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MIKRONIEK

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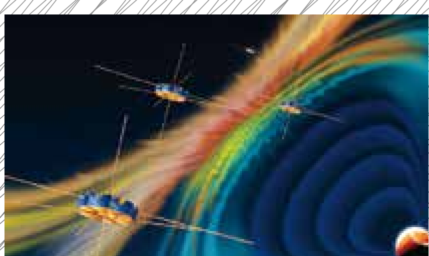
- INTERFEROMETRIC **CTE** MEASUREMENTS
- PRECISION **LATHES**
- **FREE-FORMED** SPECTACLE LENSES
- REDEFINING THE SI UNIT OF **MASS**



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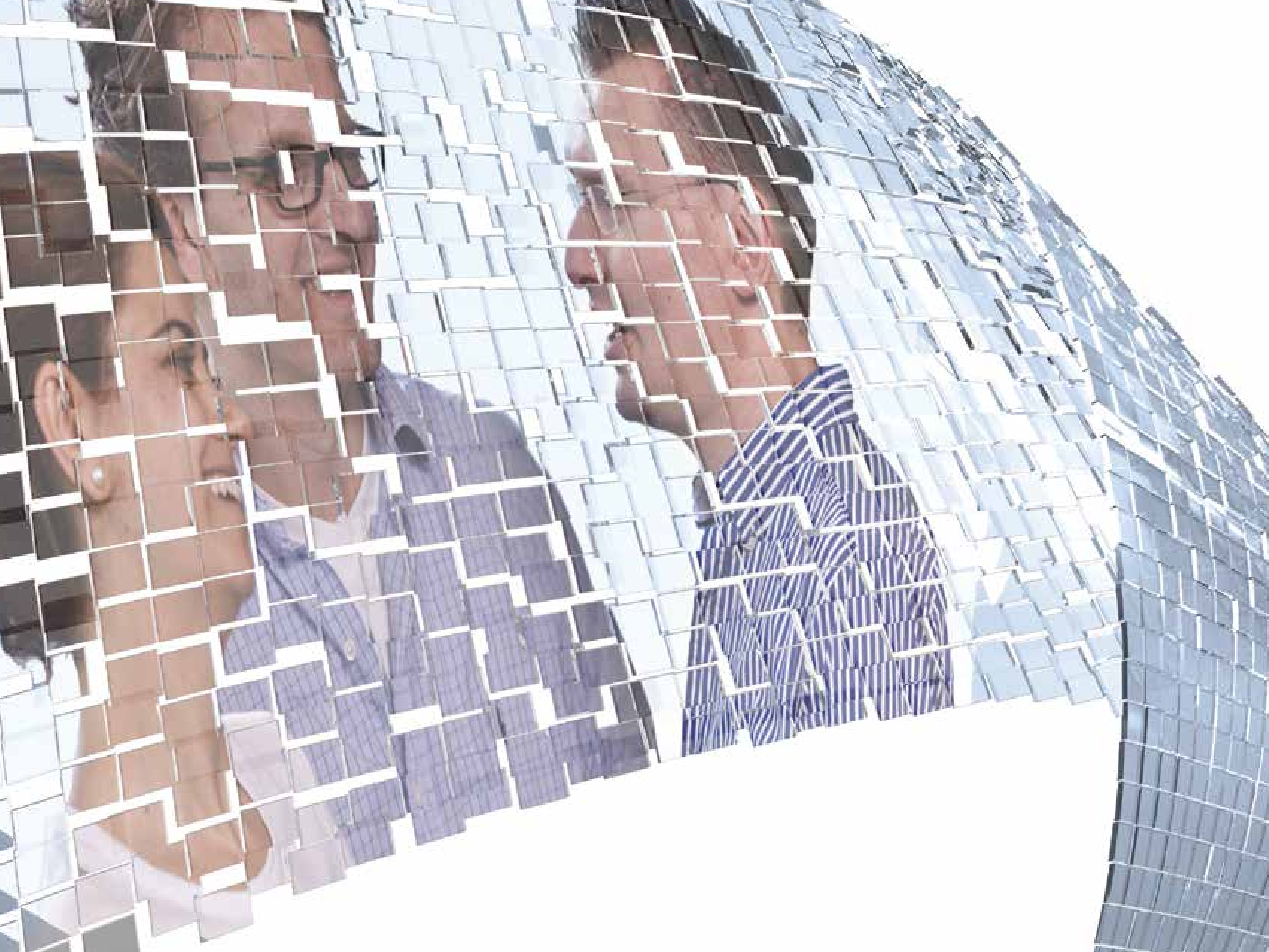

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The main cover photo (the Avogadro Project Silicon-28 sphere) is courtesy of PTB. Read the article on page 18 ff.

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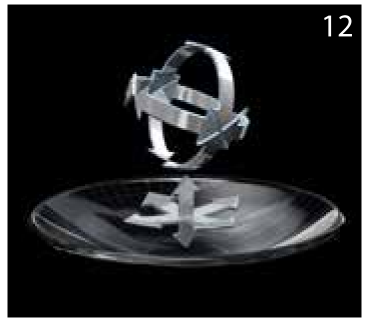

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FEATURES

MIKRONIEK EDITOR'S 10TH ANNIVERSARY

Ten years ago DSPE was looking for a chief editor of Mikroniek. Amongst others we interviewed Hans van Eerden after his application for the job of Mikroniek editor.

From the beginning we agreed that Hans was our best candidate. We are very glad that we selected him as our editor for Mikroniek. Hans proved to be very responsible, creative and accurate in his job of realising six issues of Mikroniek every year. He is passionate about making a good magazine and he likes the freedom he has within DSPE to create an attractive Mikroniek.

During a lunch at the combined Vision, Robotics & Mechatronics / Photonics event in the Koningshof in Veldhoven on 4 June, Hans (van Eerden) and Hans (Krikhaar) concluded that they would like to extend the period of collaboration by another ten years.

Focus for improvement now is on the distribution of Mikroniek around the world, to promote the precision engineering discipline. And to make the competencies of the Dutch high-tech industry better known in the world, and ultimately to create more economic value for the Netherlands.

Hans Krikhaar
President DSPE

2005

2015

Hans van Eerden

COEFFICIENT OF THERMAL EXPANSION OF MATERIALS AND JOINTS

With growing demands on the accuracy of ultra-high-precision instruments, including machine tools, semiconductor device manufacturing and scanning probe microscopy, there is a need to optimise the thermal stability of the tools. Hence, the coefficient of thermal expansion (CTE) of materials, but also of joints and sensors, plays a key role. With its specialised interference comparators PTB provides highly accurate measurement of the CTE based on absolute length measurements of gauge block shaped samples.

HAGEN LORENZ, RENÉ SCHÖDEL, JENS FLÜGGE AND MICHAEL VOIGT

Introduction

Interferometric length measurements of gauge blocks (GBs) with the objective to extract the coefficient of thermal expansion (CTE) very accurately is a well established technique at PTB [1] and has been offered to customers for many years. In addition to the CTE determination, the absolute length measuring interference comparators of PTB are often used to characterise other material properties, such as long-term stability, length relaxation or even compressibility.

This paper reports on a new field of application: the characterisation of more complex samples like joints, sensors and actors. In the preparation of material joints it is important to achieve a high degree of parallelism between the surfaces involved in the length measurement.

Accurate temperature measurement is a key part in dimensional measurements. Due to the absence of self-heating, thermocouples are advantageous, especially under vacuum conditions where the most precise interferometric measurements are possible. For this reason thermocouples are widely used for measuring the temperature of the samples, e.g. in gauge block metrology. This paper deals with the characterisation of thermocouples with respect to long-term stability and validity of different types of thermocouples.

AUTHORS' NOTE

Hagen Lorenz (Member of Interferometry on Prismatic Bodies Working Group), René Schödel (Head of Interferometry on Material Measures Department), Jens Flügge (Head of Dimensional Nanometrology Department) and Michael Voigt (Member of Interferometry on Prismatic Bodies Working Group) all work at the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig (Germany).
This article is in part based on a presentation at High-Tech Systems 2015 in 's-Hertogenbosch, the Netherlands.

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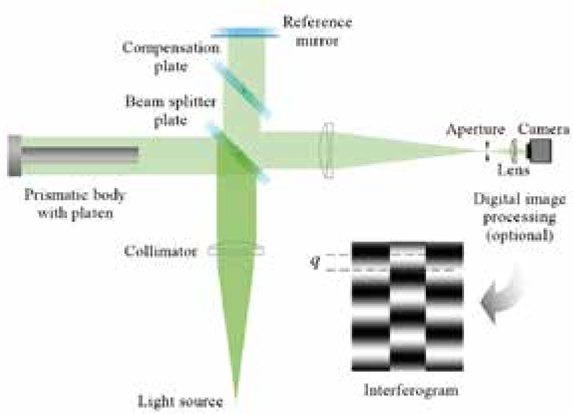
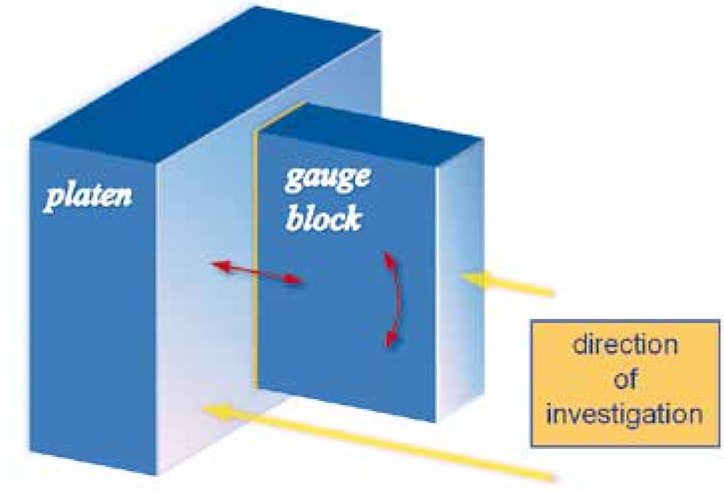
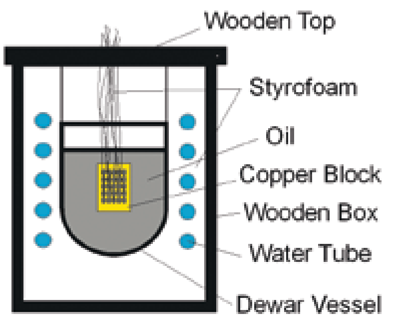
Imaging interferometry

Measurements were performed at PTB's interference comparator INKO6 [2] in air and the Precision Interferometer (PI) in vacuum [1]. Three stabilised lasers of different wavelengths were used subsequently in the measurements, and imaging phase stepping interferometry was applied. The basic principle of the interferometer type used is shown in Figure 1. Without going into the details, with these comparators the absolute length of samples can be measured on a level of approx. 3 nm for the INKO6 and less than 1 nm for the PI.



1 *Principle of the Twyman-Green interferometer for gauge block measurements.*





2 *Indication of the measurement direction for length and angle measurements using the imaging interferometer.*
3 *Two screwed copper blocks with thermocouples.*
4 *Oil bath.*

In order to improve the thermal equilibrium within the PI, a residual pressure of 0.1 hPa is applied. Prismatic bodies (as GBs) can be exchanged, stored in the laboratory at 20 °C and restored into the interferometer to its original position. Besides the length measurement itself, the orientation of the front face of a GB with respect to the end platen and its sensitivity to temperature changes can be determined by interferogram analysis.

In gauge block calibrations the GB is attached to a platen by so-called wringing. In this approach the optical step height that is measured by interferometry represents the actual length of the GB. For the investigations of joining techniques a GB can be connected to a platen by an alternative joining technique. In that case the joining layer contributes to the optical step height that is measured. Assuming that the GB is stable, the properties of the joining technique can be extracted by measuring changes of length and angle, as indicated in Figure 2.

In the PI, the temperature was varied between 10 and 40 °C, so that the length is measured as a function of the temperature, from which the CTE of the material is determined. For investigation of thermal stability and drift the length and orientation of material samples or joint connections is measured repeatedly near 20 °C. In this approach the length was extrapolated to the exact reference temperature of θ = 20.000 °C.

