A Simple Technique for Accurately Measuring the Dihedral Angle of a Roof-Top Mirror

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Abstract
A simple, compact and inexpensive optical system is described which allows the dihedral angle of a roof-top mirror to be measured accurately. The system fits on a desktop and can be used to set and monitor the dihedral angle of the mirror. The ability to make adjustments while monitoring the angle is particularly useful when epoxy is used to secure the two plane mirrors that form the roof-top, since epoxy will tend to shrink as it cures.

Introduction
Since its development, the Martin-Pulpett interferometer (MPI)[1] has found extensive use in mid- and far-infrared astronomical and laboratory spectroscopic studies.[2,3,4] The MPI differs from a classical Michelson interferometer[5] in two principal respects: first, the dielectric beamsplitter is replaced by a wire grid polarizing beamsplitter and second, the plane, fixed and moving mirrors of the interferometer are replaced with roof-top mirrors. In addition, input and output polarizers are required in the MPI design.

The roof-top mirrors are key components of the MPI and while they are simple in concept, the problem of their alignment can be non-trivial. In general, a MPI with non-orthogonal roof-top mirrors will have four input and four output beams. Associated with each beam is an Airy diffraction pattern formed at the detector by the condensing optics. In order to maintain a high degree of interferometric modulation, the dihedral angles of the fixed and moving mirrors must be such that the diffraction patterns from each of the four output beams coincide within their central spots. The accuracy required of the dihedral angle thus depends on both the mirror aperture, D, and the wavelength of observation, λ.[2,6]

To a good approximation, $\lambda/4D$ is the maximum allowable error in the dihedral angle.[2] For example, for λ = 350μm and D = 75mm, the dihedral angle must be 90° ± 4′, an error that is discernible with the unaided eye. However, as polarizer fabrication methods improve, MPIs are being used at shorter wavelengths, and for λ = 10μm and D = 50mm, the dihedral angle must be 90° ±10″. While a Fizeau interferometer[5] can be used to measure the angle of a roof-top mirror, such systems require an extended monochromatic source and tend to be bulky and expensive. In this article we describe a simple, compact and inexpensive optical method for measuring the error in the dihedral angle of roof-top mirrors at the arcsecond level.

Alignment technique
The alignment technique is based on the priniciple of autocollimation and uses a commercially available refracting telescope, commonly known as a finder telescope.[7] In our case, the 80mm diameter, coated achromat objective lens has a focal length of 500mm. The eye lens has focal length of 12mm, yielding a magnification of 42x, and includes a double crosshairs reticle which, for astronomical purposes, is normally illuminated with a red LED. The telescope features a dew cap, a cylindrical extension in front of the objective, which helps to prevent the formation of dew on the lens. We have replaced the low intensity red LED with a new generation high intensity white LED,[8] which increases the amount of light directed outwards to the roof-top mirror, thus making it easier to observe the reflected crosshair images.

A schematic of the alignment telescope is shown in Figure 1. Initially the position of the reticle is adjusted so that it lies in the focal plane of the objective lens (this is readily accomplished by first focusing on a star or distant object). In this condition collimated beams corresponding to each element of the illuminated crosshairs are projected outwards from the objective lens towards the roof-top mirror. The adjustable roof-top mirror (one design is shown in Figure 2), is then positioned in front of the telescope inside the dew cap which conveniently acts as a light baffle. In practice, this baffle together with the high intensity white LED, allows the dihedral angle to be measured under ambient laboratory lighting conditions.

In this autocollimation technique, the outward beam is reflected back to the objective lens by the roof-top mirror, producing an image of the crosshairs in the focal plane, where it can be examined with the eye lens in the same way that one would examine the image of a star. Deviations of the dihedral angle from 90° will appear as a doubling of the crosshair image as indicated in Figure 1. If the dihedral angle exceeds 90° the doubled images will appear to diverge as the eye lens is moved inward; conversely if the angle is less than 90° the doubled images will appear to converge as the eye lens is moved inwards.

