DTU Library

Considerations on the Construction of a Powder Bed Fusion Platform for Additive Manufacturing

Andersen, Sebastian Aagaard; Nielsen, Karl-Emil; Pedersen, David Bue; Nielsen, Jakob Skov

Published in:
Physics Procedia

Link to article, DOI:
10.1016/j.phpro.2017.08.004

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Andersen, S. A., Nielsen, K-E., Pedersen, D. B., & Nielsen, J. S. (2017). Considerations on the Construction of a Powder Bed Fusion Platform for Additive Manufacturing. *Physics Procedia*, *89*, 3-10. https://doi.org/10.1016/j.phpro.2017.08.004

Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 89 (2017) 3 – 10

Physics Procedia

Nordic Laser Materials Processing Conference, NOLAMP_16, 22-24 August 2017, Aalborg University, Denmark

Considerations on the construction of a Powder Bed Fusion platform for Additive Manufacturing

Sebastian Aagaard Andersen[a], Karl-Emil Nielsen[a], David Bue Pedersen[a], Jakob Skov Nielsen[a]

*

[a] *Technical university of Denmark,2800 Lyngby, Denmark*

Abstract

As the demand for moulds and other tools becomes increasingly specific and complex, an additive manufacturing approach to production is making its way to the industry through laser based consolidation of metal powder particles by a method known as powder bed fusion. This paper concerns a variety of design choices facilitating the development of an experimental powder bed fusion machine tool, capable of manufacturing metal parts with strength matching that of conventional manufactured parts and a complexity surpassing that of subtractive processes. To understand the different mechanisms acting within such an experimental machine tool, a fully open and customizable rig is constructed.
Emphasizing modularity in the rig, allows alternation of lasers, scanner systems, optical elements, powder deposition, layer height, temperature, atmosphere, and powder type. Through a custom-made software platform, control of the process is achieved, which extends into a graphical user interface, easing adjustment of process parameters and the job file generation.

Peer-review under responsibility of the scientific committee of the Nordic Laser Materials Processing Conference 2017

Keywords: Selective Laser Sintering; Selective Laser Melting; Additive Manufacturing, 3D-printing

* Sebastian Aagaard Andersen. Tel.: +45 30630689
E-mail address: seaa@mek.dtu.dk

Peer-review under responsibility of the scientific committee of the Nordic Laser Materials Processing Conference 2017
doi:10.1016/j.phpro.2017.08.004

1. Introduction

This paper will give an overview over recent activities and considerations constructing a set-up for consolidating metal powders into objects by means of laser radiation, also known as powder bed fusion (ASTM International, 2013). Complete systems are industrially available from vendors, yet mentioned systems have the major drawback that process parameters for all sub-systems are predefined by the vendor and therefore not accessible to the end-user. Commercial systems are often limited to proprietary software and feedstock powders. From the users perspective, this is mostly fine, as it ensures process stability, but from a research point of view, it is unacceptable. The motivation for constructing an experimental powder bed fusion system is therefore to uncap the possibilities of powder bed fusion presented by modifying and optimizing subsystems, and achieve full control over job planning and scan strategies.

A general example of such a set-up can be seen in Fig 1. The set-up consists of following modules:

- Laser source
- Scanner system
- Scan window
- Powder delivery system
- Powder bed

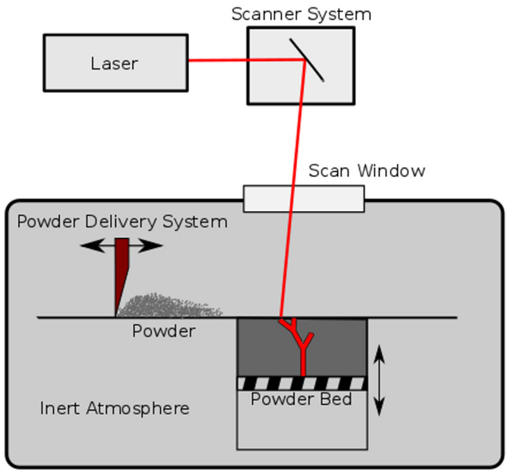

Fig 1: General functionality.

Industrial systems are equipped with one or several fiber lasers capable of delivering an output in the range 200W – 1000W. A scanner system is used to maneuver the laser beam around to selectively consolidate the particles in the powder bed. The scanner system usually consists of two galvanometric mirrors and a fθ-lens, providing scan-speeds up to 10 m/s. The powder delivery system (PDS) uses either a scraper or a roller to coat and recoat the powder bed with a uniform layer thickness and density, minimum layer thickness of 0.02 mm. The material processing takes place in a chamber with protective atmosphere.