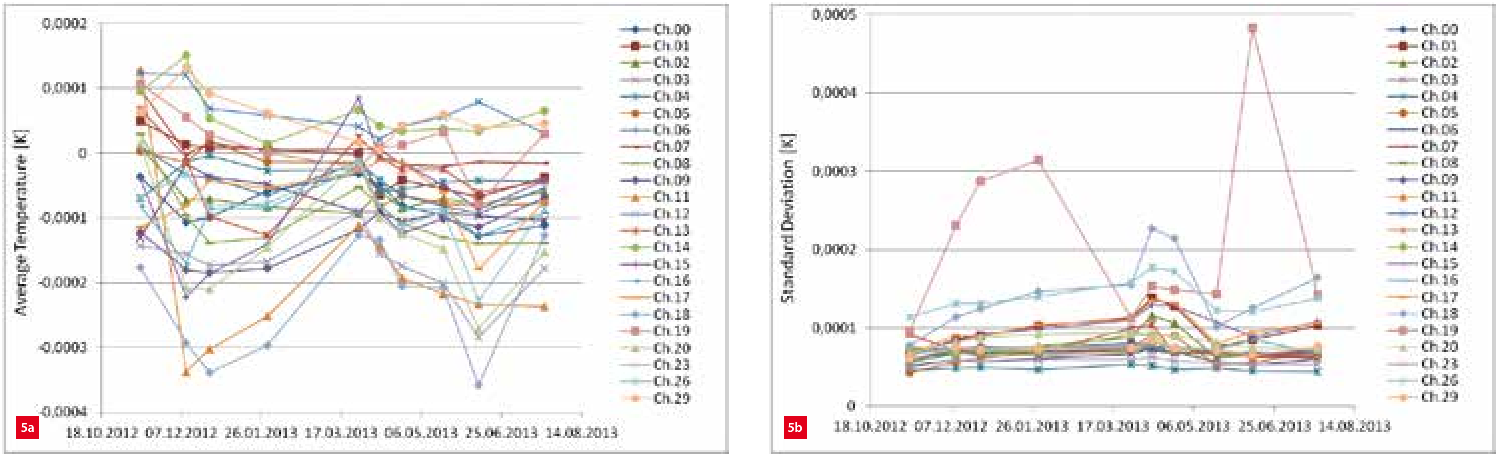
Temperature measurement using thermocouples

In precision temperature measurements near room temperature normally platinum resistance thermometers (PRTs) and increasingly thermistors are utilised. These types of sensors generate a self-heating due to the measurement current, which is especially a problem in vacuum. An alternative can be the use of thermocouples to measure temperature differences to a reference PRT at a point with good thermal conductivity, and the temperature field around the samples.

The surface temperature of the GBs in the interferometer is measured by thermocouples. The temperature of a nearby copper block, used as reference point for the thermocouples, is measured using an AC-bridge (F700, Automatic Systems Labs.) together with a PRT PT-25 resistor.
The total measurement uncertainty of the temperature measurement is below 1 mK at 20 °C.

Besides the advantage of absent self-heating, thermocouples suffer from a low sensitivity ranging from about 6 to 60 µV/K, dependent on the material pairs used. Therefore, at PTB a temperature measurement set-up with a newly developed ultra-low-noise chopper amplifier [3] is used together with a switching unit based on bistable mechanical relays.

For investigation of the stability, thirty thermocouples have been manufactured from different material pairs made by different manufacturers and having different wire dimensions. For the test of the stability of the physical zero-point thermo voltage, the two measurement points have been brought into a good thermal contact, while maintaining electrical insulation. For this purpose, the first measurement points of all thermocouples were mounted together on one copper plate. The other measurement points were mounted on the opposite side of a second



5 *Examples of measurements.*
(a) Values averaged over one day.
(b) The associated standard deviations on selected days over a period of nine months.

copper plate with the same dimension. These two copper plates were screwed together, as shown in Figure 3.

To get a more homogenous environment, the connected plates were located in an oil bath stored in a Dewar vessel. The Dewar vessel was additionally insulated by Styrofoam layer, on which a winded water tube was fixed. The whole set-up is housed by a wooden box. A scheme of the set-up is shown in Figure 4. A thick Styrofoam layer below a wooden top insulates the aperture of the Dewar vessel. Using a thermostat and a water circle the temperature of the oil bath can be changed slowly.

The whole set-up was located in a temperature-controlled room, with a specified temperature of 20.0 ± 0.5 °C. The thermocouples were measured over a time interval of about nine months. During this time also investigations on the influence of mechanical strain and thermal gradients were carried out.

Figure 5 shows, for some exemplary measurement days, values averaged over one day together with the corresponding standard deviations. A difference between different thermocouple types or geometries could not be observed under the given environmental conditions and the measurement noise of the electronics. From these measurements it can be concluded, that the long-term stability of the measurement system is better than 1 mK.

To check for differences in the characteristic curves of the individual thermocouples, the two copper blocks were separated and located in the two different oil baths as described above. First, one of the baths was heated up. During the subsequent passive cooling phase, measurements of all thermocouples have been performed for a temperature range of about 0.2 K.

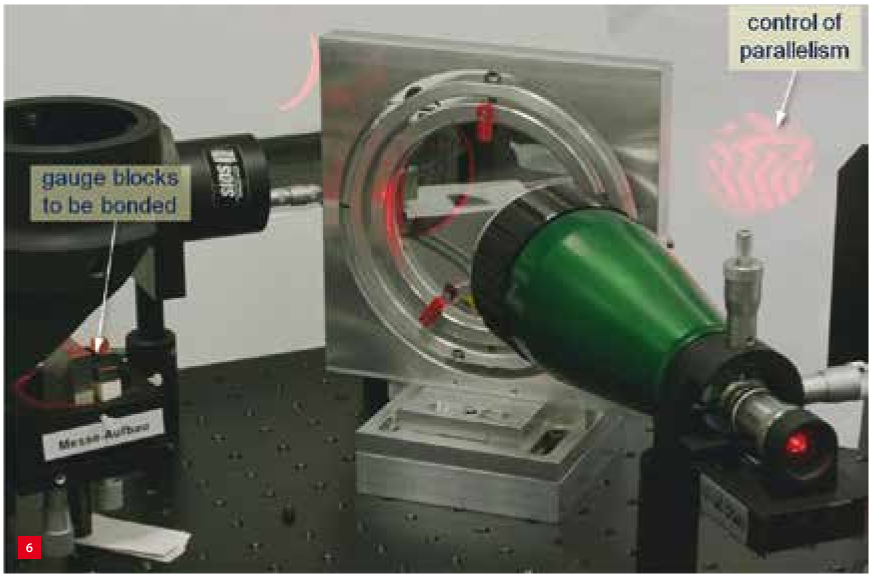
For the type-T thermocouples (in use for the CTE measurements) over the temperature range of 0.2 K only individual deviations of ± 0.2 mK were observed. Therefore, it seems possible to use the thermocouples to measure the temperature difference between the sample and an external PRT as well as the temperature field around the sample without individual calibration.

Preparation of representative specimens

In order to enable investigation of joining techniques, including wringing, bonding, screwing, gluing and soldering [4-7], representative connections were fabricated at Fraunhofer Institute for Applied Optics and Precision Engineering IOF in Jena (Germany) and at PTB. The interferometric measurements required high parallelism and flatness of measurement surfaces. Therefore, the joints were made of GBs or specially manufactured parts with highly parallel surfaces.

One of the end faces was attached to a flat platen made from the same material. Most of the joints consisted of hardened steel GBs. Steel is a common construction material with high stiffness and can be very hard. One disadvantage of steel is the relatively high CTE value of $(11.5 \pm 1) \cdot 10^{-6}\ K^{-1}$, which varies between individual GBs. Also, silicon single-crystal GBs were used, which have a lower thermal expansion and do not undergo micro-structural transitions with changing temperature.

While some joining techniques like wringing or bonding automatically keep the parallelism of the manufactured part, others like gluing or soldering may add an additional layer. To ensure the parallelism during the gluing process, this was done under interferometric control as shown in Figure 6.



As not all materials react instantaneously to a temperature change, the relaxation behaviour has to be considered. A temperature change can even result in dimensional instability. A joint/connection consists of different materials with different thermal expansion, interacting with each other at a common interface or interlayer. The overall behaviour is not only the sum of the behaviours of the isolated parts but also of their interaction. Preferably, the mutual interaction should be rigid or elastic, but also friction or creep may occur. Connecting agents, like screws or glue, can cause relative movements which are not predictable straightforwardly.

In order to investigate a number of materials and joining techniques, interferometric measurements were carried out in air as well as in vacuum. Especially when adhesives were applied to join parts, attention was paid to the influence of vacuum and humidity conditions.

6 *Interferometer set-up for parallelism control during the gluing process.*

7 *Steel GB screwed onto a platen.*
(a) Photograph.
(b) Phase topography, λ = 532 nm.
(c) Length corrected to 20 °C.

Screwing (bolting) joints

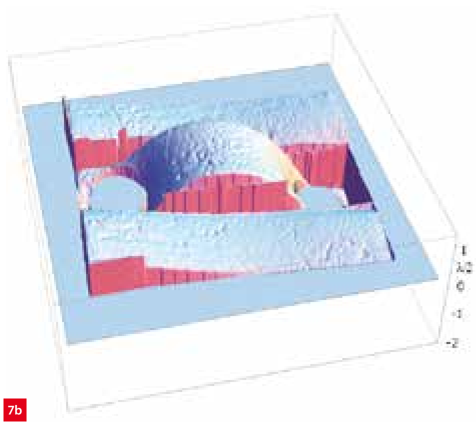
A steel GB and platen were bolted with two M3 screws to each other, a torque of approx. 1 Nm was applied (Figure 7). It is important that parts as well as screws, screw nuts and washers are perfectly clean and fit smoothly into each other. Any dust or sliding of frictional surfaces could lead to time-dependent stress relaxation. And the release of internal stress would cause dimensional changes. The overcoming of critical frictional forces can also be triggered by temperature variations when the parts have different CTEs.

As a result, no drift was detected in the PI at 20 °C during one year, also the angles in all directions remained constant within measurement uncertainty. Additionally, the temperature was cycled between 10 and 30 °C at t = 50 d, which did not cause any residual length change. The CTE of the joint, $11.9 \cdot 10^{-6}\ K^{-1}$, is comparable with that of typical GB steel. In between the measurements the samples were stored under laboratory conditions and no load was applied to the joint. Therefore, these measurements are not intended to be representative for all screwing connections in practical use.

Adhesive joints

In order to improve the stability of adhesive joints, spacers were used to produce a hard contact between the GBs. 10 Vol.% of spherical glass beads (soda-lime glass, HELIOS Optics) were added to the two-component epoxy UHU+ Endfest300 (with $CTE_{EP} \approx 90 \cdot 10^{-6}\ K^{-1}$). The glass beads had a nominal size distribution between 0 and 50 µm, as given by the manufacturer. The end faces of two steel GBs were joined by an adhesive layer with a final thickness of 70.6 ± 0.3 µm, which approximately coincides with the largest glass beads observed under the microscope. Between measurements the specimen was stored in air with relative humidity of 40-60% so that moisture might constantly diffuse into the glue joint.

