Measurement of Highly Parabolic Mirror using Computer Generated Hologram

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ABSTRACT

For evaluating the surface of parabolic mirror (90 mm, F/0.76), two different null test have been discussed. After designing, encoding, and fabricating the CGH(computer generated hologram), the null CGH test was performed. An autocollimation test with a flat mirror was also performed and these testing result were compared

Keywords: null test, null CGH test, CGH, null optics, parabolic mirror, autocollimation test

1. INTRODUCTION

By using aspheric optics, system performance can be improved by reducing the number of optical elements. An asphere used in modern optical system requires with larger diameter, faster focal ratios , and better surface qualities.
Interfoerometric optical testing with null corrector is used for measuring aspheric surfaces to high accuracy. Optical interferometry is a relative measurement of the wavefront difference between the reference and test wavefront. The application of CGH in optical interferometery allows complex aspheric surfaces to be measured easily without using expensive null optics. The CGH is designed to produce a wavefront that matches the shape of the ideal test asphere.
An error in the null test would cause the final asphric surface to be fabricated to the wrong shape The method of verifying the null test is to compare results from two independent null test. Since the null optics and test method are considered independently, agreement between the two tests indicates a high probability that both are useful.

2. NULL CGH DESIGN

The aspheric surface under test is a parabolic mirror(90 mm, f/0.76) which has the design data given in the Table 1. A schematic drawing of the null CGH test setup is given in Fig. 1.

A Fizeau interferometer with He-Ne laser operating at 633 nm is used. The CGH is placed in the test arm of an interferometer and gives the test system an autocollimation optical scheme. The spatial filter is used to block the unwanted orders of diffraction.

Table 1. Design data of parabolic mirror

Radius	120 mm
Conic constant	-1.0
Diameter	110 mm
Clear aperture	90 mm
Material	Fused silica
Maximum sag from vertex plane	8.4 mm
Maximum sag from best fit-radius	0.073 mm

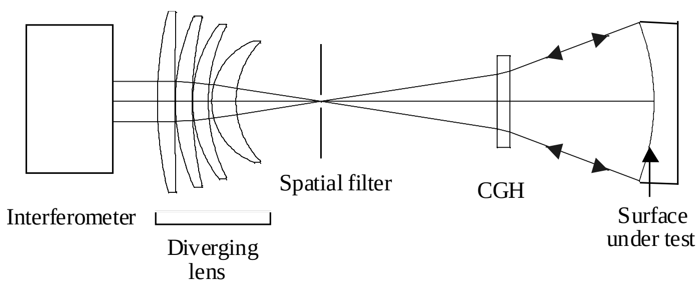

Fig. 1: Optical layout of Null CGH test

To derive CGH function, parabolic mirror is regarded as an object plane and spatial filter is regarded as an image plane as shown in Fig. 2. It is assumed that the normal rays to parabolic mirror exactly focus into the image point I.

OPL' is the optical path length from off-axis object point on parabolic mirror to image point I. OPL_0 is the optical path length from on-axis object point on parabolic mirror to image point I. OPL' and OPL_0 are given by

$$OPL'(r) = O'H' + H'I \qquad (1)$$

$$O'H' = \sqrt{(H'_x - O'_x)^2 + (H'_y - O'_y)^2 + (H'_z - O'_z)^2} \quad (2)$$

$$H'I = \sqrt{(I_x - H'_x)^2 + (I_y - H'_y)^2 + (I_z - I'_z)^2} \quad (3)$$

$$OPL_0 = OH + HI \quad (4)$$

$$OH = | H_z - O_z | \quad (5)$$

$$HI = |I_z - H_z | \quad (6)$$

Choosing the arbitrary reference point as on-axis and applying the initial assumption, the CGH function is given by

