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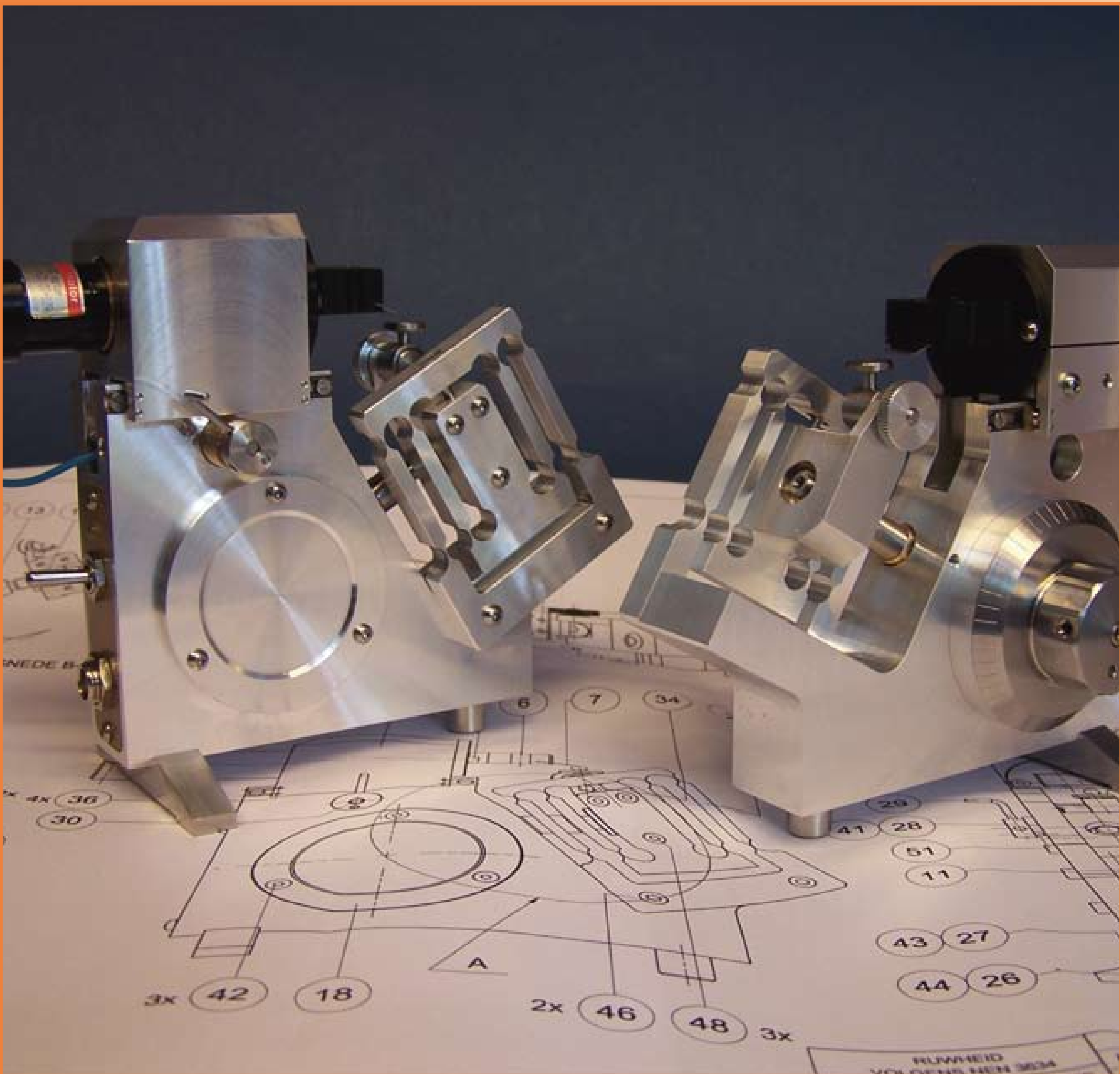

Reducing production cost: Advanced control in a high-speed wire bonder
Precision measurement of form and contour • Improved stress prediction in adhesives
LiS to offer bachelor in applied precision engineering • ASPE Annual Meeting
Photonic integrated circuits: A new approach to laser technology

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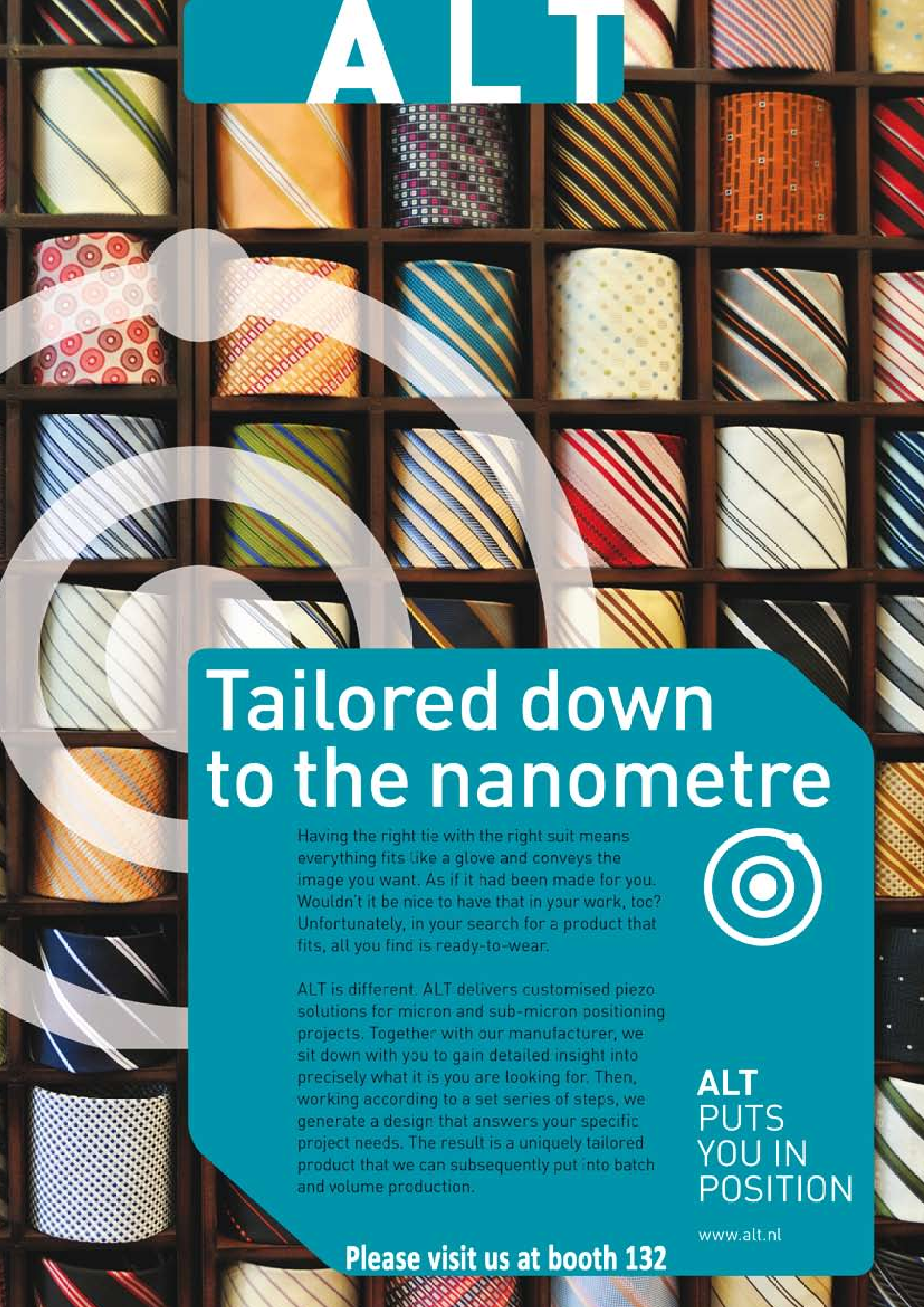
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Mikroniek - 2012

In this issue

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The cover photo (prototype made by LiS student for a research institute) is courtesy of LiS (Leiden Instrument Makers School).

editorial

Precision and industrial design: not such unlikely partners

Industrial design is a discipline that is traditionally concerned with aesthetics and user friendliness. At first glance, the world of high-tech instruments, with their cutting-edge technology and pure functionality, seems far out of the reach of design. However, the profession has seen an evolution that has greatly expanded its scope.

With functional differences decreasing between the various manufacturer products, competition must now take place on other features and not just on the core function alone. Ingenuity is oftentimes invisible, leaving the shell of the instrument to convey the message of quality, performance and reliability. Technology cannot do this on its own. Industrial design is about translating qualities; by presenting a strong brand in a consistent way, and by producing an exterior that radiates self confidence and innovation.

If precision instruments are to function effectively, the human aspect is an essential part of the design. These types of equipment are operated and maintained by people who must work in comfort and safety. By taking basic ergonomic considerations into account, products can be designed that are a pleasure to work with as opposed to a hindrance.

In the process of creating precision instruments, the trend leans towards concurrent design within specialist networks: mechanical engineers, software developers and also industrial designers. Consequently, designers are now well-trained in the idiom and the skills of these partners. This synergy leads to more satisfying products in a shorter time. The designer's main focus used to be the shell, but they now participate in the first steps of the instrument architecture. They now lay the foundation for service access, ease of operation and pleasing looks.

When the inner processes are concealed and complex, a smooth workflow usually requires a well-designed user interface. Consumer electronics show how convenient the operation of complex functions can be made, and professional users expect the same level of operational ease. This challenges the designers. A solid understanding of what the product must do, and how the operator will work with it, is essential in coupling interface to hardware.

The field of industrial design has come a long way. It is now a mature discipline that is fully embedded in today's complex development processes and specialist networks. In the abstract products built around advanced technology, its contribution particularly helps build the bridge between well-invented principle and a successful marketing proposition.

Thomas Paulen, CEO, and Robert Fienieg, Senior Designer High Tech, VanBerlo

Advanced control in a high-speed wire bonder

The cost of a standard discrete semiconductor product is largely determined by assembly, packaging and testing, and not by the die that is inside. So, lowering this 'die-free package cost' can substantially reduce the total cost of a device. In keeping with this objective, ITEC, a department of NXP Semiconductors, has developed a wire bonder that is 50% faster than its current generation wire bonder. This was achieved by a design that enables the performance of faster movements. To avoid compromising product quality, improvements in the applied control algorithms were required. These improvements will be discussed in this article.

• *Thiemo van Engelen* •

NXP is a semiconductor company that focuses on high-performance mixed-signal (HPMS) semiconductors, but still sells a lot of standard discrete products. The standard products market is a low-cost, high-volume market with NXP producing billions of devices each year. One of the properties of these devices is that the cost of a product is determined for a large part by assembly, packaging and testing, and not by the die that is inside. This means that lowering this 'die-free package cost' can give a substantial reduction of the total cost of a device. ITEC, a department of NXP, supports this by developing assembly, molding and test equipment for the standard products assembly sites of NXP. One method of reducing the cost is to make the

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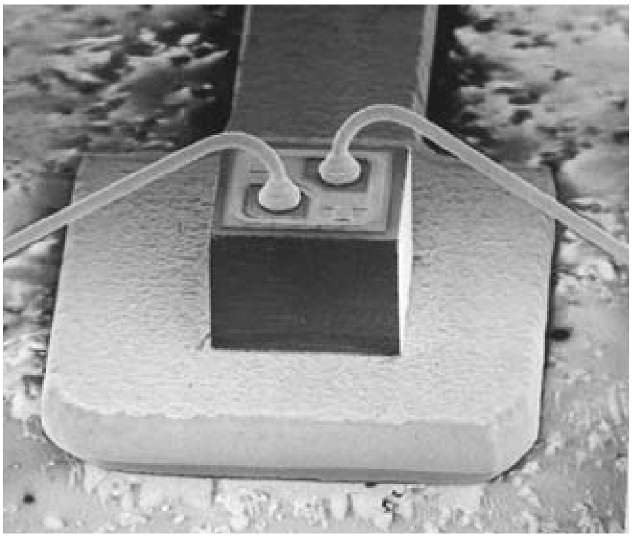


Figure 1. Transistor after wire bonding.

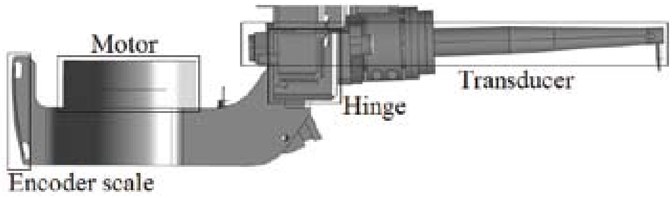


Figure 2. The Z axis mechanics.

equipment run faster, producing more with the same amount of equipment.

Problem description

One of the steps in the assembly process is wire bonding. A wire bonder places 23µm thin wires between the die and the leads of the package. Figure 1 features a SOT23 transistor without the plastic casing, which clearly shows the wires. A wire bonder contains at least three servo axes: X, Y, and Z. Of these, the Z axis is the most important one for the work that is presented here, because this moves up and down an ultrasonic transducer which carries the wire at its tip. Using ultrasonic energy together with force that is applied using the Z motor, a thermosonic bonding process is performed that connects the wire to the die or the lead.

One of the main quality criteria of a wire bonder is the ability to produce a constant ball bond on the die. Because the size of the ball bond is for a large part determined by the impact velocity when the ball is hitting the die, a constant velocity on the tip of the transducer is required in the last part of the movement towards the die.

The current generation of ITEC wire bonders can bond a SOT23 transistor in 150 ms, resulting in 24.000 transistors per hour. The goal for the next generation wire bonder is to reduce this time to 100 ms per product, resulting in a production of 36.000 transistors per hour. Of the original 150 ms cycle time, roughly 50 ms is used up by processes that cannot be shortened. This means that the remaining movements would have to take 50 ms instead of 100 ms.

