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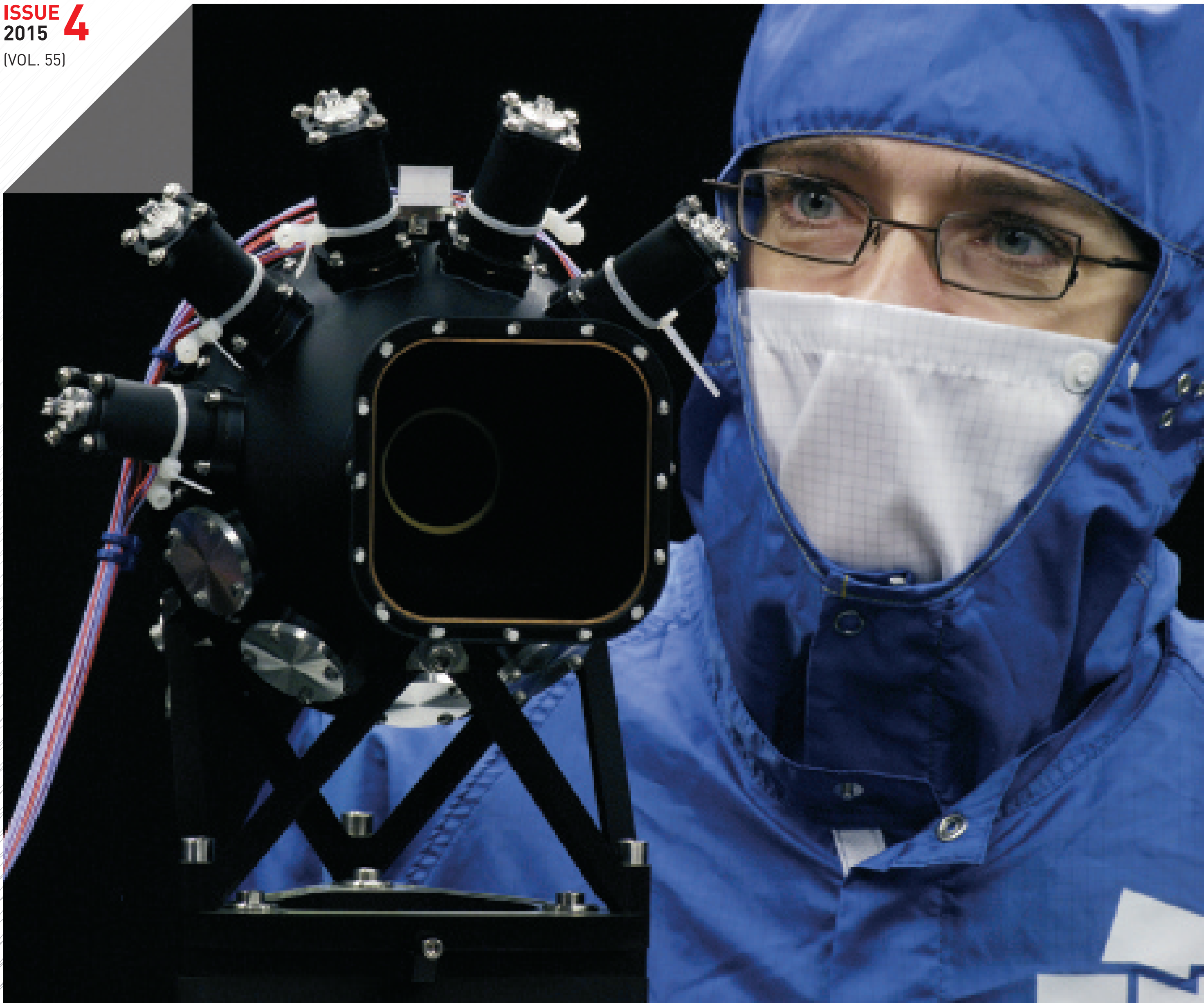
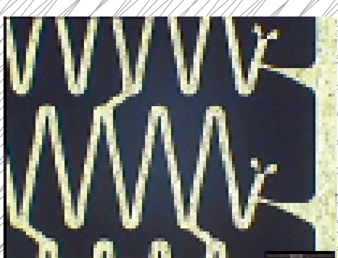
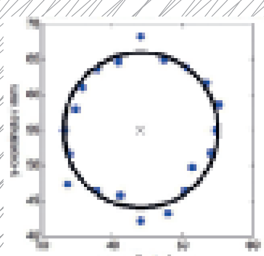
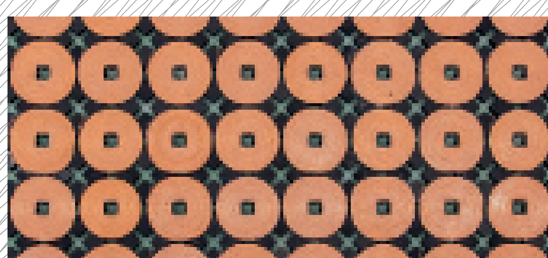
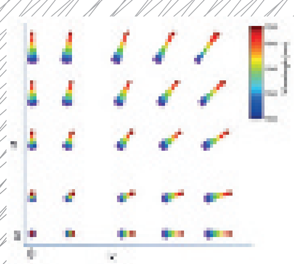


- **OPTICS AND OPTOMECHATRONICS WEEK**
- LOW-COST **SMART** SENSORS
- **ADAPTIVE** MICROMACHINING
- **CEILING** ROBOT
- LASER **MICROJET**









Mikroniek is a publication of the DUTCH SOCIETY FOR PRECISION ENGINEERING www.dspe.nl

60th anniversary

DUTCH SOCIETY FOR PRECISION ENGINEERING

DSPE Optics and Optomechatronics Week 2015

28 September - 2 October 2015
Delft University of Technology, the Netherlands

28 September – DSPE Optics and Optomechatronics Symposium + Fair
29 - 30 September - Course Optomechanics
29 - 30 September, 1 and 2 October - SMETHODS+
Trainings and Hands-on Practice on Optical Design and Simulation

Organisations are invited to exhibit September 28

28 SEPTEMBER - SYMPOSIUM + FAIR

Chairman Symposium
Prof. dr. Jos Benschop - sr. Vice President Technology ASML

Speakers who already confirmed:

Optical Metrology for micro-parts
Prof. dr. Ralf Bergmann - Managing Director BIAS, Bremer Institut für angewandte Strahltechnik GmbH

Design guidelines for stable opto-mechanics
Ir. Ruud Beerens - Senior Architect Opto-Mechanics ASML

Adaptive optics mirror
Drs. Teun van den Dool - Senior System Engineer TNO

Speckle dynamics to monitor pulsatile flow
Dr. Nandini Bhattacharya - Assistant professor Optics Group TU Delft

Spectrally resolved frequency comb interferometry for absolute distance measurement
Dr. Steven van den Berg - Research Scientist VSL

Mechanics for Light Control
Wolfgang Robra Msc. - Head Development Hittech Prontor

German industry association SPECTARIS: The top 5 themes of the Photonics members
Dr. Wenko Süptitz - Manager Photonics Association

High throughput slide scanners for Digital Pathology
Dr. Bas Hulsken, Chief Technology Officer Digital Pathology Solutions Philips Group Innovation

29 - 30 SEPTEMBER - COURSE OPTOMECHANICS (2 DAYS)

Opto-mechanics will cover subjects on optics and optics mounting alignment, dynamics and thermal stability or material stability. A wide variety of examples from space, astronomy, defense and industry will be used to clarify theory. The course will be presented by mr Daniel Vukobratovich Senior Scientist at Ratheyon as well as professor at Tucson University.

29 - 30 SEPTEMBER, 1 AND 2 OCTOBER - SMETHODS+ COURSE ON OPTICAL DESIGN (4 DAYS)

Hands-on training in design and optimisation of optical imaging systems supported by a theoretical introduction. At the end of the session, trainees will be able to specify an optical imaging system, propose the general layout, and understand the methods used to characterize its performance.

INVESTMENT (prices excluding VAT)

Symposium + Fair - Euro 175

28 September - Exhibition stand during symposium, space 8m^2, including posterwall, electricity and standing table - Euro 400.

29 - 30 September - Course Optomechanics (2 days) - Euro 790.

29 - 30 September, 1 and 2 October - Course SMethods (4 days) - Euro 1700.

INFORMATION AND REGISTRATION

www.opticsweek.nl

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TNO innovation for life
TUDelft
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Professional journal on precision engineering and the official organ of DSPE, the Dutch Society for Precision Engineering. Mikroniek provides current information about scientific, technical and business developments in the fields of precision engineering, mechatronics and optics.
The journal is read by researchers and professionals in charge of the development and realisation of advanced precision machinery.

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The main cover photo (featuring the DSPE Optics and Optomechatronics Week 2015) is courtesy of TNO/Fred Kamphues. Read the preview on page 12 ff.

IN THIS ISSUE

ISSUE 2015 4

EDITORIAL

A WEEK FULL OF OPTICS AND OPTOMECHATRONICS

In everyday life, we use lots of devices that employ optics and optomechatronics, such as a camera, binoculars, a beamer, but also the glasses on your nose. If we look at professional applications, we see plenty of optics and optomechatronics in the measurement industry, such as microscopes and interferometers, but also in space travel and astronomy. There are satellites with high-resolution cameras, stargazers such as the Hubble Telescope and the Very Large Telescope in Chile, which consists of adjustable mirrors that together form one huge mirror. Closer to home, there are the wafer scanners from ASML with optical and optomechatronical systems with nanometer precision and stability.

The system notion is important in all these developments. The disciplines of optics, mechanics and mechatronics have to work closely together to arrive at an optimally functioning system. We only achieve an optimum result if we get the utmost out of the optics as well as the mechanics and mechatronics. It must be possible to translate the perfect optical design into mechanics, and actuation must be possible via the mechatronics, but the perfect mechanical or mechatronic design must also fit the optical design.

A function is created if the parts of the design connect optimally with one another. That happens automatically if the various disciplines get in depth into each other's discipline. You then create transition zones in which you can jointly arrive at the best solution.

DSPE helps people gain in-depth knowledge of each other's discipline by bringing experts together. To do that, we have special interest groups, for example. These groups organise networking and training activities for specific disciplines. Two years ago, the special interest group of Optics and Optomechatronics started organising an Optics and Optomechatronics Symposium in Eindhoven. As follow-up to that successful event, we are now organising the DSPE Optics and Optomechatronics Week to be held at the Delft University of Technology. This will again be an excellent opportunity to meet each other.

We start the week with a symposium with lectures and a trade fair about optics, optomechanics and optomechatronics with speakers from the Netherlands and abroad chaired by Jos Benschop, VP of technology at ASML, followed by two courses in the field of optics and optomechanics. The two-day optomechanics course given by Daniel Vukobratovich is a unique opportunity to follow this intensive and practical training for optomechanical designers. The SMETHODS+ Course on Optical Design is four days of hands-on training in the design of optical imaging systems in combination with a theoretical introduction.

We work together with several organisations, such as Holland Instrumentation, the high-tech network in the Dutch province of Zuid-Holland, and our German counterparts united in SPECTARIS, the industry association for optomechatronics in Germany.

You are cordially invited to join us in the week from 28 September to 2 October.

Cor Ottens
Chairman, DSPE Special Interest Group Optics and Optomechatronics
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WORK IN PROGRESS: SMART MICROMACHINING

The European ADALAM project aims to develop a sensor-based adaptive micromachining system for zero-failure manufacturing, based on ultrashort-pulse laser ablation and a novel depth measurement sensor, together with advanced data analysis software and automated system calibration routines. The technology developed will generate new solutions for manufacturing of high-quality and innovative products, such as adaptive micromilling of 2.5D structures, defect detection and removal, and texturing of complex tool features.

GUILHERME MALLMANN, KEVIN VOSS, STEFFEN RESINK AND ALBERT BORREMAN

Miniaturisation, advanced high-performance materials and functional surface structures are all drivers behind key enabling technologies in high-end production. Ultrashort-pulse lasers have enabled new machining concepts, where the big advantages of laser machining are combined with a quasi-non-thermal and hence mild process, which can be used to machine any material with high precision.

Current laser-based machine systems for microprocessing are built on a precision motion axis combined with a scanner using galvanometric moving mirrors. An innovative machine concept is presented by the company Lightmotif (Figure 1). This system enables high-precision micromachining of different structures over workpieces from small to large sizes (Figure 2).

However, there is a significant barrier for the full exploitation of the potential process characteristics, namely the lack of a smart/adaptive machining technology. The laser process in principle is very accurate, but small

AUTHORS' NOTE

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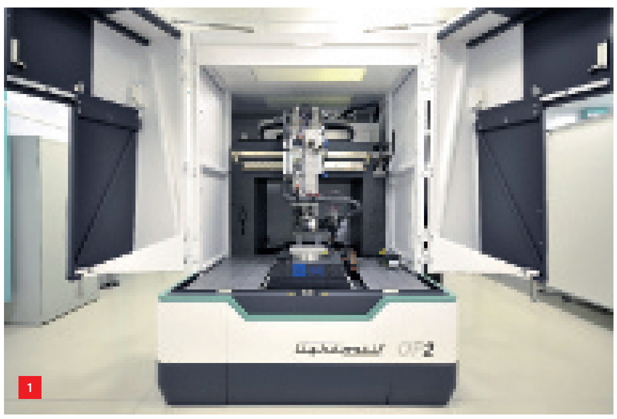

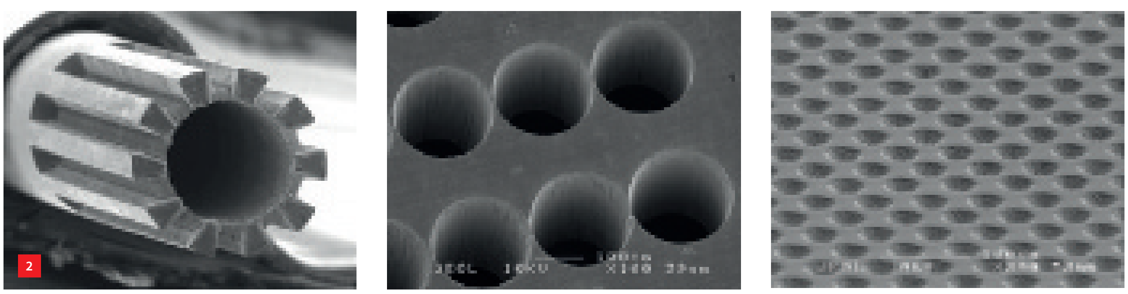

1 *Enschede-based Lightmotif, a Dutch spin-off from the University of Twente and the M2i institute, recently introduced a 5-axis laser micromachining system. The system features a picosecond laser, a 5-axis motion platform and a galvo scanner, enabling step-and-scan micromachining.*

2 *Examples, from left to right, of micromilling, -drilling and -texturing. (Source: Lightmotif)*

deviations, e.g. in the materials to be processed, can compromise the process results and the product functionalities to a very large extent. Therefore, feedback systems are needed to keep the process stable and constant, warranting an accurate result.

Objectives

In the context presented above, the ADALAM project was set up to develop an adaptive laser micromachining system using innovative feedback control. It should enable a reliable acquisition of real process information and its feedback to the machine system. Consequently, the hitherto limited machining application can be extended, being so able to adapt to variations caused for example by differences in material properties and fluctuations in the workpiece shape or laser output power.

Furthermore, it allows an accurate workpiece calibration in terms of its machine position and real shape. Because off-line measurements are time-consuming and compromise accuracy due to reclamping, the solution should be an inline measurement system that enables truly adaptive machining and does not hinder accessibility of the working area.

The complete ADALAM system will be based on ultrashort-pulse laser ablation and a novel depth measurement sensor associated with advanced data analysis software and automated system calibration routines. The sensor can be used inline with the laser ablation process, enabling adaptive processes by fast and accurate 3D surface measurements.

The first specific objective is to design and implement a complete solution for an inline topography measurement, based on low-coherence interferometry, and analysis for monitoring before, during and after the laser micromachining. Automatic point cloud analysis for smart feature detection and characterisation will produce qualified feedback to the micromanufacturing system.

Additionally, an adaptive process as well as the machine architecture and an adaptive control based on the inline measurement system will be designed. The synchronisation with the inline measuring system and data analysis software will enable processes to reach zero-failure manufacturing goals. Furthermore, the calibration of the measurement system, as well as of the complete solution (machine architecture + inline measurement system), regarding aspects such as traceability and certification will be addressed.

Applications

The adaptive laser micromachining system will be usable for a large variety of applications, each requiring a special adaptation of the control software. The system will therefore be developed in a modular approach, enabling a straightforward development of future new applications. Within the ADALAM project, three industrial end-user applications will be addressed.

In this article, the focus is on adaptive micromilling with an ultrashort-pulse laser for machining precise 3D structures into any material. It may be exploited for the production of micro-moulds, precision stamps and other tooling applications. The other two applications are defect detection and removal on workpieces, and shape recognition and texturing of complex tool features.

The sensor concept

The inline topography measurement concept (Figure 3) integrates a frequency domain low-coherent interferometer (FD-LCI) set-up in the beam path of the laser micro-machining system. The integrated sensor can be used to:

- measure the surface topography while machining a part, in order to adapt the micromachining process, leading to much higher machining accuracies and no defects;
- measure the surface topography before machining, to scan for existing surface defects that can be removed in an automatically generated machining process;

ADALAM

The European ADALAM project was set-up to deliver convincing evidence to SMEs of the benefits of the use of adaptive ultrashort-pulse laser based manufacturing systems and the monitoring and control with inline dimensional metrology as well as final quality assurance. All these goals lead to a considerable enhancement of the exploitation and usage of material and resources and the consequent generation of high-quality final products.

This Horizon 2020 project runs from 2015 to 2017 and is being coordinated by Unimetrik, a Spanish metrologic service company and calibration laboratory. Within the project one working group concentrates on the development of the inline high-precision measurement system under the coordination of the Fraunhofer Institute for Production Technology IPT in Aachen, Germany. Contributors include the Spanish companies Unimetrik and Datapixel, the German company Sill Optics, as well as the Dutch companies Demcon, Focal and Lightmotif.

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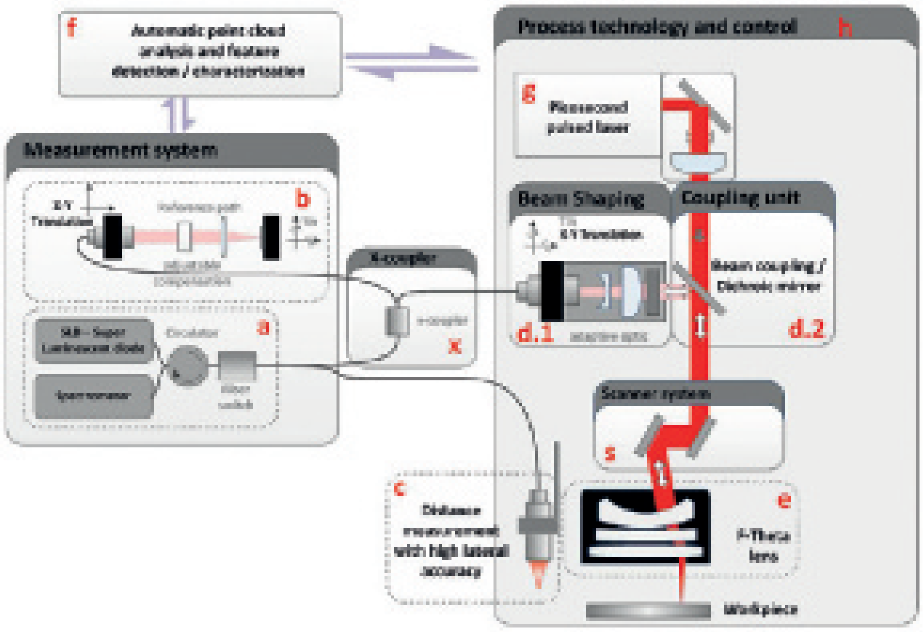

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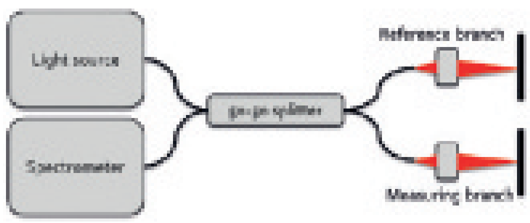
a. Spectral domain low-coherence interferometer
b. Automatically adjustable reference path system
c. External distance measurement sensing head with high lateral accuracy
d.1 Beam shaping unit for adjusting the measurement beam
d.2 Coupling unit for coupling the measurement beam into the laser beam
e. F-theta lens
f. Software for an automatic point cloud analysis and feature detection/ characterisation
g. High-power picosecond-laser source – switchable pulse length/synchronisation
h. Integrated adaptive laser micro-machining system
s. Optimised scanning objective with enhanced numerical aperture and lateral accuracy
x. Fibre-optic splitter



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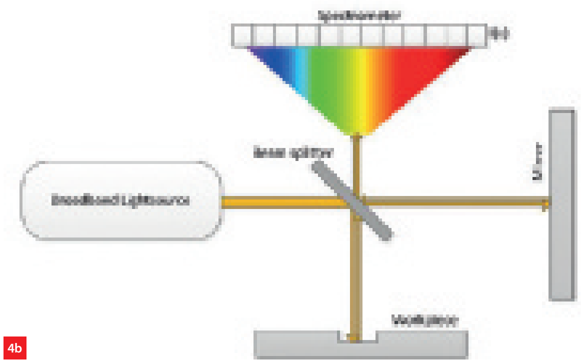


4b

- measure complex shaped objects prior to machining, to precisely align the machining pattern to the workpiece;
- quickly validate results after machining.

Interferometry principle

The low-coherence interferometry (LCI) solution is based on a Michelson interferometer set-up (Figure 4) [1]. The difference with normal low-coherence interferometers, which use a piezo element to find the maximum interference point, is that the depth/height information is gained by analysing the spectrum of the acquired interferogram.

The calculation of the Fourier transformation of the acquired spectrum provides a back reflection profile as a function of the height. (In the time domain, time of flight corresponds to distance covered, i.e. the measured height.) For the generation of the interference pattern a measurement and a reference path are used, where the optical path difference between these arms is detected.

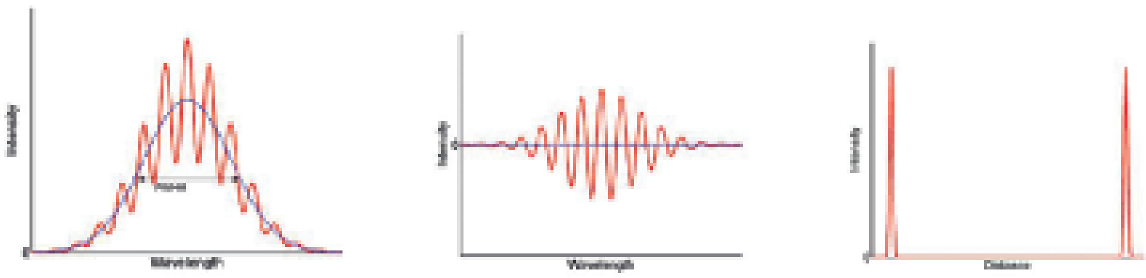
3 Conceptual design of inline topography sensor in a laser micro-machining system.
4 Michelson interferometer set-up.
(a) Schematic.
(b) Principle, showing the light paths, with the reference arm on the right (beam splitter to mirror) and the measuring arm below (beam splitter to workpiece).

Increasing the optical path length difference will result in more spectral modulation.
Figure 5 shows the signal processing for translating the measured spectrum into a distance measure. From the measured signal the unmodulated 'background' spectrum is subtracted. A Fourier transform of this shows two peaks, one being the mirrored version of the other. The next step is performing a Gaussian fit on one the peaks in the Fourier transform to obtain subpixel accuracy. The position of the fitted peak is a simple linear function based on the centre wavelength used and the path length difference.

