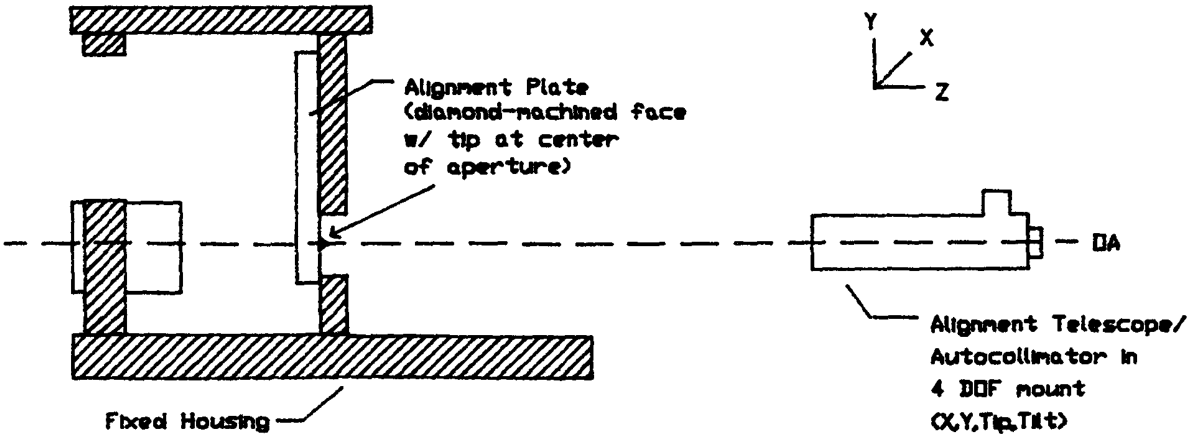

Figure 4. Optical Axis Determination.

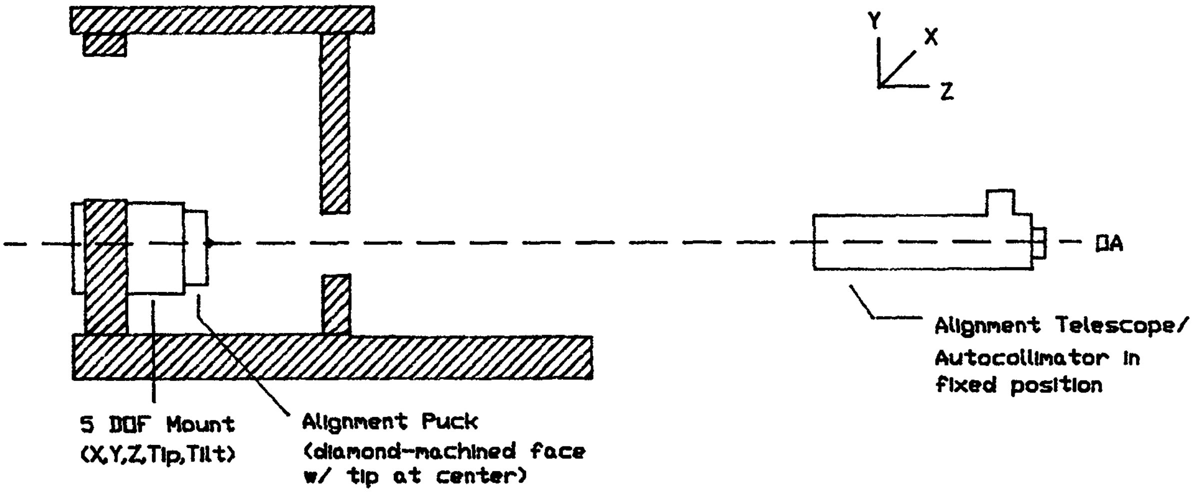

Figure 5. Secondary Alignment.

