FIRST INDUSTRIAL 3D METAL PRINTING SYSTEM DEVELOPED AT THE SPEED OF LIGHT

Three years ago, Additive Industries started developing the first truly industrial 3D metal printing system, building on the mechatronic and system engineering experience of the Dutch Brainport region. In one year a functional model was realised, and one year later, in 2015, a beta version was presented, which is now being tested by launching customers. Currently, the first production machines are under construction. The MetalFAB1 system offers substantially improved performance over the 'prototyping' machines available in the market.

Additive Industries, based in Eindhoven, the Netherlands, was the initiator of the AddLab consortium (read the article on page 32 ff.) to expand its knowledge of the 3D-printing process and to have printing machines available for testing new concepts. After the AddLab programme was finished as planned, Additive Industries continues development, with forty people on board at the moment. Launching customers are testing the beta version of the MetalFAB1 and the first machines in a first production series are already under construction. To this end Additive Industries continues its collaboration with development and production partners recruited from the Brainport ecosystem: system suppliers NTS-Group, MTA and VHE Industrial Automation, and a multitude of second- and third-tier suppliers.

1 *The MetalFab1 6-module version, with from left to right the controls module, two build chambers, a human-machine interface, the stress-relief heat treatment furnace, a storage module (for build plates and printed products), another human-machine interface, and the (un) loading or exchange module. (Photos: Bart van Overbeeke/Additive Industries)*

The industrial-grade additive manufacturing machine – using the well-known laser-based powder bed fusion process, and integrated Additive World software platform – will, so Additive Industries promises, deliver up to a tenfold increase of reproducibility, productivity and flexibility as compared to the machines available in the market, which were engineered for making prototypes or one-off products. According to Additive Industries, the improved performance is achieved by robust and thermally optimised equipment design, smart feedback control and (auto-)calibration strategies, elimination of waiting time and automation of build plate and product handling.

The modular design of the MetalFAB1 system – a customer-driven venture, not a technology-driven development – allows for customer- and application-specific process configuration. Multiple build chambers with individual integrated powder handling make this industrial 3D printer the first to combine up to four materials simultaneously in one single machine (each print chamber will be used for one material only, as switching materials requires extensive cleaning). The size of a single build envelope (420 x 420 x 400 mm^3) places the MetalFAB1 among the largest 3D metal printers available.

Rob van Haendel, Lead Mechanical Engineer, can address some of the challenges encountered in the development phase, but details of the design of the machine cannot be published, as Additive Industries is in the middle of developing a patent portfolio. "Our machine architecture concept is new to the 3D-printing world, because of the automation and feedback loops, but to us, 'born and bred' in the Brainport region, it was not new at all. Here the mechatronic approach is customary: collecting as much information from the machine as possible and using this for intelligent control."

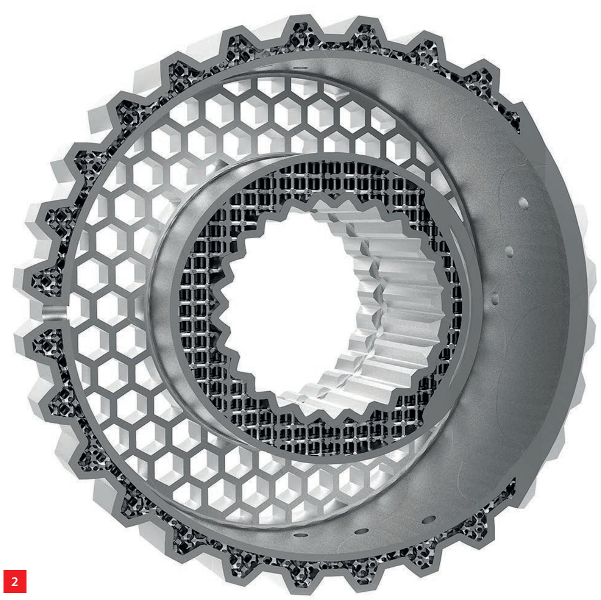
Modular architecture

The design of the MetalFAB1 is built upon a modular architecture, which is a characteristic feature of many high-tech mechatronic systems originating in the Brainport region. The development process is guided by the well-known V model, which is perfect for controlling the interfaces between modules. "At the system level you can define the interfaces between the various modules, which can then easily be outsourced. This allows us to focus on the things that are not so easy to specify, such as integrated software, process and application development, for which we are still in the learning curve."