The axial resolution for tomographic measurements and the FD-LCI measurement range when using a Gaussian-shaped light spectrum are given by [1]:

$$z_{resolution} = 0.44 \cdot \lambda_0^2 / \Delta\lambda$$

$$z_{range} = N/(4n) \cdot \lambda_0^2 / \Delta\lambda$$



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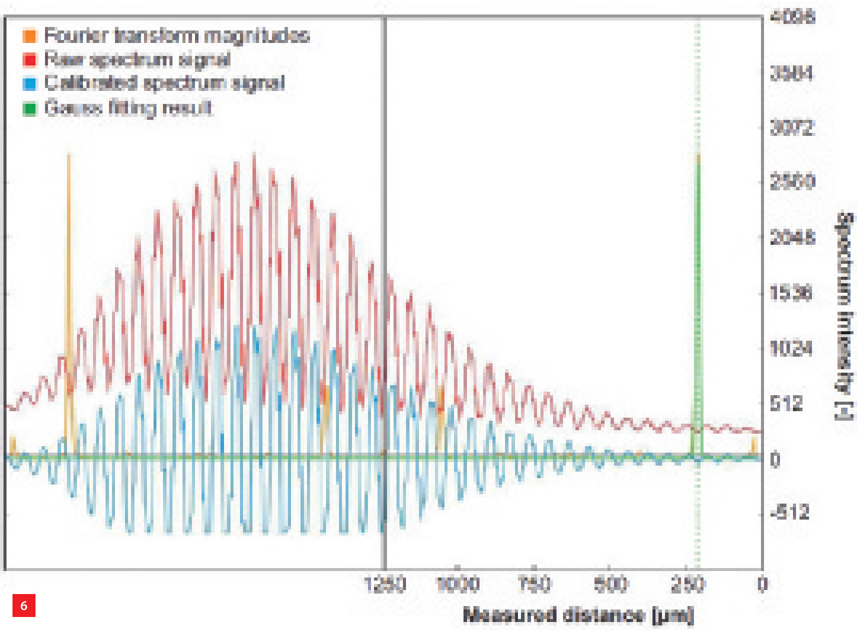

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Here, λ_0 is the centre wavelength, and $\Delta\lambda$ the FWHM of the light source. N is the number of pixels of the detector, and n is the assumed average sample refractive index.

In applications with just a single reflecting surface, a polynomial fitting over the Fourier transform-generated reflection peak leads to a sub-pixel accurate depth measurement. This calculation is represented in Figure 6.

The first generation sensor

Previous to the ADALAM project, the Fraunhofer IPT developed an FD-LCI set-up as an inline topography sensor to be used and integrated into laser structuring systems [2]. Figure 7 shows the complete solution, Figure 8 displays a representative topography measurement result. The results obtained were very promising, providing the starting point for the ADALAM project.

5 *Processing of the LCI signal into a distance measure. From the measured spectrum (a) the background (blue) is subtracted (b). The result is then Fourier transformed to a distance measure and its mirror part (c).*

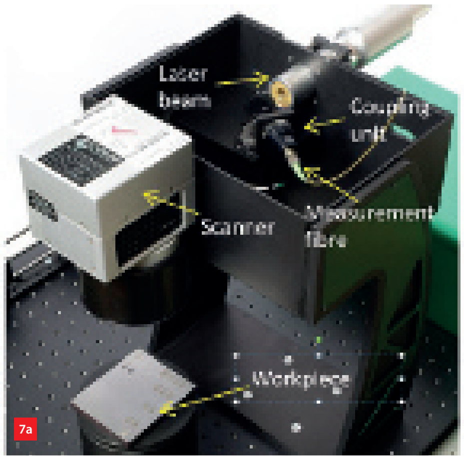
6 *Signal processing in the frequency domain (interference signal with (red) and without (blue) background) and in the time domain: back-reflection profile as a function of depth (orange); peak detection and distance determination (green).*

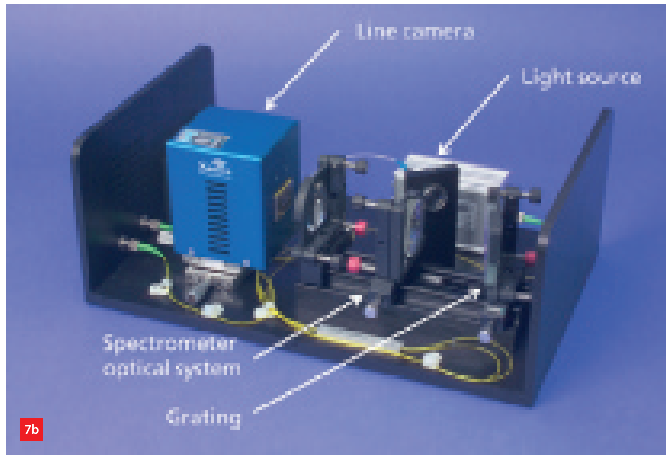
Within the ADALAM project, the inline measurement system will be based on the existent measurement system concept from the Fraunhofer IPT. An optimised unit will be developed and integrated in a laser machining system from the company Lightmotif. The first system integration will be implemented for a set-up using an infrared laser source and a telecentric scanning lens.

The machine set-up specifications (e.g. laser wavelength and optical path) determine the development scope for the adaptation and optimisation of the measurement system. The coupling of laser and measurement beam is achieved using a dichroic mirror, which reflects the laser beam and transmits the measurement beam. For this reason both beams are composed of light from a different wavelength range.

Challenges

One of the biggest challenges within the ADALAM project is the required accuracy and repeatability of the manufacturing process. These requirements lead to very tight axial and lateral tolerances for the measurement system. Especially the required lateral accuracies, under 10 µm, demand special developments on the measurement system and on the optical system of the laser processing machine. The large shape and feature variations of the workpieces to be manufactured, including large variations in reflection, before and after the process represent further challenges.
Laser micromachining units use mostly telecentric scanning lenses, also called telecentric f-theta lenses. Such a lens is optimised to improve the process robustness by enabling a constant focal plane as well as generating a linear correlation between scanner angle and surface position [3]. To reach these specifications the lens is optimised for the laser wavelength, which inherently leads to optical aberrations for other light beams with a different wavelength. As a consequence, a series of optical effects influence the measurement beam, which need to be analysed and corrected.





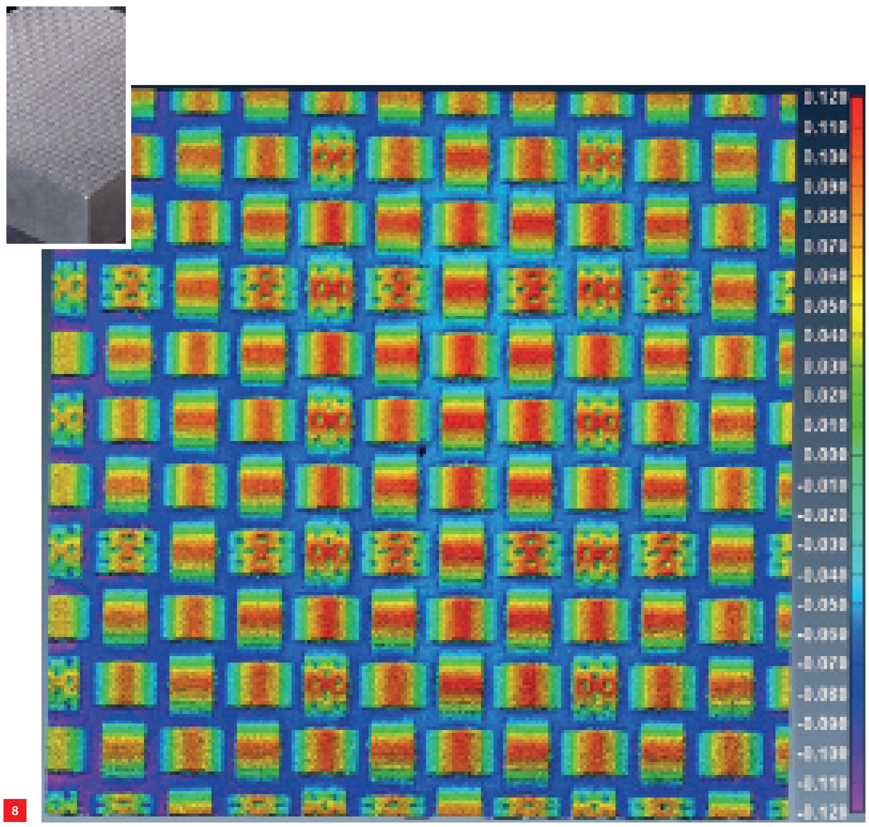
7 *The FD-LCI system implemented at the Fraunhofer IPT.*
(a) Micromachining set-up with inline depth measurement.
(b) The measurement system unit unveiled.

Besides these aspects, there are challenges involving the influences of the mechanical set-up on the measurement beam itself, e.g. due to the machine's moving arm. The vibrations induced by this arm can introduce all kinds of unwanted optical path variations, caused by polarisation changes or length variations.

Aberrations

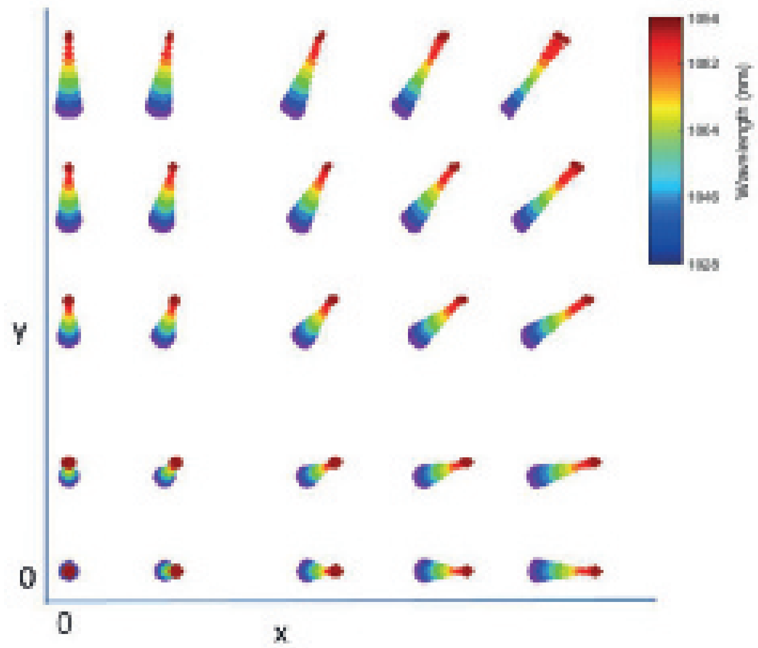
To obtain, using a telecentric f-theta lens, the smallest spot size for the measurement beam and consequently the best lateral accuracy, all the wavelengths need to be focused on the same position and on the same focal plane. To satisfy the telecentric condition the scanning mirror needs to be placed at the Fourier plane of the lens, which is located at the focal length distance in front of the lens.

A typical f-theta lens is optimised for a single wavelength. However, in this application the lens will have to handle a wide spectrum including both the laser and the LCI beams. Typically, optical glasses present dispersion issues (wavelength dependency of the refractive index) when working with a wavelength range (non-monochromatic light). As a consequence, the f-theta lens has a wavelength-dependent focal length. Furthermore, the level of telecentricity varies as well with the beam wavelength. Therefore, a beam that differs in wavelength from the 'optimal' value is expected to have a variation in position and focal plane with respect to the target laser wavelength. This has a deteriorating effect on the LCI spot size and shape, as well as on the lateral measurement resolution. Secondly, due to the curved shapes of the glass components of a lens, the amount of accumulated dispersion will vary with the scan position. This also affects the measurement beam, leading to an effect on the recorded LCI signal.



8 *A topography measurement of a workpiece (shown in the inset) obtained with the Fraunhofer IPT FD-LCI system, used to validate its machine integration. Relative height range from –0.12 mm to 0.12 mm.*

The reference arm is designed to match the position-related dispersion of the lens. Within the ADALAM project an optimised telecentric f-theta lens is in development by Sill Optics to minimise the optical aberration over the measurement wavelength range. However, such an optimised lens alone is not sufficient for the more demanding applications. Any remaining aberration errors need to be corrected by the adaptive optics.



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9 *Initial simulation results of the spot quality for a typical f-theta lens as a function of the position in the scan field (30 x 30 mm). The relative dimensions of the spots are exaggerated for illustration purposes. The legend in the upper right corner features the wavelengths.*

Adaptive optics

As mentioned, the implementation of an FD-LCI sensor in a micromachining system poses several challenges, two of which require the implementation of adaptive optics:

- Aberrations on the measurement spot introduced by the f-theta lens.
- Changes in reflectivity due to workpiece variations.

The first challenge is met by the adaptive optics of the beam shaping module (Figure 3, d.1). This module will be able to adjust the measurement beam's position, angle, diameter and divergence such that, after passing the f-theta lens, it will be at the desired location with the desired shape. Therefore, this module has a high number of degrees of freedom (DoFs), all of which need to be controlled at bandwidths similar to the measurement frequency, i.e. in the order of several kHz.

A typical solution for such a module that compensates the most important (apart from chromatic) aberrations would be a microelectromechanical system (MEMS) with mirrors. However, because the beam diameter is large (> 10 mm), the mirrors also need to be large, which precludes a MEMS. Within ADALAM a large mirror/lens mechatronic system is currently in development which can meet the combined demands of a high number of DoFs, a high bandwidth and a relatively large mirror/lens size and mass.

The second challenge is met by the adaptive optics of the reference path (Figure 3, b). Workpiece reflectivity can change abruptly from almost fully reflective to almost non-reflective between one measurement location and the next. Therefore, the adaptive optics in the reference path need to be able to maximise the LCI signal, again requiring a system with a bandwidth in the kHz range.

An additional challenge is that the reference path reflectivity not only needs to be optimised to match the workpiece reflectivity, but that it also needs to determine the workpiece reflectivity first in order to define the control input. This increases the requirement on the speed of the system even further. Within ADALAM, several concepts have been developed by Demcon for this system and will be validated on a custom test set-up.

The adaptive optics currently being built by Focal comprise a large number of actuators which utilise inputs from a wide range of sensors (e.g. cameras, encoders), calibration data and system estimations. Specialised algorithms for controlling these adaptive optics are being developed.

Simulations

Simulations were performed to estimate the spot quality for a typical telecentric f-theta lens as a function of scan position. The initial results (Figure 9) show that the spot shape depends strongly on the scan position ('smearing') and that the long wavelengths are positioned further from the centre of the scan field. The spot in the upper right corner displays the maximum 'smear', approx. 70 μm. Taking into account the diffraction limit of the system, the effective smear is nearly 100 μm, which is about four times worse than the diffraction limit itself.

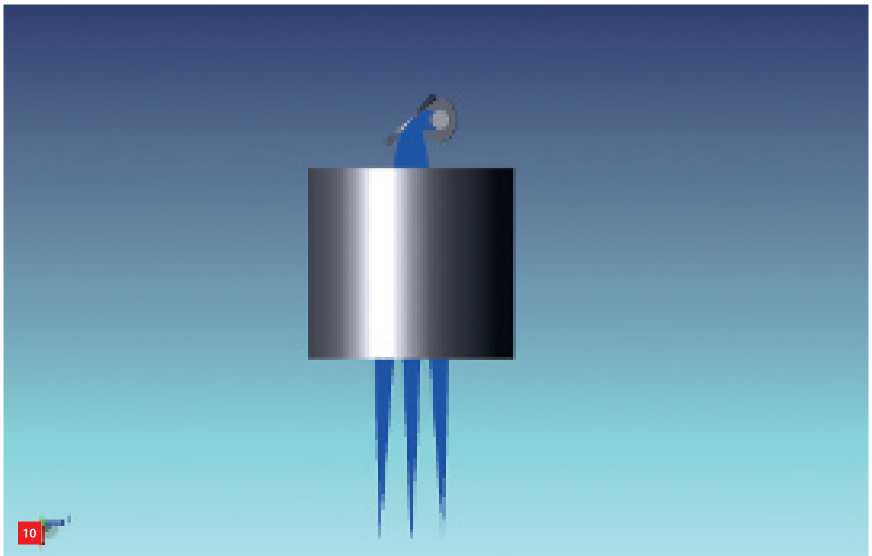
The 3D representation of the simulation results (Figure 10) shows that shorter wavelengths (blue) are focused on a different plane (negative z position) than the longer milling laser wavelength (1,064 nm). Furthermore, the lateral position of the focal spot differs slightly for each wavelength.

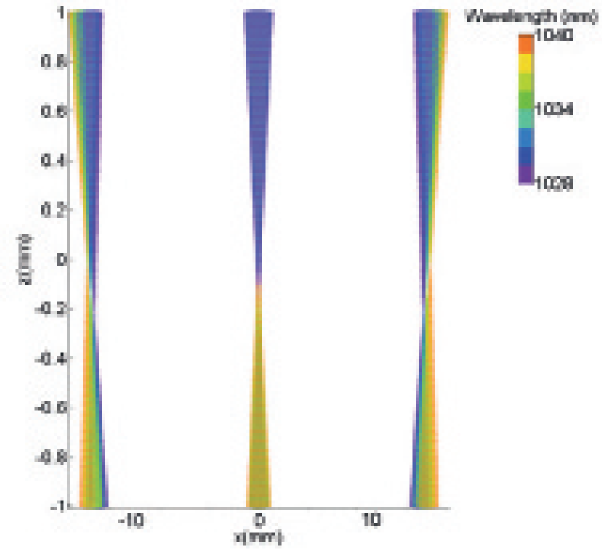
The impact of these aberrations on the measurement resolution affects, however, initially only the lateral accuracy as well as the light coupling. Consequently, it affects the detection of surface features with small lateral shape changes. This effect varies with the type of scanning lens used and therefore needs to be evaluated for every optical set-up.

Further work

Based on the previous results, the design and implementation scope within ADALAM encompasses:

- An optical high-precision distance measurement system optimised for the ultrashort-pulse laser characteristics (high power and ultrashort pulse duration), machine optical system and process axial and lateral tolerances.





- An optimised scanning objective with enhanced numerical aperture and lateral accuracy (reduced laser and measurement spots) as well as reduced focal depth and chromatic aberration regarding the measurement beam wavelength.
- An active alignment unit for beam coupling and sensor integration based on adaptive optics.
- Automatic point cloud analysis software for feature detection and characterisation for the generation of qualified information.
- Evaluation and calibration methodology to ensure high-fidelity and reliable data.

In some cases, for example when determining not only the height but also the shape of a defect, the lateral resolution of the inline measurement system may not be sufficient. Additionally, for maximum lateral resolution, a sensing head with high numerical aperture (NA) will be developed and attached to the machine scanning unit bypassing the machine's built-in optics of the scanning head (Figure 3, section c). The measurement system device will address both sensing paths using an optical switch, being able therefore to measure through the processing optics as well as through the high-NA sensing head.

Finally, the prototype of the inline measurement system will be integrated in a laser micromachining platform for further testing and evaluation. ■

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[2] Schmitt, R., Pfeifer, T., Mallmann, G.F., "Machine integrated telecentric surface metrology in laser structuring systems", *Acta Imeko* Vol. 2 Nr. 2, pp. 73-77, 2013.
[3] Furlong, B. et al., "Scanning lenses and systems", *Photonik international*, no. 2., pp. 20-23, 2008.

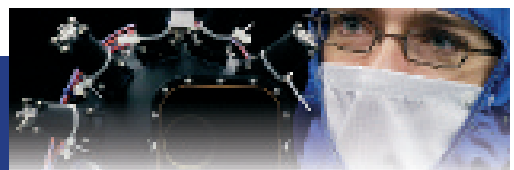
10 *Simulation results for three beams imaged by the f-theta lens (on the left, shown here as a black box), in the centre and two (mirror-symmetric) off-centre positions, respectively. The 3D representation (on the right) shows the effect of dispersion and the shift in position and focal plane of the spot.*

UNIQUE OFFER WITH A SYMPOSIUM AND TWO COURSES

The first Optics and Optomechatronics Week will be organised from 28 September to 2 October 2015, opening with a symposium at Delft University of Technology, the Netherlands. The event, which features a unique collaboration between Dutch and international organisations, comprises a symposium and two courses. The week brings outstanding speakers and lecturers from semicon to medical, from industry to academia, from Europe and abroad, presenting the latest trends and high-tech details.

DUTCH SOCIETY FOR PRECISION ENGINEERING

DSPE Optics and Optomechatronics Week 2015
28 September - 2 October 2015
Delft University of Technology



WWW.OPTICSWEEK.NL

The programme of the first Optics and Optomechatronics Week features three events:

- *28 September*
  DSPE Optics and Optomechatronics Symposium + Fair
- *29-30 September*
  Optomechanics course
- *29-30 September, 1-2 October*
  SMETHODS+ course on optical design

Symposium

The DSPE Optics and Optomechatronics Symposium is the second edition of the bi-annual event, which kicked off successfully two years ago in Eindhoven, attracting over 150 engineers. The target group includes engineers who can learn about the latest developments, managers who can get a quick overview of trends, and sales managers looking for new opportunities. Chairman of the day will be Prof. Jos Benschop, Senior Vice President Technology, ASML. The venue is the Aula Conference Centre in Delft.

Programme

Prof. Ralf Bergmann
Managing Director, BIAS (Bremer Institut für angewandte Strahltechnik), www.bias.de
Optical metrology for micro-parts

Optical metrology is a key technique when it comes to precise and fast measurement with a resolution down to the micrometer or even nanometer regime. Following an overview of optical metrology techniques, the rapidly emerging field of Computational Shear Interferometry

INFORMATION AND REGISTRATION

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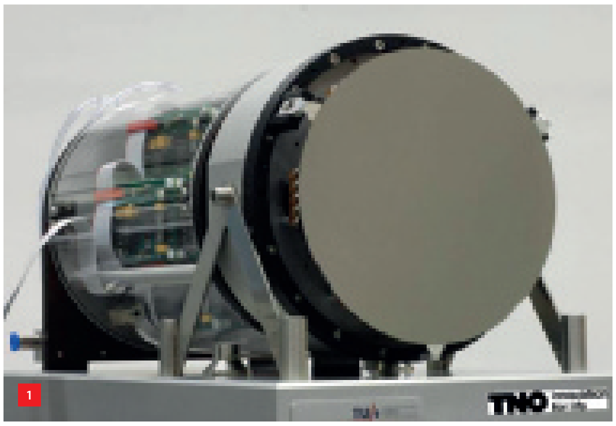
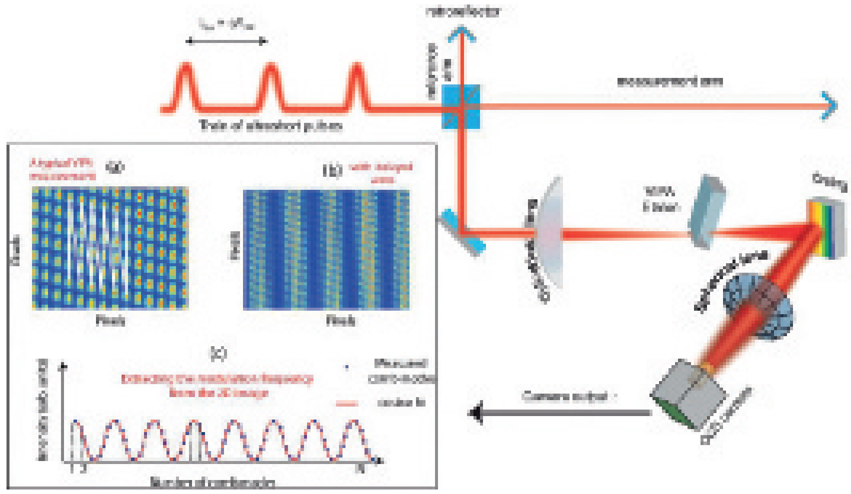




1 Deformable mirror realised by Eindhoven University of Technology and TNO (not yet for high optical power).

2 Schematic set-up for spectrally resolved frequency-comb interferometry.

(CoSI) will be discussed. CoSI allows for determining arbitrary wave fields from a set of shear interferograms. It combines standard microscopic imaging with an axial resolution of a few nanometers and the possibility to use cheap and eye-safe low-brilliant light sources. Additionally, the technique allows for refocusing recorded images numerically, after the measurement.

The role of coherence of the underlying wave field and the reconstruction of the information derived from the object's sheared representations will be discussed. Experimental results of Digital Holography and quantitative phase-contrast imaging as well as Differential Interference Contrast (DIC) microscopy suitable for micro-objects will also be shown. Quantitative DIC microscopy is a versatile tool for the investigation of reflective and transparent specimens.

Ir. Ruud Beerens
Senior Architect Opto-Mechanics, ASML, www.asml.com
Design guidelines for stable opto-mechanics

Optimising the time-to-market is of great importance for the high-end products of ASML, as it enables increased revenues for its customers. Concurrent engineering is a means to reduce time-to-market. Quality, on the other hand, is maintained by having multi-directional information lines between the parallel operating planning paths running over multiple types of interfaces; e.g. system-to-system, system-to-module, discipline-to-discipline and concept-to-design. Risk mitigation is key throughout the entire process; hence architects and engineers are equipped with design guidelines. A clear example covering multiple interface types is that between optical functionality and stable hardware, i.e. stable opto-mechanics.

Drs. Teun van den Dool
Senior System Engineer, TNO, www.tno.nl
Adaptive optics for high optical power

Optics systems have evolved from using spherical elements only, through non-spherical components, free-form, and more recently active and adaptive optics. This evolution often enables implementation of optical systems with improved performance using fewer components in a smaller volume. With the development of adaptive optics, mechatronics has explicitly entered the optical design domain. Not only in the sense that actuators (deformable mirrors), (wavefront) sensors, and controllers are needed, but the development of a deformable mirror (Figure 1) in itself also involves many disciplines like optical, mechanical, thermal, and electronics design. This presentation will show how all these disciplines have to interact, weigh interests and compromise to arrive at a well-balanced solution, especially in the case that the deformable mirror has to cope with a high optical heat load.

