Deformable Mirror Characterization for Efficient Fiber Coupling

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Abstract. Randomized divergence is considered stochastic and device characterization undertaken to estimate its maximum angular extent.

Keywords: deformable mirror, optical efficiency, speckle.

1 Introduction

Our company's high-frequency deformable mirror technology for speckle reduction is described in Fig. 1. Its randomized divergence has a small angular extent which allows optically efficient coupling into small core diameter optical fiber. For example, half-angle divergence of 1.5 deg can be coupled into 0.22 N.A. multimode optical fiber with $0.22/\sin 1.5 \approx 8\times$ demagnification which is sufficient for a ⌀800 µm spot on the mirror to be imaged into the entrance face of a fiber with core ⌀100 µm, see [1].

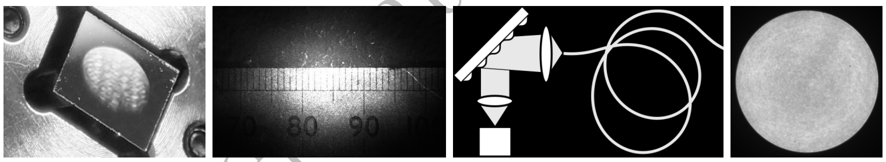

Fig. 1. [Left] Random surface deformations are excited at frequencies up to 1.5 MHz in a 3 mm × 4.5 mm elliptical region. Reflectance $\geq$ 95% and damage threshold $> 1\,\mathrm{W\,mm^{-2}}$ for wavelength-appropriate mirror coatings. [Center, left] Light from a ⌀1 mm beam incident to the mirror is diverged randomly within a small angular extent. [Center, right] Coupling lens images illuminated patch on mirror into entrance face of optical fiber. [Right] Exit face of ⌀200 µm 0.39 N.A. multimode fiber acquired with 20 µs sensor exposure period; good homogeneity versus the typical rice grain pattern.

For optical efficiency and temporal stability, the coupling optical system should accommodate the maximum angular extent of randomized divergence. Due to the random nature of mirror surface deformations, as evidenced by their generation of uncorrelated speckle patterns, we consider angular extent as stochastic. See Fig.2 which shows how the randomized divergence of different 20 µs sensor exposure periods varies significantly; as do tip and tilt angles which result in variation of position.

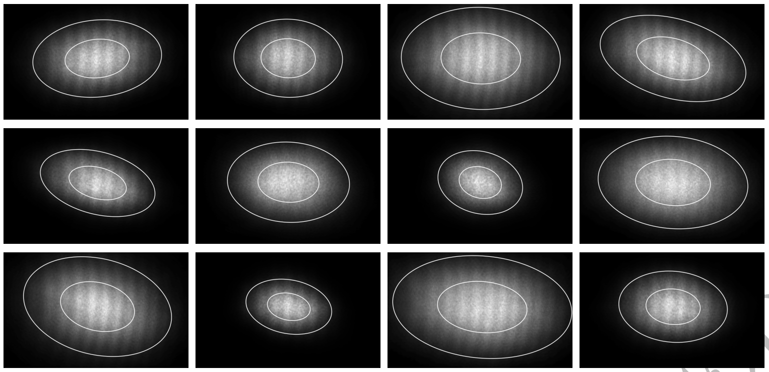

Fig. 2. Light from Thorlabs S4FC $\lambda = 520\,\text{nm}$ laser source, collimated into a $\varnothing 500\,\mu\text{m}$ beam, randomly diverged by mirror directly onto the 1920×1080 pixel sensor of a Basler Ace acA1920 camera operating at 1 Hz with a 20 µs exposure period. Interference fringes arise from its protective window. The contours of best-fit 2-D Gaussians are plotted at 1σ and 2σ distances.

2 Characterization

A deformable mirror was configured such that its half-angle divergence was approx. 1.5 deg when observed visually. Over 1000 images were acquired. For this first investigation, we assumed both divergence and position as 2-D Gaussian. Standard deviations and centroids are shown in Fig. 3. Taking the 2σ contour as the extent of randomized divergence and the 3σ contour as the extent of tip and tilt, the half-angle of maximum extent was calculated to be approx. 3 deg.

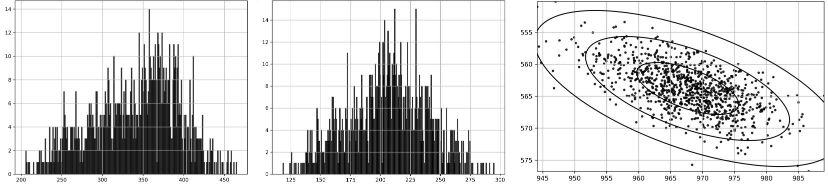

Fig. 3. [Left pair] Histograms of standard deviations along major and minor axes of best-fit 2-D Gaussians for 1000 images. [Right] Centroids of image regions. Best-fit 2-D Gaussian contours are plotted at 1σ, 2σ and 3σ distances.

References

1. Shevlin, F. High-Frequency Homogenization of Laser Illumination Through Stationary 0.22 N.A. Multimode Optical Fiber, Laser Display and Lighting Conference, Yokohama, Japan (2023.)