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Xinyang Chen, Chaoyan Wang, Lixin Zheng, Jianqing Cai, Yuanyuan Ding, "Measurement of interactive matrix and flat-surface calibration of OKO 109-channel deformable mirror using ZYGO-GPI interferometer," Proc. SPIE 11552, Optical Metrology and Inspection for Industrial Applications VII, 115521Y (10 October 2020); doi: 10.1117/12.2575904

Event: SPIE/COS Photonics Asia, 2020, Online Only

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ABSTRACT

Deformable mirror (DM) is the most main wavefront corrector in adaptive optics, which can be used to compensate optical aberrations through changing the reflective mirror's surface frequently. However, a commercial piezoelectric DM can't have an ideal flat initial surface under zero-voltage condition due to limitation of thin mirror fabrication and support structure of actuators behind of mirror. Optical aberrations generated by this initial distortion will seriously attenuate the performance of DM's close-loop control, so a flat-surface calibration of mirror needs to be carried out before DM properly correct optical aberrations. In order to properly control the optical figure of the DM we have to obtain an interactive matrix which is the response of optical surface to the DM actuator's stroke. We measured a serious of surface phase data of OKO 109-channel DM through self-collimation using a ZYGO-GPI interferometer directly, then construct the interactive matrix by zonal and modal methods. After several close-loop iterations, the initial RMS surface error of OKO 109-channel deformable mirror, 1.506 λ has been remarkably reduced to 0.145 λ.

Keywords: Adaptive optics, laser interferometer, deformable mirror, interactive matrix

1. INTRODUCTION

Adaptive optics (AO) is a very important optical technique for real time compensation of dynamic wavefront aberrations existing in many optical systems widely. Deformable Mirror (DM) is the most main wavefront corrector in adaptive optics. DM can compensate enormous phase aberrations through changing the reflective mirror's surface frequently. However, a commercial piezoelectric DM can't have an ideal flat initial surface under zero-voltage condition due to limitation of thin mirror fabrication and support structure of actuators behind of mirror. Optical aberrations generated by this initial distortion will seriously attenuate the performance of DM's close-loop control, so a flat-surface calibration of mirror needs to be carried out before DM properly correct optical aberrations.

There are two methods applied to flatten calibration of DM. One is to measure the height difference of the mirror surface at each actuator with the interferometer and reduce the differences to zero iteratively[1]. Another method is to measure the DM's optical response to strokes of every actuator, so called Interactive Matrix (IM). Arcidiacono C, et al carried out a flat-surface calibration of OKO PDM50-109 DM in 2015. Measurements of surface phase are based on TriOptics μPhase 500 interferometer [2]. The clear aperture of DM is 50 mm, while the interferometer only produces 10 mm collimated beam, a set of beam expander lens were introduced to match that calibration. Considering possible extra aberrations from the expander lens, we plan to use ZYGO-GPI interferometer which can produce 150 mm collimated beam to measure interactive matrix and realize the new flat-surface calibration of OKO PDM50-109 DM.

2. MEASURING SETUP

Figure 1 shows a ZYGO GPI interferometer is equipped with a standard lens which can produce 150 mm diameter high-quality collimated beam. Although the clear aperture of OKO PDM50-109 deformable mirror is 50 mm, the optimal correction aperture is only 40 mm [3].

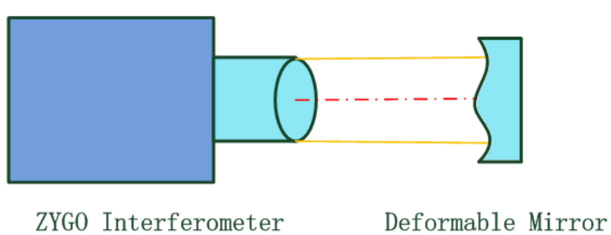

Figure 1 The diagram of measuring setup

Optical Metrology and Inspection for Industrial Applications VII, edited by Sen Han, Gerd Ehret, Benyong Chen,
Proc. of SPIE Vol. 11552, 115521Y · © 2020 SPIE · CCC code: 0277-786X/20/$21 · doi: 10.1117/12.2575904

OKO PDM50-109 DM has 109-channel piezoelectric actuators. Figure 2.a shows the position of all actuators. Each actuator maximum stroke is 6 μm at +300V voltages and actuator pitch is 4.3 mm. Figure 2.b is a cross section of initial DM surface profile with all zero voltage channels. Obviously, the main initial aberration is defocus.