The modular architecture also enables an easy upgrade of the system. For example, up to now an operator is required for loading build plates and unloading the printed products. This can, however, easily be robotised. Furthermore, in principle it is possible to expand the build volume of the system. But this does require a considerable hardware engineering effort, as the footprint of the system roughly equals three times the build plate dimensions in both horizontal directions.

Material qualification

The MetalFAB1 is delivered with a baseline process developed by Additive Industries, but it is up to the customer to help fine-tune the process and tailor it to his needs, according to Van Haendel: "For each material we select one qualification, considering aspects such as availability and cost price, which we use in all the tests. We release the results and help our customers tweak the settings if they decide to use another material specification."



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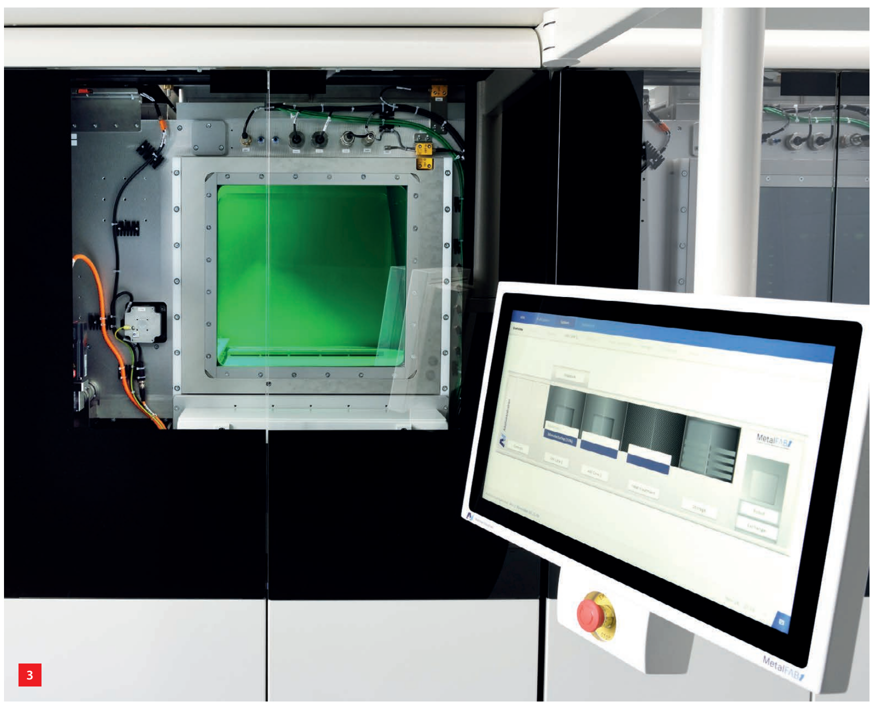

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2 *One of the MetalFAB1 beta systems was sold to GKN Powder Metallurgy, the world's leading manufacturer of precision automotive components. (Image: GKN)*

3 *The build chamber with human-machine interface.*

Each material to be printed requires its own process development. A so-called fishbone diagram contains over 60 parameters that are relevant in the process. The optimal settings for these parameters are all material-specific. Materials for which the process has been developed up until now include aluminium, tool steel, stainless steel 316, titanium, and inconel. Cobalt-chrome and various aluminium alloys are on the wish list.

Powder handling

A particular material challenge is powder handling, Van Haendel says. "At one moment it behaves like a fluid, in other cases it is more like a solid." The powder handling has been automated, but this required a lot of experimenting and hardware iterations, as it is not an easy subject for extensive simulations. The design was set up in such a way that no risk of inflammation is present. For example, the process is conducted under an argon or nitrogen atmosphere, in order to keep the oxygen concentration below 1%, as well as for disposal of 'welding' fumes. The argon or nitrogen flow is filtered and recirculated. The oxygen concentration is monitored continuously; if it becomes too high the pump for powder evacuation is switched off immediately.

Lasers

In the MetalFAB1 the printing process can be executed with one to four lasers, which run in parallel but can individually melt patterns in the powder layer under hand. The exits of the laser guides are located closely together above the build plate, at a relatively large height. This configuration was chosen to minimise the deviation of the beam orientation from vertical as much as possible (and hence the deformation of the laser spot from circular to elliptical). The set-up is modular; laser units can be added at a later stage, up to the maximum of four. The productivity increase by adding lasers is nearly linear. This feature is one of the factors in the promised tenfold increase in productivity. A MetalFAB1 print module with four lasers can print up to 1 m^3 of metal in one year.