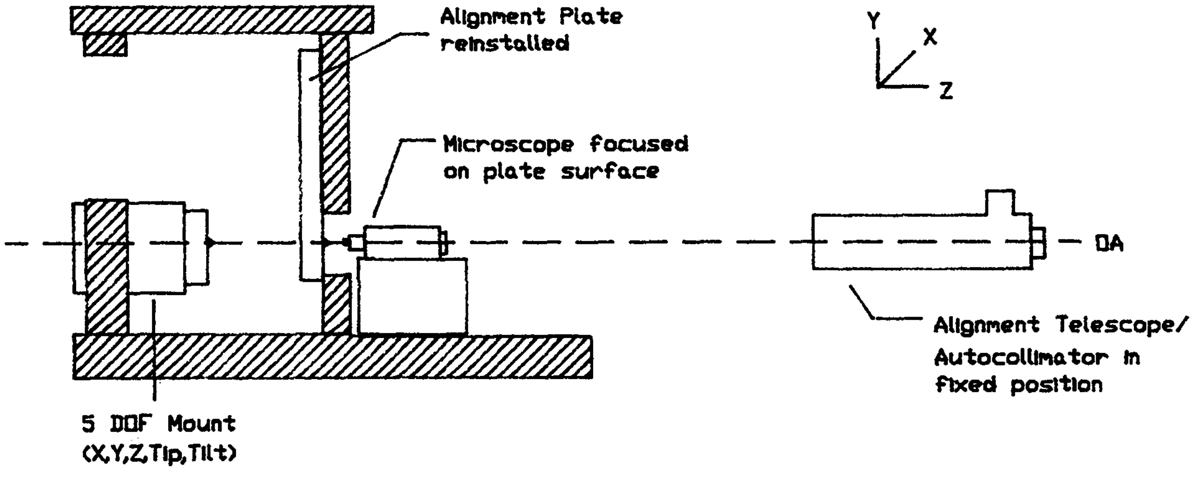

Figure 6. Primary Back-Plane Determination.

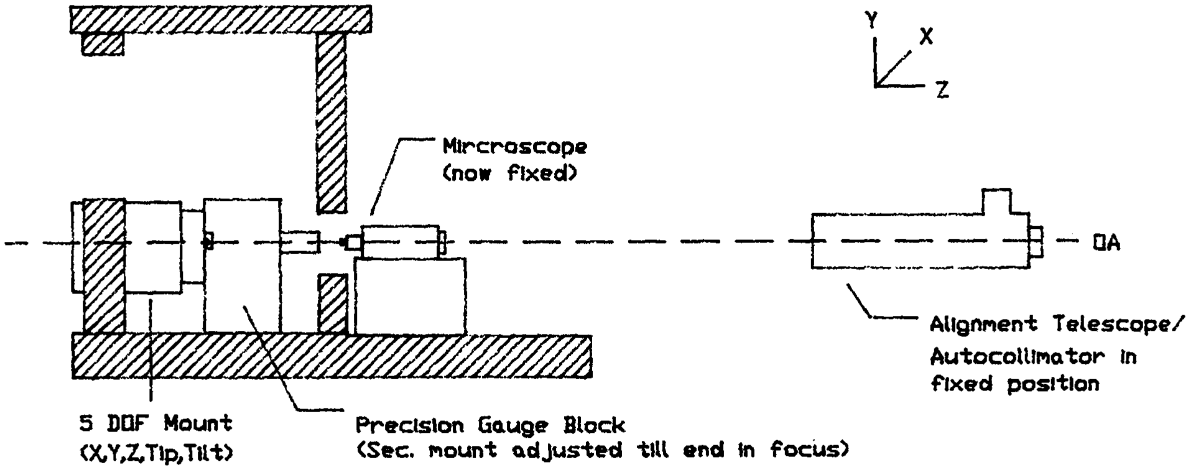

Figure 7. Primary-Secondary Spacing Adjustment.

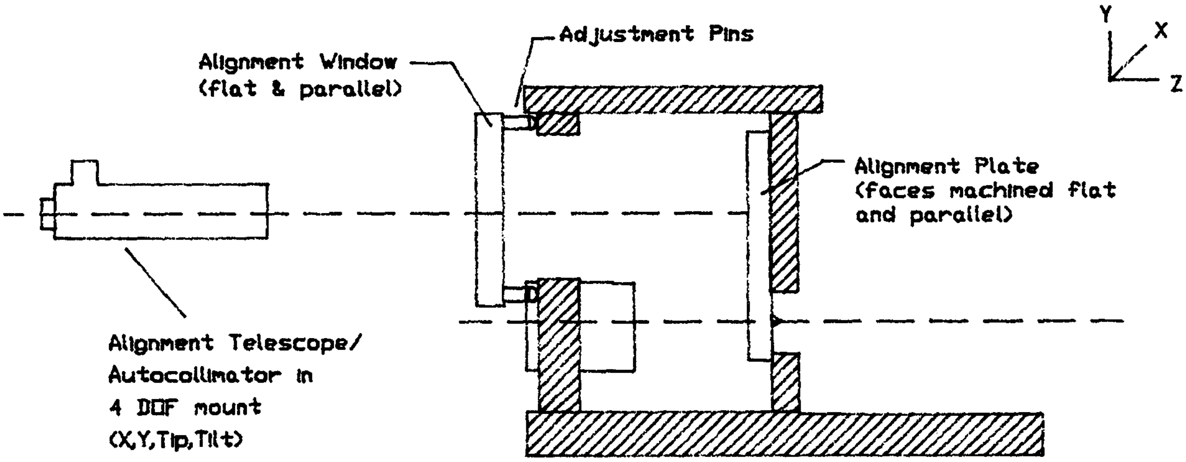

Figure 8. Alignment Window Adjustment.

