Floating on a flowerBed

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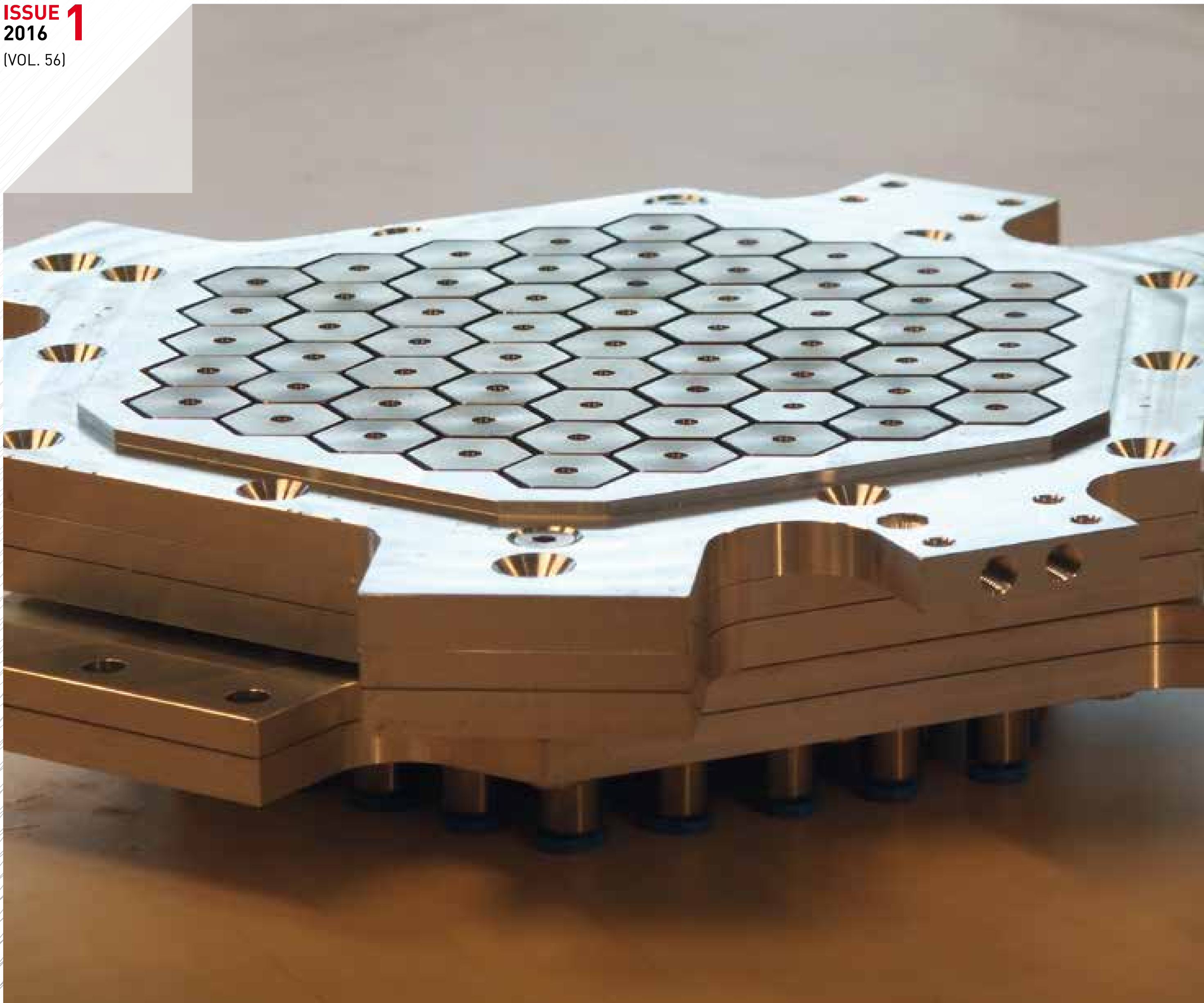

- **CONTACTLESS** TRANSPORT
- LARGE-SERIES **HYBRID** MANUFACTURING
- **THERMAL ISSUES** IN ADDITIVE MANUFACTURING
- **CARBIDE** WEAR PARTS

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The main cover photo (featuring the FlowerBed) is courtesy of TU Delft. Read the article on page 5 ff.

