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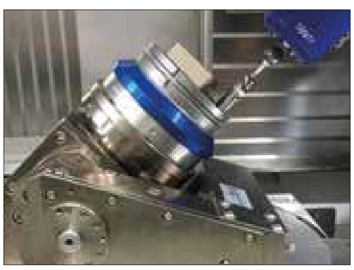

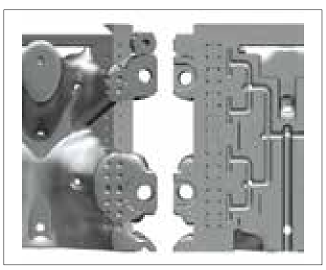

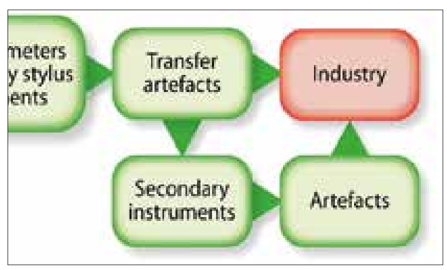

- THEME: PRECISION SENSORS
- METAL AM PARTS MANUFACTURABILITY
- DSPE OPTICS WEEK 2019 REPORT
- PRECISION FAIR 2019 PREVIEW

DSPE

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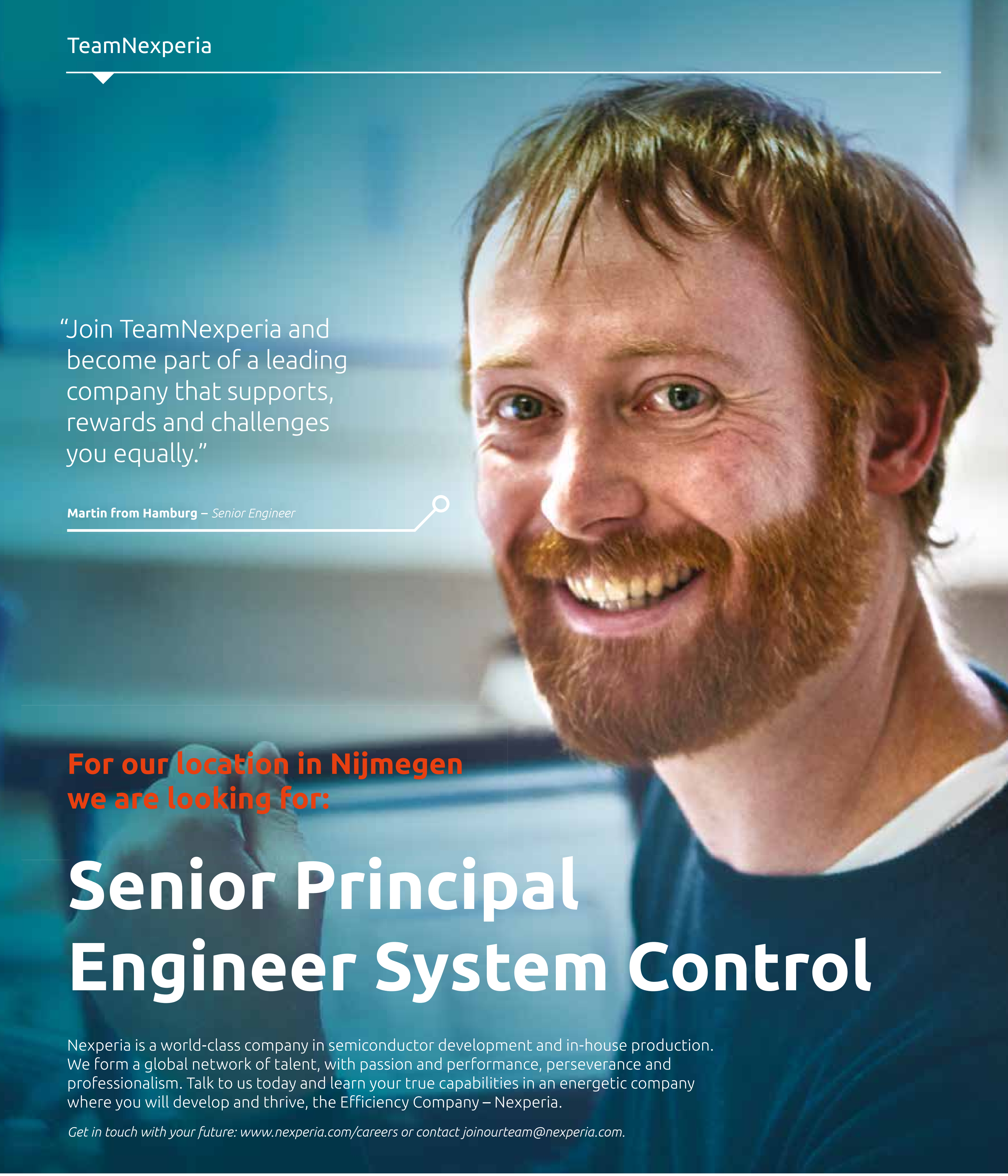
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The main cover photo (representing a free-moving carrier designed as part of a flexible multi-agent positioning system) is courtesy of Rogier Bos. Read the article on page 5 ff.

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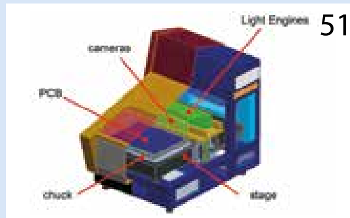

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FEATURES

THE IMPORTANCE OF **PRECISION KNOWLEDGE EXCHANGE** – AT SYMPOSIA, IN COURSES, AT THEME DAYS, ONLINE, IN MAGAZINES AND AT FAIRS

Four weeks ago, DSPE organised the Optics Week; please read the report in this issue of Mikroniek. After a fruitful and interesting symposium, three days of a new course on optomechatronic system design followed. It was excellent, a breathtaking course! The best course you can get in the world on this subject, in my humble opinion. Thanks to the teachers; Lennino Cacace, Gabby Kroes, Jan Nijenhuis and Pieter Kappelhof. At times like this, DSPE feels like a warm bath, connecting people and facilitating knowledge exchange in the precision engineering community. That's important.

Are you engaged in optomechatronics and did you miss out on these events? What a pity. You could have benefited from them!

Last June, DSPE organised a theme day on engineering for particle contamination control, which is crucial for modern-day precision engineering and has become a very important subject in the Dutch precision industry. Are you involved in contamination control issues and did you miss out on the event? What a pity. The knowledge exchanged there might have helped you in the future.

Maybe DSPE is insufficiently known yet in the wider precision engineering community. Therefore, we aim to improve our marketing. The DSPE website is an important instrument in that respect; it's my personal ambition to grow our website into a portal which precision engineers like to visit frequently. Using artificial intelligence and social functionality, we aspire to grab your attention on an almost daily basis.

The theme of this Mikroniek issue is Precision sensors. When systems don't sense, they don't know and cannot act correctly. Sensing is crucial for actuation aimed at improving the situation. It's the same with humans; when they don't sense, i.e. collect information and knowledge, they don't know and cannot act correctly. So, it all starts with collecting and exchanging knowledge. What better place to start than at the Precision Fair on 13-14 November 2019 in Veldhoven.

See you at the fair.

Hans Krikhaar
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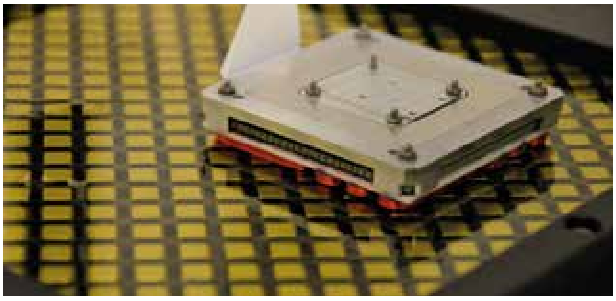
MULTI-AGENT MAGLEV

A nano-precision-capable, multi-agent, flexible positioning platform can be used to increase (metrology) throughput in semiconductor industry by parallelisation of measurements. It is based on magnetic levitation (MagLev) and 6-DoF control, combining large x- and y-motions with sub-nanometer scanning resolution in a single stage. The system architecture of this flexible positioning platform has the ability to operate many devices in parallel. Each device can function as a lab-on-instrument to perform various tasks at the nanoscale, e.g. metrology, inspection, deposition, transport, cleaning, etc. A demonstrator set-up was successfully designed, built and tested.

LUKAS KRAMER, TEUN VAN DEN DOOL AND GERT WITVOET



AUTHORS' NOTE

Lukas Kramer, Teun van den Dool and Gert Witvoet all work at the Department of Optomechatronics, TNO, Delft (NL). This article is based on their presentation [10] at the 8th IFAC Symposium on Mechatronic Systems (MECHATRONICS 2019), Vienna, Austria, Sept. 4-6, 2019.

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Introduction

To increase the cost efficiency and quality of semiconductor devices high-throughput production methods, together with fast measurement and inspection steps, are needed. With device features becoming increasingly smaller down to the nanometer level, standard optical inspection tools no longer suffice. Many alternative inspection and verification techniques are however inherently slow, rendering them virtually useless as in-line production tool in a semi-conductor fabrication process; examples include scanning electron microscopy (SEM), near-field optical techniques, and scanning probe methods (SPM) such as atomic force microscopy (AFM).

A possible way to overcome this and increase the through-put of such measurement techniques is by parallelisation, i.e. by operating many measurement devices in parallel. Examples of such systems are multi-beam lithography tools [1, 2], multi-SEM [3], and the parallel AFM system developed by the Netherlands Organisation for Applied Scientific Research (TNO) [4, 5]. Where the first two solutions have a fixed beam layout, in the latter tool the individual AFM heads have been miniaturised, offering much larger flexibility in the positioning of the measurement heads relative to the surface (e.g. wafer or reticle) to be inspected. Still, the parallel AFM system [5] is somewhat limited in positioning and timing flexibility, as the individual heads are positioned by external mechanical arms and each head makes the same nanoscale scanning movement after initial placement of all heads.

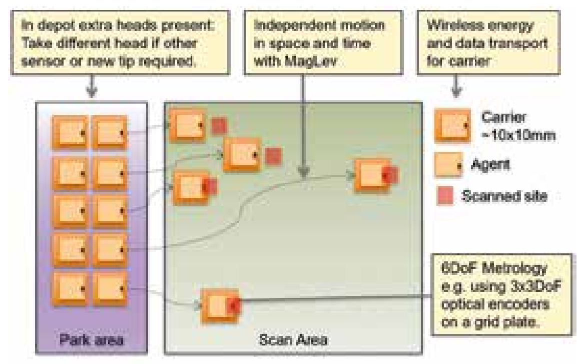
The ultimate goal in parallelisation is combining various tasks at the nanoscale in a single measurement device, in which each task can be performed independent in space and time. As a next step in reaching this goal, TNO is developing a flexible multi-agent positioning system. The system consists of a multitude of independent, free-moving carriers, each of which can be controlled in six degrees of freedom (6-DoF) and positioned towards any desired region of interest (RoI). Moreover, each carrier holds an agent that can perform various tasks at the nanoscale, such as an SPM, SEM or AFM. As such it can be used as a completely miniaturised lab-on-instrument.

Here, a first demonstrator for this multi-agent platform is presented. The design and realisation of a small-scale flexible positioning platform is discussed, suitable for holding a miniaturised AFM to carry out wafer or reticle measurements.

The demonstrator design was driven by the architectural trade-off regarding the actuation and positioning possibilities to scan the agents at the RoI. Several solutions have been considered, such as:

- Magnetic levitation (MagLev): electromagnetic bearing with planar motor.
- Air table: air bearing combined with air propulsion.
- Piezo stepper: integrated piezo-walkers in the carriers.
- Pick & place robot: positioning all agents with a pick & place robot, before the wafer or sample is loaded into the system.

After comparison with several trade-off criteria (e.g. speed, performance, cost, complexity, and contamination), MagLev actuation with 6-DoF control has been selected as the most flexible solution [6]; it can combine large x- and y-scanning



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Example use case of the multi-agent MagLev positioning platform; each agent can freely move around in the scan area to carry out individual measurement tasks.

range with sub-nanometer resolution in a single stage.

System description

This section describes the multi-agent system architecture and provides an example use case as high-throughput metrology tool. Next, the demonstrator concept is explained, which is meant to verify the architectural concept and assess potential development risks.

System architecture

The developed system architecture of the multi-agent positioning platform is illustrated in Figure 1. The system should contain as much agents as possible, to parallelise tasks in the scan area and thereby increase system throughput. Each agent is a lab-on-instrument and is designed for a specific task or multiple tasks at the nanoscale. Examples of such tasks can be wafer inspection (using, e.g., optical, AFM, or SEM heads), mask repair, cleaning and pick & place of large quantities of small features (e.g. for microLED displays).

The carrier of each agent has the function to position and potentially scan the agent at the RoI, and can therefore be identical for each agent. The highest throughput can be achieved when each agent can perform its tasks independent in time and position relative to the other agents.
The target specifications are based on a typical AFM measurement, motivated by design of the parallel AFM system [5]; for a single carrier they are summarised in Table 1. As such, these specifications are applicable for all kinds of demanding positioning and scanning tasks.

Demonstrator concept

The first crucial step in the development of the multi-agent positioning platform is demonstrating the sub-nanometer

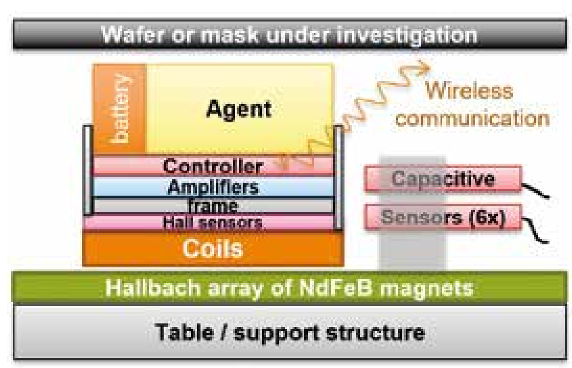
Table 1
Target specifications for the carriers of the flexible positioning platform.

Specification	Value
Scanning area (x,y)	> 500 mm x 500 mm
Vertical range (z)	200 µm
Position accuracy (x,y,z)	10 nm
Position resolution (x,y,z)	< 1 nm
Acceleration	> 10 m/s^2
Carrier size	From 50 mm x 50 mm to 10 mm x 10 mm
Number of carriers	> 50

scanning performance with electromagnetic actuation and local controller optimisation. Therefore, a demonstrator carrier was designed, built and tested.

Electromagnetic planar motors with large *x*- and *y*-range, controlled in 6-DoF, exist in many different configurations and can in general be divided in moving-coil and moving-magnet systems. To limit the control complexity and required electronics for the demonstrator, here the moving-coil principle [7] was chosen. For the final system still either a moving-coil or moving-magnet concept can be chosen, based on a trade-off between performance, complexity and cost.

The conceptual layout of a demonstrator carrier in vertical and planar direction is shown in Figure 2 and 3, respectively. The moving-coil configuration can be combined with different layouts of permanent magnets; here, the electromagnetic actuation consists of a 2D Halbach array of magnets [8], and four three-phase coil forcers. Each forcer can produce horizontal forces F_x and F_y and a vertical force F_z. The carrier (coarse) position is measured with four Hall sensor sets where each set provides a local *x*-, *y*- and *z*-position measurement. The Hall sensors cannot achieve sub-nanometer scanning performance;



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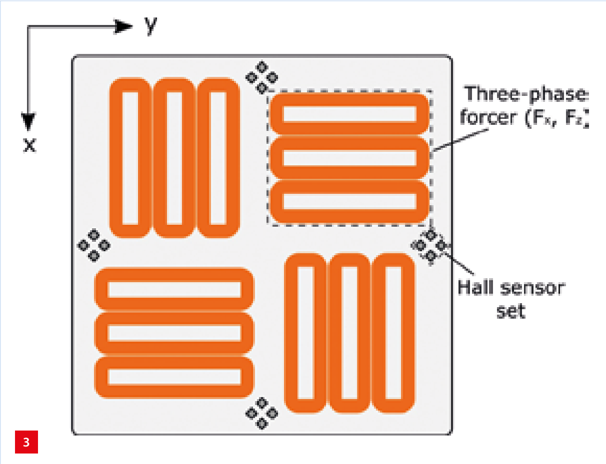
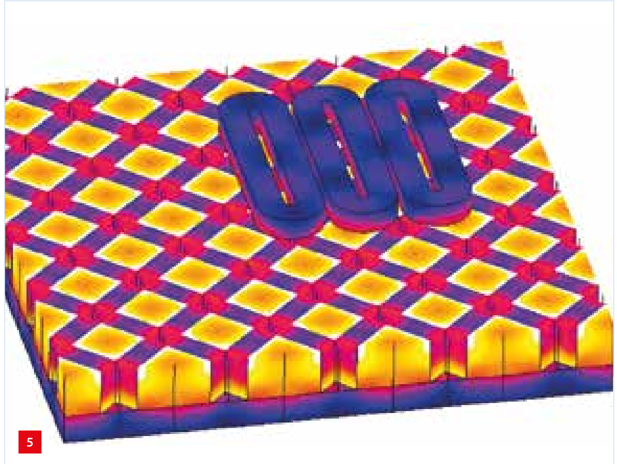
Conceptual z-layout of a single carrier. The power supply, coil amplifiers and control are not on-board in the demonstrator carrier, but can be integrated in a design update. The capacitive sensors are used for design validation and are mounted in a separate bracket.



Conceptual 2D (x,y) layout of the carrier actuation and sensing.



3D electromagnetic FEM model of a single forcer.

therefore, local scanning performance will be verified using local position measurement of the carrier with capacitive sensors, mounted in a separate bracket.

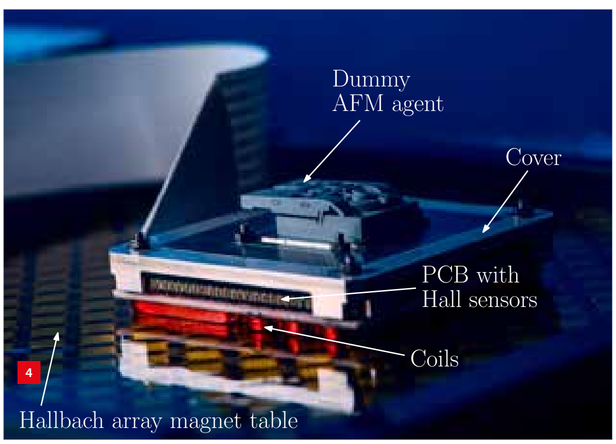
The coils and PCB with Hall sensors were connected to the main carrier frame, which can also hold the controller and amplifier. For the demonstrator, the amplifiers, power, and controller were connected with a flexible cable to limit demonstrator complexity. In a next version of the demonstrator, the flexible cable can be removed by integrating the control electronics and amplifiers with a small battery on the carrier.

Demonstrator design

In this section the design of the demonstrator is further explained. The carrier has an *x*,*y*-size of 50 mm x 50 mm, motivated by a miniaturised AFM agent design by TNO, a 3D-printed version of which is shown in Figure 4. Future carriers are anticipated to be as small as 10 mm x 10 mm.

Actuation force

The first estimations for the demonstrator design were a mass budget and achievable electromagnetic force. The total



Realised 50 mm x 50 mm carrier with coils, Halbach array of magnets and 3D-printed miniaturised AFM agent. (Photo: Rogier Bos)

mass of a carrier and agent was estimated to be below 200 g, which requires a total lifting force of at least 2 N (0.5 N for each forcer). The achievable three-phase electromagnetic force for a single forcer was first estimated with 2D FEM (finite-element modelling) and after that improved with 3D FEM by the company Magnetic Innovations. The final coil and magnet dimensions were derived from the optimal parameters defined in [9], where the dimensions of the planar motor are a balance between force, power dissipation and weight.

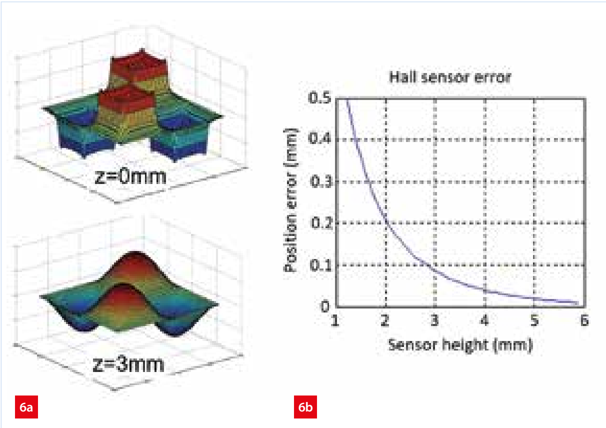
The 3D electromagnetic FEM model of a single forcer is shown in Figure 5; it was used to verify that a single three-phase forcer is able to generate a vertical and lateral force of 0.5 N at a fly-height of 0.5 mm (distance between coils and magnets) at a maximum current density of 10 A/mm^2.

Sensors

Small sub-nanometer resolution sensors are required for the final system such that each carrier can achieve sub-nanometer scanning performance. These sensors are currently not available in such a small form factor, therefore TNO is developing a tiny optical encoder. Meanwhile, for validating (local) sub-nanometer resolution, external capacitive sensors will be used, while Hall sensors will be used for coarse positioning. The Hall sensors provide a compact sensor solution for coarse (micrometer) positioning, by using the same Halbach magnetic field for measuring the carrier position. The magnetic field amplitude in z-direction B_z is approximately a 2D sinusoidal field at sufficient distance between the Halbach array and the Hall sensors:

$$B_z(x,y) = B_{za}\cos(x\pi/\tau_{mf})\cos(y\pi/\tau_{mf})$$

Here, B_{za} is the magnetic field amplitude of the 2D magnetic field (at constant height) and τ_{mf} is the magnetic pitch of the Halbach array of magnets. Therefore, when using four Hall



Hall sensor characterisation.
(a) Magnetic field amplitude shape in z-direction (B_z), for a Hall sensor distance z of 0 and 3 mm above the Halbach array, respectively.
(b) Maximum height position error, dependent on the sensor height above the Halbach array.

sensors, mutually spaced by $\frac{1}{2}\cdot\tau_{mf}$ within a single set (as indicated in Figure 3), a sin/cos encoder principle can be used to extract the local *x*-, *y*- and *z*-position of a single Hall sensor set [10].

The magnetic field in *z*-direction is not a perfect 2D sinusoidal field, but includes higher-order spatial harmonics that become significant at smaller distances to the Halbach array, see Figure 6a. At a Hall sensor height of 0 mm, the higher harmonics are clearly visible (square-wave signal), while at a distance of 3 mm mainly the fundamental sinusoidal spatial frequency is dominant. Therefore, a height position error will occur when assuming a perfect 2D sinusoidal magnetic field.

The position error decreases with the distance between the Hall sensor and the Halbach array, as shown in the plot of Figure 6b. However, since the Hall sensor noise increases with distance and the actuator efficiency decreases with air gap size, it was chosen to position the Hall sensor sets at a nominal distance of no more than 4.5 mm above the Halbach array during operation. Finally, by using four Hall sensor sets as shown in Figure 3, the 6-DoF carrier position is calculated.

