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How to ensure reproducible laser beam parameters in selective laser melting processes

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Abstract

Previously unobtainable parameters can be determined with non-contact measurement of the laser beam. The measuring process itself is extremely fast, saving time and money in both production and troubleshooting. How can these advantages be used in selective laser melting? And are the measurement results accurate and repeatable as the measurement technologies described in the ISO standard? The paper describes the challenges on the way to non-contact laser beam measurement in additive manufacturing.

Keywords: additive manufacturing; selective laser manufacturing; laser beam parameters; non-contact measurement;, Rayleigh scattering; serial production; reproducibility; quality; troubleshooting

1. Introduction

In production systems for selective laser melting (SLM), several lasers often work simultaneously on one component, or various parts are manufactured simultaneously using several laser sources in a single system. As the productivity of SLM systems goes up, so do the demands on their availability and the reproducibility of the manufactured parts. To guarantee this in the long run, the technicians and engineers responsible for the system must know the critical parameters of the focused laser beam and be able to quickly understand any changes they see in it. This is where conventional measurement techniques reach their limits – and where the non-contact approach shines.

Five years ago, Ophir, a brand of MKS Instruments, introduced the BeamWatch technology for non-contact measurement of laser beams. For the first time, it was possible to measure the beam profile of high-power lasers without any restrictions on the power. As the laser beam passes through the instrument's housing, the beam parameters are determined indirectly by measuring the Rayleigh scattering. Inside the measurement system, the electric field of the laser radiation induces oscillation in the dipole molecules of the ambient air – or a process gas – at the laser's frequency, creating a corresponding elastic scattering. This can then be measured with a CCD or CMOS camera, and an integrated software calculates the beam and beam-quality parameters. Over the past few years, the company has adapted the technology to various areas of application. For example, BeamWatch AM was developed specifically for use in SLM systems (Fig. 1).

Fig. 1. Ophir BeamWatch AM is especially developed for the use in selective laser melting processes.

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2. ISO compliance of non-contact beam analysis

The non-contact measurement technology for laser beam profiling is relatively new, therefore it has not made its way into the ISO 11146 standard yet. Nevertheless, it is of high relevance for the users of fiber laser technology to trust on the accuracy and repeatability of their measurements. In order to proof the ISO compliance of the non-contact measurement technology, measurements were taken using Rayleigh Scatter based beam profiling methods and other beam profiling technologies.

By comparing the ISO compliant measurements taken with a beam profiling camera and a scanning-slit beam profiler with the different measurements made with non-contact beam profilers, it was shown that the measurements made with the various non-contact measurement devices based on Rayleigh scattering meet all of the requirements of ISO 11146 including second moment beam widths derived from moving slit measurements. The maximum deviation from the mean for each of the three reported results (W0x, W0y, Θx, Θy, Mx2, and M^2y) is less than 3.75%. There is excellent consistency between the four Ophir instruments tested employing three different technologies and four different calibration standards, giving confidence that BeamWatch based on Rayleigh scattering is a reliable technology for measuring beam quality (Simmons and Kirkham).

3. Non-contact measurement in additive manufacturing

Measuring lasers in additive manufacturing places special demands on the instruments. For one, the fine metal powders used mean that the environment is never really dust-free; this affects both classical measuring instruments and the optical systems themselves. Furthermore, processing takes place in closed production chambers (Fig. 2), which often provide little room for placing and aligning additional measurement devices.

Fig. 2. Production chamber of an SLM system at the Fraunhofer IAPT (©Fraunhofer IAPT)

Non-contact measurement of a laser beam takes place within a compact housing sealed by a pneumatic shutter and purge gas. Because the measurement device’s calibrated distance is calculated from the base plate, this eliminates time-consuming manual alignment of the Z-axis; the system is simply moved to the position indicated on the device by raising or lowering the work platform (Fig. 3).

