Automated adaptive optical system for laser beam shaping using spatial light modulator

Ilya Galaktionov
Institute of Geosphere Dynamics RAS
Moscow, Russia
galaktionov@activeoptics.ru

Alexander Nikitin
Institute of Geosphere Dynamics RAS
Moscow, Russia
nikitin@activeoptics.ru

Vladimir Toporovsky
Institute of Geosphere Dynamics RAS
Moscow, Russia
topor@activeoptics.ru

Julia Sheldakova
Institute of Geosphere Dynamics RAS
Moscow, Russia
sheldakova@activeoptics.ru

Alexis Kudryashov
Institute of Geosphere Dynamics RAS
Moscow, Russia
kud@activeoptics.ru

***Abstract* — The automated adaptive optical system with phase-only special light modulator and intensity analyzer are assembled and tested. The experimental results of the flattop and doughnut intensity distributions formation are presented.**

Keywords* — *beam shaping, phase-only spatial light modulator, intensity analyzer, beam shaping algorithm, adaptive optics

I. Introduction

Conventional adaptive optical systems are generally used to obtain the diffraction-limited focal spot in the far field [1]. However, there are a few tasks when the desired intensity distribution should be obtained at the target plane [2]. One of the promising ways to achieve this is to use adaptive optical tools and methods that allow to obtain the desired intensity distribution of the light by controlling its wavefront [3]-[8]. For example, it is necessary for the high-quality laser beam cutting, laser fusion, laser thermal processing etc. There are a few scientific groups who working on this problem and also applying conventional deformable mirrors, membrane mirrors for astronomy, etc. [9]-[13].

The idea of this work is to automate the process of the desired intensity distribution formation by means of setting the control signals to the phase-only spatial light modulator (SLM) [14], [15] and getting the feedback signal from the intensity analyzer placed at the focal plane of the focusing lens.

II. Beam shaping algorithm

The intensity distribution $I(x,y)$ could be considered either as Gaussian or as a flat one, and initial phase distribution $\varphi(x,y)$ was flat at starting point. Far field was calculated by combining the phase and intensity distributions using the principle of free space propagation:

$$I_{simulated}\left(k_x,k_y\right)=\left|dxdy\sqrt{I\left(x,y\right)}\cdot\right. \cdot\exp\left(2\pi i\frac{\varphi\left(x,y\right)}{\lambda}\right)\cdot \left.\cdot\exp\left(2\pi i\left(k_x x+k_y y\right)\right)\right|^2, \quad (1)$$

where $k_x=\frac{x}{f\lambda}$, $k_y=\frac{y}{f\lambda}$, and $\varphi(x,y)=\varphi(\vec{Z})$, $\vec{Z}$ is a vector of Zernike coefficients, f is focal length of the lens.

Zernike coefficients were found for beam formation using hill-climbing method by minimizing merit function Φ through change of Zernike coefficients (2). The merit function Φ was calculated by summing the absolute difference between the simulated intensity distribution at the focal spot and the desired shape ($I_{desired}$):

$$\Phi=\sum\sum\left|I_{desired}(x,y)-I_{simulated}(x,y)\right|^2. \quad (2)$$

When Zernike values are determined, they should be reproduced with a phase control device, and in the ideal situation the desired result should be reached.

The main steps of the intensity distribution formation algorithm (based on hill-climbing algorithm [16]) are as follows:

1. Analytically calculate $I_{desired}$ (it depends upon the desired shape of beam),
2. Simulate far-field shape $I_{simulated}$ using formula (1),
3. Compute merit function Φ ($I_{desired}$, $I_{simulated}$) using formula (2),
4. Select new Zernike coefficients and calculate new phase distribution $\varphi(x,y)$ according to Zernike coefficients,
5. Calculate new $I_{simulated}$,
6. Compute new merit function Φ ($I_{desired}$, $I_{simulated}$),

Repeat steps 4-6 until the best Zernike coefficients are found.

III. Experimental setup & results

The scheme of the assembled experimental setup with the SLM is presented in Fig. 1.