Mechanics and electronics

The carrier was designed in 3D CAD by starting with the dimensions of the coils and layout of the sensors (Figure 7). A miniaturised design of an AFM agent, developed by TNO, was included to get a realistic design of the carrier. The main design drivers for the mechanical design were:

1. low mass, to achieve high accelerations and low power dissipation;
2. low centre of gravity (CoG), because the electromagnetic actuator does not actuate at the CoG;
3. high mechanical stiffness and eigenfrequencies, such that a high closed-loop control bandwidth can be achieved.

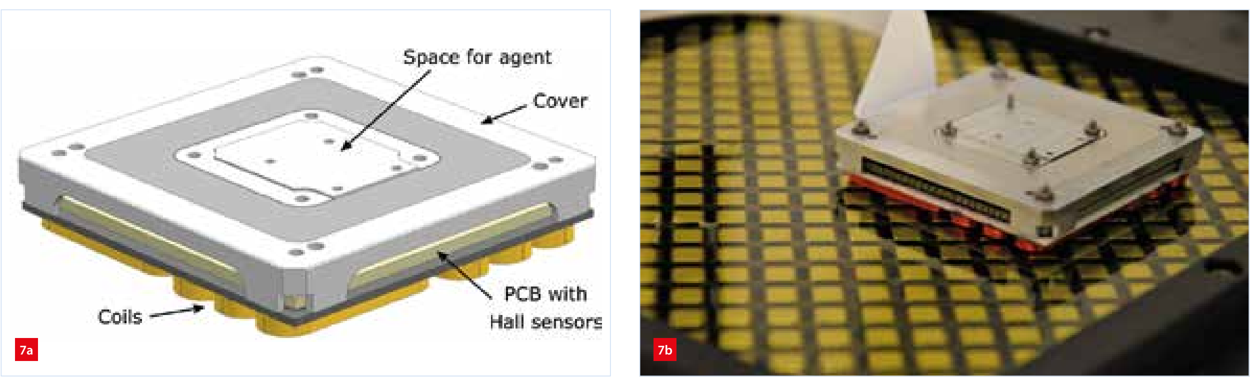
The goal for the closed-loop control bandwidth was set at 200 Hz, such that floor vibrations and other disturbances can be sufficiently reduced. This typically requires mechanical eigenfrequencies in the range of 1 to 2 kHz. Modal analysis showed a first internal eigenfrequency of 1.9 kHz. Reducing the carrier size in future generations, will typically result in higher mechanical eigenfrequencies and therefore a higher achievable control bandwidth.

The CAD model was also used to estimate the mass and inertia of the carrier, which was required to design the initial PID controllers of the unstable MagLev system.

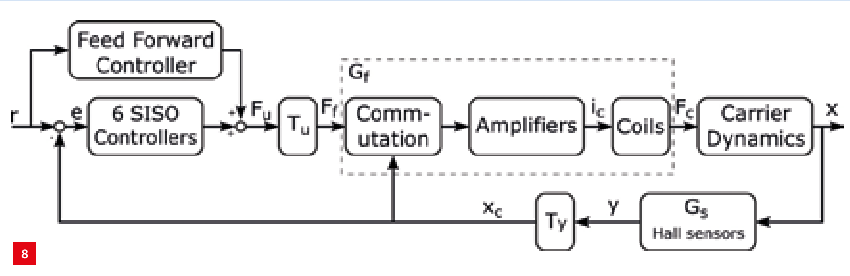
The Hall sensors and signal amplifiers were integrated on a custom PCB on the carrier, which was connected to the fixed world by a flexible cable / flex-print (Figure 4). The control scheme presented above ran on a general-purpose Real-Time Linux control system with a sample frequency of 5 kHz. The coil current was controlled by using linear current amplifiers.

Control scheme

The 6-DoF control for the coarse positioning of the demonstrator carrier was kept simple and local controller optimisation was used to enable high-performance scanning at the RoI. The 6-DoF control layout is shown in Figure 8. The control scheme includes an actuator input transformation T_u and sensor output transformation T_y



The carrier.
(a) 3D CAD model with coils, PCB and cover for the capacitive sensors.
(b) Realisation on the Halbach array.



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Control scheme for positioning of the carrier; the system is decoupled in six rigid-body DoFs by an input and output transformation T_u and T_y; x is the actual position of the carrier, and x_c is the rigid-body position of the carrier as estimated from the Hall sensor readings.

to decouple the system in six rigid-body DoFs, such that each single-input, single-output (SISO) PID controller controls one rigid-body DoF of the carrier. The current commutation from forcer forces F_f to individual coil currents i_c is a standard non-linear sinusoidal three-phase commutation strategy with superposition of vertical and horizontal force [7].

The static decoupling matrices T_u and T_y were derived from the rigid-body equations of motion of the carrier (neglecting stiffness and damping with respect to the fixed world):

$$M\ddot{q} = G_f F_f$$

$$\bar{y} = G_s q$$

Here, M is a diagonal matrix containing the carrier's mass and inertias, q are the six rigid-body DoFs of the carrier, $\bar{y}$ are the Hall sensor readings and F_f are the actuator input forces. With three-phase commutation for each forcer, the carrier has eight independent force inputs F_f (four vertical and four lateral) to actuate six DoFs, generating an over-actuated system; the matrix G_f is a geometrical model translating these actuator forces into rigid-body forces and torques around the carrier's CoG. To find T_u this G_f should thus be inverted such that the power dissipation in the coils is minimised.

Table 2
Main specifications of the realised demonstrator.

Specification	Value
Carrier mass	53 g
Max. force (x,y / z)	1 N / 2 N
Max. acceleration (x,y)	> 2 g
Max. speed	> 1 m/s
Vertical range (z)	400 µm
Coarse position resolution with Hall sensors	0.5 µm rms
Carrier size	50 mm x 50 mm

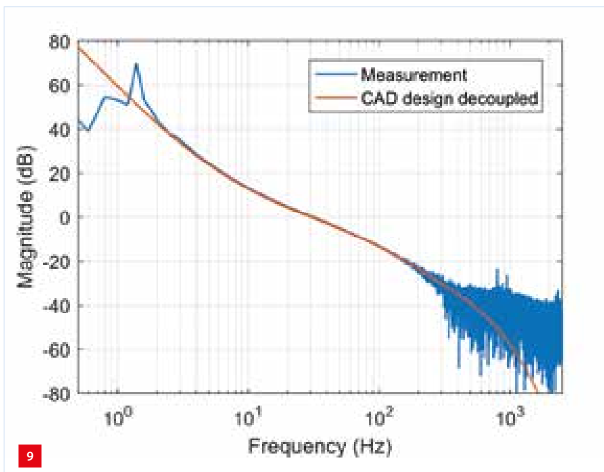
In a similar way, the matrix G_s is a geometrical model translating the six DoFs of the carrier into x-, y-, z-readings at each of the four Hall sensor sets, thus creating an over-sensed system. Hence, to calculate the rigid-body motion from these twelve Hall sensor readings, a least-squares solution was used to calculate the output transformation matrix T_y. The designed PID controllers for the decoupled plant were such that open-loop bandwidths of about 50 Hz for each axis are obtained.

Demonstrator experimental results

The demonstrator carrier has successfully been built and tested. The main specifications of the realised demonstrator carrier are summarised in Table 2. The realised carrier has a lower mass than initially expected, which allows for higher acceleration and larger vertical position range.

The mean required current at a fly-height of 0.5 mm is approximately 0.15 A for each forcer to generate the required lifting force of 0.52 N, which is in good correspondence with an expected current of 0.13 A from the 3D electromagnetic FEM model.

The open-loop frequency response functions (FRF) from controller error e to carrier output x_c were identified with closed-loop system identification, using the initial low-bandwidth PID controllers that were based on the CAD model. The measured decoupled FRF is obviously 6 by 6; for clarity only the x-axis is shown in Figure 9 as an example, and it is compared with the CAD-based FRF estimation. Their resemblance confirms the modelling and decoupling accuracy. The FRF measurements were used to increase the open-loop control bandwidth to, e.g., 50 or 70 Hz. The closed-loop response to a second-order reference input (maximum acceleration and speed of 10 m/s^2 and 0.2 m/s, respectively) is shown in Figure 10 and shows that accelerations of 10 m/s^2 can be easily achieved.



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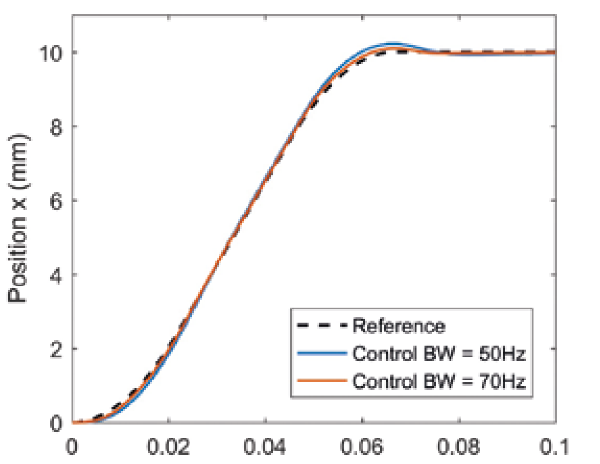
Example of a measured open-loop FRF (e to x_c in Figure 8) for the x-axis, using closed-loop system identification. Blue is the measured FRF, while red is the design based on CAD parameters.



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Measurement of a second-order reference input without feedforward control and a feedback control bandwidth of 50 and 70 Hz, respectively.

The demonstrator precision is illustrated in Figure 11, showing (cumulative) power spectral densities of the translational and rotational closed-loop error along or around the *z*-axis at an arbitrary location. These errors sum up to 0.5 µm and 33 µrad, respectively, which is mostly dominated by the noise of the Hall sensors. It is therefore very likely that the planned future inclusion of nanometer-accurate sensors will improve the positional precision of the MagLev stage to the nanometer level as well.

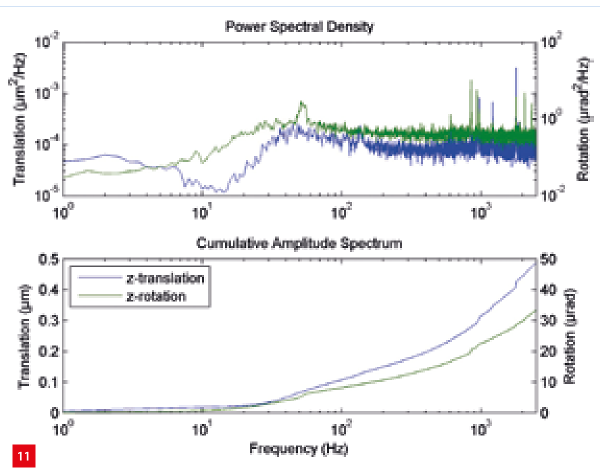
Conclusions and discussion

Overall it can be concluded that the carrier demonstrator works as expected and is very promising for further development of the nano-precision, multi-agent positioning platform. The demonstrator test results correspond very well to the models and calculations from the design phase. The low carrier mass of 53 g compared to the initial mass budget of 200 g provides a comfortable mass budget (147 g) to integrate demonstrator agents in the system. The carrier can currently achieve accelerations up to 2 *g*, which can be increased further by increasing the current levels.

A controller redesign is expected to be able to increase the closed loop bandwidth from the current 70 Hz to several hundred Hz. In its current form the technology is already suitable for several applications such as flexible, micrometer-precision, fast and parallel, pick & place tools.

The next validation step for the demonstrator carrier is integrating sub-nanometer capacitive sensors and local controller optimisation to verify sub-nanometer scanning performance. In parallel, a new optical encoder sensor is developed at TNO, that is small, has large range, and offers sub-nanometer resolution.

For a complete application-specific system, a trade-off has to be made between moving-magnet and moving-coil system, based on performance, complexity and cost. The electronics of the carrier and agents can be miniaturised and integrated in the platform to remove the flexible cable to the fixed world and thus enable true parallel operation without parts colliding or getting entangled. The different functionalities at the nanoscale should be miniaturised to enable small agents. And to control multiple agents in parallel, path and task planning should be further developed and integrated. Finally, wireless power transfer can be included as well.



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Spectral densities of the closed-loop error (both translation and rotation) at an arbitrary location with Hall sensors.

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DEGREES OF FREEDOM IN TURBINE MANUFACTURING

With its multi-axis PROKOS XT grinding machine, Blohm Jung simultaneously addresses complexity, flexibility and quality issues in modern manufacturing. For maintaining the machine's volumetric accuracy of +/– 25 micron, Blohm Jung extended its volumetric compensation process, developed for conventional 5-axis machines, to a 6-axis version. IBS Precision Engineering helped them develop their procedure using the Rotary Inspector, a special wireless probe system, for measuring the three rotational axes. As Blohm Jung's launching customer, MTU Aero Engines uses the compensation software for multiple PROKOS XT machines in the manufacturing of turbine components.

Complexity and precision are two of the biggest challenges of modern manufacturing, not only in the products but also in the machine design, given the increasingly tight demands regarding the accuracy of machined products. Typically, precision is specified in the tens of microns range. In addition, flexibility is a dominant characteristic of modern, or smart, manufacturing. This refers to, for instance, low-volume, high-mix manufacturing, with small-series or even one-piece flow production and frequent product changes.

One of the consequences is that similar products and different parts of one product (family) have to be processed on different machines but have to meet the same specifications, yielding consistent quality and allowing machine-independent workpiece assignment. Combined, these challenges demand for a qualification procedure that ensures precision during operation of multiple machines. At MTU Aero Engines, for example, turbine manufacturing is a high-complexity, high-precision process requiring true 6-axis grinding (Figure 1).

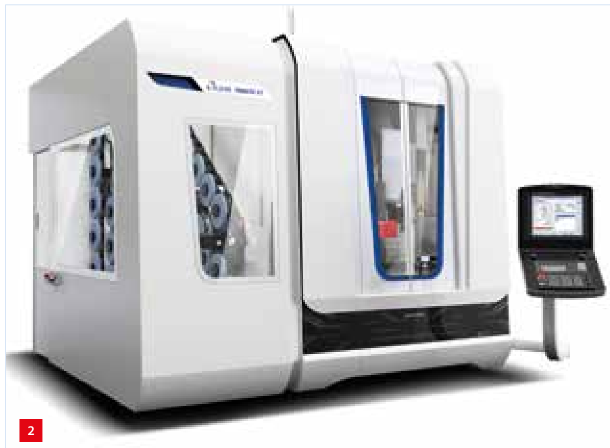
EDITORIAL NOTE

This article was contributed by IBS Precision Engineering.

Volumetric accuracy

The PROKOS XT is a recent addition to the BLOHM portfolio of surface and profile grinding machines (Figure 2). This 6-axis grinding centre was developed for the

1 Turbine manufacturing at MTU is a high-complexity, high-precision process requiring true 6-axis grinding.



2 BLOHM PROKOS XT 6-axis grinding centre.

automated machining of complex workpieces and can also execute drilling and milling operations, next to grinding. The addition of a sixth axis was designed to enable the machining of complex products in one run, without changeover in clamping.

Axes of a (grinding) machine inevitably have geometric errors, originating from production and assembly of the machine itself, wear during its lifetime (backlash or bearing problems) and environmental factors in operation. The errors include radial, tangential and tilt errors in the rotational axes and guideway errors in the linear axes. Blohm Jung has developed a volumetric compensation process to minimise these errors via the control software and achieve maximum volumetric accuracy in the interaction between all six axes. This process uses Siemens VCS (Volumetric Compensation System) software to apply compensation functions to the Sinumerik machine control. The volumetric compensation process has already been used successfully with 5-axis machine tools for a number of years. After a machine tool has been installed, all degrees of freedom of all axes are precisely measured. Compensation values are determined for the geometric errors that showed up and stored in the machine control. If the VCS software function is activated in the control, it uses these values to compensate for the errors and improve the precision of the machine. This procedure can be repeated during the operational lifetime of a machine.

Partner profiles

Blohm Jung GmbH
The product portfolio of Blohm Jung GmbH extends from surface grinding machines through application-oriented universal machines to customer-oriented production machines. The experience gained from over 35.000 delivered machines worldwide, combined with service and technology specialists that support customers throughout the entire lifecycle of their machines, ensure great production efficiency. The brands BLOHM and JUNG are members of the United Grinding Group, headquartered in Bern, Switzerland.

WWW.BLOHMJUNG.DE

MTU Aero Engines AG
Headquartered in Munich, MTU is Germany's leading engine manufacturer, engaging in the development, manufacture and support of commercial and military aircraft engines in all thrust and power categories and industrial gas turbines. MTU's focus is on low-pressure turbines, high-pressure compressors and turbine centre frames. Core competencies include high-tech manufacturing, maintenance techniques, inspection and testing expertise, as well as comprehensive systems knowledge.

WWW.MTU.DE

IBS Precision Engineering
Headquartered in Eindhoven (NL), IBS Precision Engineering is a specialist in precision metrology and the development of machines and modules for ultra-precision applications. They supply measuring systems and components for, amongst others, semicon, aerospace, automotive and machine tool markets. For specialised needs, IBS designs and delivers product measurement machines and scientific instruments. Traceable accuracy down to the nanometer scale, application of latest standards and ground-breaking technology is offered.

WWW.IBSPE.COM

Rotary Inspector hardware. (Photos: Nicole Minneboo, IBS)
(a) The Trinity measuring head.
(b) The master ball (shown on an EROWA mount).

A first on 6-axis machines

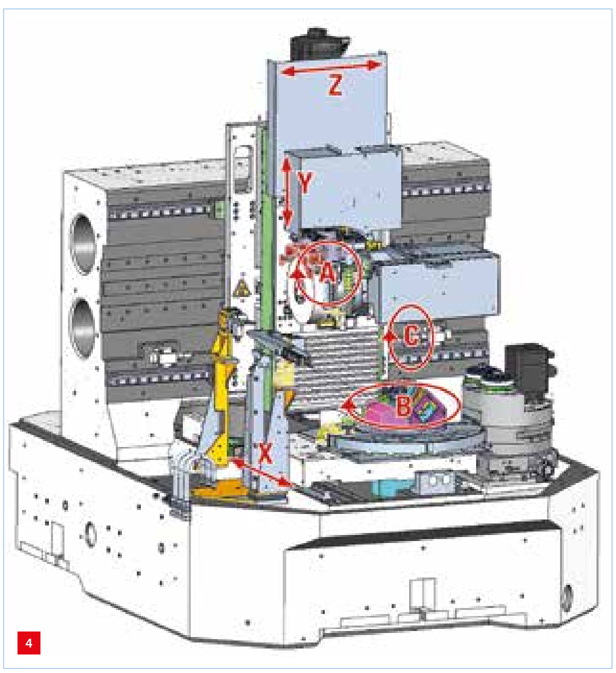
Applying the volumetric compensation procedure to the 6-axis PROKOS XT machine, however, was new to Blohm Jung and posed two challenges; the acquisition of the error data and the algorithms for converting these data into compensation settings for the machine. Concerning suitable measuring systems for precise acquisition of error data, for the linear axes a straightforward solution was selected; a laser measurement system capable of measuring errors in six degrees of freedom along a linear axis. Measuring the three rotational axes, however, had no precedent.

For measurement of the three rotational axes, MTU introduced Blohm Jung to the Rotary Inspector solution from IBS Precision Engineering, which can provide confirmation of the true positioning accuracy of a tool relative to the workpiece for (normally) 5-axis machines, under dynamic conditions. Mimicking normal operation of a machine, the Rotary Inspector can check the volumetric accuracy of all machining axes by moving them simultaneously.

Rotary Inspector

IBS had designed the Rotary Inspector to determine (and correct) critical geometric and dynamic performance parameters of 5-axis machines. Based on measurements according to the ISO 10791-6 standards, the Rotary Inspector measurement software can determine the total 5-axis machine tool accuracy within minutes and also calculate the pivot line offsets and squareness errors. Extensive measurement results can be condensed into two characteristic numbers; the Q value as the maximum geometrical error, providing an upper boundary for the dimensional accuracy, and the P value as the largest dynamic error, representing the surface finish.

The Rotary Inspector (Figure 3) includes a Trinity wireless measuring head, which is placed in the spindle, and a master ball, which can be placed on the product table using an optional EROWA mount for accurate positioning.



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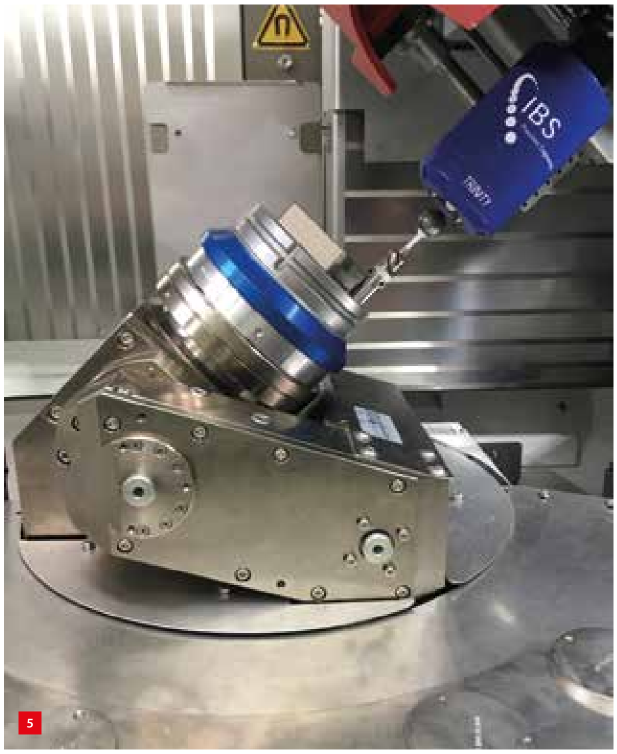
Schematic of the 6-axis PROKOS XT machine showing the three linear axes (X, Y and Z) and the three rotational axes (A, B and C).



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The first application of the Rotary Inspector for measuring a 6-axis machine.

Coordinate transformations

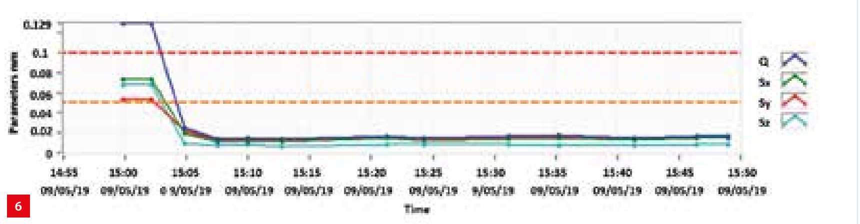
The biggest challenge in developing the 6-axis application was not only the measurement of all six axes, but the interpretation of the measurement results and their translation into compensation values, requiring a thorough understanding of the construction of the machine. The Rotary Inspector solution covers a total of 21 standard 5-axis machine types/configurations. This was the first application of the Rotary Inspector for measuring a 6-axis machine.

The PROKOS XT configuration (Figure 4) features three linear axes (X, Y and Z) and three rotational axes (A, B and C); it can be considered as a 5-axis machine with an additional tipping axis (C) sitting on the B-axis under an 45° inclination angle. Naturally, this adds to the complexity of defining the required coordinate transformations. Errors measured in the measuring head coordinate system have to be transformed to errors in machine coordinates (such as squareness and position errors of the rotary axes) and subsequently converted into an optimisation of the kinematic chain in the machine.