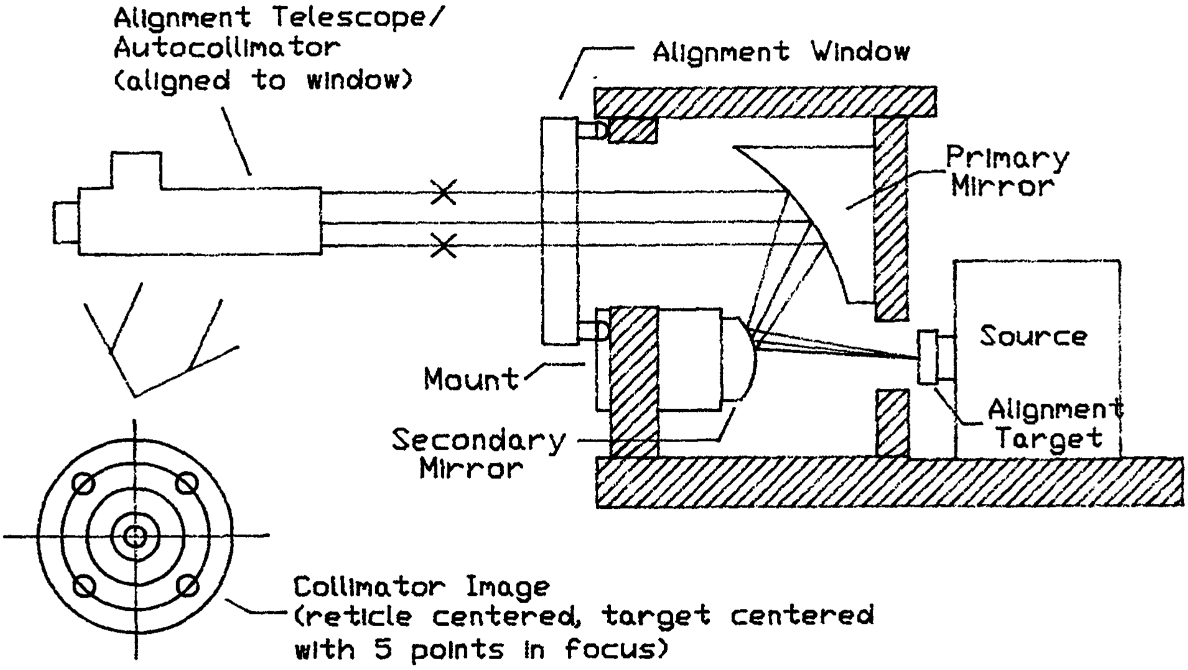

Figure 9. Source Assembly Alignment.