Dr Nandini Bhattacharya
Assistant Professor Optics Group, TU Delft, www.tudelft.nl
Speckle dynamics to monitor pulsatile flow

Portable devices for monitoring of cardiovascular parameters are becoming imperative nowadays. This leads to a significant interest to create low-cost reliable devices. In this regard optical methods have been most promising and a lot of applications have come up for diagnostics and monitoring. Their main advantage is that they can be non-invasive and low-cost. Many optical portable devices are susceptible to motion-induced artifacts. Results will be presented of an experimental study of detection of fluid pulsation based on multi-exposure speckle images to detect fluid pulsation in the presence of artifacts caused by the relative motion between the sample and the illumination source. In-vivo measurements were shown to agree with the in-vitro case. It was found that a minimum collection of two pixels from the speckle image is sufficient to extract relevant results.

Dr Steven van den Berg
Research Scientist, VSL, www.vsl.nl
Spectrally resolved frequency-comb interferometry for absolute distance measurement

The invention of the femtosecond frequency-comb laser has been a step change in the field of optical-frequency metrology, with a wide outreach to other fields, like high-resolution spectroscopy, femtosecond-pulse shaping and absolute distance measurement. Using the frequency comb as a source, the output of a Michelson interferometer is measured with a high-resolution spectrometer, which is able to spectrally resolve the individual wavelengths on a camera (Figure 2). A distance is determined from the measured interference patterns, acquired with a fast single shot image. Comparing frequency-comb measurement results with the measured displacement of a counting laser interferometer for distances up to 50 m, an agreement on the sub-micrometer level was found (< 10^{-8} at 50 m).

With the prospect of frequency-comb lasers becoming smaller, cheaper and easier to operate, this measurement scheme opens up the possibility for field applications, not only in the field of surveying or dimensional metrology, but also in space, for example distance measurement between satellites.

Dr Wolfgang Robra
Head Development, Hittech Prontor, www.prontor.com
Light Control by Mechanical Devices

To control the opening width or precise timing of a beam of light, there is no way around the use of mechanical devices. By an example, the challenge is shown to be met to full specification. In lens barrels for cameras, the f-stop is usually controlled by a diaphragm whilst exposure time is controlled by a separate blade system. Whereas central blade shutters, once the heart of every photographic camera, are used today only for particular applications, e.g. in airborne metering. The patented system designed and made by Hittech Prontor combines diaphragm and shutter in one blade system, using piezo actuators and position-controlled blades.

3 *The Philips Ultra-Fast Digital Pathology Scanner.*

Dr Bas Hulsken
CTO Digital Pathology Solutions, Philips
High-throughput slide scanners for Digital Pathology

Philips has developed a sophisticated yet easy-to-use digital pathology solution designed around the needs of pathologists and offering exceptional image quality. By digitising the images that pathologists normally view through a microscope, Philips' goal is to offer integrated solutions that help to enhance the operational efficiency and productivity of pathology departments.

Engineered to meet the needs of modern high-volume pathology labs, the IntelliSite Ultra-Fast Scanner (UFS) combines exceptional image quality with high speed and throughput (Figure 3). All slides are scanned at high resolution, providing visibility to cellular detail. The IntelliSite UFS uses multi-sensor technology and parallel processing, allowing a single slide to be scanned in 60 seconds at 40x equivalent for a 15mm x 15mm scan area. The presentation details the challenges of high-speed imaging, and how these challenges were addressed in the Philips slide scanner.

Wolfgang Singer
Principal Scientist CRT-Optics Corporate Research and Technology, Carl Zeiss, www.zeiss.com
Perspectives and challenges of Smart Optical Systems

Smart optical systems are stable and reliable when operating under varying conditions or for different objects. Such systems typically require adaptive optical means and a

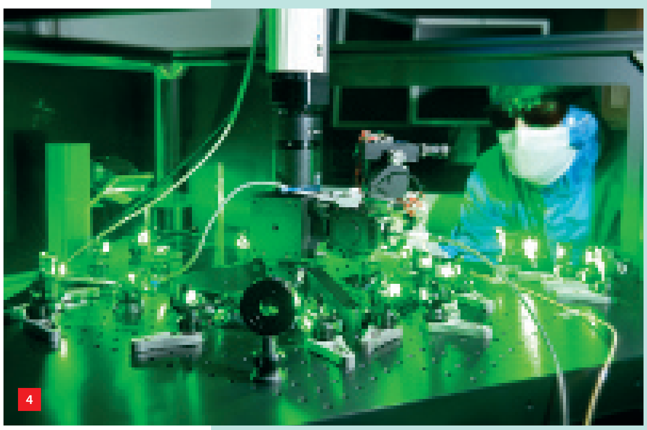
control unit providing the signal to drive the adaptive optics. Applications range from handheld optical systems with dynamic stabilisation, and microscope lenses with correction for different immersion liquids, to optical lithography systems with active compensation of almost any deviation from the perfect state.
Some fundamental challenges regarding applications of smart optical systems will be presented and illustrated for optical vision devices and optical microscopy. Limits and perspectives will be discussed using different examples of visual perception and high-NA fluorescence imaging of biological samples, as well as design limitations and applicative limitations. Different approaches of adaptive optical means, such as LC-spatial light modulators, deformable elements, and movable optical elements, will be compared.

Dr Wenko Süptitz
Manager Photonics and Precision Technology trade association, SPECTARIS, www.spectaris.de
German industry association SPECTARIS: The top 5 Themes of the Photonics members

< No abstract available at publication date. >

Courses

Optomechanics
The 2-day Optomechanics course – targeted at (systems) engineers, Ph.D. students and technicians – will cover optics and optics mounting alignment, dynamics and thermal or material stability. A wide variety of examples from space, astronomy, defence and industry will be used to clarify theory and many practical analytical tools will be presented (Figure 4). The course will be delivered by Daniel Vukobratovich, Senior Scientist at Ratheyon as well as Adjunct Professor in the College of Optical Sciences, University of Arizona, USA.
Typical materials aspects that are addressed are stress-optics coefficients, thermal properties, dimensional stability and drift. The course will provide an impressive amount of data, which can help in material selection or prediction and understanding of a wide variety of materials used in optical systems.
Optomechanical design topics such as control and prediction of the deflection of systems and optical elements will be discussed, as well as kinematic design and a-thermal design. Understanding of precision motion and vibration isolation is important in the design of stable optical systems. Examples and practical analysis tools will be presented.



4 *The Opto-mechanics course features a wide variety of examples from space, astronomy, defence and industry.*

Regarding lens and mirror mounting not only standard lens, mirror or prism mounts but also the design of windows or domes mountings will be presented. Generic aspects of mechanical mounts or the use of elastomeric mounts will be discussed. Use and design aspects of the classic lens barrel will also be addressed.

SMETHODS+ optics design
The 4-day SMETHODS+ course provides hands-on training in design and optimisation of optical imaging systems supported by a theoretical introduction. At the end of the session, trainees will be able to specify an optical imaging system, propose the general layout, and understand the methods used to characterise its performance. On simple systems, they will be able to select a starting point, run the optimisation and estimate tolerances. On more complex cases, they can interact efficiently with highly skilled experts. Topics include general optical systems, classification and combinations of optical elements. Practical exercises will be done with two-lens and two-mirror combinations. The design of multi-element optical systems, e.g. triplets, Gauss lenses, telephotos, Kepler and Galilean telescopes, eyepieces and microscope objectives, will also be presented. Various optical design programs will be used, such as Zemax, CODEV and Synopsys. The hands-on training will deal with realistic optical design problems: how to start an optical design, how to develop it and how to make a decision when to stop.

WWW.OPTICS.ARIZONA.EDU/RESEARCH/FACULTY/PROFILE/DANIEL-VUKOBRATOVICH
WWW.SMETHODS.EU

INCREASING THROUGHPUT AND ACCURACY OF PROCESS CONTROL SYSTEMS

The constant challenge in semiconductor and electronics manufacturing is to increase yield and output with shrinking dimensions and increased 3D complexity of chips. This means in-line inspection and metrology systems must provide 100% analysis at a high precision while maintaining high throughput. The latest innovations in ultra-high-resolution image sensors can support the goals of increased accuracy and speeds with the appropriate camera implementation. The cameras need to provide the necessary image quality, consistently and at the full frame rate.

GRETCHEN ALPER

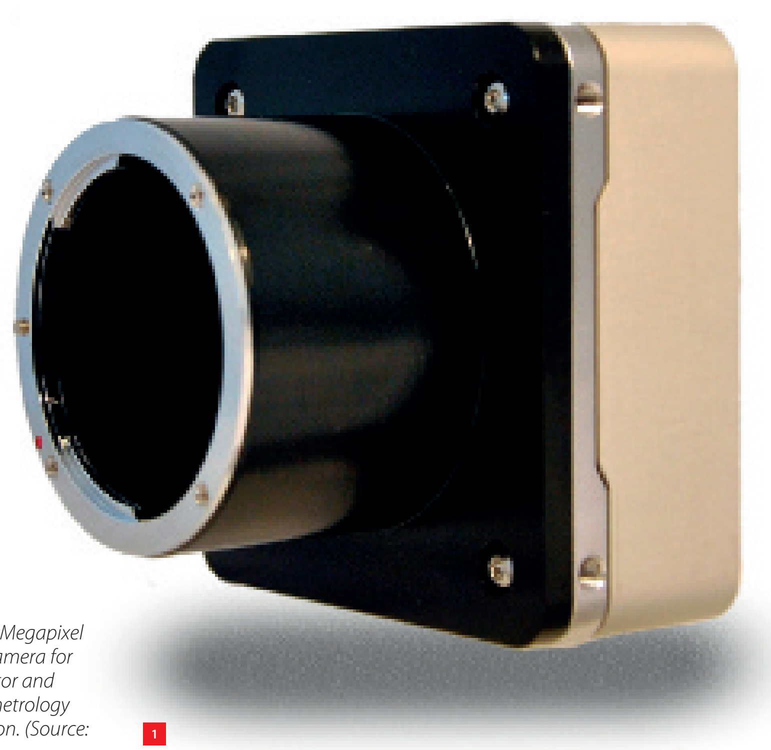
AUTHOR'S NOTE

Gretchen Alper is marketing & media specialist at Adimec, with headquarters in Eindhoven, the Netherlands. Adimec designs, manufactures, and markets high-performance industrial cameras for equipment manufacturers in machine vision, healthcare and security. This article is an edited compilation of blogs on the Adimec website.

www.adimec.com

While we tend to call any camera designed for industrial applications a 'machine vision camera', this is a really broad category. Machine vision cameras include the low-end industrial cameras used for applications like positioning and mainstream cameras that are designed for general inspection applications such as food and paint quality verification. The standard approach with mainstream cameras is to take a good sensor, add in a bunch of functions and a cost-cutting design. These cameras are often selected based on resolution, frame speed, and price criteria. Image sensor innovation is driving what can be done with mainstream cameras, and they can be used more widely than before.

However, if an imaging chain is used to differentiate the system involved or if the quality of the starting image is critical to the overall accuracy of the system, then a metrology camera is required (Figure 1). Metrology cameras incorporate the specific design and processes as discussed here which enable the image data to meet the measurement requirements of smaller technology nodes.



1 *A typical, 12-Megapixel metrology camera for semiconductor and electronics metrology and inspection. (Source: Adimec)*

Smaller details, high quality

One of the simplest ways to detect and measure smaller details is to increase the resolution of the image sensor and subsequent camera. Previously this had been a challenge because the frame rates of very-high-resolution CCD image sensors were way too slow to keep up with the throughput requirements of in-line measurement systems, such as 3 fps (frames per second) for 16 Megapixels. Now there are several new high-resolution cameras available using CMOS image sensors that can produce CCD-like image quality at impressive frame rates, such as 25 Megapixels at 72 fps, which represents 1.8 Gigapixels per second.

While there are many excellent global shutter CMOS image sensors available, no components are perfect. The advantages of larger resolution are only realised if the entire image sensor is usable. With more than 25 million pixels or even 1 million pixels on an image sensor, not every single pixel can perform perfectly. Uniformity challenges also increase, as a larger optical field of view requires more complex optics.

With metrology cameras, special attention is given to ensure the best pixel data. To achieve this, it takes an efficient camera design and manufacturing process for defect pixel and blemish correction, accurate sensor alignment, and sensor tuning to maximise the parameters most important for measurement accuracy.

For the most usable pixels available, the image sensor must also be optimised for registration of the smallest details. With a full understanding of the image sensor, variations between sensors, and the image sensor performance under different conditions, sensor optimisation tunings can be determined.

By tuning the sensor to specific settings, camera manufacturers can reduce the amount of defects the sensor generates. Defects and non-uniformity generation depend not only on the sensor design but also on the conditions it is operated in, like temperature. Critical artifacts in the camera and sensor combination can be minimised to increase the operational image range. Camera-embedded calibrations can also be done automatically in the field to adjust to system conditions, such as temperature variations, optics imperfections, and clocking. These measures among others provide the maximum dynamic range, uniformity, linearity, etc., for detection of small details and accurate measurements.

No variations

Variations in the image should be smaller than the variations one is trying to measure. Also, critical to the accuracy of automated measurements is consistent data such that the variations identified are not those from the camera or cameras. Cameras with consistent performance reduce the metrology variability and serve to better determine the process discrepancy. With both consistent images and camera-to-camera consistency (when multiple cameras are used per measurement or multiple tools are used per process line), any changes detected can be determined as process deviations, allowing root-cause analysis to take corrective action.

Image-to-image consistency is maintained through a robust camera design as well as embedded functions mentioned above. Camera-to-camera consistency is achieved through detailed sensor mounting and alignment processes as well as a rigorous, individualised assembly and test procedure process so that mechanical and electrical adjustments can be made.

Precise sensor alignment and specialised verification procedures are all measures that would be taken with metrology cameras, but may not be done with most mainstream cameras. If there is any tilt in the mounting and positioning of the sensor, one edge of the image could be sharp while the other edge is blurry making part of the image unusable. The alignment of the image sensor in the camera is key to have an optimal optical path and high-quality image data for the entire resolution. If the alignment is not precisely centered, part of the image could be unusable impacting the number of false negatives in the inspection.

Increasing throughput

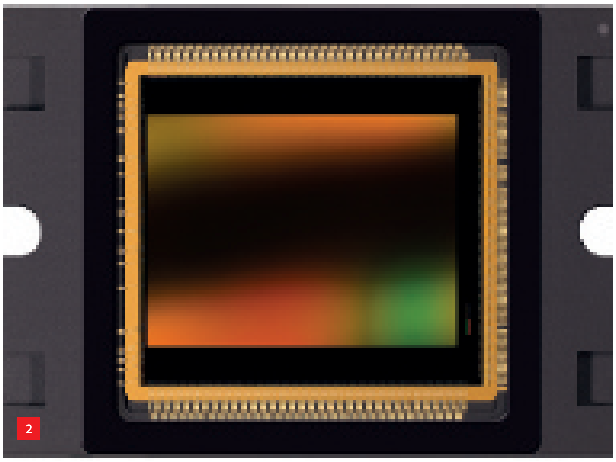
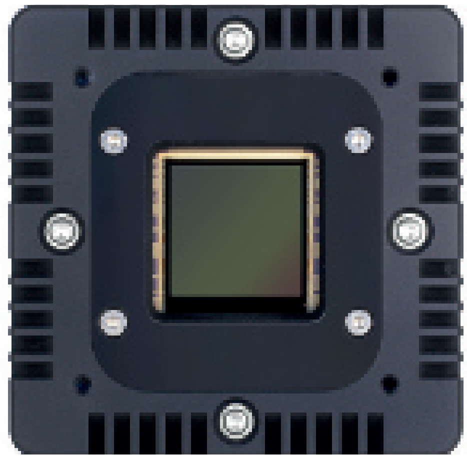
These are some of the ways high-performance metrology cameras increase accuracy in semiconductor or electronics inspection and metrology systems.
They can increase throughput through:

- Increased data acquisition time.
- Reduced number of scan positions/images per device.

Increased data acquisition time

Higher throughput can be achieved through higher frame rates. With measurements requiring multiple images per sight, as is typical in many 3D methods, the overall speed of the system can be increased with the ability to acquire the images faster. Some OEM cameras also offer region-of-interest (ROI) functionality, which can reduce the image to only necessary information and further increase the frame rate.

One of the challenges with OEM industrial camera design is to ensure no image quality loss when running at full speeds. This means starting with an excellent image sensor. Some

2 The 12-Megapixel, 300-fps CMV12000 image sensor from CMOSIS [1].
3 An Adimec 25-Megapixel CMOS global shutter camera applying the VITA 25K image sensor from ON Semi [2], delivering high-resolution images of 5,120 x 5,120 pixels at 32 fps.

of the best in their class are the CMV12000 from CMOSIS [1] (Figure 2) and the VITA 25K from ON Semi [2] (Figure 3), which offer 12 Megapixels and 25 Megapixels, respectively, and both are high-speed global shutter CMOS image sensors.

These sensors are designed to handle these high data rates within a critical timing tolerance to reliably produce quality images. Then within the camera, the image sensor must be driven strategically to provide the best performance and then combined with a reliable interface to ensure no quality is lost. There are several new high-speed interfaces to handle the data rates of the latest image sensors. CoaXPress [3] is one such interface. For example, a 12-Megapixel camera can provide 187 full frames per second over CoaXPress (8-bit data).

Reduced number of scan positions

To improve the efficiency of inspection equipment, the path travelled by the devices/objects under test needs to be planned optimally with minimal movements. A metrology camera with 12 or 25 Megapixels, for instance, provides a larger field of view capturing more of the object per image, reducing the number of scan positions per object (Figure 4). But in order for the full benefits of the larger field of view to be realised, every pixel must be usable, which requires uniform, blemish-free images. This can be achieved with some of the measures previously mentioned.

Protecting pixel data integrity

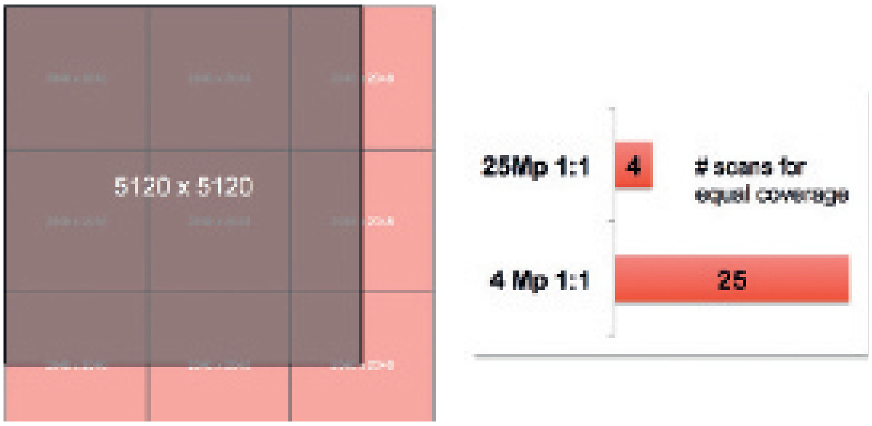
In addition to some of the performance advantages of metrology cameras, that are driving the sensor in a specific way for an application to increase performance, there are also steps in manufacturing to protect the pixel data integrity. The care for the camera in its manufacturing process can reduce incoming inspection, saving time-to-customer.

Unlike many mainstream cameras, high-performance metrology cameras are manufactured in a cleanroom-like environment (low dust levels) to minimise any added particles, as any dirt on the sensor can impact the performance. Additional cleaning processes can often be included in the outgoing inspection if necessary to save time on the receiving processes. While the core camera specifications satisfy many of the measurement requirements, the design and handling of the camera during its manufacturing can support the other needs of the system. These are some things to consider to avoid a lot of workarounds later and hopefully reduce some frustrations.

Microscopy

In many high-end inspection and metrology systems, microscopy is a common optical set-up to acquire the images. Two illumination techniques are frequently used: dark field and bright field illumination. ‘Bright field’ means the microscope and camera look at the reflection of light on the object that is examined. ‘Dark field’ means the microscope and camera look at the scattering of light on the object that is examined. Scattered light is typically used to inspect small features and look for cracks and defects that are not otherwise visible.

This means that high dynamic range, limited defect pixels, and linearity (and more) are all required to get accurate information from the entire image area. Of course the image sensor determines some of the performance, but the camera manufacturer can tune the sensor to optimise the camera accuracy parameters. Because these systems are used in-line for manufacturing, this all must be possible at fast throughput rates, which is supported by the combination of high resolution (fewer movements) and high frame rates.



4 *When using a 25-Megapixel (5,120 x 5,120 pixels) image sensor as compared to a 4-Megapixel (2,048 x 2,048 pixels) sensor, the number of scans required is reduced by a factor of more than six.*

Structured illumination profiling

Structured illumination profiling includes measurement methods using structured light patterns to extract 3D surface profiles. There are various ways to use structured light patterns, but one of the common approaches in the semiconductor industry is phase-shift measurements. With phase-shift measurements, a moving pattern is used to extract a phase map image from the object. This phase map can be translated into a height measurement map through triangulation.

Stability over time and temperature is important when relying on information extracted from several images. Uncontrolled variations in pixel grey values from image to image limit the accuracy. Careful camera design can ensure that image uniformity is maintained over time. Because multiple images are used per measurement, faster image acquisition has a bit impact on throughput.

Conclusion

To continue innovating, semiconductor and electronics process control equipment manufacturers rely on metrology cameras with uniform and stable images at constantly increasing frame rates and resolutions. The extra steps done with design and manufacturing of metrology cameras may provide the performance leaps required in new technology nodes as well as eliminate workarounds and adjustments. ■

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[2] www.onsemi.com
[3] www.coaxpress.com

THE CEILING ROBOT

After three successful prototypes of high-tech magnetically levitated planar motors, containing a moving member that moves below a working process, the focus of the research at Eindhoven University of Technology into fully contactless *xy*-positioning systems has now been flipped upside-down. This has resulted in the development of the Ceiling Robot, the first-in-the-world magnetically suspended planar motor with integrated contactless energy transfer system and a completely contact-free operation above a working process.

TIMO OVERBOOM AND JOHAN SMEETS

Introduction

Planar motors have been developed for many applications, such as automated assembly lines, laser cutting processes, wafer stages, LCD manufacturing, inspection systems, and machine tools. They replace cascaded *xy*-positioning devices that combine two orthogonal linear-motion stages arranged in a gantry or a cross.

Magnetically levitated planar motors enable motion in multiple degrees of freedom (DoFs) with a single moving body (translator), resulting in a small system size, low moving mass, high acceleration levels, good tracking performance, and potentially a long stroke. These motors use magnetic fields as a bearing system, and, therefore, do not suffer from the drawbacks associated with roller or air bearings, such as mechanical friction. An extended planar stroke and a completely wireless operation of the translator are achieved by integration of a contactless energy transfer system. This system provides energy to the translator and auxiliary devices, and replaces a cable connection to the translator.

Most applications rely on a motion system that operates below some process. As such, the translators in planar motors are usually levitated and propelled in the plane above a stationary frame. However, for the inspection or assembly of electrical components on printed-circuit boards, for instance, planar motion and suspension underneath a stationary frame or the ceiling, is preferred.

Suspended planar motors have been applied in these kinds of applications but they all use air bearings. To counteract the gravitational force and suspend the translator from the stationary frame using magnetic fields only, an attractive force between both parts is required. This attractive force should comprise an active and passive part; the passive attraction force prevents the translator from falling down in case of a power failure while the active force is used for stabilisation. The attractive orientation of the force makes the magnetically suspended planar motor essentially different from its magnetically levitated counterpart because the latter uses a force of repulsion.

Principle

The research into the magnetically suspended motor started with the investigation of decoupling methods for combined magnetic levitation and propulsion with linear induction motors, permanent-magnet (PM) linear synchronous motors or hybrid linear reluctance motors [1] [2]. A comparison among these different types of motors has resulted in a configuration for the magnetically suspended planar motor comprising a stationary checkerboard PM array and four iron-cored linear synchronous motors embedded inside the translator, as illustrated in Figure 1.

The linear motors are arranged in pairs along the *x*- and *y*-direction, and are rotated 45° with respect to the structure of the alternating PM array [3]. In this configuration, a passive attraction force larger than the weight of the translator is created between the laminated iron cores of the linear synchronous motors and the PM array. This force provides passive gravity compensation for a reduced power dissipation and passively clamps the translator to the stationary PM array when the planar motor is not operated. Additionally, fail-safety is offered because the passive force prevents the translator from falling down in case of a power failure.

AUTHORS' NOTE

Timo Overboom and Johan Smeets performed their research within the Electromechanics and Power Electronics group at Eindhoven University of Technology, the Netherlands. They completed their Ph.D. theses under the supervision of prof. E.A. Lomonova and dr J.W. Jansen. Their project was funded by the Dutch Ministry of Economic Affairs, through the IOP EMVT programme.