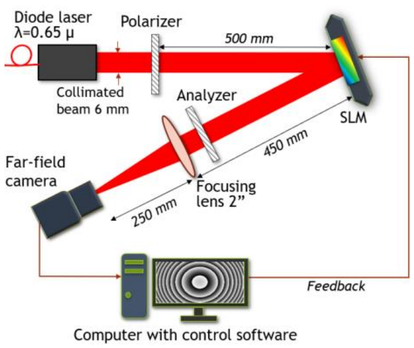

Fig. 1. Scheme of the experimental setup

A collimated laser beam (wavelength 0.65 µm) of 6 mm diameter propagated through the polarizer, reflected from the SLM, propagated through the analyzer and focused on the CCD camera with the micro-objective to analyze the intensity distribution of the focal spot. The camera provided image data to the computer. We used the SLM made by Jasper Display Corp. (1920×x1080 pixels, 12.5×x7.1 mm active area) [17]. It operated in an 8-bit regime. The CCD camera with ½” sensor was used as an intensity analyzer.

Using the experimental setup described above we obtained the intensity doughnut and flattop intensity distributions with the encircled energy presented in the fig. 2.

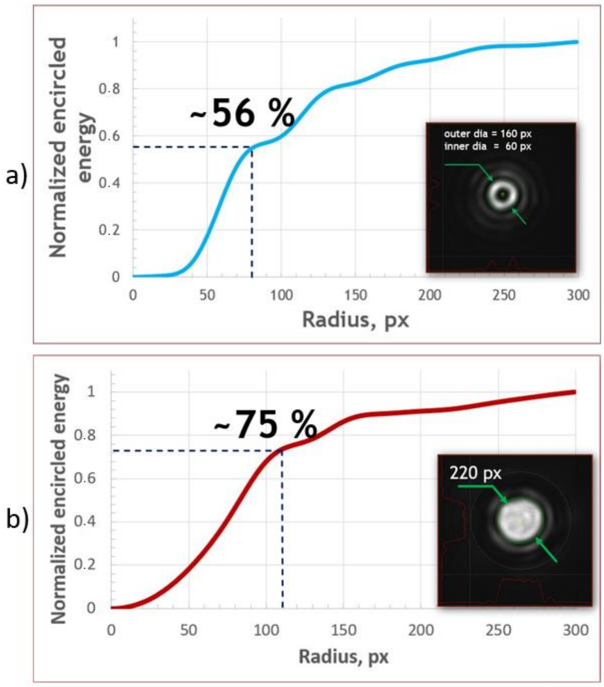

Fig. 2. Encircled energy: (a) doughnut, (b) flattop intensity distributions

It can be seen that for the doughnut intensity distribution almost 60% of the initial energy was concentrated in the clearly seen ring whereas for the flattop intensity distribution 75% of the initial energy was concentrated in the central part of the beam.

IV. Conclusion

The obtained experimental results clearly show that the adaptive optical system with the automated control algorithm can be rather efficient for the laser beam shaping tasks. Using the SLM as a control device and the CCD camera as an intensity analyzer allows to achieve the desired intensity distributions of the laser beam in the far field. The results obtained show that the suggested software and hardware solution could be efficiently used in such applications as high-quality laser beam cutting, laser fusion and laser thermal processing of the materials.

References

[1] Akahane, Y. Characterization of wave-front corrected 100 TW, 10 Hz laser pulses with peak intensities greater than 1020 w/cm2 / Y. Akahane, J. Ma, Y. Fukuda, M. Aoyama, H. Kiriyama, K. Yamakawa, J. Sheldakova A. Kudryashov // Review of Scientific Instruments. — 2006. — Vol. 77(2). — P. 023102.

[2] Cherezova, T. Doughnut-like laser beam output formation by intracavity flexible controlled mirror / T. Cherezova, S. Chesnokov, L. Kaptsov, A. Kudryashov // Opt. Express. — 1998. — Vol. 3(3). — P. 180-189.