This paper is divided into three parts focused on programming, the optical system and powder handling respectively.

2. Programming

Enveloping the entire process into a coherent software platform allows full control of the powder bed consolidation. The process is grouped into different stages, see Fig 2. Initially the computer-aided design (CAD) is stored as an STL file, being the de facto standard format used in additive manufacturing (AM). Next, the STL file is processed through a slicer software, generating a job-file in for the form of g-code, a numerical control language. Efficiency is increased by addressing computational heavy tasks prior to production. Interpreting the .STL-file, changing job-parameters, process-settings and actually generating the job-file is all tasks that falls in this category and is therefore carried out on a dedicated workstation pre-production. Transmitting the content of the job file is done in situ, one command at a time, awaiting an 'ok' from the microcontroller send as confirmation of execution, before sending the consequent command, Fig 2.

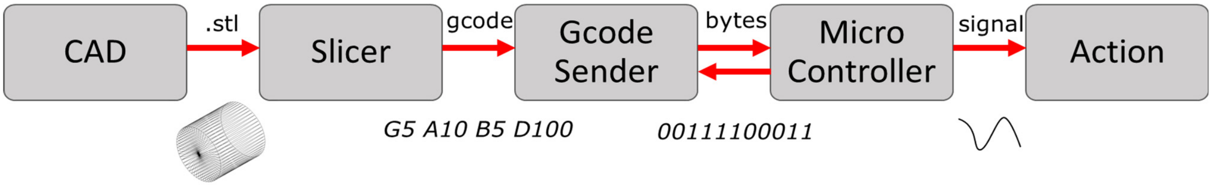

Fig 2: Schematics of process flow.

Generation of the job file is done in a custom-made slicer, see Fig. 3, developed to give full access to the planning process. The CAD file has to be parsed through a slicer dividing the geometry into cross-sections with a predefined layer thickness. The slicer allows adjustments of geometrical traits as size and orientation, but also job-parameters as scan speed, hatch density, and more. The cross-sections are then converted into tool paths (gcode), including the extra parameters that are not directly related to the geometry e.g. laser on/off and speed. These codes are stored in a job file and sent via a custom-made gcode sender to the microcontroller, which is responsible for sending the relevant signals to the laser and other components.

The graphical user interface (GUI) displayed in Fig 3, enables implementation of any .STL-file, easy parameter change and a visual feedback giving the operator full control of the job planning.

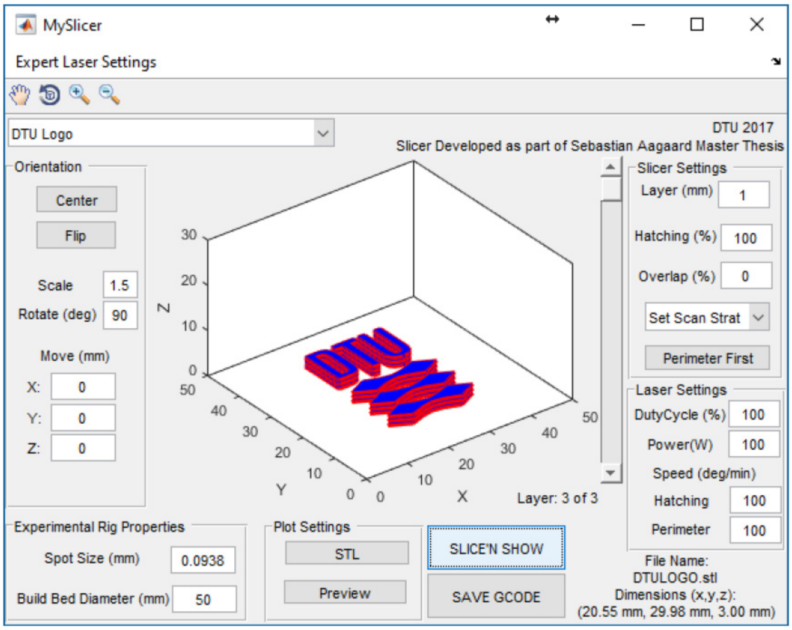

Fig 3: GUI of slicer. Current case is a DTU-logo is loaded, and sliced into three layers with a layer height of 1 mm.