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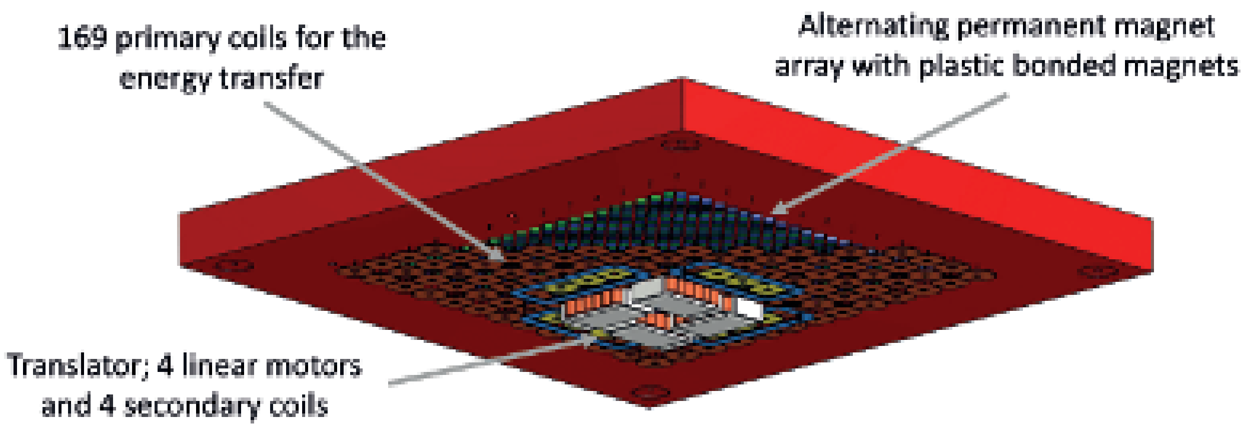


1 *Schematic overview of the magnetically suspended planar motor with integrated contactless energy transfer system.*

Each linear motor is separately excited as a three-phase synchronous motor to control the planar motor in six DoFs. The three-phase currents produce an electromagnetic propulsion (x-) and normal (z-) force. Both force components are decoupled by the dq-decomposition of the phase currents (into the direct and quadrature components, respectively). Depending on the orientation of the linear motor, a propulsion force is created in the x- or y-direction by injecting a q-axis current. A d-axis current creates an electromagnetic normal force. Because the passive attraction force is larger than the weight of the translator, a negative d-axis current is supplied for magnetic suspension.

Contactless energy transfer

Similar to a transformer, the contactless energy transfer (CET) system wirelessly transfers energy between a primary and a secondary coil by means of resonant inductive coupling. These CET systems are typically designed for a stationary application, such as the wireless charging of a mobile phone, because the amount of transferred energy is extremely position-dependent. However, when embedded inside a planar motor, the CET system should be able to transfer energy to the translator, irrespective of the position. Preferably, the same amount of energy is transferred at every position to limit the temporary storage capacity of energy at the moving translator.

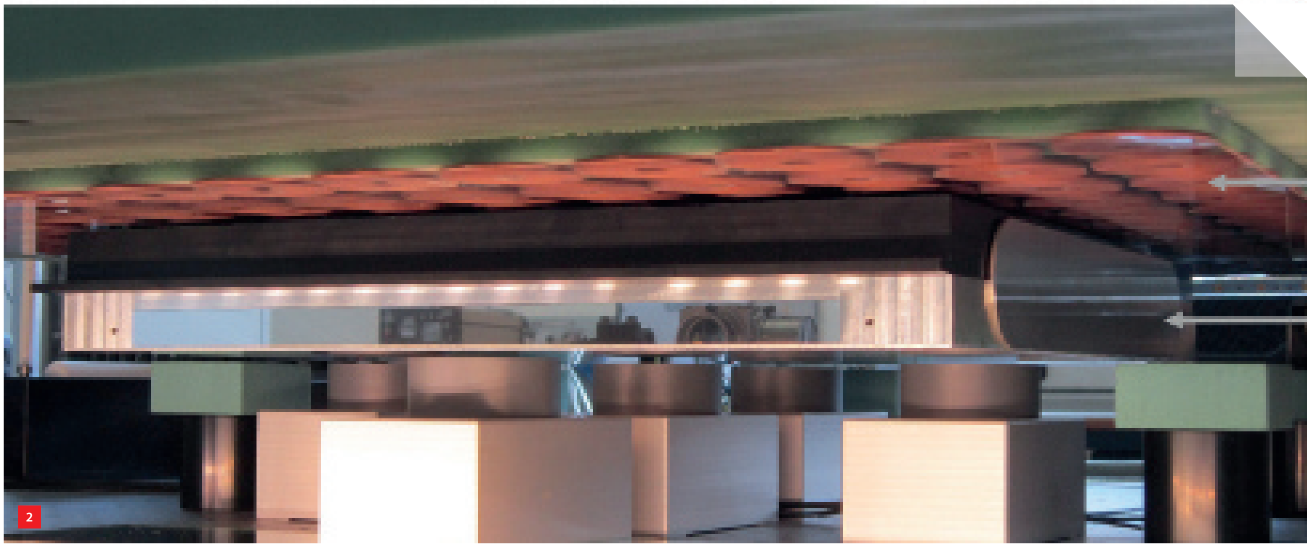
To allow for long-stroke planar motion of one or more secondary coils (which are fixed to the translator), the CET system should contain a stationary array of primary coils. The position dependency of this special CET system has been analysed by relating the variation in mutual inductance as a function of the relative displacement between the primary and secondary coils to the design parameters and system configuration [4] [5]. The analysis has resulted in a set of design considerations for the CET system with a low position dependency.

Summarised, the variation in transferred energy is reduced by optimising the dimensions of the primary coils. Furthermore, a high energy density is obtained when energy is transferred from multiple primary coils to a single secondary coil. For the contactless energy transfer system embedded inside the planar motor, a combination is chosen where one secondary coil receives energy from a set of three primary coils, as illustrated in Figure 1. In total, four secondary coils are fixed to the translator to transfer a large amount of energy. By dynamically switching the set of active primary coils, each secondary coil only receives energy from the three nearest primary coils. Hence, an efficient operation of the CET system and a low variation in transferred energy is achieved.

Design and integration

For the design of the magnetically suspended planar motor with an integrated CET system, analytical models for the calculation of the three-dimensional magnetic fields, force, temperature distribution, efficiency, and output variation of the CET system have been derived. The magnetic field models are based on the harmonic modelling technique, which has been extended to model the 3D fields around coils and permanent magnets, including the presence of soft-magnetic materials and complex geometrical structures [6] [7]. The analytical models enabled the evaluation of many different configurations with various requirements in a short amount of time and find the best design for the integrated system.

The integration of the CET system into the planar motor has a number of implications for the geometry of both systems and the material selection. Firstly, to embed the array of primary coils within the planar motor, the array is placed inside the gap between the translator and the stationary frame. In the considered design, the height of the primary coils has been set equal to 2 mm for a sufficient



2 *The realised magnetically suspended planar motor with integrated contactless energy transfer. This prototype was demonstrated at the Precision Fair 2014 and presented during the DSPE 60 Years Event at the same fair.*

3 *Exploded view of the translator.*

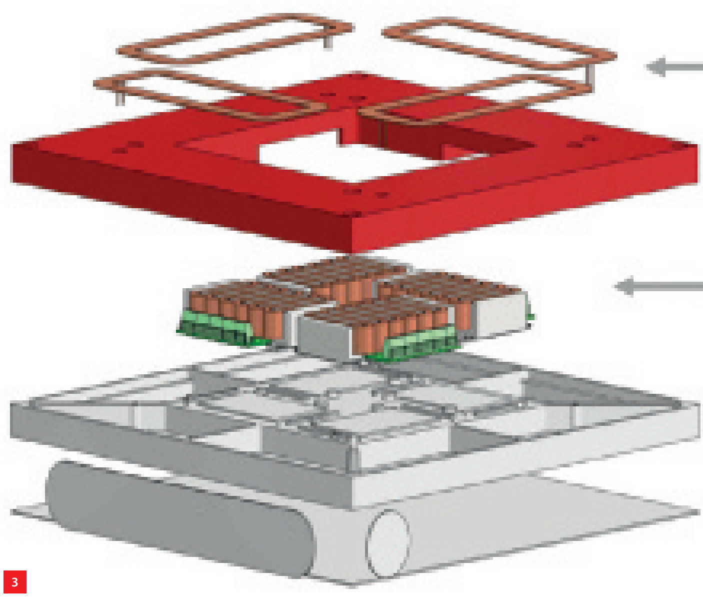
transfer of energy. To operate the planar motor with a mechanical air gap of at least 1 mm, the clearance between the linear motors on the translator and the stationary permanent magnets is larger than 3 mm.

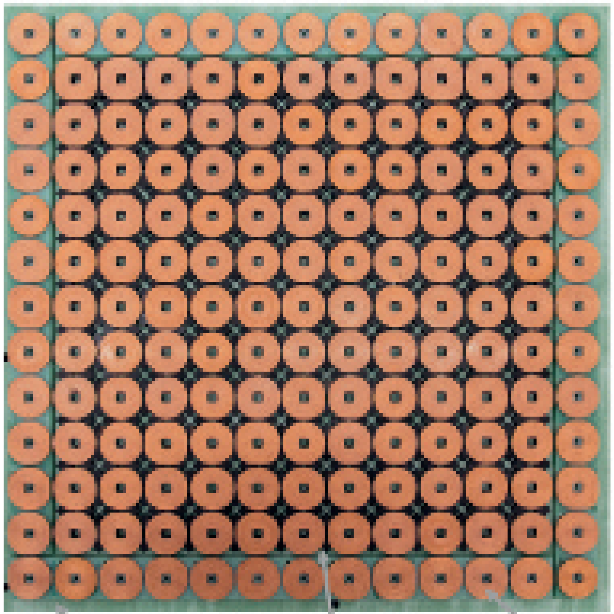
Secondly, because the resonance frequency of the CET system is in the order of 100 kHz, the presence of electrical conducting materials should be minimised to avoid a reduction in the efficiency of the CET system due to eddy-current losses. Based on the last requirement, the permanent magnets are made of plastic-bonded NdFeB material with a limited remanence of 0.68 T. Furthermore, the array of magnets is glued to a non-magnetic and non-conducting epoxy-resin glass-fabric back-plate.

Finally, it has been shown that, contrary to magnetically levitated planar motors, the large clearance of more than 3 mm and the use of low-performance plastic-bonded magnets do not affect the power dissipation of the planar motor with magnetic suspension.

Prototype

A fully operational prototype of the magnetically suspended planar motor with integrated CET system (Figure 2) was realised for experimental verification [8]. The translator contains the four linear motors and the four secondary coils, as is illustrated in Figure 3. The linear motors are mounted to an aluminium carrier, while the secondary coils are glued to a PVC cover. The carrier and cover have





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cavities to reduce the weight and provide space for the rectifiers of the secondary coils. All together, the translator has a total mass of 8.9 kg. An additional load of 3 kg can be attached to the translator. In the current set-up, the three-phase current amplifiers for the linear motors are not located on the translator but are wired to the motors with flexible cables inside a cable track.

4 *Photo of the stationary part, 169 primary coils glued on top of the magnet array.*

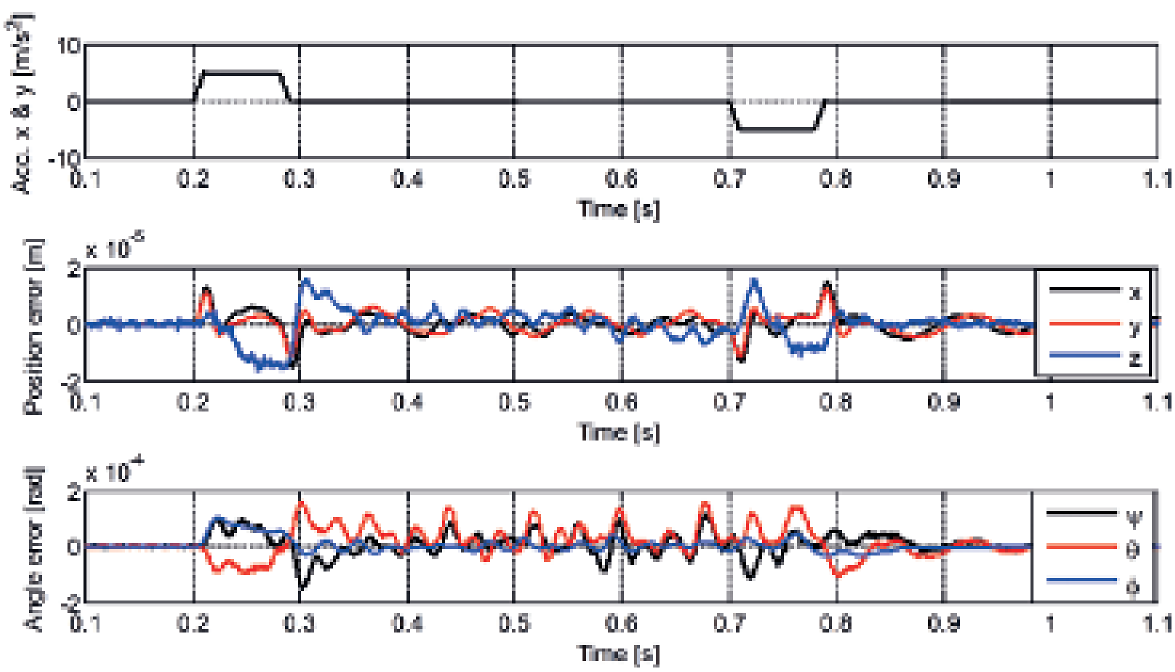
5 *Acceleration profile and position and rotation errors of the magnetically suspended planar motor.*

As shown in Figure 4, the stationary side (i.e. the ceiling) comprises a non-magnetic and non-conducting epoxy-resin glass-fabric plate. An array with 924 plastic-bonded permanent magnets is glued to the epoxy plate. The array covers an area of 522 x 522 mm^2, allowing a total planar stroke of 250 x 250 mm^2. 169 primary coils made of Litz wire are glued to the bottom surface of the PM array. Each coil is connected to its own half-bridge converter, which is placed on top of the epoxy plate (Figure 2).

The set of active primary coils is switched when the translator is propelled in the plane, because only the twelve primary coils closest to the four secondary coils efficiently contribute to the energy transfer. A transparent polyethylene sheet protects the primary coils and magnets from impacts of the translator. The position and orientation of the translator is measured using a combination of inductive sensors and laser interferometers.

Measurement results

Because the planar motor is an active magnetic bearing, it has to be controlled in six DoFs. The translator is propelled over large distances in the *xy*-plane, while it is operated underneath the stationary frame with a mechanical gap length of 1.5 mm in the *z*-direction. The rotations of the translator around the three axes are controlled to 0 rad (to minimise the roll, pitch and yaw angles during long-stroke planar movements). All DoFs are individually stabilised by SISO (single-input, single-output) controllers, with a closed-loop bandwidth of 40 Hz.



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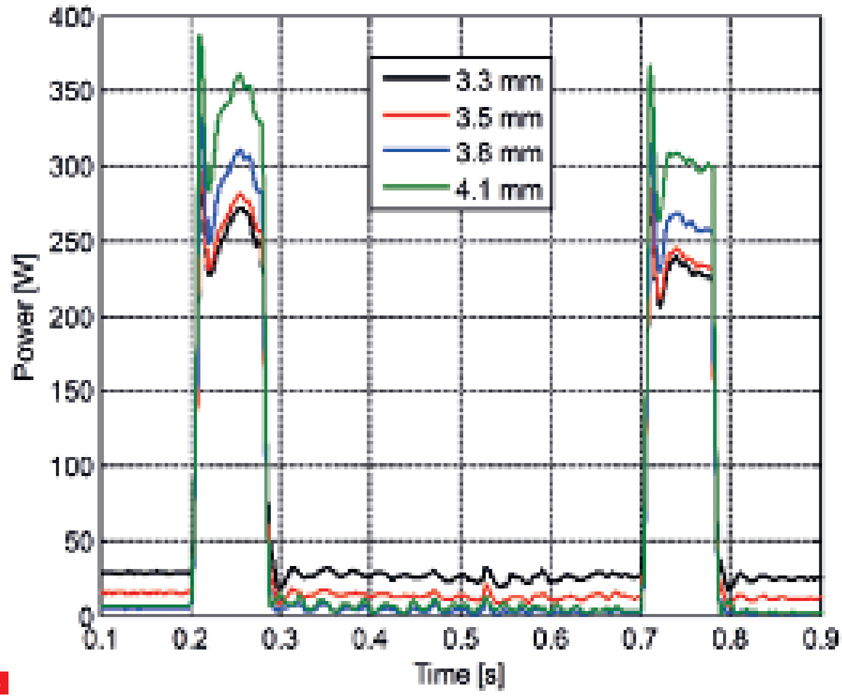

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For the considered motion profile, the Ohmic losses created inside the coils of the linear motors are shown in Figure 6. Between 250 and 300 W is dissipated during peak acceleration. However, when the translator moves with constant velocity, less than 5 W is required. In this case, the planar motor only has to suspend the weight of the translator. All of the weight is fully compensated by the passive normal force, which is created between the permanent magnets and the iron cores of the linear motors. Actually, to guarantee fail-safety, this force is slightly larger than the weight. The planar motor only has to produce a small repulsive force to suspend the weight. As a result, the power dissipation for suspension is very small.

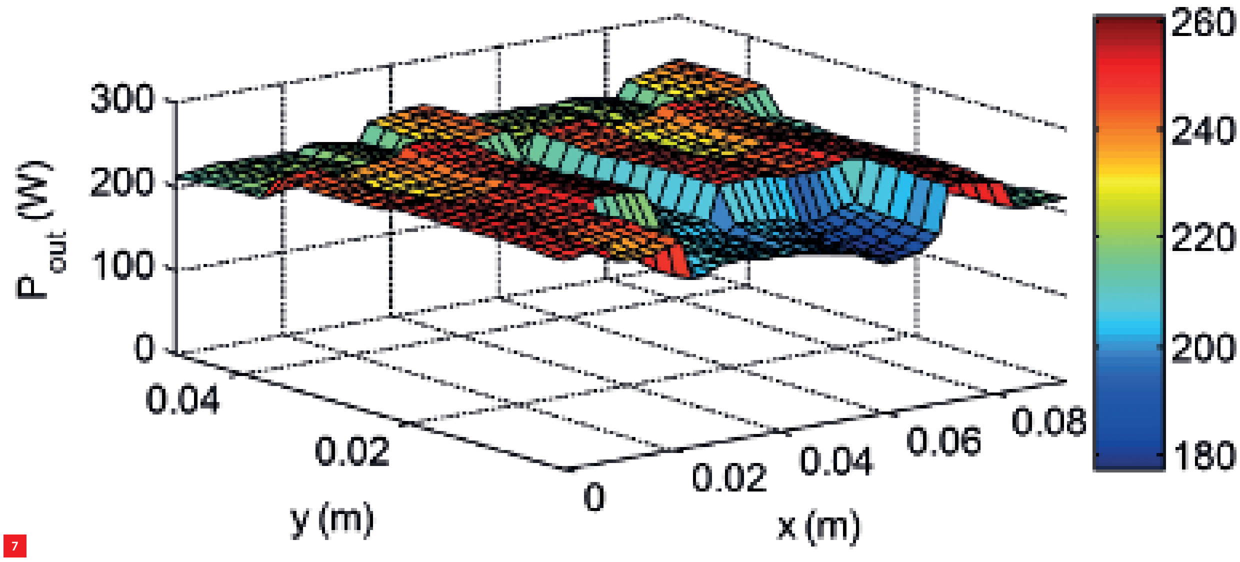
The integrated CET system has an average output power of 230 W and a variation of 32% between the maximum and minimum amount of transferred energy, as shown in Figure 7. The sudden variation in the transferred energy occurs when the set of active primary coils is switched and it is caused by the slight mismatch between the operating frequency of the CET system and the resonance frequencies of the various primary coils.

The translator follows a third-order motion profile with a maximum acceleration of 5 m/s^2 and a maximum velocity of 0.4 m/s. The reference acceleration profile for a displacement of 200 mm in the *x*- and *y*-direction is shown in Figure 5. This figure also shows the position and rotation errors during the long-stroke movements of the translator. Their maximum values are 15 μm and 100 μrad, respectively.

6 *Power consumption of the magnetically suspended planar motor for various air gap lengths between the permanent magnet array and the linear motors.*

7 *Output power of the CET system integrated in the magnetically suspended planar motor as a function of translator position.*

The resonance frequency differs among the primary coils due to the variations in the inductances of the coils and the values of the resonant capacitors. A small variation in these components results in a deviation from the desired resonant frequency, and, consequently, a significant change in the output power of the CET system. Although the plastic-bonded magnets have a low electrical conductivity and the aluminium carrier has been placed far from the CET system, significant losses are created by the eddy currents inside these parts, resulting in a total efficiency of the CET system equal to 71%.



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Closing

The scientific work described here has resulted in new analytical methods for the operation and design of wireless planar motion systems with magnetic levitation/suspension and integrated contactless energy transfer. Based on this work, a new generation of planar motors will be designed and constructed, where the main challenge is to achieve higher acceleration levels and nanometer position accuracy. ■

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SPIN-OFF, MANIPULATION AND CONTROL

AUTHORS' NOTE

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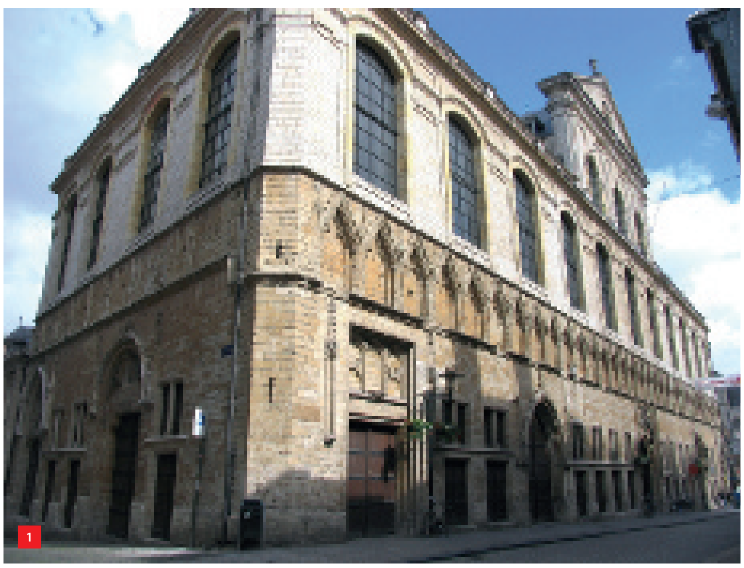
The 15th International Conference & Exhibition of the European Society for Precision Engineering and Nanotechnology (euspen) was held in Leuven, Belgium, 1- 5 June 2015. The conference hosted by the KU Leuven university attracted almost 370 international delegates and boasted a full exhibition hall accommodating almost 50 organisations. There were 36 oral presentations in total and 150 poster presentations. The conference keynotes featured technology spin-off processes, haptic manipulation and numerical control.

HENKJAN VAN DER POL AND DISHI PHILLIPS

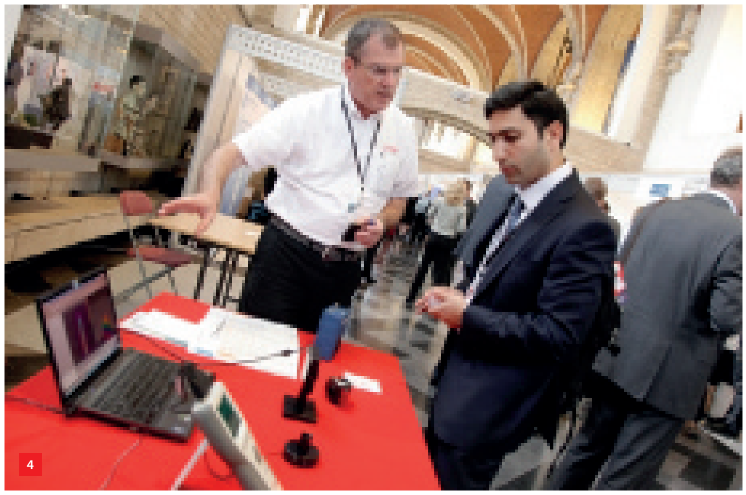
KU Leuven is not only the oldest, but also the largest, university in the Dutch-speaking world. The university has its origins in 1425 and the institute has over 57,000 students today. The euspen conference was held in the main building (Figure 1) of the university, originally built in 1317 as the hall of the guild of drapers and it is now still used as office of the rector and for Ph.D. defence ceremonies. Unique merits of the KU Leuven technological department are the close collaboration with the medical department (nearly 9,000 students) and the academic hospital, and the high number of successful technological spin-offs, such as Materialize, LayerWise (acquired by 3D Systems), LMS (Siemens), Krypton (Metris) and Metris (Nikon Metrology). The event was hosted by prof. Reynaerts and em. prof. Van Brussel of KU Leuven, who were both personally involved with many of these spin-offs.