To meet the cycle time of 100 ms, the acceleration of the Z axis had to be increased from 300 m/s^2 to 800 m/s^2. When using these accelerations without further changes, then the velocity settling on the tip of the transducer is not good enough to produce within specification. This deterioration of the settling is explained in the section on the mechatronic behaviour of the Z axis. To counter this, two improvements were made in the motion control software, namely optimal feedforward generation and trajectory filtering. These improvements will be discussed, as well as their results.

Mechatronic behaviour of the Z axis

In this section, the mechanics and control system of the Z axis will be presented and why the higher accelerations lead to deteriorated settling behaviour. Figure 2 shows the mechanics of the Z axis. It consists of a voice-coil motor and encoder scale connected to a main support structure of aluminium. This structure is connected with hinges to an XY table. The support structure also contains a clamp bush that clamps the ultrasonic transducer that is made mainly of steel.

The mechanics of the Z axis can be modeled by two masses connected with springs and dampers. The model is shown in Figure 3. Mass m_1 is the mass of the main support structure including the motor and z_1 is the encoder position. The hinges that connect the Z axis to the XY table are modeled by k_1 and d_1. Mass m_2 is the mass of the transducer. The clamping of the transducer is modeled by k_2 and d_2; z_2 is the position of the tip of the transducer, where the wire is carried.

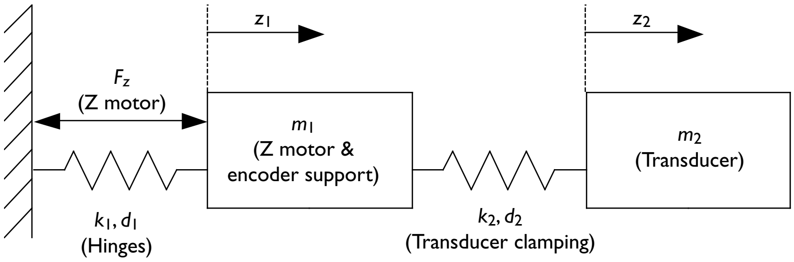


Figure 3. Model of the Z axis.

The transfer function is given by:

$$H(s) = \frac{z_1}{F_z(s)} = \frac{1}{m_1 \cdot s^2 + d_1 \cdot s + k_1 + m_2 \cdot s^2 \cdot \left(\frac{d_2 \cdot s + k^2}{m_2 \cdot s^2 + d_2 \cdot s + k_2}\right)} \qquad (1)$$

Using the motion control software that was already available, the frequency response of the Z axis was determined. The response is presented in Figure 4. It shows a behaviour that corresponds to the given model for frequencies up to 2 kHz.

When looking at the frequency response, the first resonance at 21 Hz is the resonance frequency of the complete Z axis in its hinges. The first anti-resonance at 718 Hz is the mass of the ultrasonic transducer decoupling from the Z motor and encoder support. Some investigations were performed to make this coupling stiffer, but rigorous changes in this area were not possible. The fact that the transducer mass is the one that actually decouples, was confirmed by performing measurements on the transducer tip using an interferometer. Figure 5 shows the measured frequency response from the Z encoder to transducer tip position:

$$\frac{z_2}{z_1}(s)$$

This also shows the expected response with a resonance at 718 Hz. This transfer function derived from the model is given by:

$$T(s) = \frac{z_2}{z_1}(s) = \left(\frac{d_2 \cdot s + k^2}{m_2 \cdot s^2 + d_2 \cdot s + k_2}\right) \qquad (2)$$

This transfer function corresponds to the measured transfer function in the sense that its gain is 0 dB for low frequencies and contains one resonance frequency, after which it declines with 12 dB/octave.
The control system for this axis consists of a feedforward and a feedback controller. With $P(s)$ being the desired trajectory, $FF(s)$ the response of a feedforward filter and

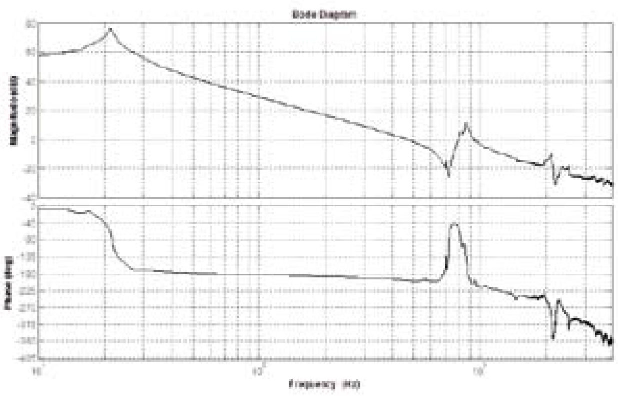


Figure 4. Z axis frequency response $H(s)$.

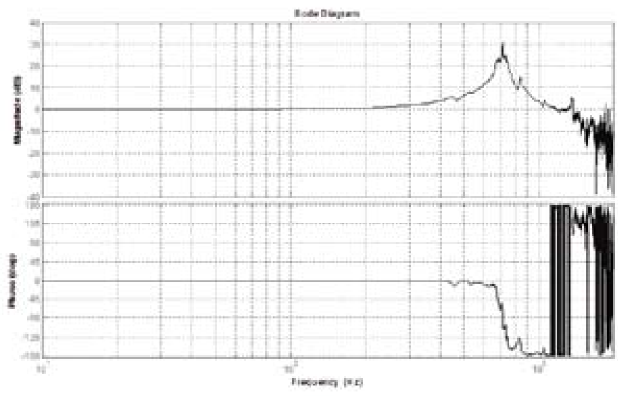


Figure 5. Measured response of $T(s)$.

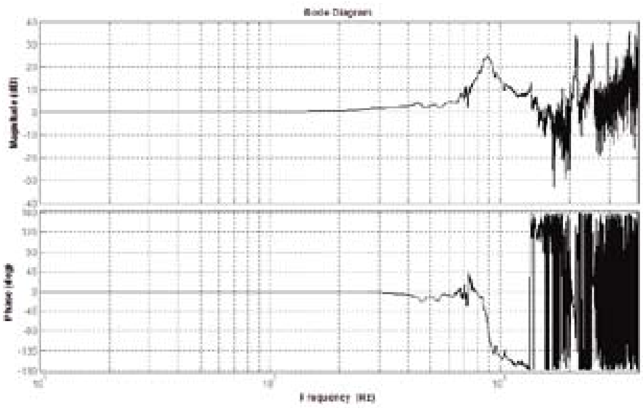


Figure 6. Total response from trajectory to tip position.

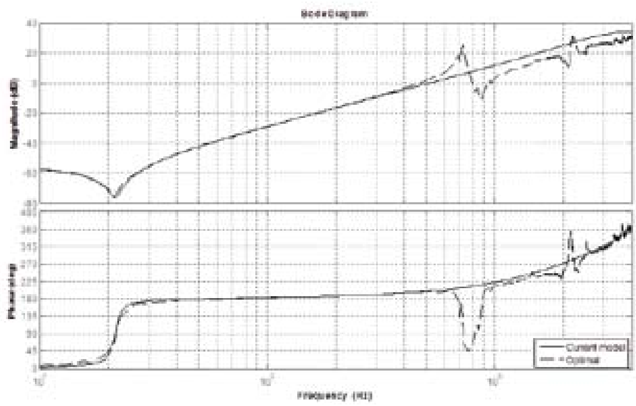


Figure 7. Current feedforward filter response *FF*(*s*).

$C(s)$ the response of the feedback controller, then the total output $F(s)$ of the complete controller is given by:

$$F(s) = P(s) \cdot FF(s) + (P(s) - z_1(s)) \cdot C(s) \tag{3}$$

The total closed-loop response for the control system is then given by:

$$\frac{z_1}{P}(s) = \frac{C(s) \cdot H(s)}{1 + C(s) \cdot H(s)} + \frac{FF(s) \cdot H(s)}{1 + C(s) \cdot H(s)} = \frac{FF(s) + C(s)}{\frac{1}{H(s)} + C(s)} \tag{4}$$

The total closed-loop response from trajectory to transducer tip is given by:

$$\frac{z_2}{P}(s) = \frac{z_1}{P}(s) \cdot T(s) \tag{5}$$

As mentioned before, increasing the acceleration of the Z axis without any corrective actions, leads to deteriorated settling behaviour and in this way to quality problems. The actual settling behaviour is determined by two factors. The first factor is the clamping of the transducer. Because this coupling is not infinitely stiff, the transducer will not follow the Z axis trajectory perfectly for the higher frequencies, as shown in Figure 5 and Equation 2. The second factor is how well the Z axis itself follows the desired trajectory. This will not be guaranteed by the controller, because of its limited bandwidth of around 300 Hz. Figure 6 shows the resulting response of the current control system from desired trajectory to transducer position, as given by Equation 5. One can clearly see the 30 dB gain at the resonance frequency of almost 900 Hz. Because using higher accelerations leads to more high-frequency energy in the trajectory, this will also lead to more energy at the resonance frequency, causing it to show in the settling.

This 30 dB gain is mainly the result of a mismatching feedforward generation. The motion software of the current generation wire bonder can perform an automatic calibration of some feedforward parameters and can determine these parameters with sufficient accuracy. However, the current feedforward generation model can only compensate a single spring and mass model: the k_1, d_1 and $m_1 + m_2$ parameters in the model. The frequency responses of the simple model and the ideal feedforward response are shown in Figure 7. One can see that the currently used simple model cannot compensate for the decoupling of the transducer mass. This results in overactuation at the resonance frequency, causing this frequency to show in the velocity settling. Besides this overactuation, there is also the problem of the resonance of the transducer.

Improvements

Two improvements have been implemented to improve the settling behaviour of the Z axis. The first improvement is to generate optimal feedforwards. One can see from Equation 4 that the Z axis will exactly follow the desired trajectory

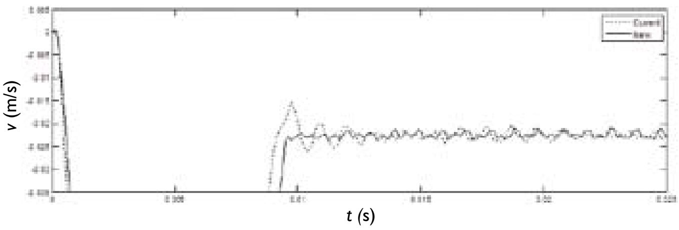


Figure 8. Velocity settling on the encoder.

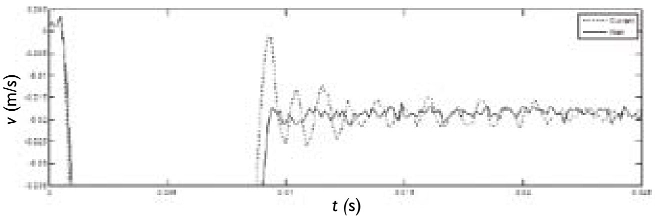


Figure 9. Velocity settling on the transducer tip.

when $FF(s) = 1/H(s)$. So a measurement of the Z axis frequency response is added to the calibrations. This response is used to calculate the desired feedforward filter response using $FF(s) = 1/H(s)$. This frequency domain filter is then used to calculate the required feedforwards for a desired trajectory by converting the trajectory to the frequency domain using FFT (Fast Fourier Transform), then multiplying the trajectory response with the feedforward response and then converting this back to the time domain. These actions result in the optimal feedforwards to make the Z axis exactly follow the desired trajectory.

This solves one of the factors that are responsible for the settling behaviour. There is still the problem of the other factor: the coupling between the Z motor and encoder support and the transducer. Although the Z axis now perfectly follows the desired trajectory, the tip of the transducer will still show a resonance at approx. 700 Hz. The solution for this problem was found in trajectory filtering.

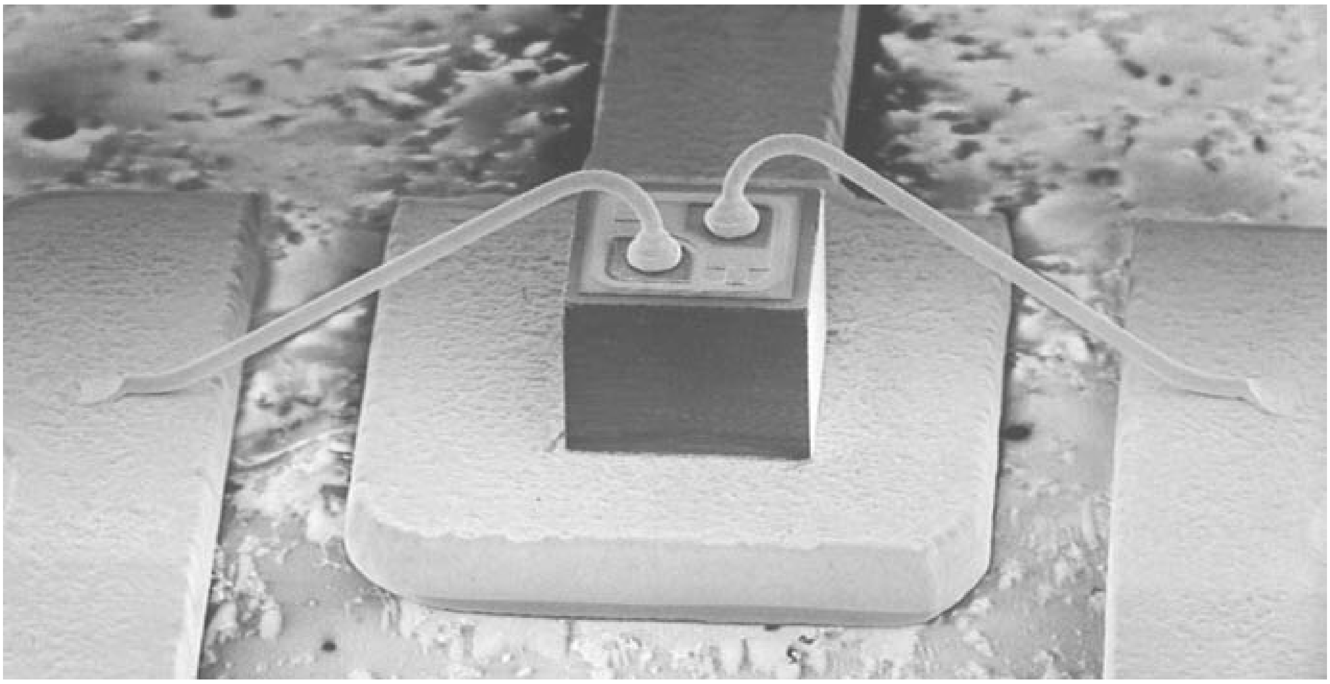
The goal of the trajectory filtering is to compensate for the resonance of the transducer. This can be done by first filtering the trajectory with a filter that has a response of $1/T(s)$. To be able to do so, the software needs to know the response $T(s)$. The exact response cannot be determined without external measurement devices or new hardware in the machine. Using external equipment is not feasible because the measurement has to be performed at least every time the machine has undergone maintenance. Hardware changes would add extra cost and complexity to the machine and are therefore also not desirable. These reasons rule out getting an exact response, so the software has to estimate the response of the transducer $T(s)$. Because the Z axis and the transducer responses show a good correlation with the ideal responses of the presented two-mass model, the error made by using estimation is small enough.