3. Optical system

The system has been equipped with a 2-axis scanner system from Thorlabs (GVS012) consisting of two mirrors mounted individually onto galvanometers (galvo). The setup is controlled by a microcontroller (Arduino RUMBA), see Fig 4, the digital signal from the microcontroller has to be converted to an analogue position signal understood by the galvanometers. This is done through two digital to analogue converters (DAC), controlled via I2C bus protocol, currently the DAC has a resolution of 12-bit. The state of the laser is controlled from the micro controller via transistor-transistor logic (TTL) signals.

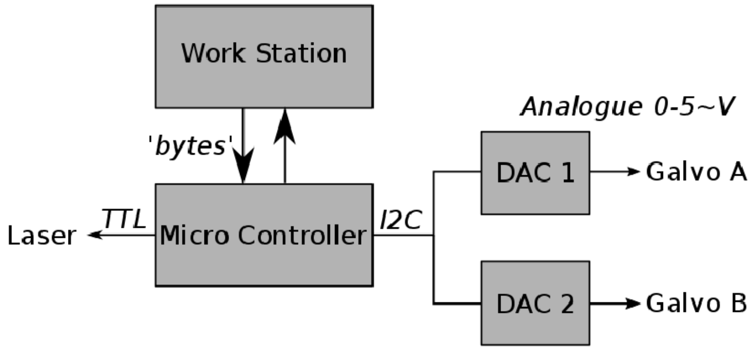

Fig 4: Schematic representation of the control of the optical system.

The custom-made firmware on the micro controller translates the commands from the job-file into actions. Current setup is discrete and limited by the 12-bit resolution of the DAC's. Each command send, carries information of the end position of the scanner mirrors, desired speed and state of the laser. This means that moves are strictly straight-line segments. To approximate straight lines in the discrete system, the incremental control of the scan mirrors are handled by Bresenhams line drawing algorithm described by (Joy, 1999). The highest possible positional control is achieved by utilizing all possible intermediate positions allowed by the 12-bit resolution.

The beam is shaped through a 254 mm fθ-lens (FTH254-1064). The movement of galvanometers alters the incident angle of the laser beam. Using a regular flat field scan lens, the displacement in the image plane would be nonlinear, and relate to $\tan\theta$. Changing the incident angle would likewise distort the spot geometry. The use of the $f\theta$ scan lens negates the nonlinear offset, distortion and ensures a constant linear displacement, relating to the focal length, f, and the incident angle, θ. This means that the rotational velocity of the scan mirrors can be kept constant for a constant velocity across the image plane.

The moving speed and accuracy of the scanning system, and the focal point position has been verified adopting the method proposed by (Hansen and De Chiffre, 1997) meant for validating coordinate measuring machines (CMM's) paint–covered steel-plates are inscribed with a grid of circles, see Fig 5.

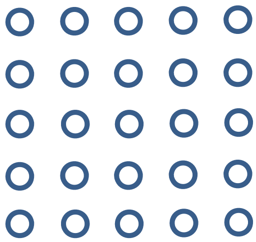

Fig 5: Pattern of circles, diameter 4.5 mm and 20 mm center to center distance.

An optical CNC measuring device, Demeet 220 is used to measure the actual position of the circlesinscribed, exposing the error of the positional error of the optical system, see Fig 6.