An additional challenge was posed by the nature of the machine. The PROKOS XT uses a bulky grinding tool mounted on a short spindle, in contrast with the conventional milling machine which has a slender tool mounted on a long spindle. This means that on this 6-axis machine the various linear and rotational axes have a limited range and not all standard motion sequences are accessible, as the measuring head under certain conditions could collide with the index table and workpiece carrier. Therefore, some of the measurements have to be performed in non-standard situations.

ISO philosophy

In the Rotary Inspector formulation, the PROKOS XT has been defined by the combination of two 5-axis types that best represents the 6-axis configuration. The measurement procedure then combines the standard tests for these two types, covering the A and B and the A and C axes, respectively, and finishes with a comprehensive ABC test.



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Typical Rotary Inspector output, showing the evolution of the Q value, i.e. the maximum geometrical error, and the underlying maximum individual axis errors (Sx, Sy and Sz). The sharp decline in all values reflects the error compensation taking effect.

Based upon the reasoning behind the ISO 10791-6 standards (Test conditions for machining centres – Accuracy of speeds and interpolations), the various elements of this test, for example one rotary axis moving with double the speed of the other axis or one axis moving in positive direction and the other in negative direction, have been merged into the 6-axis test. This does not make the 6-axis test 'ISO-certified', as there is no 6-axis ISO standard, but it represents the best approach following the ISO philosophy. In this way, a major step towards the reliable qualification of 6-axis machines has been taken.

Partner quotes

Blohm Jung: "Unique selling point"

"MTU was our launching customer for the 6-axis PROKOS XT machines. They introduced us to IBS and we decided to collaborate to integrate their Rotary Inspector in the VCS volumetric compensation process. With the aid of Blohm Jung's new VCS procedure, customers can use 6-axis grinding machines flexibly for the production of various products and parts of product families. Now they can improve not only the volumetric accuracy of their machine using the VCS, but also the comparability and consistency between different machines, as well as ensure high technological availability with constant workpiece quality.

"Currently, the VCS is a USP of Blohm Jung. We plan to further strengthen our position in the high-end grinding and profiling market by integrating volumetric compensation into our service offerings; for instance, checking the volumetric precision and applying the required compensation will be an integral part of maintenance intervals. Also, the VCS will be added to other products in our portfolio case by case."

Matthias Guhlke, senior key account manager Turbine at Blohm Jung, Hamburg

MTU: "The step from 5 to 6 axes"

"For calibration of our machine tools we have been working with the Rotary Inspector and Spindle Check tools from IBS for two years now. Today, the complex geometry of workpieces requires a 6-axis grinding machine and for this we needed a 6-axis calibration procedure, to ensure 25-micron accuracy over the full working range of a machine. We had to develop a dedicated procedure, in collaboration with machine builder Blohm Jung, machine control supplier Siemens and metrology expert IBS.

"Our operators regularly test their machines using simple touch probes. When any deviations show up, such as vibrations or incorrect parameter settings, our measurement engineers come in to conduct a VCS volumetric compensation procedure. They use a Renishaw XM60 laser to check the straightness and the orthogonality of the linear axes and the Rotary Inspector for checking the kinematics of all six axes.

"Currently, we have three 6-axis grinding machines in operation and a fourth and fifth one are underway. Thanks to the Blohm Jung VCS process employing the IBS Rotary Inspector we can manufacture products with consistently high quality and precision on all of these machines."

Matthias Scherm, Plant Services-Engineering at MTU Aero Engines, Munich

IBS: "Trusting the machine"

"Machine builders as well as users can apply our Rotary Inspector solution for qualifying their machine and performing acceptance tests. The Trinity measuring head literally 'sits' on the machine, undergoing all movements that occur during live machining – and in the present case it is really the six axes moving simultaneously. Laser measuring set-ups do not allow this kind of dynamic measurement. The measurement is completed in minutes and the procedure can be conducted on a regular basis, for example weekly or monthly, and also ad hoc, depending on the workload or after a crash.

"As the Rotary Inspector covers all six axes under operational conditions, the calibration gives the user confidence in their machine. They know they can trust their machine; it is within specification regarding volumetric accuracy and the machine control is doing what it should do.

"Being a Siemens Product Partner enables us to bring together the Rotary Inspector measurement expertise with their machine compensation software. We were delighted to support Blohm Jung, and hence MTU, with the introduction of their ground-breaking machine."

Theresa Spaan-Burke, innovation director, and Joris Janssenswillen, system engineer, at IBS Precision Engineering, Eindhoven

PLEADING FOR A COMPLETE FRAMEWORK

The adoption of optical methods for measuring surface geometry, both form and texture, in advanced manufacturing is accelerating fast. However, there still is no specification standards infrastructure in place for calibration. This article discusses why this is the case and takes a future-gazing look at how we might go about introducing such a calibration framework.

RICHARD LEACH

Slow and often damaging contact measurement systems are rapidly being replaced on the shop floor with robot-mounted (visible-spectrum) optical sensors that can whizz through a programmed measurement routine at alarmingly high speeds and produce vast amounts of useful data. New commercial optical measurement systems are added to the catalogue almost every day. Therefore, it seems amazing that we still do not have a specification standards infrastructure in place that allows such optical systems to be calibrated or only allows calibration in some specialised cases.

The exceptions are the conventional optics and semiconductor manufacturing industries, who already have well-established calibration infrastructures for optical measurements of surface geometry. But these infrastructures are less developed for many precision manufacturing industries that rely on machining of complex surface geometries. Highly complex freeform geometries and textures, as found for example in the automotive, aerospace and medical parts industries (see Figure 1), mean that many of the established calibration techniques for optical surface measurements may not be directly relevant.

In addition, with the industrial uptake of additive manufacturing techniques, the complexity of the resulting geometries, both texture and form, is leading to new measurement challenges (see Figure 2).

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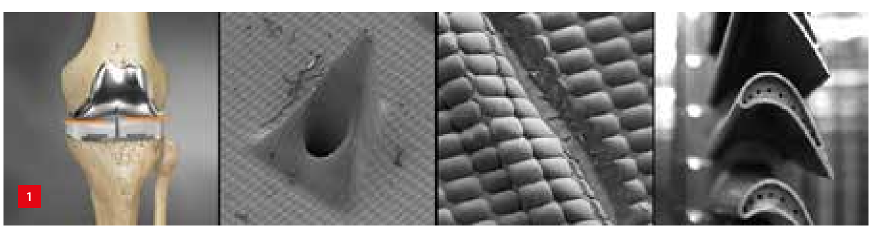

Examples of functional surfaces with complex geometries.
From left to right: additively manufactured freeform knee replacement, microneedle for medical application, microlens array in a camera, and turbine blade with cooling holes.

Lack of trust

It is commonplace in many manufacturing industries to hear users expressing alarm about the comparability of optical instruments with contact methods of measuring surface texture and form, and these concerns are often borne out in formal comparisons. In many cases, the difference between the results from optical and contact instruments can be explained after critical assessment of the measurement conditions and sample geometries, but the damage has already been done. Adoption of optical instruments in many manufacturing industries has been slowed, despite the apparent growth and huge potential.

Where does this lack of trust come from? As stated above, one of the primary reasons for this lack of trust when measuring complex surfaces is the lack of a calibration framework for optical instruments, where calibration is the process of comparing a measurement result to a reference result in order to establish traceability. It is relatively simple to understand and model the physical interaction of a contact probe tip with a surface, but it is not so simple to model the equivalent optical interaction – it is a more complex physics problem and this is the crux of the issue.

Framework

To address this issue in the surface texture measurement community, a framework was developed by the author when working as a principal research scientist at NPL, Teddington, UK. This framework is now being refined by an ISO working group (ISO technical committee 213 working group 16), in an attempt to simplify the problem by introducing a number of common or instrument-independent metrological characteristics.

These characteristics are instrument parameters that can be determined with a suitable material measure (artefact) and procedure, and the resulting parameter values can then be propagated through a measurement model to give an estimate of measurement uncertainty. Examples include

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Examples of objects with complex form from additive manufacturing. From left to right: roof car bracket (BMW), aerospace bracket (Airbus), bike parts (Renishaw), and structural steel part (Arup).

the instrument noise level, the amplification coefficient for the instrument scale and the lateral resolution.

The framework only applies if certain well-defined assumptions about the measurement scenario are adhered to, but it is a solid start and will significantly enhance the kudos of optical instruments in the manufacturing industry. So far, a specification standard has been published that lists and defines the metrological characteristics (ISO 25178 part 600). ISO 213 working group 16 is currently drafting a standard (ISO 25178 part 700) that will inform instrument users how to determine the metrological characteristics and, therefore, establish traceability (through calibration) of their measurements.

However, this infrastructure only applies for surfaces with relatively simple texture – if the optical interaction with the surface is too complex, then non-linear effects mean that the simple metrological characteristics are not enough to allow a rigorous estimation of uncertainty. Part 700 will mention these non-linear effects in passing but will not address them normatively.

Interaction models

At the University of Nottingham, in collaboration with a number of instrument manufacturers, we are developing rigorous models that will allow prediction of the interaction of any optical instrument with any surface geometry, at least in the first instance, when we assume that materials effects such as translucency are negligible. This means we have had to develop a rigorous theory of scattering from a surface (which includes effects such as multiple scattering, shadowing and surface plasmons) combined with models of the illumination, propagation and detection processes.

Once we have such models, and we are not completely there yet, then we can use them as 'virtual instruments'. This is an approach used in the contact coordinate metrology world; a virtual measurement system considers the various influence factors and simulates the measurement using an accurate model that mimics the real measurement process. The influence factors can be varied based on appropriate stochastic models using a Monte Carlo method, and a large number of simulated measurements can be generated for estimating the final measurement uncertainty. Early work with coherence scanning interferometry [1] is showing promise and we intend to move towards other instrument modalities, such as imaging confocal microscopy and focus variation microscopy.

Optical coordinate measurement

In the world of optical coordinate measurement, for example with laser triangulation or fringe projection systems, there is work in the standards committee (working group 10) to bring optical instruments into the performance verification framework that has been developed for contact coordinate measuring systems. But performance verification, i.e. determining whether an instrument is operating according to a technical specification, is not calibration.

With the exception again of the optics industry, there seems to be little research into how to apply the same principles to calibration of such instruments. Calibration of optical coordinate measuring systems is not currently being addressed in the standardisation committee but is clearly needed in the manufacturing industry.

In the contact coordinate measuring world, substitution (using the instrument as a comparator, usually only in a single axis) can be applied in simple cases, and virtual instruments can be used in more complex measurement scenarios. However, such virtual instrument models are not available for optical instruments nor is it completely obvious how to develop them.

Again, at the University of Nottingham, we are starting along the road to establish a framework for optical coordinate measuring systems. We will first attempt to define a set of metrological characteristics that can be used at least in simple measurement scenarios. We will in parallel develop virtual optical coordinate measuring systems that can be used to estimate uncertainty with any geometry. This step is challenging due to the large effect that the surface texture and materials properties have in the measurement, and due to the typical optical configurations used in commercial instruments (essentially, many of them are not shift-invariant, which precludes the use of conventional transfer function approaches).

Primary instruments

Lastly, at Nottingham, we are also designing a primary optical coordinate measuring instrument, i.e. one that measures coordinates on a surface with direct traceability to the meter and one in which we can estimate the magnitude of the various influence factors.

So, let's end on a provocative note. If it proves possible to develop a primary optical instrument and virtual models for the optical instruments used in industry, then we may be able to dispense with contact systems as a necessary part of the traceability chain (see Figure 3 for an example). Indeed, at least one of our collaborators has done this in the texture world for simple measurements using coherence scanning interferometry. If the primary instruments can be made simple enough, then it would be possible for each company to have such an instrument in the gauge room (where they now have contact instruments). They could then apply the metrological characteristics framework, or virtual instrument software, to estimate uncertainty for their shop-floor instruments.

Invitation

This all-optical world – dystopian, perhaps, to the contact instrument vendors, utopian to all other parties – may be some time off or even science fiction, but we are taking the first tentative steps in this direction. Of course, the sceptics (including the author) will not be happy until almost every step along this path has been verified by comparison to traceable contact measurements, so there needs to be a community effort to make this happen. We end with a call to arms: the reader is invited to share this dream and come along with us on this topographic (bumpy) ride.

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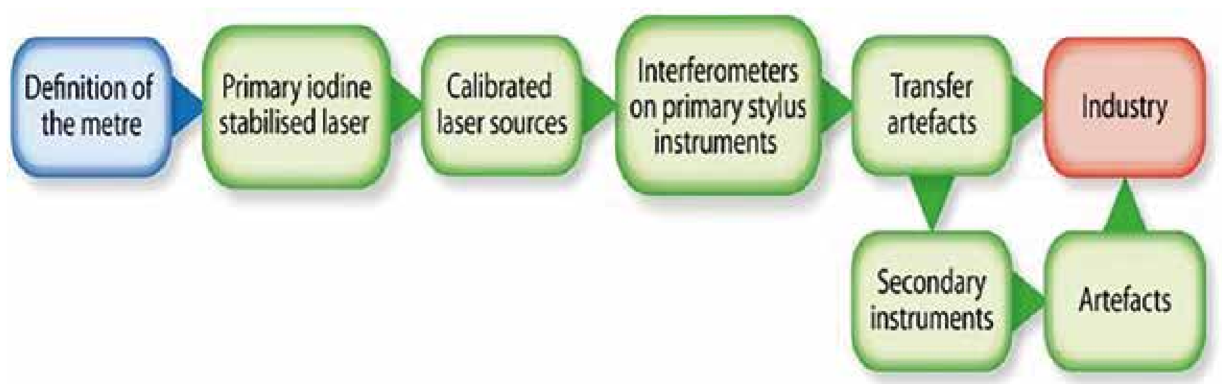

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The typical traceability infrastructure for surface texture measurement.

THERMAL CONSTRAINT IN TOPOLOGY OPTIMISATION

Numerous challenges of additive manufacturing (AM) are tackled in the European Horizon 2020 project PAM² by studying and linking every step of the AM process cycle. For example, PAM² researchers from the design, processing and application side have collaborated in this work to optimise the manufacturability of metal AM parts using an improved Topology Optimisation (TO) approach, including a thermal constraint. Additionally, the project is focusing on modelling, post-processing, in- and post-process quality control and industrial assessment of AM parts, with the aim of moving beyond the state-of-the-art of precision metal AM.

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Can Ayas, Matthijs Langelaar and Fred van Keulen are involved as supervisors from TUD. Wim Dewulf is involved as supervisor from KU Leuven. Ann Witvrouw is the project coordinator of PAM², and research and innovation manager at KU Leuven in the Department of Mechanical Engineering.

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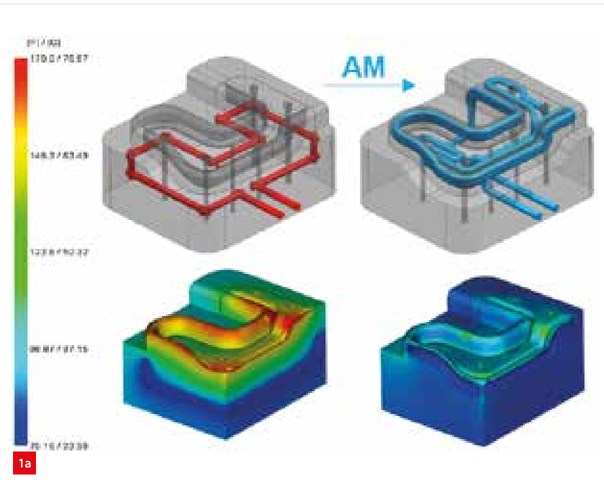
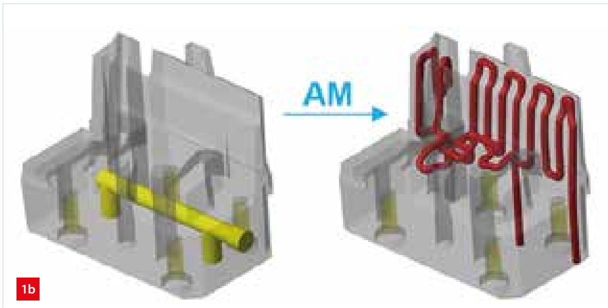
Introduction

Additive manufacturing (AM) stands for a group of technologies where parts are built up layer by layer. AM has gained popularity during recent years primarily due to the reduced design-to-production time and the form freedom offered. However, several technological challenges still remain, such as a limited precision due to shrinkage, build-in stresses and dross formation at overhanging structures and a limited process stability and robustness. AM-printed parts often do not come out of the printer with the desired dimensions and shape.

Therefore, we need to make sure that we design the parts and choose the printing direction and process in such a way that the manufacturability is optimised. In this work, a novel Topology Optimisation (TO) approach has been developed to enhance AM manufacturability and, as a result, to improve the final AM product. A case study of an injection mould insert illustrates this new Design-for-AM (DfAM) method. This work has been done within the PAM² consortium, where every step of the AM process cycle is studied. Therefore, links can be made between the initial design and the final result.





Two AM redesigns of the cooling system of mould inserts.
(a) Courtesy of Milacron (with heat transfer simulation).
(b) Courtesy of Renishaw.

Improving manufacturability of AM parts

General concerns and common solutions

Improving the manufacturability of AM parts and ensuring that their desired dimensions, quality and surface finish are reached is a common theme in the PAM² project. Enhancing the precision of AM parts has direct implications for an industrial environment where the reduction of tolerances, a higher production output and a diminished need for post-processing are always desired. An industrial example is therefore presented in this work. By the use of novel TO techniques, developed within PAM², a metal mould insert for injection moulding has been redesigned for improved precision.

PAM² consortium

PAM², which stands for Precision Additive Metal Manufacturing, is a European Horizon 2020 MSCA project in which six academic and six industrial participants collaborate on improving the precision of metal AM. PAM² started in December 2016 and will run till the end of November 2020. The specific metal AM technology studied here is LPBF (laser powder bed fusion), where successive layers of powder are molten selectively by a laser to form the 3D AM part.
Research is done for each process stage of AM, going from the design stage to modelling, fabrication, measurements and assessment. For each step the aim is to progress the state-of-the-art with the goal of improving the final AM part precision and quality by implementing good precision engineering practice.

The overall objective of PAM² is to ensure the availability of high-precision AM processes and (computational) design procedures. Detailed objectives are:

1. to develop advanced (computational) design tools, enabling competitive designs, better use of AM possibilities against minimal design costs, and reduced time-to-market;
2. to develop better modelling tools for first-time-right processing;
3. to optimise selective laser melting process strategies for improved part precision and feature accuracy;
4. to understand the link between post-process metrology and in-process observations, creating the basis for in-process quality control and process stability;
5. to develop innovative in-process and post-process techniques to reduce or remove roughness, porosity and internal stresses and to improve dimensional accuracy and mechanical properties.

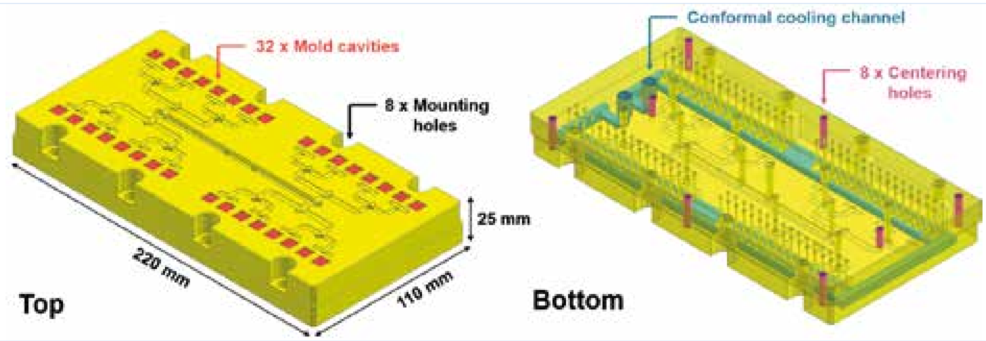
PAM² researchers from the design, modelling, (post-)processing, metrology and application side are encouraged to form collaborations across the different process stages and to continuously interact with each other. Moreover, the developed research is tested on common relevant industrial end-user parts. Successful examples of such collaborations are the theoretical prediction and experimental validation of keyhole porosities [1], prediction of post-anneal AM microstructures [2], a novel benchmark part allowing the comparison of different AM machines [3], improvement of as-printed downward-facing surfaces [4, 5], and the development of novel in-process and post-process measurement methods [6, 7].
Besides ensuring that you get what you want, PAM² also aims to push the limits in terms of precision. As a result, low surface roughness [8, 9], reduced edge effects [10] and high-precision CT techniques [11] are obtained.

Injection mould inserts made by AM
Injection moulding is a method to obtain products by injecting molten plastic materials into a mould, and then cooling and solidifying them. When producing a mould using conventional manufacturing technologies, the starting material is a massive metal alloy part. This part undergoes many different processing steps before assuming its final shape. First, several cooling channels and ejector pin holes are drilled and plugged. Next, final finishing steps are performed to obtain the right surface quality and dimensional tolerances.

By using AM, a part that is already near-net-shape can be produced. Only the final finishing steps for obtaining a smooth surface are still required. Moreover, by employing DfAM, the design of the mould itself can be improved by, for example, defining a more efficient path for the conformal cooling channels that enhance the thermal management of the mould (see Figure 1), or by decreasing its weight while maintaining the same performance. Removing excessive material that doesn't contribute to the mould's overall performance has great benefits as it can drastically reduce the manufacturing time in the LPBF machine. This step is however often not performed because of poor knowledge of the AM design guidelines and because the removal of excessive material is not the primary objective in the specific application. One solution to implement this step is the use of TO.

Case study: Injection mould insert

Topology optimisation was performed on a metallic mould insert which is to be produced by LPBF of maraging steel 300 material. The case study, to be employed for the injection moulding of ABS parts, has been provided by a large manufacturer of consumer goods. The design of the mould insert had already been partially optimised for AM, with a simple conformal cooling channel running beneath the mould cavities (Figure 2). The reduction of weight, for the purpose of reducing LPBF production time and material use, however had not yet been considered in the design stage. TO was therefore selected as an optimal solution to perform this last step before the fabrication of the insert.



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Original design of the injection moulding insert.

Topology Optimisation

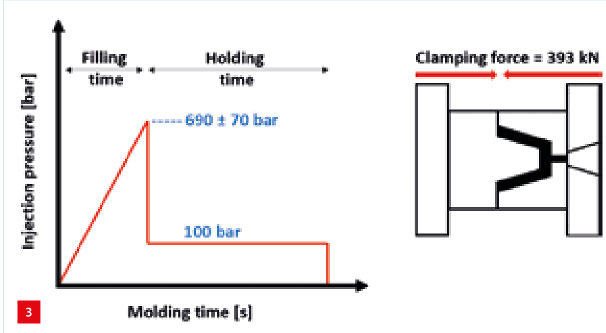
TO is a computational design tool which is used to find the optimal material distribution for a predefined objective and a set of constraints. One commonly solved TO problem is to find the optimal material layout such that the final design has maximum stiffness against a given set of loads for a prescribed maximum allowable volume. This is commonly referred to as a compliance minimisation or a stiffness maximisation problem in literature [12]. Designs found using TO are typically geometrically intricate and hence difficult to manufacture using conventional manufacturing techniques. However, the enhanced design freedom allowed by AM makes it possible to realise these designs. TO allows, on the other hand, for a proper exploration of the vast design space and it assists designers in finding optimal topologies.