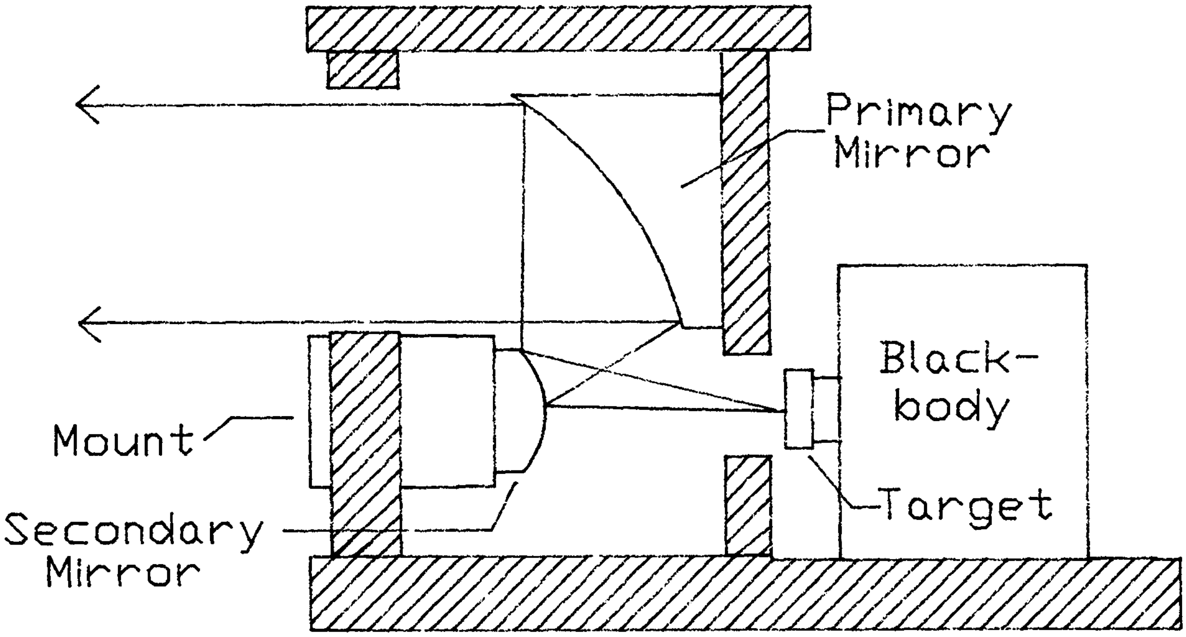

Figure 10. Aligned Collimator.

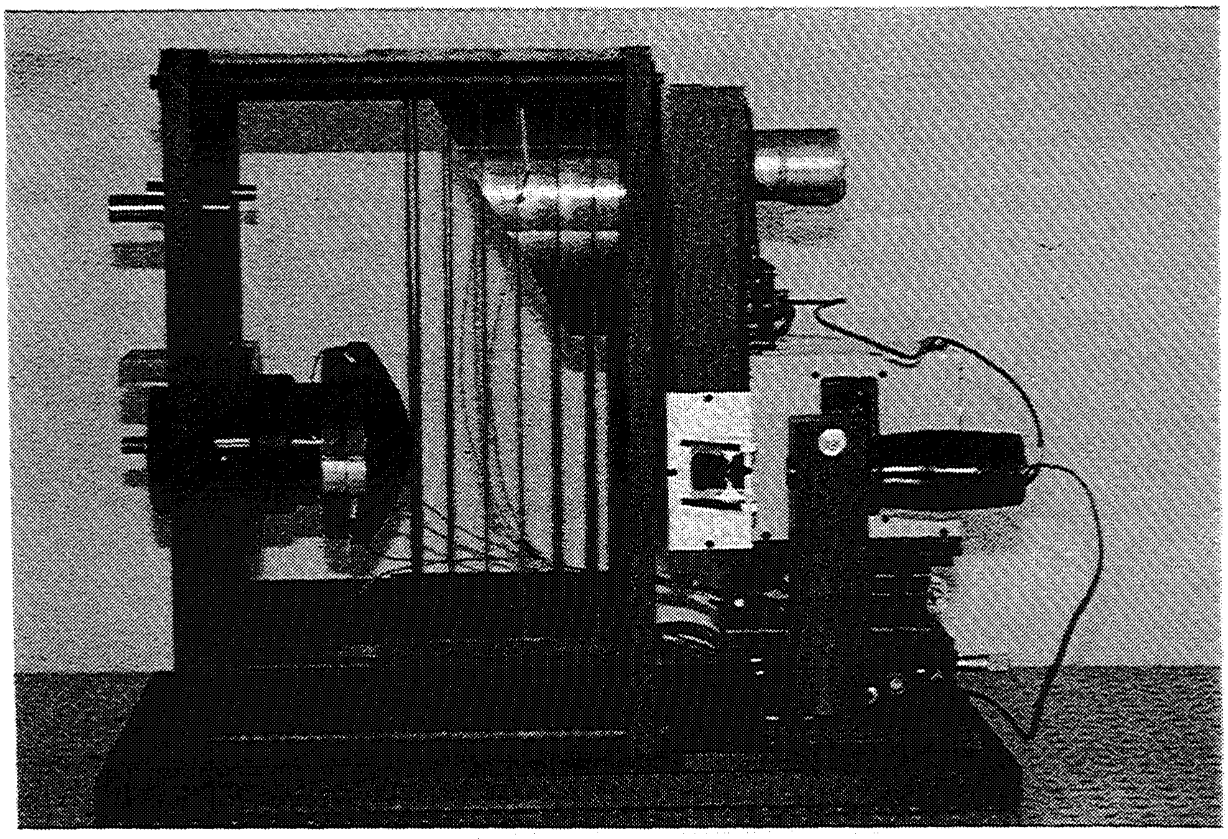

Figure 11. Prototype Infrared Collimator.