So the goal is to get good estimates of the parameters in Equation 1. These estimates can be based on the frequency response of the Z axis, together with some initial values of the parameters. After the measurement of the Z axis response, the software tries to fit the response of Equation 1 to the measurement using a non-linear fit algorithm. After the fit, accurate estimates of the parameters of the model are available and using these parameters, the response of the transducer can be calculated using Equation 2. From this response, a 4th-order compensation filter is calculated, which is then applied to the desired trajectories to compensate for the response of the transducer.

Results

With the improvements from the previous section, the settling has improved. Figure 8 shows the velocity settling on the encoder in the old and the new situation. One can see that in the new situation, the encoder settles faster to a constant velocity. More important is Figure 9, showing the velocity settling measured on the tip of the transducer. This also shows a better and faster settling behaviour, resulting in better product quality, even at the higher accelerations that are required to reach the 100 ms cycle time.

There is however a number of reasons why the settling is still not ideal. The first is that the feedforwards are close to ideal, but not truly ideal. This is because the response of the Z axis is not constant over time and over all positions. The second reason is that the trajectory filtering is only an estimate of what is really needed. The behaviour at the tip of the transducer is more complex than the model that is used. The third reason is that movements on other axes influence the Z axis, causing disturbances. Because the other axes also use higher accelerations, there trajectories also contain more high-frequency disturbances, which cannot be removed by the PID controller because of its limited bandwidth.



Precision measurement

Modern manufacturing processes require quality control through 100% or sample-wise checking with the aid of geometrical measurements. Such measurements include determining dimensional and surface properties. The latter traditionally includes defining roughness values, but is increasingly extended to the inspection of form and contour. Coordinate measuring machines (CMMs) can perform such measurements, but – besides other disadvantages – need cumbersome conversion of XYZ coordinate data. Special form and contour measuring machines are better equipped to such tasks. They are the result of further development of roughness measurement instruments on one hand and roundness measuring machines on the other hand.

• *Frans Zuurveen* •

The Fraunhofer Institute for Production Technology IPT in Aachen, Germany, took the initiative to spread the know-how of form and contour inspection specialists by organising a seminar on 16 October 2012, entitled “Measuring Technology in Precision Manufacturing – Form and Contour”. Managers of Mahr, Werth Messtechnik, Jenoptik, TU Chemnitz and the Fraunhofer IPT gave very interesting lectures. IPT capped off the meeting with a demonstration of Mahr and Jenoptik form and contour measuring instruments.

Standards and directives

The measurement of form deviations is a field prone to misunderstanding, especially concerning the definition and interpretation of form tolerances in technical drawings.

Author's note

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

Sophie Gröger of the Technical University Chemnitz, Germany, distinguished between form and waviness. She described a feedback loop carried out by a design engineer, a measuring technician and a machining craftsman. The design drawing specifies form tolerances, the craftsman makes a product that conforms to these specifications as best as possible, and the measuring technician checks if the product does indeed conform. The feedback consists of an adaptation of the manufacturing process based on the measuring results.

A clear example of measuring a contour is the definition of roundness, as part of measuring the form of a cylinder. Figure 1 explains how you can separate roundness and roughness by filtering measurement results. The mathematical algorithm most frequently applied is the Gaussian filter. Unlike a ‘brick-wall’ filter, which transmits 100% of the amplitude of all frequencies below the cut-off frequency and 0% beyond it, a Gaussian filter smooths out the cut-off curve according to the Gaussian distribution function. When measuring roundness, the frequency standard is not specified in Hertz but in UPR, undulations

# of form and contour

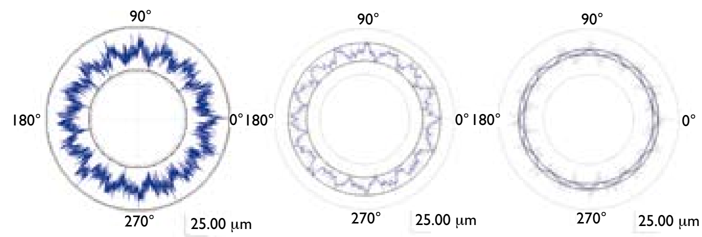


Figure 1. From left to right: unfiltered roundness measurement results, Gauss-filtered below 150 UPR, Gauss-filtered below 15 UPR. Deviations of 45.7, 20.0 and 5.0 µm, respectively. In the last case, the roughness has been filtered out and the real roundness contour remains.

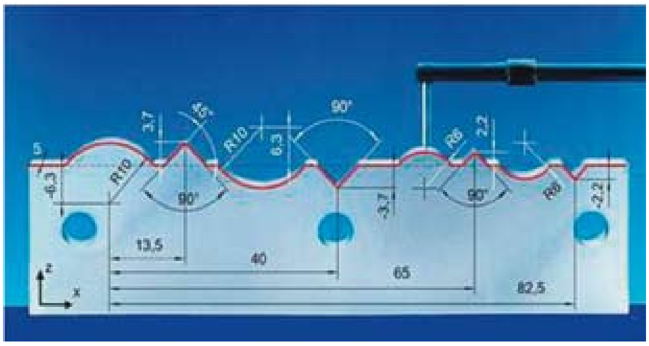
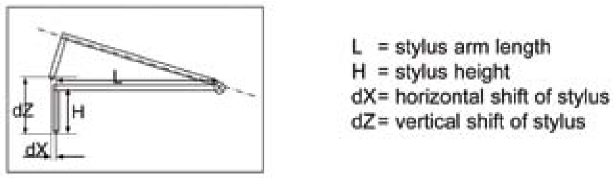


Figure 2. Application example of the contour measuring standard profile according to VDI/VDE 2629.

per revolution. Standardised UPR values are 5, 15, 50, 150, 500, 1500, etc. DIN and ISO also define the minimum value of measuring points per revolution: for 15, 50, 150 and 500 UPR at least 105, 350, 1050 and 3500 measuring points.

One other roundness standardisation subject is the definition of the reference form. The unroundness may be specified as the difference of the radii of the largest inside contouring circle and the smallest outside contouring circle with the same centre point. Another definition is the quadratic mean value in relation to the best fitting circle.

Sophie Gröger concluded her lecture with an extensive list of existing standards for form and filtering procedures. She also showed the contour measuring standard defined by VDI/VDE in norm 2629, see Figure 2. The benefits of all these standards are accelerated product development, comparability of production results, improved export possibilities, a reduction of manufacturing risks and interchangeability of assembly parts.



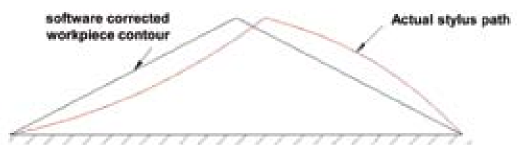


Figure 3. The actual and software corrected path of a tactile stylus when measuring a roof-like profile.

Tactile contour measurement

Heinz-Joachim Kedziora, head of the Surface Metrology Development Department at Mahr in Göttingen, Germany, explained the evolution in contour measuring over the past four decades. At first, instruments worked in an analog fashion, with a tactile stylus that describes a circular path. Later a straight path of the stylus could be achieved by applying a parallel linkage system. A further development was the introduction of a computer with a dedicated program that corrects errors such as those due to the non-straight stylus movement. Figure 3 illustrates this correction system: the actual stylus path and the software-corrected path.

Kedziora explained that today high-end contour measuring instruments describe a horizontal path of at most 260 mm with a minimal measuring point distance of 0.05 µm. The stylus movement resolutions in the X and Y directions are better than 0.001 µm. The stylus movement magnification factor amounts to 250,000x at tactile stylus radii of 2 to 500 µm. The smallest tactile force is only 1 mN and the amplitude of the signal noise in profile measurements is less than 20 nm.

A typical example of such a high-end contour, roughness and roundness reference-type ultra-precise measuring instrument is the Marform MFU 100, see Figure 4. It has

Figure 4. The ultra-precise Marform MFU 100 high-end contour, roughness and roundness measuring instrument, which serves as a reference instrument.

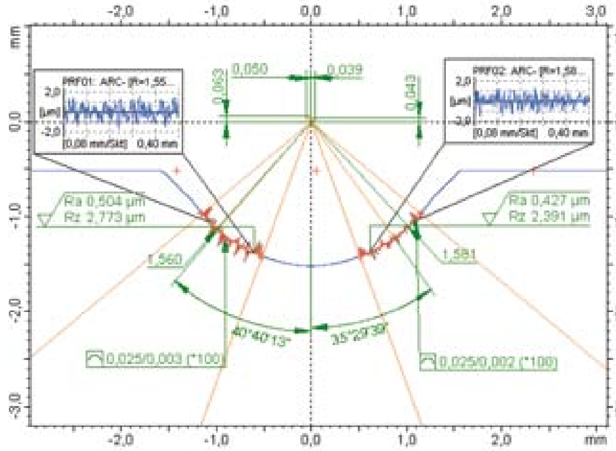


Figure 5. Result of measuring form and roughness of a ball-bearing runway.

an active air-conditioned cabin to guarantee its precision in the nanometer range: roundness error of 0.02 µm, axial run-out deviation of 0.04 µm. The instrument not only includes a tactile sensor but can also operate with a highly sensitive optical sensor. The rotary table is fitted with sensitive adjusting screws for correcting workpiece run-out after a first pre-run for measuring workpiece eccentricity. The maximum parallelism deviation of the Z axis to the rotating centre line is only 0.5 µm at a straightness deviation smaller than 0.3 µm.

Figure 5 shows an example of measuring the form and roughness of the runway of a ball bearing. The software separates form and roughness by calculating a best-fit regression circle. Variation of the filtering cut-off frequency gives insight into the relationship of real form and contour disturbing roughness.

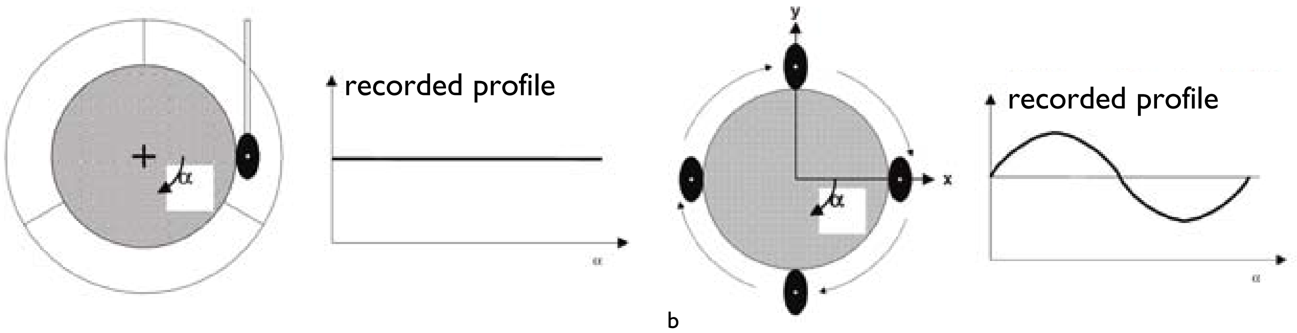
Dedicated contour measuring versus CMM

Mahr was established as a measuring company more than 150 years ago, and expanded its activities by taking over Feinprüf in 1970 and the well-known roughness measuring specialist Perthen in 1973. Today, Mahr's product range also includes CMMs. Such universal measuring instruments can also measure form and contour. However, as Kedziora explained, dedicated contour measuring instruments such as the Marform MFU 100 are better equipped to such tasks.

Characteristics of contour measuring instruments are the cross-sectional measuring principle, the fast attainment of a large number of measuring points, the integration of ideal reference contours, the flexibility in the presentation of results, the easy operation and the simultaneous definition of dimensional, positional and form deviations. Characteristics of co-ordinate measuring machines are the measuring in Carthesian orthogonal XYZ coordinates and the point-by-point definition of surfaces and contours.

Rainer Bartelt, Head of the Mahr Academy, which provides instruction and training to users of Mahr equipment, also compared dedicated contour and form measuring instruments to CMMs. He emphasised the conformity of the horizontal X measuring axis with Abbe's comparator measuring principle: dimension and standard should be in one line to avoid first-order deviations due to angular guiding flaws. Moreover, such dedicated instruments use reference forms for straightness and roundness. By contrast, CMMs only use straightness references. Furthermore, CMMs have to work with higher tactile forces for reasons of measuring stability. Bartelt showed a practical example of the influence of the form deviation of a tactile ball stylus. Such a deviation doesn't influence the results when measuring roundness with a contour measuring machine, see Figure 6a. But when measuring with a CMM, the resulting profile shows a sine-formed distortion, see Figure 6b.

a



a b

Figure 6. Influence of the form deviation of a tactile ball stylus on roundness profile definition.
(a) No influence when measuring with a dedicated contour measuring machine.
(b) Real profile deformation when measuring with a CMM.

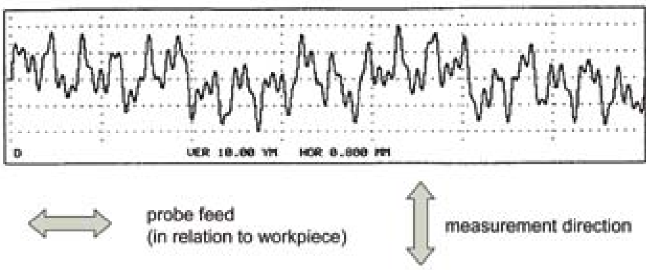


Figure 7. Registered profile when measuring shaft straightness.