This mutually benefitting relationship between TO and AM is very well recognised and a number of researchers have focused on integrating AM constraints within the TO algorithm. One commonly investigated AM constraint is that of overhangs or downward-facing surfaces. It is well-known that overhanging features are difficult to manufacture by AM. Multiple TO methods are therefore proposed such that resulting designs avoid overhanging features, thus enhancing precision in AM parts [13, 14]. This trend of addressing AM constraints within the TO method is, besides being a topic of research, also starting to find its way into commercial CAD packages.

For this specific case study, first a standard density-based TO was used to minimise the mass of the component while ensuring adequate mechanical response under a prescribed loading condition [15]. With this method no consideration was given to AM-specific constraints. Next, commercially available TO software [16] with geometry-based AM constraints was used to achieve a similar mass reduction.

Finally, an in-house TO method that was developed in the PAM^2 consortium [17] was utilised. This method tries to determine local overheating, or 'hotspots', during LPBF manufacturing via a simplified AM process model included in the standard TO algorithm. The aim was to create a TO-optimised design in which the above-mentioned hotspots are avoided. All three TO-optimised designs are briefly compared, and the advantages of implementing manufacturing constraints into the TO algorithm are discussed.

Initial case study design and requirements
All mould inserts need to possess some minimum

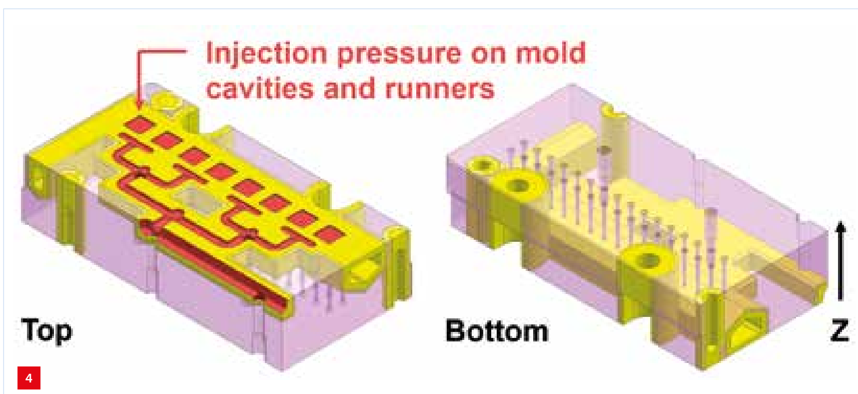


General injection moulding parameters for the examined case study.

requirements given by the process. To withstand the injection moulding process, the mould needs to be stiff enough not to deform during the injection cycle, it needs to be chemically inert not to react with the plastic, and, if possible, it should be made of a corrosion-resistant material considering that usually the cooling medium is water. Moulds also need to be very resistant to fatigue to ensure long life during multiple temperature cycles.

The exact degree to which each of the above-mentioned requirements are satisfied depends on the mechanical properties and the viscosity of the plastic material that is processed and on the injection moulding machine itself (e.g. the number of moulded parts that are to be produced per shot). The general injection moulding parameters for the case study have been provided by the manufacturer (see Figure 3). The mould insert material of choice was maraging steel 300, which is known for its superior strength and toughness without loss of ductility. This steel is also easily heat-treatable, and a simple age-hardening will confer excellent hardness and strength with good wear resistance.

TO set-up
The formulation of the optimisation constraints and loading conditions is one of the most critical steps in a TO problem. The actual case study functionality, as well as limitations imposed by the TO tool used, need to be taken into account. Moreover, the design space in which the TO code can



Design space (pink) and keep-in space (yellow) for the case study TO problem formulation; Z is the AM building direction.

operate should be simplified as much as possible to reduce computation time, while maintaining the critical features that shouldn't be reshaped by the TO algorithm.

For this reason and in view of the almost perfect double symmetry of the case study, the TO was set up to consider only one quarter (comprising eight cavities) of the original mould insert. Moreover, features like the mounting holes, the centring holes, the mould cavities and runners plus the cooling channel (keep-in features in Figure 4, yellow colour) have been excluded from the TO design space and were not modified during the optimisation. The design space, in pink, was the volume where the TO could optimise the material layout for the given set of loads, boundary conditions and constraints, with the target of maximising the performance of the system.

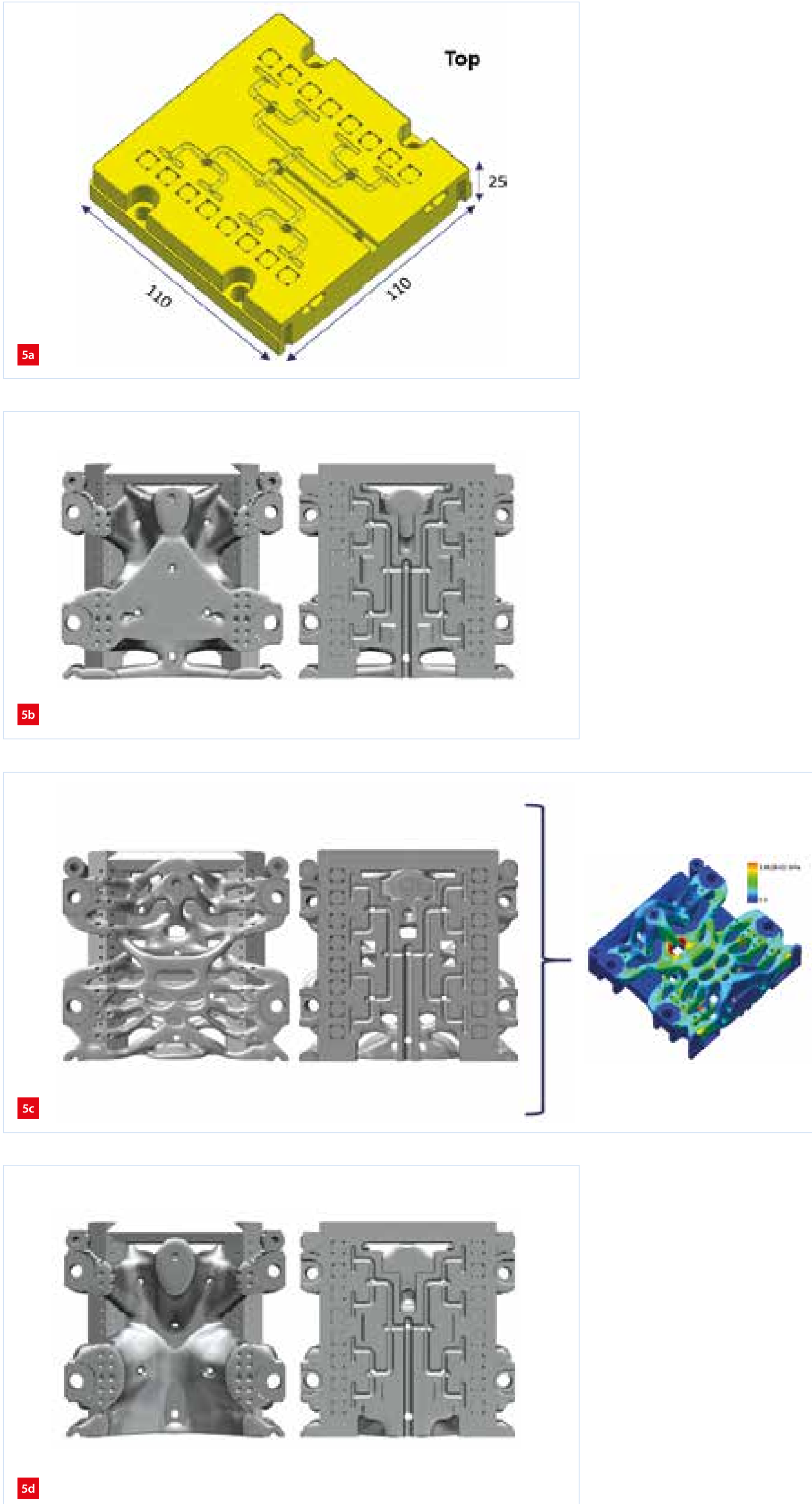
The loading condition tried to mimic the injection pressure load on the runners and mould cavities using the maximum possible pressure (760 bar, Figure 3) multiplied by a 1.5 safety factor. The water pressure in the channel was considered to be negligible. Mounting holes and centring holes were set as fixed surfaces for all six degrees of freedom. The mechanical properties of the maraging steel 300 were acquired from [18].

Figure 5a shows the original half mould insert and Figure 5b shows the optimised design obtained from a standard density-based TO [15]. For the latter no AM constraints were implemented and manufacturability might therefore be at risk.

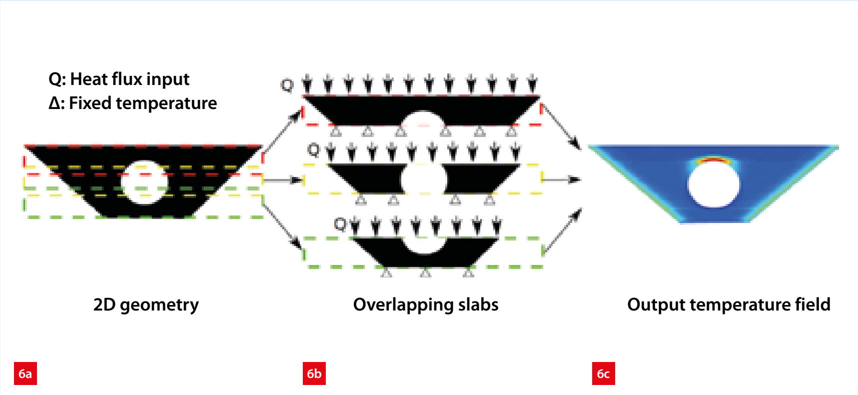
Commercial platform
To improve manufacturability of the mould insert, TO has first been performed with commercial software [16] that already implements AM constraints in the optimisation set-up, like overhang prevention or self-supporting control. The tool applied purely geometrical AM constraints, where the building direction (Z in Figure 4) and a minimum overhang angle of 45° [19] should be defined a priori.

The optimisation goal was to create the stiffest part for a given mass target, i.e. the strain energy was minimised. Moreover, the maximum Von Mises stress and maximum displacement, calculated after the finite-element analysis (FEA) step in the TO algorithm, should remain within prescribed boundaries to avoid stress concentration or inadmissible deformation of the insert while in operation. A displacement < 130 μm was considered acceptable based on suggested values from available literature [20].

For the implemented loading conditions and constraints, a reduction of ~50% in mass was obtained (Figure 5c), from the original weight of 4.3 kg to a weight of ~2.1 kg after TO.



Original design of a mould insert half (the TO design space being half of this) and optimised designs (each showing bottom (left) and top view).
(a) Original half mould insert design.
(b) Optimised design obtained from a standard density-based TO algorithm.
(c) Optimised design from the commercial TO software which adopts geometrical AM constraints, with on the right the corresponding Von Mises stress distribution (bottom view).
(d) Optimised design from the novel in-house heat accumulation TO method.



Hotspot detection method [17].
(a) A wedge-shaped geometry (example) decomposed into a set of overlapping slabs.
(b) Individual slabs with applied boundary conditions.
(c) Temperature field obtained by aggregating temperature information from all the slabs.

The maximum stress was 366 MPa, well below the yield stress of the employed material, while the corresponding maximum calculated deformation was 101 µm.

Novel in-house developed TO method

Within PAM^2 a novel TO method [17], which addresses the issue of AM-associated local overheating within the standard TO algorithm, was developed. First a simplified model of the AM process, which emulates the layer-by-layer heat addition and identifies zones of local heat accumulation in a given design, was created (see Figure 6 for a 2D case). Localised steady-state thermal analysis was used for this model as it offered significant computational gain, making it possible to integrate the model within the TO method.

The obtained temperatures were, because of this simplification, only indicative and hence not equal to the actual in-process values. However, it was found that this simplified model could rightly identify the heat accumulation locations. Hence, the model has been implemented as an additional constraint within a density-based TO method, while sensitivities were calculated using the adjoint method. The method of moving asymptotes (MMA) [21] has been used for the optimisation. Figure 5d shows the design obtained using this TO method with thermal constraint.

All three results (Figure 5b, 5c and 5d) were topology-optimised adopting the same set of load conditions and fixing constraints and having the same mass target (reduction of ~50% in mass). It was however expected that the manufacturability would improve by taking AM constraints into account (both 5c and 5d) and that an AM constraint based on the identification of local overheating (Figure 5d) was more desirable than a purely geometrical AM constraint (Figure 5c). This is studied in the next paragraph.

Results

The goals of this study were twofold:
1. To demonstrate how the implementation of TO in the design stage of a mould insert could be useful to decrease the total mass of the part, consequently reducing LPBF production time and hence costs.
2. To show how the implementation of a local overheating filter in the TO could improve the manufacturability of an AM part.

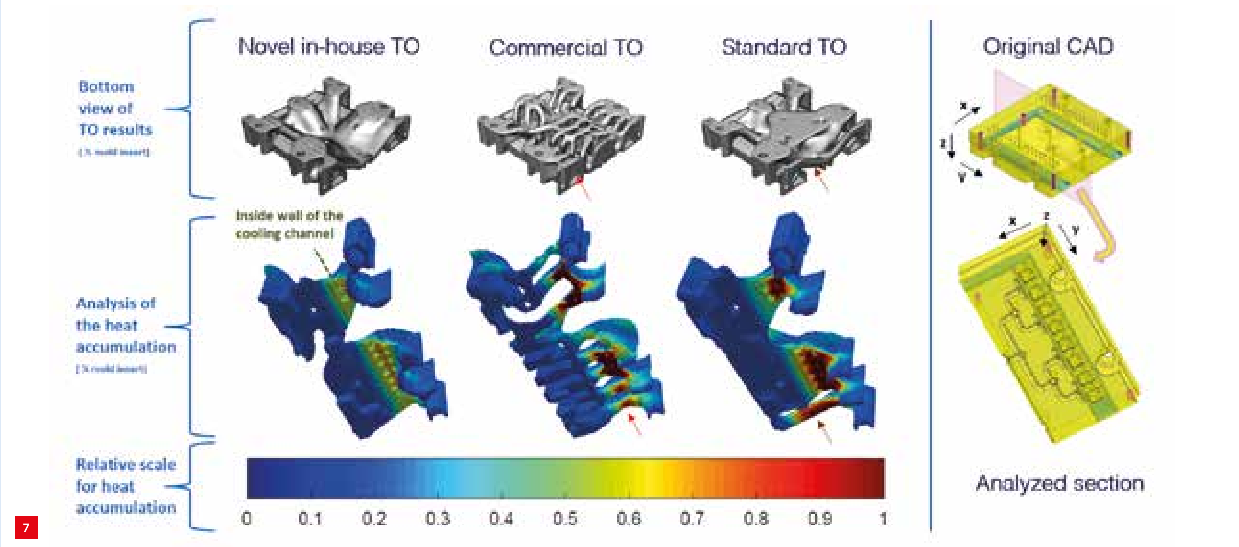
For the case study a reduction of ~50% in mass of the part was already achieved by standard TO (Figure 5b). Accordingly, the simulated LPBF production time was decreased by ~43%, from ~23 hours for the original design to ~13 hours for the optimised insert (fabrication parameters from [18]). However, performing TO without considering manufacturability constraints could result in a design that cannot be successfully manufactured with the AM process selected.

Commonly available commercial TO software does not guarantee avoidance of local overheating issues. If local overheating is present, defects such as dross and sag formation could still appear on downward-facing surfaces and thus decrease the obtained surface quality or impose the use of supports to avoid build failure. Including AM constraints in the TO stage is therefore fundamental and the choice of the correct constraints to be applied is still an open research discussion.

To prove that local overheating can still be present with purely geometrical AM constraints, a comparison with the hotspot detection method [17] was performed for all three optimised designs of the case study (Figure 5b-d). The resulting temperature field plots are reported in Figure 7.

It is clear, looking at the relative scale, how the novel in-house TO tool with the thermal AM constraints avoids or limits the occurrence of heat accumulation both in downward-facing regions of the optimised part and on the inside wall of the cooling channel. Consequently, for the same mass target, it is expected that an optimised design without local overheating can be printed with a greater geometrical accuracy and surface quality as compared to the other two designs in Figure 7.

At the same time, it must be disclosed that for the in-house TO design possibly higher deformations (> 130 µm displacement) during operation could occur, given the different distribution of the material in the design space. Therefore, more extensive FEA examinations should be performed on all the TO designs to evaluate the compliance with respect to the acceptable maximum stresses and deformations.



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Obtained TO designs for the case study, with the analysis of the heat accumulation during LPBF manufacturing performed with the PAM² novel in-house TO tool.

Discussion

Using TO for AM is extremely important since it allows to employ all unique capabilities of this manufacturing technology. TO is already often used for lightweight applications such as those encountered in aerospace. The mould insert example studied here shows that it is also very beneficial to use TO for tooling aplications. Care should however be taken to avoid overheating during the AM process. Such AM-safe designs can be made by using a TO algorithm with an integrated thermal model, which was developed within the PAM² project. The thermal analysis confirms that overheating is indeed avoided by using this novel TO method.

Future outlook

While thermal simulations already show the benefit of using the TO tool with integrated thermal model, an experimental validation is also planned within the PAM² scope. The unique concept of linking researchers from the different parts of the AM process cycle (from design to assessment and back) within PAM² makes this kind of validation feasible. Many more such cross-discipline results are expected before the end of the project in November 2020.

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Tempcontrol – the specialist in temperature measurement and control

For more than 40 years, Tempcontrol has supplied temperature sensors on customer specifications and in standard constructions. Founded as a trading company, mainly active in the field of temperature measurement and control, in 1980 Tempcontrol started producing electronic temperature sensors such as thermocouples and resistance thermometers, mostly on customer request. By virtue of its flexibility and expertise an excellent reputation has been achieved in the fields of industry, research and development. Based on its high level of expert knowledge, Tempcontrol has been appointed member of the Dutch Technical Committee on Temperature and Humidity.

Temperature is an important parameter in many processes, systems, machines or parts thereof. Temperature variations or drift, but also unwanted temperature differences, can considerably affect the performance of a machine or system. Proper measurement and control of temperature in a process has a positive effect on the lifetime of machines, ensures minimal downtime and improves performance.

Customer-specific temperature solutions

Tempcontrol develops and manufactures customised and standard temperature sensors, specialising in tailor-made solutions. When a standard solution is not satisfactory, Tempcontrol helps to develop temperature sensors that fit in the process: for instance, with quick response, high accuracy, long-term stability, resistance to high or low temperatures, or resistance to high pressure, vibrations or shocks; nearly anything is possible.

The sensors come in all shapes and dimensions, from ultra-miniature to robust or very long multiple assemblies. Tempcontrol manufactures platinum temperature reference standards thermometers suitable for calibration purposes up to 400 °C, 600 °C and 720 °C.

Tempcontrol produces a wide range of temperature sensors.

Tailor-made solutions for temperature measurement.

Quality instruments

Tempcontrol started as a trading company and this mentality is still in their roots. They represent a range of quality brands of instruments for measuring, controlling and recording temperature, humidity and dew point. These brands include ASL/Wika, INOR, Ascon-Tecnologic, Kambic Metrology, MBW Calibration, Dostmann Electronic, Guissani, Novasens Sensortechnik and Weidmann.

Facilities

Based in Nootdorp (NL), Tempcontrol houses a production department, a cleanroom and a calibration and research lab where temperature sensors can be measured, optimised, calibrated and stabilised. Testing (long-term) and examination of temperature sensors is also possible.

Markets

Tempcontrol supplies to almost all industries where temperature is a critical factor: medical and food, aviation and shipping, semiconductor, plastics, defence, pharma, petrochemistry, machine and equipment construction, installation companies and laboratories, etc.

INFORMATION
WWW.TEMPCONTROL.NL

"OPTOMECHATRONICS IN EINDHOVEN IS TOP-NOTCH"

Eight years ago, DSPE started a certification program for post-graduation education in precision engineering. Three years ago, Nikolai Vasiljevic was the first one to meet the requirements for the so-called bronze certificate. The courses he took during his Ph.D. had effect on his career as well as his personal development.

JESSICA VERMEER

In 2011, DSPE launched their certification program for post-graduate education. The goal of the initiative was to enhance the offer by certifying certain courses that fit within a precision engineering program. The initiative emerged two years before that, when the Philips Centre for Technical Training was disbanded and the educational programs were splintering and partially disappearing. Dutch high-tech could not afford such a loss.

DSPE decided to map the complete offering and guard its quality by setting up a certification program. Candidates can follow certified trainings, for which they could gain points (approximately one per course day). A total of 45 points would grant the title certified precision engineer (CPE). This was later split up into a bronze certificate for 25 points, silver for 35 and gold for 45 points.

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1

Nikola Vasiljevic did his Ph.D. research in Denmark, designing, developing and testing a long-range, mobile infrastructure for atmospheric and wind energy research.

In 2016, Nikola Vasiljevic was the first to reach the bronze level. The Serbian researcher was doing his Ph.D. at the Technical University of Denmark (DTU) in the Wind Energy department. He was designing, developing and testing a long-range, mobile infrastructure for atmospheric and wind energy research. This WindScanner system, which is based on multiple scanning wind lidars, maps wind flow. Vasiljevic' background is in electrical engineering and computer science. For his Ph.D. project he was looking for a good course which would provide fundamental and practical knowledge about the motion control tuning. He felt he was lacking some of the practical aspects of what he was doing. By chance, he got to know about the courses from High Tech Institute.

High-tech industry of Eindhoven

High Tech Institute (HTI) offers the most CPE-certified trainings by far. Vasiljevic' main reason for joining his first course was the way the topic was presented. "For optomechatronics a lot of literature is available, but it is complicated to actually use it practically. The majority of courses I took did focus on the practical aspects in designing complex optomechatronic devices. That is how I always learn, i.e. by building things and understanding them through practice and then turning to books and literature for more detailed knowledge."

Since he was aware of the position of the Eindhoven region in the high-tech industry, he took his chance and enrolled in the first course at the HTI. "Optomechatronics in Eindhoven is top-notch compared to the rest of the world. Many of my friends from the School of Electrical Engineering from Belgrade University came to Eindhoven to do a Ph.D. or to work in Philips." He considers the high-tech industry in Eindhoven to be extremely healthy. "You don't often see that level of exchange between different companies. People regularly move between companies within the region, contributing to knowledge exchange.

Despite competition, there is also a certain level of openness." The first course he took, 'Motion control tuning', was a great experience. "I was amazed by the knowledge I got from those six days. The way the course was organised containing a well-balanced mix of theoretical and practical aspects of motion control tuning. That is what got me to continue and look into other courses like 'Advanced motion control tuning'."

So, following that first course, he took several additional courses. "There were other courses which appealed to me, such as 'Experimental techniques in motion control tuning' and 'Metrology and calibration of mechatronic systems'. My background is in measurement techniques, wind sensor development, and metrology, so almost the entire curriculum applied to my topic."

At his own university in Denmark, Vasiljevic would probably have had to go for a full semester course to acquire the necessary knowledge. Also, he thinks the practical aspects could not have been taught by standard academic professors. The HTI teachers come from years of experience in the industry. They built practical knowledge backed by the theory. "The university obliged me to obtain ECTS points (European Credit Transfer System, ed. note) and I was able to convert these courses into credit points."

