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# Novel beam diagnostic concept for laser scanner systems

Andreas Koglbauer[a,*] , Otto Märten[a], Stefan Wolf[a], Reinhard Kramer[a]

[a]*PRIMES GmbH, Max-Planck-Str. 2, 64319 Pfungstadt, Germany*

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## Abstract

The industrial exploitation of additive manufacturing demands a solid knowledge and control of the influential factors dominating the process quality, including the laser scanning system as a key component. But the limited space and the variety of possible beam incidence angles and positions inherent to such systems, constitute special framework conditions, only inadequately provided by state-of-the-art beam diagnostic devices.

We present a novel beam diagnostic concept that meets these requirements, and addresses scanner specific measurement tasks, like the examination of the field flatness, pincushion distortion, position dependent focal shift, or accuracy of position and marking speed. The working principle is based on the detection of scattered laser light from a pattern within a glass plate, allowing the reconstruction of the light path and derivation of the beam width. All above-mentioned quantities can be measured with high resolution and reproducibility. The current state of the experiments is presented, and the prospects of this novel measuring technology for scanner system diagnostics are discussed.

*Keywords: 3D printing; selective laser melting; additive manufacturing; laser beam diagnostics*

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## 1. Introduction

In recent years, additive manufacturing (AM) and metal 3D printing has grown from a laboratory prototyping application to a versatile tool in a wide range of scientific and industrial sectors and is meanwhile sustainably changing our industrial manufacturing landscape. With its unique capabilities this technology opens up unseen opportunities in design freedom or modification processes flexibility. These can be directly translated into an accelerated product development cycle and thus have a direct impact on the economic efficiency. Consequently, with the goal to exploit metal based generative techniques like selective laser melting (SLM) as a reliable industrial production method, e.g. for low volume series, arises the need for quality and repeatability, and thus process control. As a matter of course, close attention has to be paid to the properties of the laser beam as the actual tool processing the metal powder.

While a variety of beam diagnostic instruments specializing on laser scanner systems exist, they often are not capable of providing a thorough description of all relevant parameters related to the beam delivery system. For example, the special geometrical circumstances of the interior of a SLM machine typically restrict the beam analysis to the scanner zero-point position. And other important parameters, like those related to the deflecting unit of the system cannot be investigated via a mere measurement of the power density distribution. This is why alternative approaches for scanner calibration, like the writing of test patterns and subsequent visual inspection are often the method of choice. To overcome these limitations, we developed a novel beam diagnostic concept, capable of addressing a majority of common scanner specific measurement task like the examination of the field flatness, pincushion distortion, position dependent focal shift, or determination of the accuracy of position and marking speed. In addition, the method is predestined to examine the precise alignment of two or more overlapping scanning fields. A crucial property of multi laser systems used for large work pieces.

## 2. Working principle

The mirror steering apparatus is a key component of any scanner system. This is why our novel measuring concept involves the beam deflection unit and measures the moving beam, instead of a stationary one. The general working principle is depicted in Fig. 1.

