# 3D focal spot control for high power lasers using adaptive optics

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## Purpose

In laser-matter interaction experiments, it is necessary to concentrate as much energy as possible in the smallest volume possible. Thus, in the case of short impulsion, the electric fields generated are sufficient to completely ionize matter or to accelerate electrons and atom nuclei up to relativistic speeds. High power lasers are used in order to reach the necessary peak powers. However aberrations in the complete laser system degrade the focal spot quality. This leads to lower peak intensity at focus. In order to optimize the interaction between the laser and the target, Adaptive Optics (AO) loops are installed on high power lasers. In this case, the intensity after the focusing optics is maximized and the focal spot obtained in the interaction chamber is diffraction limited.

The next step is the need to concentrate the light power at a very precise location. For instance, this is very important to focus not before or after the target surface or a gas jet edge. Interaction also occurs in capillaries and it is very important (and time consuming) to align the light mode with the capillary mode.

Therefore, in addition to focus shape optimization, the AO loop can also be used to control the 3D-position of the focal spot in the interaction chamber. We will present experimental results of focus displacement controlled with an AO loop. The dynamic and resolution in terms of focus control that can be achieved with the DM will be also discussed.

## Methods

The 3D-position control of the focal spot (or the 3D-control of the laser pointing) presented here is made thanks an AO loop coupling a SID4 wave front sensor (from Phasics) and a Deformable Mirror (DM from NigthN). Instead of locking the loop on a flat wave front, we make it converge to a wave front including adequate tilt and defocus. Tilt moves the focal spot transversely whereas defocus moves it axially. A calibration step is then necessary to match the focus 3D space frame to the wave front alteration frame.

It should be noted that to move by 1 focal spot transversely, a tilt of 1 wave across the beam pupil is necessary. To move by 1 Rayleigh range axially, a defocus of 1 wave across the pupil is necessary.

The focus location control is made by using part of the DM dynamic range. This is possible because the dynamic range of large (> 100 mm) bimorph DM used on the high power laser facilities is well above what is needed for encountered aberrations. The additional dynamic range is then used for focus control. Since, in practice, small location corrections are of interest, they require less than one wave of wave front deformation to perform.

## Results

The 3D-position control was tested with our experimental set-up in which the focal spot was observed on a classical CCD sensor (640×480 pixels; 1pixel = 7.4µm). Even if in practice distances will be very smaller, a precise validation of the 3D-position control was made for important focus displacements. The 3D-positionning of the focal spot was validated with the following process with 3 steps. First, the loop is closed (step1) and a diffraction limited spot is obtained on the CCD sensor (outer left image on the figure 1). Afterwards, the CCD sensor is just moved along the 3 directions (step2) with micrometer linear stages (few focal spots transversely and more than 250 focal spots axially). The corresponding camera image is given in the inner left image on the figure 1. Because of the important difference between the displacement ranges the effect is less evident transversally than axially. From the distance of the CCD displacement, a combination of tilt and defocus was calculated and used as order for a new loop (step3), the focal spot then obtained is shown in the figure 1 (inner right). We take care that at the end of this new loop, after the addition of the calculated phase map, the residual RMS is comparable to the residual RMS obtained at the end of the first loop which gives the initial diffraction limited focal spot. This ensures that the focal spot quality is unchanged as visible on these results.

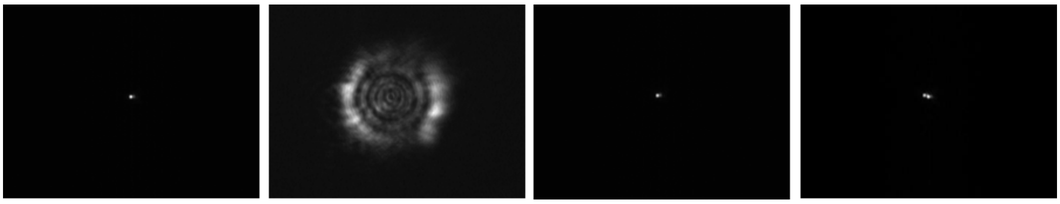

Fig. 1. Camera images obtained at the different steps of the process: initial diffraction limited focal spot (outer left – step1), image camera after CCD displacement (inner left – step2), focal spot obtained after compensation of the CCD displacement (inner right – step3), sum of the previous focal spots (outer right)

On the figure 1, the comparison of the two focal spots obtained, the initial diffraction limited spot (outer left image) and the second focal spot (inner right image) obtained after compensation of the CCD displacement, allows to validate the system ability to control the 3D position of the laser pointing. By comparing these 2 focal spots on the figure 1 we can see that the focalization adjustment is correct. However, on the outer right image which is only the sum of the 2 previous focal spots of the figure 1, we can note a small difference in terms of x and y position of the focus. In fact, the 2 spots are not perfectly superposed as they should be. Because the axial displacement is quite important, we see here the inclination difference between the optical axis and the displacement axis of the camera.

In terms of focus positioning, the DM offers a dynamic of few focal spots transversely with a 1µrad resolution. The dynamic in the axial direction is a lot more important because curvature is a natural deformation mode of the DM. In fact, the accessible displacement along the optical axis is in the order of 700 focal spots.

## Conclusions

In this paper we show how it is possible to use an AO loop in order to simultaneously obtain a diffracted limited spot and to control its localization. Combining these two aspects of the focal spot (quality and 3D-position) by using only one AO loop allows optimizing the interaction between the laser and the target. Moreover during the loop process it is possible to change in real time the focus position in the chamber by modifying the combination of tilt and defocus added on the phase map used as order for the loop.

In most cases the DM dynamic range is sufficient to control the focal spot position in the laser-matter experiments. However, if this is not the case for very specific applications a solution consists to outsource the laser pointing control. In this case, the DM can be located in the motorized mount. In such a configuration, the DM is only used to correct the laser chain aberrations and to control the axial focus position whereas the motorized mount is used to control the transverse position of the focus in the chamber.