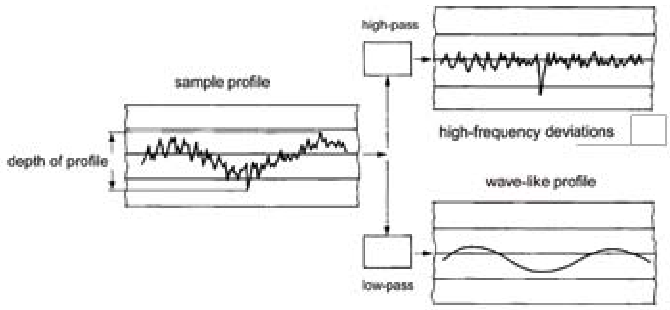


Figure 8. Applying a high-pass or a low-pass filter to separate roughness from wave-like form deviation.

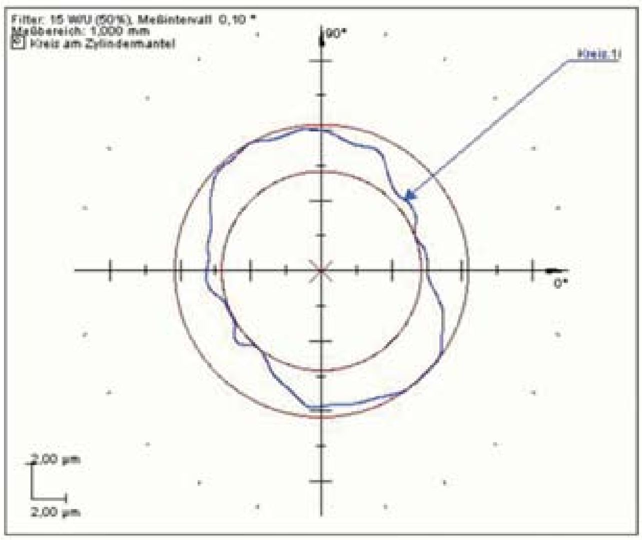


Figure 9. Roundness measurement by applying a low-pass filter with a cut-off frequency of 15 UPR (undulations per revolution). The measured roundness deviation is 2.67 µm.

Tactile and optical probing

In his lecture, Rainer Bartelt first explained the origin of surface deviations in workpieces. A shaft may become deformed by movement deviations of the tool-bearing slide of a lathe to the centre line of the main spindle. Resonance vibrations in the lathe may cause wave-formed roundness deviations. Roughness also originates from the ‘fingerprint’ of the cutting tool on the workpiece. When measuring shaft straightness with a contour measuring instrument, the registered profile shows a combination of straightness deviation and roughness. In general such a registered profile doesn’t represent the real form because the vertical magnification is much higher than the horizontal magnification, see Figure 7.

Figure 8 illustrates the separation of waveform and roughness by applying a high-pass filter or a low-pass filter. Figure 9 shows how roundness can be measured by using a low-pass filter.

Bartelt also showed a cost-effective but accurate form tester, the Marform MMQ 200, see Figure 10. It has been especially designed to measure cylindricity. One of the possible applications is the measurement of helical grooves on a shaft, which may cause fluid leakage, e.g. in hydraulic systems. Such grooves can be due to cutting or grinding processes. Figure 11 shows a practical realisation of the contour measuring standard profile as shown in Figure 2. This profiled shaft is used to calibrate and inspect a form tester.

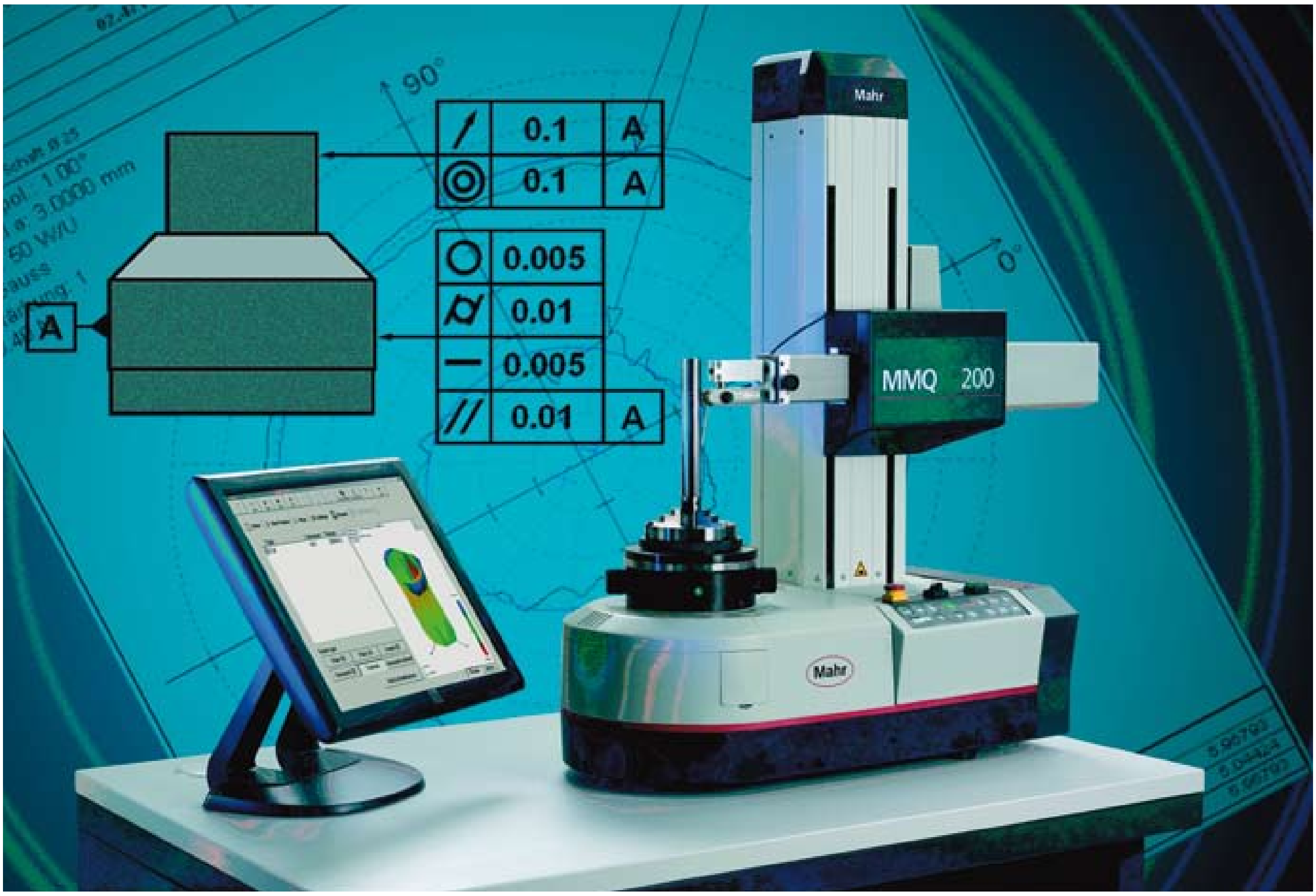


Figure 10. The Marform MMQ 200 cost-effective high-precision contour measuring instrument, especially designed to measure cylindricity.

Optical contour shadow measurement

Hommel-Etamic is part of Jenoptik, Division Industrial Metrology, with can trace back its roots to the optical laboratory Carl Zeiss started in Jena in 1846. Uwe Siefke explained how Hommel-Etamic nowadays produces contour shadow instruments for measuring form and dimensions. They work principally with an optical ray path similar to that of the profile projectors from the 1960s. Needless to say, the sophisticated contour measuring instruments of Hommel-Etamic represent the latest technology standards in shadow-optical shaft measurement.

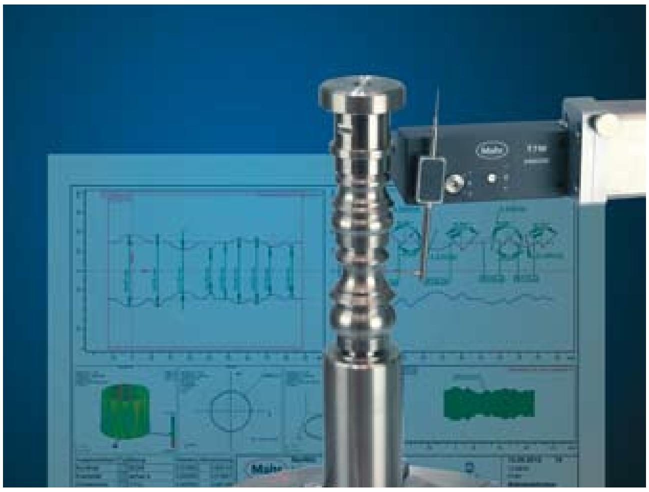


Figure 11. The contour measuring standard profile according to VDI/VDE 2629 machined in a shaft.

Figure 12 shows the measuring principle. A parallel light beam in a Hommel-Etamic Opticline CA618 measuring instrument with automatic temperature compensation produces a shadow image on a high-resolution optical sensor. A threshold value for the successive grey-scale steps serves as an adjusting criterion for measuring a diameter. This is one of the steps in a complete contour measurement cycle. Figure 13 shows the principle of the diameter definition. The number of complete or partially shadowed pixels on the sensor provides a value for the diameter.

Figure 14 shows how a roundness deviation diagram results from many measured diameters related to synchronised angular position measurements. To this end, the instrument is fitted with an angular encoder. A remarkable feature is the software-driven automatic filtering of artefacts due to dirt. For water-based cooling fluids, spraying with compressed air suffices to acquire

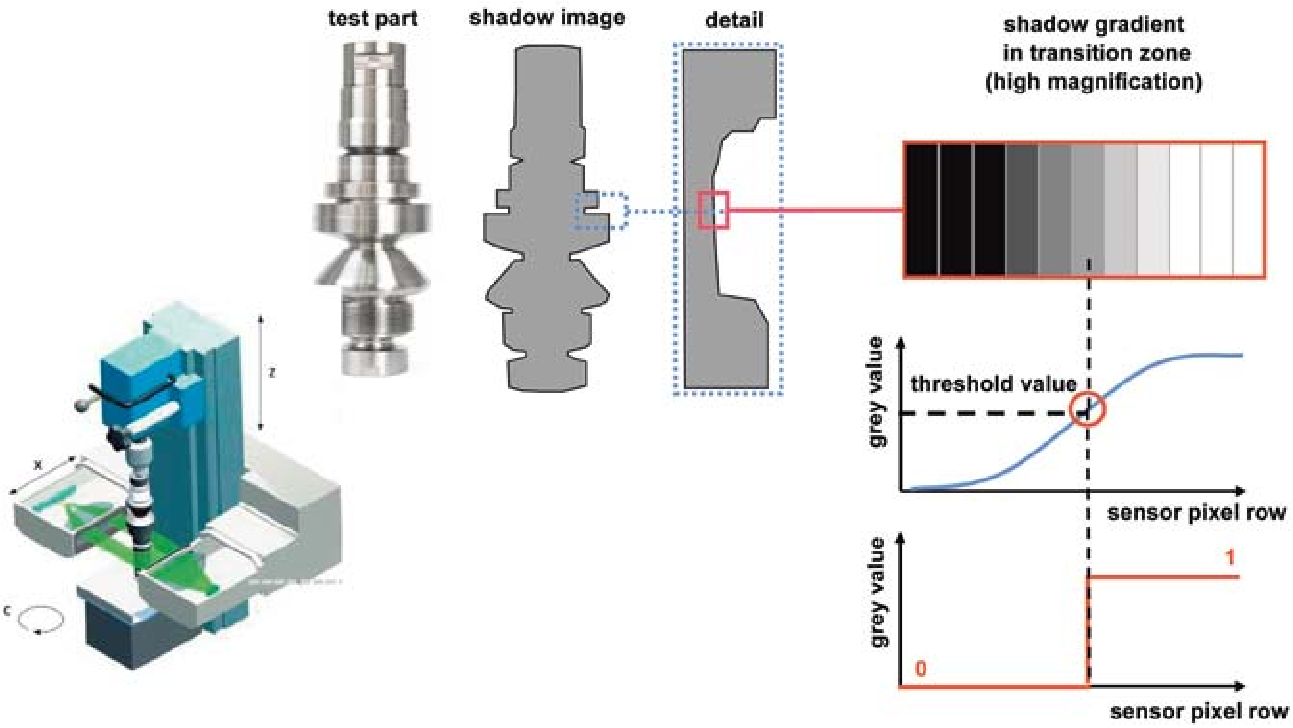


Figure 12. Measuring a test part in a Hommel-Etamic Opticline. A threshold value for the grey-scales serves as an adjusting criterion for measuring a diameter.

reliable measuring results. Oil-based fluids, however, should be cleaned off.

The shadow contour measuring machines of the CA (Contour Automatic) series can be delivered with tactile probing sensors. They measure individual face run-outs (one circular track), total face run-outs (many circular tracks) and lengths. This option also facilitates measuring 'hidden' surfaces that are invisible in a shadow image. Figure 15 shows the results of measuring a turbine rotor with shaft. Another example is the form and contour measuring of a crankshaft. Especially interesting is the measurement of the form of one of the shoulders of a connecting rod journal of this crankshaft. Figure 16 shows the measured profile before and after a finishing rolling treatment.

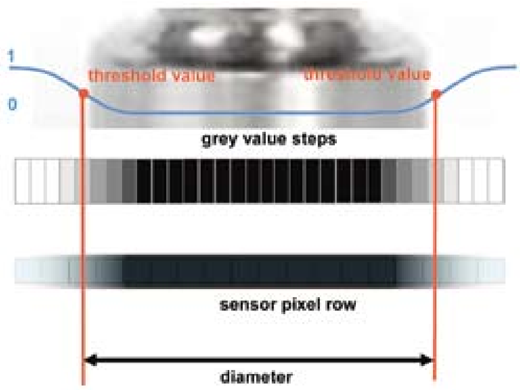


Figure 13. Complete diameter definition by counting the number of dark pixels.