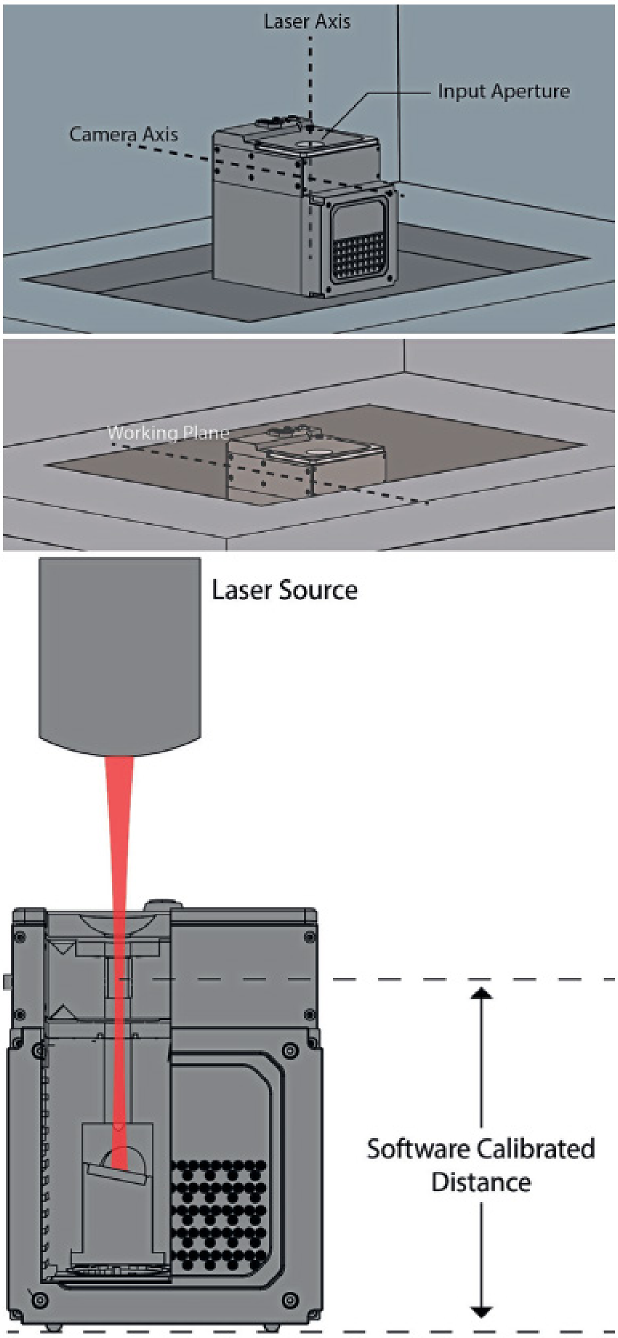

Fig. 3. Measuring principle and application of non-contact beam measurement.

In just fractions of a second, the integrated camera returns up to 2048 beam profiles, from which the system computes all the relevant beam parameters. Since the laser beam isn't touched at any time, it remains entirely unaffected by the measurement device; nor can the beam damage it. After leaving the measuring chamber, the laser beam hits an optical deflector and is guided to the power-measuring beam trap, which is equipped with a heat sink. At a maximum power of 1 kW, one can measure continuously for up to two minutes before a cooling cycle is required. The operator is thus spared having to interpret the measurement results and doesn't need to monitor the condition of the transducer – or even take it into account. The measurement results are reproducible and reliable.

4. Troubleshooting

High-quality parts are produced on an selective laser melting system. During the quality inspection it becomes obvious that the surface quality has suddenly decreased rapidly: The surface of the material is porous. In order to solve the quality problems, the experts employ a non-contact measuring system.

In another case, the measurements indicate a focus shift after the appearance of quality problems. The experts suspect that either some parts were not properly cooled or that a lens or protective window might be damaged. A physical check reveals that a protective glass plate is indeed broken. The flaw is quickly fixed.

In both cases, such conclusions could heretofore only be drawn after elaborate experimental investigations. For this purpose, the user would have had to contact a technician from the system manufacturer and trigger an unspecified service order. But now, non-contact measuring technology makes it possible to localize and assess the reasons for the quality problems directly. In this example, the errors could be addressed by the local experts.

Using the crosshairs, the compact system is placed on the shutter in the center of the processing field, so that the laser beam hits the device vertically. The height of the focal plane is already calibrated for the non-contact measuring system, so the measurement can be carried out immediately. Within a few seconds, the integrated software delivers the results. For the first time, the engineers can directly observe the focus shift of the laser beam, on site and with temporal resolution.

