11th CIRP Conference on
Photonic Technologies [LANE 2020]

Industrial Paper

# OCT sensor for layer height control in DED using SIEMENS machine controller

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**Abstract**

In order to gain "First Time Right" parts in laser additive manufacturing processes with cw sources sensor technology is required not only with high temporal and spatial resolution for evaluating the result of the treatment, the measurement has to provide information which can be directly implemented in a closed loop control. Especially in the context of Industry 4.0, digitalization and predictive maintenance reliable sensors get much more into focus. In DMD processes with powder the material itself also is a source of noise when it comes to sensors coaxially mounted onto the processing head.
A group of scientists from Siemens and Precitec developed a solution for accurate and controlled DMD processes based on the OCT sensor and the SINUMERIK® controller. The direct communication with the Siemens machine control now also the "Digital Twin" concept becomes reality. By controlling the feed rate of the process "First Time Right" is not a pious hope anymore.



*Keywords: Laser Additive manufacturing; First-time-right; Industry 4.0; Digital-Twin*

## 1. Introduction

Sensors based on OCT (optical coherence tomography)/ low coherence interferometry are different to all the other technologies because the measurement is not affected by the process emissions [1], [2] and thus open new horizons in laser materials processing. The use of this method in laser applications has risen in the last years. Since its first appearance in 2008 [3], application examples were shown for laser cutting [4], selective laser melting [5], laser micro machining [6], laser drilling [7] and laser welding [8]. For the latter, a huge potential is foreseen [9][10].

Many industries are working to make products more durable and efficient. For this it is necessary to increase the surface properties with regard to abrasion, corrosion and erosion resistance of the workpieces. For this modification of surfaces, laser cladding has become established as a key technology. Unlike other coating technologies, such as e.g. flame spraying a laser offers the possibility to precisely control the introduced energy. This allows a de-fined application of single layers right up to full generative production. Not only surface treatment has established itself as a field of application for the Direct Metal Deposition process, direct "printing" or the production of near net shape structures is an essential field of application for laser DED.

Although the nozzle technology has been continually improved, the powder efficiency is below 100%, which correlates directly with the track width. According to the data sheet, the best powder nozzles have an efficiency of 98% at the optimum track width [11]. Compared to other processes, such as plasma build-up welding, laser cladding convinces with a minimal heat load on the component and extremely low distortion of the workpiece. In the field of repair processes, it has become established especially for the regeneration of worn blade tips of aircraft and gas turbines [12].

Especially sensor technology is a leading part related to Smart Factory and predictive maintenance and even process control. Transforming machine elements into intelligent cyber physical systems involves the integration of smart sensors for condition and process monitoring.

## 2. New sensor concepts for Directed Dnergy Deposition (DED)

### *2.1. Low-coherence interferometry in laser materials processing*

OCT technology (Optical Coherence Tomography) is an imaging technique based on low-coherence interferometry (LCI). It is a long-established medical examination procedure [13]. An interferometer with a light source of low coherence length is used to measure distances and the composition of human tissue, e.g. the cornea. The short coherence length is achieved using light sources that emit broad spectrum light. The applied light sources are typically super luminescent diodes (SLDs) with a range of some 10 nanometers, or a Swept Source Laser. In 2006, Precitec Optronik GmbH launched a thickness and distance sensor based on spectral domain OCT and this was adapted to material processing applications with laser sources of high beam quality. The adapted technology al-lowed distance measurement to the required accuracy of about 10 microns, even over long distances.

However, the real innovation and thus the basis of a technological leap in the field of process monitoring/control is the fact that the accuracy of the interferometric measurement is not affected by the electromagnetic emissions from the vapor capillary or the adjacent areas. The intensely bright emissions caused by the high-power beam material interaction are not coherent with the light emitted by the low coherent light source of the measuring system and thus only the measurement system light is involved in interference between the reference and the measuring path. Based on an accurate adjustment of the measurement beam coaxial to the processing laser, this technology for the first time provided an exact measurement of the depth of the keyhole, independent from seam geometry or processed material. The only restriction is in the dimension of the measurement point compared to the spot size of the processing beam and the measuring range in the axial direction.

### *2.2. OCT Measuring Principle*

Interferometric measuring principles are found in several applications. Most of these implementations are based on the interference of coherent light with itself. The basic interferometer hereby consists of a light source, a beam splitter, two reflecting surfaces and a photo detector. The relative distance between the two reflecting surfaces affects the interference pattern of the reflected light beams. The most prominent interference patterns are hereby found in the temporal or spectral domain. The subsequent analysis of the interference pattern reveals the relative distance between the two surfaces. As these interference patterns are the results of the coherence of the light used, they are only affected by the light source itself and the relative displacement of the mirrors; external illuminations, in particular process emissions, do not interfere with the interference pattern and have no influence on the measured distance.

The integration of this measuring principle into laser welding optics allows to measure the distance to a surface in proximity to the focal spot. This surface plays the role of one of the described mirrors. The measuring beam is focused onto the surface by using the same focusing optics as the working laser Figure 2. A separate real mirror and the beam splitter are mounted in an enclosure apart, whereas the light source and the photo detector are in-stalled in an electrical device. By tilting or translating the light beam coupling into the welding head, the position of the measuring spot can be varied relatively to the focal spot of the working laser. Hence, any kind of topography measurements can be achieved by scanning the surface with the measuring beam. If the measuring beam is aligned to the working laser, it will enter the keyhole and reflect at its bottom: the penetration depth can be measured.

