Active, Multi-aperture Beam Integrator for Application Adapted Laser Materials Processing

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Laser processing applications such as heat treatment require the transformation of the raw intensity distribution into a beam profile of homogeneous intensity. Further the adaption of this profile to altering working geometries results in improved energy coupling and in more efficient material processing. For the utilization of CO_2-laser radiation an optical system is developed that both transforms the raw intensity distribution into a homogeneous beam profile and contains the ability to continuously change the spot size independently into two directions.

1 Introduction

Laser heat treatment applications often require constant energy coupling along with the working plane. For this reason beam spots of smooth, homogeneous intensity are required. Altering working geometries together with the use of constant spot sizes result in a waste of energy and decreases the overall efficiency of the process.

The utilization of CO_2-laser radiation for the processing of thermoplastics exhibits considerable advantages due to improved absorption characteristics of the material. This motivates the development of a beam shaping system for both homogenization and spot size variation to adapt to altering working geometries.

To transform the raw intensity distribution of the radiation source into a homogeneous beam profile on the working plane several optical designs exist which theories have been fairly discussed in literature [1][2]. However, for the homogenization of laser radiation at 10.6 µm without the utilization of any crystal optics just a few designs can be identified [3][4]. However, they all do not exhibit fully explicit design for an active variation of the spot size and therefore do not maintain altering working geometries.

2 Concept

Imaging beam integrating systems generally allows for both homogenization and spot size variation (Fig. 1). The application of multifaceted elements (MLA) first separates the input distribution into many several intensity shares that finally are superimposed in the focal plane of an integrating lens. From 1^{st} order approximation the spot size can be calculated as [1]

$$D = p\frac{F}{f_1 f_2}\left[(f_1 + f_2) - a\right]. \qquad (1)$$

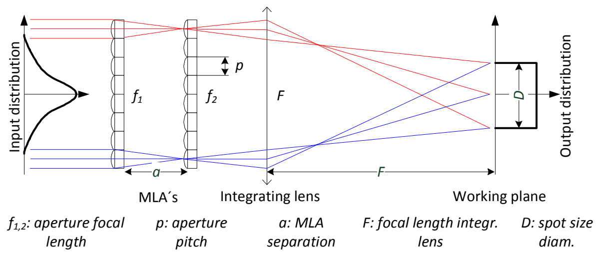

Fig. 1 *General lens design of imaging beam integrator*

3 Solution

The general design of the imaging beam integrator serves in a modified form for the proposed optical system. Instead of transmissive MLA´s, faceted mirrors allows for the almost wavelength independent homogenization without any crystal optics and lead to an off-axis optical design (Fig. 2). The beam shaping is realized with two groups of faceted elements with cylindrical apertures. They enable a rectangular beam profile in the focal plane of a mirror telescope. The application of two groups of faceted mirrors facilitates the homogenization independently into two directions and therefore expands the ability to vary the spot size.

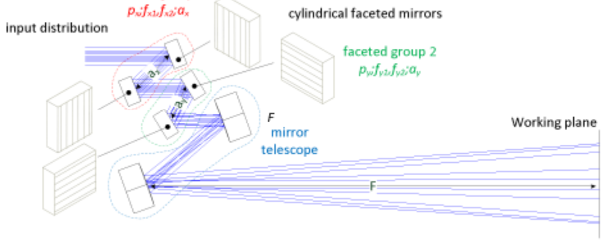

Fig. 2 *Reflective off-axis beam integrating system*

A change in linear distance within each faceted group either changes the height or the width of the rectangular spot. This is analytically described by

$$D_{x,y} = p_{x,y} \frac{F}{f_{1_{x,y}} f_{2_{x,y}}} \left[\left(f_{1_{x,y}} + f_{2_{x,y}} \right) - a_{x,y} \right]. \quad (2)$$

With a change of $a_{x,y}$ the folding angle of the off-axis system has to be maintained, too (Fig. 3). Therefore the linear motion also precise rotary motion has to be applied at each faceted mirror and is most challenging to the automation of the optical system. The integration of position controlled piezo-electric actuators allows for the required motion with very high accuracy. Additionally a very compact design can be realized.

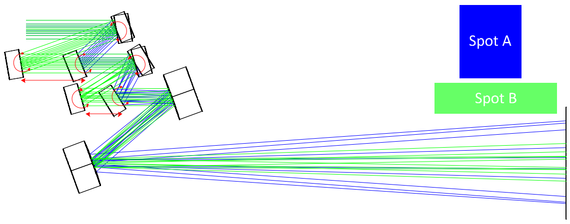

Fig. 3 *Orientation of optical components*

4 Results

Both homogenization and spot size variation have been successfully validated at two different wavelengths. Fig. 4 depicts crisp intensity distributions for different spot sizes that have been acquired for a wavelength of 632.8 nm (HeNe).

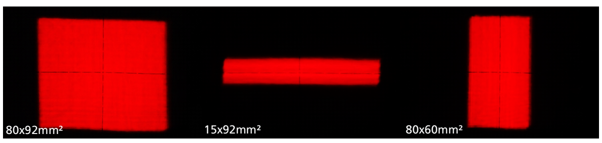

Fig. 4 *Measured intensity distributions at 632.8 nm*

Tab. 1 lists the available spot dimensions of the beam integrating system.

	min. value	max. value
Spot width	15 mm	85 mm
Spot height	40 mm	100 mm

Tab. 1 *Available spot dimensions*

Burn in tests at 10600 nm exhibit interference patterns with a spatial period of ~2 mm (Fig. 5).

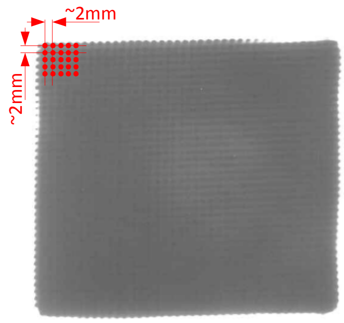

Fig. 5 *Burned in spot geometry at 10600 nm*

These patterns occur by interaction of the coherent irradiation source and the superposition of the intensity shares. They can be approximately calculated using (3) [2]

$$\text{Period} = \frac{\lambda F}{p}. \quad (3)$$

For the proposed system the focal length of the mirror telescope F=900 mm and the aperture pitch of p=5 mm of the faceted mirrors result in a period of 2.09 mm and coincide with the experimental results.

5 Conclusion

Reflective optical components avoid the utilization of crystal optics like ZnSe and further allow for almost wavelength independent beam shaping. The imaging beam integrator serving as the general layout of the system is modified to expand the dynamic performance to change both width and high of the spot size. The most important aspect that has to be covered by future work is to minimize disturbances by local intensity peaks caused by interference effects.

References

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