Keynotes

This successful track record was the subject of the first conference keynote on spin-off processes, by prof. Koenraad Debackere of KU Leuven. A second keynote



1 *Euspen Conference venue, the University Hall in Leuven.*
2 *Dr Mandayam Srinivasan (MIT, USA) delivering his keynote on haptic manipulation.*



3 *The conference attracted nearly 370 participants.*
4 *Impression of the exhibition hall, which was filled with almost 50 organisations.*

was delivered by Dr Mandayam Srinivasan on haptic manipulation (Figure 2). His work in the Research Laboratory of Electronics at MIT (Cambridge, USA) is relevant for rehabilitation of the hand, intelligent prosthesis design and the development of autonomous robot hands.

The last conference keynote was by Dr Carsten Hamm (Siemens, Germany) on numerical control for ultra-precision machining. He made clear that it is extremely challenging to optimise machine behaviour if very diverse specific machines need to be controlled by a general controller and limited or no knowledge about the machine to be controlled is available.

Tutorials and workshop

Before the conference kicked off on Tuesday 2 June, euspen started on Monday with two tutorials and a workshop. The tutorials involved "An Engineering Approach on Mechatronic Machine Concepts: Dynamics & Control in Machine Design" (tutor: Ir. Henry Stoutjesdijk, Philips Innovation Services, the Netherlands) and "Full-field Optical Metrology for Micro and Macro 3D Engineering Structures" (tutor: prof. Malgorzata Kurjawinska, Warsaw University, Poland).

The workshop on the latest advances in optical topography measurement was facilitated by prof. Richard Leach (University of Nottingham, UK). Commercial manufacturers of optical instruments (Bruker Nano, Mitutoyo, Olympus, Alicona) presented their latest technologies in terms of hardware, calibration, specifications and usability. A number of instrument types were presented, including hybrid designs. Prof. Jörg Seewig from the University of Kaiserslautern (Germany) gave an update of the latest standardisation initiatives.

Topics

Over 400 participants and exhibitors from all around the world attended the conference (Figure 3) and exhibition (Figure 4). Again, many participants from Japan, Korea, China and Taiwan delivered important contributions, mainly on precision manufacturing and advanced simulations.
The overall topics for the event were:

- Precision Mechatronic Systems and Control
- Precision Cutting Processes
- Other Precision Machining, Additive & Replication Processes
- Metrology
- Precision Mechanics for Micro-Biology
- Important & Novel Advances in Precision Engineering & Nano Technologies

euspen

The European Society for Precision Engineering and Nanotechnology is a community linking industrialists, researchers, respected authorities, new and established players worldwide. It provides an entrepreneurial platform that enables companies and research institutes to promote their latest technology developments, products and services and keep up to date with those in the field.

Euspen was formed in 1999 with funding from the European Commission. Its mission is to advance the arts, sciences and technology of precision engineering, micro-engineering and nanotechnology, promote its dissemination through education and training and facilitate its exploitation by science and industry.

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Medical applications

Just like previous years, the link between precision engineering and medical applications was made in several oral presentations. Examples include the deep brain stimulation device studied by the academic group of prof. Maarten Steinbuch at Eindhoven University of Technology, the force sensing needle for robot-assisted retinal surgery developed by the Leuven group of prof. Dominiek Reynaerts, and an industrial contribution by Demcon about a laser scanning device for the monitoring of inflammation of joints due to rheumatoid arthritis.

Precision manufacturing has always been a central topic, mostly involving precision cutting or replication processes. Additive manufacturing technologies are gradually entering this playground, as was explained by Michael Mischkot from the Technical University of Denmark.

Posters

In between the oral presentations, poster sessions were held and all posters were judged. The work of Jasper Wesselingh from Zeiss SMT about electromagnetic damping of precision machines was awarded the first prize. Electromagnetic dampers excel in simplicity and are especially suitable for machines where contamination is critical. Wesselingh demonstrated a very clear connection between design optimisation, modelling and experimental results. The other two prizes were awarded to posters on machining aluminium matrix composites reinforced by diamonds, and temperature control systems for hot embossing and injection moulding, respectively.

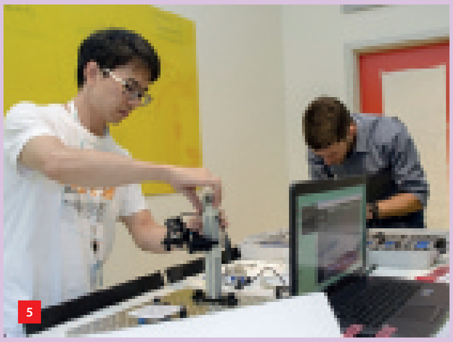
Conclusion

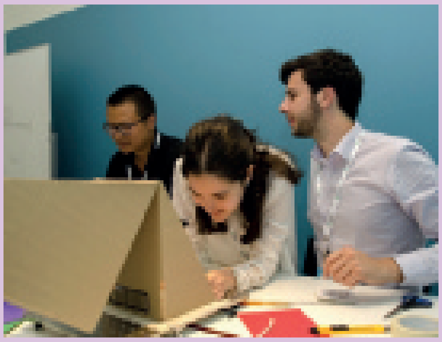
On Friday 5 June, the event was concluded with tours to KU Leuven University, the world-leading nanoelectronics research institute, imec, and several KU Leuven spin-off companies.
For the 15th time, the euspen conference was great for networking and the exchange of academic progress. In 2016, the conference will be hosted by the University of Nottingham, on 30 May to 3 June. ■

euspen Challenge 2015

One month after the euspen conference, the euspen Challenge 2015 was held in Stockholm, Sweden, from 7 to 9 July. In line with the overall networking objectives of euspen, the Challenge benefits students and industry alike. Students gain great national and international teamwork exposure and develop engineering, networking and business skills. In a similar way, industry may tap into the cream of new talent in precision engineering and make unique connections in prominent research institutes.

The international competition is designed to identify students throughout Europe with potential to be future leaders in the field of precision engineering and nanotechnology. National heats were held across Europe earlier in 2015 identifying the best national students, who came together to compete in international teams for the coveted title of euspen International Challenge Winners in Stockholm. During the event (which was held at and supported by the KTH Royal Institute of Technology and Hexagon Metrology Nordic AB in Stockholm), students were required to address a technical challenge and to conclude with a presentation of their solution (Figure 5).





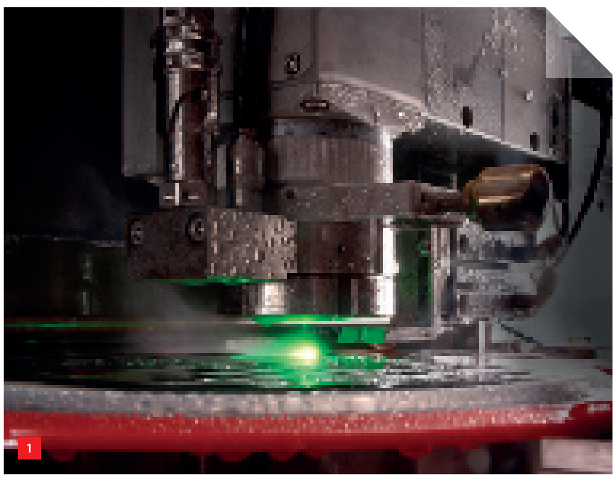
5 *Impressions of the euspen Challenge 2015.*

The technical challenge in 2015 centred on high-precision metrology using low-cost imaging sensors. The challenge was to design and build an optical coordinate measuring machine (CMM) in order to achieve maximum accuracy on a low budget. Issues to be focussed upon were appearance and functionality of the prototype, design and construction of the machine, verification of performance, and a review of the innovative aspects of the solution, the economics of its production, the compelling nature of the allied business case, and the overall quality of the presentation.

THE HYBRID LASER MICROJET IS COOL AND PRECISE

State-of-the-art laser machining is generally classified as a thermal technology. Recently though, the very first 'cool' material removal technology has become available exclusively through the Laser MicroJet (LMJ) principle – even into the micro realm of extremely hard and brittle materials. This advanced waterjet-guided laser technology constitutes a revolution in precision within the rapidly maturing field of laser machining – not only in the eyes of Swiss LMJ pioneer Synova.

JAN WIJERS



1 *Laser MicroJet machining.*

Actual conditions of parts while functioning over extended periods up to the limit under heavy loads and at elevated temperatures nowadays increasingly require the use of tough-to-machine materials. To master the challenging requirements, industry is urgently searching for high-tech processes for fine-cutting, ablation, (edge) grinding, dicing, drilling and even surface structuring. These should be able to process products with increasingly finer details and high overall precision in an economical way out of a constantly widening spectrum of technical alloys.

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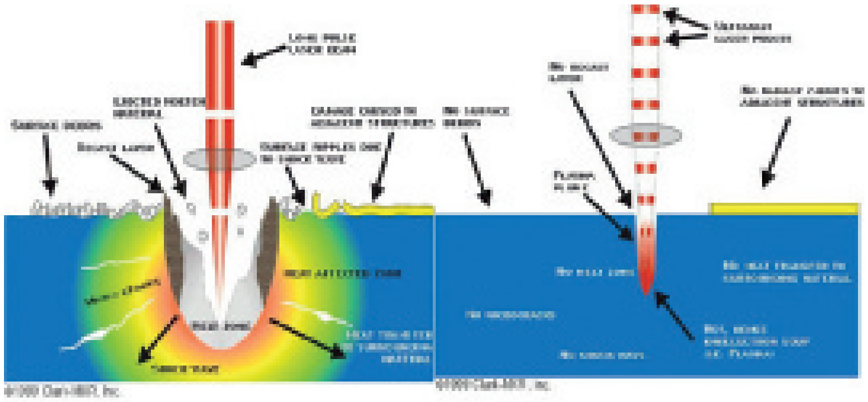
At the same time, it can be noted that dimensions, geometries and basic materials are being subjected to a redesign drive towards lightweight and miniaturised configurations. On top of that, the emphasis is switching to those machining technologies that in themselves function without physical contact and wear, thereby preventing thermal and mechanical loads.

Consequently, a revival trend can be detected towards 'cooler', contactless material removal processes, up against competing cutting processes such as (diamond) disc or wire-cutting and (fine) stamping with tool wear. Those 'new' processes are mostly of alternative types such as waterjet machining (WJM), electrochemical machining (ECM), spark erosion (electro discharge machining, EDM) as well as advanced pulsed derivatives of laser machining. Next to that, classic laser beam machining (LBM) is well accepted in industry.

Cooler solutions

Conventional lasers feature a very short working length around the focal point – millimeter range – and inherent divergence of the beam. Nevertheless, the biggest disadvantage while removing stock is that the high-density beam is converted into thermal energy at the surface of the part. Independent of the laser-source characteristics, this concentrated light will result in an intense heat input locally. Resulting melting and vaporisation bring about



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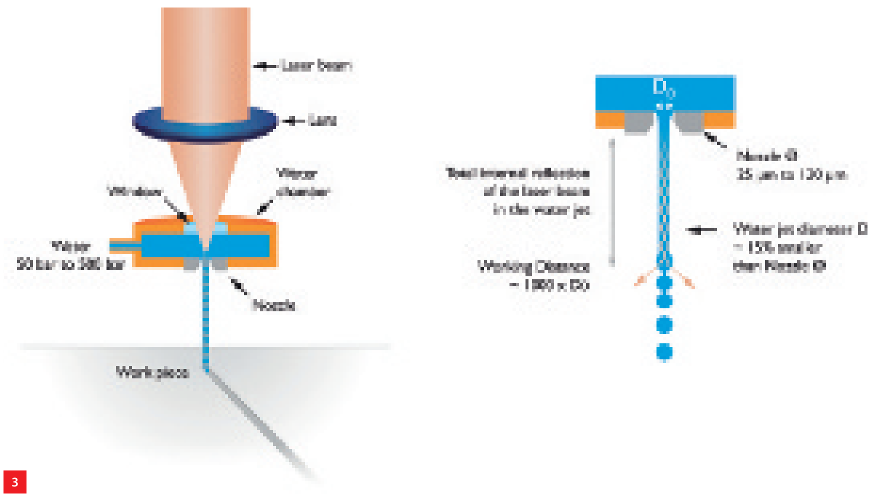

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unwanted thermal load, e.g. metallurgical restructuring of the parent material (subsurface damage, heat-affected zones, re-solidified particles and micro-cracks; see Figure 2). Moreover, working with traditional lasers rounds off geometry details. In general, shielding gasses are required to suppress these phenomena so as to obtain the required quality of cut.

What is striking is that either mechanical or electronic pulsation is addressed nowadays as a solution in case standard processes fail to do the job: ultrasonic machining (USM, Sauer) or precision electrochemical machining (PEM, PemTec). Quite recent R&D allows for solid-state lasers to be pulsed in a controlled manner to extremely short durations, typically into the nano- and picosecond pulse range. These ultra-short-pulse lasers are to a certain extent redefining micro- and precision machining into radically modified solutions.

Almost any material can be ablated without overheating and structural changes at least up to the threshold between pico- and nano-pulses. Hence the ratio between pulse and interval time together with the pulse energy can be tuned so that the material instantaneously atomises like a flash and excessive heat does not get time to interact deeper into the bulk, resulting in the part staying cool (Figure 2).

2 *Impact of long- and short-pulse lasers. (Reproduced with permission from Clark-MXR, Inc.)*

3 *The Laser MicroJet principle; see text for explanation.*

4 *Comparison of the conventional (left) and the 'wet' laser machining lay-out.*

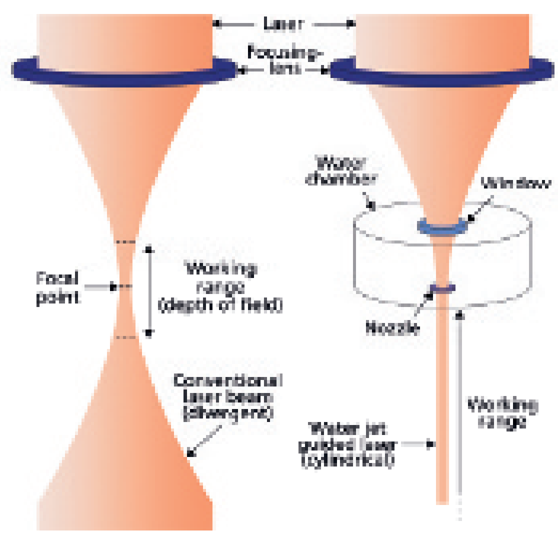
Smart water-assisted laser

The combined LMJ technology was introduced almost twenty years ago. Figure 3 clarifies the principle, Figure 1 shows the implementation in practice. It was invented and since then continuously developed by Synova, a start-up from the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. Integrating laser and water jet machining in a sole hybrid machining head introduced an innovative technology "that links W-EDM (wire-EDM, ed. note) quality to laser speed", as Dr Bernold Richerzhagen, the inventor and Synova president, likes to say.

Right from the start this still unique 'wet' approach to laser machining proved to be a powerful industrial tool on the market, strongly competing with LBM, EDM and WJM. Up to now, Synova has been presenting new claims, greatly exceeding the earliest goals. The striking difference in beam handling is immediately clear (Figure 4) when comparing the traditional photonic laser principle with the advanced LMJ. In both processes the main laser beam is optically focussed to a narrow spot of a defined diameter.

Fundamental phenomena

Looking closer at the LMJ set-up, Figure 3 shows how a concentrated beam enters through a quartz window into a pure-water-filled pressure chamber, passes this key component and enters the waterjet nozzle on the opposite side. H_2O is aptly transparent to the selected pulsed lasers in



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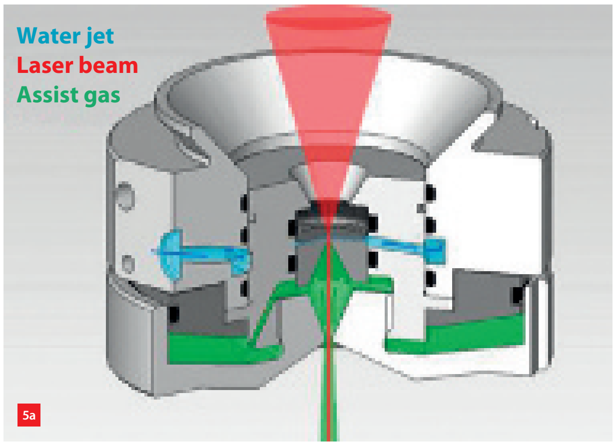

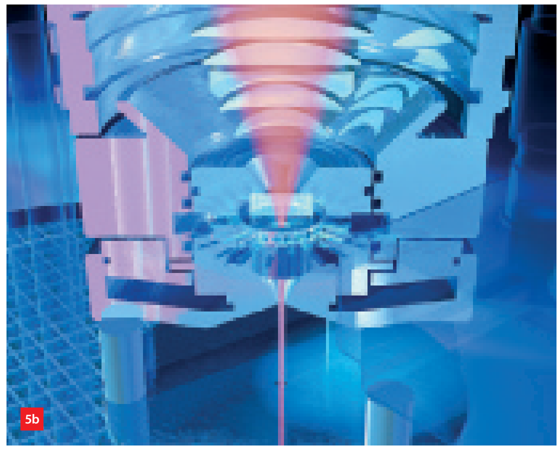

characteristic wavelengths between 220 nm (UV) and 1,100 nm (IR). Using the difference in refractive index between light (n = 1) and water (n = 1.3) at the interface allows for optics with large numerical apertures.

The LMJ platform uses diode-pumped solid-state Nd:YAG lasers with either 1,064 nm wavelength or most frequently 532 nm (frequency-doubled, green) or 355 nm (tripled), or modern fibre lasers (emitting at 1,070 nm). Pulsing decreases the resulting heat influx even more. Near-UV types are very promising for future applications. Diode-lasers, however, show too high an absorption in water. At the moment, applied laser power ranges in general between 20 and 200 W.

The compact pressure chamber is in itself a masterpiece of engineering in terms of its functional complexity (Figure 5). A special diamond nozzle (diameter D, 30-150 µm) is mounted at the exit to generate an ultra-fine waterjet with a diameter of approx. 0.83·D, as thin as a human hair. Mounting a bigger nozzle diameter increases cutting speed. The low-pressure laminar jet – low meaning on average 50-300 bar, as compared to 6,000-8,000 bar for waterjet cutting – guides the separate laser pulses over the entire, exceptionally long and yet perfectly cylindrical working distance (≤ 100 mm or max. 1,000·D) straight to the surface of the workpiece – without the divergence of classic LBM that leads to a V-shaped bore.

5 *The pressure chamber as the heart of the LMJ.*
(a) Schematic.
(b) Artist impression.

Synova strategy

Synova (75 employees, of which more than 25 engineers) operates five LMJs in its fully equipped application lab (Figure 6) – plus two in the job shop – at its Lausanne headquarters in Switzerland. Several dedicated micromachining centres serve as customer support, spread all over the world.
To expand the existing technology and application fields even further, research is being done mostly in a collaborative project manner with several leading industrial and scientific laboratories such as EFPL Lausanne, EMPA (Swiss Federal Laboratories for Materials Science and Technology), BFH (Bern University of Applied Sciences, Switzerland) and Fraunhofer ILT (Aachen, Germany). Producing professional wet laser micro-cutting configurations on demand is done in-house. Top-ranking machine manufacturers and engineering agencies – such as Disco, Rena, Posalux and Makino – are co-developing as well, ensuring that the latest trends in machine tool building will be integrated in new LMJ generations.

6 *Impression of the application lab at Synova's headquarters.*

Breaking news this spring was the acquisition of a 33.4% equity stake by De Beers Group, the world's leading diamond company. This raises expectations concerning the progress of the high-tech LMJ development.

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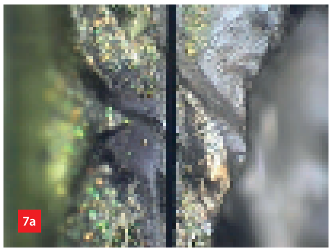
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7d

The LMJ principle is more or less identical to that of an optical glass fibre, but here the beam is contained inside the waterjet. The jet simultaneously takes care of focussing the laser beam (through total reflection of the beam at the water-air interface inside the jet) and cooling the workpiece. Naturally, over the long working distance the pressure of the jet decreases and eventually the jet breaks up into droplets.

Operating principle

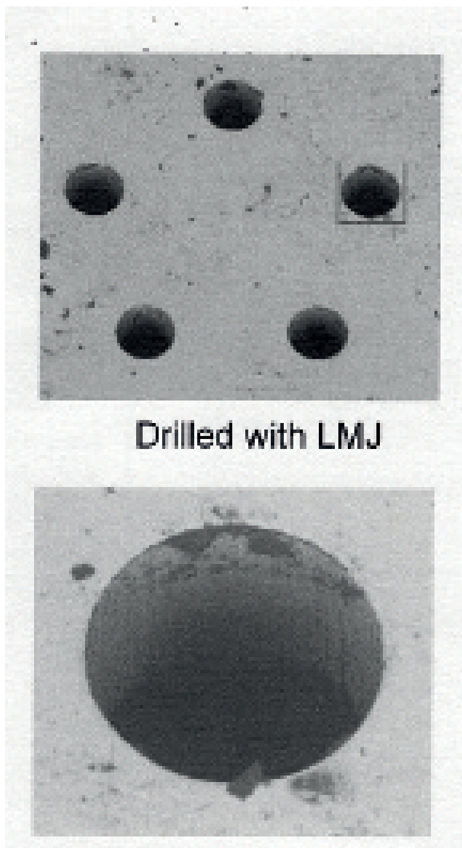
On hitting the top surface, the actual laser energy is efficiently transferred to the material to be processed, while simultaneously a plasma is generated, separating the water and the part. Within each pulse the stock removal principle is based on heating, plasma generation, ablation and cooling (around room temperature).

Relatively fast, the workpiece traverses, CNC-controlled, over the programmed trajectory by way of an X-Y-table, using linear motors as dynamic drives for increased cutting speed. With each quick pass the narrow contour is automatically ablated downwards – corresponding in width to the waterjet diameter + 2 to 5 µm. The grooving is done in thin layers of approx. 25 µm without adjusting the focus and yet attaining an identical quality of cut. Foils of maximum 400 µm thickness have however been cut in one pass. The smallest kerfs just go down to 20 µm, while in the laboratory tests are even running down to a minimum of 10 µm.

An integrated water system filters, deionises, degasses, pressurises and controls (e.g. the pH value) the water supply. The force of the water jet effectively expels the molten particles, eliminating burrs and contamination. Both jet and beam complement each other perfectly in a highly productive way at an acceptable cost-of-ownership and return-on-investment level. In a unique, cool and most efficient manner, this hybrid 'wet' laser integrates the advantages of both WJM and pulsed LBM in one precision technology. In this way, the combined effect of 'water and fire' exceeds by far that of the individual components.

Intrinsic technological advantages

LMJ is a versatile and contactless, no-wear industrial process with high reliability. 2D and freeform, omni-directional precision machining is achieved with high accuracy and a directly applicable surface quality (down to 0.3 µm R_a; finishing operations are superfluous in most cases) with high depth-to-diameter aspect ratios in one set-up from one side. Figure 7 shows some examples. No complicated and expensive focussing system is required (Figure 7d), neither are shielding gasses. The clean cut – with a repetition precision of approx. 3 µm over the full 300 mm stroke – exhibits no side effects (or only on a reduced scale, as compared to the traditional laser cut) such as burrs, re-deposition, contamination, outgassing, thermal damage



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7 *Examples of LMJ machining.*
(a) A diamond cut.
(b) A CuBe blade spring.
(c) A brass watch part.
(d) Curved parts, cut without focal adjustment.

8 *A sharp-edged and clean LMJ-drilled hole (160 µm diameter).*

Table 1. Range of application-oriented LMJ platforms.

LCS	Laser Cutting System
DCS	Diamond Cutting System
LDS	Laser Dicing System
LSS	Laser Stencil System
LGS	Laser Edge Grinding System
HLS	Hybrid Laser Saw
MCS	Makino Cutting System (Figure 9)

9

10

9 *The Makino Cutting System, MCS, to date the LMJ platform with the largest clamping table and the largest working range.*

10 *The modular LMJ-iP integration platform.*

like heat-affected zones, oxidation or induced mechanical stresses (no micro-cracks or warping). This is due to the low process forces (< 0.1 N) and the cooling effect of the jet.

Eliminating some of the problems associated with 'dry' LBM results in high-fracture-strength components with acute-angled edges on the top and bottom of a cut, and at the entrance and exit of holes, with smooth parallel sides (Figure 8). LMJ features much sharper corners and even minimal radii at the bottom of a blind cut. Several main application areas are solely based on this distinguishing feature.