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FEATURES

THE SECRET INGREDIENT OF HIGH-TECH SYSTEMS

In November last year, Additive Industries, the company I founded together with Jonas Wintermans in 2012, launched its first industrial additive manufacturing system, aka 3D metal printing system, MetalFAB1. Developed by a team of excellent mechanical and software engineers, materials scientists and system integrators in a record time of just over two years.

This incredible project was possible only because of a secret ingredient we added to our system and software development that made the difference between failure and success... It is an ingredient that is found naturally in this region around Eindhoven, the Netherlands. It was developed decades ago and it has been polished and refined ever since. And today it is still being tested, improved and applied broadly. This secret ingredient is embedded in the DNA of the people living in the southern part of the Netherlands. Eindhoven especially bears fruit from this ingredient, so it seems. And it is used both in the development process and in the supply chain where the realisation of new high-tech ideas takes shape.

Our company is addicted to this ingredient from the start, because without it we wouldn't have lived to see this day. It makes work fun, it creates new insights, it breeds better solutions, it allows us to focus, it gives access to a complete ecostructure of high-tech equipment competences. It gives us an infinite capacity and at the same time saves money. It is open within and restricted on the outside. But most importantly, especially today, it allows us to share and multiply our successes. With our partners.

This ingredient is **teamwork**.

The world's first industrial metal additive manufacturing system, MetalFAB1, is the prime example of what teamwork can do. From the start we have built a team within Additive Industries. A dream team it is. With a large variety of backgrounds, characters, competences, positions and years of experience. But with one shared value and common denominator: the drive to deliver. We aim high, think big, work hard and celebrate the successes while enjoying the ride (and an occasional beer).

The teamwork is extended beyond our team, as we were lucky to find development partners with competences we lacked, knowledge we needed and capacity we craved for. The start was sometimes a little bit strange. Our demands were unusual, our expectations were high, our pockets empty and ambitions seemed unrealistic. But these partners gave us the benefit of the doubt, some directly, others after a nudge or two. And, critically, they decided to trust us, as we trusted them and they became part of our team.

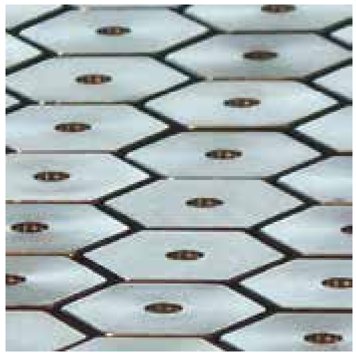
And then magic happened, we went to work and ideas became designs, designs became parts, parts became subassemblies and modules. In the last quarter of 2015 these modules were joined to become one system and they are the perfect metaphor for this project and our secret ingredient.

Daan Kersten
CEO Additive Industries
www.additiveindustries.com

(Photos by Bart van Overbeeke, © Additive Industries)

FLOATING ON A FLOWERBED

By applying a thin pressurised air film beneath a substrate, it can be levitated as well as transported and precisely positioned in all planar degrees of freedom. This avoids mechanical contact and reduces risk of damage and contamination of sensitive surfaces. Two fundamental ways of realising this combination of functions have been invented and built. High-precision positioning accuracy in the nm range and multiple-g accelerations have already been achieved in the lab. Industrial implementation is expected in the near future by a dedicated start-up.



