Optical metrology of solar reflector panels with a high density Hartmann sensor

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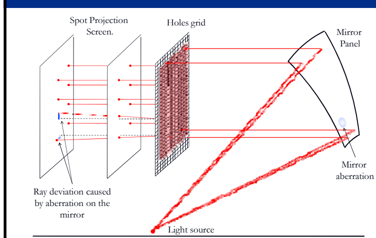
The Solar Reflector Panel. Is made of glass and shaped by a special mold at the Steward Observatory Mirror Lab.

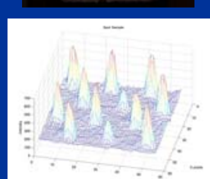
NEED To test replicated glass reflector panels molded at the Mirror Lab for a solar con-centrator. The panels already a good focus with 90% on the energy in a disc of 0.7 ° diameter, little larger than the 0.5 ° solar disc.(see image bottom right) The goal is to map the residual errors of the surface so the mold surface can be improved. A new metrology process has been developed, since normal methods are too sensitive or cannot resolve the small scale ripples formed in the molding process.



NEW METHOD We have developed an inverse form of the Shack Hartmann wavefront sensor with high spatial resolution to resolve the ripples. A point light source is placed at the focal point of the panel, which reflects the light back in the direction of focused sunlight. If the mirror were perfect, the light from the source will be reflected as a parallel beam. Errors in the reflector cause ray deviations, which are measured by passing the beam through a grid with 11,000 holes at ¼" spacing.

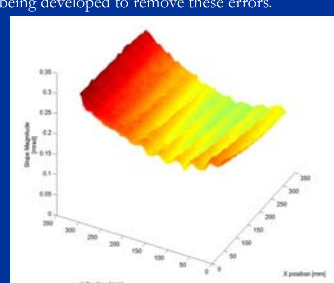
METHOD: The rays from the holes are projected onto a diffusing screen where is imaged from behind by a rigidly attached camera. Two images are recorded, first with the screen near hole grid, then with the screen displaced back. If the mirror is perfect the rays coming out from the grid will all be parallel, and the two patterns will be the same. Otherwise, angled rays will show as an offset in spot position between the two images. Thus the surface slope errors can be measured at every point on the reflector, using a software developed in MATLAB for this purpose. The rays from the holes are projected onto a diffusing screen where is imaged from behind by a rigidly attached camera. Two images are recorded, first with the screen near hole grid, then with the screen displaced back. If the mirror is perfect the rays coming out from the grid will all be parallel, and the two patterns will be the same. Otherwise, angled rays will show as an offset in spot position between the two images. Thus the surface slope errors can be measured at every point on the reflector, using a software developed in MATLAB for this purpose

Spot finding algorithm. To compute the mirror aberrations is necessary to find each spot location in the image shown below and reference them. The spot finding algorithm takes the convolution of the image with a special shape returning the highest value of each spot and then a center of gravity algorithm find the center with sub pixel accuracy.



This image show a 3D profile of the dots and their large intensity dispersion even on a small region.

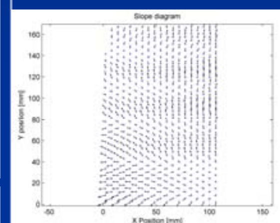
RESULTS: The tests performed on the panel clearly show that superposed on the expected parabolic shape of the mirror are ripples over almost all the surface of the mirror, with different amplitudes. The spatial frequency is about one cycle per inch and the maximum amplitude cause and angular deviation of the light of approximately 8 miliradians peak to valley in the worst areas. Also several circular bumps and edge droop is measured. Corrections to the mold machining program are being developed to remove these errors.



Slope computation algorithm. Once the spot location is obtained their position is correlated with a reference position for each slope. From this information the motion of the spot on the projection plane (XY) is obtained and the travel of the screen is kno so the local slope can be obtained as:

$$\Delta x_{nm} = x2_{nm} - x1_{nm}$$
$$\Delta y_{nm} = y2_{nm} - y1_{nm}$$
$$|\Delta|_{nm} = \sqrt{\Delta x^2_{nm} + \Delta y^2_{nm}}$$
$$Slope_{nm} = \frac{|\Delta|_{nm}}{\Delta z}$$

where n and m are the row and column pixel position of each spot. As a result a slope magnitude and also the direction is obtained providing complete information about the local aberrations of the mirror.



A plot of the slopes of a small section of the mirror is shown on the image above. In this case magnitude and direction of the slope are represented. In the next image the modulus of the slope is taken and is represented as a color diagram. This sample of the worst part of the mirror show ray direction errors of up to 0.5° peak to valley.

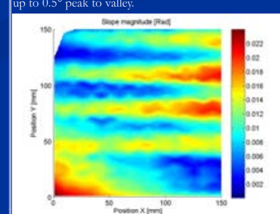


Image of the Sun. Below is an image of the sun created by the mirror without coating so the intensity shown correspond to only 8% of the total incident radiation. The effect of the ripples and other aberrations can be seen as ghosts that send part of the incident radiation outside the sun image. As it can be seen that ghost can extend by approximately the same size of the sun which correspond to an angular size of 0.8° This result is very consistent with the measured slope errors.

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