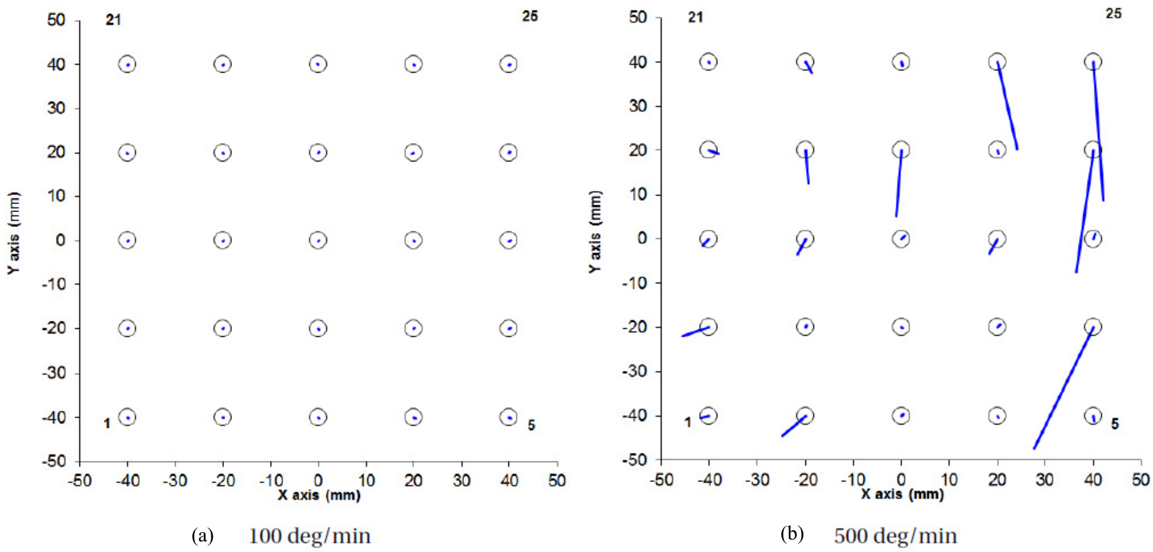

Fig 6: Offset of circle centre coordinates compared to intended, offset scaled 10x (a) scan speed: 100 deg/min; (b) scan speed: 500 deg/min.

The blue lines indicate the positional offset from nominal to the actual position enlarged by a factor 10.
Fig 6 shows that lower scanning speeds, where the galvanometers moves by 100 deg/min have a negligible positional error, but increasing the scan speed to 500 deg/min enlarges the positional error.

Investigating the scanning speed the laser is set to pulse at a known frequency. The scanner-system is then set to move from minimum to maximum, first along one axis at a time and lastly diagonally. The distance between the marks left by the pulses on the test plate reveals the speed across the scan field, found to be constant. In the current setup, the maximum speed is limited by the processing speed of the microcontroller, and is currently at 7.5 m/min. All the discrete positions in each move command is utilized, ensuring the highest positional control. All non-laser moves where positional accuracy is not important is done instantly, and therefore the overall job time is kept low.

The firmware, microcontroller and scanner system are successful in reproducing the geometrical traits of the sliced part. The parameters are altered via the custom made GUI and experimentally used. The platform constructed shows to be viable, in accuracy and customizability.

4. Powder delivery

To handle the powder efficiently it is necessary to know the properties of the powder in question. Grain-size, shape, size-distribution and material plays a significant role in the quality of the final product. For instance, the presence of big particles in the powder will improve the ductility but the ultimate tensile strength will decrease as presented by (Spierings et al., 2010). Overall, it is necessary to achieve the highest level of density possible.

While distributing the powder the build-in ability to flow is an important feature of the powder. The Hausner ratio (Geldart et al., 2006) gives an indication of the flow-ability of a powder. The ratio defined is the relation between tapped density and apparent density (1).

$$H = \frac{\rho_{tapped}}{\rho_{apparent}} \tag{1}$$

Powders with good flow-ability will gain little in terms of density, by forcing the compaction. In table 1 the relation between ratio and flow-ability is presented.

Table 1: Hausner ratio and flow-ability

Flow-ability	Hausner ratio
Excellent	1 – 1.11
Good	1.12 – 1.18
Fair	1.19 – 1.25
Passable	1.26 – 1.34
Poor	1.35 – 1.45

If the density of the powder is still not satisfactory one must consider the size distribution of the grains. A powder with a very narrow Gaussian distribution of relatively big size grains will include a high level of gaps even if it has a good flow-ability, Fig 7.

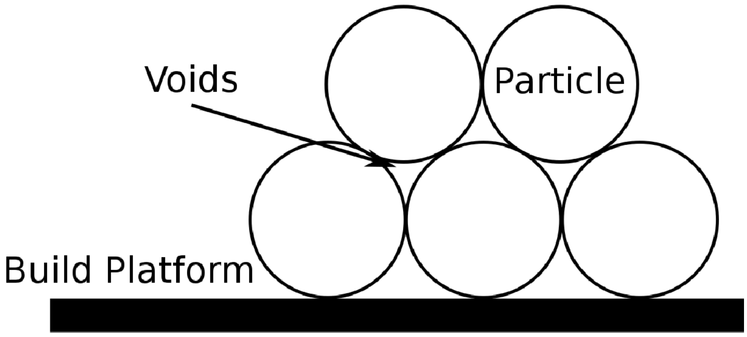

Fig 7: Voids between particles.