7a



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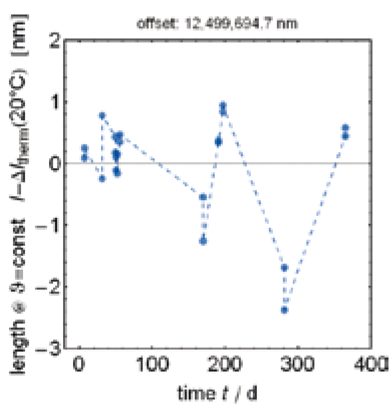

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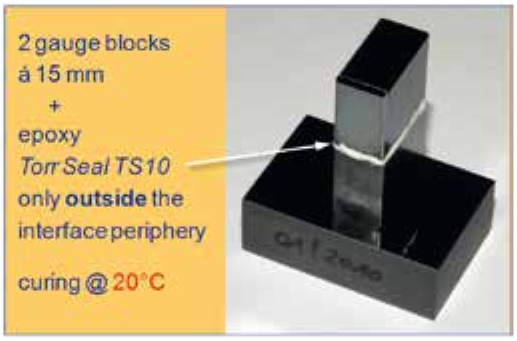

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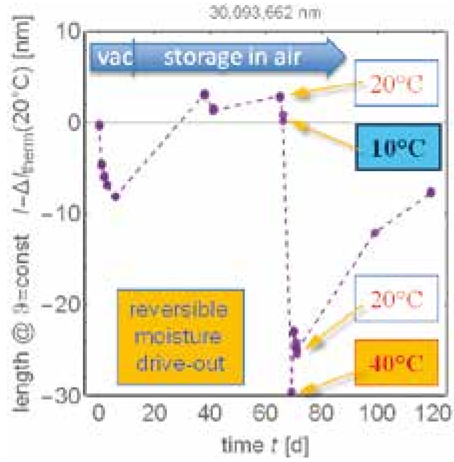

8b

A curing relaxation by nearly −100 nm was observed in INKO6 during approx. 50 days, but was followed by an accelerated length increase (probably moisture swelling) of approx. +80 nm during 400 days and a final saturation. It was concluded that glass beads do not appear to be suitable as stabilising spacers.
The CTE (20 °C) of the joint which was measured in the range of 19 to 25 °C was $(13.13 \pm 0.02) \cdot 10^{-6}$ K^{-1}, and therefore approx. $1.5 \cdot 10^{-6}$ K^{-1} larger than that of GB steel.

A hard contact between the end faces of silicon GBs was approached without adhesive in between. A band (≈1 mm thick) of low-outgassing epoxy Torr Seal TS10 was only acting on the periphery of the contact interface (Figure 8a). Probably due to epoxy curing at 20 °C in vacuum, a total length relaxation of only a few nm was measured (Figure 8b). After taking the joint out of the interferometer, the length increased by +12 nm, probably due to moisture swelling, and stayed constant after 40 d. Because there was no epoxy trapped between surfaces, the diffusion of moisture only took a short time to reach equilibrium.
The measured thermal expansion of the joint between 10 and 40 °C followed that of silicon which had been determined previously to a 2nd-order approximation according to Table 1. As a result of the higher temperature and the vacuum, the joint length had changed by −30 nm. After storage in air, the length before the thermal cycle was almost restored (increase of > 20 nm). From this observation, it is concluded that the thermally induced instability is caused by the temporary degassing of water at 40 °C, and that the joint length ultimately depends on temperature as well as on the humidity.

Conclusions

CTE measurement of prismatic material samples is an established service at PTB. The measurement equipment can be used in the same way to measure the CTE of joints, sensors and actors in longitudinal as well as in lateral direction. The preparation of representative sample joints as well as measurement results has been exemplarily demonstrated for a screwed and two glued connections. Additionally to CTE measurements, also time-dependent drift and the influence of humidity or gases on dimensions can be determined with the same set-up.

8 *Adhesive joint on a silicon platen.*
(a) Photograph.
(b) Length, corrected to 20 °C using 2nd-order approximation for Si, first seven days in vacuum chamber of precision interferometer, storage in air follows.

Table 1. Thermal expansion.

Taylor approximation: $\Delta l_{therm}/l$ =		
Specimen	**Linear term**	**Quadratic term**
2 x 12.5 mm wrung steel GB1	$(11.478 \cdot 10^{-6} \pm 1.9 \cdot 10^{-9})$ K$^{-1} \cdot (\theta - 20$ °C)	+ $(1.20 \cdot 10^{-8} \pm 1.2 \cdot 10^{-10})$ K$^{-2} \cdot (\theta - 20$ °C)^2
2 x 12.5 mm wrung steel GB2	$(11.152 \cdot 10^{-6} \pm 1.9 \cdot 10^{-9})$ K$^{-1} \cdot (\theta - 20$ °C)	+ $(1.09 \cdot 10^{-8} \pm 1.2 \cdot 10^{-10})$ K$^{-2} \cdot (\theta - 20$ °C)^2
Screwed steel GBs	$(11.90 \cdot 10^{-6} \pm 4.2 \cdot 10^{-9})$ K$^{-1} \cdot (\theta - 20$ °C)	+ $(1.25 \cdot 10^{-8} \pm 5.3 \cdot 10^{-10})$ K$^{-2} \cdot (\theta - 20$ °C)^2
Glued steel GBs (glass beads)	$(13.13 \pm 0.02) \cdot 10^{-6}$ K$^{-1} \cdot (\theta - 20$ °C)	
Silicon single crystal	$2.555 \cdot 10^{-6}$ K$^{-1} \cdot (\theta - 20$ °C)	+ $4.58 \cdot 10^{-9}$ K$^{-2} \cdot (\theta - 20$ °C)^2

Acknowledgements

The work described in this paper was part of the "Thermal design and dimensional drift" project, a European joint research project within the European Metrology Research Program (EMRP). The EMRP is jointly funded by the countries participating within EURAMET (European Association of National Metrology Institutes) and the European Union. ■

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COLUMN

DOES IP EXIST IN THE 3D PRINTING WORLD?

Last December NASA made quite a statement on the revolutionary potential of 3D printing. In less than a week the space agency drafted a ratchet wrench design and sent it to the International Space Station, where it was printed in less than four hours.

Considering that it costs more than €9,000 per kilogram to send something into orbit, and that 3D printers are available from €69, the possibilities of 3D printing, also known as Additive Manufacturing, seem endless. And not just in space or in the far future; see the titanium case on the right.

However, this kind of revolutionary innovation simultaneously sparks an essential debate on the position of intellectual property (IP) rights within this industry of literal copying. Today it still takes hours to print a simple object. But with the prices of printers dropping and technology rapidly improving, it is only a matter of time before a 3D printer will be a common sight in every household. Gartner predicted that worldwide sales of 3D printers will reach 217,000 units in 2015, up from 108,000 in 2014. By 2018 this number will have exploded up to 2.3 million.

With these numbers of 'manufacturers', it will become increasingly hard to identify and stop anyone from illegally copying and selling protected products. In that sense it is reminiscent of the illegal download problems of the music industry. One single download won't do much harm, but millions of these downloaders could seriously damage an industry. The big difference being that downloading, even when done by an individual, is illegal, whilst the (3D) copying of a product for personal use is not. Even patents don't protect this private production and use of goods.

Lost court cases in the past over video recorders and cassette recorders as devices that enable copyright infringement already indicate that there is no point in trying to stop 3D printers. And with the innovation it provides, it would also be a nonsensical thing to strive for. So what can be done to prevent unlimited copying of designs and products? If whatever you're bringing out on the market is not patented, or otherwise protected, copying and selling of it will be almost impossible to stop. All it takes is a 3D scanner, a 3D printer and raw materials. However, even a patent is no guarantee to success. If the music industry has taught us anything, it is that rampant suing will most probably only be highly expensive and ineffective.

Instead of trying to stop the unstoppable, we should be an active part of the endless opportunities 3D printing has to offer, even if this requires a new way of looking at intellectual property. Nokia tried this adaptive approach by releasing a 3D print design which allows customers to easily design and print custom covers for smartphones. Such a licensing system could just as easily apply to specific parts of machinery that need to be repaired or replaced. The ease of 3D printing is fully exploited while the IP rights of the designer are protected. In the end, it's this exchange between innovation and IP rights that will mark the path forward. Ultimately, the 3D designers of the future will also want their products protected. We will just have to see how the legal framework of this future will shape out.

Wouter Kempes
Patent attorney, DOGIO Patents
www.dogiopatents.nl

3D printing titanium

An example from this year: the Hittech Group, a Dutch system supplier, started cooperating with Norsk Titanium to produce titanium parts. One party provides rough 3D prints of parts while the other machines them to their exact shape. Traditionally, solid blocks of titanium were used, of which up to 90% would have to be removed by machining. These kinds of substantial cost reductions are only the tip of the 3D print iceberg.

INDIVIDUALLY FREE-FORMED SPECTACLE LENSES

In the beginning, eyeglasses were characterised by spherical forms that were ground and polished. Advancements in eye care, however, such as corrections for astigmatism, have created a demand for toroidal forms. Moreover, lens manufacturing has been further complicated by the introduction of multifocal lenses. The completely free-formed Rodenstock spectacle lens, which can be individually adapted by point-to-point machining of the lens' back plane, constitutes a spectacular highlight in the world of eye care.

AUTHOR'S NOTE

Frans Zuurveen is a freelance writer who lives in Vlissingen, the Netherlands.

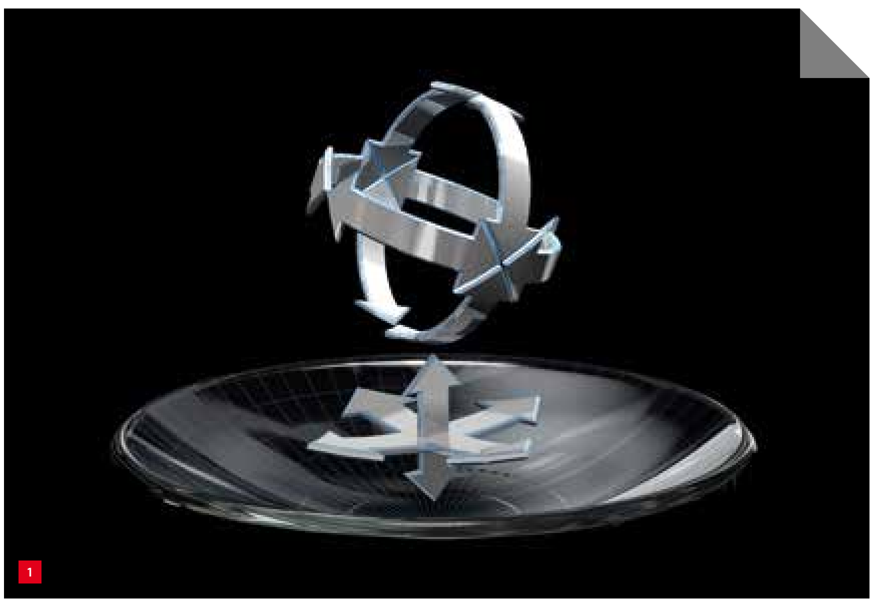
FRANS ZUURVEEN

Until the start of this century, multifocal lenses were made by moulding the multifocal transition region on the front plane of a blank made of transparent plastic [1] [2] (for a glossary of ocular terms see the box). This progressive curvature region was carefully machined in the casting moulds required for the plastic polymerising process. The transition region integrated the focal correction for far vision with the correct number of diopters for near sight (reading).

Lenses were manufactured according to an optician's prescription, which dictated the required individual corrections, in a process that involved grinding and polishing the back plane of the lens. The lenses are correcting the defocus and the astigmatism of the wearer's eye, with the change of the curvature in the progressive region compensating for the wearer's lack of accommodative power. Relatively simple toroidal-shaped grinding and polishing tools, each making the required pivotal movements, could be used for such corrections.

The drawback of this procedure is that it requires a huge stock of multifocal blanks covering the complete range of focal corrections for near and far vision, each with corresponding transition areas. An additional drawback is that the only type of astigmatism that can be corrected is that associated with far vision, which differs in most cases from that associated with near vision.

The constraints of this conventional technology can be overcome using the sophisticated Rodenstock ILT (Individual Lens Technology), see Figure 1, employing an individually shaped back surface for the corrections. Then, one only needs to have blanks with spherical front planes in stock, covering a much smaller range of sphere radii [3].

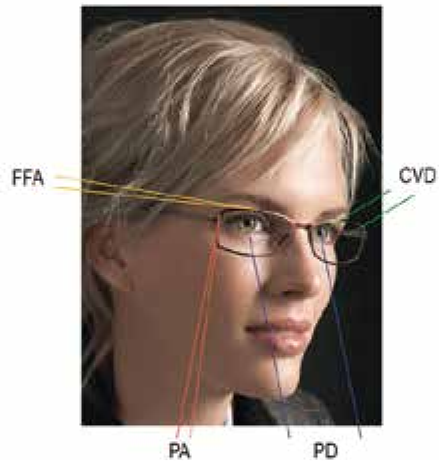


1 *Manufacture of the free-formed back plane of a Rodenstock individually adapted Impression spectacle lens. (All figures copyright Rodenstock)*

This limited range of plastic casting and polymerising moulds can also be manufactured more easily.