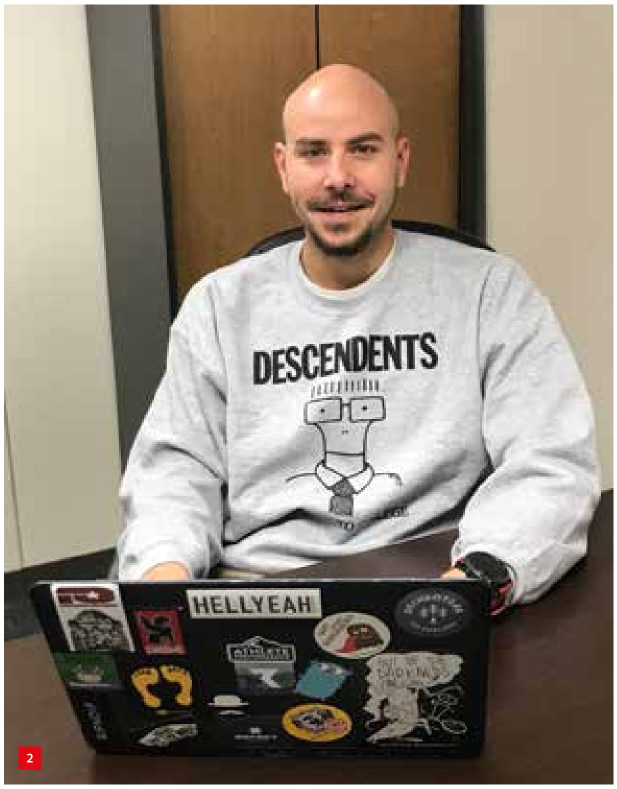
The next course he took was the Optomechatronics summer school. As a Marie Curie fellow, he had sufficient funding for continuous education, which was the main source of funding for five additional courses, which covered probably all topics of optomechatronics, except for software development.

Knowledge and networking

After obtaining his Ph.D., Vasiljevic was hoping to develop a second generation of the long-range WindScanner system. That did not happen, unfortunately. Still, the courses brought him a great deal. "Especially the networking part of the courses. I became a good friend with Adrian Rankers and Pieter Nuij, both lecturers from HTI and associated with DSPE. We keep regular contacts."

In total, the investment was comparable to what one would need for an MBA degree. "It should be a good proof of your capabilities." Vasiljevic still thinks he didn't manage to fully exploit the knowledge he gained, since he didn't develop the second generation of his tool. "Still, I improved the device with the knowledge I gained."

After his Ph.D., Vasiljevic considered finding a job in Eindhoven, but in the end did not find a good match. "Human resources like to have standardised people coming into their company. Since I do various things, from software development and optics to controlling and data science, well beyond the role of narrow specialist or system architect, it is hard to label me and put me in pre-established company moulds."



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Nikola Vasiljevic reflecting on his CPE training: "I am to be a senior researcher soon. Also, in the wind energy department, I am considered as an optomechatronic and a go-to person if there are some issues with motion systems."

Currently, he is still working in research. "Being a part of a research environment especially in the domain of technology and engineering requires you to continuously build new skills and new knowledge since it is the only way to survive in the landscape where funding is scarce. Therefore, in my opinion researchers these days are more capable and adaptable compared to pre-moulded R&D engineers, which are favourites of HR personnel."
He cannot point to a single aspect the CPE certification that is the most valuable to him. "I would say a blend of everything. Practical knowledge, making a sound foundation to continue learning by yourself. Small groups of up to 16 or 20 people, getting to know the teacher. Networking among peers."

He definitely feels the ECTS points he got from his CPE training affected his career in a positive way. "I am to be a senior researcher soon. Also, in the wind energy department, I am considered as an optomechatronic and a go-to person if there are some issues with motion systems." Looking ahead, Vasiljevic would like to put his experience in optomechatronics forward, such that one day he can take up the role of system architect and make new and exciting optomechatronic designs. “My main concern is that if not used eventually the gained knowledge might evaporate. It would be a great opportunity to get a taste of how it is to actually work in the high-tech industry. Maybe one day I will work in Eindhoven, at the heart of high-tech industry.”

European program

Building on DSPE’s successful CPE program, euspen (European Society for Precision Engineering and Nanotechnology) has introduced the ECP^2 (European Certified Precision Engineering Course Program) short-course assessment standard. The aim of the ECP^2 is to support continuous professional development in precision engineering from a European perspective. First courses from other European countries have now also been certified.

INFORMATION
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TWO PREMIERES

On 13 and 14 November 2019, the 19th edition of the internationally renowned Precision Fair, the annual meeting point for precision engineering, will be held in the NH Conference Centre Koningshof in Veldhoven (NL). At this free event, attendees can visit some 300 exhibitor stands from specialised companies and knowledge institutions, including over 50 from DSPE members. They can also take their pick from the extensive lecture programme and participate in the International Meet & Match Event. This year's fair features two premieres: partnerland Switzerland and the Young Technology programme.

Following the example of the Hannover Messe, this edition of the Precision Fair will have a partner country, which for this first time will be Switzerland. Under the banner of trade associations, Swiss precision companies and knowledge institutions will visit the exhibition, deliver presentations and participate in the exhibitors' buffet on Wednesday evening. Dutch trade fair visitors can come into contact with interesting Swiss parties, such as from the watch industry.

This year sees the inaugural Young Technology programme, set up at the request of exhibitors. Graduates, Ph.D. students and start-ups will be able to present their research and development work in three-minute pitches and poster presentations. Candidates for these pitches, which must be about precision technology and may not be commercial, have been put forward by universities of technology and exhibitors, among others.

Awards

At the end of each fair day, event partner DSPE will organise an award ceremony. On Wednesday 13 November, the Rien Koster Award will be presented to a mechatronics engineer/designer who has made a significant contribution to the field of mechatronics and precision engineering. On Thursday will be the Wim van der Hoek Award for the best graduation project in the field of design in mechanical engineering. The nominations are presented on page 61.

Mikroniek will report the highlights in its December issue.

INFORMATION AND FREE REGISTRATION
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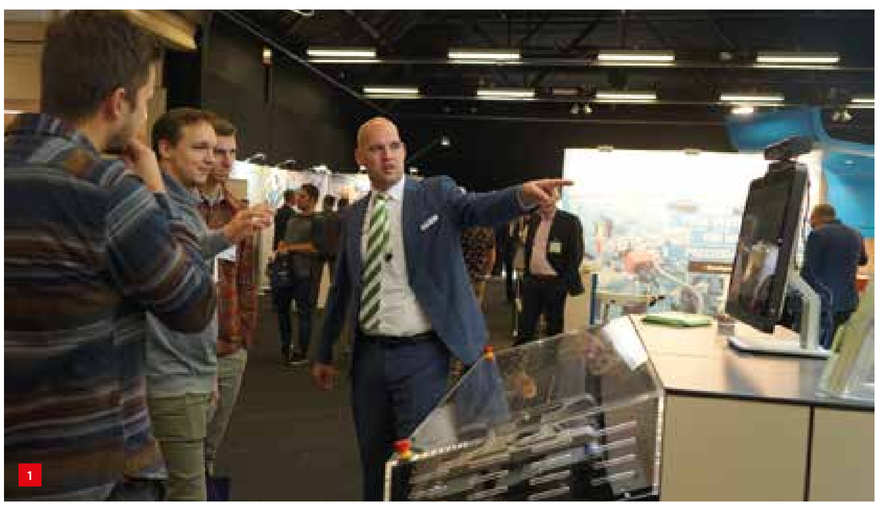
DSPE members exhibiting at the Precision Fair 2019

Stand	Number	Stand	Number
169	BKB Precision	17	Mitutoyo Nederland
64	Brainport Industries	77	Molenaar Optics
162	Bronkhorst Nederland	135	Newport Spectra - Physics
126	Ceratec Technical Ceramics	177	MTA
93	Connect 2 Cleanrooms	27	NTS-Group
130	Demcon	238	Oude Reimer
275	DSPE	43	Pfeiffer Vacuum Benelux
73	Eltrex Motion	285b	Philips Innovation Services
171	Ertec	138	PI Benelux
139	Etchform	159	Settels Savenije Precision Parts
140	Festo	104	Sioux CCM
294	Fontys Hogeschool Centre of Expertise HTSM	145	SMC
103	Frencken Europe	119	Sumipro
37	Groneman	81	Technobis Group
34	Heidenhain Nederland	50	Teesing
105	Hembrug Machine Tools	141	Tegema
40	Hittech Group	95	Te Lintelo Systems
136	IBS Precision Engineering	101	Ter Hoek
293	Inholland Delft Precision Engineering	276	The House of Technology
277	Janssen Precision Engineering	229	Thermo Fisher Scientific
292	Leidse instrumentmakers School	290	TNO
5	Maxon Motor Benelux	286	TU Delft
267	Mecal	284	TU/e High Tech Systems Center
129	MEVI Fijnmechanische Industrie	231	UCM
68	Mikrocentrum	112	VDL ETG
203	MI-Partners	19	Zeiss



1 *Impression of the Precision Fair 2018. (Photo: Mikrocentrum)*

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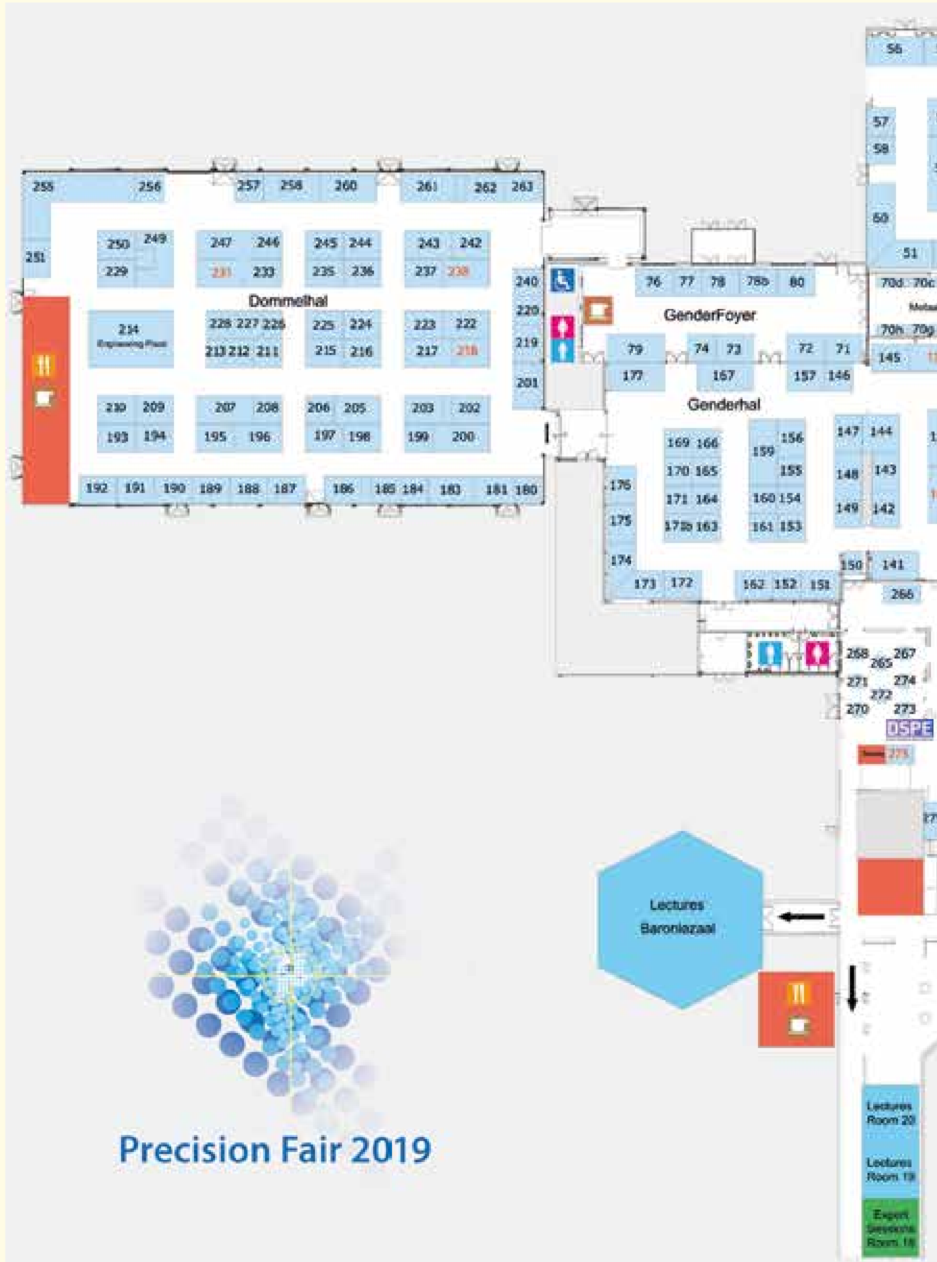

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www.pi.ws/benelux

Precision Fair 2019

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INNOVATIONS ON DISPLAY

ACE Stoßdämpfer (stand number 207)

Profile dampers now RGA-tested

ACE's TUBUS profile dampers are now RGA-tested (RGA = residual gas analysis), which makes them – in specific conditions – suitable for vacuum cleanroom applications. The dampers contain, as opposed to standard dampers, no colourants.

WWW.ACE-ACE.COM

Aerotech, (stand number 157)

IFOV – Infinite Field of View

IFOV is Aerotech's solution for the synchronisation of linear or rotary servo axes with laser scanners. It produces significant throughput improvements and eliminates stitching errors and part quality issues due to overlapped and mismatched laser processing. By combining the high dynamic capabilities of galvo scanners with the travel range of servo stages, parts significantly larger than a scanner's traditional field of view can be processed continuously with no need to stitch individual working areas together. IFOV improves processing quality as well as throughput on large parts. It also expands the working area for any galvo system beyond what is possible with optics alone, and removes the trade-off between laser spot size and available working area by extending the field of view regardless of optics selection.

WWW.AEROTECH.COM

Capable (stand number 198)

Cleanroom cable assembly production

In recent years, 'clean production' has become increasingly important in the complex market for tailor-made cable assemblies. Capable has succeeded in obtaining a NEN EN ISO 14644 class 6 classification cleanroom, which makes the producer of customer-specific specialty cables, cable assemblies and connectors one of the first companies in its sector to meet the standard. It is mainly customers in the semiconductor and aerospace industry that currently enjoy the benefits and guarantees offered by the Capable cleanroom.

WWW.CAPABLE.NL

Connect 2 Cleanrooms (stand number 93)
Bespoke modular cleanrooms

Each organisation's processes and facilities are unique, so C2C works collaboratively from its Utrecht (NL) base to develop the most appropriate cleanroom to transform production areas. Process flow is balanced with the factors that provide regulatory compliance, such as air changes and pressure differential. Through site surveys, technical support and digital modelling, a robust design package ensures the technical specification will deliver on its requirements.

A partner of Kingspan, C2C uses its Precision panels to deliver a fully flush cleanroom solution with market-leading airtightness. The integrated envelope solutions include air return panels, lighting, flooring, windows and doors. Ranging from entry level cleanrooms with a fast turnaround to full turnkey facilities, C2C has been delivering its cleanroom solutions since 2002 – working with world-leading precision technology brands such as ASML, Eriks and Microsoft.

WWW.CONNECT2CLEANROOMS.COM

Conway Nederland (stand number 183)
ConFeed

The ConFeed module is designed for feeding, singulating, orienting and positioning of bulk products. The autonomously operating module provides a well-defined takt time (down to 3.0 s), a robot working area of 400 mm x 300 mm x 250 mm, a maximum robot speed of 1 m/s and a quick and simple I/O handshake for positioning of the product.

WWW.CONWAYNEDERLAND.NL

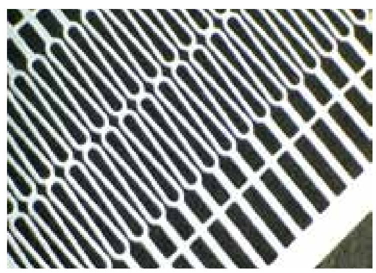
Cumatrix (Advanced Chemical Etching, stand number 02)
Aluminium etching

Photochemical etching is a subtractive method by means of which metal is removed selectively to produce the required pattern or geometry. It is characterised by its flexibility, speed, and very low tooling costs. For aluminium, however, the conventional method of etching suffers from a number of serious drawbacks that make the process inconsistent and unreliable for large volume production of high-quality aluminium parts.

Through intensive R&D work, Advanced Chemical Etching (ACE) has developed a far more consistent method for etching aluminium. The new process is more controllable and more repeatable, and it produces parts that meet much higher quality standards. It is now used on a full production scale to etch hundreds of aluminium sheets daily, and as a result of continuous improvement work over the years the yield of the process has now reached a very high level.

In the new process, control of the etching solution is achieved through a dedicated feedback control and dosing system that monitors the critical parameters of the solution and actively keeps the solution at the required level. Analysis is carried out off-line using an X-Ray Fluorescence (XRF) unit. The process also includes a new automated post-etch cleaning line, for improving the surface finish of the aluminium parts whilst also ensuring that no metallic or non-metallic contamination is present on the finished product. Complex patterns can be etched in any grade of aluminium in thicknesses from 70 μm to 2.5 mm and in sheet sizes up to 600 mm x 1,500 mm. Add to this the ease with which different designs can be etched and tested in a relatively short period of time and at a low cost, and you have a reliable and flexible process to manufacture aluminium parts from prototype to large production volumes.

WWW.CUMATRIX.COM



Gentec Electro-Optics (Te Lintelo Systems, stand number 95)
Testing laser power

Gentec-EO offers portable laser power meters.

High-power laser-based technology has changed the fundamentals of metal and non-metal manufacturing processes and has boosted the productivity of many industries by enabling high cutting speeds, high-quality edges and less energy consumption. For (automated) cutting applications it is generally used in continuous manufacturing with uninterrupted flow; a malfunction may thus affect the efficiency of the whole business. Raw laser power is the key parameter that controls the yield, combined with the assist gases and motion control system. Gentec-EO, specialised in laser beam and terahertz source measurement and analysis, offers solutions for laser power testing.

A basic laser cutting system consists of a high-power laser resonator and a laser head. First, high-power laser cavities integrated in the cutting system might lose their output power stability over time for several reasons. In kW laser systems, the performance of the laser might also decline during the cutting of high-reflective materials such as copper and brass due to the back reflection of the laser radiation through the beam-delivery path. Additionally, deterioration of the components in the laser head, such as nozzle, focusing lens or gas inlet, over time may cause performance losses.

A periodical output power test according to the production plan will help to take the relevant precautions before possible system problems occur. While testing high-power laser, it is important to use a proper power meter that can handle the laser's output power. Today, while laser output power levels increase, laser power detectors have also been revolutionised, and there are power meters that can handle tens of kW of laser output power. Besides the maximum laser output power, other crucial parameters such as laser beam diameter and wavelength also determine the proper power detector.

WWW.GENTEC-EO.COM

Mytri (stand number 125)
Precision granite

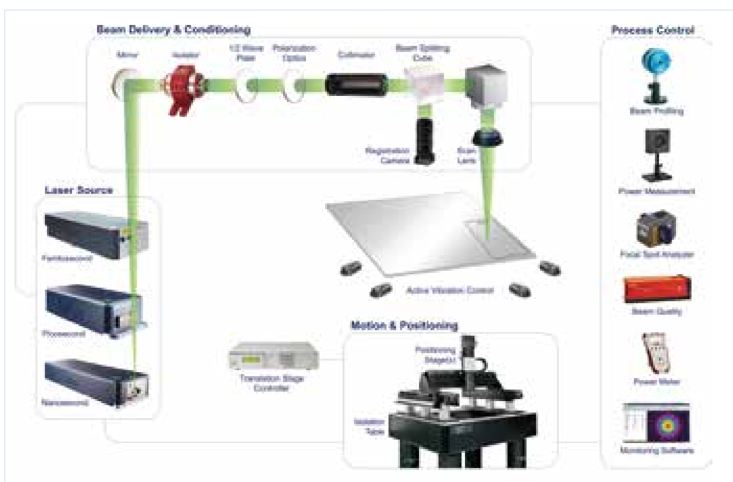
Mytri has been an established name within the precision measuring industry for over 70 years. The company produces precision granite surface plates, concentricity test benches, measuring beams, straight-edges, squares, as well as basic components for various measuring machines. The technical management has 35 years of experience in precision granite, to any measurable accuracy.

WWW.MYTRI.NL

Newport Spectra-Physics (stand number 135)
Surround the Workpiece

MKS Instruments, which integrated the Spectra-Physics, Ophir and Newport brands within its Light & Motion division, introduces its 'Surround the Workpiece' offering. This includes product design and development, system level integration, research and development, component selection and maintenance, repair and calibration services in the field of laser-based guidance and control for manufacturing processes.
Spectra-Physics combines laser technologies with deep application expertise to deliver lasers for precision industrial and scientific research applications. Ophir specialises in laser and LED measurement, including laser power and energy meters and laser beam profilers. Ophir also provides high-performance IR thermal imaging lenses and optical elements, and optics for CO_2 and high-power fibre laser material processing. Newport completes the concept with solutions including motion control, optical tables and vibration isolation systems, photonic instruments, optical and optomechanical components.

WWW.MYTRI.NL



Oude Reimer (stand number 238)
Post-EMO presentations

For many companies in the metalworking industry, the EMO trade fair last September in Hannover (Germany) was the highlight of the year. Among many others, brands like Haimer and Chiron, represented by Oude Reimer, presented their innovations at the EMO. At the Precision Fair, Oude Reimer will inform the wide precision engineering community in the Benelux and beyond about these innovations.
The Haimer Group, a leader for tool shrinking and balancing technology, showed how modern tool management works with high-quality, process-reliable components, consistent digitalisation and fully automated tool presetting using a robot cell. The basis is the high-quality product programme, which ranges from a wide variety of tool holders and tool presetting devices to solid carbide tools and sensors. All these components are bundled in so-called Tool Room solutions, a functional, ergonomic workplace design. New software that facilitates the consistent exchange of tool data finally links them to a digital Industry 4.0 system. A world premiere at the EMO was Chiron's DZ 25 P fixe axis, designed for productive machining of large components in the automotive industry and aerospace. The 25 series presents a fine combination of productivity, precision and flexibility. With a spindle distance of 800 mm, the DZ 25 P fixe axis is predestined for double-spindle machining of aluminium structural components. It is operated and loaded on separate sides, which allows ideal access to the work area and a good insight into the process. The machine only requires a small footprint and exhibits excellent dynamics performance.

WWW.OUDEREIMER.NL

Innovations presented previously at the EMO, from brands represented by Oude Reimer at the Precision Fair.
(a) Haimer DAC connects CAD/CAM, tool management, shrinking, tool presetting and balancing devices as well as the machine tool and ensures a consistent data flow up to machine tool control.
(b) The DZ 25 P fixe axis from Chiron.

Piezosystem Jena (Te Lintelo Systems, stand number 95)
SCANIUS-LINE XY-stage

The new XY-stage solution from the SCANIUS-LINE combines expertise in the field of nano-positioning with longer travel of up to 150 mm. The system is completely piezo-driven, therefore transmitting the motion directly and without friction, avoiding unwanted vibrations at high velocity. Furthermore, the system does not generate any magnetic field and there is consequently no risk of any unwanted interaction. The LC3 controller was specially developed in order to run dual-mode standing-wave piezo-motors in quasi-static or dynamic positioning applications. The piezo-motors can be controlled via PC or joystick using the integrated USB 2.0 interfaces.