Resolution

Additive Industries typically aims at a layer thickness of 50 µm, but values down to 30 µm, usually for relatively small products, can be attained in the MetalFAB1. The material specification, for example regarding the powder size distribution, has to match this layer thickness. A related parameter is the offset at the beginning and the end of a printing pass. This offset is required when the edge of the laser focus does not coincide with the edge of the melt pool. In this respect the melting behaviour, determined by the material's heat conductivity, has to be taken into account.

The vertical resolution of the printing process depends on the pitch of the motion stage that guides the build plate, whereas the horizontal resolution is determined by the optical system that steers the laser beam over the 2D layer to be printed. Inaccuracies are introduced by process variations and the discretisation of the product in the design software. For small products the accuracy of the MetalFAB1 is +/– 50 µm, and for larger products a length measure has to be added, arriving at a maximum of 0.2 mm inaccuracy for such products.

Thermal aspects

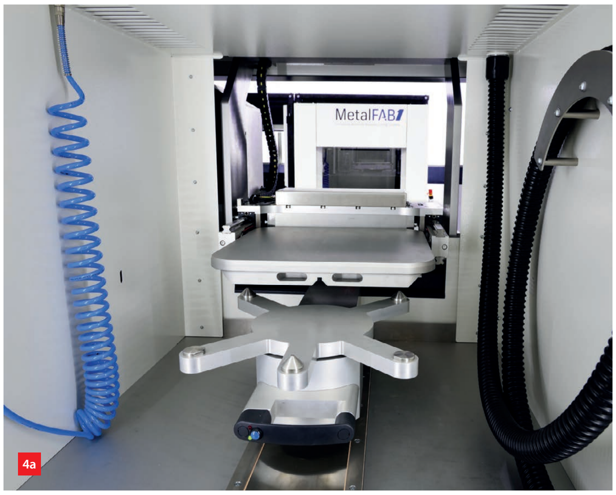
A highly critical phenomenon is of a thermal nature. The lasers for the selective melting process (up to four, 500 W each) inject a maximum to 2 kW of power in the part that is being printed. This will therefore heat up, to approximately 200 °C, depending on the specific material. The exact value can be calculated in advance. Especially for aluminium, with its high thermal expansion coefficient and relatively low melting point this is relevant.

For optimum quality, the part has to retain this temperature during the entire process, with the aid of a closed-loop controller. This means that in the beginning the build plate has to supply a high amount of additional heat to the part to reach this level quickly. After a while, a steady state will be reached, with the laser(s) injecting heat to the top of the part, and the build plate to the lower part of the product. The thermal effects require that the build plate is made of the same material as is used for printing. This also facilitates an easy start of the build-up process, with a good (welding) connection of the first printed layer to the build plate.

For the relaxation of mechanical stresses introduced by the thermal regime, the MetalFAB1 comprises a heat treatment furnace. This is currently the only integrated post-processing option. Outside the machine the printed piece first has to be separated from the build plate with the aid of a band saw or wire-erosion. Further post-processing can then be performed. Additive Industries aims to integrate further post-processing steps in the MetalFAB1 in the future.

Calibration

One of the biggest mechatronic challenges was posed by the optical calibration. The laser spot has to be focussed on exactly the right position, within a few micrometers. This accuracy is absolutely necessary when the multiple laser beams, with a focus diameter of 100 µm, for example, have to be focussed on the same position. Rob van Haendel: "This requirement has to a large extent determined the machine layout." Because of the industrial character of the machine, the calibration routines have been automated. Calibration objects are available that can be supplied by the robot of the machine at a customer's request.



4 *Handling functionality.*
(a) The (un)loading unit or exhange module.
(b) The robot for handling (and transporting between modules) of build plates and printed products.

Validation

The MetalFab1 printing process can achieve a density of over 99.5% as compared to bulk material. Considerations that determine the optimum density include productivity (a higher density specification will lower the productivity, because smaller line widths have to be printed) and thermal effects. Higher laser power will generate a more complete melting process, but when too much laser power is delivered, the part in production will become too hot and deformation will increase.

For validation of the printed parts, Additive Industries initiated collaboration with the US company Sigmalabs: its pyrometer and photo diodes were incorporated in the functional model for monitoring the melt pool. The information from these sensors can be combined intelligently to produce a statement about the quality of the printing process. This information has to be correlated with the outcomes of tests of, for example, tensile strength and fatigue behaviour in order to be able to be conclusive about the quality of the printed product. Monitoring the external geometry of the product during printing is not useful because of thermal effects (warping, shrinking after cooling). After the product has cooled down, measurements can be made with a 3D scanner or a coordinate measurement machine. Their results will support the end qualification of the printed product. ■

INFORMATION
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