$$\Phi(r) = OPL' (r) - OPL_0 (r_o) \quad (7)$$

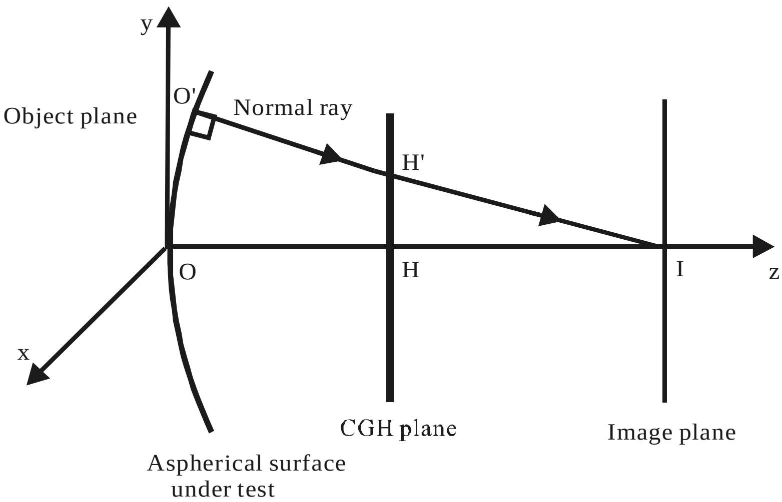

Fig. 2: Geometry for defining a CGH such that it returns the same wavefront as a perfect parabolic mirror

Fig. 3 is the optical prescription for designing null CGH used to test the parabolic mirror. Fig. 4 shows the CGH function calculated using the optical prescription shown in Fig. 3. The wavefront residual and the ray aberration for +1 diffraction order at image plane are shown in Fig. 5. The wavefront residual at 633 nm test wavelength is less than 0.01 waves and the ray aberration is less than 0.01 µm.

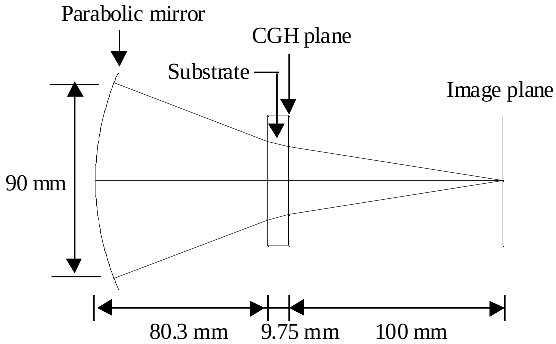

Fig. 3: Layout with prescription for null CGH design.

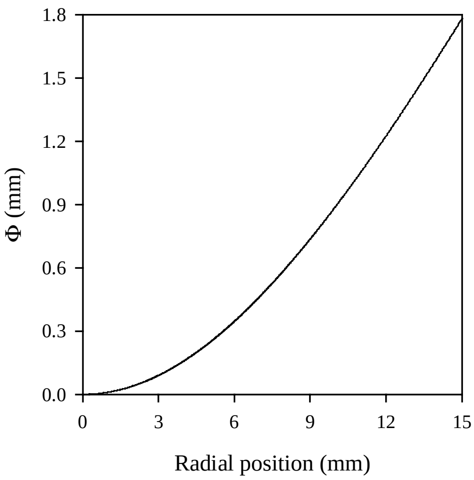

Fig. 4: CGH function for testing a parabolic mirror.

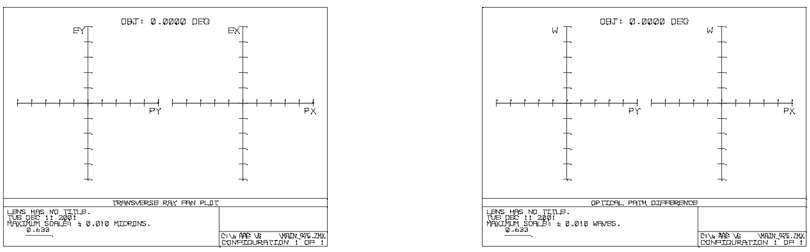

Fig. 5: Ray aberration and wavefront aberration plots for +1 diffraction order.

