Monitoring system for the quality assessment in Additive Manufacturing

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Abstract: Additive Manufacturing (AM) refers to a process by which a set of digital data -representing a certain complex 3dim design - is used to grow the respective 3dim real structure equal to the corresponding design. For the powder-based EOS manufacturing process a variety of plastic and metal materials can be used. Thereby, AM is in many aspects a very powerful tool as it can help to overcome particular limitations in conventional manufacturing. AM enables more freedom of design, complex, hollow and/or lightweight structures as well as product individualisation and functional integration. As such it is a promising approach with respect to the future design and manufacturing of complex 3dim structures. On the other hand, it certainly calls for new methods and standards in view of quality assessment. In particular, when utilizing AM for the design of complex parts used in aviation and aerospace technologies, appropriate monitoring systems are mandatory. In this respect, recently, sustainable progress has been accomplished by joining the common efforts and concerns of a manufacturer Additive Manufacturing systems and respective materials (EOS), along with those of an operator of such systems (MTU Aero Engines) and experienced application engineers (Carl Metrology), using decent know how in the field of optical and infrared methods regarding non-destructive-examination (NDE). The newly developed technology is best described by a high-resolution layer by layer inspection technique, which allows for a 3D tomography-analysis of the complex part at any time during the manufacturing process. Thereby, inspection costs are kept rather low by using smart image-processing methods as well as CMOS sensors instead of infrared detectors. Moreover, results from conventional physical metallurgy may easily be correlated with the predictive results of the monitoring system which not only allows for improvements of the AM monitoring system, but finally leads to an optimisation of the quality and insurance of material security of the complex structure being manufactured. Both, our poster and our oral presentation will explain the data flow between the above mentioned parties involved. A suitable monitoring system for Additive Manufacturing will be introduced, along with a presentation of the respective high resolution data acquisition, as well as the image processing and the data analysis allowing for a precise control of the 3dim growth-process.

Introduction

During the process of laser sintering, a workpiece is produced in layers. For this purpose a powder coating is evenly distributed over a construction platform and a laser melts the powder according to a height-dependent contour of the CAD model.

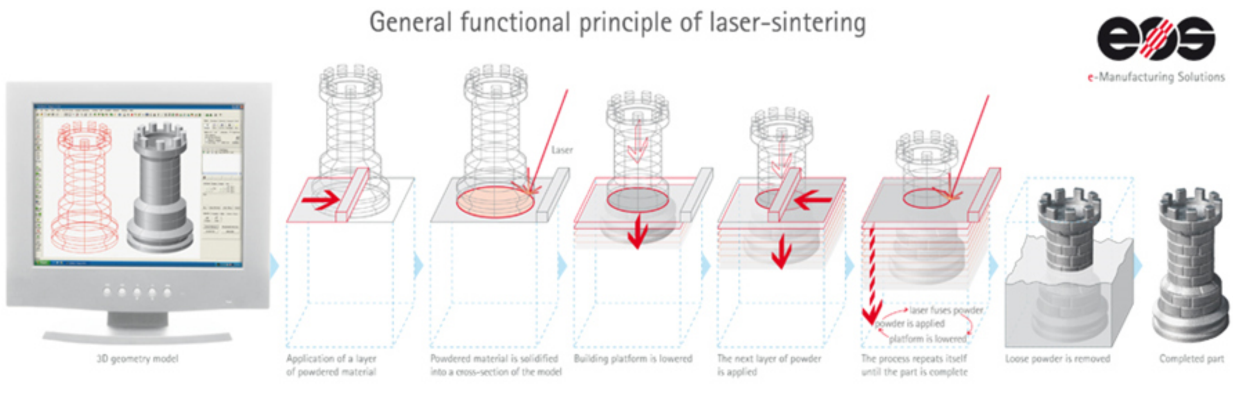


Figure 1: Principle of Sinter Laser Melting (Additive Manufacturing). Building process can last a long period due to the amount of layers for tall objects.

The Need for a Quality Control

Once the layer has been fully manufactured the construction platform lowers, a new powder coating is distributed over the finished layer and the process starts again. Over time, the complete part is produced in this way. The entire process can require a number of days with tall and solid parts. Without process controls the question therefore arises as to whether process defects may also lead to part defects. In order to answer this question, optical tomography has been developed.