The crosshairs, which form part of the eye lens assembly, can be conveniently set at any angle by simply rotating the assembly. Set-

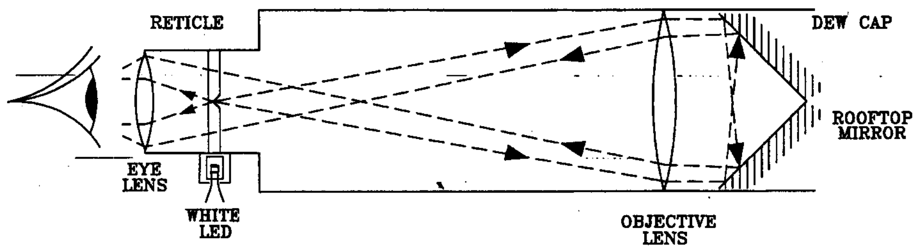

Figure 1. Diagram of the alignment telescope showing the path of two rays striking a roof-top mirror whose dihedral angle is less than 90°.

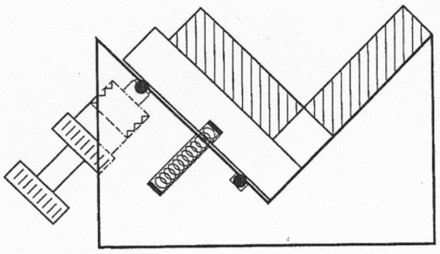

Figure 2. A diagram of an adjustable roof-top mirror assembly. The lower mirror is secured with epoxy, the upper mirror can be tilted by means of the differential screw to adjust the dihedral angle.

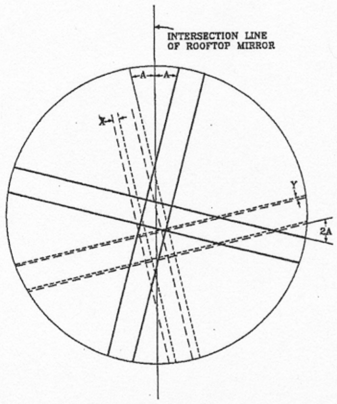

Figure 3. A diagram of the cross hair images (dashed lines) seen when the illuminated reticle (bold lines) is oriented at an arbitrary angle, *A*, with respect to the intersection line of the roof-top mirrors and the dihedral angle is not 90°.

ting the crosshairs at an arbitrary angle, *A*, with respect to the intersection line of roof-top mirrors yields images similar to those in Figure 3, which makes it easier to see the reflected images against the brighter object. The angular separations of the images are given by $X = 4\delta \cos(A)$ and $Y = 4\delta \sin(A)$, where δ is the deviation of the dihedral angle from 90°. The accuracy that can be achieved with this alignment technique depends on the scale of the crosshairs and the focal length of the objective lens. The reticle used in our design has a line width of 20μm and a spacing of 0.2mm. We have found that it is relatively easy to estimate the angular separation to 1/10 of the reticle spacing (i.e., 20μm). With a 500mm objective focal length, this corresponds to an angle of ~8". Since the observed angular separation of the images is 4δ, an arbitrary dihedral angle can be determined to an accuracy of 2". The increase in contrast of the overlapping crosshair images as the dihedral angle approaches 90° makes it possible to set the dihedral angle to a precision of 90° ±1′′.

Conclusion

The compact optical system described above fits on a desk and allows one to adjust the dihedral angle of a roof-top mirror while viewing the reflected crosshair images, in a well-lit laboratory environment. It has been used to test, and monitor the change in, the dihedral angle of a variety of roof-top mirror designs at the arcsecond level. In particular it has played a key role in monitoring the change in angle that occurs when the low expansion epoxy, used to secure the plane mirrors, shrinks as it cures. We have found that changes in the dihedral angle of ~10" are not uncommon. Furthermore, since the final hardening of the epoxy tends to take place rapidly, it is easy to miss the last window of possible adjustment. Finally, the system is extremely useful for quickly checking, often in situ, the dihedral angle of any roof-top mirror.

Acknowledgments

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