The phase CGH with binary circular grating pattern is designed to be used in the 1st order transmission mode. It has a circular aperture with a diameter of 15.5 mm as shown in Fig. 6. It contains 2971 rings. The spacing between adjacent rings decreases with increasing ring radius and the smallest ring spacing is 3.00 μm on the edge of the CGH. The ring pattern on the CGH has a 50 % duty cycle and the grating groove depth of π radian. The CGH was written directly on fused silica substrate using a circular laser writing system in IAE of Russia. Table 2 summarizes the stated parameters for phase CGH.

Table 2. CGH structure parameters

(λ : 632.8 nm)

Parameter	Value		
		Alignment CGH	
	Main CGH	For CGH (A1)	For tested lens (A2)
Grating type	Binary phase grating	Binary amplitude grating	Binary phase grating
Material (chrome)	n_{chrome} = 3.6 - i4.4		
Material (glass)	Fused silica (n_{glass} = 1.46)		
Operating mode	Transmission	Reflection	Transmission
Diffraction order	1st order	3rd order	3rd order
Smallest grating spacing	3.2 μm	3.3 μm	3.09 μm
Grating groove depth	1λ (2π radian)	Chrome thickness: 100 nm	1λ (2π radian)
Grating duty-cycle	50 %		

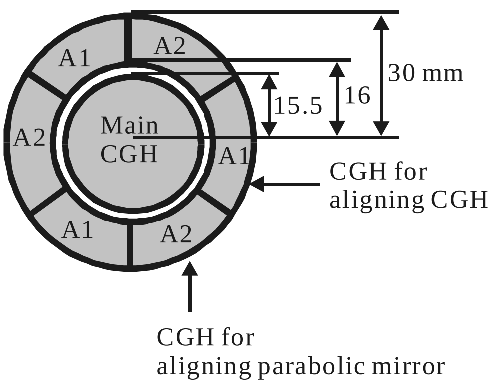

Fig. 6: CGH composition

3. EXPERIMENTS AND RESULTS

The parabolic mirror with design data given in Table 1 was fabricated in KRISS(Korea Research Institute of Standards and Science).

3.1 Null CGH test

The system for Null CGH test was constructed as shown in Fig. 1. The parabolic mirror was measured 4 times and then the data were averaged to reduce random errors in the measured wavefront phase function. To reduce alignment error, wavefront tilt, power, and high frequency noise were removed from raw phase map. Fig. 7 shows the final phase map. It can be seen that the parabolic mirror has a surface error of P-V 0.36 λ and RMS 0.05 λ

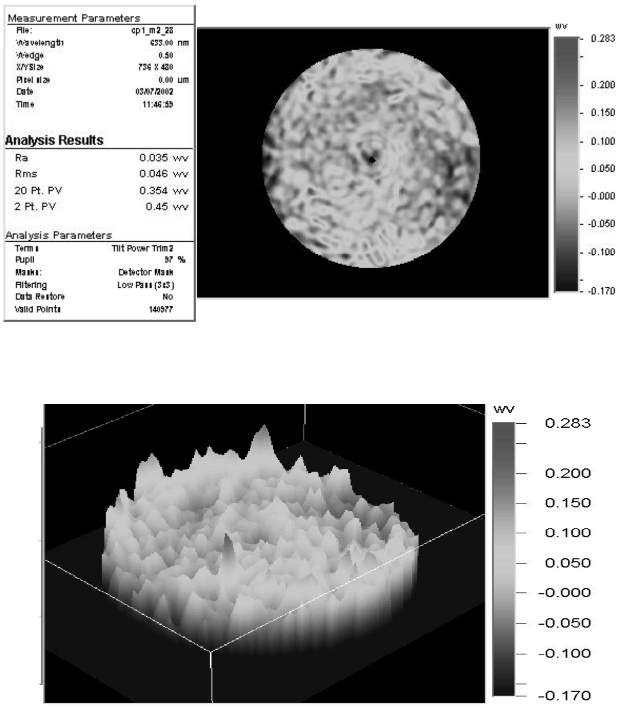

Fig. 7: Wavefront phase map after removing power, tilt and high frequency noise.