WWW.PIEZOSYSTEM.COM

Prior Scientific Instruments (stand number 296)
NanoScan OP400 nanopositioning piezo objective scanner

The NanoScan OP400 provides the fastest step and settle time of any objective positioner available. Incorporating capacitive feedback sensors, it also has market-leading positioning accuracy and resolution. Compatible with most microscopes and objective lenses the system has user-configurable settings optimised for different objective sizes, weights, and performance needs. Users can select the best setting for their application.

WWW.PRIOR.COM

PM (stand number 33)
MSR miniature slide

The next generation of miniature slides, MSR, has been developed following the increasing demand for smaller, compact linear slides that are capable of moving faster and more precisely. The miniature slides are developed for maximum output in micro-assembly and pick & place machines. The MSR miniature slide can also be used in applications for repetitive small movements in tight spaces in combination with relatively high loads.

The MSR miniature slides come in six sizes and are available in different lengths and strokes, from 4 mm rail width and 5 mm stroke to 15 mm rail width and a maximum travel of 112 mm. The smallest miniature slide (4 mm rail width) has an overall height of just 4 mm and overall width of 7 mm and is 10 mm long.

All parts are manufactured from corrosion-resistant steel and high-precision cylindrical rollers are used for the bearings. The rollers are arranged in a crisscross pattern; meaning that each roller is oriented at a 90° angle relative to the one next to it, and being kept in a stainless steel cage. This design enables the slide to support loads and moments from all directions and it also contributes to high stiffness. The maximum acceleration is 200 m/s^2 and maximum load capacity is over 7,800 N.

All MSR slide variants feature an advanced and robust anti-cage creep mechanism. This retains the roller cage in position under the most demanding conditions, such as high accelerations and vertical mounting orientation. It guarantees that the stroke can always be achieved, even in the harshest environments. The miniature slides can easily be mounted into the application. They are all preloaded in-house by means of geometry pairing of the cylindrical rollers within tolerances of just 0.5 μm. This results in nearly frictionless motion with a high-precision stroke and a smooth running behaviour.

The MSR miniature slide is unique in its class. The combination of crossed-roller technology and anti-cage creep mechanism in such small slide dimensions was previously considered impossible.

PM.NL

Tecnotion (stand number 148)
QTL-A torque motor series

Tecnotion's largest, yet very compact, torque motor series to date provides a high torque density for the generated torque. The series comes in four diameters (210-230-290-310 mm) and three heights (65-85-105 mm), with or without a cooling ring. The motor features enhanced thermal management enabled by the cooling channels, which allow it to run at a high continuous torque of up to 329 Nm even in combination with high duty cycles and dynamic movement profiles. The low stack height in combination with the diameter results in a high torque density.

The brushless motor has a large inner diameter suitable for routing multiple cables through it, thereby allowing flexibility in the application. It therefore suits a wide variety of markets including rotary indexing tables, printing, material handling, packaging and laser cutting. The largest motor in the 310 series can reach an ultimate torque of up to 779 Nm. The maximum speed for the smallest motor in the 210 series is 779 rpm at 680 Volt DC.

WWW.TECNOTION.COM

The QTL-A torque motor family; left without cooling ring, right with cooling ring.

Mevi Group – system supply, engineering and high-precision machining for the high-tech industry

For over 50 years, Mevi Group has covered all the links in the high-tech industrial supply chain, supporting customers from a first concept up to and including final realisation and implementation on site. Mevi is a family-owned business with its own engineering, manufacturing and assembly facilities, and a staff of 125 people over two sites in the Netherlands, one in Belgium and one in Czechia.

Mevi's mission is to offer the high-end technology sector the one-stop shop address for machined precision parts, ranging from design and development to production and installation of advanced modules and machines.
Mevi's proposition is:
- Short time-to-market, with a high quality standard.
- A fully integral solution, from concept to proto to volume production in one flexible organisation.
- An agile organisation, with highly skilled partners and subcontractors.
- Low cost risk, large volume bandwidth, large supplier base and a success guarantee.
- Solution focus.

High-precision machining is one of Mevi's competences.

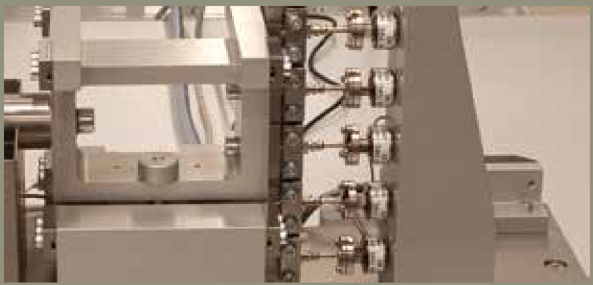
Competences
Drawing from a broad set of skills and competences, covering engineering, machining and assembly, Mevi serves a wide range of high-tech markets, including, but not limited to, semicon, automotive, medical, (aero)space and printing.

Engineering
- Solutions in the field of mechatronic and robotic automation.
- Test equipment and assembly tooling solutions.
- Precision-mechanical solutions.
- Designs according to law and regulations (CE-compliant).
- Project management.
- Siemens NX, Inventor, Ansys, Matlab, LabView.

High-tech machining
- Manufacturing of proto and volume parts and assemblies.
- 3- and 5-axis milling, turning, mill-turn machining, grinding and EDM.
- High-accuracy machining, up to 1 µm, R_a 0.05 µm.
- Quality control/measuring techniques up to 0.6 µm.

Assembly
- Assembly area of 1,400 m².
- ISO 7 cleanroom (grade-1 capable).
- High-precision gluing.
- Installation and commissioning of projects at customer's location.
- Shop floor equipped and laid out for efficient system and module assembly.

Partnership
Mevi is built on a strong belief in partnership, according to director/owner Jacco Colen. "We have a committed, flexible organisation, with a high standard of quality, and are proud of the long-term relationships we have with our customers."



Close-up of a low-force fatigue damper test, which was developed and realised by Mevi.

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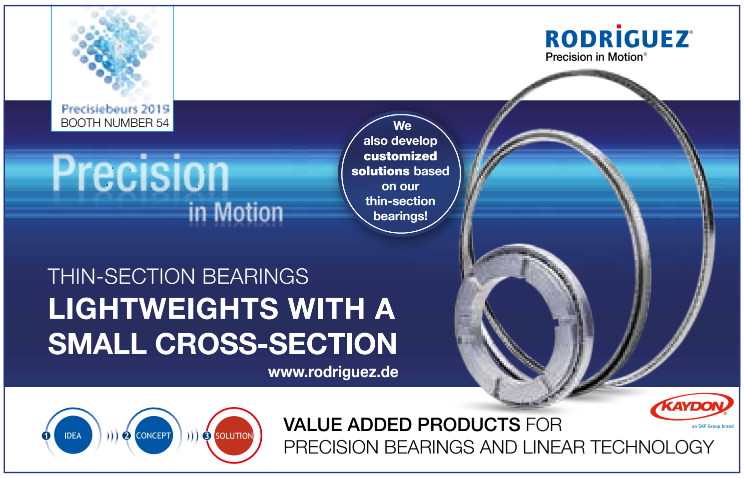
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CALEIDOSCOPIC SYMPOSIUM AND SUCCESSFUL COURSE PREMIERE

The fourth DSPE Optics Week, held from 30 September to 3 October 2019 in Eindhoven (NL), featured a symposium and a new three-day course. At the symposium, complemented by a modest exhibition, companies and research institutions from the Netherlands, Germany and China presented highlights of the design and thermo-opto-mechanical modelling of complex optomechatronic systems, such as lithography machines, 3D printers and electron microscopes. The new course for optomechanical system design, which bundled together the broad expertise of some of the Netherlands' most experienced system architects and designers, was a huge success; a new edition has already been planned.

Chairman of the day Jelm Franse, senior director Mechanical Development at ASML, opened the symposium in his characteristically relaxed style. Then he handed the floor to Paul Urbach, professor of Optics at Delft University of Technology (TU Delft), director of the Dutch Optics Centre and past president of the European Optical Society EOS, who provided the broad context for the day, presenting his views on current developments and challenges in optomechanics and optomechatronics.
One of the appealing topics he dwelt upon was the use of metamaterials in the manufacturing of optical components, for example flat lenses that exhibit no spherical aberration. "This is not so very different from diffraction optics, but metamaterials is a much fancier name."

Thermo-opto-mechnical challenges

Andrey Tychkov, sr. optical design engineer at ASML, gave a presentation on modelling the high-power laser beam delivery system in ASML's EUV source (Figure 1). The goal of modelling, he explained, is to understand the system's thermo-opto-mechanical behaviour and ultimately industrialise its operation.

DSPE Optics Week track record

In 2013, at the initiative of DSPE, the one-day DSPE Optics and Optomechatronics Symposium took place in Eindhoven. This was successfully continued in 2015 in the form of an Optics Week in Delft (NL), featuring an optics and an optomechatronics course in addition to the symposium.
To extend the scope abroad, DSPE organised the Optics Week 2017 in the German city of Aachen in collaboration with representatives from well-known German companies and institutes. In addition to the symposium and courses, there was a demonstration day at the Fraunhofer institutes IPT (production technology) and ILT (laser technology).

This year, the Optics Week returned to Eindhoven for its fourth edition. The symposium took place at Fontys University of Applied Sciences on 30 September, while from 1-3 October a new course on optomechanical system design had its premiere. The week was organised by DSPE in collaboration with RWTH Aachen University and the Fraunhofer Institutes IPT and ILT. Other partners were Brainport Industries, Holland Instrumentation, Optence, PhotonicsNL, Spectaris and Cluster NanoMikroWerkstoffePhotonik.NRW.

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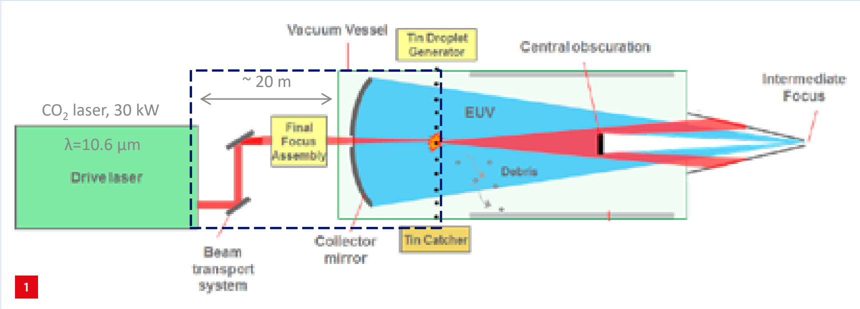
CO_2 laser pulses are fired at tin droplets to generate EUV radiation. This requires the utmost precision, as the droplets are only 30 μm in diameter and, at the impact location, are moving at a speed of 50 m/s. Therefore, any effect that



Overview of the CO_2 laser beam transport and focusing optics in the EUV source.

disturbs the laser beam should be mitigated. This includes the beam quality and alignment that is delivered by the laser, the quality and alignment of the optics in the beam transport system (about 20 m long), and thermal deformations of the optics. This last effect is not to be underestimated, as the 30-kW laser delivers a pretty high thermal load on the beam transport optics.

Tychkov described how ASML uses thermo-opto-mechanical modelling (TOMM) to come to grips with the thermal challenge the delivery system provides. TOMM comprises Zemax for ray tracing and optical analysis, Ansys for thermal deformation calculations, and Matlab for overall control of the modelling process. Laser radiation induces thermal deformations on a mirror surface, which in turn influences the radiation load (beam size, intensity profile, wavefront) on the next mirror, etc. In this way a steady state can be calculated. For transients, all mirrors have to be deformed simultaneously in the simulations, which further increases the computational effort.

Results from the simulations showed good correspondence with experimental findings. This means that TOMM can be used not only to reproduce the beam transport system for troubleshooting, but also to predict system performance for design evaluation purposes. To fit TOMM comfortably within the design process, it needs to become faster in order to do parameter scans, e.g. tolerance and sensitivity analysis.

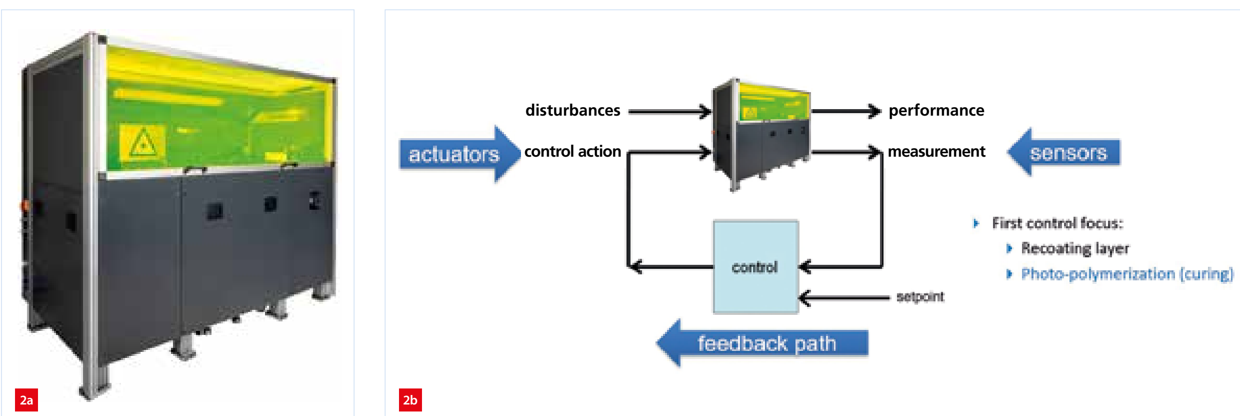
Finite-element analysis (FEA) is the most time-consuming part, but it can be sped up by using a library containing an extensive set of results based on FEA calculations of any conceivable mirror load and deformation. Then during a TOMM run, each time-consuming FEA calculation of a mirror deformation can be replaced by a result that is instantly retrieved from the library.

A next step is to integrate the various software applications into Matlab. Once all modelling is performed in one system, solvers can be applied (machine learning) to automate system diagnostics by pointing at the most probable cause of any problem with beam quality.

Curing control

Gregor van Baars, senior system engineer and project manager at TNO Technical Sciences in Eindhoven, talked about process control in additive manufacturing (AM) equipment. AM (3D printing) has been on the rise for years now, but there are still a lot of product quality and equipment productivity issues. The integration of process control strategies into AM equipment is expected to be key for improvement in these areas. This is the research topic of the Ph.D. work of Thomas Hafkamp at Eindhoven University of Technology (TU/e), whose work provided the basis for the presentation.

The AMSYSTEMS Center, a collaboration between TNO and TU/e's High Tech Systems Center, has continued the development of the Lepus 3D printer, which started at TNO. Lepus uses the VAT photo-polymerisation AM technique: liquid photo-polymer resin solidifies when irradiated with UV light. A light engine (array of laser diodes) is used for this type of UV curing.
For inline process control, Fourier-transform infrared spectroscopy (FTIR) has been used and modified to real-time monitor the concentration of monomer in the resin and hence the conversion rate in the polymerisation process during the '3D-printing'. Figure 2 shows the Lepus printer and the real-time control loop.



The Lepus 3D printer and the loop for real-time control of the printing process.

Van Baars presented first results of parameter identification and demonstrated that real-time conversion control is feasible at sub-voxel (sub-'pixel') scale, using a 'simple' PI control law. Encouraged by these early results, he expects that more advanced control will yield even better results. Future research activities will also be aimed at scaling up the control from sub-voxel to layer level, and ultimately product level.

Modern computational (opto)mechanics

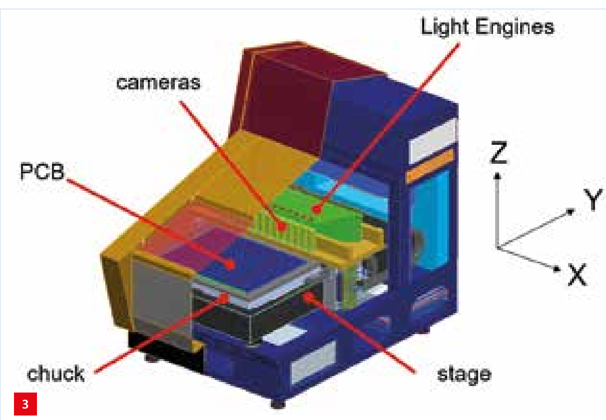
Continuing on the AM track, Fred van Keulen, professor in the chair of Structural Optimization and Mechanics at TU Delft, explained how modern mechanics can contribute to optomechanics. He focused on modern computational mechanics, which he characterised as dealing with multi-functional, either linear or nonlinear, and either static or dynamic mechanical (design) problems, and capable of the simulation of product performance as well as production.

A well-known method in modern computational mechanics is Topology Optimisation (TO), which owes its current popularity to the rise of AM. TO offers extensive design freedom resulting in complex geometries that in many cases can only be manufactured using AM. In this way, optical mounts (for example) can be designed and manufactured so that they can compensate for thermal effects in order to achieve optimal optical performance.

One of the current challenges is to include (transient) thermal effects in the nonlinear optimisation, as this dramatically increases the computational complexity. In Delft, model reduction techniques for constraining the computational burden are being explored, for example by using thermal mode-shapes to define reduced-orders models.

60,000 rpm

Fred Couweleers, senior optical designer at Hittech Multin, based in Den Haag (NL), presented a laser direct-write system for PCB production (see Figure 3) that was co-developed by Hittech Multin, Laser Direct Imaging Systems and other partners. For high throughput, the focused laser beams of the direct-write system must be moved across the PCB surface as quickly as possible. To that end, a fast-spinning polygon prism is used at 60,000 rpm for shifting the focused laser beam spots, to achieve an 8 kHz scanning frequency. This polygonal scanner is driven by a motor coupled to its spindle.



Design of a laser direct-write system for PCB production.

Early designs exhibited problems with insufficient motor power, wear caused by eigenfrequency-induced vibrations, and imbalance due to misalignment between the motor and the spindle. A new motor and controller were chosen to deliver enough torque to spin-up the spindle fast enough while the temperature stays well below the maximum allowed motor temperature. Dedicated alignment tooling was developed for gluing the various parts together. A calibration sensor was developed for measuring the position of the light engines with respect to the PCB. Preparations for dynamic balancing and the balancing itself are also important for reaching the target of 60,000 rpm. This presentation, Couweleers concluded, touched upon just a few optomechatronic details in the myriad of system design choices that make up the complete tool design.

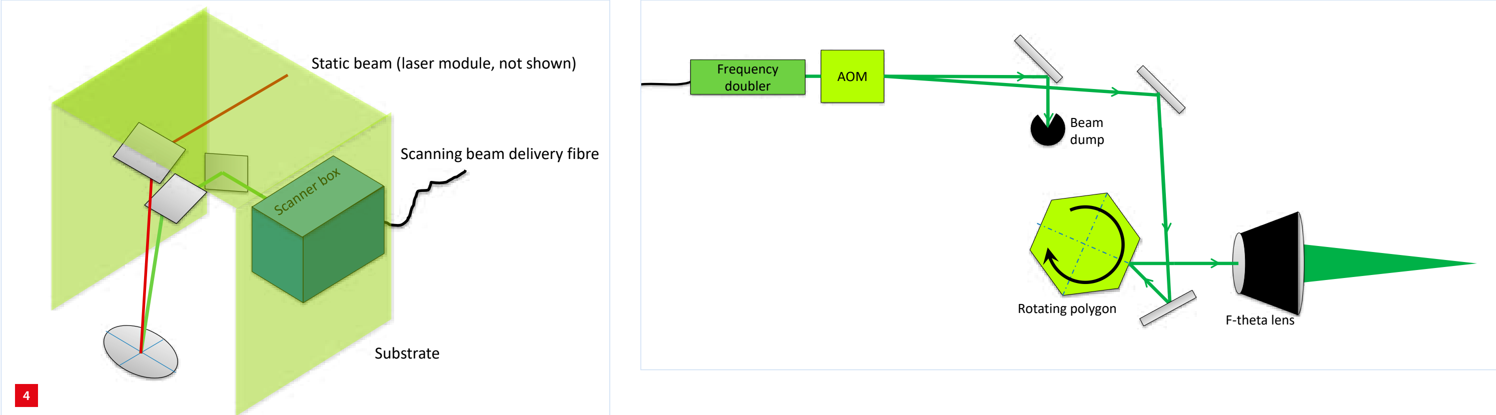
High-throughput electron microscopy

Andries Effting, CTO of Delmic, a high-tech company based in Delft that produces correlative light and electron microscopy solutions, presented the development of a high-throughput electron microscope. Electron microscopy (EM) provides high-resolution images, required for example in life sciences and material sciences applications, but it is relatively slow.

To increase throughput, an aperture array can be inserted into the electron beam path to create multiple beams. Alignment of the multi-beam with respect to the sensor (an array of pixels) is then crucial. An optical microscope, as an add-on, can assist in the alignment and ensure optimal image quality. A consortium including Delmic is aiming to push the EM acquisition speed into the gigabytes per second regime.

Productisation of optomechanical modules

Pieter Tak, lead mechanical engineer at VDL ETG in Almelo (NL), talked about the productisation of optomechanical modules for semiconductor manufacturing equipment. This concerns taking a system design from benchtop set-up or proof-of-principle to an industrial module (or machine). Productisation involves making such modules suitable for assembly, integration and service, accounting for the fact that the equipment will not be manufactured in large volumes. Given a particular system design, optimisation for manufacturing, assembly, service and thus cost is still possible, Tak stated.



General layout (left) and working principle of the scanner box. AOM is an acousto-optical modulator.

To illustrate his point, he presented the productisation case of a scanner box module; general layout and working principle are shown in Figure 4. This module is to be used for dopant activation by locally heating up and briefly (nanosecond range) melting the silicon of a wafer that is moving under two high-power laser spots (one fixed rectangular and one scanning spot).

Specific productisation issues included:

- serviceability: the desired two separable modules were not realised because of alignment risks;
- adjustability: mirror-by-mirror adjustment, as more advanced solutions could not be realised within the project time schedule;
- thermal effects: dissipation mapping executed and thermal mitigation strategy implemented;
- safety: thermal switches placed at beam failure locations.

Optical expertise plays a crucial role in this kind of project, Tak concluded, but – to his wonder as a mechanical engineer – some information is missing. “Optical products have no published mechanical tolerances”, he said.

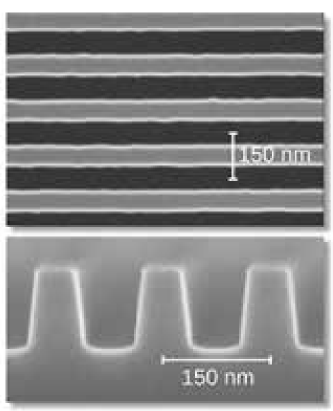
International scope

Although the Optics Week returned to Eindhoven after its excursion to Aachen two years ago, the scope was still highly international. At the symposium, the participants represented a large range of nationalities and several speakers came from abroad.

From China there was Jonee Li, head of the Optical Business unit GM at Shanghai Precision Measurement Semiconductor Technology (part of the JINGCE Group). He started with a product & technology overview of the group, which is a turnkey solution provider of inspection & metrology systems for the semicon, flat-panel display and new energy industries. As a case he presented the system design of a 300-mm integrated film metrology tool. Li claimed that it was the industry’s first ellipsometer-based integrated tool of its kind, with the additional option of a spectral reflectometer for thick-film metrology. He discussed the tight space constraints imposed on the design for inline application, the compact sensor and the polar-coordinate stage, as well as focus and alignment considerations. For example, the best focus solution was found to be ‘under the lens’, rather than triangulation or ‘through the lens’. To conclude he gave an overview of the precision-optics industry and research in China.