[3] Galaktionov, I. Focusing of a Laser Beam Passed through a Moderately Scattering Medium Using Phase-Only Spatial Light Modulator / I. Galaktionov, A. Nikitin, J. Sheldakova, V. Toporovsky, A. Kudryashov // Photonics. — 2022. – Vol. 9(5). — P. 296.

[4] Sheldakova, J. LC phase modulator vs deformable mirror for laser beam shaping: What is better? / J. Sheldakova, I. Galaktionov, A. Nikitin, A. Rukosuev, A. Kudryashov // Proc. SPIE. — 2018. — Vol. – 10774. — P. 107740S.

[5] Sheldakova, J. Stacked-actuators deformable mirror vs bimorph mirror for laser beam shaping / J. Sheldakova, I. Galaktionov, A. Nikitin, A. Rukosuev, V. Toporovsky, A. Kudryashov // Proc. SPIE. — 2019. – Vol. 10904. — P. 109041K.

[6] Sheldakova, J. Miniature bimorph deformable mirror for laser beam shaping / J. Sheldakova, I. Galaktionov, A. Nikitin, A. Rukosuev, V. Samarkin, V. Toporovsky, A. Kudryashov // Proc. SPIE. — 2020. – Vol. 11266. — P. 112661L.

[7] Galaktionov, I. The use of modified hill-climbing algorithm for laser beam focusing through the turbid medium / I. Galaktionov, A. Kudryashov, J. Sheldakova, A. Nikitin // Proc. SPIE. — 2017. Vol. – 10090. — P. 100901K.

[8] Galaktionov, I. Laser beam focusing through the dense multiple scattering suspension using bimorph mirror / I. Galaktionov, A. Kudryashov, J. Sheldakova, A. Nikitin // Proc. SPIE. — 2019. Vol. – 10886. — P. 1088619.

[9] Hoffman, O. Model-based analysis of highly dynamic laser beam shaping using deformable mirrors / O. Hofmann, O. Pütsch, J. Stollenwerk, P. Loosen // Procedia CIRP. — 2018. — Vol. 74. — P. 602-606.

[10] Béchet, C. Beam shaping for laser-based adaptive optics in astronomy / C. Béchet, A. Guesalaga, B. Neichel, V. Fesquet, H. González-Núñez, S. Zúñiga, P. Escarate, D. Guzman // Opt. Express. — 2014. – Vol. 22. — P. 12994-13013.

[11] Salter, P. Adaptive optics in laser processing / P. Salter, M. Booth // Light Sci Appl. — 2019. — Vol. 8. — P. 110.

[12] Brunne, J. Adaptive Fresnel mirror for ultrashort-pulse laser beam shaping / J. Brunne, M. Wapler, U. Wallrabe, A. Treffer, M. Bock and R. Grunwald // 2012 International Symposium on Optomechatronic Technologies (ISOT 2012). — 2012. — P. 1-2.

[13] Wu, Z. Laser beam shaping with magnetic fluid-based liquid deformable mirrors / Z. Wu, Z. Zhang, X. Kong, J. Wu, T. Wang, M. Liu, S. Xie // Chinese Phys. B. — 2017. — Vol. 26. — P. 074201.

[14] Aurélie, J. Spatial light modulators / J. Aurélie // Photoniques. — 2020. — Vol. 101. — P. 59-64.

[15] Li, R. Stimuli-Responsive Actuator Fabricated by Dynamic Asymmetric Femtosecond Bessel Beam for In Situ Particle and Cell Manipulation / R. Li // ACS Nano. — 2020. — Vol. 14. — P. 5233–5242.

[16] Skalak, D. Prototype and Feature Selection by Sampling and Random Mutation Hill Climbing Algorithms / D. Skalak // Proc. of the eleventh international conference on machine learning. — 1994. — P. 293-301.

[17] Reflective LCOS Web Site [Electronic resource]. — Access mode: https://www.jasperdisplay.com/slm-products/ark-overview/ (03.02.2023).