Non-contact distance adjustment technique for Null lens systems using variable numerical apertures

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1. Summary

A technique for adjusting the distance of a Null lens system is presented. It has been noted that the usually strict tolerances for the distance between the Null lens system and the test mirror are relaxed when numerical aperture is reduced. A mechanical iris is used to throttle the numerical aperture so small that regardless of actual wavefront aberrations due to distance errors, a diffraction limited wavefront is seen. Using gradually opening aperture, the tolerance limits of the diffraction limited wavefront from distance errors are mapped and used for fine, non-contact adjustment.

2. Introduction

A common way to measure aspherical surfaces is using a Null lens system such as an Offner. After passing through the Null lens system, the aspherical wavefront is transformed into a spherical or flat wavefront, depending on the design. It can be then read with spherical or flat interferometric techniques (respectively) so that the errors it displays are in relation to the desired aspherical wavefront. Offner type Null lenses are easy enough to design, but very difficult to manufacture and adjust to correct distances due to often tight tolerance limits.

Off-the-shelf lenses can be used as Offner Null lenses (with reduced resolution but can be even $\lambda/25$ of PV), but the remaining dimensions still cause problems, such as the distance between the Null lens and the test mirror. Small distances can be measured with reference rods or micrometers, but the distances between Null lens and test mirror are often several meters and require extremely accurate non-contact type measuring techniques. Below is presented a non-contact measuring technique using variable numerical aperture to map the correct distances to diffraction limited zones of the test mirror.

This technique assumes that all the other, comparatively smaller distances are measured correctly, and all components are adjusted to the optical axis without decenter or tilt. This paper is purely a discussion and does not include any actual test results.

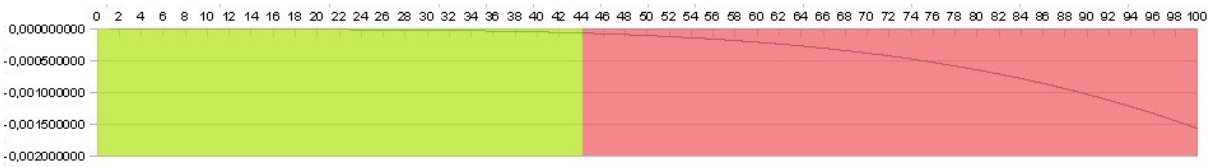
3. Theory

The aspherical mirror has central areas where the difference between aspherical and spherical wavefronts cannot be distinguished due to the difference between sags being less than the maximum resolution of the wavelength used. For conic surfaces, the aspheric coefficients are equal to zero, and the Sag equation reduces to

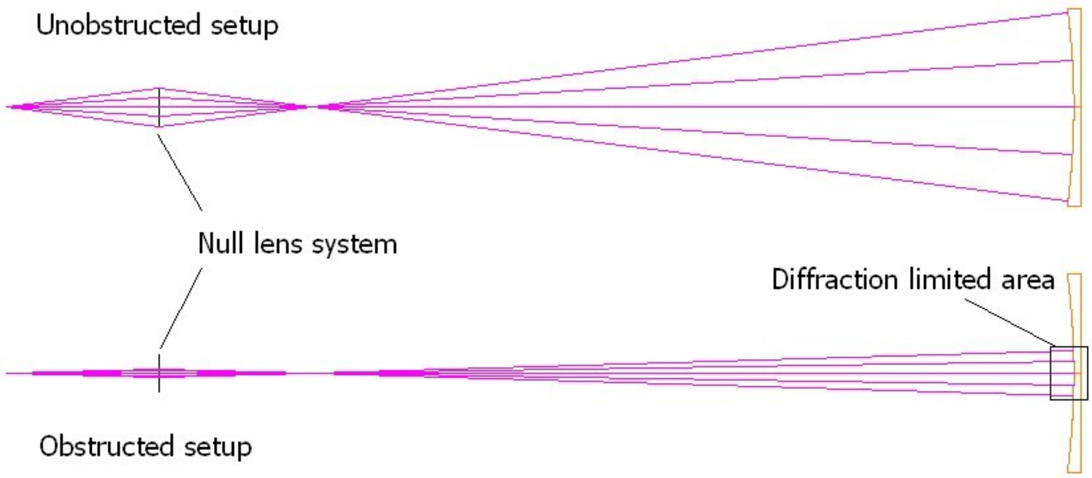
$$Z(s)=\frac{C s^2}{1+\sqrt{1-(1+K)c^2 s^2}} \quad ,$$

where Z is the distance from the vertex, C curvature of the surface, s height from the optical axis and K conic constant.