MARTIJN KRIJNEN, VUONG HONG PHUC AND RON VAN OSTAYEN

Introduction

In high-tech industry thin, fragile, cost-intensive products, such as silicon wafers and solar cells or glass sheets (flat-panel displays), are routinely handled and used. These substrates are susceptible to contamination, damage or even breakage as a result of any mechanical contact. Currently, special product carriers and transport systems are used for the transport of these substrates in and between the many stages that these products undergo during their manufacturing. In these existing systems mechanical contact is inevitable.

It is a strategic goal of the high-tech industry to introduce zero-contact handling and transport systems. In other words, from the introduction of the substrate at the start of the production line to the release of the product at the end of the line, there should be no (avoidable) mechanical contact between substrate and production line.

Note that existing systems that are sometimes referred to as 'contactless' are in fact only carrying the substrate without contact, but in order to transport or position the substrate accurately and fast, most of these systems still rely on mechanical contact.

Other contactless systems, such as Bernoulli grippers, which apply a levitation technique based on the Bernoulli principle, cannot freely move the object in all planar degrees of freedom (DoFs). They merely float the object to reduce contact, and rely on edge effects to maintain a centred position of the substrate on the gripper. Other systems exist that use magnetic and electric levitation, and are able to produce in-plane forces. These are promising concepts, where high precision is possible. However, they rely on specific magnetic and electric properties of the material. In air-based levitation the material itself plays a lesser role.

The concepts presented in this article are able to handle various substrates: Si-wafers, solar panel surfaces, flat-panel displays and glass, but also foil.

Operating principle

The concept is based on air-bearing technology, i.e. two surfaces with a thin film of pressurised air in between that separates both surfaces. Note that although in this article air is used as the acting medium, it is in fact possible to realise the same functionality using any gas, and with some consideration and design modifications liquid media can be used as well.

The gas-bearing concept is in itself promising in precision design, because it avoids many traditional engineering issues, such as friction, wear, backlash and lubricants. Although the concept is well-known, used mainly because of its extremely low, viscous friction, it is possible to increase this viscous traction to a level where it can be effectively used in an actuator.

A schematic example of the concept is shown in Figure 1. The actuation surface is divided into an array of regular

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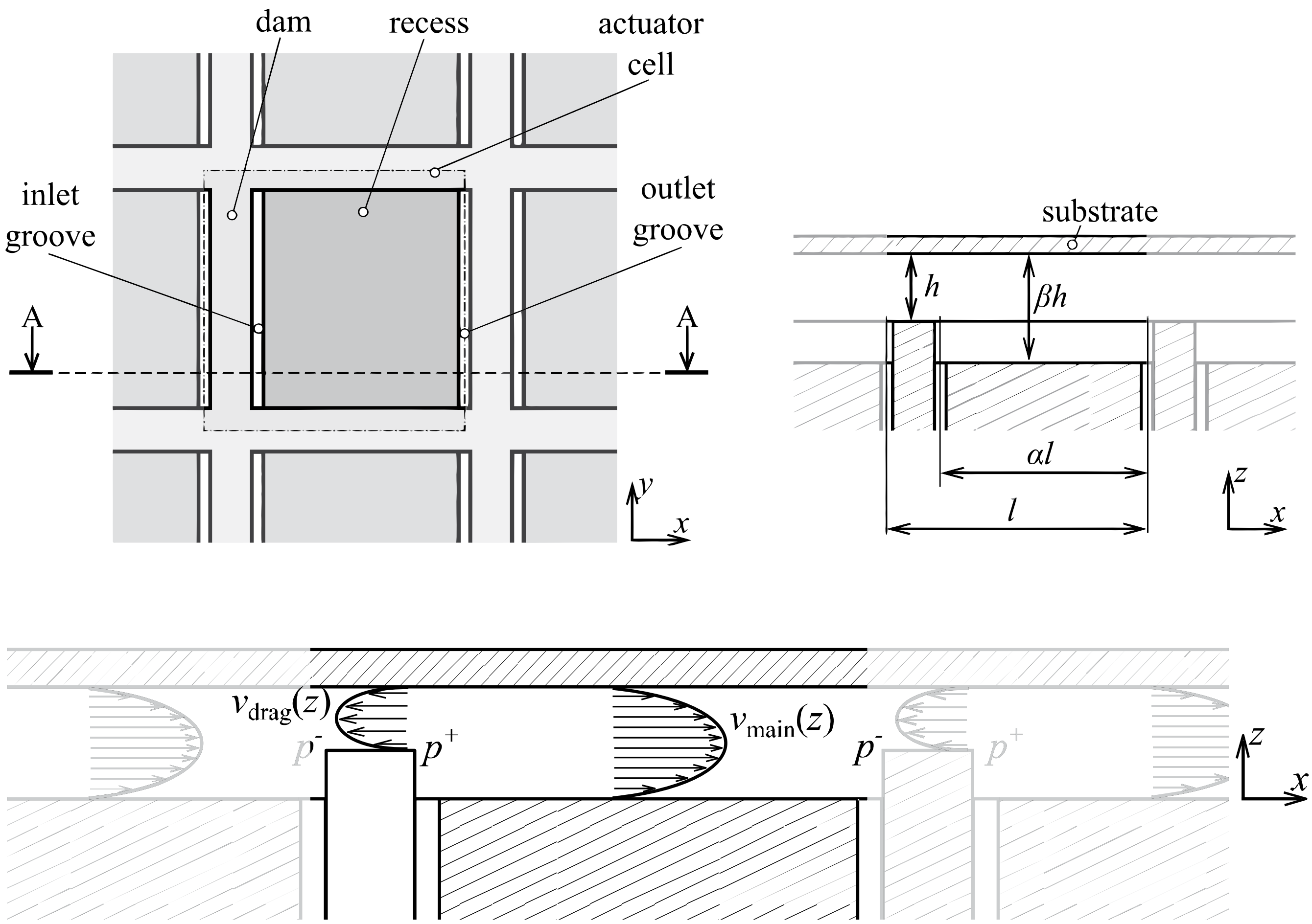