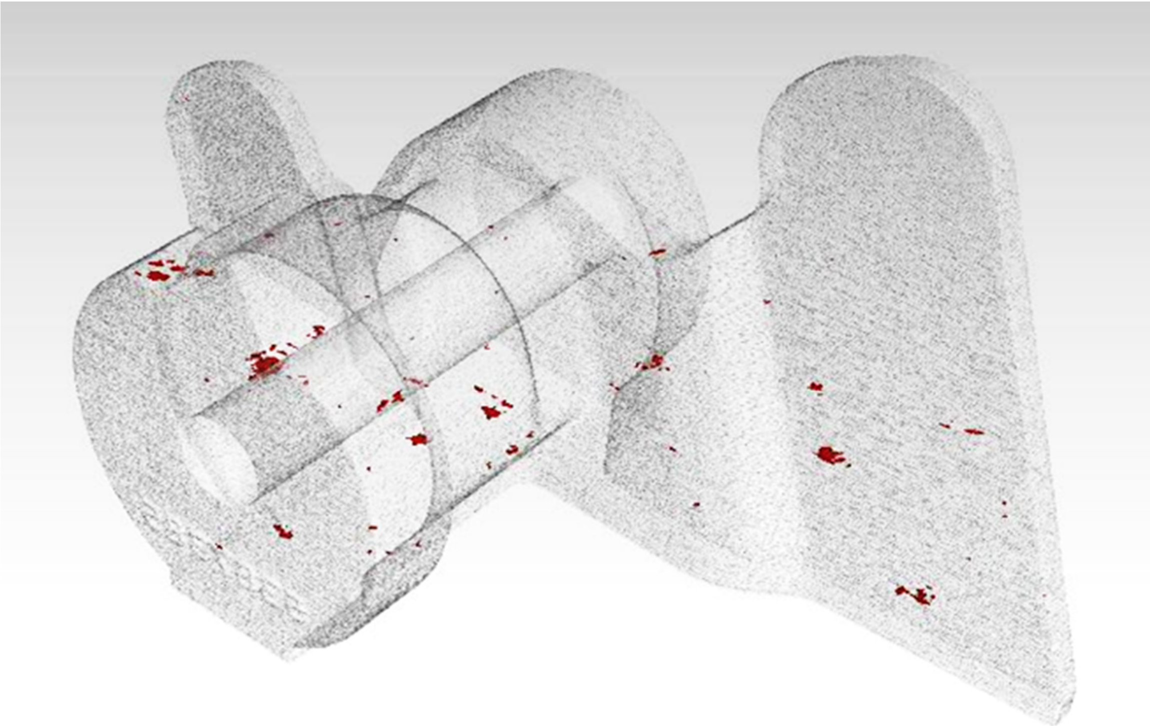


Figure 2: Optical Tomography is an imaging tool that provides high resolution radiation data from the melting process and depicts areas with deviations in geometry and temperature.

This development is only possible through the consolidation of expert competence from a range of different application fields, which are briefly introduced in the following.

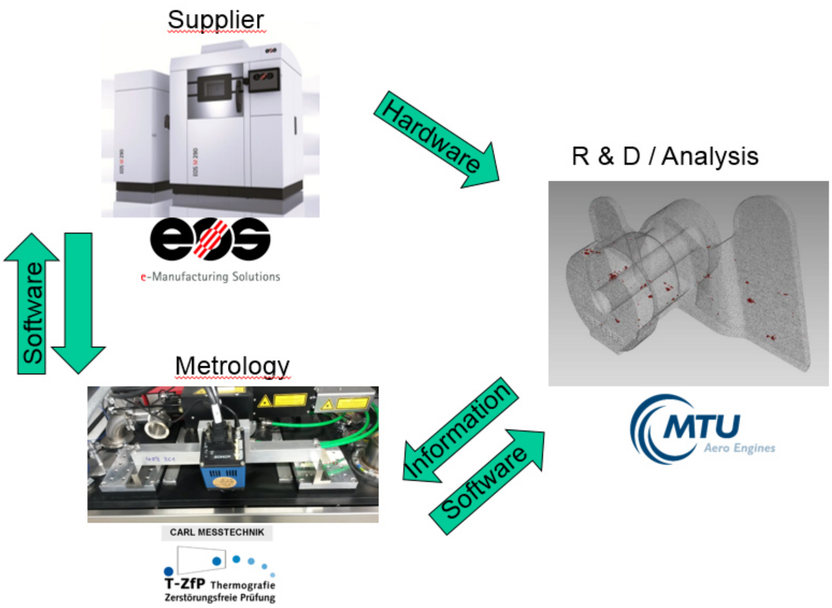
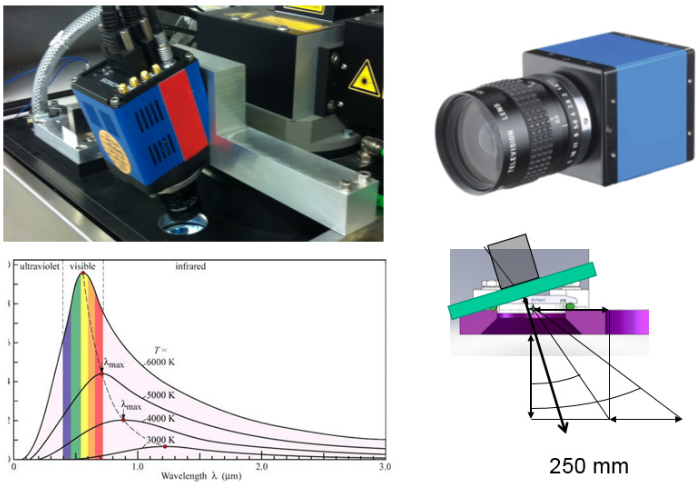