The crux of this procedure lies in determining the individual free form. This involves not only correcting the sphere, cylinder and axis deviations of a person's lens and cornea, for far and near vision, but also establishing the individual as-worn position of the spectacle frame.

Rodenstock has developed two instruments to determine the necessary data: the ImpressionIST and the DNEye Scanner. The ImpressionIST is a 3D video centration device for eye lenses and the DNEye Scanner measures individual eye aberrations. These two instruments are essential tools for opticians and can be used to provide the Rodenstock lens factory with the necessary data for producing an optimally adapted, free-formed back plane.



2 *Ophthalmic terms specifying the differences between the real and ideal positions of a spectacle lens in a frame: FFA = face form angle, PA = pantoscopic angle, PD = pupil distance, CVD = cornea vertex distance (the distance between the cornea and the lens).*

Glossary of ocular terms

Astigmatism: The failure of an optical system to focus a parallel beam as a single point, focusing it, rather, as a line segment.
Ciliary muscle: Ring of muscle around the eye lens controlling its curvature and hence the degree of accommodation.
Coma: Optical error occurring when a beam enters an optical system obliquely, resulting in a pear-shaped focusing spot.
Cornea: The transparent coating of the eye, covering the iris and pupil and delivering the main portion of the eye's optical power.
Defocus: Deviation from accurate focus, because of a lens not having the correct radius of curvature. In the human eye defocus arises when the powers of the cornea and the crystalline lens do not match the length of the eyeball.
Diopter: The power of a lens expressed as the reciprocal of the focal length in meters.
Keratometric: Concerning the curvatures of the cornea.
Multifocal: Formed from two spherical regions having different radii of curvature with a transition region having a gradually changing radius, to compensate for presbyopia.
Opthalmic: Pertaining to the human eye.
Presbyopia: Age-related loss of accommodative power.
Retina: Layer covering the inner wall of the eyeball containing photoreceptors, neurons, and supportive tissue.
Spherical aberration: Aberration due to the spherical form of one of the lens surfaces, resulting in different focussing spots for rays at different distances from the optical axis.
Toroidal: Having the form of a torus, which is comparable to that of a doughnut, locally characterised by two different radii of curvature.
Trefoil: Optical aberration whereby a point of light is not imaged to a single focussing point but rather to a trefoil-formed spot.
Vertex: One of the two points where the optical axis intersects a lens surface.
Vitreous humour: Glass-like, fluidal interior of the eye.

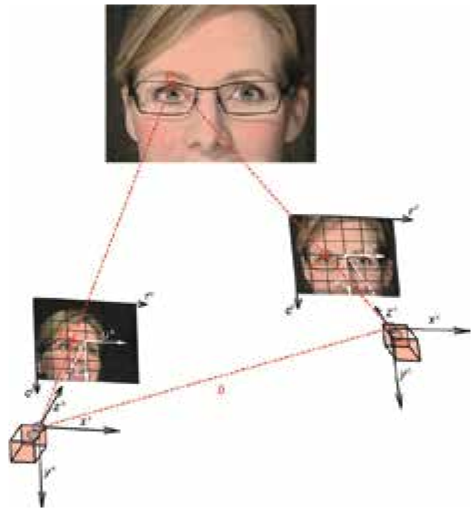
The ImpressionIST

The individual as-worn position of a spectacle lens in its frame is expressed in specific ophthalmic terms (see Figure 2). *PA*, the pantoscopic angle, is the forward tilt of a lens. *FFA*, the face form angle, is half the angle between the left and right lens in a horizontal plane [4]. In so-called sports frames, in particular, this angle is relatively large and thus has considerable influence due to oblique incident rays. The vertex distance or *CVD* (cornea vertex distance) is the distance between the lens and the cornea. Along with all the aforementioned quantities, the ImpressionIST instrument has to determine the position of the pupil with respect to the frame in the as-worn position.

Figure 3 shows the third generation of the ImpressionIST video centration system [5]. The main components of this system are a semi-transmitting mirror and two video cameras positioned behind the mirror, making them invisible for the client. The two cameras provide a stereoscopic system, which enables accurate 3D measuring when the distance between the cameras as well as the two angular positions are calibrated quantities (see Figure 4). The ImpressionIST is the only stereo centration system on the market; other systems use only one camera and scales of dots with known distances to be mounted to the frame for measuring. So, those other systems are more cumbersome than the practical Rodenstock system.

Some ImpressionIST measuring results are shown in Figure 5. As can be seen, the instrument can determine not only frame positions with respect to the pupil centre, but also pupil distance and various angular deviations. The optician can save these data in the system's computer memory. These data with the prescription values will then be sent to the Rodenstock factory together with data obtained from the client's eye measurements in the DNEye Scanner

3



4

3 *The ImpressionIST instrument for measuring differences between the real and ideal positions of a spectacle lens in its frame.*

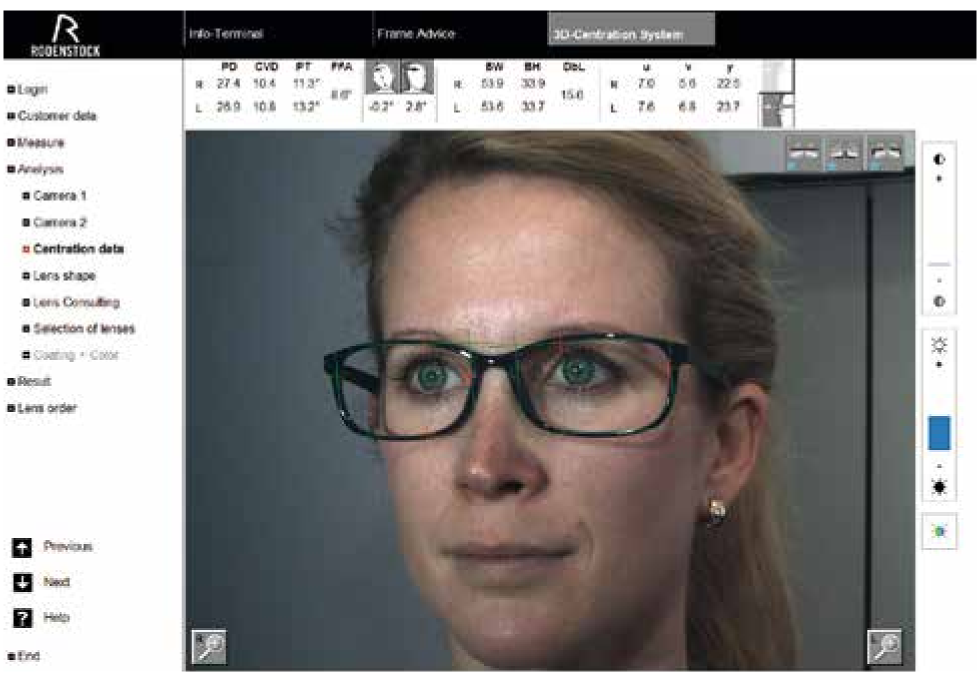
4 *The stereoscopic ImpressionIST video centration system: once the camera distance b and angular positions of both cameras are calibrated, the observing optician can determine every frame point and the client's pupil centres.*

(discussed below). Technicians at the factory can then calculate the back plane free form and machine it in a blank. In the final stage, the ImpressionIST is used to help the optician correctly mount the lenses in the frame.

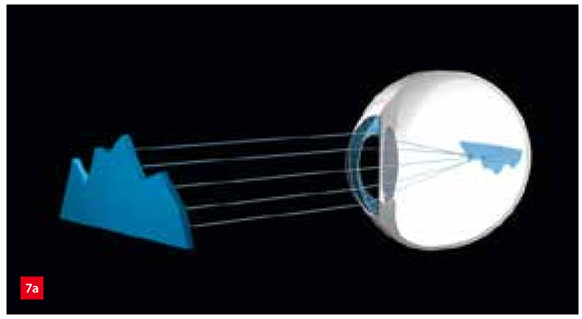
The DNEye Scanner

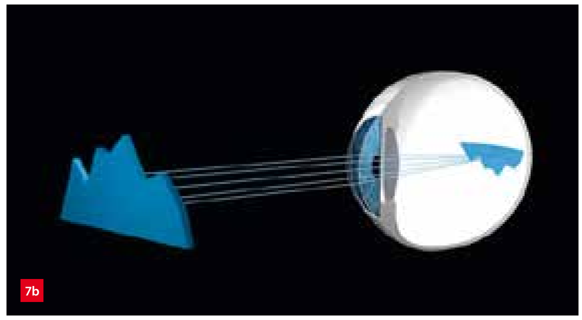
Figure 6 shows a picture of the Rodenstock DNEye Scanner, which is designed to measure low-order and high-order aberrations of the eye [6]. Low-order aberrations are defocus and astigmatism, traditionally characterised in terms of quantities of spherical power of so many diopters and cylindrical angle and power, as well. High-order aberrations include coma, spherical aberration, trefoil and high-order astigmatism. Because the effect of aberrations on vision depends on pupil diameter, the DNEye Scanner measures them at both maximum pupil dilation under dark conditions and minimum dilation in bright light (see Figure 7).

5



5 *Measurement results provided by an ImpressionIST video centration system, which facilitate the correct mounting of lenses in a frame and also provide data for the geometric dimensions of the backplane free form.*





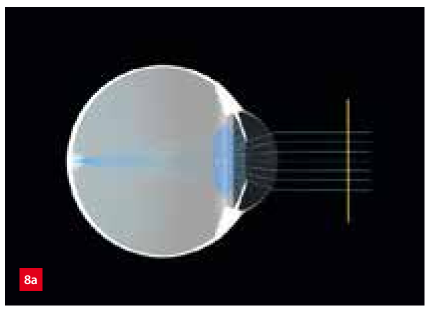
6 The Rodenstock DNEye Scanner with a keratoscope in front: a set of concentric LED rings for measuring aberrations of the anterior surface of the cornea.

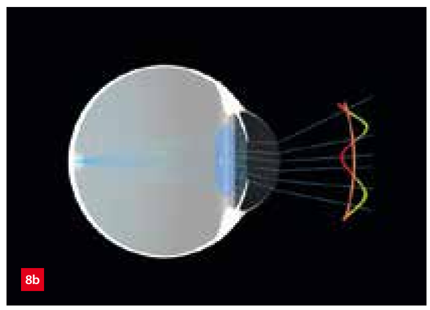
7 Spherical aberration.
(a) With fully dilated pupil.
(b) With minimally dilated pupil.

8 Wavefronts emitted by an IR point source on the retina.
(a) Ideal undeformed wavefront.
(b) Deformed wavefront after passing through vitreous humour, lens and cornea, including low- and high-order aberrations. (The orange arc illustrates the effect of the low-order aberrations, whereas the colourful line depicts the wavefront including low- and high-order aberrations.)

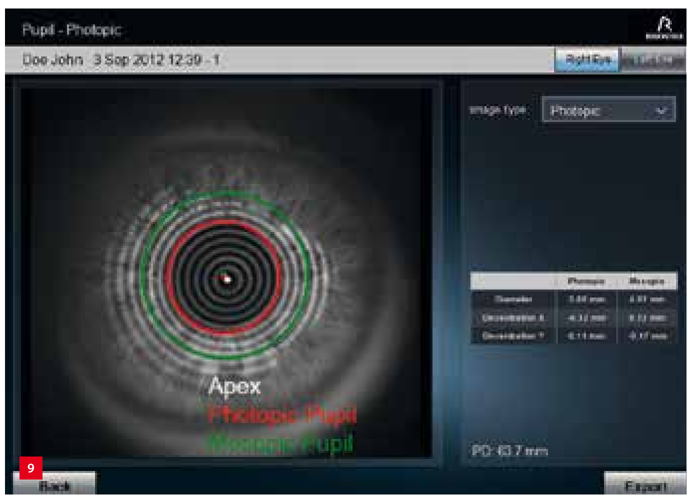
9 Iris image display of the DNEye Scanner with the image of the reflections of keratoscope rings on the retina through the pupil.