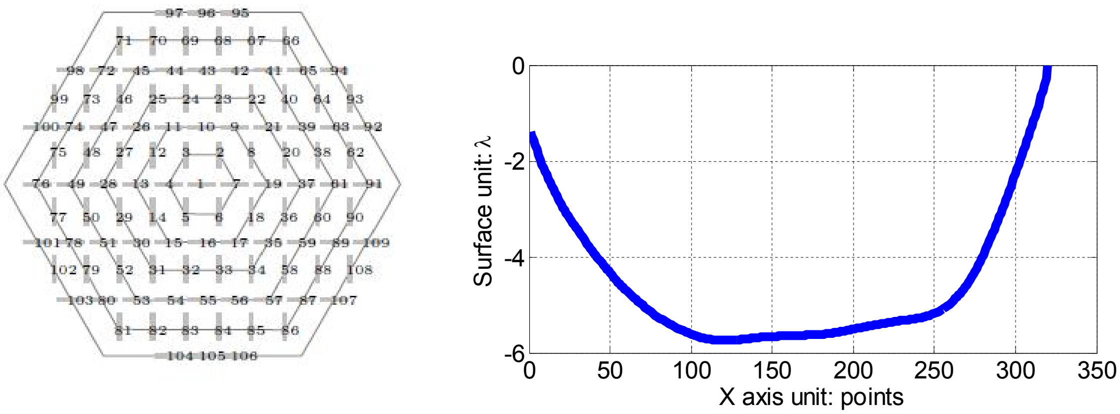

Figure 2 (a)The geometry of the 109-channel DM actuators; (b)The cross section of initial DM surface with all zero voltage channels

3. MEASUREMENT OF INTERACTIVE MATRIX

Figure 3 shows the process of IM measurement and flatten calibration of DM. There are three steps in order to obtain the actual DM surface response to all 109-channel actuators strokes as follows.

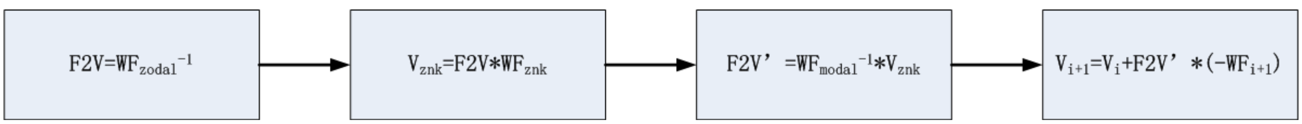

Figure 3 The process of interactive matrix measurement and flatten calibration

3.1 Zonal interactive matrix

Firstly, normalized voltage value V=0.5 (V=1 is defined as input voltage = full range voltages 300V) is applied to each channel one by one, and every time, the corresponding wavefront phase vector [$m^2 \times 1$] (m is the dimensions of wavefront phase, given the phase map is square) are measured synchronously by ZYGO-GPI interferometer. After finishing all single-push of actuators, these 109 phase data vectors will be combined into a single matrix WF_{zonal} [$m^2 \times 109$]. Its generalized inverse matrix is F2V [$109 \times m^2$], which is also called zonal interactive matrix.

3.2 Channel commands based on Zernike phases

As we know, any random wavefront phase can be decomposed into a sequence of standard Zernike phases such as tip, tilt, defocus, et. al according to Zernike Polynomials[4]. Supposing the i-th item of Zernike phase is $WF_{znk\text{-}i}$ [$m^2 \times 1$], so the corresponding channel command vector $V_{znk\text{-}i}$ = F2V* $WF_{znk\text{-}i}$. This command is outputted to the DM, new wavefront phase $WF_{modal\text{-}i}$ [$m^2 \times 1$] are measured synchronously by ZYGO-GPI interferometer again. For all the Zernike of interest (e.g. Zernike items = n), we can merge every command vector $V_{znk\text{-}i}$ into a total channel command matrix V_{znk} [109*n] and also combine all $WF_{modal\text{-}i}$ into a single matrix WF_{modal} [$m^2 \times n$].

3.3 Modal interactive matrix

Finally, according to the expression in the third block of Figure 3, we can calculate the modal interactive matrix F2V'[$109 \times m^2$].

4. FLAT-SURFACE CALIBRATION

On the basis of this modal interactive matrix F2V' and initial phase WF_0 measured by ZYGO-GPI interferometer, a channel command used for DM surface correction is produced according to the expression in the fourth block of Figure 3.

Due to the influence of the inherent characteristic "hysteresis" of piezoelectric ceramics, the above process needs to be carried out iteratively. We found that the DM surface error can reach a stable state after 25 iterations.