Figure 3: Involved Companies during the development of a monitoring system

Cooperations

EOS is a manufacturer of Additive Manufacturing Systems and is responsible for the provision of machines and process technology.
MTU Aero Engines is a user of this technology in the production of jet engine parts. At the same time, tensile testing and other material testing is carried out here using accompanying samples, in order to guarantee the endurance and quality of the products.
Carl Messtechnik makes its expertise available in the field of optical measurement technology and collaborates with both EOS and MTU.
Through a constant exchange of knowledge in the fields of machine technology, materials technology and measurement technology an optimum process has been developed, which facilitates the detection and control of process defects.



Used Spectral Range	: 900-940 nm
Sensor Format	: 2500 x 2100
FOV	: 250 x 250 mm
Spatial Resolution	: ~0,1 mm
Temperature Range	: 600°C – ?
Frame Rate at Full Res.	: 100 Hz
Interface	: Camlink

Aperture → Shading Effects
Fixed Focus

Mounting → Geometric Aberration
Position

Figure 4: s-CMOSCamera Technology in the visible range of the electro-magnetic spectrum is used to obtain radiation data from the melting process.

Technology

The measurement technology does not require cost-intensive infra-red cameras, because within the welding process temperature range - of around 1300°C - a sufficient portion of the radiant energy in the visible range of the electromagnetic spectrum can be used for measuring. In order that no spurious radiation is detected from the environment or the laser, suitable filters are used to restrict the radiation spectrum. Another major advantage that results from the use of sCMOS cameras is the high utilisable spatial resolution of the detectors.

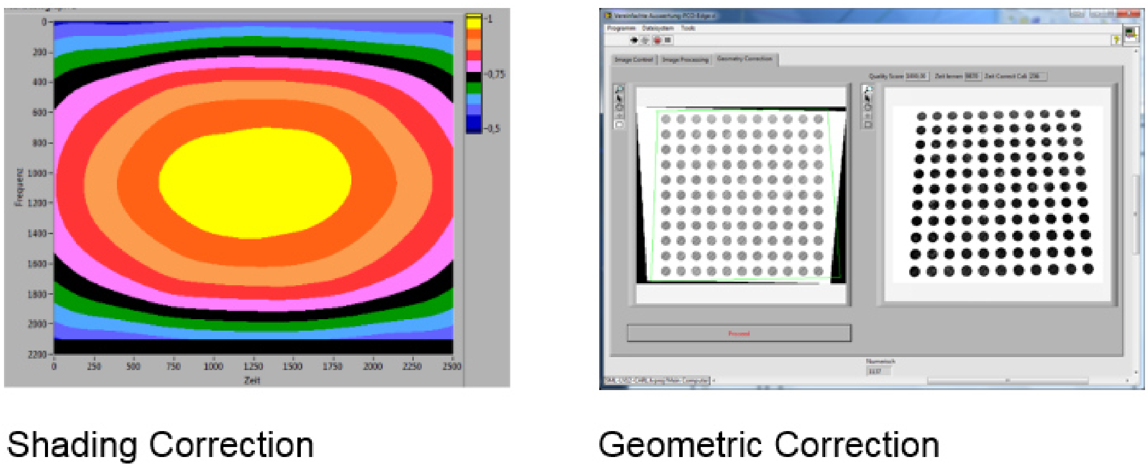


Figure 5: Due to the mounting position of the camera and the used optical filters, different correction methods are required to obtain comparable images for each monitoring system.