The DNEye Scanner works by projecting a point source from an infrared photodiode on the retina of an eye. This point source emits a wavefront that starts out as spherical but deforms as it passes through the vitreous humour, lens and cornea (see Figure 8). The optical designers integrated a Shack-Hartmann sensor into the scanner for evaluating the wavefront, as discussed in more detail below.



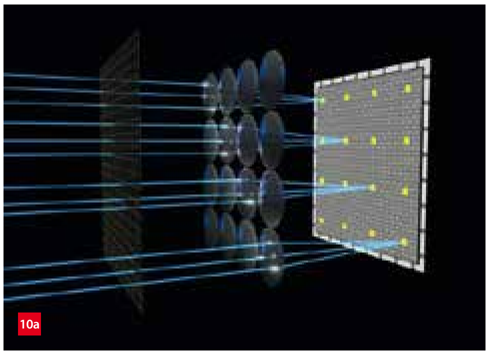


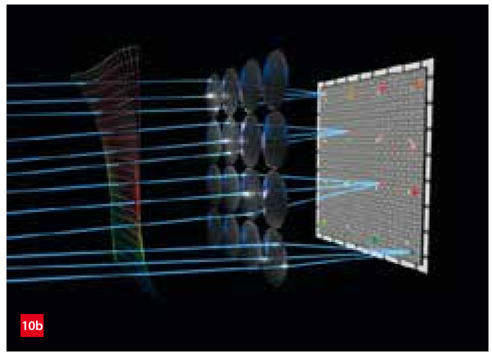
One of the most striking parts of the DNEye Scanner is a set of concentric LED rings called the Placido disk or keratoscope. This is a well-known ophthalmic instrument used to measure shape of the anterior (front) surface of the cornea. It projects the illuminated rings onto the cornea and assesses their reflection by measuring the distortion in the ring-formed image (see Figure 9). Although this topographic cornea measurement is not needed for lens design, it can be an extra aid for opticians when fitting contact lenses.



Using the Shack-Hartmann sensor

The Shack-Hartmann wavefront sensor consists of a square array of tiny lenses of equal focal length, called lenslets. Each lenslet focusses on a part of a photonic CCD chip with infrared light-sensitive dots having a pitch that is much smaller than the lenslet array pitch (see Figure 10). When a





part of the wavefront is focussed on a position differing from the point were the lenslet's optical axis crosses the flat plane of the CCD unit, the sideways deviation is a measure of the local tilt of the wavefront.

The principle behind the Shack-Hartmann sensor was formulated as early as 1900, but it took until 1970 before a practical implementation could be realised. Manufacturing an array with such high orientational and dimensional demands is a real precision engineering challenge.

During the wavefront measuring procedure, the client is asked to focus on a virtual target. Rodenstock has succeeded in finding a way to get the eye changing from an un-accommodated state to an accommodated one by moving the target from infinity to very close-up, whereby the ciliary muscle goes from being fully relaxed to fully contracted. This allows the DNEye Scanner to measure any and all aberrations during both far and near vision. All this information has to be translated into measurements of eye aberrations, which is performed by calculations in the DNEye Scanner software.

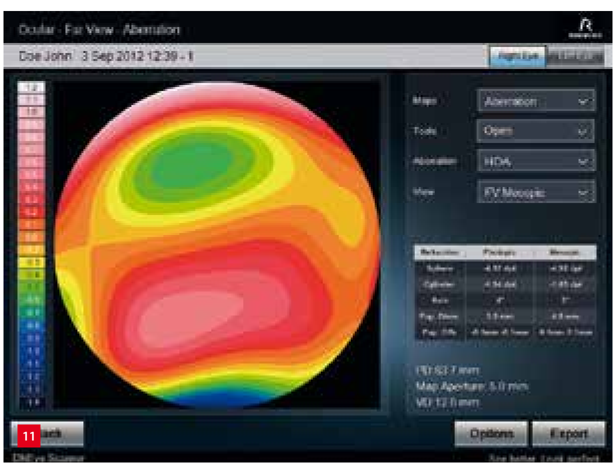
10 *The Shack-Hartmann sensor in the DNEye Scanner combines a square array of lenslets with a CCD sensor. (a) Ray pattern for an ideally flat wavefront. (b) The same for a deformed wavefront.*

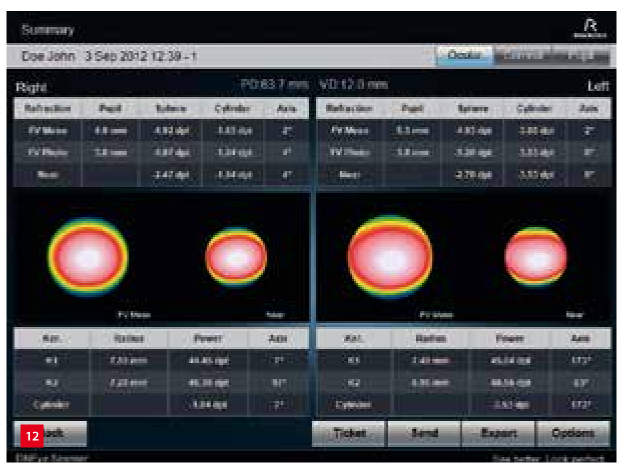
The DNEye Scanner provides measurement results in different ways. Figure 11 shows high-order aberrations in a single wavefront. Figure 12 gives a complete overview of aberrations in the left and right eye for both near and far vision, based on the software calculations referred to previously. The display also provides various other quantities, such as the objective refraction, pupil sizes and some keratometric values.

Free-form calculating algorithms

Rodenstock's mathematicians developed a special DNEye algorithm for calculating the ideal sphero-cylindrical combination for each and every point on the lens. This combination is based on the prescription, the distance for which the respective point is used, the pupil size associated with that distance derived from the pupil sizes measured with the DNEye Scanner, and the aberrations for distance and near view measured with the DNEye Scanner [7] [8].

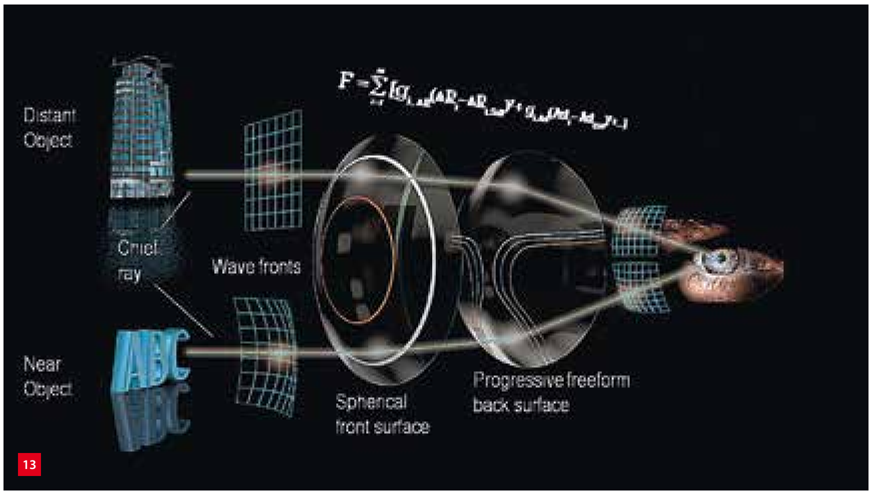
The final step is to find a surface that provides the calculated sphero-cylindrical powers for each point of the lens in the as-worn position, using data provided by the ImpressionIST instrument. Another algorithm has been designed for this





11 *Display of high-order aberrations in a single wavefront. The dominating aberration of the wave front depicted here is coma.*

12 *A complete results overview for the aberrations in both eyes.*



13 *Schematic illustration of the ILT algorithm iterative process for optimising the lens' back surface for near and far vision; the data in the formula are explained in the accompanying box.*

task, called the ILT algorithm. This works according to an iterative process for optimising the lens' back surface, starting with a preliminary surface. After that, the effect of the lens on an incoming local wavefront is simulated for each individual point on the lens using the algorithms described in [9] [10]. These simulations take the low-order and high-order aberrations of the lens into account. The results are evaluated and the surface is modified as needed. These steps are repeated until the lens meets the set criteria (see Figure 13).

In conclusion

The ImpressionIST and DNEye Scanner measurement results presented and their translation into free-form data are, indeed, very impressive, certainly justifying the name 'Impression lenses'. Of course, the overall aim of these tools is not to impress others with the high-tech know-how of Rodenstock's scientists. The aim is to provide customers with multifocal spectacle lenses that provide the highest possible viewing comfort for both near and far vision. ■

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ILT algorithm

$$F = \Sigma_{i=0}^{n} [g_{i,\Delta R} (\Delta R_i - \Delta R_{i,soll})^2 + g_{i,ast} (Ast_i - Ast_{i,soll})^2]$$

ΔR_i = actual spherical power at position *i*
$\Delta R_{i,soll}$ = intended spherical power at same position
Ast_i = actual cylindrical power at position *i*
$Ast_{i,soll}$ = intended cylindrical power at same position
$g_{i,\Delta R}$ = factor for the difference in spherical power at position *i*
$g_{i,ast}$ = factor for the difference in cylindrical power at same position

This formula provides a simplified explanation of the ILT algorithm, e.g. neglecting higher-order aberrations. For each point on the lens, the light emitted by the object enters the front surface, passes through the lens material and leaves it through the back surface, which is individually calculated by the algorithm. The shape of the incoming wavefront (depicted as two different blue meshes) depends on the distance of the object. The lens will be designed to deliver a wavefront to the eye that is perceived as a clear image (also depicted as blue meshes). In successive iterative steps, the function *F* is minimised.

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REDEFINING THE SI UNIT OF MASS

UK-based Heason Technology has recently completed the design and supply of a UHV-compatible and completely non-magnetic 3-axis manipulator, commissioned for use by PTB. The manipulator is being used to microposition a very special one-kilogram silicon sphere that could play a significant role in the redefinition of the kilogram.

The mass standard, the kilogram, is currently defined as the international prototype kilogram (IPK). The IPK is a 135 year old platinum-iridium artefact that is held at the International Bureau of Weights and Measures (BIPM) in Sèvres near Paris with about 80 'national prototype' replicas distributed world-wide to metrology institutes. Over the years, inevitably minuscule variations between the IPK and these replicas occur, which has led to the foundation of the international Avogadro Project, aimed at redefining the unit of mass for the International System of Units (SI), the kilogram, in terms of a constant on the basis of atomic mass.

To that end, two pure silicon-28 spheres with a roundness delta of less than 50 nanometers over a 93.6 mm diameter – believed to be the roundest objects in the world – have been produced (Figure 1). These have been extensively analysed for their crystal perfection and measured to determine the sphere diameter and resulting volume. From this data, the specific number of a certain type of atom (isotope) contained in the 1 kg mass of the silicon-28 sphere can be predicted with a degree of certainty. In this way the Avogadro constant, N_A, can be established and recognised as the new definition of mass.

The ongoing project has returned some very promising results and many milestones have been achieved but more exhaustive work is scheduled well into the future. Surface contamination is still a concern and a barrier to obtaining the levels of measurement certainty required. Therefore, the German national metrology institute, Physikalisch-Technische Bundesanstalt (PTB), is analysing, amongst many other aspects, the surface properties of these high-purity silicon balls using a synchrotron beam to determine the influence of this contamination at the atomic level on the sphere diameter and consequent volume. The Heason 3-axis manipulator is used inside a vacuum chamber to position the sphere relative to the synchrotron radiation beam for surface spectroscopy work.

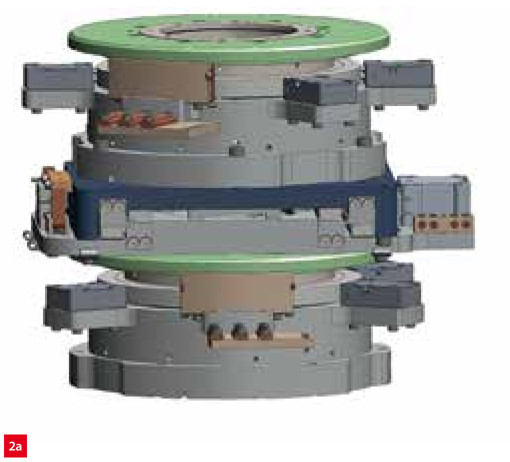
EDITORIAL NOTE

This article is based on a Heason Technology press release.