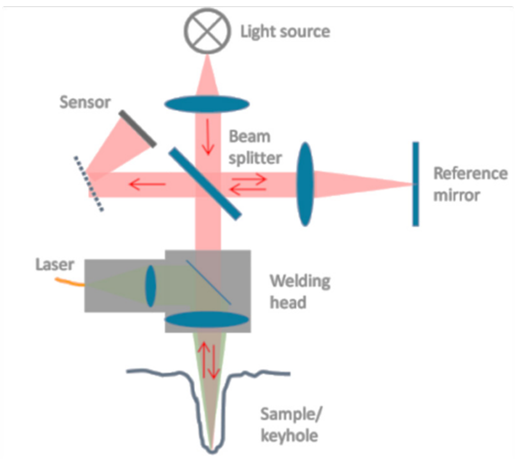


Fig. 1. Interferometric measuring principle through a welding head

Fig. 2. Ruggedized sensor light collimation (top) and fiber coupling - (back) mounted on a modular laser welding head Precitec YC52

## 3. Application example: feed rate control in 3D printing

With respect to demand for complete monitoring or even control the additive manufacturing processes – nowadays sometimes labeled 3D printing – like LMD and LPBF are not distinguished from other laser applications. Precitec demonstrated in miscellaneous applications, that OCT is the promising sensor technology for acquiring the most dominant information, the topology of the processing result and due to the coaxial adaptation, this is possible in-situ. Possible process error situations in 3D printing with LPBF like pores, distortion, coating defects, layer offsets or even the so-called balling effect result in topography changes and therefore are picture perfect to be detected and measured with the OCT technology.

Just recently this year Siemens and Precitec demonstrated a fully close-loop-controlled LMD process by integrating the OCT technology into the SINUMERIK control. What is true for other laser manufacturing processes also holds true for LMD, even the metal powder blown to the work-piece surface does not change the exact surface topology measurement and so the metered value can be used as input for a control loop.

This work was carried out in a funded project by European commission called PARADDISE http://www.paraddise.eu] - A Productive, Affordable and Reliable solution for large scale manufacturing of metallic components by combining laser-based ADDItive and Subtractive processes with high Efficiency [14].


Fig. 3. Adaptation of the OCT sensor to an LMD head

As described earlier in this paper the integration of the OCT system to a processing head is straightforward as this is a point measuring system and the transmissivity/ reflectivity of the optical components in the head can be fixed to the wavelength of the sensor device. Especially in this application the measuring spot is fully co-axial to the processing laser and together with SIEMENS and RWTH Aachen a model was developed and implemented into the SINUMERIK which exactly derives the final wall/ track height from the distance measurement. In the closed-loop program module the height variations are compensated by feed rate adaptation.

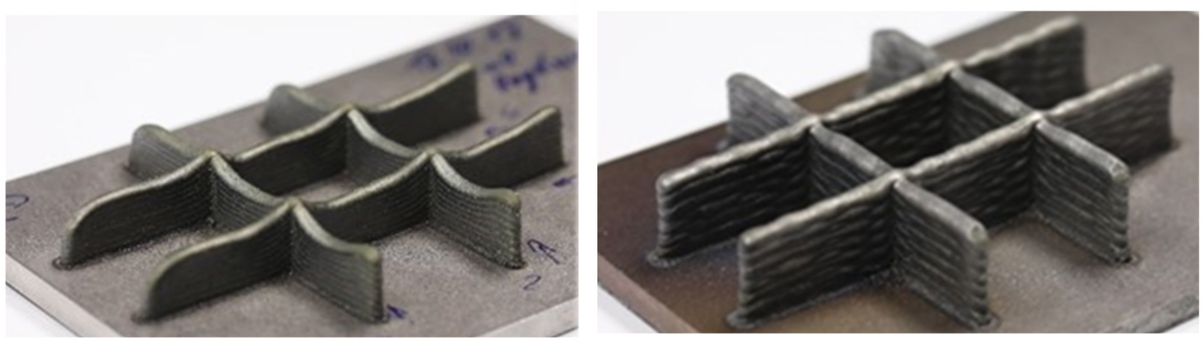

Fig. 4. Results of the closed-loop-controlled process in comparison to a non-controlled

## 4. Conclusion and outlook

Low-coherence interferometry is a technology rapidly finding its way into laser material processing applications. It has a very high temporal and spatial resolution and is suitable for coaxial integration. Robustness against any kind of process emissions make it suitable for all kind of process monitoring and process control tasks that are based on distance or topographic measurements.

Various sensor technologies are used for different tasks in the field of laser welding. Although these technologies are mature, improvements in closed-loop control, pre- and post-process monitoring of complex joint geometries and remote welding as well as more accurate in-process monitoring are required.

This paper demonstrated the abilities of the In-Process Depth Meter [15] to fulfill these tasks. Using it as a tool to measure the keyhole enables understanding of the laser welding process. The combination of the sensor with a quality assurance system such as the Laser Welding Monitor [16] allows autonomous detection of weld defects that remain unseen by conventional sensors. By feeding the laser source with a power signal, the sensor offers closed-loop control of the penetration depth. The fourth shown application example demonstrated the ability to compete with current pre- and post-process sensors.

Upcoming developments might include the 3D modeling of the keyhole's geometry, all-in-one sensors for simultaneous pre-, in- and post-process monitoring and self-tuning welding robots. Also, other laser applications, such as 3D printing by LPBF or LMD, will benefit from the advantages of the low-coherence interferometry.

## Acknowledgements

This work was supported by the European Commission in the project PARADDISE (A Productive, Affordable and Reliable solution for large scale manufacturing of metallic components by combining laser-based ADDItive and Sub-tractive processes with high Efficiency) coming out of the call topic FOF-13-2016 Photonics Laser Based Production.

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