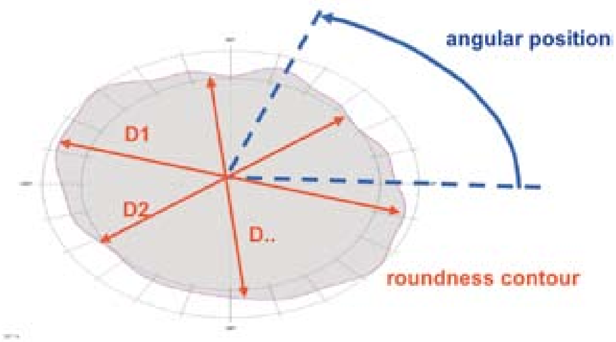


Figure 14. Correlation of diameters and angular positions for defining roundness deviations.

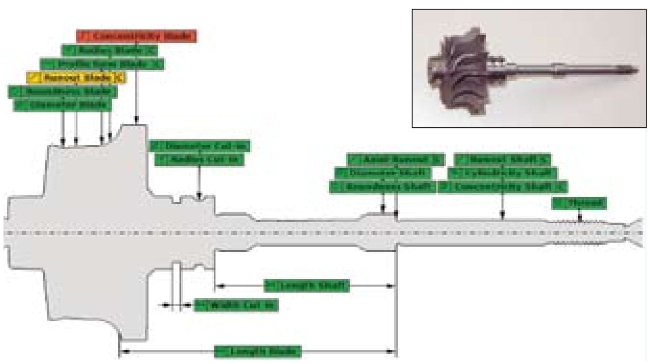


Figure 15. Measuring a turbine rotor with shaft; the test part is shown with result markings.

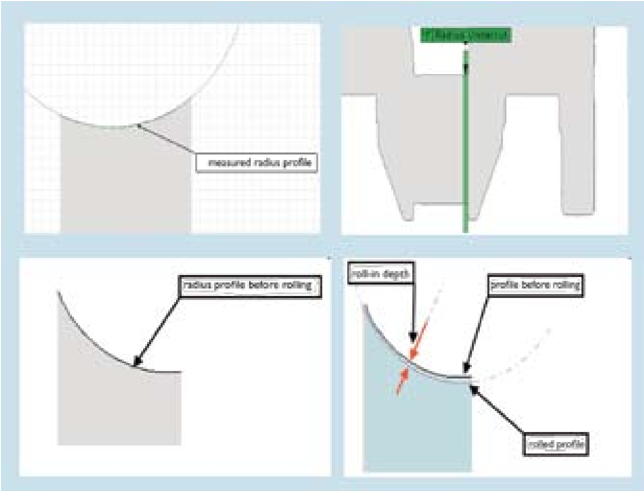
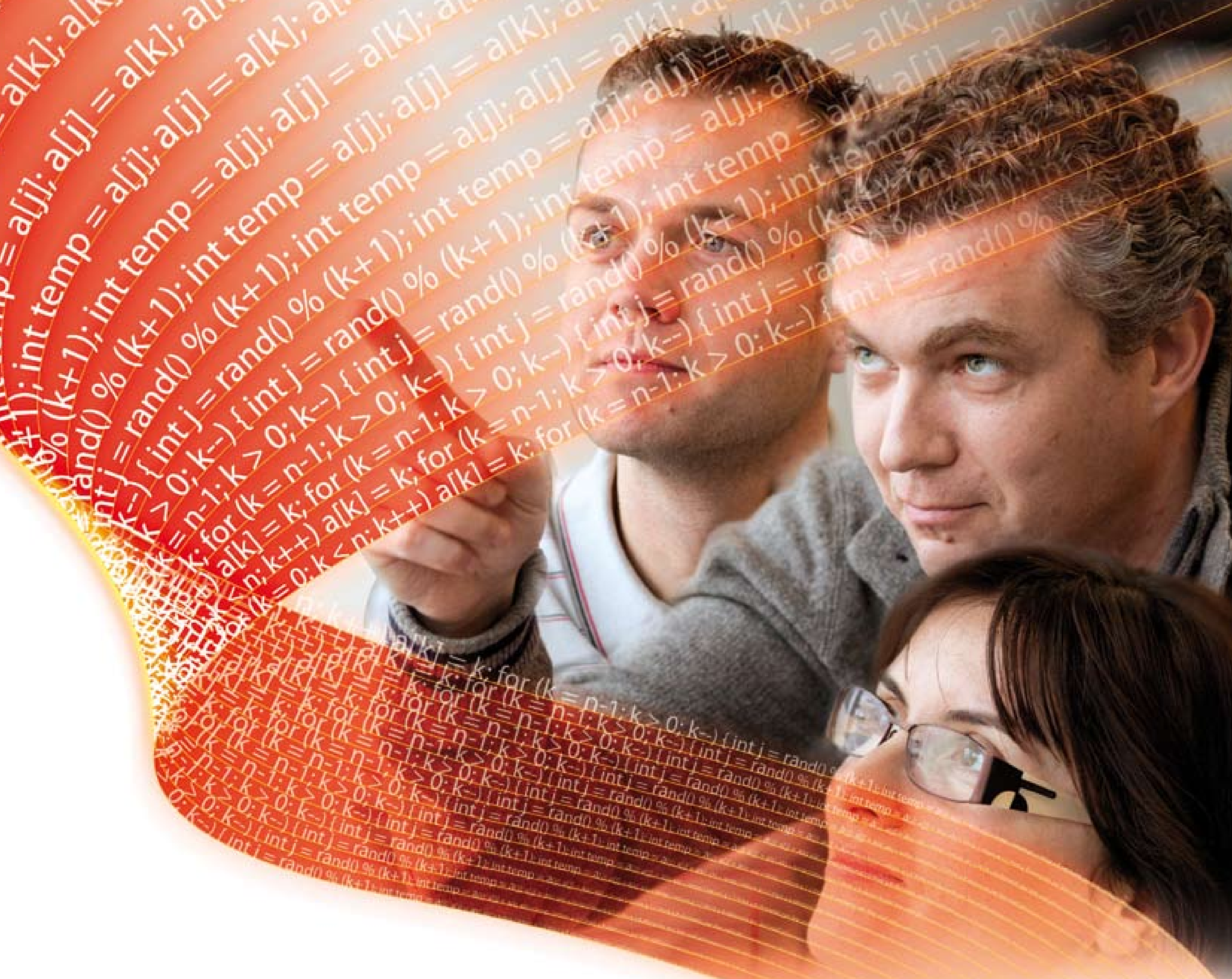


Figure 16. Measuring the form of a connecting rod journal of a crankshaft before and after finishing by rolling.

In conclusion

The seminar at the renowned Fraunhofer IPT gave the various participants an excellent opportunity to demonstrate their individual solutions to a difficult precision engineering problem: how to define deviations in form and contour. Obviously, tactile and optical solutions compete in speed, precision and functionality. The author's impression is that the tactile contour measurement instruments win in terms of precision, whereas the optical shadow measurement instruments win in terms of speed and functionality.

All in all, it was reassuring to observe that German firms with famous roots dating back centuries continue to be strong rivals to younger companies at the other end of the world.



Improved stress

Adhesives are widely used in optomechanical structures for bonding optical components to their mounts. The main advantage of using adhesives is the excellent strength-to-weight ratio, while the limited dimensional stability and loadability is a disadvantage. The design of stable optical mounts requires the accurate prediction of stresses and deformation in bonded joints, using viscoelastic material models because of the strong temperature- and loading history-dependent behaviour of adhesives. However, representative material data for adhesives is difficult to find. Therefore, an experimental framework has been established to determine relevant mechanical properties. This article discusses the results of characterisation experiments and the modelling techniques used.

• *Jan de Vreugd, Martijn te Voert, Jan Nijenhuis, Joep Pijnenburg and Erik Tabak* •

Mounting optical components for use during space missions is challenging. Both the bonding connection and the optical components have to withstand high acceleration loads during launch and extreme temperatures while operating in space. Furthermore, the stability of optical mounts should not be affected by external loadings. Prediction of mount stability and bond failure is therefore necessary. For the accurate prediction of stresses in bonded joints, representative material data is needed. The available material data is often limited to properties such as Young's modulus and the coefficient of thermal expansion (CTE) at room temperature while neglecting non-linear behaviour under changing temperature and aging conditions [2].

The material data needed for reliable stress calculation and bond failure prediction requires the input of non-linear

Authors' note

The authors all work at TNO Optomechatronics in Delft, the Netherlands. This article is based on a paper presented at the SPIE Astronomical Telescopes + Instrumentation 2012 conference, held on 1-6 July in Amsterdam, the Netherlands.

The models discussed in this article were used in the mount design in the EUCLID and TROPOMI programmes as described in the article on ultrastable bonded optical mounts for harsh environments in the previous issue of Mikroniek [1].

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prediction in adhesives

temperature-dependent behaviour. Polymers like adhesives show strong temperature-dependent behaviour. The creep and relaxation behaviour of adhesives during mechanical and thermomechanical loading causes a redistribution of stress and strain levels in bonded joints. Optical mounts being used in a space environment are subjected to dramatic changes in temperature. Polymers are rigid glasses below a certain, material-specific temperature known as the glass transition temperature (T_g). At temperatures above T_g the polymer behaves in a soft and flexible manner and is either an elastomer in the case of thermoset material or a viscous fluid in the case of a thermoplastic material. Since material properties show profound changes in the region of T_g, the glass transition temperature is of major technological importance. The glass temperature thus determines the lower usage temperature limit of a rubber and the upper limit of a thermoplastic or thermoset material. Also, other physical properties such as heat capacity, thermal expansion coefficient, mechanical damping, electrical properties and tensile strength change dramatically at T_g.
In order to improve the existing adhesive material models, viscoelastic characterisation experiments were performed on five different adhesive types, hereafter named A to E (see Table 1).

Table 1. Adhesive types discussed in this article.

Material	Details
A	UV-curing adhesive
B	Epoxy
C	Electrically conductive silicone rubber
D	Silicone rubber
E	Elastomeric epoxy

This article describes the measurements carried out to obtain the following mechanical properties as a function of temperature:
- CTE,
- viscoelastic shear modulus,
- viscoelastic Young's modulus,
- elastic temperature-dependent bulk modulus.

CTE measurements
The coefficient of thermal expansion was measured in a broad temperature range, –150 °C to +100 °C. For this purpose, adhesive samples were manufactured with the following dimensions: 30 mm x 5 mm x 0.5 mm. A miniature tensile tester of TA instruments was used for CTE measurements. This tensile tester was fitted with a programmable furnace. By heating the samples with a heating rate of 1 °C/min and measuring length changes, the coefficient of thermal expansion could be calculated. The measured thermal strain values of materials A, B, C, D and E are given in Figure 1.

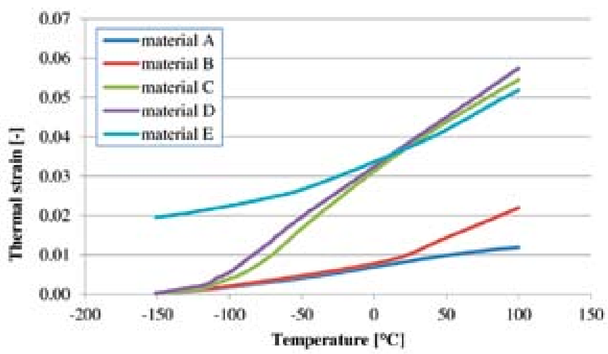


Figure 1. Thermal strain of different adhesives.

The thermal strain ϵ_{th} is defined as (l_0 is the initial length, at room temperature):

$$\epsilon_{th} = \frac{\Delta l(T)}{l_0} \qquad (1)$$

The coefficient of thermal expansion α (or CTE) is defined as:

$$\alpha(T) = \frac{d\epsilon_{th}}{d(T)} \qquad (2)$$

The resulting temperature-dependent CTE is modelled with the following equation [3]:

$$\alpha(T) = k_1 + \frac{1}{2} k_2 (1 + \tanh[C(T - T_g)]) \qquad (3)$$

Note that the $\tanh[C(T - T_g)]$ part changes from –1 below T_g to +1 above. Therefore, k_1 and $k_1 + k_2$ represent the linear coefficient of thermal expansion in the glassy and rubbery state, respectively. The coefficient C determines the smoothness of the slope change. The CTE values of the different sets of adhesives thus modelled are presented in Figure 2. The ratio of CTE between the glassy and rubbery region is about 3 for epoxies and 4-5 for silicone rubbers.

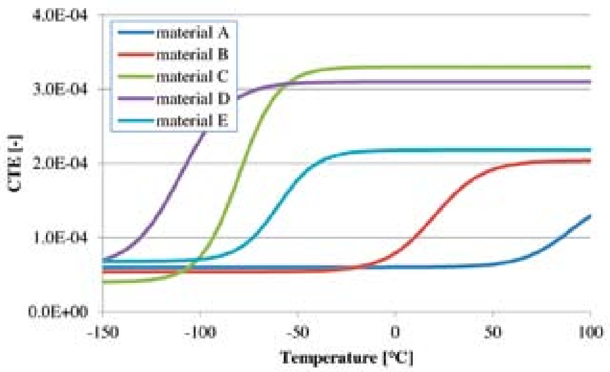


Figure 2. Temperature-dependent coefficient of thermal expansion of different adhesives.

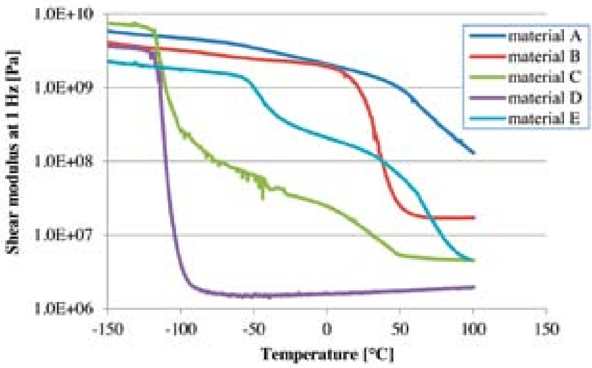


Figure 3. Shear storage modulus as a function of temperature at 1 Hz.