Specification

The demanding specification for the positioner covered base and upper rotary axes with 370° and 110° travel respectively with positional repeatability of 0.01°; and with a central horizontal 55 mm travel linear stage with repeatability specification of 10 microns. In order to ensure the optimal stiffness for minimum deviation through the Z-axis of the manipulator, these key specification factors necessitated extremely tight radial and axial run-out values

1 *A copy of the Avogadro Project Silicon-28 sphere – showing a copy of the IPK in reflection. (Image courtesy of PTB)*


2a


2b

2 *The Heason 3-axis sphere manipulator used by PTB.*
(a) Design.
(b) Realisation.

for the rotary stages and equally confining pitch, yaw, roll for the linear stage. For each axis, the quadrature encoder feedback resolution needed to be ten times higher than the positional resolution to enable the servo motion control system to perform optimally.

The very restricted volume of the vacuum chamber meant that the overall dimensions available for the manipulator were just 300 mm in diameter and 500 mm in height. Further challenges necessitated a 75 mm clear aperture through each positioning stage for instrumentation feed-through and restricting the axes' travel with the use of customised hard-wired limit switches. The vacuum level was specified to 10^{-9} mbar and required the stage to be subjected to pre-heating to 120° C for outgassing in addition to a completely non-magnetic component inventory to be employed throughout the whole assembly.

Stages

The choice of piezo-ceramic motors for all axes, from Heason's distribution partner Nanomotion, provided the perfect solution for the drive and control. These very compact, completely non-magnetic, motors are arranged on the periphery of each rotary stage, creating rotary motion by driving a ceramic ring. Using the same principle, the linear stage is equipped with a ceramic strip. A combination of three 2-element HR-2 motors for each rotary axis are synchronised to provide the very fine positioning resolution required. A single 8-element HR-8 motor is used for the linear stage.

Position feedback is achieved using compact exposed optical rotary and linear encoders from Numerik Jena with glass discs and strips integrated into the assembly. All stages have ceramic ball-type caged bearings and the titanium support structure and housings, which have sufficient air gaps and spacing to allow trouble-free vacuum outgassing, were specified to provide maximum stage stiffness.

Heason Technology

Heason Technology has developed its own in-house design and build service over several years and has a large portfolio of proven application successes for motion system installations in UHV (ultra-high vacuum) for synchrotron sources and many other equally demanding research and manufacturing environments. The UK-based motion control specialist works with a select number of global motion control equipment manufacturing partners for specialised components to undertake such tasks.

UHV-compatible connectors and cables, and other vacuum-compatible materials such as PEEK were specified throughout with all cabling arranged outside of the manipulator housing with a simple harnessing system. The positioning system has a relatively low duty cycle requirement with slow positioning followed by longer motion breaks for surface measurements where the piezo-ceramic motors' inherent locking ability provides complete stability.

To be continued

The 3-axis sphere manipulator (Figure 2) was supplied to the German technical consultancy firm Precision-Motion which provided the motion control system. PTB is now busy using the Heason manipulator and the results they obtain will be forthcoming over time – perhaps with the announcement of further encouraging results for the new definition of mass. ■

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"PRECISION IS IN OUR BLOOD"

AUTHOR'S NOTE

Frans Zuurveen is a freelance text writer who lives in Vlissingen, the Netherlands.

In 1915, Charles Schaublin started a factory producing tools for the Swiss watch industry. His basic lathes are in no way comparable with today's Schaublin 202 TG, which not only turns but also mills and grinds. Moreover, the 202 TG not only machines 'easy' materials like aluminium and brass but also extremely hard steels. Incomparable lathes of course, but all of the 250,000 Schaublin cutting machines that were manufactured in the course of a century have one property in common: precision. That's why Rolf Muster, CEO of Schaublin Machines, says: "Precision is in our blood."

FRANS ZUURVEEN

When driving through the Swiss Jura to the Schaublin premises in Bévilard many signs with the word 'Décolletage' can be observed. This is the French word for the production of small watch components in large series. This makes it clear that the region means an enormous market for Schaublin precision lathes. And it justifies the decision of Charles Schaublin one century ago to start his activities here. This is not the only marketing region for Schaublin, however. The respected company has eighty dealers at its disposal around the world and produces about 500 machines a year. See Figure 1 for Schaublin's past and present.

The most important part of a lathe is the spindle in the headstock. That's why Rolf Muster calls this essential component 'the heart of the machine'. How Schaublin succeeds in manufacturing spindles with extremely small run-out deviations is explained below.

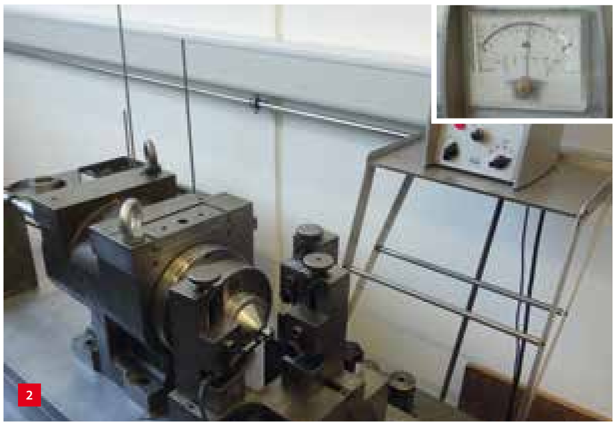
Headstock spindles

One of the most important parts of the Schaublin factory is the spindle assembly workshop. After assembling, each and every headstock spindle is tested for its run-out deviation, which always has to be less than 0.5 μm. Figure 2 shows the testing set-up, with a calibrated steel sphere in the spindle collet and a very sensitive Tesa inductive displacement

1a

1b

1 Schaublin's past and present.
(a) One of the first lathes, produced at the beginning of the 20th century.
(b) Today's 202 TG hard-turning, hard-milling and grinding machine.



2 *Measuring spindle run-out with a Tesa inductive displacement sensor. In the inset, the upper scale with a range of ±3 μm shows a run-out deviation smaller than 0.2 μm.*

transducer touching the sphere. In this case the deviation amounts only 0.2 μm.

What is the secret of manufacturing such high-precision headstock spindles? In the first place the selection of precision bearings, being not hydrodynamic or hydrostatic sleeve bearings but precision ball bearings from renowned manufacturers, SKF or FAG. Every headstock spindle is supported by five 15° or 25° angular contact ball bearings, three at the – highest loaded – front side and two at the back side. The complete bearing assembly is pre-tensioned, of course. Schaublin applies hybrid ball bearings with steel inner and outer races and ceramic rolling elements from silicon nitride (Si_3N_4). They are provided with long-life special grease lubrication.

When describing headstock spindles, the drive system also has to be mentioned. In the case of the versatile 202 TG machine the spindle is directly driven by a brushless synchronous motor integrated in the headstock assembly. Its speed varies from 50 to 7,000 min^{-1}, thanks to a variable-frequency alternating-current electrical feed. To keep thermal expansion as low as possible, the headstock assembly is thermostatically water-cooled.

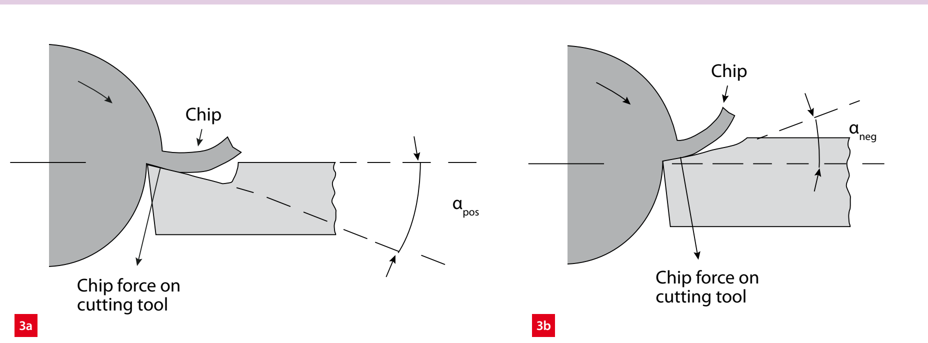
Hard turning and milling

The advantage of hard turning and milling is that an extra grinding operation can be disposed of, thus avoiding an extra reclamping operation. But machining of hardened steel imposes heavy demands on the machine and the cutting tools. PCBN (poly-crystalline cubic boron nitride) bits with negative rake angle must be used for the tools (see the box below). To avoid vibrations the machine has to be extremely stiff with a stable base frame, rigid guideways and a sturdy headstock with small run-out. All these demands are fulfilled in the Schaublin 202 TG, which is able to perform hard-cutting operations up to 65 HRC.

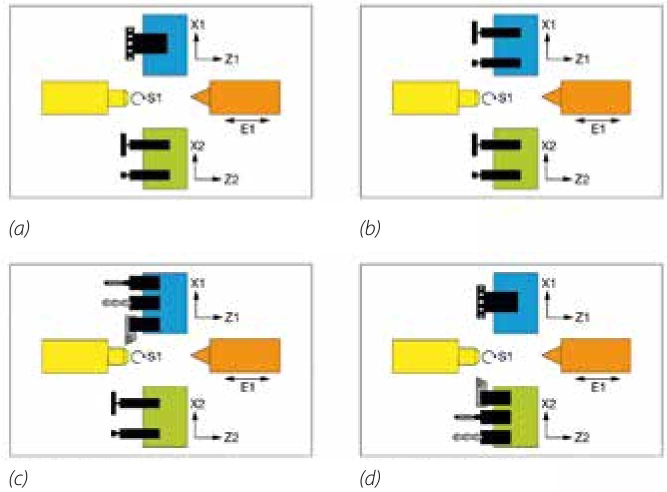
Negative rake angle

Conventional machining of unhardened materials usually requires a positive rake angle α_{pos}, because this is a real cutting process. But the machining of hardened steels resembles some kind of 'pushing and pressing away' process, which asks for a negative cutting angle α_{neg} (see Figure 3). In some respects this process might be compared to the removal of hardened workpiece material with one single abrasive particle from a grinding disc, also characterised by a negative rake angle.

Hence, turning of hardened steel with PCBN asks for a negative cutting angle. But when using a conventional non-rigid lathe, turning with a negative cutting angle causes vibrations due to the high cutting forces. These vibrations work out badly on workpiece shape and roughness. The resonance frequencies of the various components of a non-rigid lathe are much lower and the amplitudes much higher than the ones in a rigid turning machine like the Schaublin 202 TG. These heavy vibrations are traditionally called 'Ratterschwingungen' (rattling vibrations), because of their notoriousness. The foregoing explains why hard turning can only be performed on turning machines with extremely high stiffness and stability.



3 *Rake angle α. (Modified from www.oocities.org/venkatej/mech/tomc/tomc.html)*
(a) Positive.
(b) Negative.



4 *Grinding two cast-iron base frames on a Camut flat grinding machine with 3.5 m stroke. The inset shows the grinding disc.*

5 *Four possible configurations of the Schaublin 202 TG. Blue and green: X,Z-carriages; yellow: headstock spindle; orange: tailstock.*
(a) Turret / Grinding.
(b) Grinding.
(c) Grinding / Linear tooling
(d) Turret / Linear tooling.

6 *Matteo Calzascia of the Schaublin R&D department shows the two X,Z-carriages of a partly assembled 202 TG.*

Schaublin uses stable nodular cast iron for its base frames, made by the Swiss Fonderie de Cortaillod (iron foundry). Schaublin even states that completely revised cutting machines have a somewhat higher precision thanks to the aged iron of their base frame.

The stable guideways of the 202 TG are the result of applying accurate Schneeberger recirculating ball-guided units. Every X,Z-carriage (the Z-direction is parallel to the headstock spindle axis) is supported by four sets of two Schneeberger units each, resting on grinded flat planes of the base frame. For that purpose Schaublin has two huge Camut flat grinding machines at its disposal with a stroke of 3.5 m and able to machine the largest Schaublin frames of 1.6 m length, see Figure 4.