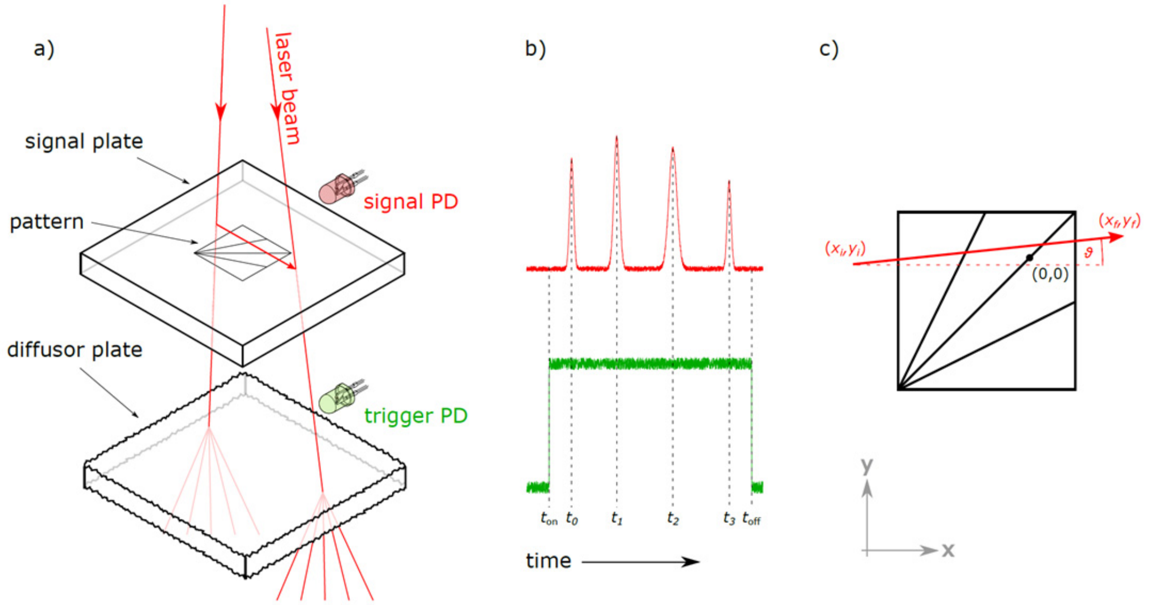

Fig. 1. Working principle. (a) A photo diode (signal PD) monitors scattered light form the laser beam crossing an in-glass pattern. Stray light from a diffuser (for beam expansion) serves as a trigger via a second photo diode (trigger PD). (b) Time resolved signal of signal (red) and trigger PD (green). (c) Vector coordinates in relation to signal pattern.

When scanning the beam in a straight line across an in-glass measuring pattern, scattered light from said pattern is collected via a signal photo diode with high temporal resolution, yielding a multiple peak sequence like the red signal in Fig. 1 b). The transmitted beam is expanded by means of a diffuser plate, to reduce the power density on the building plate, which serves as absorber. In addition, a second photo diode (trigger PD) monitors the laser switching times. From the width of the signal peaks and their relative spacing, we can deduce not only the beam size, but reconstruct the path the beam has taken over the pattern (see Fig. 1 c). This incorporates start- and end-point of the vector and allows for an absolute position measurement in the building area of a SLM machine. Also the data allow us to determine the marking speed in the measurement plane. It should be noted, that the determination of the beam size has been proven to be independent of the marking speed, or the orientation in which the beam is crossing the pattern as demonstrated by Koglbauer et. al. (2018).

Based on the described working principle we set up a prototypical measuring device. It is adapted to work in the parameter range typical for current 3D metal printing machines working with laser systems in the NIR (power levels and spot sizes up to 1 kW and down to 25 µm radius). Even in this early stage of development, the instrument is compact enough to be positioned at different transverse locations in the scanning field. While this technique only provides a 1D integrated linescan of the power density distribution, instead of a 2D representation, the additional measurands accessible allow analysis beyond the scope of conventional beam diagnostics. In the following, this will be clarified on the basis of concrete calibration examples typical for laser scanner systems.

## 3. Application examples

For our experiments we use a laboratory scanner setup, consisting of a 400 W single mode fiber laser at 1070 nm in combination with a galvo scanner unit and a fused silica $f\theta$-objective with a nominal focal length of $f = 420$ mm. As a reference, the resulting focus in the scanner zero-point position was measured with one of our established camera based systems[1], yielding a beam waist of $w = 37.4$ µm, a full angle divergence of $2\theta = 19.5$ mrad and a beam quality factor of $M^2 = 1.07$, resulting in a Rayleigh length of $z_R = 3.84$ mm.

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[1] PRIMES MicroSpotMonitor

### *3.1. Beam caustic and propagation parameters*

One of the essential calibration tasks in a scanner system is to bring the working plane (i.e. the plane in which the geometric dimensions are reproduced correctly) and the focal plane of the scanner in coincidence with the powder surface. For this purpose, we measured a beam caustic by moving the device by means of the building plate's translation stage along the direction of propagation. The measured beam radius as a function of the axial position is plotted in Fig. 2 (red circles), together with the determined marking speed in the corresponding plane (green triangles).

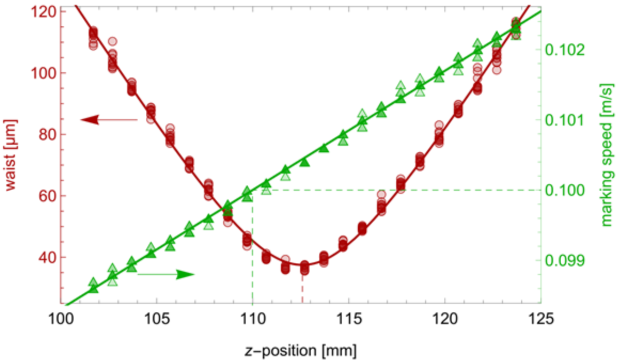

Fig. 2. Measurement of the beam propagation parameters in the scanner zero-point position. Beam radius (red circles) and marking speed (green triangles) as a function of the direction of propagation.

The results for the beam propagation parameters ($w = 37.5$ µm, $2\theta = 19.7$ mrad, $M^2 = 1.08$, $z_R = 3.81$ mm) are in excellent agreement with the reference measurement. The marking speed shows the expected linear dependence with the distance to the objective. Comparing the plane in which the programmed marking speed of 0.1 m/s is achieved (green dashed vertical line) which can be interpreted as the working plane, with the focal position (red dashed vertical line), we see a discrepancy of about 2.6 mm. It follows, that the divergence of the optical system has to be adjusted, in order to compensate for this difference. A task that can be reviewed in a simple manner using the presented device, which so far relied on the production of test patterns and subsequent visual inspection.