This lies at around 5.5 MB, with a resultant resolution of 0.1 mm on the part surface. Depending on the lens used and the installation position in the machine, two undesirable effects result and it is necessary to correct these. The first of these effects is so-called shading, which causes a deterioration of contrast at the edge of the detector. The second effect is geometry distortion, which prevents a precise dimensioning of the defect. Because every measurement system is subject to these uncertainties, all systems are adjusted and calibrated in the machine prior to final assembly. The consequence of this is that all systems deliver reproducible and comparable results.

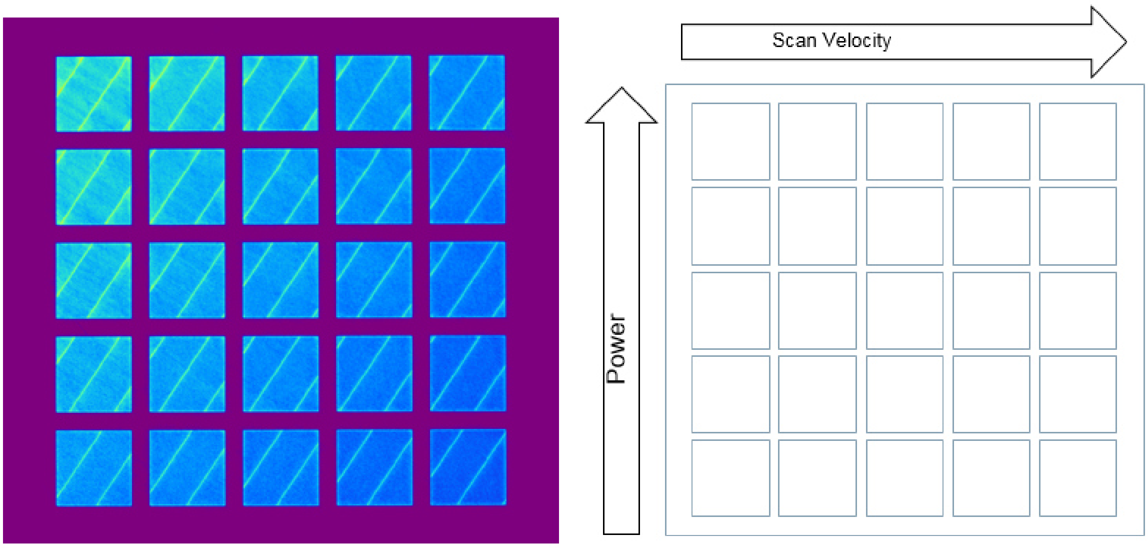


Figure 6: The camera system has a very high radiation sensitivity. The energy input per unit length is a well-defined parameter for the welding process. Even low deviations can be measured with the monitoring system and any possible problems of the AM control could be identified.