As the particles collapse when melted the solidified material will take up less space than the corresponding powder did. Not only is there now missing powder around the solidified material, but the printed part will not have the expected dimensions.

One commercially available powder is the gas-atomized maraging steel 1 (MS1) from vendor EOS, designed for use in powder bed fusion systems, see Fig 8. The spherical nature of the gas atomized powder particles tends to pack

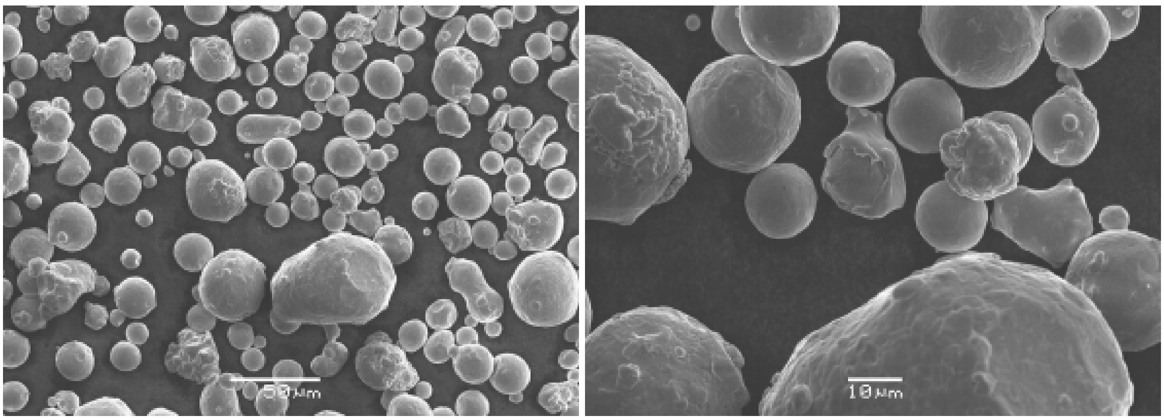

Fig 8: SEM image of EOS MS1 spherical gas atomized powder particles.

more efficiently as proposed by (Egger et al., 1999). It is an obvious solution to mix two or more batches of size-distributions, so that the small particles can fill out the voids between the larger particles. The diameter ratio should be 1:10 or higher with 30% small particles, to have an effect, but then an increase in powder density of up to 15% is possible. Doing this, one must consider the proper handling mechanisms of the powder to avoid powder segregation (Ahmad and Smalley, 1973).

The printing area of any machine is made essentially of two parts: the powder delivery system (PDS) and the printing compartment. The latter is a cavity with a stage to move the powder bed up or down, see Fig 1. This moving build plate has to be sealed against the walls so that the powder cannot exit and prevent atmospheric air from entering. It is limited how many ways this can be done and the influence on the final product is insignificant as long as the sealing works. In this case the vertical movement of the powder bed is tested at 50 µm increments with deviations lower than 2 % for most of the data points.

The PDS on the other hand has a significant influence on the outcome of the print job, depending on the flowability of the powder. The shape and inter-particular friction between the different particles governs how well the powder flows. Materials with low flowability must be forced into high density layers.

For the present set-up, it is decided to construct another modular system as can be seen in Fig 9.

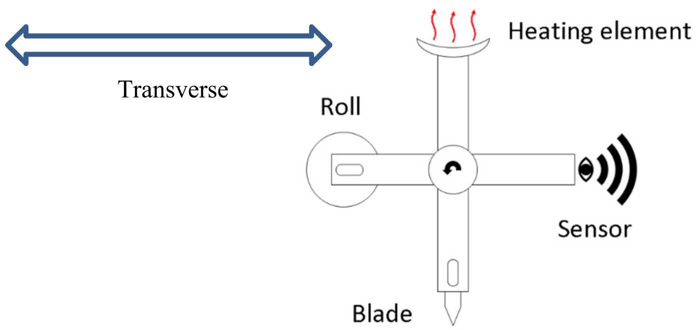

Fig 9: Schematics of powder delivery system.

The different tools on the PDS allow using the better tool for the job by rotating the revolver and bring a new tool into working position. Thereafter an axis will transfer the tool across the build plate. If necessary all tools can be optimized or changed.

The blade used to re-coat the powder bed is essentially a knife with a straight edge. This has to be calibrated to ensure the edge is parallel to the build plate. The roll is not passive, but will be set to roll counter-direction to the movement. Not counter-rolling leads to a build-up of material that is unwanted as it causes difference in layer thickness in the individual layer. Diameter and surface of the roll can be changed. For some materials pre-heating can be necessary, therefore a heating element is available.