Viscoelastic shear modulus

The Young's modulus E of materials is usually measured with a uniaxial stress-strain test. In such a test, the build-up of stress is measured as the specimen is elongated at a constant rate. Tests are carried out with rectangular bars or dog-bone shaped specimens according to ASTM standards. However, since the mechanical behaviour of viscoelastic materials depends on loading time and loading speed, stress-strain tests are not suited for determining viscoelastic properties. Commonly used methods to derive viscoelastic properties include creep experiments, relaxation experiments and dynamic experiments. The latter is the most commonly used in characterising viscoelastic materials. In this work, dynamic mechanical experiments (DMA) were performed to determine the viscoelastic shear modulus.

A dynamic mechanical analyser (Anton Paar MCR 301) was used for determining viscoelastic properties of adhesives. For determining the shear modulus, a sinusoidal torsional strain of 0.05% was applied at the following frequencies: 0.3, 1, 3.2 and 10 Hz. The specimens were heated from –150 °C to +100 °C at a heating rate of 1 °C/min. The sample geometry was 50 mm x 5 mm x 0.5 mm. Resulting shear storage modulus values at 1 Hz are given in Figure 3.

From Figure 3 the glassy and rubbery shear modulus can be determined. The glass transition temperature is determined as the temperature at which the properties suddenly change. Table 2 gives an overview of these

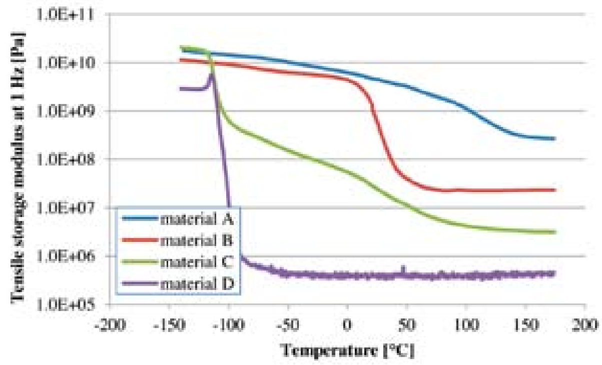


Figure 4. Tensile storage modulus as a function of temperature at 1 Hz.

results. The viscoelastic Young's modulus was determined in a similar way by performing sinusoidal tensile experiments at the same frequencies; the results are given in Figure 4.

A significant difference of typically 2-3 orders of magnitude between glassy and rubbery elastic behaviour was found for all adhesives. Materials C and D show two transition regions. These materials are compounds of epoxy and rubber materials, which results in multiple transition regions.

Within the context of small-strain theory, the constitutive equation for an isotropic viscoelastic material can be written as:

Table 2. Derived properties from DMA experiments.

Material	Glassy shear modulus [GPa]	Rubbery shear modulus [MPa]	Glassy tensile modulus [GPa]	Rubbery tensile modulus [MPa]	T_g [°C] (DMA)	T_g [°C] (CTE)
A	7.3	–	17.5	275	–110	–110
B	4.2	17.0	11.6	22.8	+25	+20
C	7.4	< 4.0	20.3	3.2	–110 / 25	–80
D	2.2	1.8	–	0.4	–50 / +75	–60
E	4.8	< 2.0	–	–	+80	+90

$$\sigma(t) = \int_0^t 2G(t-\tau)\,\frac{de}{d\tau}\,d\tau + I\int_0^t K(t-\tau)\,\frac{d\Delta}{d\tau}\,d\tau \qquad (4)$$

Where σ is the Cauchy stress, e is the deviatoric part of the strain, Δ is the volumetric part of the strain, $G(t)$ is the shear relaxation kernel, $K(t)$ is the bulk relaxation kernel, t is current time, τ is past time, I is the unit tensor [4]. Finite-element analysis software ANSYS uses the following kernel functions:

$$G(t) = G_0\left[\alpha_\infty^G + \sum_{i=1}^{nG} \alpha_i^G \exp\left(-\frac{t}{\tau_i^G}\right)\right] \qquad (5)$$

$$K(t) = K_0\left[\alpha_\infty^K + \sum_{i=1}^{nK} \alpha_i^K \exp\left(-\frac{t}{\tau_i^K}\right)\right] \qquad (6)$$

Where G_0 is the glassy shear modulus, K_0 is the glassy rubbery modulus, τ_i are relaxation times, $G_0 \cdot \alpha_\infty^G$ is the rubbery modulus, while $\alpha_\infty^G + \sum_{i=1}^{nG} \alpha_i^G = 1$.

A viscoelastic material model should therefore contain the parameters G_0, K_0, τ_i, α_∞ and α_i. The τ_i and α_i terms are the so-called Prony terms. Normally, fifteen Prony terms are sufficient for the accurate fitting of material data.

The viscous properties of materials are heavily dependent on temperature. Thermorheological simplicity is an assumption based on the observation of many glass-like materials, like adhesives, of which the relaxation curve at high temperatures is identical to that at a low temperature if the time is properly scaled. In essence, it assumes that the relaxation times (of all Prony coefficients) obey the following scaling law:

$$\tau_i = \frac{\tau_i(T_g)}{A(T, T_g)} \qquad (7)$$

Where $A(T, T_R)$ is called the shift function, of which many definitions exist. This work uses the WLF shift function:

$$\log_{10}(A) = \frac{C_2\,(T - C_1)}{C_3 + T - C_1)} \qquad (8)$$

Where T is the current temperature, C_1 is a reference temperature which is often chosen to be the glass transition temperature, C_2 and C_3 are fitting parameters.
The shear kernel $G(t)$ of material B is given in Figure 5, the WLF model of material B is given in Figure 6.

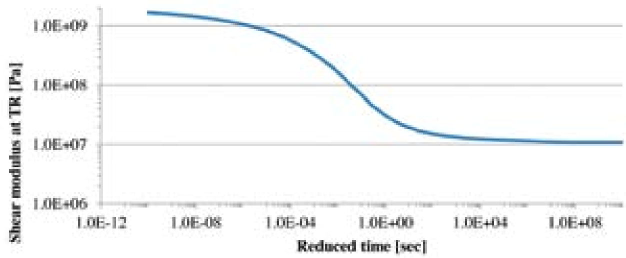


Figure 5. Kernel function $G(t)$ of material B.

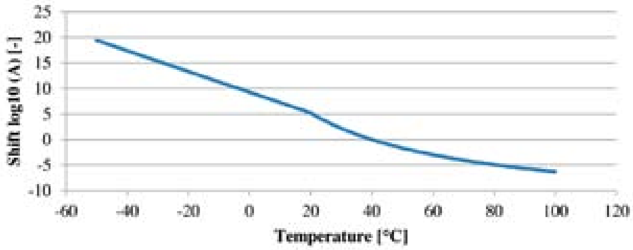


Figure 6. Shift function of material B.

For details about modelling of experimental results and implementation in finite-element code, please refer to [4, 5, 6].

Bulk modulus

The bulk modulus K is defined as the resistance to hydrostatic compression. In the case of viscoelastic materials, the bulk modulus depends on temperature. In various research projects, it has been shown that creep or relaxation behaviour in purely hydrostatic compressed loading cases is of minor influence. Therefore, this work assumes that the bulk modulus is independent of loading history [7]. The temperature bulk modulus is not directly measured but is obtained from shear (Figure 3) and tensile (Figure 4) experiments:

$$K(T) \approx \frac{G(T)E(T)}{9G(T) - 3E(T)} \qquad (9)$$

Results are presented in Table 3.

Table 3. Glassy and rubbery bulk modulus as determined from experiment.

Material	Glassy bulk modulus [GPa]	Rubbery bulk modulus [MPa]
A	9.7	-
B	17.7	10.4
C	24.3	-
D	-	5.9

Since the shear experiment was not carried out completely in the rubbery region of material A, the rubbery bulk modulus could not be determined for this material. The tensile experiment with material D failed in the glassy region, hence the glassy bulk modulus was not determined.

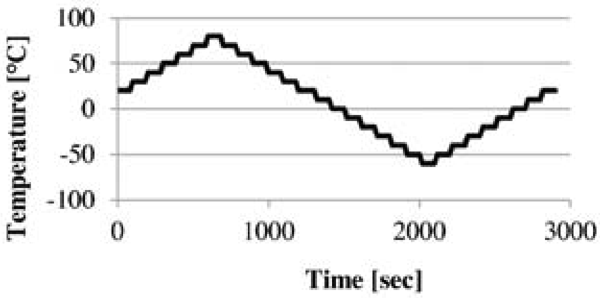


Figure 7. Temperature profile applied to the double-layered panels.

The bulk compliance β is modelled with the Tait equation [3,7]:

$$\beta = k_1 s_0 + \frac{1}{2} k_2 s_0 \left[1 + \tanh(C(T - T_g))\right] + \frac{c_1}{B(T)} \qquad (10)$$

Where

$$B(T) = b_1 \exp(-b_2 \cdot T).$$

The coefficients k_1, k_2, C_1, T_g are the same as used in the CTE model of Equation 3. The parameters s_0, c_1, b_1, b_2 are fitting parameters. The bulk modulus K is equal to:

$$K \approx \frac{1}{\beta} \qquad (11)$$

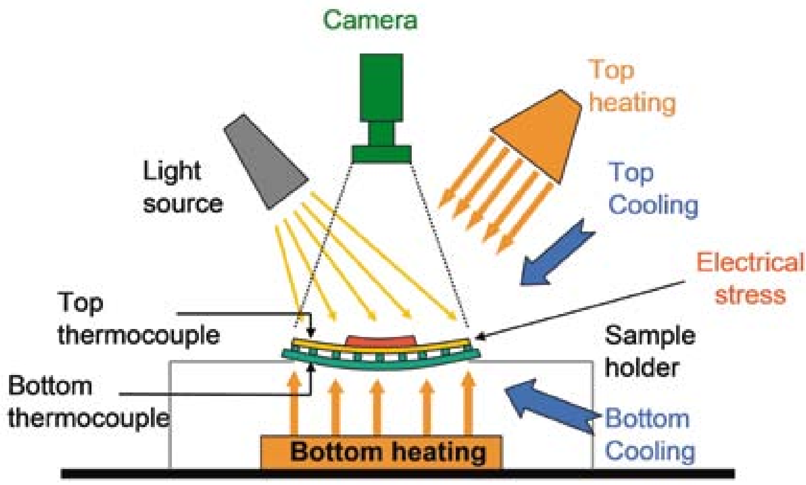
The model described above is an elastic temperature-dependent model. Therefore, it is not needed to define the Prony terms τ_i^K and α_i^K. If one does, all α_i^K terms should be zero. The temperature dependent α_∞^K term is implemented in ANSYS by defining a table.

Validation experiments

For validation purposes, aluminium plates were moulded with adhesive materials A, B, C, D and E. In this way, double-layered panels were created. Due to CTE mismatch, the panels would warp as a result of a thermal loading. The dimensions of the double-layered panels were as follows: width x length 60 mm x 60 mm, thickness aluminium 0.2 mm, thickness of the adhesive layer 0.5 mm. The panels were exposed to a thermal loading, while the warpage of the panel was immediately detected. An INSIDIX Topography Deformation Measurement (TDM) device was used to determine the topography of the panels. With the same device, the temperature of the panels was programmed as shown in Figure 7.

The TDM, shown in Figure 8, measures the surface shape of samples of interest in a non-intrusive way. By projecting fringe patterns onto the surface of a sample and recording shadow patterns, the topography of the sample surface can be calculated. Heating/cooling elements in combination with a thermocouple connected to the double-layered panel were used to control the temperature. The warpage was measured at elevated temperatures during a thermal ramp (see Figures 9 and 10).

a



b

Figure 8. Topography and Deformation Measurement.
(a) The INSIDIX device.
(b) The measurement set-up

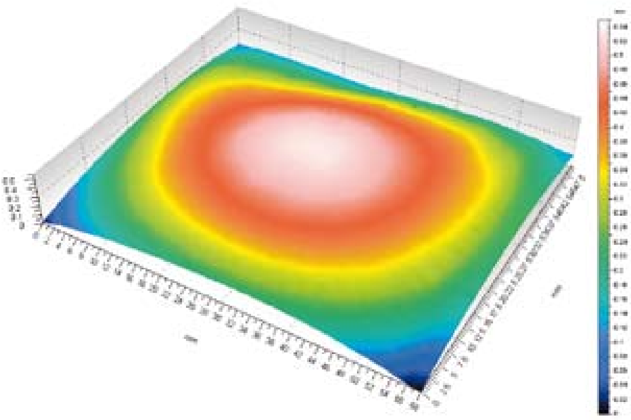


Figure 9. Topography of a double-layered panel at 80 °C.

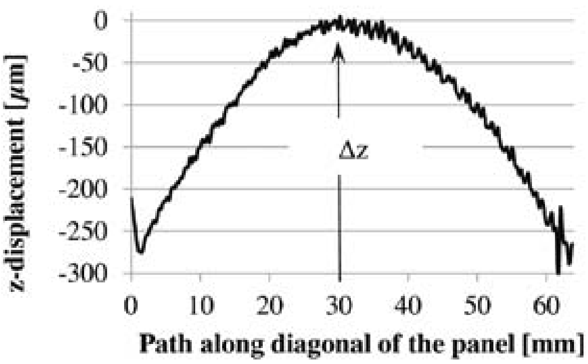


Figure 10. Out-of-plane deformation of a panel at 10 °C.

The thermomechanical deformation of an aluminium panel covered with adhesive B is shown in Figure 11. The deformation was compared with finite-element calculations. The double-layered panel was modelled with twenty node elements. A transient thermal loading was applied as shown in Figure 7.

As shown in Figure 11, warpage predictions obtained with the viscoelastic model are in line with the measured warpage for the full temperature range. An elastic material model results in warpage overprediction at temperatures above 20 °C. The elastic model is suitable for stress and deformation calculations at temperatures below 20 °C since this adhesive shows negligible creep or relaxation behaviour below 20 °C. Small creep effects are found around the glass transition temperature. These small creep effects were also determined from finite-element simulations. Since the heating rate was rather high in the experiment, the creep effects are small in this example.