The final speaker at the symposium was Frank Scholze, head of the EUV Radiometry group at the Physikalisch-Technische Bundesanstalt PTB, the German National Metrology Institute based in Braunschweig and Berlin. He talked about the use of EUV (also referred to as XUV, for eXtreme UV) scatterometry/reflectometry for the characterisation of nanostructured surfaces, where thickness can be determined by interference patterns in reflectance. He showed as an example the reconstruction of silicon nanostructures produced with e-beam lithography (Figure 5).

A highly appealing application of EUV reflectometry appears in the PTB Avogadro project, dedicated to the redefinition of the SI-kilogram, using a ‘perfect’ Si crystal sphere. Here, EUV reflectometry was used to measure the thickness of the oxide layer that degrades the ‘perfection’



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Top view and cross-section of lamellar silicon gratings fabricated with e-beam lithography as prototype samples for PTB’s EUV scatterometry investigations. (Image: PTB) of the sphere. The redefinition of the kg requires an uncertainty of less than 10^{-8}. This implies the necessity to correct for the nm-thin oxide.

This talk illustrated once again the broad technological and international scope of the DSPE Optics Week symposium and concluded the extremely interesting fourth edition, as witnessed for example by the large number of questions provoked by the presentations; not even a post-lunch dip was observed. To be continued in two years.

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Optomechanical system design course premiere

The second part of the Optics Week, on 1-3 October, was filled with the Optomechanical system design course. DSPE organised this course in order to promote the importance of optomechanical system design, as no course on this topic is currently being offered in Europe. The first edition attracted a full house with some 35 participants, senior engineers as well as young talents, coming from Dutch high-tech companies as well as from abroad, including from Germany, Russia, China and Spain, which was represented by a large delegation from the Instituto de Astrofísica de Canarias, based in the Canary Islands.

The course targeted mechanical, mechatronic and optical engineers, offering a broad overview of this omnipresent multidiscipline. It contained numerous design examples that illustrated the tricks of the trade in optomechanical system design, which increasingly impacts the overall performance of high-tech systems. One of the objectives of the course was to help engineers from the various disciplines develop a common optomechanical language. The teachers were experienced system architects and designers: Lennino Cacace (AC Optomechanix and TU Delft), Pieter Kappelhof (Hittech Group), Gabby Aitink-Kroes (SRON) and Jan Nijenhuis (TNO).

The first day of training took the step from optics to optomechanics by starting with the layout of optical systems and the influence of component positioning errors on system performance, and included an exercise for the participants. Day one continued with optical concepts for optomechanical engineering and finished with tolerancing for optomechanical systems. In addition, participants were provided with the system engineering tools that contribute to optimum cooperation between the optical and mechanical engineer.

The second day was all about mechanics for optics. Subjects included the design of alignment mechanisms and the mounting of optical components with the aid of clamping or adhesive bonding. The (thermal) stability of optical systems and optomechanics under cryogenic conditions, featuring the instrumentation for astronomy, were left for the final day. The course concluded with a discussion on the exercise concerning the influence of component misalignment on system performance.

Given the huge turnout and the participants' positive reception of the course, a second edition of this special course has already been planned for March 2020 in Eindhoven. The waiting list is filling rapidly...

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Participants and teachers of the first Optomechanical system design course.


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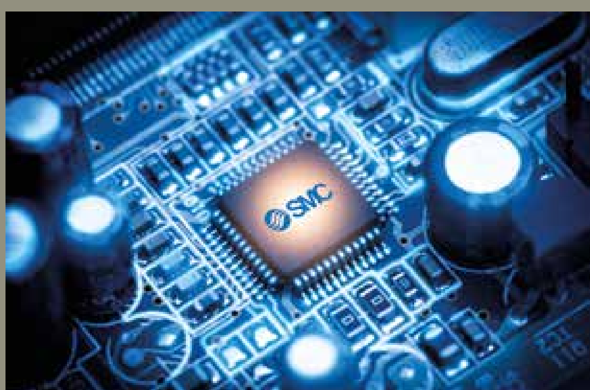
The evolution from basic pneumatics to more sophisticated automation solutions has granted SMC a global market share of more than 30%. With 12,000 basic products and over 700,000 variations SMC offers solutions from air preparation, instrumentation, through to valves, and actuators covering practically every single step in the automation process. To date there are 36 manufacturing plants worldwide, all having ISO 9001 and ISO 14001 accreditation. This ensures consistency of manufacture and ultimately a long and reliable operating life.

Semiconductor industry

One of SMC's key markets is the electronic semiconductor industry. This sector is rapidly developing new technologies to produce ever smaller and better microchips. Therefore, the production in the semiconductor industry requires the highest purity.



The electronic semiconductor industry is one of SMC's key markets.

SMC has been working closely with leading companies in the semiconductor industry for many years. Knowing what is important, SMC carries everything from heat exchangers to valves for explosive and toxic gases, and systems that can mix chemicals accurately resulting in products with a very low contamination in high-vacuum applications.

Broad portfolio

SMC's portfolio includes virtually all products for this industry:

- components for ultra-high-purity fluids and gases;
- temperature control equipment;
- valves for high vacuum;
- products for the removal of static electricity;
- products for the cleanroom;
- PFA products.

Decisive advantage

SMC's experts know this industry very well and are able to offer the right solution. They are constantly researching new products and developing technologies that become the standard for the entire industry. As a partner, SMC accepts every challenge and consistently strives to offer its customers a decisive advantage.

SMC Technology Center Eindhoven

In the high-tech electronics area of Eindhoven, SMC Netherlands operates a modern multifunctional technology center, offering industrial services close to its customers. Technology Center Eindhoven provides customised subassemblies which can also be built in the ISO 6-validated cleanroom.

Meet SMC at the Precision Fair

SMC experts are present at the Precision Fair 2019 in Veldhoven (NL) on 13 and 14 November. At booth 145 they will present SMC's latest innovations for the semiconductor industry.

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NEW DIMENSIONS IN TRAINING

The demands are high on mechanical designers. They must be able to construct well, know about various materials and different production technologies, have knowledge of the Machinery Directive, CE Marking and ISO standards, and so on. And at the customer's table, they have to make the trade-off between their technical potential and their company's commercial interests. Inventas offers a wide range of courses in these competences. A recent addition is the Model-Based Definition course, which helps designers, purchasers and production people to be in agreement about the interpretation of the latest standards for dimensions and tolerances in drawings, or rather 3D models.

Today, by far the majority of countries and companies worldwide adhere to ISO standards that are translated per country and issued in the Netherlands by the Dutch Institute NEN in Delft. These standards ensure that industry can work together worldwide thanks to a clear and unambiguous technical language. Designers in the world-leading Dutch Brainport region and elsewhere who are involved in product creation can interpret a 2D drawing or 3D model in the same way and collaborate across national borders. Market leaders such as ASML are currently looking for ways to make production drawings even more efficiently and to record product information in 3D. Component suppliers, system suppliers and the customer must understand and speak the same technical language.

1

Jos van Grinsven, founder and trainer at Inventas: "For product designs to become successful, drawings have to be unambiguous and clear, so that all parties involved – from OEMs and suppliers to training institutes – are aligned and speak the same language." (Photos: Rik van den Wildenberg)

Challenges in the Brainport region

One of the challenges for the Brainport region, says Jos van Grinsven (Figure 1), founder and trainer at Inventas, is to keep the leading position in technology. "One of the elements to achieve this is creativity, inevitably". New ideas, innovation and cooperation are important to keep our economy strong and competitive. Creative designs, good communication in the supply chain and the right commercial attitude are unavoidable.

"Let's zoom in on these three elements. Creativity, the knowledge and skills in mechanics and mechatronics give the designer the power to innovate. Good communication with specialists in electronics and software are essentials. The communication tool for the designer is the technical drawing. One condition for success is that all people involved in the supply chain understand what a drawing is about and what the symbols and designations in the model or drawing actually mean.

"The pitfall is that there is a proliferation of agreements here, as a result of which constructors, work planners, buyers and production people no longer understand what the designer actually means. As a result of this, it takes too much effort and time for a manufacturer to reach the market. For product designs to become successful, drawings have to be unambiguous and clear, so that all parties involved – from OEMs and suppliers to training institutes – are aligned and speak the same language. We can achieve this by working more efficiently, meaning a good mutual understanding for all of us."

Model-based definition

From the semicon, but also the automotive and other markets, there is a need to make a number of efficiency steps in the process from 3D design to production. For example, by

Inventas

Fourteen years ago, mechanical engineer Jos van Grinsven founded his own training institute, Inventas, in Nuenen (NL). He had always enjoyed passing on his knowledge and experience, which he wanted to further professionalise with Inventas. As a teacher of design principles, he mainly provided training at Fontys University of Applied Sciences during the first few years. He developed his own teaching materials, drawing heavily on the famous Dutch canon of (precision) mechanical design, with teachers such as Wim van der Hoek, Rien Koster and Herman Soemers.

Nowadays Inventas provides a wide range of mechanical engineering training for companies, large OEMs as well as SMEs. This is done based on in-house trainings and open registration, in Nuenen or, for example, at the Brainport Industries Campus in Eindhoven (NL). Van Grinsven works with a dozen freelance teachers who have earned their spurs in mechanical engineering practice and fully control their didactic skills.

Course participants cover all age groups, from school leavers who are immediately sent on a course by their new employer for brushing up on practical skills to senior engineers who want to improve communication with clients about their designs or learn the latest definitions for dimensions and tolerances. In cooperation with Bos Business Training, Inventas also offers orientation on leadership and management and training in consultative selling.

Design for manufacturing

The target students of Inventas include engineers at higher professional education (HBO) and university (WO) level, and nowadays also at intermediate technical (MBO) level, because due to the acute lack of technically trained employees, more and more knowledge and skills are also expected of an MBO-educated professional. Because MBO students learn in a different, more practical way, current learning materials are also made suitable for them in the training courses. Conversely, some HBO and WO students still have insufficient feeling for the feasibility and manufacturability of their designs, which is why there's paid a lot of attention to this in courses. Manufacturers must also have knowledge of manufacturing and assembly techniques.

NEN partner

As partner of NEN, Inventas trains engineers according to the latest international standards on Geometrical Dimensioning and Tolerancing. Since the standards are hard to use as training material, Inventas has translated all designations into easy to understand workbooks, with lots of practical exercises.

New developments

- Design Principles
  Jos van Grinsven and Susan van den Berg (lecturer at Fontys) are developing a new method with a workbook and a HBO-level textbook, written by Van den Berg.
- Applied Materials
  Work is being carried out with various metallurgists on a new course in applied materials science at HBO-/WO-level. Many different materials and alloys require knowledge from the mechanical designer. Therefore, dedicated training material and coaching is necessary and will be provided next year.

Course portfolio

- Design Principles
- Calculus for Designers
- Geometrical Dimensioning and Tolerancing (2D and 3D)
- Model-Based Definition
- Reading Technical Drawings
- Tolerance Analysis
- CE Marking
- Drive Technology
- Statics and Strength Theory and Practice
- Materials Science (refresher course)
- Applied Materials Science
- Finite Element Method
- Methodical Design
- Design for Manufacturing
- Dynamics and Control Engineering (in preparation)
- Orientation on Leadership and Management
- Consultative Advising for Engineers

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automating or simplifying the dimensioning and tolerancing of drawings, in any case: standardising. Mechanical design has evolved from the former 2D drawing to model-based definition (MBD). In a 3D model, the designer nowadays has to provide all information that is relevant to production; the product manufacturing information (PMI).

The challenge with the transition from 2D drawing to 3D model is that we are free to translate and rotate the model without the fixed views that we are used to on the 2D drawing. The result is that the agreements on dimensions, tolerances and other properties (such as straightness, flatness, parallelism and angular purity) that were previously associated with the notation in 2D, have become view-dependent. This is the reason why supplementary agreements have been made for, for example, shape and directional tolerances, and in some cases the meaning of existing agreements has even been changed. Most of those agreements and symbols are laid down in NEN-EN-ISO1101 and related GPS standards (Geometrical Product Specifications).

Sustainable design

But there is more in a designer's life than just standards, Van Grinsven concludes with a personal note. "Creativity together with the application of proven design principles may bring us to a higher level. Designs comprising less material and having the same or even higher strength and/or stiffness are contributing to sustainability. All resulting in cheaper constructions, requiring less raw materials and commodities, thus contributing to the sustainability our country needs so badly."

High-tech lab room

The trigger for Van Grinsven to start his own training institute was the observation that after a standard course, what is learned often sinks away quickly. Inspired by the Karin de Galan Training School, every module of a course is therefore structured at Inventas, according to:

- theory: the teacher introduces the theory in a short time;
- feedback: the teacher examines whether the students have understood;
- exercises: the students autonomously make exercises to acquire the knowledge and skills they have learned – in particular the structure of these exercises, that's the pinch of didactics.

Van Grinsven: "It's all about interaction between the trainer and the student". With this method, Inventas is as close as possible to practice. Where necessary and possible, the participants are offered study materials and practicals during a course to try and experience things for themselves. Inventas maintains contacts with numerous companies, which a group of course participants can visit, for example, to become acquainted with the practice of certain production technologies. The high-tech industry is the 'lab room' for Inventas.

Creativity and learning

For Inventas, the 'educational space' is the classroom, not the 'cloud'. Van Grinsven believes that e-learning can work well for certain disciplines, but deliberately sticks to classroom transfer of knowledge and skills for his work area (Figure 2). This is because of the group dynamics, learning from each other and exchanging experiences by interaction.
The field of mechanical design does not only consist of calculation tasks, which can be assessed as 'correct' or 'incorrect'. Creativity is an important part of the work of a mechanical engineer and that is difficult to put in an e-learning module. Feedback on creativity can be given much better in a dynamic, classroom setting, according to Van Grinsven.

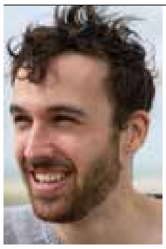
2

Inventas sticks to classroom transfer of knowledge and skills, because of the group dynamics, learning from each other and exchanging experiences by interaction.

NEW DESIGN PRINCIPLES RECOGNISED BY THE 2019 WIM VAN DER HOEK AWARD NOMINATIONS

The art of mechanical design is highly regarded in the Dutch high-tech industry. One of the founders of this discipline, Wim van der Hoek, worked for Philips's production mechanisation and was a part-time professor at Eindhoven University of Technology. While he passed away earlier this year at the age of 94, his ideas, laid down in a series of well-known mechanical engineering design principles, are still highly topical. New generations of designers build on them, as witnessed by the 2019 Wim van der Hoek Award nominations, for students who have applied existing or new design principles in their graduation work. The award will be presented on 14 November, under the auspices of DSPE, at the Precision Fair (see page 37 ff.).

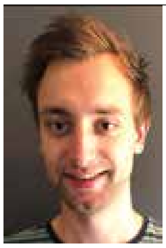
Candidates



Paul van den Hoogenhof (Eindhoven University of Technology)

Design of a thermally actuated objective lens focus system

"In his work on a lens focus system, Paul has shown competency in the mechanical design for nanometer-accurate positioning, as well as on a broader level in the full system design and integration by combining analytical modelling, simulations and experimental verification. Along with a design that more closely matches the desired operating range of the existing system, Paul has taken promising steps towards creating and controlling relatively fast thermal actuators that allow for very accurate and stable positioning. He has demonstrated good analytical skills and an ability to practically apply his knowledge to a variety of fields in an industrial environment."



Sven klein Avink (University of Twente)

Flexure mechanism with increased dynamic performance by overconstraining using visco-elastic material

"Sven has shown himself to be a multidisciplinary and enthusiastic student, who combined a good understanding of design principles and numerical analysis with an eagerness to explore the field of rubber technology. He studied a way of overcoming the limits that are imposed by the commonly used design principle of exactly-constrained design. To that end, he developed a visco-elastic material and demonstrated in a self-designed set-up how it can be used to 'overconstrain' a flexure mechanism without the usual disadvantage of overconstraining, i.e. a sensitivity to misalignments (assembly tolerances). Sven's work has the potential to lead to a new design principle in which a custom visco-elastic material is used to combine the best of both worlds, of exactly constrained and overconstrained design, respectively."

Dominic Scheffers (Fontys University of Applied Sciences)

Hybrid guide – A revolution in translation for the ultra-high-vacuum industry

"In a very short time, Dominic has mastered designing with ceramics, an art that was previously rather unknown to him, and has realised a working prototype of a hybrid straight guide. For example, he demonstrated that his design works well and meets the requirement that the correct pre-tension can easily be applied. The hybrid straight guide also has a much lower rolling resistance than the existing ceramic straight guide and it is quieter. First, Dominic made a thorough analysis of the causes of rolling resistance in the current v-groove guide. He incorporated the results into a creative design that eliminates one of the most important sources of rolling resistance. The basic principle for his design of the guide was completely new and not known from the Koster and Soemers textbooks. He reported clearly and gave a comprehensible oral presentation, during which he could demonstrate the working prototype."

UPDATE AND INVITATION: WIM VAN DER HOEK BIOGRAPHY

Following the death of Wim van der Hoek, DSPE announced that it was preparing to publish a book devoted to his life and work. The biography was to be presented at the 2019 Precision Fair in November; however, this date has turned out to be too optimistic. Due to the amount of information available, more time is required for finishing the book. Publication is now scheduled for spring 2020; the exact date to be announced.

Meanwhile, design and manufacturing companies in the field of precision engineering are invited to submit contributions featuring their views of Van der Hoek's legacy, his impact on their technology and business, and a concrete example of a construction in which one or several of his design principles have been applied successfully.

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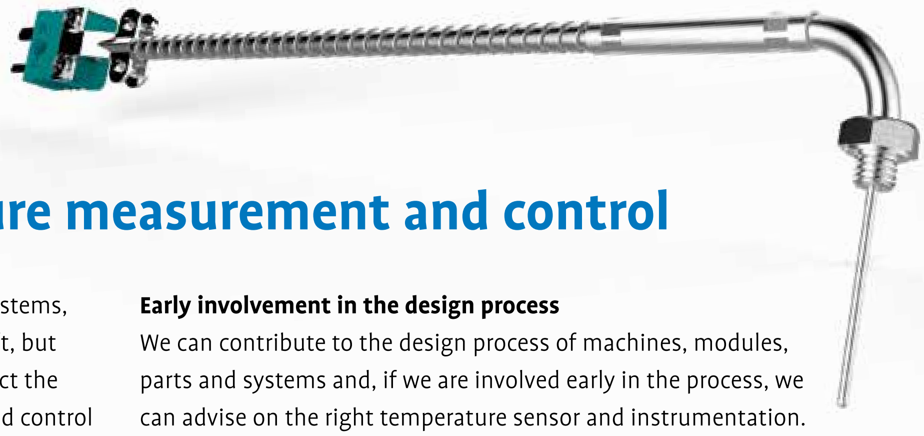


The specialist in temperature measurement and control

Temperature is an important parameter in many processes, systems, machines or parts of machines. Temperature variations or drift, but also unwanted temperature differences, can considerably affect the performance of a machine or system. Proper measurement and control of temperature in a process have a positive effect on the lifespan of machines, ensure fewer downtime and improve performance.

Customized temperature sensors

Tempcontrol develops and manufacturs customized and standard temperature sensors, specializing in tailor made solutions. With over 40 years of experience, we are always able to find the right solution for each specific application. A quick response time, high accuracy, long-term stability, resistance to high or low temperatures, nearly anything is possible.

Early involvement in the design process

We can contribute to the design process of machines, modules, parts and systems and, if we are involved early in the process, we can advise on the right temperature sensor and instrumentation.

At our location we have a production department, a warehouse, a cleanroom and a calibration and research lab. Here we develop, produce, measure, optimize, calibrate and stabilize temperature sensors and instrumentation. Testing (long-term) and investigation of temperature sensors is also possible.

In addition, we can provide high-quality instrumentation and precision measuring equipment from quality brands such as AsconTecnologic, ASL/Wika, Dostmann, Inor, MBW, Giussani, Kambic and Weidmann.

Temperature sensors in many designs

Controllers

High quality measuring equipment

Transmitters, isolators

Tempcontrol supplies to almost all industries where temperature is a critical factor: medical and food industry, aviation and shipping, semiconductor and plastics industry, defense industries, pharma and petrochemicals, machine and equipment construction, installation companies and laboratories etc. Visit **www.tempcontrol.nl/solutions** for our full product portfolio.

UPCOMING **EVENTS**

31 October 2019, Eindhoven (NL)
Digital Twin Conference
This new event from Techwatch focuses on the real-life application of digital twin technology, with a variety of use cases, from manufacturing to healthcare.

WWW.DIGITALTWINCONFERENCE.NL/PROGRAM

4-8 November 2019, Leiden (NL)
LiS Academy Manufacturability course
5-Day course targeted at young professional engineers with a limited knowledge of and experiences with manufacturing technologies and associated manufacturability aspects.

WWW.LISACADEMY.NL

7 November 2019, Delft (NL)
TNO Optical SATCOM Day
This conference features recent developments, future challenges and technology roadmaps for optical satellite communication, including high-throughput optical ground stations, free-space QKD systems, multi-beam optical terminals and integration of satcom into 5G.

INFO-OPTICALSATCOMEVENT@TNO.NL

13-14 November 2019, Veldhoven (NL)
Precision Fair 2019
Nineteenth edition of the Benelux premier trade fair and conference on precision engineering, organised by Mikrocentrum. See the preview on page 37 ff.

WWW.PRECISIEBEURS.NL

21 November 2019, Utrecht (NL)
Dutch Industrial Suppliers & Customer Awards 2019
Event organised by Link Magazine, with awards for best knowledge supplier and best logistics supplier, and the Best Customer Award.

WWW.LINKMAGAZINE.NL

27-28 November 2019, Berlin (DE)
SIG Meeting Micro/Nano Manufacturing
Meeting hosted by euspen, focusing on novel methodological developments in micro- and nanoscale manufacturing, i.e. on novel process chains including process optimisation, quality assurance approaches and metrology.

WWW.EUSPEN.EU

10-11 December 2019, Utrecht (NL)
International MicroNanoConference 2019
A wide range of technologies are presented, covering fields such as Health & Life Science, Agro & Food, Sustainability & Energy, and Manufacturing & Engineering.

WWW.MICRONANOCONFERENCE.ORG

11-12 December 2019, Den Bosch (NL)
AgriFoodTech 2019
Fourth edition of event on system design, integration and automation within the agri and food sectors, featuring innovations such as sensors, drones, robots, big data, vision technology and LEDs.

WWW.AGRIFOODTECH.NL

28 January 2020, Veldhoven (NL)
CLEAN 2020
This theme day, organised by Mikrocentrum, provides an expert's view on cleanliness. Speakers from academia and industry will present new developments, discuss process and cost optimisation, review quality control and share best-practice applications.

WWW.MIKROCENTRUM.NL

26-27 February 2020, Aachen (DE)
SIG Meeting Thermal Issues
Meeting hosted by euspen, on measurement and simulation of thermal effects as a major contributor to errors on machine tools, measuring equipment and workpieces.

WWW.EUSPEN.EU

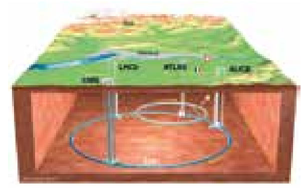
4-5 March 2020, Veldhoven (NL)
RapidPro 2019
The annual event showcasing solutions for prototyping, product development, customisation and rapid, low-volume & on-demand production.