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1 *Basic principle of the contactless actuator, with the larger flow to the right creating a net viscous force on the substrate above.*

surface sections where each section consists of a pocket surrounded by dams. A typical actuator section has an in-plane length of 10 mm. The optimal pocket depth is related to the intended fly height of the substrate; for a typical fly height of 10 μm a pocket depth of 40 μm is advised. Each pocket has at least one high-pressure inlet and at least one low-pressure (sub-ambient or vacuum) outlet.

The pressure distribution under the substrate is determined by the geometry in combination with the inlet and outlet pressures. The average pressure under the substrate balances the distributed weight of the substrate that is being carried. Note that due to this combination of high-pressure inlet and vacuum outlet (push-pull concept) it is straightforwardly possible to flip the vertical orientation of the system and carry a substrate without contact hanging beneath a transport system.

The pressure difference creates a flow through the pocket from inlet to outlet, and a smaller flow across the dam that separates the pockets. Both flows are indicated in Figure 1. Due to the viscous shear of the flow a traction force on the substrate is created.

There are two variables that influence this traction, which can therefore be used to control the force on the substrate. The first variable is the pressure. By increasing the pressure difference between inlet and outlet both the flows as well as the force acting on the substrate increase. This allows the creation of a certain system with a fixed geometry, and by controlling the pressure the substrate can be positioned. Positioning systems operating on this principle are denoted to be of Gen-I (generation 1).

The second variable is the geometry. By changing the depth of the pockets, the flow distribution and the effective surface area for the pressure difference to act on will change, resulting in a change in traction imparted on the substrate. Systems operating on this principle are denoted to be of Gen-II.

Research on Gen-I was started in 2007 [1], followed by research on Gen-II in 2011 [2]. Both concepts are viable and comparable in performance, and research continues into both concepts. The combination of both concepts in one system is promising as well (Gen-III) and is another subject of study. Gen-III is not further described in this article.

