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# ACTIVE IMAGE RESTORATION WITH A FLEXIBLE MIRROR

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## Abstract:

Using a feedback-regulated moveable mirror we have stabilized the fringes of a Michelson stellar interferometer against shifts introduced by a 1000-ft light path through turbulent air; motion pictures will be shown of this system in action. We will also present preliminary results for a novel six-element flexible mirror to be used in an image sharpening system for a 30" telescope.

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*Work performed under the auspices of the U. S. Energy Research and Development Administration.

+ Presented by Frank Crawford

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Except on unusually calm nights at the best locations, atmospheric seeing limits the resolving angle of large telescopes to about 1 sec of arc, the diffraction limit of a 10 cm diam telescope. Our goal is to obtain diffraction limited images from large telescopes, by real-time compensation of the phase distortions introduced by the atmosphere.[1]

We intend to compensate the phase at different segments of the telescope aperture by means of a small flexible mirror located near the focus of the main mirror and consisting of separately moveable segments. Phase distortion due to atmosphere close to the telescope should be correctable over a large field of view; distortions due to the entire height of the atmosphere should be correctable over a field of view of about 1 arc sec, the size of the isoplanatic patch.

We use the light from the object under observation in order to determine the required phase shifts; we require no nearby bright unresolved star. Our technique consists in moving the flexible mirror segments so as to maximize the image sharpness.[2] For an extended object (but lying within the isoplanatic patch) the image sharpness can consist of the integral of the square of the light intensity integrated over the image plane. For an unresolved star the sharpness can be simply the intensity through a pinhole in the image plane, of a size equal to the expected diffraction limited image.

We have so far built three flexible mirrors. The first one started with a circular optical flat 1/4 in thick and 2 1/8 in diameter. Six circular grooves of 3/8 in O.D., located with centers at 60° intervals on a 1 1/2 in diam circle, were trepanned almost through the flat from the back side. Pushing or pulling on the remaining center post gives a moveable mirror segment of about 3/8 in diameter. An iron cylinder was glued to each center post and pulled on by a small solenoid. We can comfortably pull each segment through about two fringes, i.e. two half wavelengths of visible light. With the solenoid we can pull but not push. We therefore bias each solenoid with a current sufficient to pull each segment about one fringe and then either allow the solenoid to relax or pull harder, under command of the feedback system. We thus have a correctable range of ± one wavelength phase distortion of the incident wave, for each mirror segment. (Our second and third flexible mirrors, described later, have ranges of at least ± 5 wavelengths.)

This first flexible mirror was installed as the secondary mirror in a 4 in diam f/12 Cassegrain telescope. As an artificial star we used a He-Ne laser located 1200 ft from the telescope. In most of our tests we used just two of the six moveable mirrors, sometimes the two closest (3/4 in apart center to center) and sometimes the farthest (1 1/2 in apart). At the plane of the objective mirror the two closest mirror segments corresponded to two 3/4 in diam. circles, 1 1/2 in apart. Therefore at the image plane the two closest mirror segments gave a two-hole interference pattern, consisting of about 4 fringes in the central lobe of the one-hole diffraction pattern. An eyepiece of 1 cm focal length gave a 100 x magnified image 1 meter beyond the primary focus. At the magnified image the fringes were thus about 2 mm apart. At the magnified image plane it would have been consistent with our "maximize-the-image-sharpness" concept to put a single slit of width 2 mm (or less) and maximize the current through that slit, but we used a different method. For a system of just two mirrors it is only worthwhile to move one mirror, since only the relative phase matters. Thus one does not aim to sharpen the (instantaneous) set of fringes, but rather to hold them fixed. For our first goal, to stabilize the two-hole fringes, we used a double slit, one slit having a width that corresponds to the distance from valley to peak, and the other identical adjacent slit extending from that peak to the next valley, on the fringe pattern. Thus the total width of the two slits is about 2 mm. One slit was looked at by a photomultiplier that produced current $I_1$, the other PM 2 producing current $I_2$. These currents were used as the input to an operational difference amplifier whose output was proportional to $I_1 - I_2$. The goal is to hold $I_1 - I_2 = 0$ (or constant, if the PM gains are not identical). To this end the signal $I_1 - I_2$ is amplified and fed back to the solenoid driving one of the mirrors. This signal causes the mirror to move so as to shift the fringe pattern back to its original position, restoring $I_1 - I_2$ to zero. This system works and will be exhibited in a 16 mm film during my presentation. To record the stabilized fringes a beam splitter was placed between the eyepiece and the double slit. Half the beam goes to the camera, half goes to the double slit, attenuated by a factor of $10^3$ for convenience before entering the slit. The signal $I_1 - I_2$ is also displayed on an oscilloscope and shown in the movie. (Sweep speed is $5 \times 10^{-3}$ sec per cm. You can thus judge the time scales of atmospheric phase distortions in 1200 ft of air, in the Berkeley hills, on a sunny afternoon.)