202 TG details

The number 202 in the name of the turning, milling and grinding machine refers to the centre height (in mm), the distance (in Y-direction) between the headstock centre and the base bed, as in all Schaublin machine designations. Figure 5 shows four 202 TG configurations, which are possible thanks to its provision with two separate X,Z-carriages and a tailstock with 660 mm stroke, as explained by Matteo Calzascia, head of Schaublin's R&D department; see Figure 6.
Each carriage can be provided with a grinding spindle with a speed of 60,000 min^{-1} for internal grinding or 25,000 min^{-1} for external grinding. These spindles with a run-out deviation less than 1 µm are produced by Meyrat SA High Precision Spindles in Biel, Switzerland.

The maximum workpiece diameter of the Schaublin 202 TG is 80 mm, the maximum workpiece length 150 mm. One of the X,Z-carriages can be provided with a turret (revolver) head with twelve positions, of which six are driven by a servo motor at 6,000 min^{-1}, see Figure 5. Figure 7 shows the constructive set-up of the 202 TG.

Proof of precision

In its demonstration workshop Schaublin provides evidence of the precision and versatility of the 202 TG. Figure 8 shows a product machined in only one clamping cycle from a blank hardened up to 62 HRC. Especially hard milling two key slots is a spectacular achievement of the 202 TG, because normally such an extra machining operation would require workpiece reclamping in another machine.

Quite a different precision product is a complicated automatic-watch oscillating mass machined from brass on a Schaublin 136 machine, see Figure 9. Note the special engraving and the tolerances specified in the drawing. To handle this product on only one machine, the product is transported from the collet in the main spindle to a counter spindle, which replaces the usual tailstock. This

configuration enables the machining of the other side of the workpiece. The counter spindle is mounted on its own guideways and travels towards the main spindle to pick up the workpiece. To facilitate machining of both sides, a highly versatile turret is applied, with tools at the front as well as at the back side.

No precision of products without precision of the cutting machine applied. That's why Georg Schlesinger, the German engineering professor (1874-1949), formulated his paper "Testing machine tools for the use of machine tool makers, users, inspectors and plant engineers" already in 1927. One of his tests for lathes was the insertion of a calibrated mandrel in the headstock's chuck to measure the parallelism of the main spindle with respect to the base bed. To that end a dial gauge had to touch the mandrel when transporting the tool carriage along the bed.

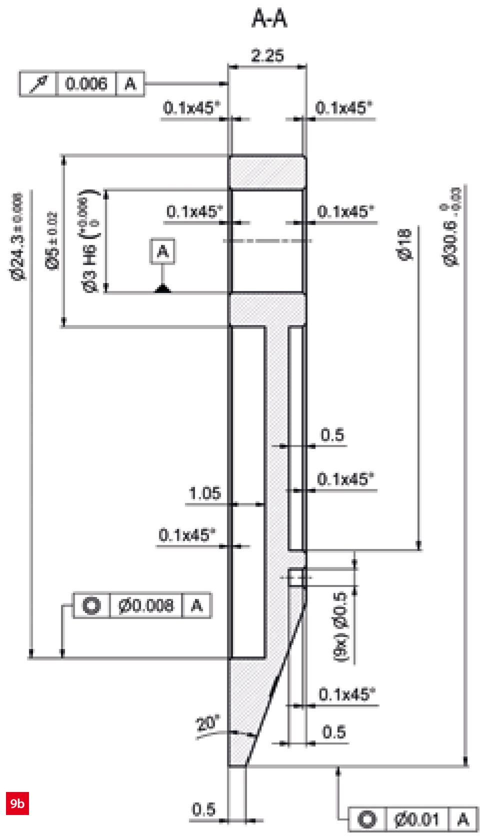
Today, these Schlesinger standards have been replaced by international standards, but no unification has been reached up to now, unfortunately. Machine tool makers in the USA make use of the ANSI-standard, their Japanese colleagues use the standard JIS B 6201 and Europeans use the German standard VDI 3441.

The problem with this lack of general acceptance is that the outcome of tests varies with the standard in use. For example, some inaccuracy results measured according to the Japanese standard are about a factor 8 smaller than the ones measured according to the VDI standard. This means that machine tool measurement data from different manufacturers cannot be compared directly. But it must be emphasised here that Schaublin always applies the most stringent standard, which is VDI 3441.

To conclude

Is the above quoted statement about the precision in the blood of Schaublin's workforce exaggerated? A bit swanky of course and physically impossible, but the visit to Schaublin quite certainly made it clear that their workers all are really convinced of their responsibility to build precision into the Schaublin products. This is a well-known characteristic of the Swiss watch industry, of course. It is good to have experienced that the whole world's precision technology can take profit from this characteristic. ■

7 The interior of a 202 TG with safety cover removed. At the left the headstock spindle, at the right two grinding spindles (in front), mounted on an X,Z-carriage, and one turret (behind), on the other X,Z-carriage.
8 A 'difficult' workpiece hard-machined on a 202 TG during no more than one clamping cycle. At the right the blank hardened up to 62 HRC, at the left the finished product with two key slots and a screw thread. Pitch of the squares is 4 mm.
9 A complicated automatic-watch oscillating mass machined from brass on a Schaublin 136 machine.
(a) Realisation (pitch of the squares is 4 mm).
(b) Design, cross-section showing the precision demands.



INFORMATION

De RidderTHO in Best is the sole representative of Schaublin in the Netherlands.

WWW.SMSA.CH WWW.RIDDER.NET

ACHIEVING PRECISION TOLERANCES IN AM

At the end of April, the American Society for Precision Engineering (ASPE) hosted its Second Annual Topical Meeting on Achieving Precision Tolerances in Additive Manufacturing on the Centennial Campus of NC State in Raleigh, North Carolina, USA. Nearly 100 people from around the world attended the conference to hear the latest research in the field, provided with a programme and an environment that stimulated discussion in a collegial atmosphere.

DANNIS BROUWER, TON PEIJNENBURG AND WENDY SHEARON

While Additive Manufacturing (AM) is a hot manufacturing process capable of creating a wide variety of components, it still has to prove its ability to deliver the required dimensional accuracy and surface finish. The ASPE series of Topical Meetings on these issues is crucial to putting AM onto the factory floor. This series is strongly driven by John S. Taylor of Lawrence Livermore National Laboratory, currently acting as immediate past president of ASPE. His goal is to connect the world of (metal) AM with that of precision engineering.

In his own presentation, Taylor discussed surface topography and highlighted an impressive list of contributing factors. Significant attention was given to so-called test artifacts that can help characterise AM process capability for form and finish. Different test artifacts were proposed, each with their specific advantages of being either complete or fast in the evaluation of AM equipment.

The Dutch

As with other ASPE meetings, there was a strong Dutch delegation present, including representatives from Delft University of Technology (TU Delft), University of Twente, and VDL Enabling Technologies Group. For a company like VDL ETG, which manufactures precision mechanical and mechatronic systems, finding the place for AM in their manufacturing environment is an important issue. At the same time, the freedom to design complex shapes using AM opens up new dimensions for optimisation, as is demonstrated at TU Delft.

The James B. Hunt, Jr. Library was the inspiring venue for the ASPE 2015 Spring Topical Meeting. Featuring the latest technological advances and the bookBot, an automated book delivery system, the library opened in January 2013 and has been named one of the most spectacular libraries in the world by the San Francisco Chronicle. (Photo by Dannis Brouwer)

AUTHORS' NOTE

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Tutorials

The programme started on Sunday, 26 April 2015, with a nice selection of tutorials. Dutch flavour was provided by Prof. Fred van Keulen from TU Delft, who lectured on topology optimisation. In contrast to size or shape optimisation, with topology optimisation the layout of a structure is optimised. Topology optimisation typically leads to complex 3D architectures, which can only be manufactured economically with traditional techniques after rigorous re-engineering and simplification. However, these complex 3D architectures are in general easy to manufacture using AM techniques.

Dr Howard A. Kuhn from the University of Pittsburgh presented AM fundamentals. His uncomplicated way of telling the story was excellent for the mixed audience. In collaboration with Prof. Van Keulen he also addressed design for AM.

In a combined workshop, Dr Marcin B. Bauza from Carl Zeiss discussed the use of X-ray Computed Tomography to measure parts made using additive processes. Mainly internal or otherwise obscured features are candidates for this technology. For a number of effects related to the interaction of X-rays and metal, the effect on measurement accuracy was discussed. Later in the Meeting, Nikon Metrology would also discuss X-ray CT and explain about the measurement process and potential pitfalls.

In the second part of the workshop, Prof. Chris Brown of Worcester Polytechnic Institute discussed roughness measurements, specifically the necessity to evaluate R_a at the proper length scale to achieve good (in some cases even, any) correlation to a parameter of interest, such as fatigue.

Metrology

Other tutorials dealt with surface topography measurement and characterisation, metrology, and geometric analysis. In the programme of the oral presentations, which featured a total of nine sessions, metrology in a broad sense was also one of the main topics. Not only in terms of methods, such as X-Ray CT, but also regarding process validation and optimisation, including standardisation of tests, and material certification. Another metrological issue is surface characterisation. The University of Rochester contributed a presentation on the characterisation of the optical surface of additively manufactured lenses.

Conclusion at the end of the ASPE 2015 Spring Topical Meeting was that there is a promising future for precision AM. However, it would be good if more examples are presented to see where the initial applications may be. Preferably, these examples would not be critical on all aspects that the AM technology needs to work on, but only on a few. So, lots of work still needs to be done to get AM into the domain of precision engineering. ■

INFORMATION

ASPE.NET/TECHNICAL-MEETINGS/PAST-ASPE-MEETINGS

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	to be planned (Autumn 2015)
Motion Control Tuning (MA)	6	HTI	18 November 2015
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	29 June 2015
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	3 November 2015
Applied Optics	6.5	MC	10 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	3 July 2015
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

Course providers

- Engenia (ENG)
  WWW.ENGENIA.NL
- The High Tech Institute (HTI)
  WWW.HIGHTECHINSTITUTE.NL
- Mikrocentrum (MC)
  WWW.MIKROCENTRUM.NL
- LiS Academy (LiS)
  WWW.LISACADEMY.NL

Content Partners

- Dutch Society for Precision Engineering (DSPE)
  WWW.DSPE.NL
- Mechatronics Academy (MA)
  WWW.MECHATRONICS-ACADEMY.NL
- Settels Savenije van Amelsvoort (SSvA)
  WWW.STTLS.NL
- Sioux
  WWW.SIOUX.EU
- Technical Training for Professionals (T2Prof)
  WWW.T2PROF.NL

UPCOMING **EVENTS**

8-10 July 2015, Golden (CO, USA)
ASPE 2015 Summer Topical Meeting
The 5th ASPE Topical Meeting on precision interferometric metrology, featuring an optional, pre-meeting tour of the National Institute of Standards and Technology in Boulder (CO).

ASPE.NET

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

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 28 ff.

DUTCH SOCIETY FOR PRECISION ENGINEERING

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

WWW.OPTICSWEEK.NL

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

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 dedicated to the manufacturability of precision components and 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

FIRST OPTICS AND OPTOMECHATRONICS WEEK

From 28 September to 2 October 2015, the first Optics and Optomechatronics Week will be organised, 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.

■ *High-end optomechatronics design: Field Selector mechanisms for the Star Separators of the Unit Telescopes in the Very Large Telescope array (VLT) operated by the European Southern Observatory (ESO) in Chile. (Photo courtesy of Fred Kamphues/TNO)*

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+ training and hands-on practice in optical design and simulation

Symposium

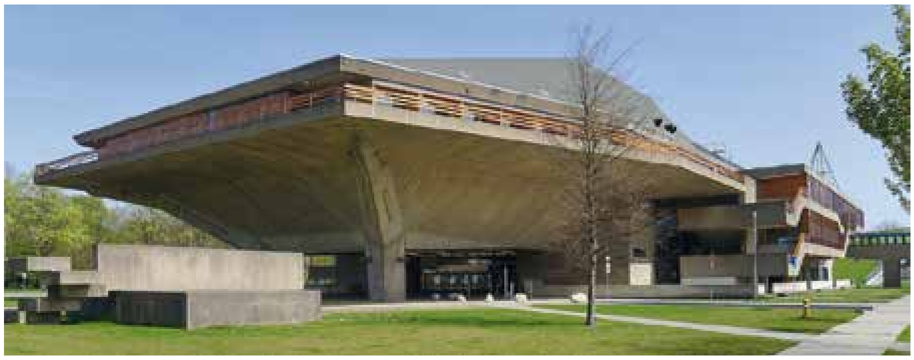
The Optics and Optomechatronics Symposium is the second edition of the bi-annual event, which kicked off successfully two years ago in Eindhoven, attracting over 150 engineers.