Conclusions and future activities

This article has demonstrated a characterisation method for determining relevant mechanical properties of adhesives. The coefficient of thermal expansion, viscoelastic Young's and shear modulus were presented for five different sets of

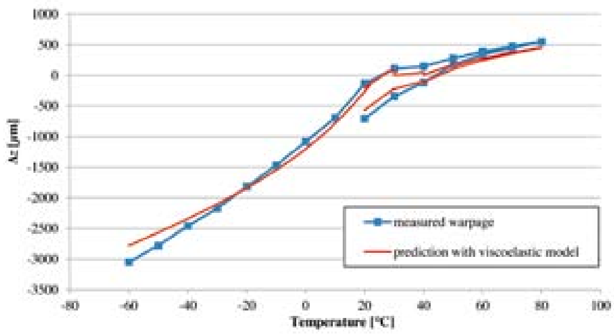


Figure 11. Warpage Δz as a function of temperature. The blue dotted line represents the measured warpage, while the straight red line represents calculated warpage obtained with the viscoelastic material model.

adhesives. A modelling method, suitable for implementation in finite-element software was discussed. These models are capable of reliably predicting stress relaxation and creep effects in bonded joints as a result of thermal loading history. Future activities include incorporation of elastic-plastic behaviour in the finite-element models to facilitate failure prediction in bonded joints.

References

[1] Pijnenburg, J., Te Voert, M., De Vreugd, J., Vosteen, A., Van Werkhoven, W., Mekking, J., and Nijland, B., "Ultrastable bonded optical mounts for harsh environments", *Mikroniek*, 52 (5), pp. 11-20, 2012.

[2] Côté, P. and Desnoyers, N., "Thermal stress failure criteria for a structural epoxy", *Proc. SPIE* 8125, pp. 81250K-81250K-12, 2011.

[3] Saraswat, M.K., Jansen, K.M.B., et al, "A characterization method for viscoelastic bulk modulus of molding compounds", *Proc. 9th EUROSIME*, pp. 1-4, 2010.

[4] Zienkiewics, O.C., "The finite element method, volume 2 – Solid mechanics", McGraw-Hill, 2004.

[5] Ward, I.M., and Sweeney, J. "The mechanical properties of solid polymers", John Wiley & Sons, 2004.

[6] De Vreugd, J., "The effect of aging on molding compound properties", Ph.D. thesis, Delft University of Technology, 2011.

[7] Zoller, P., et al, "Apparatus for measuring pressure-volume, temperature relationships of polymers to 350 degrees C", *Rev. Scient. Instr.*, 47(8), pp. 948-952, 1976.

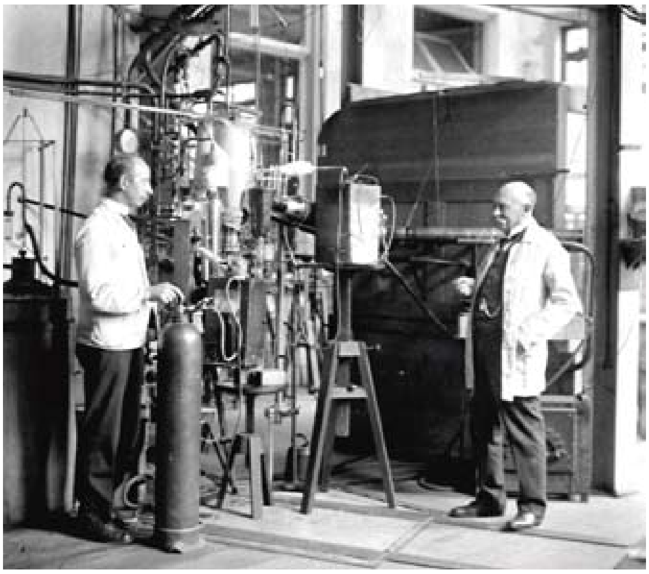
LiS plans to offer in applied precision

There is increasing demand for skilled technical specialists who are able to bridge the gap between innovative ideas and their realisation by actually constructing functional precision instruments and prototypes. Precision engineering aims to design and construct products with high accuracy of shape and dimension, or quick and accurate positioning. The Leiden Instrument Makers School (Leidse instrumentmakersschool, LiS) plans to build on its illustrious heritage to develop a Bachelor of Engineering degree in applied precision engineering that specifically addresses this competence gap in industry and research institutes within the top sectors high-tech & materials and life sciences & health.

• *Aad J. van Strien* •

Hindsight

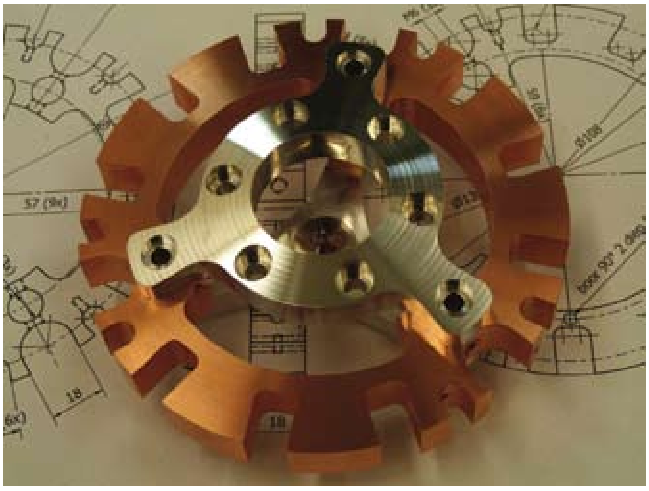
Scientific research used to be a gentleman's pastime. Around 1900, Professor Heike Kamerlingh Onnes of the Leiden University physics department turned his considerable entrepreneurial energy into improving access to modern research instruments. This required him to educate craftsmen able to translate the musings of academics into real-life instruments of research. To that end he started the Leiden Instrument Makers School in 1901 – the LiS. In his 1913 Nobel Prize acceptance speech he explicitly thanked his senior instrument makers for their invaluable contributions in discovering superconductivity.



Professor Heike Kamerling Onnes (right) together with research instrument maker Gerrit Jan Flim next to the helium liquefier used in the discovery of superconductivity (picture taken around 1919, source: Museum Boerhave).

Today the LiS is an independent, well-regarded, small but growing Dutch MBO school (senior secondary vocational

bachelor degree engineering



Selected examples of specialty precision components.

level) of about 200 students. During four years of intensive technical education and training its students become well-regarded and sought-after precision technology graduates.

Insight

The availability of excellent craftsmen who can bridge the gap between esoteric, ill-defined academic ideas and reality by actually constructing functional precision research instruments proved to be an extremely successful innovation for Dutch science and engineering. During the

long history of the LiS more than two thousand highly qualified craftsmen who can build complex, innovative precision instruments were able to fulfil the ever increasing demand by universities, research institutes and high-tech industries.

Maintaining a strong focus on quality and excellence of education rather than on growth allowed the LiS to deliver the required excellent technical specialists. The explicitly nurtured links between universities, research institutes, high-tech businesses and start-ups allows the LiS to continuously improve its curriculum and teaching approach, and to continuously realign to ever-changing demands.

Author's note

Aad J. van Strien serves as vice chairman on the LiS board. Readers who are interested to help shape and implement the LiS-HBO strategy described in this article – by contributing their time and expertise or sponsoring in other ways – are invited to contact the author.

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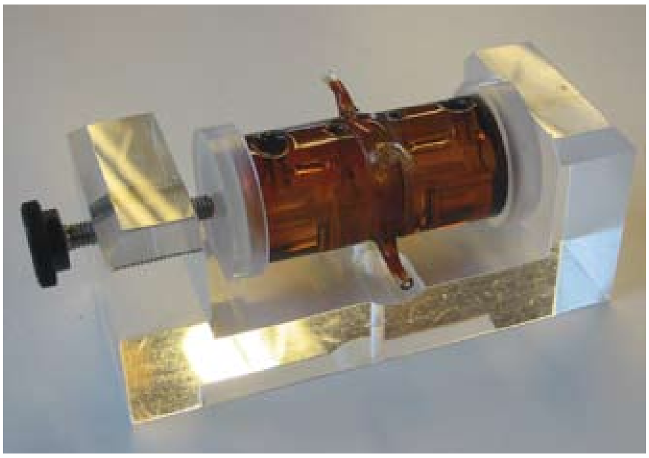
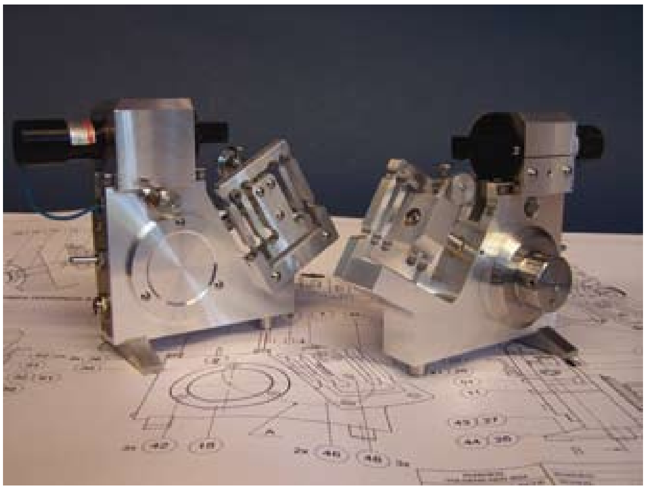




Examples of prototypes made by LiS students for research institutes.

These links also help close the ever-present financial gap between governmental education funding and the high cost of maintaining modern machines and hiring the excellent educational staff necessary to keep up to date with technology developments. Explicit integration of selected commercial projects into the project roster of students further ensures alignment of education with demands of future employers.
During discussions with researchers, high-tech industry managers, top sector directors and governmental representatives it became clear that there is a growing demand for excellence, depth and breadth in precision engineering specialists. Combining the traditional LiS topics, for instance, glass with precision mechatronics, or micro precision milling with photonics, or digital electronics and ceramics, or new materials and additive prototyping, significantly increases the demands on students and educators alike.

Foresight

These increasing educational demands from the field have led the LiS board to decide that enhancing the school's educational portfolio needs to be undertaken. This resulted in a number of activities to add to its current Research Instrument maker degree (level 4 according to the European Qualification Framework) a precision engineering associate degree (level 5) and a bachelor degree (level 6). All are applied technology degrees and will have the same level of excellence and quality that the LiS has offered for more than a century.

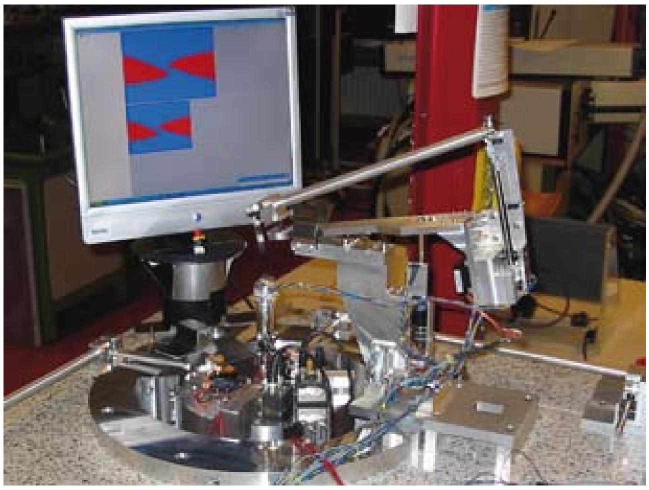
Mission

The mission of the LiS is to provide outstanding middle and higher level education in applied technology aimed at: Conceiving, designing and building innovative high-tech precision devices that integrate various technologies into a unique instrument of high quality.
Life sciences and health technologies will be the initial focus of the new degrees. LiS graduates have always excelled in their unique competences to conceive and create a wide range of innovative multidisciplinary precision instruments. For example, integration of different technologies in precision instruments as used by high-tech companies, universities and research institutes in life sciences and health specific applications.

Vision

Building on its foundational insight that excellent craftsmanship is vital to research, development and innovation, the LiS will enter into productive collaborations with other scientific and technical education institutes and businesses to enable an innovation bridge between idea and reality.
LiS graduates especially excel in:
- Innovation: conceive, design, and make unique innovative precision instruments.
- Precision: unique integration of multidisciplinary technologies with high accuracy in shape and dimension, and rapid and precise positioning.

Advanced multidisciplinary projects that reach into the envisaged bachelor level.



- Excellence: connecting science and craftsmanship, keeping up to date on many state-of-the-art technologies, and developing new applications.

The combination of different teaching levels that build on each other results in an educational environment that is conducive to innovation and meets the increasing demands of businesses and research institutes alike.

Strategy

This, of course, is easier said than done. Therefore the implementation strategy is one of stepwise refinement and continuous adjustments. The LiS strategy can be summarised as follows:

- Developing, in partnership with potential employers, a modern curriculum that emphasises turning ideas into reality; the first curriculum contours are already visible.
- Offering a few specifically developed extra-curriculum modules starting in 2013 and growing into a fully-fledged bachelor degree three years later.
- Adding specific focus on life sciences and health technology applications.
- Appointing most staff on a part-time basis, allowing them also to work in high-tech business and research institutes to maintain their own competences.
- Closely cooperating with universities and other colleges to enable a quick start-up, ensure excellence and high quality.

Conclusion

The newly conceived LiS-HBO (higher professional vocational education) will take several years to mature. During this period significant effort will be invested in developing a curriculum that uses modern didactic approaches embracing project-based practical learning that combined with high levels of knowledge leverages the existing LiS infrastructure of staff, machines and equipment. The aim is to become a national institute offering educational excellence in precision engineering.

A new approach to

A brief review of InP-based photonic integrated circuits (PICs) is given with a specific focus on integrated lasers and amplifiers. A new way of fabrication of PICs called generic integration technology is presented together with selected examples of active integrated circuits, like multi-wavelength laser sources, discretely tunable lasers, WDM transmitters, ring lasers, etc.