3. 2 Autocollimation test

Autocollimation test uses a point source at the focus of the parabolic mirror to create collimated beam on reflection and a flat mirror which retroreflects the collimated beam into point source. A schematic drawing of the autocollimation test setup is given in Fig. 8. In Fig. 9, the parabolic mirror has a surface error of P-V 0.31 λ and RMS 0.04 λ after the removal of power, tilt, and high frequency noise.

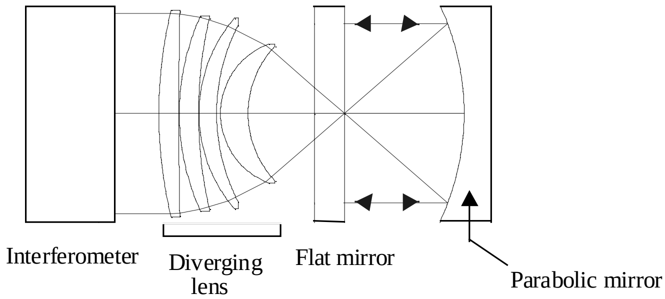

Fig. 8: Optical layout of autocollimation test

Table 3 summarizes the surface errors obtained by null CGH test and autocollimation test. Reference data is the result of autocollimation test performed in KRISS. From Table 3, it can be seen that the surface errors obtained by null CGH test were correct within an uncertainty of P-V 0.05 λ and RMS 0.01 λ.

Table 3. Results from null CGH test and autocollimation test

(λ= 633 nm)

	Null CGH test	Autocollimation test	Reference data
P-V wavefront error	0.36λ	0.31λ	0.31λ
RMS wavefront error	0.05λ	0.04λ	0.04λ

4. CONCLUSIONS

We have evaluated the null CGH test for a parabolic mirror(90 mm, f/0.76). The aspheric surface error is measured by using a flat mirror without complex null optics.

The null CGH test using Fizeau interferometer and the autocollimation test with flat mirror were performed. To validate the autocollimation test, another autocollimation test was performed.

From the comparison of testing results, the surface errors measured by null CGH test were verified within an uncertainty of P-V 0.36 λ and RMS 0.01 λ.

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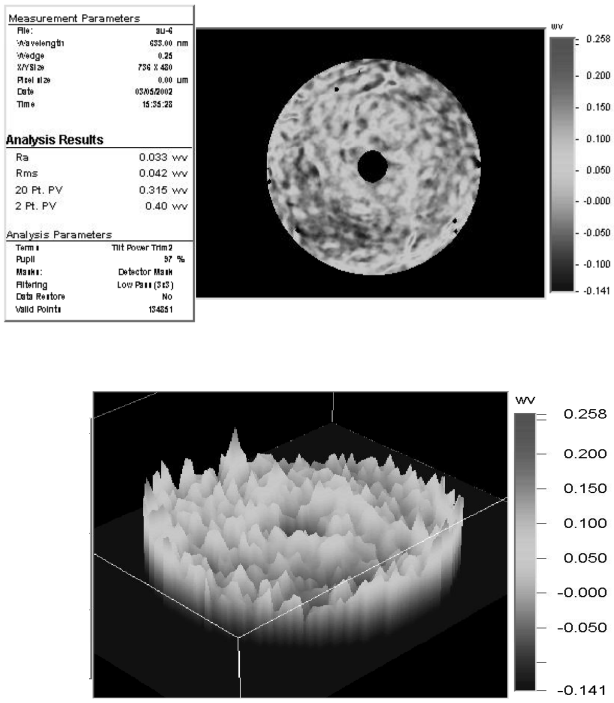

Fig. 9: Wavefront phase map after removing power, tilt and high frequency noise.

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