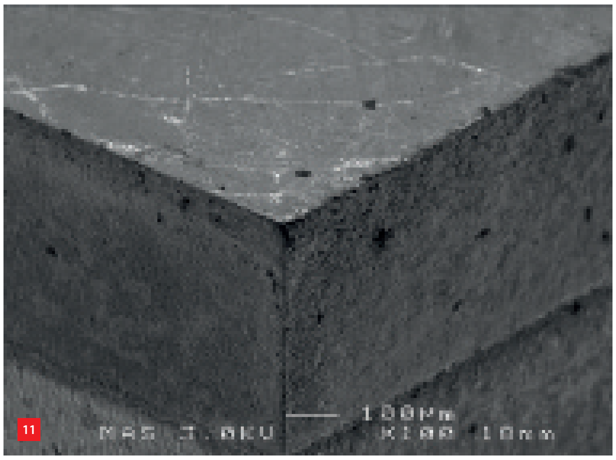
Typically, a wide array of ultra-hard, brittle, tough or very sensitive, either conductive or isolating materials can be tackled as long as the specific absorption is high enough for the laser wavelength selected (reason why CO_2 is excluded). Amongst them are natural and synthetic mono- and polycrystalline (PCD) diamonds, high-temperature metals and alloys (CuBe, invar, W, WC, Mb, Ni, Ti, Co, Cr), ceramics (AlN, SiN, Si_3N_4, ZrO_2, CBN), carbides of silicon and tungsten, semiconductors (Si, Ge, GaAs, InP), fibre composites (including CFRP) as well as modern coatings. Only the machining of transparent plastics and fabric, glass, wood, paper and textiles is not feasible.

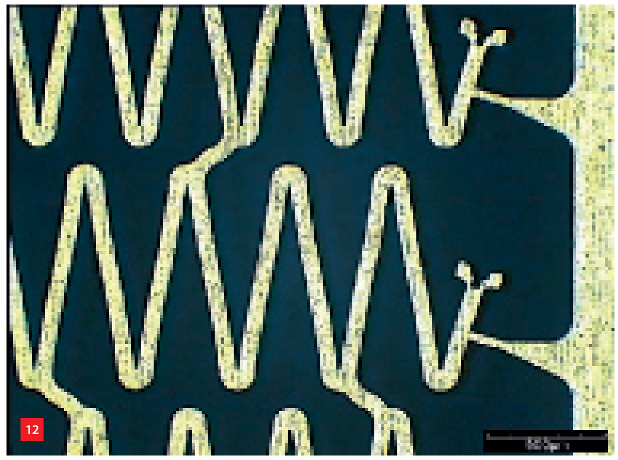
Applications

Today the application field is spread very wide, from electronics, automotive, die & mould, medical, photovoltaics, semiconductors and high-tech parts to consumer goods production, micromachining and wafer processing. Table 1 gives an overview of application-oriented LMJ platforms. However, the many inherent potentials are still not generally known. The level of consumables usage such as energy and water (max. 1 l/min) is almost negligible. The challenge with this new industrial process now is to expand its technology database, as only a rather restricted set of parameter values (for material type, hardness, surface roughness, thickness, etc.) has been tested to date.

In response to customer demand, Synova developed the LMJ-iP integration package as an extension of the line of turnkey systems (Figure 10). This complete module is a flexible alternative offered to companies who either want to build their own dedicated LMJ system or integrate it into production facilities. The iP comes with all the core subsystems such as optical head, laser source and water unit as well as adequate training.

Safety aspects for the LMJ are covered by a proper set of built-in and interlocked measures. For example, the laser is switched off automatically if the water pressure drops below a certain level. So when operating the class-4 laser system with the door closed there is no danger for the operator optically, hydraulically or mechanically. Fumes are





11 *A 'wet' laser dicing cut (left) compared to a traditional wire-EDM cut (right).*
12 *Extremely narrow kerf in a NiTi stent.*

extracted by the integrated exhaust system. Some of the small footprint machines so far delivered are 'clean room fit' or 'vacuum fit'.

Wafer and doping

The LMJ technology already well-established in a number of sectors is by far best known in wafer processing, whether separating circuits in straight cuts or freeform contouring of special geometries. Both smaller cutting width, finer details and a micro-crack-free end-zone raise the yield, at an absolutely minimal loss of precious material (Figure 11).

The main differentiating feature of the latest innovation is spreading an additional inert water film by an extra nozzle as a far more effective flushing agent over the surface. Removing the bulk of the ablation debris without disturbance, there is no further need for surface protection as the LMJ process becomes even cleaner. Compared to the existing way of producing semiconductors, far less contamination by rebounding particles occurs thanks to optimised chip removal without additives, gasses, photo resist or any other type of coating.

Calling on the help of a waterjet-guided laser an LMJ procedure totally contrasting with the standard one – laser pipe cutting – could be developed for producing stents. These medical instruments can now be fine-cut precisely out of foil and formed and welded in a secondary operation (Figure 12).

Laser chemical processing (LCP) has been under development for a while now, with ultra-pure water substituted by a specific chemical solution in the LMJ procedure. The latest LCP system is now being offered as a unique blend of geometrical machining freedom (grooving without masks) for passivating layers and a doping system for raising the efficiency of Si solar cells by implanting selective emitters.

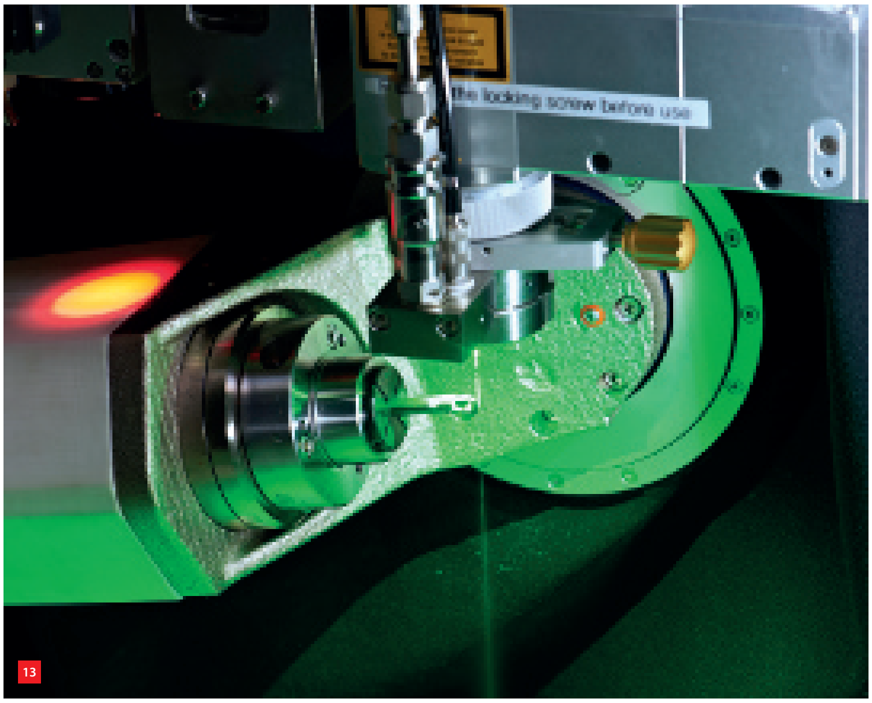
Roadmap

Lots of expertise has been collected in practising the cutting-edge LMJ technology over the years in quite different application fields. As a consequence, more directly applicable technology and machining strategy settings will in the near future be incorporated in the memory of the CNC control, as is for example nowadays fully accepted in EDM die sinking and wire-cutting.

Synova is focussing more and more on state-of-the-art tooling and die & mould manufacturers and other SMEs, in a direct confrontation with precision EDM. This summer, the first in-house built 5-axis TCS/TDS50 was unveiled (with 50x50 mm working range), which – small in price and footprint – even competes on a one-to-one basis with EDM in producing advanced fine-cut tooling in wear-resistant new technical materials (< 200 nm R_a average; Figure 13). This more complex multi-axis machine features in-process measuring by way of a Renishaw touch probe, following the trend in advanced machine tools.

Furthermore, following the LMJ history a trend can be detected towards increasing both the water pressure – from originally 50-250 bar up to 500 bar – and the laser power from an average 100-200 W towards maximum 500 W. In this way, appropriate process innovations are being tested towards new applications such as machining thicker CFPR stock.

Micro- and precision drilling – usually in the trepanning mode – have an enormous LMJ potential in industrial use, if only looking at the immense number of holes produced each day. Within this application segment there exist quite



13 *New 5-axis TCS/TDS50 cutting tool.*

divergent requirements as to geometries, strategies, diameters, angles of attack, tolerances and so on. Think of all the small cooling, lubricating and venting holes, guidance and measuring bores and single or multiple gas or liquid injection nozzles, simultaneous production of chamfers, leading and trailing edges and special types of fan shapes or turbulated ('corkscrew') holes for optimising modern high-performance gas turbines in industry.

A European Union project (PARD - LMJ) is in full swing for realising LMJ drilling process adaptations that deliver holes with large length-diameter ratios without being disturbed or blocked by debris. Also, future options are foreseen in the direction of fully-automated processing under autonomous process control.

Conclusion

Combining the two modern technologies of classic laser machining and water-jetting in a smart, very promising way expands existing possibilities and opens new perspectives. The multiply patented Laser MicroJet technology solves major 'dry' laser machining problems, e.g. by enabling a spectacularly longer working distance and higher cooling power. As described above, the characteristics of this typical 'wet' LBM synergy – together with the customised machine tools realised – show proven advantages and near inconceivable possibilities on the way to general acceptance in industry. ■

LMJ in the Netherlands

The very promising LMJ machining technology is available in the Netherlands via the well-known EDM job shop Ter Hoek Vonkerosie in Rijssen (Figure 14), operating an MCS300 (built by the Japanese Makino Milling Co., and sold by Synova) as of September 2014.

14 *Bird's eye view of Ter Hoek's EDM job shop.*

GENERATION AND CUSTOMISATION OF REFERENCE DATASETS

AUTHOR'S NOTE

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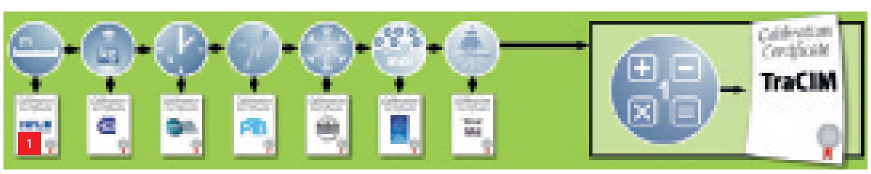
Results in coordinate metrology heavily depend on calculations performed on a measured point cloud. Whereas the infrastructure ensuring the traceability by calibration of hardware and instrumentation is well established, this is not the case for the traceability of computed results by software verification. A possible approach was developed in the European TraCIM project: the use of reference datasets which consist of (at least) an input-output pair known to be mathematically correct.

GERTJAN KOK

Introduction

In metrology, traceability requires that measurement results can be linked to references (such as measurement units) through a documented unbroken chain (Figure 1). If the chain involves computation, it is necessary that all computational links are recognised explicitly and known to be operating correctly. This requirement is particularly acute in coordinate metrology involving complex geometries. Since there are in the order of 40,000 coordinate measuring machines in the EU, each relying on complex algorithms to measure a range of parts, the impact of poorly performing software is potentially large.
Before software and computed results played such an important role, establishing traceability was achieved through a series of calibrations, performed according to documentary standards, using purely physical reference standards. For metrology systems involving significant computation, there are few comparable traceability mechanisms in place.



1 *Traceability requires that measurement results can be linked – through a documented unbroken chain – to references. Besides measurement units these references include datasets for software verification; these were developed in the TraCIM project.*

The impact of poorly performing software has been observed in the field of gear metrology, where an inter-comparison among world-leading coordinate measuring machine (CMM) manufacturers showed that the influence of software, i.e. different software packages producing different results, was about a factor of 20 greater than other uncertainty contributors. In the measurement of camshafts, typical tolerances on form are of the order of 0.5 μm while an analysis of the performance of assessment algorithms has shown discrepancies of up to 10 μm [1].
See also [2] for an evaluation by NIST of software aimed at solving maximum-inscribed, minimum-circumscribed, and minimum-zone (Chebyshev) fit objectives. It was found that not all software packages return correct solutions.

In dimensional metrology, the reliance on complex algorithms is increasing rapidly. Optimisation of part performance has meant that geometries of greater complexity are used in engineering. Many standards for part assessment, such as the ISO Geometric Product Specification (GPS) tolerancing system [3], require algorithms that minimise the maximum deviation from measured data to the CAD model, and require sophisticated optimisation algorithms to perform the analysis. At present, there is practically no information on the quality and correctness of the software implementing these algorithms.

In fact, there is no agreed methodology for evaluating the software for fitness for purpose.

A way of verifying software and establishing traceability is by using reference datasets which consist of an input-output pair known to be mathematically correct (up to the number of displayed decimal digits). Hereby it is important to note that the computational task or computational problem to be solved is unambiguously defined.

An example of a computational problem allowing multiple and mathematically different definitions is fitting a 3-dimensional circle to a point cloud based on the least-squares criterion. This can be defined as minimising the sum of the squared distances of the points to the circle rim in a truly 3-dimensional sense, or by projecting the points first to a best-fit plane, and subsequently determining the best-fit 2-dimensional circle in this plane. Another example is the choice of defining distances as orthogonal to a surface, or taken along the z-axis of the coordinate system.

Similar issues with respect to software quality and verification arise throughout the scientific community, as several scientific publications had to be withdrawn due to errors in the software. See e.g. an editorial in Nature Biotechnology [4].

Reference data generation

RDG (reference data generation) is a key step in the assessment of software. An appropriate number of reference datasets must be generated to ensure that the full range of problems intended to be solved by the software is adequately covered.
For many computational aims, approaches for reference data generation are well known. RDG is typically implemented in one of the following ways:

- Forward RDG, in which reference input data is taken and used to produce corresponding reference output data.
- Reverse RDG, in which reference output data is taken and used to produce corresponding reference input data.

Forward RDG typically requires the availability of 'reference software' known to produce correct output. This reference software processes reference input data to produce reference output data. The construction of reference software can be both complicated and costly. It may involve a detailed mathematical analysis, complete enumeration of all candidate solutions, and comparison of several implementations on several machines to get enough confidence in the software. Availability of extended-precision arithmetic helps to strongly reduce the effect of round-off errors in the software.

Reverse RDG generally requires an analysis of the computational aim to be achieved so that reference output data can be processed to obtain reference input data, and in some cases this is much simpler to implement than forward RDG. For computational aims involving a least-squares optimisation the so-called null-space method [5] is often used in this context. The essence of this method is that perturbations are applied to a point cloud X^* containing points $\boldsymbol{x}_i^* = (x_i^*, y_i^*, z_i^*)$ lying on a curve/surface (e.g. circle) in such a way that the solution parameters $\boldsymbol{a}$ (e.g. circle centre and radius) for the best fit curve/surface to the perturbed point cloud X remain unchanged. Below, this method will be presented in more detail.

Let $d_i = d(\boldsymbol{x}_i, \boldsymbol{a})$ denote the distance of point $\boldsymbol{x}_i$ to the curve or surface parameterised by $\boldsymbol{a}$. Denote the sum of the squared distances of the m data points by

$$D(X, \boldsymbol{a}) = \sum_{i=1}^{m} d^2(\boldsymbol{x}_i, \boldsymbol{a}) \qquad (1)$$

Then the optimisation problem can be posed as to find $\min_{\boldsymbol{a}} D(X, \boldsymbol{a})$.

The points $\boldsymbol{x}_i$ can be written as $\boldsymbol{x}_i = \boldsymbol{x}_i^* + d_i \boldsymbol{n}_i^*$, where $\boldsymbol{x}_i^*$ is called the footpoint of $\boldsymbol{x}_i$ on the curve/surface – it is the point on the curve/surface closest to $\boldsymbol{x}_i$. The vector $\boldsymbol{n}_i^*$ denotes the outward normal at $\boldsymbol{x}_i^*$. Let J^* be the Jacobian matrix with

$$J_{ij}^* = \frac{\partial d}{\partial a_j}(\boldsymbol{x}_i^*, \boldsymbol{a})$$

It turns out that if $J^{*\mathrm{T}} \boldsymbol{d} = \boldsymbol{0}$, then $\boldsymbol{a}$ is the solution to the optimisation problem (1), where $\boldsymbol{d} = (d_1, \ldots, d_m)$.
Note: Strictly speaking it needs also to be checked that the Hessian matrix containing the second derivatives is strictly positive definite, which is mostly the case for relatively small perturbations $\boldsymbol{d}$. Furthermore, the solution $\boldsymbol{a}$ corresponds to a local solution, which in the majority of cases is also the global solution. $\boldsymbol{J}^{\mathrm{T}}$ denotes the transpose matrix of $\boldsymbol{J}$.

This procedure can be reversed by starting with a solution vector $\boldsymbol{a}$ and data points $\boldsymbol{x}_i^*$ lying on the surface/curve, then calculating the normals $\boldsymbol{n}_i^*$, and the matrix $\boldsymbol{J}^*$. Subsequently one has to find perturbations d_i such that $J^{*\mathrm{T}} \boldsymbol{d} = \boldsymbol{0}$.
This can be done by calculation of the QR-factorization [6] of J^*, i.e. $J^* = Q\,R$, and writing the factors Q and R as follows:

$$J^* = [Q_1 \quad Q_2] \begin{bmatrix} R_1 \\ 0 \end{bmatrix}$$

Now for any vector $\boldsymbol{b}$ of appropriate length, the perturbations $\boldsymbol{d} = Q_2\, \boldsymbol{b}$ are such that $J^{*\mathrm{T}} \boldsymbol{d} = \boldsymbol{0}$, and if $\boldsymbol{b}$ is sufficiently small, the point cloud $X = \{ \boldsymbol{x}_i = \boldsymbol{x}_i^* + d_i \boldsymbol{n}_i^* \}$ has as best fit solution $\boldsymbol{a}$. There is still freedom to choose $\boldsymbol{d}$ in such a way that it has a particular covariance structure, or that the resulting point cloud X is close to real measurement data.

This null-space method is very broadly applicable to least-squares fitting problems. The big advantage is that the reference solution $\boldsymbol{a}$ is exactly known for the point cloud X, instead of only approximately, which would be the case if the perturbations $\boldsymbol{d}$ would have been chosen in a completely random way.

Generation of datasets

In the framework of the TraCIM project (see the box), datasets for (amongst others) least-squares optimisation problems were created. This included datasets for standard geometric elements (circle, plane, etc.), NURBS surface fitting (position and rotation only, fixed surface parameters), polynomial regression curves, and line shape fitting (like Gaussian profile fits). In the project also some limited work has been done regarding Chebychev (minimum zone) fits of geometric elements. Benchmarking reference datasets will become available on [8] and [9].

In order to ensure the correctness of the generated reference datasets, they were generated according to the following steps (see also Scheme 1):

1. Starting with the desired solution parameters $\boldsymbol{a}$ and the simulated measurement noise σ, a point cloud $\{ \boldsymbol{x}_i = (x_i, y_i, z_i) \}$ (i.e. reference input data) is generated using the null-space method in extended precision using 100 decimal digits.
2. A forward fitting routine is applied to the point cloud and it is checked that at least 50 digits of the reference solution $\boldsymbol{a}$ are found back. If a discrepancy is found, either the input data generation of step 1 or the fitting routine of step 2 may be erroneous.
3. The reference input data (x_i, y_i, z_i) is rounded to 16 decimal digits so that it can be easily loaded into software using standard double precision, and reference input and output are saved to text files.
4. The generated text files are loaded into the software once more and the fitting routine is applied to the input data and calculated results are compared with the loaded reference result. This step is performed in order to reduce risk of errors when writing the reference dataset to the file.

Customisation of datasets

As to explore the entire space of input data to which the software may be applied, one should be able to customise the reference datasets. This customisation can be done by selecting appropriate parameters in the generation process, but also by applying a mathematical projection of measurement data to a null-space in the generation process. The result is a reference dataset which closely mimics real

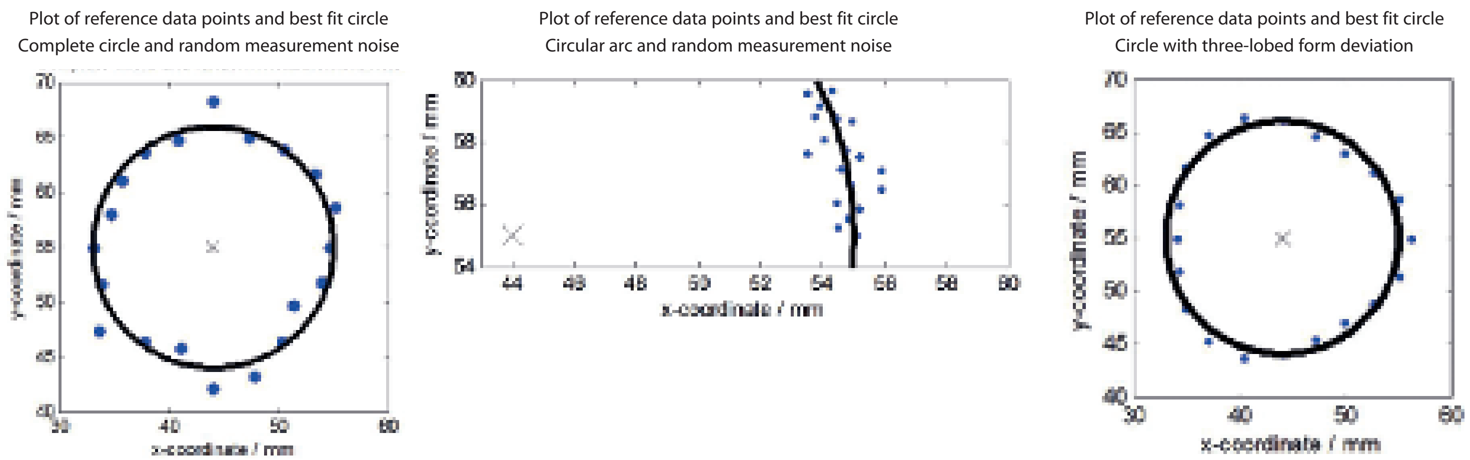
EMRP TraCIM research project

The EMRP project NEW06 TraCIM 'Traceability for computationally-intensive metrology' [7] is part of the European Metrology Research Programme (EMRP).
Partners in the project include:

- NPL (United Kingdom)
- Cesky Metrologicky Institut Brno (Czech Republic)
- Istituto Nazionale di Ricerca Metrologica (Italy)
- Physikalisch-Technische Bundesanstalt (Germany)
- Univerza v Mariboru (Slovenia)
- VSL (the Netherlands)
- Hexagon Metrology PTS (Germany)
- Mitutoyo CTL Germany (Germany)
- Werth Messtechnik (Germany)
- Carl Zeiss Industrielle Messtechnik (Germany)
- University of Huddersfield (United Kingdom)
- Westsächsische Hochschule Zwickau (Germany)
- Ostfalia Hochschule Wolfenbüttel (Germany)
- University of York (United Kingdom)

Start → Create reference data pair using null-space method for least-squares computational aim using 100 digits. → Validate forward fitting routine by fitting parameters and check for 50 correct digits. → Round data to 16 digits (supplemented with zeros) and perform new fit with validated forward algorithm. → Save data to file, reload data, and apply once more the fitting routine. Check criterion: $4\cdot10^{-15}$ → End

Scheme 1. *Procedure for generation of reference datasets for least-squares fitting problems.*



2a 2b 2c

2 *Three reference datasets for a two-dimensional circle fit based on the least-squares criterion.*
(a) A full circle with random measurement noise.
(b) Data for a small circular arc.
(c) A full circle with a three-lobed form deviation.

measurement data, but for which the solution is exactly known, and not only approximately. In Figure 2 three reference datasets are plotted: a full circle with random noise, a circular arc and a full circle with a three-lobed form deviation.

Customisation of datasets can also be used to create special cases with e.g. datasets having points occurring more than once, or datasets with all points being perfectly aligned.

Performance metrics

When comparing the test results of test software with the reference results a decision has to be taken regarding which magnitudes of the differences between test and reference results are acceptable, and which are not. For typical measurements using CMMs one may require that uncertainties of computed results should be better than 1 nanometer in order to be completely irrelevant compared to other sources of uncertainty. This approach may be valid when e.g. fitting a full circle to a point cloud (Figure 2a).

However, when fitting a small arc of a circle to data, small perturbations in the data may induce much larger variations of the radius and centre point of the fitted circle, due to the conditioning of the fitting problem (Figure 2b). It may thus be unreasonable to require a correspondence of better than 1 nm between test result a_{test} and reference result a_{ref}. Software quality can be quantified by defining a performance metric P that takes into account the sensitivity of the output result due to perturbations in the input result, e.g. in the form

$$P = \log_{10}\left(1 + \frac{|a_{test} - a_{ref}|}{S\,u}\right)$$

Here, S denotes an overall sensitivity coefficient of result a to perturbations of relative size u to the input data (e.g. calculated using a Monte Carlo procedure). u may be chosen equal to the measurement uncertainty or to the working precision of the computer (approximately 10^{-16} for standard double-precision arithmetic). P will be approximately equal to the number of decimal digits that are lost in the computation in excess of the number of digits that are expected to be lost due to the conditioning of the problem.