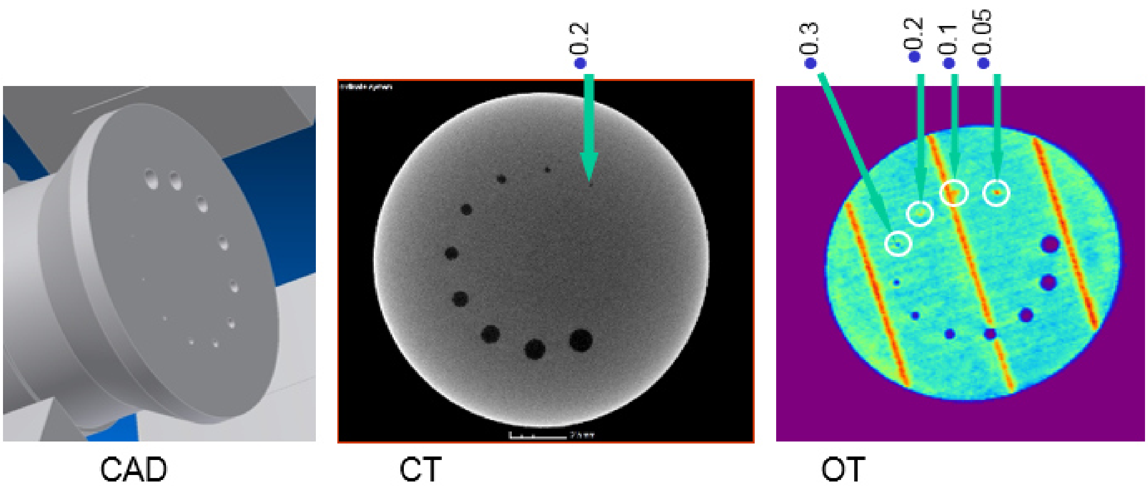


Figure 7: The camera system also has a high spatial resolution. The comparison of CT and OT demonstrates the potential for the detection of even small variations in geometry or radiation deviation.

Two examples follow, showing the high thermal and high spatial resolution of the measurement system. If the speed of the laser or the laser intensity alter, this results in a change in the absorbed/emitted radiation in the vicinity of the molten pool, which is detected by the camera system. The so-called energy input per unit length (J/mm) can be detected in this way using measurement equipment, and corrected in the event of a control error. Due to the high spatial resolution it is possible to detect the smallest defect. Comparisons of CT and OT indicate what is feasibly possible.

Realisation

The monitoring system registers 100% of the surface with high resolution and analyses each complete layer online. To date, various defect mechanisms have been identified and defined in their thermal characteristics with the smallest deviations. The entire construction job is precisely documented throughout the production process and recorded upon completion of the construction job. This provides users with part assurance and machine operators with process assurance.

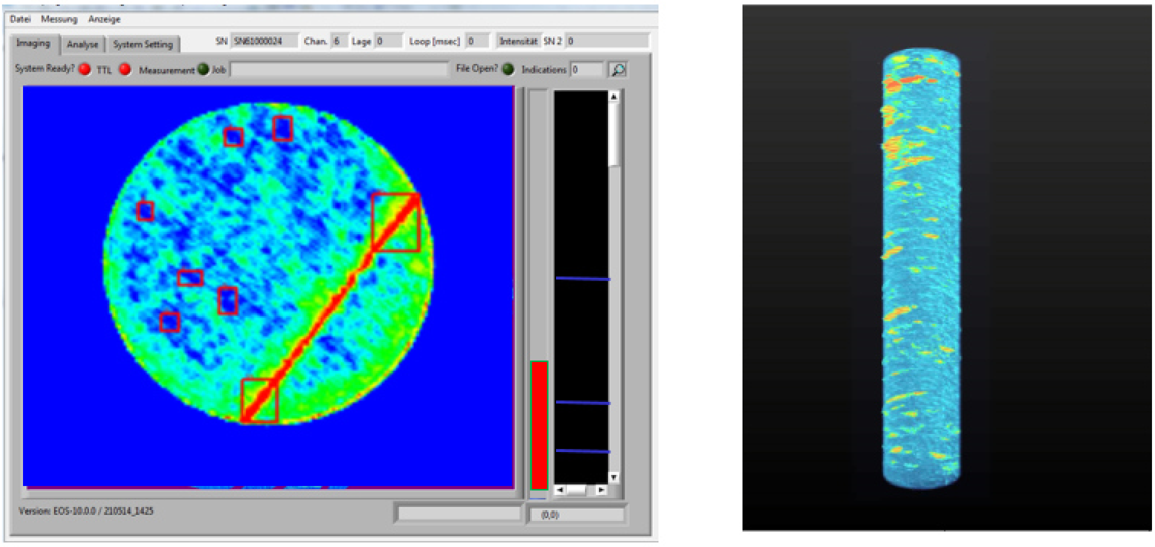


Figure 8: The software surface signalises any indications to the operator and the melting process can be optimised during the building process.

At the present time, the entire Additive Manufacturing machine line of MTU Aero Engines is equipped with a monitoring system. The machines run in two-shift operation and all construction jobs are logged using measurement technology with OT. This results in constant improvement of the OT and AM technology.

Figure 9: Each AM machine at the MTU Aero Engines machine shop is equipped with a monitoring system

Next Steps

The next planned development stage of the monitoring system encompasses communication via OPC with the machine's process computer. Feedback from a machine controller or the regulation of process parameters is possible through this, without actively stopping the construction process.

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