If one compares the two graphs in Fig. 4, it becomes clear that, in the illustration on the left, seemingly higher-order modes or diffraction effects play a role, whereas in the illustration on the right, a Gaussian beam profile, i.e. TEM00, is present. In the case on the left, the secondary maxima – and especially the different focus positions and beam direction from X- to Y-axis – have led to a reduction in power density in the enlarged focal spot. The detectible losses in surface quality were caused by the undesired irradiation of the component along the machining path. The lower power density resulted in increased porosity of the components themselves – causing a strength problem.

If, as in this case, the beam delivery is adjusted poorly, and parts of the laser power are vignetted, thermal effects may occur in addition to the observed direct diffraction effects. Finally, laser power was absorbed by at least one optical mount, which was thus warmed up. Not only the frame itself, but also the optical element was heated on the one side, which in this case presents as an asymmetrical deformation of the laser beam. What was possible to visualize here in real time through imaging would otherwise be laborious to determine empirically using conventional methods, and it would also require partial dismantling of the beam delivery. On the basis of the measurement results alone, engineers were able to adjust the machine's beam path onsite and restore the desired processing quality.

No matter whether it is the operator or a service technician from the system manufacturer using the non-contact measurement technology, measuring the beam and beam quality parameters saves time and money when troubleshooting. Errors can be localized and corrected much faster – and more reliably.

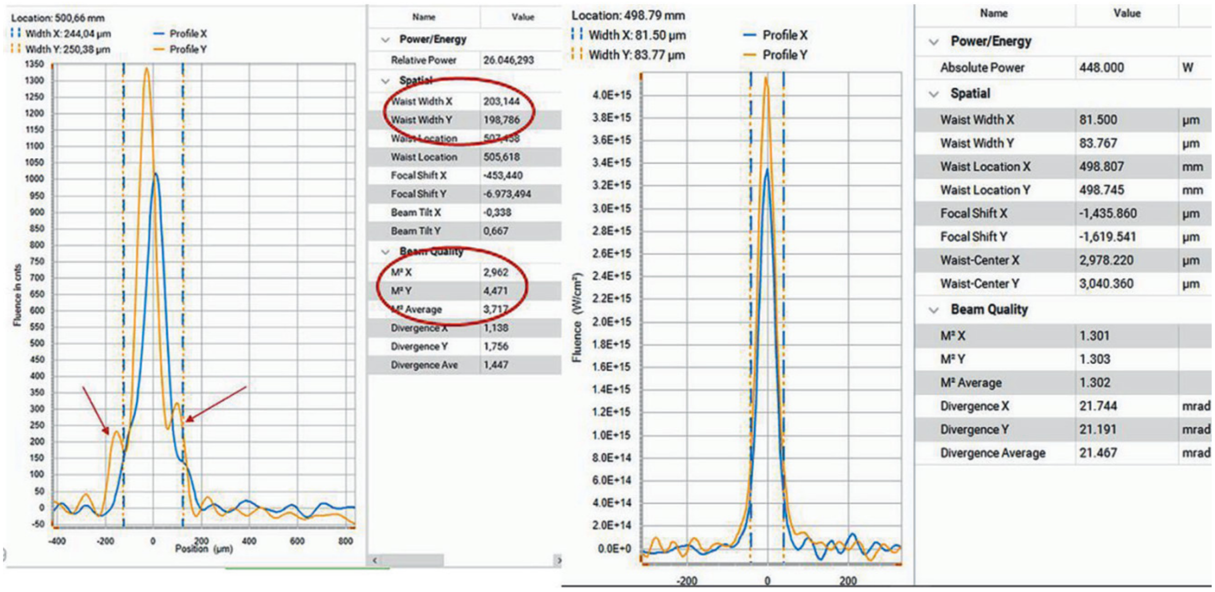

Fig. 4. Measurements on an SLM system at the Fraunhofer IAPT: On the left the laser system with quality problems, on the right the laser system with perfect results (©Fraunhofer IAPT)

5. Conclusion

Non-contact measuring of the laser beam in additive manufacturing makes it possible to obtain previously unmeasurable parameters, such as the power or a focus shift over time. Furthermore, measurements are taken very quickly and require no complex adjustments or calibration. The BeamWatch technology thus simplifies many additive manufacturing processes, saving time and money for both manufacturers and users of selective laser melting systems.

References

Simmons, J., Kirkham, K., 2019, ISO compliance of non-contact, real-time beam analysis, https://www.ophiropt.com/laser--measurement/knowledge-center/article/13236