A general problem of AM of any kind is verifying that the product has the desired dimensions and geometries. Therefore, a room for an inspection system has been left open on the revolver.

Using a blade as recoating tool the amount of powder deposited on the powder bed is measured after each pass of the re-coater at a layer height of 0.2 mm, showing that the powder coverage of the powder bed seems to be independent on the transverse speed of the re-coater.

5. Conclusion

Investigation and construction of a modular powder bed fusion platform for additive manufacturing has been realized. Throughout this process, the demands and understanding of a completely user controlled system have become increasingly clear. Full control of the process is granted only if all sub systems are carefully controlled and understood. Therefore, the software platform is key to efficient control of the sub-systems. The platform of the custom job planner is chosen to allow future implementation of computational heavier simulations.

The optical system can deliver scanning speeds up to 7.5 m/min with reasonable geometrical accuracy. Geometrical accuracy has until now only been tested on a steel plates. The powder delivery system shows promising traits, but the positional accuracy of the blade/roll relies on a stepper motor, if the holding torque is surpassed the position becomes unknown and is therefore unusable. Positional feedback must be included to overcome this challenge

Knowledge and careful implementation of build material, electronics and mechanical elements are vital for a reliable and stable process. Through considerations on preprocessing, powder properties, optical systems and processing an open powder bed fusion platform has been developed, allowing full parameter control and experimental implementation.

6. Future Works

During the development of the powder bed fusion platform, the concept of the next generation rig has evolved. To obtain information about the process in situ, future version must be equipped with sensors, monitoring the atmosphere, positioning, scan speed and layer height.

The custom-made slicer should include additional functionality. E.g. implementation of optimized scan strategies, like the ones proposed by (Mohanty et al., 2013, 2014, 2015) to avoid deformations during processing, should be introduced directly into the custom-made slicer allowing scan strategy optimization per geometry.

References

Ahmad, K., Smalley, I.J., 1973. Observation of particle segregation in vibrated granular systems. Powder Technol. 8, 69–75. doi:10.1016/0032-5910(73)80064-6

ASTM International, 2013. BS ISO/ASTM 52900:2015 Additive manufacturing. General principles. Terminology. Rapid Manuf. Assoc. doi:10.1520/F2792-12A.2

Egger, G., Gygax, P.E., Glardon, R., Karapatis, N.P., 1999. Optimization of powder layer density in selective laser sintering. 10th Solid Free. Fabr. Symp. 255–263.

Geldart, D., Abdullah, E.C., Hassanpour, A., Nwoke, L.C., Wouters, I., 2006. Characterization of powder flowability using measurement of angle of repose. China Particuology 4, 104–107. doi:10.1016/S1672-2515(07)60247-4

Hansen, H.N., De Chiffre, L., 1997. A Combined Optical and Mechanical Reference Artefact for Coordinate Measuring Machines. CIRP Ann. - Manuf. Technol. 46, 467–470. doi:10.1016/S0007-8506(07)60867-1

Joy, K.I., 1999. Breshenham's Algorithm. University of California.

Mohanty, S., Hattel, J., 2014. Cellular scanning strategy for selective laser melting: Capturing thermal trends with a low-fidelity, pseudo-analytical model. Math. Probl. Eng. 2014. doi:10.1155/2014/715058

Mohanty, S., Hattel, J.H., 2015. Cellular scanning strategy for selective laser melting: Generating reliable, optimized scanning paths and processing parameters 93530U. doi:10.1117/12.2079957

Mohanty, S., Tutum, C.C., Hattel, J.H., 2013. Cellular scanning strategy for selective laser melting: evolution of optimal grid-based scanning path and parametric approach to thermal homogeneity, in: Klotzbach, U., Lu, Y., Washio, K. (Eds.), Proceedings of Spie, the International Society for Optical Engineering. p. 86080M. doi:10.1117/12.2004256

Spierings, A.B., Herres, N., Levy, G., 2010. Influence of the particle size distribution on surface quality and mechanical properties in additive manufactured stainless steel parts. 21st Annu. Int. Solid Free. Fabr. Symp. - An Addit. Manuf. Conf. SFF 2010, August 9, 2010 - August 11, 2010 397–406. doi:10.1108/13552541111124770