When the numerical aperture of the Null lens system is throttled so that only the central areas of the mirror are illuminated (i.e. only diffraction limited areas where $Z(s) < \lambda/10$), one would see a perfect wavefront being formed.

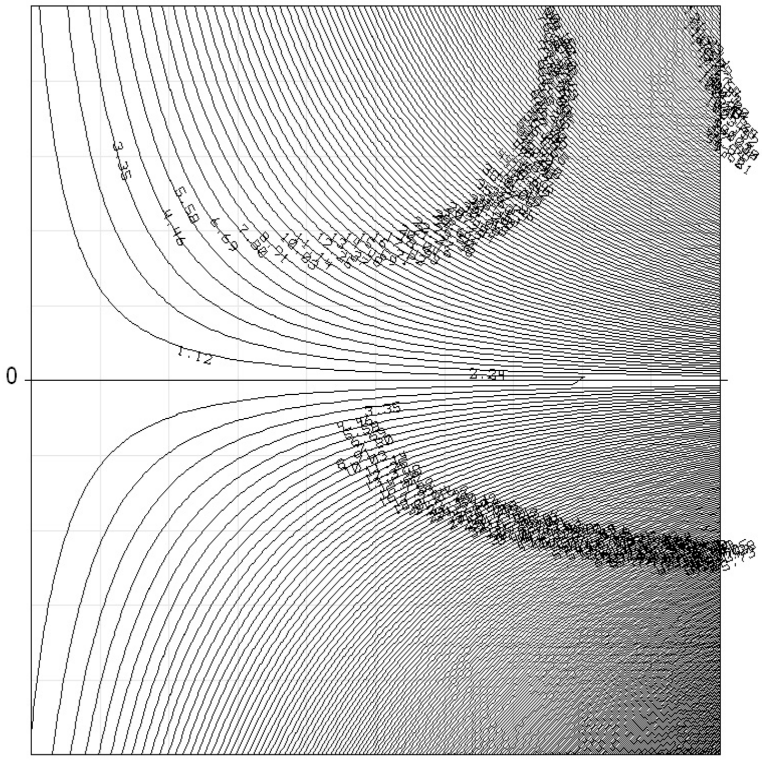


Picture 1: Sag difference between an aspheric mirror D=200mm, R=1000mm and K=-1 compared to a similar spherical surface. The green represents diffraction limited central areas. Red denotes area where the difference in sag is detectable (i.e. over λ/10 with wavelength of 633 nm).



Picture 2: Two layouts showing the unobstructed setup (above) and the obstructed initial test setup (below) with an Iris positioned to the front of the Null lens system to throttle the numerical aperture.

Picture 3 shows that when the numerical aperture is small, the tolerances for the distance error are very relaxed, and when the aperture grows, i.e. includes more zones from the mirror, the gradient of the wavefront error grows.



Picture 3: Map of the wavefront error. Vertical axis represents the error of the distance between Null lens system and test mirror. Horizontal axis represents the numerical aperture of the Null lens system, with increasing values to the right.

4. Practical adjustment

Practical adjustment relies on the assumption that the distance between the Null lens system and the mirror is the only unverified dimension. The adjustment proceeds as follows:

1. A mechanical iris is located before the Null lens system and centered to the optical axis. The initial aperture of the iris is adjusted so that the light passing through the iris and Null lens system will only illuminate small area in the center of the mirror.
2. Distance to the mirror is adjusted to the minimum wavefront error.
3. Aperture of the Iris is opened slightly.
4. Repeat from step 2 until the maximum aperture of the Null lens system is achieved.
5. The actual error of the mirror is the smallest wavefront that is achieved.

5. Discussion

A Väisälä Two-Slit Interferometric test can be used instead of Iris and an interferometer. Väisälä Two-Slit Interferometric test involves a mask placed in the exit pupil of the mirror. Light reflecting back from specific slits of the mask form interference at their common foci, and the distance on the image plane, between the interference patterns and calculated focus represents the wavefront error. If the mask is prepared so that two slit pairs are constructed (to different diameters) to 1) represent the minimum diffraction limited area and 2) the edge, with maybe some slits in between for ease of adjustment, it may be possible to identify the interferometric patterns to the corresponding slits and the wavefront errors they represent in a snapshot mode.