MAPAL DRILLS AND CHUCKS

Additive manufacturing (AM) used to be a production technology for prototypes or small series. But MAPAL Dr. Kress KG in Aalen, Germany, has succeeded in producing drills with complicated cooling channels in large series, as well as precision hydraulic chucks. It combines conventional cutting and grinding technology with additive manufacturing in an innovative hybrid process.

FRANS ZUURVEEN

1 *A Mapal QTD drill with a carbide insert.*

Dr Georg Kress started Mapal in 1950. One of their first products was a single-bladed reamer with two guiding pads, for which they acquired an Italian patent. At first the reamer didn't function at all but then the first Mapal engineers succeeded in developing a one-blade reamer that really did work. Gradually, Mapal expanded its product range to become a wide range of cutting tools.

In the 70s, the manufacturing programme was drastically restructured. The manufacturing of tap drills and dies, and subsequently the thread roller tools, was discontinued. Mapal then concentrated on fine-boring tools with blades for precision machining of bores. Later, the product programme widened out to many sorts of metalworking tools for reaming and fine-boring, drilling, milling, turning, clamping and measuring. Nowadays the Mapal Group employs over 4,500 employees.

Insert drills

High-performance drills are provided with a liquid-cooling channel to allow higher cutting speeds. For a long tool life, the preferred material for cutting edges is carbide. But because of the high price of carbide, Mapal has so-called QTD drills in its product range with a relatively inexpensive drill holder from tool steel with a carbide insert on top, see Figure 1. Originally, the circular cooling channel was situated in the centre of the drill. But because the body's cross-section was weakened by such a central bore, the minimum diameter of conventionally machined insert drills was limited to 13 mm.

Recently, Mapal introduced AM in its workshops by acquiring two M1 Cusing systems from Concept Laser with a working volume of 250 mm x 250 mm x 250 mm. (Cusing is a combination of the words *concept* and *fusion*.) By combining conventional cutting and grinding with 3D printing, Mapal could expand the product range of QTD insert drills to smaller diameters down to 8 mm, see Figure 2. This hybrid technology enabled Mapal to create drill holders with differently shaped cooling channels. An extra feature was the positioning of helically formed channels out of the drill centre, making the drill holder considerably stronger and stiffer. Moreover, tests showed that non-circular channels provided better cooling performance.

Large-series production

This application of AM can be considered as large-series production, because 121 drill holders are additively manufactured in one production cycle. Each drill holder is 3D-printed on a conventionally machined ISO 9766 shank, making this a hybrid technology. Depending on the drill

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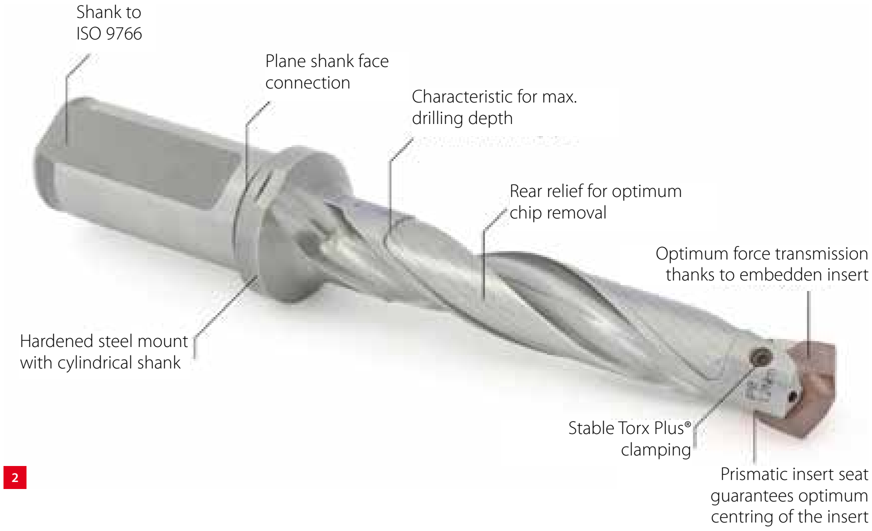