In order to facilitate the calculation of S and of related sensitivity measures we included into our reference datasets the partial derivatives $\partial a_j/\partial x_i$, $\partial a_j/\partial y_i$ and $\partial a_j/\partial z_i$ for all components a_j of the output reference result to all components x_i, y_i, z_i of the input reference data.

Formal software certification

Computational routines included in metrological software packages may be assessed with publicly available benchmarking datasets to get a first idea on their correct performance. In order to obtain more confidence and establish full traceability a formal verification of the software by a national metrology institute (NMI) is required. VSL offers this service for a variety of computational tasks [9].

Conclusion

Due to the growing importance of computations in metrological software, there is also an increasing awareness for the need of software verification. In the TraCIM project some work was performed to address this need by creating reference datasets for a variety of problems, and by defining performance metrics that allow a fair assessment of the software under test.

Acknowledgment

This work has been undertaken as part of the EMRP Joint Research Project NEW06 'Traceability for computationally-intensive metrology', co-funded by the Dutch Ministry of Economic Affairs and the European Union. The EMRP is jointly funded by the EMRP participating countries within EURAMET (European Association of National Metrology Institutes) and the European Union. ■

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UPCOMING **EVENTS**

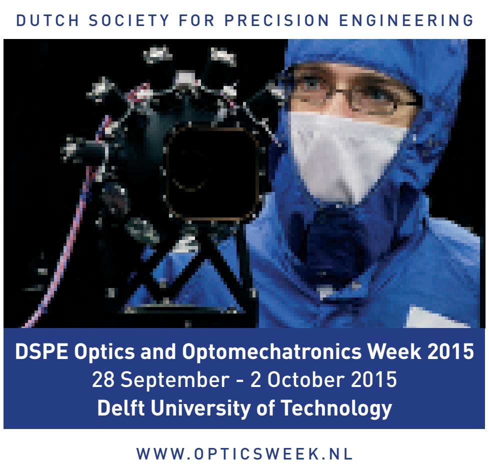
10 September 2015, Eindhoven (NL)
Annual conference High Tech Platform
Second edition of the annual conference of the Mikrocentrum platform. The theme of this event is "Inspiration & Innovation".

WWW.MIKROCENTRUM.NL/HIGH-TECH-PLATFORM

21-24 September 2015, Den Haag (NL)
MNE 2015
The 41st international conference on micro- and nanofabrication and manufacturing using lithography and related techniques is devoted to recent progress and future trends in the fabrication and application of micro- and nanostructures and devices.

WWW.MNE2015.ORG

28 September - 2 October 2015, Delft (NL)
DSPE Optics and Optomechatronics Week 2015
First edition of this event, featuring a symposium on Monday 28 September and two courses on the following days.
See also page 12 ff.



WWW.OPTICSWEEK.NL

1 October 2015, Den Bosch (NL)
Bits&Chips Smart Systems 2015
Second edition of the annual event on embedded systems and software, focussed on the development of networked technical information systems. Combination of Bits&Chips Embedded Systems (since 2002) and Bits&Chips Hardware Conference (since 2008). The target group includes academia, researchers, designers, engineers and technical management.

WWW.BC-SMARTSYSTEMS.NL

7 October 2015, Bussum (NL)
13th National Cleanroom Day
Event for cleanroom technology users and suppliers in the fields of micro/nano-electronics, healthcare, pharma and food, organised by the Dutch Contamination Control Society.

WWW.VCCN.NL

8 October 2015, Eindhoven (NL)
PiB day VDL ETG
DSPE and VDL ETG organise a Precision-in-Business day for DSPE members. Topics include VDL ETG's transition from 'build-to-print' to 'build-to-spec' and the combination of technology roadmapping and system architecture.

WWW.DSPE.NL/CENTRAAL/EVENTS/PIB-VISITS-VDL-ETG

13-15 October 2015, Karlsruhe (DE)
DeburringEXPO
Trade fair for deburring and polishing technology. Read also the article on page 44 ff.

WWW.DEBURRING-EXPO.COM

1-6 November 2015, Austin (TX, USA)
30th ASPE Annual Meeting
Meeting of the American Society for Precision Engineering, introducing new concepts, processes, equipment, and products while highlighting recent advances in precision measurement, design, control, and fabrication.

ASPE.NET

2-6 November 2015, Leiden (NL)
LiS Academy Summer School Manufacturability
Summer school targeted at young professional engineers with a limited knowledge of and experiences with manufacturing technologies and associated manufacturability aspects.

WWW.LISACADEMY.NL

18-19 November 2015, Veldhoven (NL)
Precision Fair 2015
Fifteenth edition of the Benelux premier trade fair and conference on precision engineering, organised by Mikrocentrum. Some 300 specialised companies and knowledge institutions will be exhibiting in a wide array of fields, including optics, photonics, calibration, linear technology, materials, measuring equipment, micro-assembly, micro-connection, motion control, surface treatment, packaging, piezo technology, precision tools, precision processing, sensor technology, software and vision systems.

WWW.PRECISIEBEURS.NL

25 November 2015, Utrecht (NL)
Dutch Industrial Suppliers Awards 2015
Event organised by Link Magazine, with awards for best knowledge supplier and best logistics supplier, and the Best Customer Award.

WWW.LINKMAGAZINE.NL

1 December 2015, Hilvarenbeek (NL)
Motion & Drives 2015
New theme day organised by Mikrocentrum. Motto: "Your motion in control".

WWW.MIKROCENTRUM.NL

8-9 December 2015, Amsterdam (NL)
International MicroNanoConference 2015
Microfluidics, nano-instrumentation and surface modification are the main topics of this industry- and application-oriented conference, exhibition and demo-event.

WWW.MICRONANOCONFERENCE.ORG

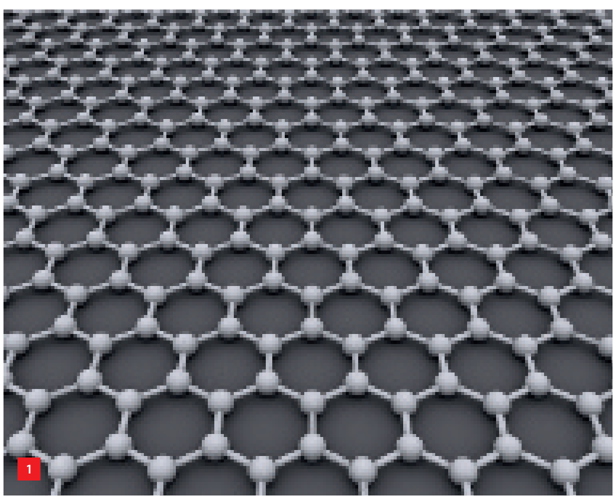
AFTER THE HYPE

The second edition of the Dutch Graphene Conference was organised by Mikrocentrum at Delft University of Technology (TUD), the Netherlands. The programme comprised a broad overview of the technology and functionality of graphene, that single layer of carbon atoms with amazing properties. From a precision engineering point of view, TUD professor Urs Staufer gave an interesting lecture on the straining properties of graphene.

Graphene (Figure 1) is a very good electrical and thermal conductor. It is also extremely strong and flexible, while at the same time being transparent. These properties hold promises for a wide range of new applications. However, realising relevant applications with graphene as the key enabler is no mean feat. After the initial graphene hype, time has now come to move towards application-inspired pull of graphene technology development.

Production

At the Dutch Graphene Conference 2015, a number of specific developments were explored concerning graphene technology and graphene-based functionality. Both new electronic and sensor functionality, as well as development of graphene as the ideal membrane for hydrogen separation, were presented.



1 *Graphene is an atomic-scale honeycomb lattice made of carbon atoms. (Image courtesy of AlexanderAlUS [1])*

The first challenge is the reliable and scalable production of graphene. Guido Janssen from the Micro and Nano Engineering group at TUD presented recent developments in graphene deposition. These will be exploited in various projects of TUD and (industrial) partners sponsored by the STW Technology Foundation, aimed at high-quality individual crystals for electronic devices and sensors, and at high-quality wafer-scale layers for industry.

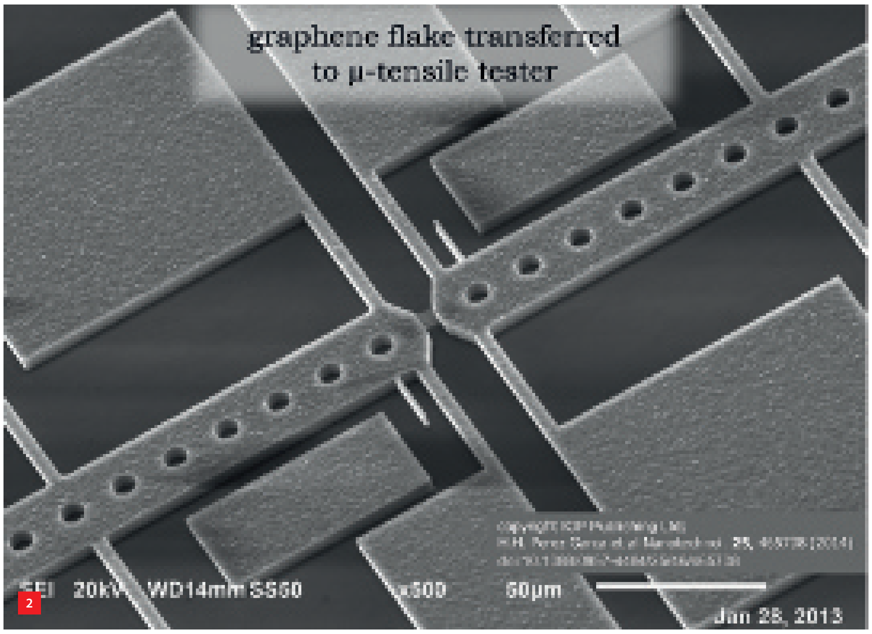
Electronic

Graphene nanoribbons (GNRs), for example, may have applications in electronics, due to exceptional electronic properties such as tunable band gaps and magnetic edge states under the condition of structural perfection at the atomic level. Pascal Ruffieux of EMPA, the Swiss Federal Laboratories for Materials Science and Technology, discussed a bottom-up fabrication strategy allowing for the growth of GNRs of atomically-precise width definition and edge control.

Another electronic application can be found in solar cells. In organic photovoltaics, graphene can be added as a mediator of the charge transfer properties. Prof. Wim Deferme of the Belgian University of Hasselt talked about the investigation into how the charges are transported after the process of charge separation and the role of graphene in this process.

Mechanical

Graphene is also known for its mechanical properties. Peter Steeneken of NXP Semiconductors in Eindhoven, the Netherlands, showed how the exceptional strength and flexibility of suspended graphene membranes enable pressure sensors with improved performance and reduced size.



The presentation of Chris de Ruijter of Promolding, based in The Hague, the Netherlands, was devoted to applications of graphene-based polymeric compounds in injection moulding and in Additive Manufacturing technologies such as FDM (fused deposition modeling) and SLS (selective laser sintering). The underlying phenomenon is that a small percentage of graphene within a polymer matrix can significantly improve its strength and stiffness (and impart electrical conductivity to the polymer).

2 *A graphene flake has been affixed in the centre of this micro-tensile device. [2]*

Prof. Urs Staufer, of the Micro and Nano Engineering group at TUD, introduced the straining properties of graphene. Theoretically, mechanical straining by 5% to 10% or more opens up the possibility to exploit new properties linked to the stressed lattice of this two-dimensional material, such as hydrogen storage or separation. In the Delft laboratories, strains of over 10% have been achieved by pulling graphene using a MEMS-based in-plane tensile device (Figure 2). This demonstrates the exceptional elasticity of graphene, which might be essential for practical applications. ■

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INFORMATION

WWW.DUTCHGRAPHENECONFERENCE.NL
3ME.TUDELFT.NL/MNE

FROM NECESSARY EVIL TO EFFICIENT TOOL

Burrs and chips are unavoidable in virtually all manufacturing processes used for series production. Today, the removal of these remnants from the production process is an absolute must for high-quality, precision parts. On the one hand, ever stricter requirements for deburring quality and process reliability have to be fulfilled; on the other hand, the deburring process continually has to be made more efficient.

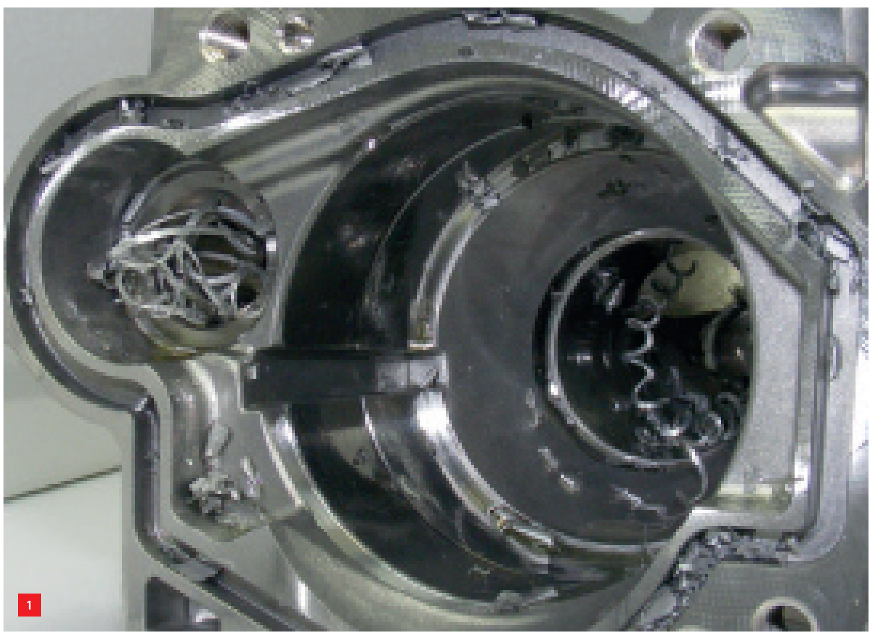
DORIS SCHULZ

AUTHOR'S NOTE

Doris Schulz is a journalist. Her agency, based in Korntal, Germany, specialises in PR solutions for technical products and services. This article was commissioned by DeburringEXPO organiser fairXperts and has already been publised (in part) in various manufacturing-related magazines.

www.schulzpressetext.de

Whether parts are manufactured by means of machining, metal forming or master forming – deburring usually doesn't fall into one of the part manufacturer's areas of core competence. And thus the removal of these remnants from the production process is often still seen as a necessary evil which increases unit costs. However, due to ever stricter requirements for product quality and functionality, intermediate and downstream processes like deburring are becoming more and more significant across all industry sectors. In addition to this, component geometry is getting continuously more complex, and parts are being made of new materials and material combinations.



1 *Where deburring is concerned, ever stricter demands are being placed on quality, process reliability and economic efficiency. (Source: Piller Entgrattechnik)*

This necessitates the use of technologies which are ideally matched to greatly varying deburring requirements and ensure good process reliability. Otherwise, not only does product quality suffer, but rather economic efficiency as well.

Predicting and minimising burrs

Machined workpieces often include difficult-to-access areas which have to be deburred, for example undercuts, grooves, slots, internal holes and holes which cross through each other. And the more complex the workpiece becomes, the more difficult it is to get at the burrs. But here as well, it's nevertheless crucial to remove burrs reliably, in accordance with the specified requirements and without adversely affecting the material. A further challenge is presented by so-called secondary burrs, which are caused by the deburring tool during the deburring process.

A model used to predict and minimise burrs makes a significant contribution to reliable and efficient deburring of workpieces made of steel and non-ferrous metals. It was developed by Berlin-based Dr.Beier-Entgrattechnik on the basis of a metal forming approach for the formation of burrs as a practical application. The goal is to provide production planning and design engineering with a tool

Trade fair for deburring and polishing technology

Which processes ensure efficient deburring with good reliability? Which new technologies are available for deburring and polishing? Which measures contribute to the reduced formation of burrs? Answers to these and many other questions are provided at DeburringEXPO, organised by fairXperts. The first DeburringEXPO will take place at the Exhibition Centre in Karlsruhe, Germany, from 13 to 15 October 2015.

The exhibition portfolio includes equipment, systems and tools for belt grinding, brushing, abrasive flow machining, vibratory grinding, blasting with solid and liquid media such as high-pressure water jets and CO_2 snow jets, abrasive water-jet blasting, magnetic-abrasive deburring, ultrasonic deburring, chemical bath deburring, electro-chemical machining (ECM), electron beam machining, thermal energy machining (TEM), mechanical deburring, buffing, polish honing, electrolytic polishing, plasma polishing, laser polishing, immersion and brush polishing, as well as measuring, test and analysis systems.

WWW.DEBURRING-EXPO.COM

based on a quick and practical means for predicting the formation of burrs, in order to optimise processes and make them more efficient.

The model incorporates findings from materials science and an engineering viewpoint of the machining and forming processes. The formation of burrs depends primarily on the material's stress-strain behaviour and the prevailing cutting forces. Elastic and plastic material characteristics are derived from the results of tensile tests. The determination or specification of cutting forces is based on relationships prevailing in the field of machining technology.

High-speed deburring

In the case of machined workpieces which are produced in large numbers, deburring takes place at the end of the automated manufacturing process, or after a sub-process. From an economic standpoint, a fully automated, high-speed deburring process which is executed directly in the machining centre or the CNC machine is the ideal solution.

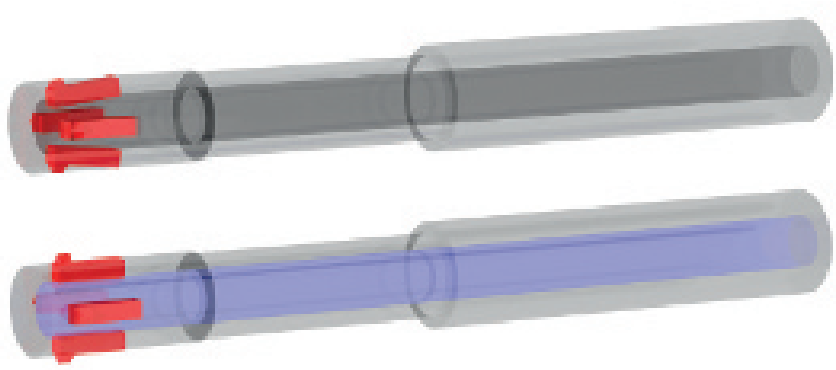
In order to prevent any slow-down of manufacturing processes with short cycle times and to assure uniform quality, reliable, automated and highly effective deburring methods are required. On the other hand, the utilised tools have to be matched to the application and must ensure that deburring results meet the specified requirements, even for complex workpieces with difficult-to-access burrs.

Furthermore, no secondary burrs may be caused by the deburring process. Special high-speed deburring (HSD) tools have been developed for applications of this sort.

The cutting force required by HSD tools is not generated by spring elements, but rather by a pressure medium, for example coolant, oil, compressed air or minimum-lubrication lines which are already available (Figure 2). This system has the advantage of maintaining force applied to the cutter at a constant level over a broad range of cutting tool deflection. The cutters are compressed the most inside a drill hole by its walls. Since there aren't any burrs here, excessive force applied to the cutter would alter or even damage the surface, and would result in unnecessary wear.

HSD tools develop the most force when the cutters are wide open, for example at the edges of drill holes where the drill first enters or exits the material, or the edge of a cross-hole or a groove which needs to be deburred – i.e. precisely where force is actually required for deburring, and if necessary for the production of a chamfer. These tools permit forward and reverse deburring, as well as the deburring of cross-holes, without any design changes.

All cross-holes, as well as the main hole's point of entry and exit, can be deburred through the main hole with an HSD tool in a time-saving fashion in a single work step. Different diameters of the cross-holes and any grooves or oblong holes that need to be deburred do not play any role in this respect. At the same time, specially shaped cutters assure that the burrs are not just bent over or pressed into the cross-holes.



2 *With HSD tools, force is built up at the cutters (red) by a pressure medium. (Source: Dr. Beier-Entgrattechnik) Top: Cutters retracted, no pressure. Bottom: Cutters activated by means of pressure.*

3 *The new CBD process permits automated deburring of oil holes which cross through each other with any diameter ratio and intersection angles of significantly less than 90°. (Source: Heule Werkzeug)*

Cross-bore deburring

The new, automated cross-bore deburring (CBD) process developed by Heule Werkzeug in Switzerland is used in first applications. It's a further development of the time-tested, modular COFA tool system, in the newest generation of which the cutter and the cutter retainer are separate (COFA is abbreviated from the German 'Kontur (Contour) Fasen', contour chamfer). The COFA design provides for increased economic efficiency, as well as improved productivity, and is opening up a broader range of applications as well.

Integrating the tool into the machining centre or CNC machine makes it possible to produce already deburred workpieces. No pre-adjustment of the COFA tool is required – the mechanically, accurately guided deburring cutter can be inserted or replaced manually, or with a jig. Its functional principle ensures uniform, radius-shaped deburring without any secondary burrs with a defined cutter at even and uneven drill-hole edges.

Forward and reverse processing is completed in a single run without reversing the spindle's direction of rotation, and without time-consuming turning of the workpiece. Part tolerances are compensated for automatically by the tool's operating principle. The COFA tool can also be used for workpieces made of difficult-to-machine materials such as stainless steel, titanium and Inconel®, starting from a hole diameter of 2 mm with practically no limits for maximum hole size.

However, use of the COFA system is limited in the case of holes which cross through each other with the diameter ratio approaching 1:1 and the intersection angle being less than 90°. Heule has developed the CBD process for applications of this sort, for example removal of internal burrs at the back of oil holes.

This tool system is also of modular design and can be integrated into the machine. But it makes use of a modified operating principle: deburring is axial (comparable to broaching) and feed is radial. As a result, the CBD process makes it possible for the first time to deburr cross-holes with nearly any diameter ratio and with intersection angles that are significantly less than 90° in an automated fashion within the machining process with a defined cutter (Figure 3). And high process reliability is achieved thanks to the strictly mechanical operating principle. ■

INFORMATION

WWW.BEIER-ENTGRATTECHNIK.DE
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PAYER OR INVENTOR?

The simple fact that you have paid for a development activity does not automatically mean that you are entitled to apply for a patent for an invention resulting from this activity. In principle, this right belongs to the person who made the invention. The right, however, may be transferred, either by law or by contract.

JOOST NELISSEN

(Source: Phantom hax0r, commons.wikimedia.org/wiki/File:Shared_IP.svg)

Companies employing inventors, in general, acquire the right to patents on their inventions, either by relying on national law or in an employment contract. The Dutch patent act is decisive for R&D activities in the Netherlands. Under Dutch law, the entitlement to inventions made by employees resides with the employer. However, increasingly, R&D activities are outsourced or are a joint effort. Cooperation, if not properly arranged, may obscure the entitlement to a patent, which may have a significant impact on future revenues generated by such R&D activities.

The mere creation of a development project and conducting work in a pre-development stage is not a sufficient basis for being entitled to a patent for an invention done later on in the development project, as Stork Prints found out, when claiming entitlement to a patent of FT Innovations (FTi). It initiated an in-house development activity, but made a no-go decision after a pre-development project. The court ruled that FTi did the actual invention subject of the patent [1].

For this reason, outsourcing of development activities might pose a risk to the outsourcing company regarding the entitlement to IP rights. In particular, when the outsourcing stretches beyond mere detailing of an invention already done, and in fact deals with finding a solution to a problem posed. Without any proper contractual arrangement, the outsourcing company might not be entitled to a patent even if it paid for the development.

In case of a joint-development contract, each of the participating companies may be equally entitled to a patent for an invention jointly made. However, this might also lead to an awkward situation, for instance if one of the companies wants to provide a license to a third party to use the patented invention or if one of the companies subsequently develops an 'own' product inspired by the joint activity. Under Dutch law, for example, such a license may only be provided when each of the patent owners agrees. Including proper IP-clauses in a joint-development contract is of high relevance for these kinds of situations.

Finally, even when you don't consider applying for a patent, but decide to rather keep the invention a secret, it is important to consider appropriation of the entitlement to a patent. A recent ruling demonstrates the possible adverse effects of the trade secret option in joint development [2]. In this case, Ruma Rubber, in return for an unlimited license, transferred the rights to apply for a patent regarding rubber compounds to Shell in a development agreement, thereby – albeit implicitly – abandoning their policy to keep the compounds a secret. The court ruled that also IP rights before the 'effective date' of the agreement belonged to Shell.