### *3.2. Thermal focal shift*

The high data acquisition rate (only limited by the time it takes to scan the vectors over the pattern), allows the observation of effects in the sub-second time regime, like the transient behavior of thermal lensing. Fig. 3 shows the beam radius, measured in one plane approximately three Rayleigh lengths above the focal point for two different power levels (20W - blue circles, 400W - red triangles). In this asymptotic region of the beam caustic a change in the spot size is directly proportional to a shift of the focal position. The measurement frequency amounts to 100 Hz. For the low power measurement, we see no significant change in beam radius over the complete time. The data for the 400 W laser exposition show a rapid decrease, associated with the thermally induced shortening of the effective focal length of the objective.

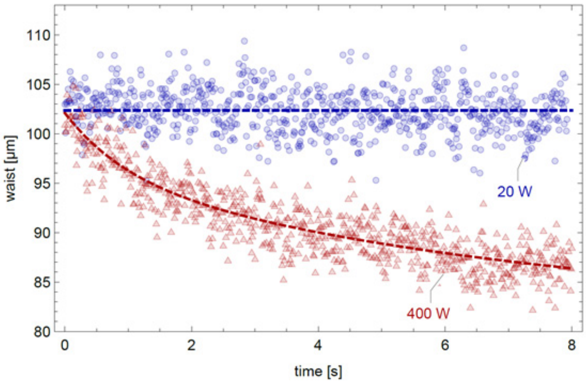

Fig. 3. Time resolved determination of the beam radius in one fixed plane $3z_R$ above the focal plane, for two power settings (20W - blue circles, 400W - red triangles).

### *3.3. Timing and synchronization*

Delays between deflecting unit and laser programming, may they originate from inertia of the mechanical components or electronic response, can lead to tracking errors. Hence, it is crucial to accurately synchronize the scanner motion to the laser switching times. Nowadays, methods to determine such a shift often involve the processing of a test specimen with specific operating points. These typically differ from the optimum parameters of the SLM process, so that a calibration at the actual process parameters is not possible.

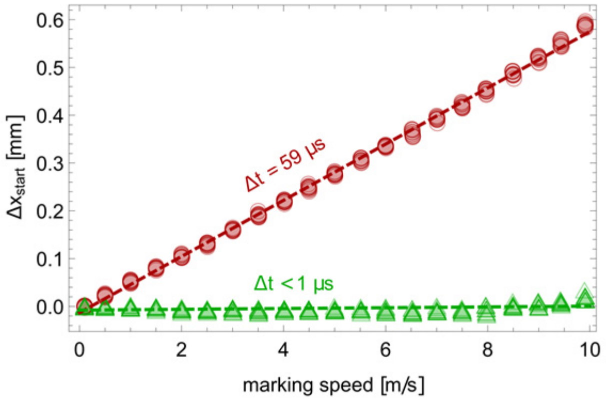

Fig.4 Switch-on delay-time calibration. Variation of the vector starting point with scanning speed for uncorrected (red circles) and corrected (green triangles) delay-time parameter.

In order to determine these delays with our novel device, we measure the same vector with ascending marking speeds. A timing error will thus manifest itself as an increasing position error as depicted in Fig. 4 (red circles) by the example of the x-coordinate of the vector's starting point. The slope of the linear regression fitted to the data directly equals the timing mismatch. Taking this into account and repeating the measurement, yields an almost perfect compensation (green triangles). The total measurement time for such a calibration curve (here with 21 different velocities and a 10-fold repetition) is less than 3 seconds and thus a significant saving in time compared to alternative methods.

## 4. Conclusion and outlook

We presented a novel technique for beam diagnostics and advanced characterization of 3D laser scanner systems, based on the light scattered from an in-glass measuring pattern. It enables us to determine scanner properties so far inaccessible to conventional beam diagnostics, including e.g. measurands demanded by certain standards in the aerospace sector (DIN 35224 (2016)). In addition to the application examples we presented in this article, the analysis can be extended to multiple transverse positions within the scanning field, allowing investigation of the field flatness, pincushion distortion, or the accurate stitching of overlapping scanning fields. We believe that the extended information the method can provide will prove to be beneficial in the better understanding and optimization of the interaction of laser source, deflection systems and imaging optics, and become a viable tool in laser scanner analysis and calibration.

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## References

Koglbauer, A., Wolf, S., Märten, O., Kramer, R., 2018. A compact beam diagnostic device for 3D additive manufacturing systems, Proceedings Volume 10523, Laser 3D Manufacturing V; 1052316

DIN 35224:2016-09: Welding for aerospace applications - Acceptance inspection of powder bed based laser beam machines for additive manufacturing