WWW.RAPIDPRO.NL

17-20 March 2020, Utrecht (NL)
ESEF 2020
The largest and most important exhibition in the Benelux area in the field of supply, subcontracting, product development and engineering, showcasing the latest innovations.

WWW.ESEF.NL

8-12 June 2020, Geneva (CH)
Euspen's 20th International Conference & Exhibition
The event features latest advances in traditional precision engineering fields such as metrology, ultra-precision machining, additive and replication processes, precision mechatronic systems & control and precision cutting processes. This 20th edition will be a landmark event at CERN, home of the largest particle physics laboratory in the world.



CERN will host euspen's 20th International Conference & Exhibition. (Image: Philippe Mouche / CERN)

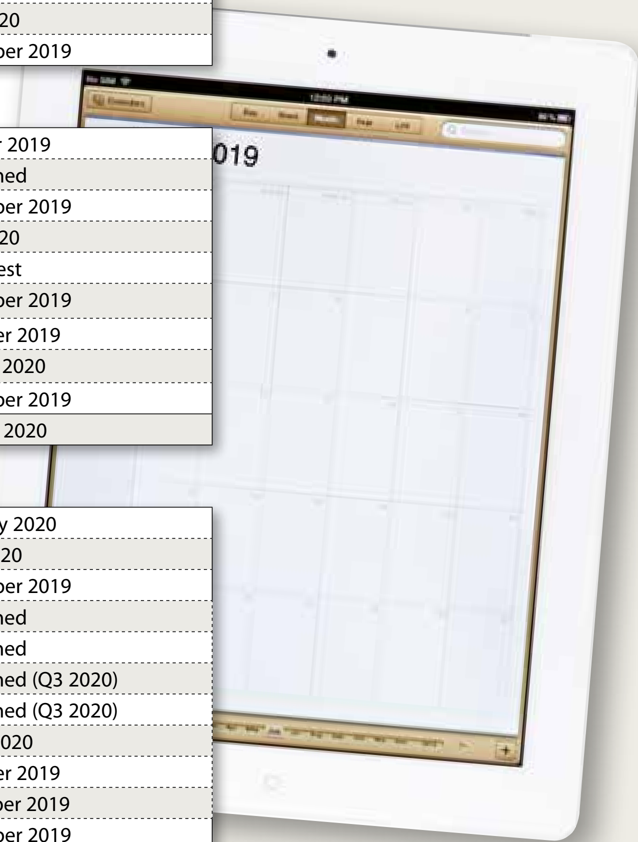
WWW.EUSPEN.EU

10-11 June 2020, Veldhoven (NL)
Vision, Robotics & Motion 2020
This trade fair & congress presents the future of human-robot collaboration within the manufacturing industry.

WWW.VISION-ROBOTICS.NL

ECP² COURSE CALENDAR

COURSE (content partner)	ECP² points	Provider	Starting date
FOUNDATION			
Mechatronics System Design - part 1 (MA)	5	HTI	6 April 2020
Mechatronics System Design - part 2 (MA)	5	HTI	4 November 2019
Fundamentals of Metrology	4	NPL	to be planned
Design Principles	3	MC	11 March 2020
System Architecting (S&SA)	5	HTI	9 March 2020
Design Principles for Precision Engineering (MA)	5	HTI	22 June 2020
Motion Control Tuning (MA)	6	HTI	27 November 2019
ADVANCED			
Metrology and Calibration of Mechatronic Systems (MA)	3	HTI	29 October 2019
Surface Metrology; Instrumentation and Characterisation	3	HUD	to be planned
Actuation and Power Electronics (MA)	3	HTI	19 November 2019
Thermal Effects in Mechatronic Systems (MA)	3	HTI	23 June 2020
Summer school Opto-Mechatronics (DSPE/MA)	5	HTI	upon request
Dynamics and Modelling (MA)	3	HTI	25 November 2019
Manufacturability	5	LiS	4 November 2019
Green Belt Design for Six Sigma	4	HI	3 February 2020
RF1 Life Data Analysis and Reliability Testing	3	HI	18 November 2019
Ultra-Precision Manufacturing and Metrology	5	CRANF	20 January 2020
SPECIFIC			
Applied Optics (T2Prof)	6.5	HTI	18 February 2020
Advanced Optics	6.5	MC	5 March 2020
Machine Vision for Mechatronic Systems (MA)	2	HTI	11 November 2019
Electronics for Non-Electronic Engineers – Analog (T2Prof)	6	HTI	to be planned
Electronics for Non-Electronic Engineers – Digital (T2Prof)	4	HTI	to be planned
Modern Optics for Optical Designers (T2Prof) - part 1	7.5	HTI	to be planned (Q3 2020)
Modern Optics for Optical Designers (T2Prof) - part 2	7.5	HTI	to be planned (Q3 2020)
Tribology	4	MC	10 March 2020
Basics & Design Principles for Ultra-Clean Vacuum (MA)	4	HTI	4 November 2019
Experimental Techniques in Mechatronics (MA)	3	HTI	10 December 2019
Advanced Motion Control (MA)	5	HTI	18 November 2019
Advanced Feedforward Control (MA)	2	HTI	to be planned (Q4 2020)
Advanced Mechatronic System Design (MA)	6	HTI	to be planned (2020)
Passive Damping for High Tech Systems (MA)	3	HTI	19 November 2019
Finite Element Method	5	MC	in-company
Design for Manufacturing – Design Decision Method	3	SCHOUT	in-company



ECP² program powered by euspen

The European Certified Precision Engineering Course Program (ECP²) has been developed to meet the demands in the market for continuous professional development and training of post-academic engineers (B.Sc. or M.Sc. with 2-10 years of work experience) within the fields of precision engineering and nanotechnology. They can earn certification points by following selected courses. Once participants have earned a total of 45 points, they will be certified. The ECP² certificate is an industrial standard for professional recognition and acknowledgement of precision engineering-related knowledge and skills, and allows the use of the ECP² title.

WWW.ECP2.EU

Course providers

- High Tech Institute (HTI)
  WWW.HIGHTECHINSTITUTE.NL
- Mikrocentrum (MC)
  WWW.MIKROCENTRUM.NL
- LiS Academy (LiS)
  WWW.LISACADEMY.NL
- Schout DfM (SCHOUT)
  WWW.SCHOUT.EU
- Holland Innovative (HI)
  WWW.HOLLANDINNOVATIVE.NL
- Cranfield University (CRANF)
  WWW.CRANFIELD.AC.UK
- Univ. of Huddersfield (HUD)
  WWW.HUD.AC.UK
- National Physical Lab. (NPL)
  WWW.NPL.CO.UK

Content partners

- DSPE
  WWW.DSPE.NL
- Mechatronics Academy (MA)
  WWW.MECHATRONICS-ACADEMY.NL
- Technical Training for Prof. (T2Prof)
  WWW.T2PROF.NL
- Systems & Software Academy (S&SA)

King Willem-Alexander officially opens Brainport Industries Campus

Earlier this month, His Majesty King Willem-Alexander officially opened the Brainport Industries Campus (BIC) in Eindhoven (NL). Brainport Industries is the platform where tier-one, tier-two and tier-three suppliers in the open high-tech supply chain in the Netherlands join forces to design, develop and manufacture leading, advanced, precise and intelligent high-tech equipment. BIC is the new location in the Eindhoven region for this high-tech manufacturing industry.

First, the King paid visits to high-tech component and system supplier KMWE, secondary vocational education institute Summa College and the Smart Industry Fieldlab Flexible Manufacturing. Then, before a crowd of 1,500 BIC employees, BIC students and guests from home and abroad, the King activated a high-tech robot to finalise a dedicated coin, later placing this coin in a special artwork, making the opening official.

The first Factory of the Future on the BIC has a size of 100,000 m^2. Here, the next generation of the high-tech manufacturing industry is trained in a state-of-the-art working and learning environment. BIC is the home front for far-reaching partnerships between suppliers, specialist companies and innovative education and knowledge institutions in the Brainport region. The campus will comprise a total of five factories.

While visiting KMWE at the Brainport Industries Campus (BIC), King Willem-Alexander talks to one of the KMWE employees. On the left is Edward Voncken, CEO of KMWE and one of the most prominent advocates of the BIC. (Photo: Frank van Beek, BIC/SDKVastgoed)

Octopus-based mechanism for the first time in OR

The LaproFlex or 'mechanical octopus', a steerable laparoscopic instrument designed for minimally invasive surgery in the abdominal cavity, has been used for the first time in an OR (operating room). Surgeons at the Haags Medisch Centrum in Den Haag (NL) are positive about the benefits that the innovative technology in the LaproFlex gave them during a gynaecological operation.

The technology behind the instrument was conceived by Paul Breedveld, professor of Medical Instruments & Bio-Inspired Technology at Delft University of Technology (NL). In fact, a report on his ideas for this technology has already appeared is this magazine - 12 years ago (P. Breedveld, "Biologisch geïnspireerde medische techniek – Stuurmechanisme voor sleutelgatoperaties", *Mikroniek* 47 (4), pp. 14-18, 2007).

Jules Scheltes, who obtained his Ph.D. in Delft in the field of medical product development and who together with Wimold Peters founded the Dutch company DEAM, has been working these past two years to market the product. Earlier this summer, DEAM received CE certification for the LaproFlex and now they are producing and selling it in Europe.

What makes the LaproFlex special is that it has a flexible tip, enabled by an ingenious steering system based on the anatomy of an octopus' tentacle, the so-called cable crane mechanism, which ensures that the scissors or grasper can be steered in every direction. Paul Breedveld and the researchers in his Bio-Inspired Technology (BITE) group have further developed this technology, which has now been globally patented, into a large number of prototypes of steerable surgical instruments.

DEAM is a spin-off company of the BITE group that develops steerable precision instruments for minimally invasive interventions. DEAM collaborates with a number of universities of technology and university medical centres. The LaproFlex is the first commercially available instrument using a cable crane mechanism and is considered to be a particularly affordable, disposable alternative to the extremely pricey Da Vinci operation robot.

Videos
DEAM Laproflex
www.youtube.com/watch?v=faZPB81RX1k

Example of the snake-like method
www.bitegroup.nl/wp-content/uploads/2015/06/Video-Tim-Krijger.mp4?_=1

The Laproflex steerable laparoscopic instrument.

WWW.BITEGROUP.NL/CATEGORY/MANEUVERABLE-DEVICES
WWW.DEAM.COM

ROS-interface in Matlab and Simulink

Last month, MathWorks introduced Release 2019b with a range of new capabilities in Matlab and Simulink. Matlab is a programming environment for algorithm development, data analysis, visualisation, and numeric computation. Simulink is a graphical environment for simulation and model-based design for multi-domain dynamic and embedded systems. The new release provides additional support of artificial intelligence, deep learning and the automotive industry.

In addition, R2019b introduces two new products in support of robotics:

- Navigation Toolbox for designing, simulating, and deploying algorithms for planning and navigation. It includes algorithms and tools for designing and simulating systems that map, localise, plan, and move within physical or virtual environments.
- ROS Toolbox for designing, simulating, and deploying ROS-based applications. The toolbox provides an interface between Matlab, Simulink and the Robot Operating System (ROS and ROS2) that enables users to compose a network of nodes, model and simulate the ROS network, and generate embedded system software for ROS nodes.

WWW.MATHWORKS.COM

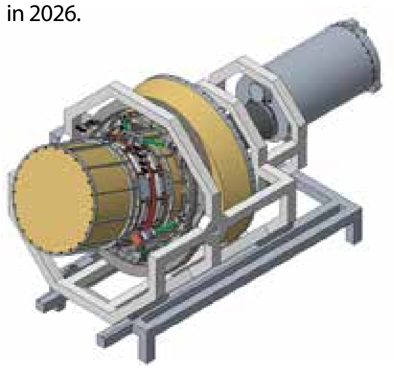
Conceptual design ready for PLATO telescope simulator

SRON Netherlands Institute for Space Research designs and builds a space simulator to test and calibrate eight out of twenty-six cameras for PLATO, the next exoplanet hunter telescope from the European Space Agency (ESA). The conceptual design is now complete. PLATO will be able to spot smaller planets in larger orbits than its predecessors. This could lead to the discovery of Earth-sized planets within the habitable zone. The telescope is even sensitive enough to measure characteristics of potential atmospheres around these planets.
The most effective method for discovering planets is to check for tiny variations in a star's brightness. This reveals a planet passing in front and blocking a bit of starlight. ESA's PLATO space telescope will use that same method, with the special feature that it monitors single stars uninterrupted for years in a row. This will allow astronomers to discover smaller planets with longer transit periods than previous exoplanet hunters. Its sensitivity will allow scientists to extract characteristics of potential atmospheres around these planets such as cloud cover and to create a catalogue for follow-up exoplanet atmospheric research.

SRON designs and builds a space simulator to test and calibrate eight out of PLATO's twenty-six cameras. SRON scientists have now finished their conceptual design. They will use the simulator to determine the size and shape of the so-called point spread function. Instead of a point of light, telescopes see a star in the form of a disk that is brightest in the centre and steeply fades towards the edge. This is due to minute imperfections in the telescope optics. In SRON's design, optics simulate a star in the sky while a radiation shield mimics the extremely low temperatures of deep space. The latter is part of another just as important test to verify the correct behaviour of the camera in space. In the end, the simulator determines if the cameras meet PLATO requirements and it provides important calibration parameters.

Because the actual flight cameras will be tested, the simulator is designed in such a way that it provides maximum safety. A single speck of dust could already lead to reduced sensitivity and false detections. "PLATO has a stringent requirement for contamination, even compared to other spacecraft, so we need to test the cameras in extremely clean conditions", says Lorenza Ferrari, SRON's project leader for PLATO. "We can only have 70 parts per million of particulates on the surface. That is 0.007%. With the naked eye you can't see under 300 parts per million."

SRON will start assembling the components for the actual simulator in August 2020. It should be ready by November 2020. PLATO will be launched in 2026.



Conceptual design of the space simulator for cameras on PLATO. (Image credit: SRON)

WWW.SRON.NL
WWW.ESA.INT

Flamingo light-sheet microscopes fitted with PI motion systems

For the ambitious Flamingo light-sheet microscopy project of the research lab around Prof. Jan Huisken at the Morgridge Institute for Research (Madison, Wisconsin, USA), Physik Instrumente (PI) supplies linear and rotary stages. The Huisken Lab is creating tailor-made optical microscopes to non-invasively explore morphogenesis and function in living organisms. The Morgridge Institute for Research is an independent biomedical institute exploring uncharted scientific territory to discover tomorrow's cures.

The PI stages are used for positioning and moving samples in the microscopes. Dr. Thomas Bocher, head of Segment Marketing Life Science & Microscopy at PI: "The use of our precision drives in the Flamingo project is a further proof of their high acceptance even in the most demanding microscopy applications." Key factors are the compact design, reliability, high precision and speed of the motion modules.

"We aim to democratise high-end light microscopy, bringing it to campuses and labs for free", explains professor Jan Huisken, co-inventor of light-sheet microscopy and director of the Medical Engineering Department at Morgridge. The project, which is supported by several sponsors, turns the idea of central research facilities upside down and makes travelling with sensitive samples obsolete. Up to now, two complete systems have been set up; for the coming months and years, Huisken and his team are planning to build several dozen Flamingo-type microscopes. The name derives from the shape of the basic version of the microscope, which resembles the bird standing on one leg.

In light-sheet fluorescence microscopy (LSFM), illumination and detection are two separate optical systems that are oriented perpendicular to each other. A laser beam is focused to form a light sheet that illuminates a thin plane within the sample. The fluorescent light that is emitted in this plane is captured and detected by an objective lens. "LSFM is a very powerful and flexible platform for gentle in-vivo imaging, offering low phototoxicity and fast image acquisition", Huisken summarises the advantages of the technology. Because of the gentle 'treatment' of the sample, LSFM is predestined for the examination of living organisms.

Compact and modular: the design of the portable Flamingo light-sheet microscope. (Image: Morgridge Institute for Research)

PI's L-505 linear stage with folded drive (left) and ultrasonic U-628.03 rotation stage are used for sample positioning and movement in the Flamingo microscope.

WWW.MORGRIDGE.ORG
WWW.PHYSIKINSTRUMENTE.COM/EN/PI-BLOG

Heidenhain at SPS 2019

Diversity enables standardisation. This will be demonstrated at the SPS 2019 trade fair, 26-28 November in Nürnberg (Germany), by rotary encoders and angle encoders from Heidenhain, AMO, and RENCO for drive control. The large variety of these encoders provides motor manufacturers as well as machine and plant producers with incomparable opportunities to adapt their drives to a wide variety of applications via the measurement technology.

For example, encoders with inductive or optical scanning, different accuracy grades, and single-turn or multi-turn functionality with identical mechanical interfaces are available for the 35-mm and 58-mm standard designs. Heidenhain's ECI/EQI 1100 and ECI/EQI 1300 inductive rotary encoders without bearing have mounting compatibility with the ECN/EQN 1100 and ECN/EQN 1300 rotary encoders with optical scanning and bearing. In practice, this means that switching from an inductive rotary encoder to an optical rotary encoder enables the robustness, overall length and accuracy to be varied according to the application. The system accuracy of a given motor can thus be improved from ±65" to ±20".

WWW.HEIDENHAIN.COM

On-machine laser scanning

Hexagon Manufacturing Intelligence is bringing laser scanning with metrology levels of precision to machine tool measurement with its new LS-C-5.8 system, designed for on-machine measuring of large freeform surfaces. The new system integrates with machine tools to create point cloud images of a part's entire surface, enabling the quick identification of fluctuations in quality and the correct alignment of a part for reworking while it is still clamped to the machine tool.

The LS-C-5.8 is a fixed blue line sensor that delivers precise results whether measuring shiny or very dark surfaces across a huge variety of applications and surface types. It combines a compact design with a large field of view so that it can be used to create point clouds on small machines and in environments where part accessibility is limited. And its software enables the comparison of the real-life part with the CAD model.

WWW.HEXAGONMI.COM

Precision business update

Aerotech
Two specialists for high-performance motion control and positioning systems, Aerotech and Micronix USA, have announced their global strategical partnership. From now on, both partners want to offer complementary precision solutions for industry and research together, in particular for high-precision nanopositioning. Aerotech manufactures high-precision motion control components and systems for laboratory and industry applications, ranging from components such as motors, controls and drives to full multi-axis systems. Micronix produces miniature adjusters with various drives (linear motor, voice coil, piezo stepper) for a wide range of applications in industry and research. The core competence of Micronix lies with manufacturing micro- and nanopositioning components for biomedicine, research, optics and various other areas.

WWW.AEROTECH.COM
WWW.MICRONIXUSA.COM

Hembrug
Danobat, part of the international Danobatgroup, has acquired Hembrug Machine Tools to strengthen its position in the field of finish hard turning and to offer customers a better and wider choice between the two complementary technologies of grinding and hard turning. Danobat is a market leader in machine tool manufacturing of grinding machines geared towards offering customised solutions. Hembrug Machine Tools, headquartered in Haarlem (NL), designs, builds and sells high-precision hard-turning machines and hybrid machines with hard-turning and grinding capacity, for which now Danobat's grinding expertise will be of use. Hembrug will also make use of Danobat's automation solutions and Industry 4.0 offerings.

WWW.HEMBRUG.COM
WWW.DANOBATGROUP.COM

Ewellix
SKF Motion Technologies, formerly part of the SKF Group, has been rebranded to Ewellix: Makers in Motion. Ewellix will exclusively focus on the development of linear motion solutions that "empower customers throughout industry to reach new heights in productivity, performance, energy efficiency and profitability." Its core areas are medical equipment, industrial automation, mobile machinery, and industrial distribution. The company has nine advanced manufacturing centres in Europe, North America and Asia, over 1,400 employees and 16 sales and customer service locations. The ambition is to "transition from being primarily a product supplier to a leading provider of linear motion solutions built around customer needs."

WWW.EWELLIX.COM

Technobis
Active Capital Company has acquired a majority stake in Technobis Group, an industrial holding based in Alkmaar (NL). The main objective of the investment is to scale-up the group and enable the accelerated roll-out of its integrated photonics solutions. Technobis develops and produces measurement equipment like crystallisation systems, for measuring the solubility properties of new drugs in the development phase. In addition, Technobis develops and manufactures turn-key medical equipment. And as a world leader in integrated photonic sensing equipment, Technobis provides sensing solutions to a range of industries such as aerospace, medical, mobility and energy.

WWW.TECHNOBIS.COM
WWW.ACTIVECAPITALCOMPANY.COM

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Festo is a leading world-wide supplier of automation technology and the performance leader in industrial training and education programs.

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Cleanrooms

Brecon Group
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E brecon@brecon.nl
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Brecon Group can attribute a large proportion of its fame as an international cleanroom builder to continuity in the delivery of quality products within the semiconductor industry, with ASML as the most important associate in the past decades.

Brecon is active with cleanrooms in a high number of sectors on:
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* Healthcare and medical devices

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Connect 2 Cleanrooms BV
Newtonlaan 115
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E info@connect2cleanrooms.com
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Developing the most appropriate cleanroom to transform your production is our passion. Our scalable and connected cleanrooms have been delivering regulatory compliance to our clients since 2002. We innovate to overcome your contamination control challenges – resulting in a new generation of scalable cleanrooms that set an unprecedented benchmark in the industry.

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TNO is an independent innovation organisation that connects people and knowledge in order to create the innovations that sustainably boosts the competitiveness of industry and wellbeing of society.

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Development and Engineering

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SEGULA Technologies Nederland BV develops advanced intelligent systems for the High Tech and Automotive industry. As a project organisation, we apply our (engineering) knowledge to non-linear systems. This knowledge is comprised of systems architecture and modelling, analysis, mechanics, mechatronics, electronics, software, system integration, calibration and validation.

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Education

LiS Leidse instrumentmakers School

Leiden school for Instrumentmakers (LiS)
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The LiS is a modern level 4 MBO school with a long history of training Research instrumentmakers. The school establishes projects in cooperation with industry and scientific institutes thus allowing for professional work experience for our students. LiS TOP accepts contract work and organizes courses and summer school programs for those interested in precision engineering.

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Sioux CCM is a technology partner with a strong focus on mechatronics.
We help leading companies with the high-tech development, industrialization and creation of their products, from concept stage to a prototype and/or delivery of series production.
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MTA is an high-tech system supplier specialized in the development and manufacturing of mechatronic machines and systems.
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Micro Drive Systems

maxon motor
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maxon motor is a developer and manufacturer of brushed and brushless DC motors as well as gearheads, encoders, controllers, and entire precision drive systems. maxon motor is a knowledge partner in development. maxon drives are used wherever the requirements are particularly high: in NASA's Mars rovers, in surgical power tools, in humanoid robots, and in precision industrial applications, for example. Worldwide, maxon has more than 2,500 employees divided over sales companies in more than 40 countries and eight production locations: Switzerland, Germany, Hungary, South Korea, France, United States, China and The Netherlands.

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FAULHABER specializes in the development, production and deployment of high-precision small and miniaturized drive systems, servo components and drive electronics with output power of up to 200 watts. The product range includes brushless motors, DC micromotors, encoders and motion controllers. FAULHABER also provides customer-specific complete solutions for medical technology, automatic placement machines, precision optics, telecommunications, aerospace and robotics, among other things.

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