It is advised to take a careful look at entitlement to IP rights before initiating a development activity, or at least in a very early stage thereof. This does not have to be targeted primarily at acquiring protection, but in any case to safeguarding all options regarding IP (patents, trademarks, designs, copyright) and the legitimate use of one's development activity. This even goes for the option to keep an invention a secret! ■

AUTHOR'S NOTE

Joost Nelissen is European Patent Attorney at AOMB IP Consultants, based in Eindhoven, the Netherlands. He is a specialist in acquiring and enforcing IP rights and guiding companies through the field of IP information.

www.aomb.nl/en

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LOW-COST, YET SMART

Technological advances allow conventional sensors to be manufactured on a microscopic scale at reduced cost, with integrated features that make them 'smart'. These smart sensors often perform bit-parts within bigger systems. Not only the features, then, but also the choices of the system designer and the combination of various sources of information count towards a smart sensor subsystem. A number of design principles may be employed to realise information-rich applications using low-cost components.

ADITYA MEHENDALE

A sensor is a device that detects events, attributes or variables and provides a signal (information), typically electrical or optical, to quantify these. It is usually beneficial to minimise the dimensions of the sensor to limit the impact on its environment and the measurand. Technological advances in MEMS (micro electro-mechanical systems), especially those fuelled by demands in the smartphone industry, allow conventional sensors to be manufactured on a microscopic scale at reduced cost, consuming less power and with integrated added features. The ubiquity of smartphones has perhaps also resulted in a trend, whereby end-users demand feature-rich devices that exploit a wide variety of sensor data.

So what makes smart sensors smart? While there is no clear definition, the additional integrated features like self-identification, diagnostics, auto-calibration, event detection, to name a few, contribute towards this label 'smart'. For interactive applications, the smartness of a sensor could lie in its ability to interact with the end user. Smart sensors often perform bit-parts within bigger systems. Not only the features, then, but also the choices of the designer and combination of various sources of information count towards a smart sensor subsystem. This calls for design rules and principles that may be employed, perhaps as a checklist, to realise information-rich applications despite the use of low-cost components.

Below, a selection of design principles for low-cost smart sensors is presented.

1. Time-based measurement

If possible, measure quantities as a function of time. Time-based measurement can be performed with low-cost devices and yet with a precision as high as 20 ppm. For comparison, a voltage-based measurement would typically achieve a 0.5% (5,000ppm) precision.

Consider the following example: a typical approach to measure the mass of a sample would be to measure its weight – effectively a force – e.g. by means of measuring the deformation of a load cell. Here, the manner of loading and inherent errors involved in measuring the load cell deformation and even the local gravitational acceleration would introduce errors in the estimation of the mass. An alternative time-based approach would be to construct an oscillator composed of this unknown mass together with a known external spring (Figure 1).

The time base of oscillation when compared to a precise time reference (e.g. a low-cost watch crystal) can yield a precise estimation of mass. If variability of the external spring is anticipated, then a smart design choice would be to employ a known reference mass to periodically calibrate it. Essentially, then, the time base is used to precisely compare two masses – one of them known (reference) and the other unknown. This leads to the second design principle.

2. Ratiometric, comparative, and differential measurement

While advances in semiconductor technology allow newer-generation sensors to shrink in size, improve in precision, and reduce in power consumption, the absolute errors

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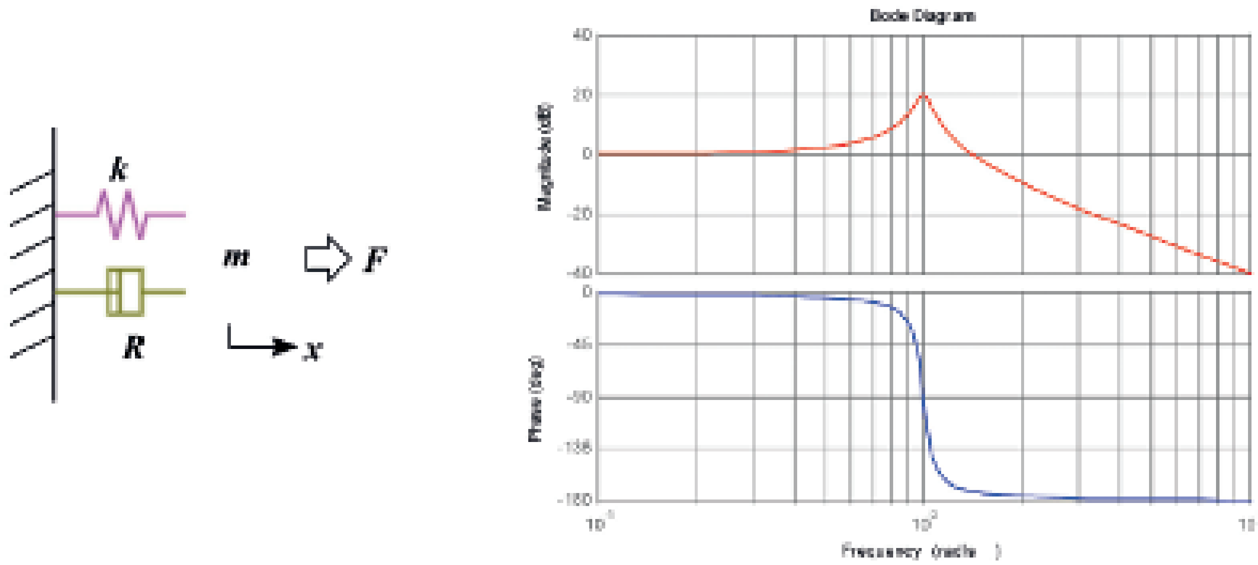

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arising due to their physical construction, operation and placement still remain. These can be reduced by a factor of 10 to 1,000 by making ratiometric and/or comparative measurements.

A classic example (does this qualify as ‘smart’? – you decide) is the front-end of a strain gauge amplifier, shown in Figure 2. The bridge imbalance is read as a difference voltage (between two balanced but oppositely loaded nodes of the bridge) and the excitation source too is read and used as a scale reference for the imbalance. While not particularly challenging to implement, such construction requires a thoughtful assessment of the system and the measurand by the designer.

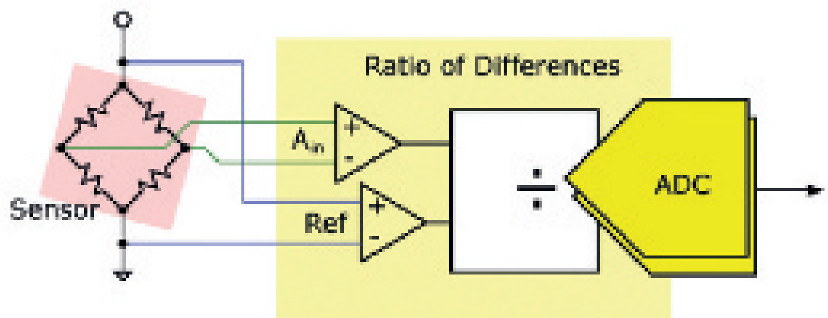
Nevertheless, when an absolute measurement must be made, for example on a voltage source, the offsets and flicker (1/*f* noise) dominate measurement errors. A common trick to measure a small voltage with a low-end multimeter prone to offset errors is to do a double measurement with reversal. One measurement is carried out, immediately followed by a second, with the measurement terminals reversed. The measurand is then indicated by half of the difference of the two measured values; the offset term is eliminated.

This too is a difference measurement; only now the two acts of measuring are separated in time, rather than space. Repeating the reversal can often attenuate the 1/*f* noise of the meter too. This concept of reversing polarity can be stretched further and done often, and this is the third design principle.

1 *Determining mass by time-based measurement of the oscillation frequency of a mass-spring system.*
2 *Measuring the voltage difference between two balanced but oppositely loaded nodes of a bridge circuit.*
3 *Modulation/ demodulation, see text for explanation.*

3. Synchronous detection

While this would have been considered an exotic technique a decade ago, the processing power available on and around smart sensors makes this a straightforward task nowadays. The basic idea is to apply a modulated (rather than a continuous) stimulus to interrogate the measurand and to demodulate the response (having prior knowledge of the modulation source) to infer measurement information (Figure 3).



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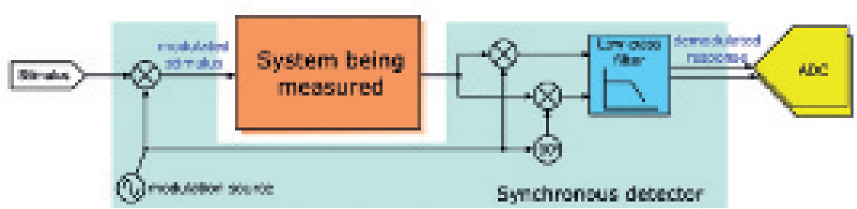

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A nuance in Figure 3 is the secondary (phase-shifted, aka 'quadrature') demodulation; this takes into account any delay in the system being measured. The designer must judiciously decide if measuring the quadrature component is essential. In some situations, the ratio of the in-phase and quadrature components (i.e. the phase angle) can provide additional information about the measurand. For example, in the resistive bridge of Figure 2, a quadrature demodulation would not provide much useful information. However, in echometry, to observe reflected waves having a path length equal to an odd multiple of $\lambda/4$ the quadrature detector of Figure 3 is essential. Furthermore, the phase angle gives information about the path length. In eddy-current-based (inductive) distance sensors, the phase angle can provide information about the target material.

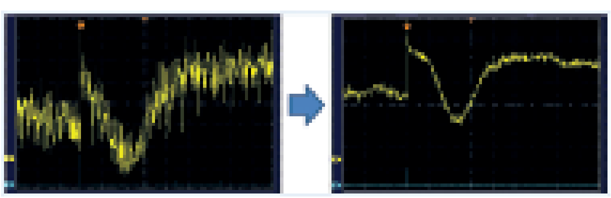
What though if a deterministic modulation of the stimulus is not possible? Apply design principle #4, especially when the measurand is buried under relatively high random noise.

4. Triggered averaging

In order to use this principle, the measurand must be a causal response to an identifiable event. An example would be distance measurement by means of an echo. A clap, a click or a ping at the source (which can be identified quite well) would be the cause of the echo. A sound measurement following the clap will contain the echo information, albeit very faint and noise-ridden. However, if the measurement is repeated n times and the ensemble of n echograms averaged, the random noise (unrelated to the clap) will diminish by a factor of $\sqrt{n}$ (Figure 4). The resulting signal may then be used to identify interesting artefacts, in this case the time-of-flight of sound to and from nearby objects.

Triggered averaging is well-known in the domain of digital oscilloscopes. Its implementation elsewhere had been difficult due to its large demands on memory and data crunching. This is no longer a bottleneck with the newer generation of microprocessors, making triggered averaging a viable technique.

The next rule is all about digitisation.



4 Averaging of triggered signals reduces random noise.

5. Consider digitisation options

In the modern device ecosystem, microprocessors may be available in the vicinity of where you'd like to sense. If this is the case, it is wise to choose the sensing technique based on the options available. To list a few:

- A single digital pin may be used to count events, like heart rate, or footsteps, or eigenfrequency (as in principle #1, time-based measurement). With two digital lines, it is possible to additionally measure phase or direction, like in a scroll-wheel.
- A spare analogue pin may be used to monitor a potentiometer voltage, or time constants of a delay element like an R-C network. Triggered averaging (principle #4) becomes possible if synchronisation is available.
- A microprocessor can do data pre-processing, reporting interesting events instead of raw data.
- By digitising analogue signals near the source and communicating digitally, better signal integrity can be maintained, and low-cost wiring may be used.
- Integrated peripherals (e.g. capacitance sensors for touch sensing) are available within modern microprocessors at little or no extra cost. Make use of these where possible. A capacitive touch sensor, for example, can just as easily function as a contactless water level indicator.

Assigning tasks to a microprocessor may lead to software and data overheads and safety-related concerns; for this consider the following design rule.

6. Look for specific integrated features

Many modern sensors have inbuilt 'value-added' features. An accelerometer (MEMS) IC sensor designed for fall detection is a good example. In free-fall, the acceleration measured by this sensor would be almost zero. As the duration of the fall is quite short, the detection of free-fall would involve polling (incessantly querying) the sensor, a fruitless and intensive task for the host processor as long as the device isn't falling. Instead, a threshold can be set on some newer sensors, whereby the sensor generates a high-priority signal ('interrupt') once this threshold is exceeded. This frees up the host processor to do other tasks or to 'sleep', thus saving power.

Some accelerometers take this a step further, and have a 'double-click' (two short acceleration spikes) identification built in, making it useful for user interaction in addition to detecting free-fall.

Some more examples:

- Angle readout (instead of flux densities) from an array of Hall sensor elements in a contactless (magnetic) angle measurement sensor will offload trigonometric calculations from the host processor.

- Distance readout (instead of raw time-of-flight data) in photo-reflective distance sensors.
- Motion alarm indication (instead of raw images) in a security camera sensor, etc.

Coming back to accelerometers, the ones used in airbag deployment have an inbuilt self-test feature, consisting of an auxiliary actuator integrated in the sensor IC. This actuator can apply an electrostatic force to stimulate the seismic mass. The sensor's registration of this actuation force is indicative of its proper functioning. This feature originated from regulations around the safety-critical nature of airbag sensors. A qualified regulatory certification, in a sense, is then also an 'integrated feature' of this particular sensor.

In conclusion, we arrive at the next design rule.

7. Take the nine-window approach

A powerful technique when designing any system (thus also a sensor system) is the nine-window approach. It is a holistic approach, borrowed from creative problem-solving techniques, especially TRIZ. Here, not only does the designer consider the system, but also its subsystems and supersystem, its past and its future. This process of zooming in on the details and zooming out to get a bird's eye view in time and space can provide an insight into the most optimal sensor architecture.

For example, the designer could:
- Use an end-stop instead of a complex servo – Does one really need that sensor?
- Add a 'tare' button to weigh-scales, to remove offset error before measurement.

	Past	Present	Future
Supersystem		Bird's eye view	Vision
System	History	Here & now	Expectation
Subsystem	Legacy	Microscope view	

5

5 *The nine-window approach*

- Place a self-cleaning CCD on a camera, to shake off dust after each operation.
- Measure the motor current and use state estimation to compute actuation force.
- Measure and compare machine sounds as an indicator of degradation.
- Instead of placing an accurate time source within the system, use time references available from DCF77 or GPS or other ubiquitous wireless or mobile networks.
- Place a sensitive component in a miniature temperature-controlled oven.

This concludes the checklist, but there are bound to be many more design rules and principles specific to particular design goals. Nevertheless, this list is a good starting point when designing a low-cost smart sensor system. ■

CPE COURSE CALENDAR

COURSE (content partner)	CPE points	Provider	Starting date (location, if not Eindhoven)
BASIC			
Mechatronic System Design - part 1 (MA)	5	HTI	28 September 2015
Mechatronic System Design - part 2 (MA)	5	HTI	5 October 2015
Design Principles	3	MC	22 September 2015
System Architecting (Sioux)	5	HTI	9 November 2015
Design Principles Basic (SSvA)	5	HTI	18 November 2015
Motion Control Tuning (MA)	6	HTI	18 November 2015
Design for Manufacturing	3	SCHOUT	to be planned / in-company
DEEPENING			
Metrology and Calibration of Mechatronic Systems (MA)	3	HTI	24 November 2015
Actuation and Power Electronics (MA)	3	HTI	to be planned
Thermal Effects in Mechatronic Systems (MA)	3	HTI	to be planned
Summer school Opto-Mechatronics (DSPE/MA)	5	HTI	to be planned
Dynamics and Modelling (MA)	3	HTI	7 December 2015
Summer School Manufacturability	5	LiS	2 November 2015
SPECIFIC			
Applied Optics (T2Prof)	6.5	HTI	to be planned
Applied Optics	6.5	MC	17 September 2015
Machine Vision for Mechatronic Systems (MA)	2	HTI	24 September 2015
Electronics for Non-Electronic Engineers – Basics Electricity and Analog Electronics (T2Prof)	6.5	HTI	12 October 2015
Electronics for Non-Electronic Engineers – Basics Digital Electronics (T2Prof)	3.5	HTI	5 September 2016
Modern Optics for Optical Designers (T2Prof)	10	HTI	to be planned (2016)
Tribology	4	MC	3 November 2015 (Utrecht) 5 April 2016
Design Principles for Ultra Clean Vacuum Applications (SSvA)	4	HTI	28 September 2015
Experimental Techniques in Mechatronics (MA)	3	HTI	11 November 2015
Advanced Motion Control (MA)	5	HTI	5 October 2015
Advanced Feedforward Control (MA)	2	HTI	2 November 2015
Advanced Mechatronic System Design (MA)	6	HTI	to be planned
Finite Element Method	5	ENG	in-company only

DSPE Certification Program

Precision engineers with a Bachelor's or Master's degree and with 2-10 years of work experience can earn certification points by following selected courses. Once participants have earned a total of 45 points (one point per course day) within a period of five years, they will be certified. The CPE certificate (Certified Precision Engineer) is an industrial standard for professional recognition and acknowledgement of precision engineering-related knowledge and skills. The certificate holder's details will be entered into the international Register of Certified Precision Engineers.

WWW.DSPE.NL/EDUCATION/LIST-OF-CERTIFIED-COURSES

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- Mikrocentrum (MC)
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- LiS Academy (LiS)
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- Technical Training for Professionals (T2Prof)
  WWW.T2PROF.NL

Motion in suspension with Festo's SupraChanger

Superconductors are opening up possibilities for entirely new, previously unthinkable applications in automation technology. They allow contact-free, frictionless manipulation of objects and bear great potentials for process automation: their dust- and abrasion-free operation is ideal for the protective transport of workpieces in highly clean environments, machines can be easily cleaned and objects can even be moved from behind walls. At the Achema 2015 trade fair (15-19 June, Frankfurt, Germany), Festo showcased the SupraChanger – an innovative application concept for superconductor technology.

Superconductors are materials which below a certain temperature can 'freeze' the field of a permanent magnet at a predefined distance and can thus hold it in suspension. The resulting air gap remains stable in any spatial position. By this means, objects can be stored contact-free without any control technology and be moved with minimal expenditure of energy. There are already various solutions for storing and moving objects without contact. But only with superconductivity is it possible at the same time to execute a rotation through 360° in any spatial direction – without the need for intricate control technology.

Superconducting systems are suitable for bigger loads and can even work through walls and in all spatial planes across their definable hover gap. This enables objects to be handled in protected and enclosed spaces or through cladding. Areas prone to contamination or which are difficult to clean can thus be protected using smooth and easy-to-clean surfaces. If non-magnetic substances penetrate the bearing, the bearing and guiding function is not impaired. This also allows use in highly contaminated areas.

With SupraChanger an application for the first time transmits a rotational movement without contact and in a controlled manner to a magnet, which levitates due to superconductivity. This effect was shown in three automatically changing, distinct applications: a centrifuge, a blender and a hovering rotary indexing table.

With SupraChanger an application for the first time transmits a rotational movement without contact and in a controlled manner to a magnet, which levitates due to superconductivity.

A possible future field of application would be laboratory automation, in which several processing steps are often performed on an object in sequence.

WWW.FESTO.COM

New Faulhaber subsidiary in Eindhoven

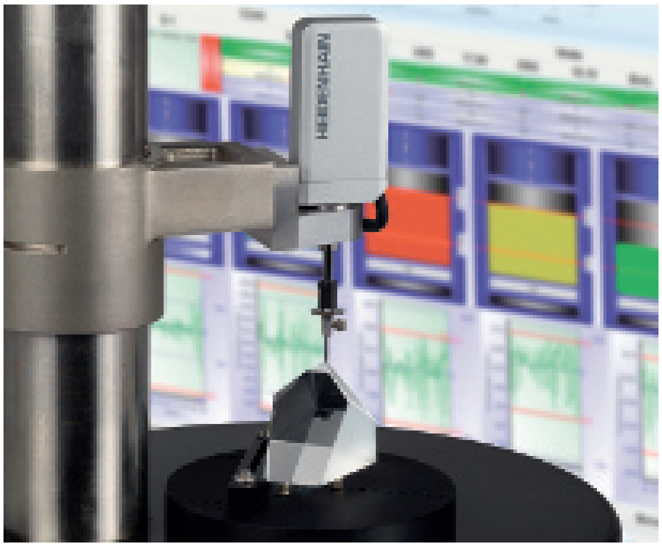
From 1 July 2015, the products and services of the Faulhaber Group are distributed in Belgium, Luxembourg and Holland by Faulhaber Benelux. The newly-established distribution company is based in Eindhoven, the Netherlands. Faulhaber was previously represented in these three countries by Minimotor Benelux.

"We can now look after the markets in Holland, Belgium and Luxembourg directly from our own company", declared Marcus Remmel, Head of Sales at Faulhaber and Managing Director of Faulhaber Benelux. "By doing this we become closer to our customers and can exchange ideas with them with greater intensity, particularly about the joint development of customer-specific products. Furthermore, we are strengthening our strategic presence in an important export market."

Faulhaber (more than 1,600 employees worldwide) specialises in the development, production and deployment of high-precision small and miniaturised 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. In addition, Faulhaber also provides customer-specific complete solutions for medical technology, automatic placement machines, precision optics, telecommunications, aerospace and robotics, among other things.

WWW.FAULHABER.COM

High-accuracy, destruction-free measurement



Destruction-free, non-tactile measuring principles are common, but these mostly optical measuring methods cannot match the precision of tactile encoders with photoelectric scanning. The great challenge is the development of a measuring device that combines high accuracy with destruction-free measurement. Heidenhain has solved this problem with its new METRO 1281 MW length gauge. It features an extraordinarily low measuring force curve between 0.01 N and 0.07 N over its entire 12 mm measuring range. Over this range accuracy is 0.2 µm, and repeatability is ≤ 0.03 µm. The new length gauge therefore provides access to new fields in tactile and high-accuracy metrology. Now it is possible, for example, to calibrate very small gears, various glass objects and wafers, or products in medical technology. This rules out the undesired deformation of workpieces by the measuring device that can falsify measuring results or even damage or destroy the workpiece. Transparent materials that repeatedly present difficulties for optical methods can likewise be measured.

WWW.HEIDENHAIN.COM

ESPS launches Robotics Experience Center

In June, ESPS, the industrial automation and service solution provider based in Almelo, the Netherlands, celebrated its 10th anniversary. Managing director Edwin Jongedijk talked about the future of ESPS and its ambitious growth goals. He foresaw a big role for robotics. Therefore, Stefano Stramigioli, professor of Advanced Robotics at the University of Twente, the Netherlands, had been invited to shed his light on the history and future of robotics in various fields.

After Stramigioli's entertaining presentation ESPS launched its brandnew Robotics Experience Center, where ESPS wants to showcase newest proven technology from the best robotics and automation brands in one inspiring environment. Visitors could see and experience industrial robotics and other high-tech automation demonstrations.

WWW.ESPS.NL

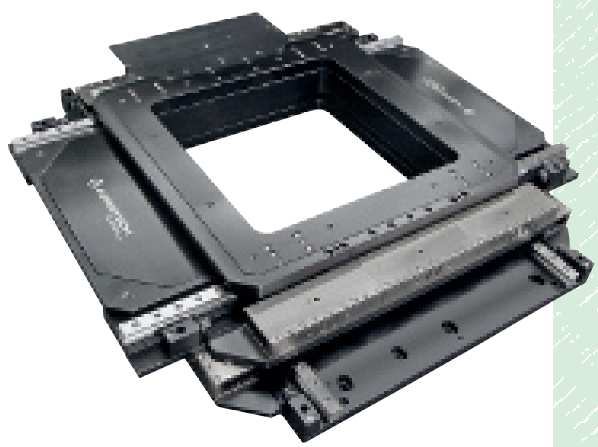
Integrated, open-frame, XY linear-motor stage

According to Aerotech their Planar$_{DLA}$ integrated, open-frame stages have high dynamics and exceptional geometric performance in a low-profile package. These stages are essential for applications ranging from two-sided LED wafer processing where high-dynamics performance and micrometer-level straightness are required, to quasi-static optical metrology where high accuracy and precise geometric performance are necessary.

The Planar$_{DLA}$ XY design is optimised for applications where straightness and flatness of motion are critical. High-precision roller bearings, precision-machined surfaces, and noncontact direct-drive linear motors driving through the axes' centre-of-stiffness result in a positioning stage with straightness down to ±0.5 µm and flatness to ±1.25 µm.

Structural elements are optimised for high dynamics and high stiffness for the most demanding dynamic applications. The Planar$_{DLA}$ achieves high servo bandwidths while at the same time maximising the clear aperture available and keeping the overall height to a minimum. The Planar$_{DLA}$ enables high-throughput, high-accuracy processing with 2 m/s velocities and 2 g accelerations.

WWW.AEROTECH.COM



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The LiS is a modern level 4 MBO school, with a long history (founded in 1901). The school encourages establishing projects in close cooperation with industry and scientific institutes, allowing for high level "real life" work. Under the name LiS-Engineering and LiS-Academy the school accepts contract work and organizes education for others.

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