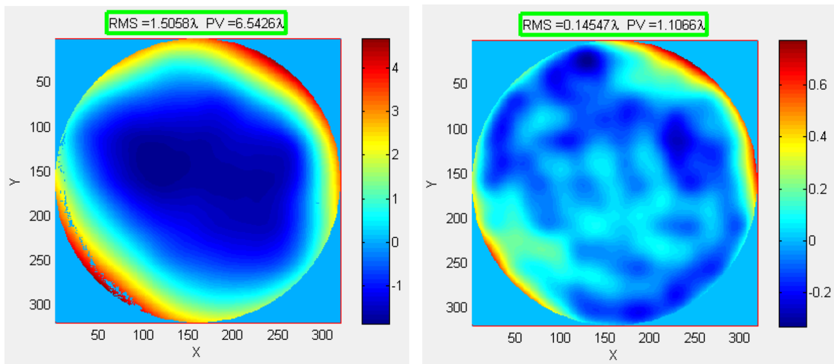

Figure 4 (a)The initial surface of DM; (b)The corrected surface of DM through 25 iterations

Figure 4 shows the surface phase (a) with all zero voltage channels; (b) corrected after 25 iterations. The initial RMS surface error of OKO 109-channel deformable mirror, 1.506 λ has been remarkably reduced to 0.145 λ . Figure 5 also shows a convergence process of wavefront phase error of DM correction. It is also noticed that there exists some large residual errors at the edge of DM. Maybe the optimal aperture of DM is less than 40 mm.

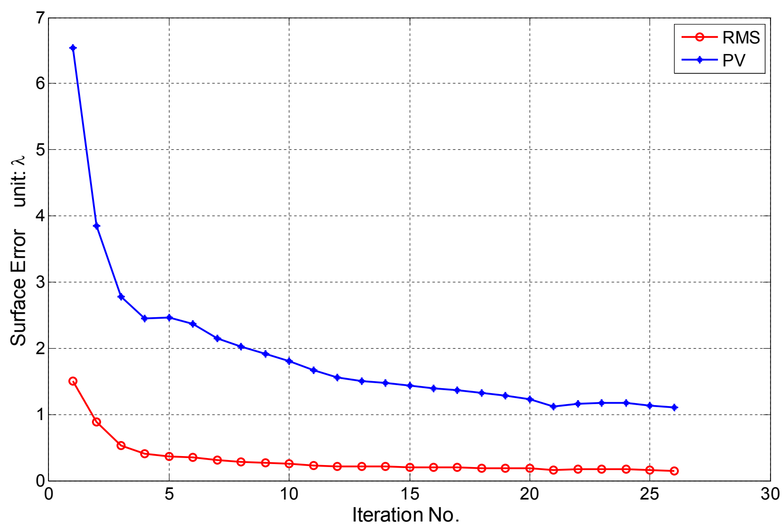

Figure 5 Wavefront phase error of DM correction

5. CONCLUSION

We realized the flatten calibration of OKO PDM50-109 deformable mirror through obtaining zonal & modal interactive matrix by utilizing ZYGO-GPI interferometer to measure the surface of DM. The RMS value of surface accuracy is increased by about 10 times, and the PV value is increased by about 6 times with respect to the initial DM surface. We also found that the large value of surface error after iterative flattening is concentrated on the edge of the mirror. The piezoelectric actuator in the corresponding area has reached the travel limit. If this high value is removed, the wavefront phase error including piston, tip and tilt will be reduced significantly. RMS value can decrease from 0.145λ to 0.091λ, and PV value from 1.106λ to 0.666λ. For applications of OKO PDM50-109 deformable mirror, a smaller aperture than 40 mm maybe a better option.

REFERENCES

[1] Lin, X., Liu, X., Wang, J., Wei, P. and Wang, F., "Flatten calibration of deformable mirror based on the measurement of the interferometer", Acta Photonica Sinica 41(5), 511-515(2012).

[2] Arcidiacono, C., Chen, X., Yan, Z., Zheng, L., Guido, A., Wang, C., Zhu, N., Zhu L., Cai, J. and Tang, Z., "Sparse aperture differential piston measurements using the pyramid wave-front sensor", Proc. SPIE 9909, 99096K-1-10(2016).

[3] Vdovin, G., Soloview, O., Loktev, M., and Patlan, V., [OKO Guide to Adaptive Optics], Flexible Optical BV(OKO Technologies), Delft, 23-25(2013)

[4] Roddier, F., [Adaptive Optics in Astronomy], Cambridge University Press, Cambridge, 26-29(1999).