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 Professor Jos Benschop, Sr. Vice President Technology, ASML. The venue is the Aula Conference Centre in Delft.

Confirmed speakers

- Prof. dr. Ralf Bergmann
  Managing Director, BIAS (Bremer Institut für angewandte Strahltechnik)
  Optical Metrology for micro-parts
- Ir. Ruud Beerens
  Senior Architect Opto-Mechanics, ASML
  Design guidelines for stable opto-mechanics
- Drs. Teun van den Dool
  Senior System Engineer, TNO
  Adaptive optics mirror
- Dr. Nandini Bhattacharya
  Assistant professor Optics Group, TU Delft
  Speckle dynamics to monitor pulsatile flow

- Dr. Steven van den Berg
  Research Scientist, VSL
  Spectrally resolved frequency comb interferometry for absolute distance measurement
- Dr. Wolfgang Robra
  Head Development, Hittech Protor
  High Speed shutter design for extreme environment



■ *Venue for the Optics and Optomechatronics Symposium 2015 is the Aula Conference Centre in Delft.*

Optomechanics course
The 2-day Optomechanics course will cover subjects on 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. 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.

Smethods+ course on optics design
The 4-day 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. ■

Information and registration
WWW.OPTICSWEEK.NL

Ter Hoek 2.0: edm and precision solutions

Early this month, Ter Hoek Vonkerosie in Rijssen, the Netherlands, celebrated its 25th anniversary. In 1990, Gerrit ter Hoek, established his company in the proverbial barn behind his home. From the start he focussed on manufacturing precision parts using wire erosion (or EDM, Electro Discharge Machining). Over the years, Gerrit and his wife Gerrie grew Ter Hoek to become a market leader in northwestern Europe. The current facility was erected in 2007, measuring 2,000 m^2 and featuring modern production facilities.

To date, Ter Hoek has some 30 employees as well as 30 advanced machines. Recent developments include AS9100 certification (for aerospace), which will be achieved later this year, and the purchase of a Laser MicroJet® machine. The Laser MicroJet (LMJ) technology from Swiss company Synova combines a laser beam with a water jet, which eliminates heat-affected zones that arise during wire eroding. Compared to wire erosion, the LMJ produces a lower surface quality of the cut, but accuracy and speed are superior. In contrast to wire erosion, the LMJ is also suitable for non-conducting materials. More on the LMJ technology in a forthcoming issue of Mikroniek.

Gerrit ter Hoek (left) explaining the EDM technology to guest speaker Prof. Herman Wijffels.

One of the highlights of the celebration was a presentation by Prof. Herman Wijffels, former Rabobank president and SER (Social and Economic Council of the Netherlands) chairman. Currently he is professor of Sustainability and Societal Change at the Utrecht Sustainability Institute of Utrecht University. In his speech he addressed the need for a circular economy that does not exhaust the natural resources of our planet, as the big corporates have done in past decades in their linear business models. Wijffels' hope for the future is on small and medium-sized enterprises such as Ter Hoek.

Anno 2015, Ter Hoek presents itself as a service provider dedicated to solving the client's real problem. To mark Ter Hoek's evolution, the anniversary celebration was used to launch a new corporate logo and pay-off: edm & precision solutions. The celebration was concluded with a flashy laser show highlighting the modern machine park and a tour of the facilities.

WWW.TERHOEKVONKEROSIE.NL

MathWorks Release 2015a

With its first 2015 release, R2015a, MathWorks introduces an antenna-to-bits wireless design solution. The offering helps wireless and radar system engineers simulate designs that incorporate multiple antennas, smart radio frequency (RF) devices, and advanced receiver algorithms. New software-defined-radio (SDR) hardware support enables over-the-air testing.

MathWorks is a leading developer of mathematical computing software. MATLAB, the language of technical computing, is a programming environment for algorithm development, data analysis, visualisation, and numeric computation. Simulink is a graphical environment for simulation and Model-Based Design for multi-domain dynamic and embedded systems.

The new release presents interesting features, such as MATLAB support for Arduino Leonardo and other Arduino boards, and a Simulink hardware support package targeting Apple iOS devices for creating apps that run Simulink models and algorithms.

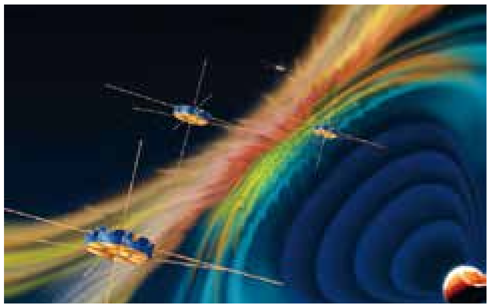
In addition, four new products were launched:
- Antenna Toolbox for designing, analysing, and visualising antenna elements and antenna arrays.
- Robotics System Toolbox for designing and testing algorithms for robotics applications.
- Simulink Test for creating test harnesses, authoring complex test sequences, and managing simulation-based tests.
- Vision HDL Toolbox for designing image processing, video, and computer vision systems for FPGAs and ASICs.

WWW.MATHWORKS.COM

Faulhaber motors in NASA research satellites

In NASA's Magnetospheric Multiscale (MMS) research project, motors from Faulhaber will help in examining the earth's magnetic field. The MMS mission should for the first time provide a three-dimensional image showing how near-earth magnetic fields disconnect and reconnect. These processes generate huge amounts of energy which can also significantly affect terrestrial electronics systems. Using the data from the MMS probes, the scientists involved also expect to better understand fundamental processes in the entire universe.

The MMS mission consists of four identical space probes that were launched into space from Cape Canaveral on 12 March 2015. Once in orbit, each probe will send out four spherical magnetic field sensors tethered to the probe by 48 m long cables in order to cover a large



■ *The MMS probes launched for examining the earth's magnetic field.*

measuring range. The cables are unwound by Faulhaber stepper motors as soon as the spacecraft reach their target area.

For absolute reliability NASA carried out a special audit on Faulhaber production and was convinced that their motors satisfy its high requirements in every respect. These requirements included high performance at a very low weight – every gram counts when a rocket is launched – and in as compact a design as possible. The motor and precision gearhead are only just longer than 56 mm. Nevertheless, the unit generates up to 0.5 Nm at the output shaft.

To ensure that they can operate perfectly in space, the ball bearings of the motors and the gearwheels of the gearheads are lubricated with a special lubricant which can also fulfil its function in a vacuum and at extremely low temperatures. Furthermore, the units comprising motor and gearhead have been given vent holes to allow the air trapped in the housing to escape when they leave the earth's atmosphere so that unwanted differences in pressure are avoided.

WWW.FAULHABER.COM

Redesign of motorised linear stages

OptoSigma, represented in the Netherlands by Molenaar Optics, has introduced its completely redesigned OSMS-series of motorised linear stages. The new stages feature significantly improved accuracy and life-cycle performance to meet stringent industry requirements. The outer-rail design enables orientation in any direction. Being available with a travel range from 35 to 500 mm, a five-phase stepping motor connects minimum size and weight with high speed and torque, enabling up to almost 200 N load capacity.

The moving table offers various threaded holes to make stacking of stages easy. Safety covers completely protect the user from moving parts in the stage interior. Optionally, the stages are available with a built-in compact scale for closed-loop operation. For these stages, OptoSigma offers a range of single- and multi-axis drivers and controllers interfacing with external computers to compose complete motion control systems.

WWW.MOLENAAR-OPTICS.NL

Tactile sensor for roughness measurement on CMMs

Hexagon Metrology introduces the Profiler R, which enables quick and easy inspections of surface profile within a regular coordinate measuring machine (CMM) program. The miniature roughness sensor offers a more accurate alternative to manual roughness measurements. Measuring all common roughness parameters, the Profiler R can be automatically swapped on to several different scanning sensors, adding surface profile inspection to the program without the need for reclamping.

The miniature roughness sensor provides a tactile surface inspection method for Leitz CMMs. Adding more measurement capabilities to the typical measurements and evaluations of the machine, it allows profile inspection to become a standard part of the quality set-up, ensuring all the relevant parameters of a workpiece can be checked. Transport and changeover times are reduced, enabling a much more efficient process for quality assurance.

Designed to measure alongside a range of scanning sensors, the Profiler R has its own clamping system. The unique integration method allows tool exchanges be made automatically using a standard tool changer, and enables very high positioning accuracy and controlled probing without the risk of errors or operator variability associated with manual roughness measurement devices.

With the ability to rotate through 360° and pivot by 180° the PROFILER R offers maximum flexibility and accessibility. After the support adaptor touches the workpiece, the measuring stylus is extended and moves along the surface to collect the measurement data, while the sensor itself remains still throughout the measurement.

WWW.HEXAGONMETROLOGY.COM

IBS wins CERN contract for ALICE detector upgrade

IBS Precision Engineering has been awarded a major contract from the European Organization for Nuclear Research (CERN) as part of the ALICE detector upgrade project. This is the largest contract of its kind to be placed in the Netherlands in recent history. ALICE (A Large Ion Collider Experiment) is one of the four detectors of the Large Hadron Collider (LHC), CERN's well-known flagship.

The ALICE detector can be considered as one of the most complex scientific instruments built by mankind. During the LHC shutdown in 2018 and 2019, CERN is planning to upgrade the ALICE central barrel detectors with a new low-material and high-resolution silicon pixel detector in order to greatly improve features like spatial resolution, tracking efficiency and read-out rate capabilities.

IBS is providing precision engineering for this advanced upgrade. They will supply a number of stand-alone systems to deliver high-accuracy sensor array positioning and interconnect. The sensor chips, to be assembled as part of the Inner Tracking System (ITS) and the Muon Forward Tracker (MFT) of the detector, are only 50 μm thick and will require ultra-precision laser soldering of up to 100 interconnects per chip. IBS will develop the automatic assembly systems to accomplish these requirements. The systems will be delivered to CERN and five institutes around the globe.

WWW.IBSPE.COM
WWW.CERN.CH

Advanced silicon carbide XY air-bearing stage

Aerotech has developed the advanced PlanarHDX, a planar air-bearing platform for semiconductor manufacturing and advanced test and inspection. Structural elements were designed using an advanced silicon carbide ceramic with a specific stiffness (elastic modulus/density) five times higher than aluminum and a coefficient of thermal expansion approximately five times lower. The resulting material and FEA-optimised structure enable 1.5 m/s scan speed and 5 g peak acceleration with a payload of up to 20 kg for extremely high throughput processing – without sacrificing dynamic tracking, geometric performance, or thermal stability.

Other design enhancements include a new air-bearing compensation strategy that increases stiffness and load capacity for demanding high-dynamic applications. Using proven air-on-air preloading in critical bearing elements improves turnaround and settling times over vacuum-preloaded designs. A proprietary reaction-mass design strongly reduces stage-induced forces in the step-axis that are transferred to the isolation system or customer's structure (optics, sensors, etc.). By minimising these dynamic forces, move-and-settle time is reduced and process throughput is increased.

The PlanarHDX is available with passive or active isolation systems. Additional axes such as Z-tip-tilt or Z-theta designs as well as custom wafer load/unload mechanisms and wafer chucks are available. Machine weldments, complex granite base structures, or enclosures can also be provided. Feedback options include low-expansion glass scale encoders or interferometer.

Advanced control features are available and Aerotech's ETM (Enhanced Throughput Module) option helps improve the positioning performance of high-dynamic motion systems by directly measuring and compensating for the unwanted motion of the machine base.

WWW.AEROTECH.COM

60th anniversary

DSPE

YOUR PRECISION PORTAL

DUTCH SOCIETY FOR PRECISION ENGINEERING

FIRST ANNOUNCEMENT

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
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