This system was also used to stabilize fringes using as a source the green spectral line of Hg, from a gas discharge "point source" located near the laser. It was also used to investigate the bandwidth which we might expect to be able to use in stabilization. This was done not by varying the wavelength to change the image size (fringe separation) but by moving the slits to a different distance from the eyepiece, so that the slits were mismatched to the fringes. We found that could easily be off by ± 15% and still get stabilization.

Our next goal is a stabilized image, rather than a stabilized fringe pattern. That would mean going to all six mirrors. Several factors weighed against pursuing this goal with our first flexible mirror: we wish to use our next working flexible mirror on an astronomical telescope, the 30 in f/8 "Leuschner" telescope in the Berkeley hills. The seeing is such that we will need a range of more than ± one wavelength. Furthermore, when we covered the Leuschner telescope's entrance aperture with a mask that corresponded to our hexagonal array of mirror segments (in the aperture plane each circular hole is 4 in diam) we found that we could not bring all six holes to a common focus. That means our flexible mirror segments need static "tilt" corrections to correct the figure of the main mirror by about 1/2 arc sec. Furthermore, with our 4 in telescope we found that when the six single-hole diffraction patterns were not perfectly aligned one on top of the other, then the side lobes of the six hole interference pattern became intolerably intense, to the point where we could barely tell which was the central maximum. This is mainly because we were not operating with a filled annular ring but with an annular ring less than half filled by our hexagon of six circular mirrors.

Our second flexible mirror consists of a linear array of six square mirrors, each 1/2 in square, the whole array being 3 in long. The mirror is made by starting with an optical flat 4 in by 2 in by 1/4 in. Square 1/16 in wide grooves that delineate the individual mirrors are cut on the back side with a vibrating "cookie cutter" that abrades its way nearly through the flat. On each of the six square "center posts" on the back side is glued a 1 in long 1/2 in O.D. 1/4 in I.D. piezoelectric tube. These are glued at their other end to a support block. Voltage can be applied between the inner and outer surfaces of each tube. We find that each mirror can move ± 5 fringes with ± 1000 volts applied. The entire 1/2 in by 3 in flat side is silvered. Thus we have a filled one dimensional mirror, corresponding to 4 in by 24 in at the entrance aperture of the Leuschner telescope. That should give us a diffraction limited image with 1 arc sec resolution in one direction and 1/6 arc sec in the orthogonal direction.

Our third flexible mirror is similar to the second, in shape. However, each of the six mirrors is a free standing independent 1/2 in by 1/2 in flat mirror. Distortions of mounting are corrected with set screws. Each mirror can be tilted as well as translated. The tilting is accomplished by dividing the external plating of the piezoelectric tube into three separate regions and applying separate voltages to each.

Our second mirror has been installed in a 12 in f/8 telescope looking at the laser, 1200 ft away, for preliminary testing. The electronics for driving the six mirrors so as to maximize the light through a pinhole is nearly completed. Thus we are nearly ready to start testing our 2nd and 3rd mirrors at the time of writing this note (April 28).

References

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