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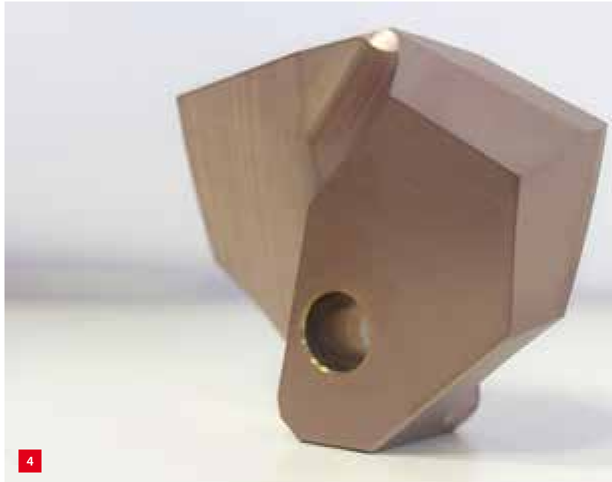
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diameter and length, the duration of one AM cycle is approximately 50 hours.

The M1 Cusing machine functions with a 200 W fibre laser with a focus diameter of 50 µm in a process called SLM (Selective Laser Melting, see Figure 3). The layer thickness amounts to between 20 and 80 µm with particle dimensions between 10 and 45 µm. To prevent corrosion, the printing takes place in an inert nitrogen atmosphere. Remarkable is the stochastic exposure strategy by deposing metal powder in chessboard-like square segments. This procedure ensures a significant reduction in stresses with less warping and better accuracy as favourable results.
For the best run-out accuracy each holder is externally ground, as well as the insert positioning planes.

2 *A QTD drill of 8 mm cross-section with a conventionally machined shank and a 3D-printed insert holder.*
3 *3D printing using a Concept Laser M1 Cusing machine. (Photos Courtesy of Concept Laser GmbH)*
(a) The machine.
(b) Working principle; a new layer of metal powder is deposed by moving the coater.
(c) 3D printing of a Mapal QTD drill on a conventionally machined shaft.
4 *A QTD insert in carbide.*

Four kinds of inserts

Figure 4 shows a QTD carbide insert, which is a product that is difficult to machine precisely. Precision is required, because these insert drills equal the performance of solid carbide drills with ISO quality 9 to 10, corresponding to a tolerance field of about 40 µm for an 8 mm bore diameter, for example. The only method to manufacture such a Mohs-scale-9 product is to machine it with a Mohs-scale-10 material: diamond. The insert is clamped into the holder with only one torque screw, see Figure 1. When replacing an old insert with a new one, the position is precisely defined because the holder supports the insert on a V-groove.

Mapal supplies four kinds of inserts (see Figure 5) for different materials: standard steel, stainless steel, aluminium and cast iron. The first, second and fourth are differently

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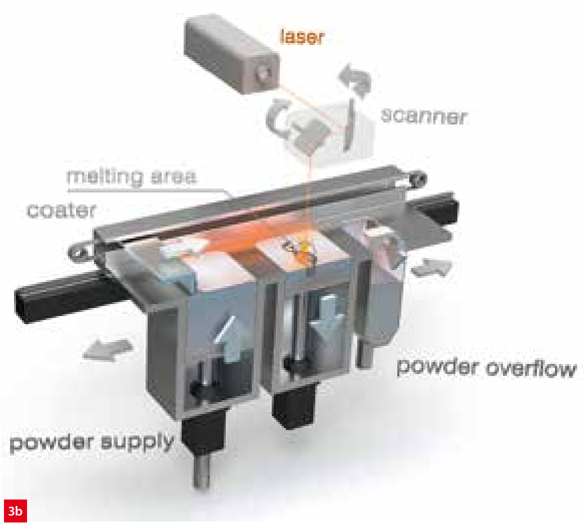

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