• *Ryszard Piramidowicz, Stanisław Stopiński, Katarzyna Ławniczuk, Paweł Szczepański, Xaveer J.M. Leijtens and Meint K. Smit* •

It is well known that the rapid development of integrated electronics, observed in the past decades, started from very simple analog systems, consisting of separate, discrete components, such as resistors, capacitors and transistors. The resulting devices occupied considerable space and were consuming high amounts of electrical power. Also the reliability was a serious problem. The situation changed in 1958 with the advent of monolithically integrated circuits, which revolutionised the way of thinking about electronic circuits. The next major breakthrough was the establishment of the CMOS (Complementary Metal-Oxide-Semiconductor) technology standard. Rapid progress of the CMOS capabilities enabled mass production of functionally advanced and relatively cheap electronic integrated circuits (ICs).

Nowadays, chips integrating even billions of elements are fabricated. The miniaturisation of electronic devices and development of integration technology enabled production of multi-functional, energy-efficient, compact and portable devices, which may be effectively operated with small-size batteries. A good example is the modern cell phone with computational power far higher than early supercomputers. All these factors caused that silicon-based ICs are now ubiquitously applied in every field of technology and everyday life.

A similar trend to miniaturisation and integration is observed in the semiconductor photonics. The rapid development of semiconductor-based photonic devices started with the invention of the light-emitting diode (LED) in 1955 [1] and semiconductor laser diode (LD) operating at room temperature in 1970 [2]. Nowadays LEDs and LDs are key elements in telecommunication, data storage and data processing systems, optical sensors and sensing networks, image processing systems, etc. The progress in semiconductor light sources was accompanied by intensive research and development of other optical components – light modulators, detectors, low-loss waveguides, couplers and (de)multiplexers, Bragg gratings, etc. At present, all of these elements are available in integrated form. A real breakthrough was the invention of the semiconductor optical amplifier (SOA) [3], which enabled both amplification of the optical signals with gain as high as 30 dB [4] and design of various types of integrated semiconductor lasers.

Apart from impressive results obtained up to now in integrated photonics, the choice of an optimal technology is still an open issue. In general, two main approaches are being developed in parallel – the first is based on silicon technologies, while the second is focused on group III-V semiconductors. This work presents InP-based photonic integration technology.

laser technology

InP-based photonics

InP-based compounds manifest excellent electro-optical properties, such as a direct band-gap that allows efficient light generation and detection, light guiding and fast phase modulation. Moreover, the emission wavelength of the ternary (InGaAs, InAlAs) and quaternary (InGaAsP, AlGaInAs) compounds can be tuned over a wide spectral range between 0.92 μm and 1.65 μm [5], depending on the composition of the elements. Simultaneously, the lattice constant can be matched with InP, so that the epitaxial growth of these compounds onto an InP substrate is possible.

Effective integration on a single platform of both passive and active components is a great advantage of the InP-based technology. Invention of the arrayed waveguide grating (AWG) in 1988 [6] started the era of wavelength division multiplexing (WDM) photonic integrated circuits (PICs). The number of components in a single chip was continuously increasing, reaching now several hundreds of components. Examples of already demonstrated large-scale photonic integrated circuits are AWG-based multi-wavelength lasers [7,8], DBR- and DFB-based WDM transmitters [9,10], filtered-feedback WDM lasers [11], mode-locked lasers [12], WDM ring lasers [8], quantum-dot-based lasers for optical coherence tomography [13], tunable lasers with integrated wavelength converters [14], integrated receivers [15], optical time domain multiplexers [16] and many others.

However, even though many InP-based large-scale PICs have been demonstrated already, the commercial success is still limited. Nowadays the market offer covers circuits which integrate relatively small numbers of components. The only truly large-scale PIC, which is commercially available, is the 100 Gb/s transmitter developed by the Infinera Corporation [10], integrating DFB lasers, electro-absorption modulators, power monitors, variable attenuators and AWG multiplexer. At the moment, photonic integration is one of the most promising technologies for fabrication of functionally advanced, compact and cost-effective devices. Generally, PICs, compared to their free-space or fiber-optic equivalents, offer advantageous performance in terms of size and weight, energy consumption, efficiency and reliability. On the other side, they can replace electronic devices, performing the same functionality with a higher operation speed and bit-rate, while consuming less energy. Undoubtedly, the major driver of the development of the photonic ICs is the telecommunication sector. However, these devices have potential applications in other fields, like fiber sensors, medical diagnostics, metrology or switching in photonic interconnects in computer backplanes.

Generic integration technology

In order to achieve the broad application of photonic integrated circuits novel, more efficient fabrication methods are required. One of the most promising solutions is generic integration technology [17]. Its primary assumption is that complicated photonic devices can be divided into basic building blocks (BBs) such as a waveguide, a phase modulator and an amplifier. Additionally, more complex components (e.g. splitters, couplers, filters) as well as whole circuits can be obtained as a combination of these fundamental elements. In order to obtain high yield the technology processes are standardised and general design rules are defined for all designers. In this approach it is crucial to guarantee the performance of every BB by maintaining its characteristic

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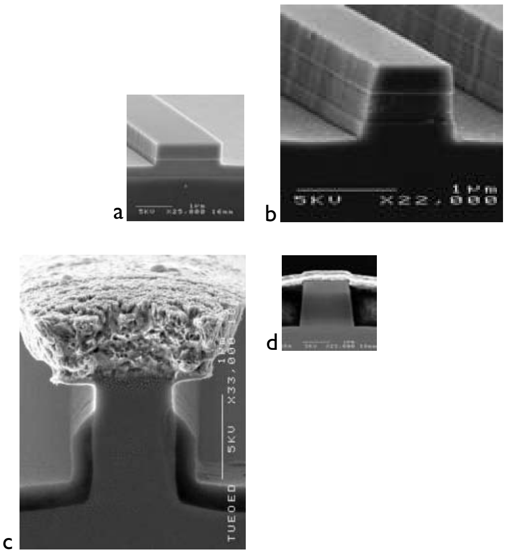


Figure 1. SEM pictures of the basic building blocks of the COBRA process [8,18].
(a) Shallowly-etched waveguide.
(b) Deeply-etched waveguide.
(c) Phase modulator.
(d) Semiconductor optical amplifier.

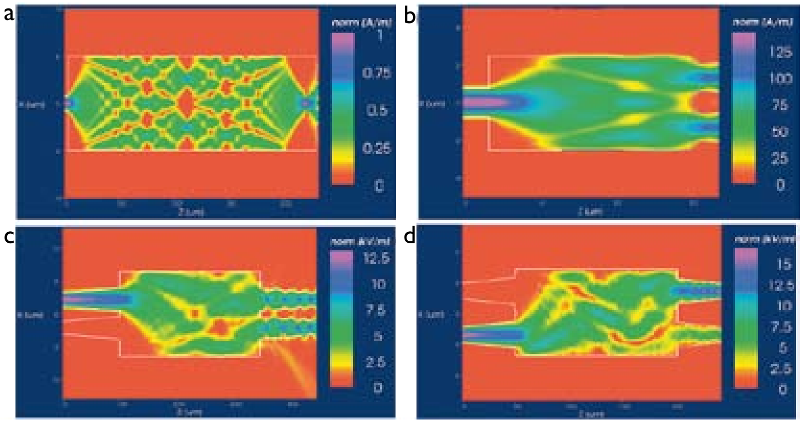


Figure 2. MMI-based components. (Acknowledgement to PhoeniX Software for the licence)
(a) General MMI structure.
(b) 1x2 (3 dB) power splitter.
(c) 2x2 (3 dB) power coupler.
(d) Power splitter with asymmetric (85%:15%) splitting ratio.

parameters, for example attenuation/losses of the waveguides, phase shift in modulators, gain in amplifiers. There is a clear analogy to CMOS, where ICs are designed using transistors, resistors and capacitors, the parameters of which are specified by foundries individually.

The concept of InP-based generic technology in photonics has been developed since 2006 in the JePPIX platform (Joint European Platform for InP-based Photonic Integrated Components and Circuits) [18,19]. The set of basic building blocks for this platform consists of shallowly- and deeply-etched passive waveguides, a waveguide with a top cladding removed for electrical isolation, an electro-optical phase modulator and a semiconductor optical amplifier. Figure 1 presents the SEM pictures of the BBs fabricated in the COBRA Research Institute. By using these basic elements, other composite building blocks can be designed and fabricated. The most important examples of such advanced BBs are presented and discussed below.

MMI-based devices
Among the most commonly used components are the MMI-based (Multi-Mode Interference) devices [20, 21], presented in Figure 2. An MMI section is a piece of a straight waveguide wide enough to support propagation of more than one mode. The principle of operation is based on the cyclic interference of the waveguide modes, due to their different propagation constants. By proper positioning the inputs and outputs of the section, one can design various devices, such as mode filters, 1xN/Nx1 power splitters/combiners, NxM power couplers and splitters with asymmetric splitting ratio [22]. Furthermore, the MMI effect can be used for design of reflectors with a high reflection coefficient [23].

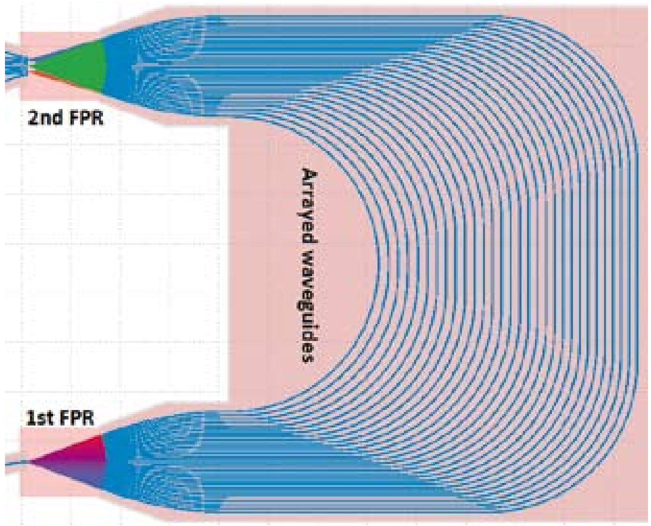


Figure 3. AWG principle of operation: the light is coupled to the arrayed waveguide, phase difference at the output causes tilting of the phase front so that the various wavelength channels are focused in different spatial positions.

AWG Multiplexer
Combination of a slab waveguide and an array of deeply-etched waveguides can form a wavelength (de)multiplexer, called AWG [6,24]. The principle of operation, schematically depicted in Figure 3, is based on introducing a phase difference among the signals propagating through various arms of the array. The optical field at the input diverges in the first free-propagation region (FPR), which is a piece of slab waveguide, and gets coupled to the

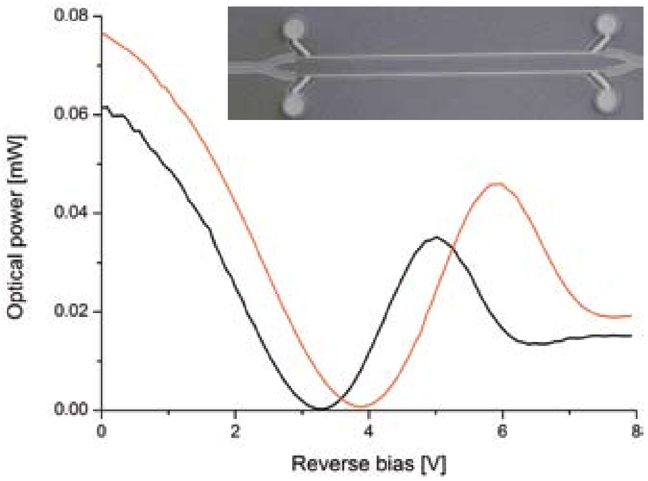


Figure 4. SEM photograph of the Mach-Zehnder modulator and and example of a power transmission characteristic as a function of voltage applied to one of the arms.

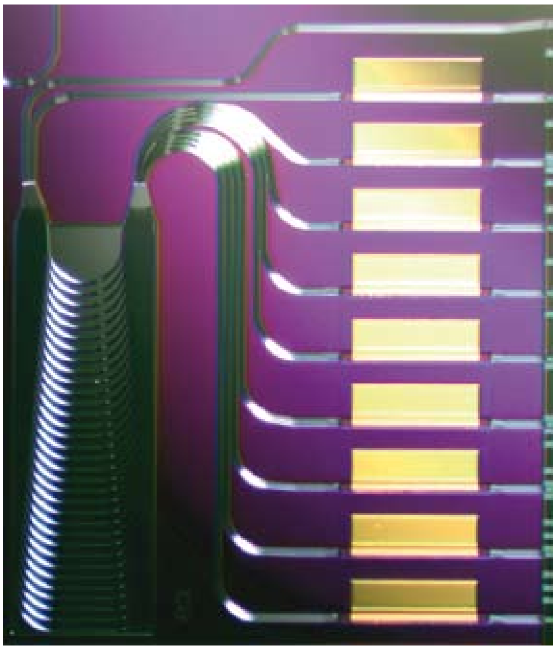
arrayed waveguides. The length of each arm is equal to an integer multiple of the central wavelength (λ_c – a parameter of the multiplexer). As a result, the signals carried in λ_c have equal phase at the output of the arrayed waveguides so that this channel is focused in the center of the second FPR. However, other channels are focused in different points, next to the central channel, as their phase front is tilted due to the different lengths of the arrayed waveguides. The AWG provides spatial (de)multiplexing of the WDM signals.

Mach-Zehnder amplitude modulator

Mach-Zehnder amplitude modulators are obtained as a combination of a 3dB power splitter, two phase modulation sections and a power combiner. Figure 4 presents such a structure, together with an example of a static power transmission characteristic. The voltage applied to one of the modulator arms causes a phase change of the optical signal. As the power transmission characteristic has a sinusoidal shape, it is suitable both for digital and analog modulation (while operating in the linear region). Alternatively, instead of combining the two arms with a power coupler, the phase shifter arms may be terminated with reflectors, which would form an amplitude modulator in the Michelson interferometer configuration.

2x2 Switch

When the Mach-Zehnder modulator structure is modified so that splitters/combiners are replaced by 2x2 power couplers, the resulting block acts as a 2x2 integrated optical



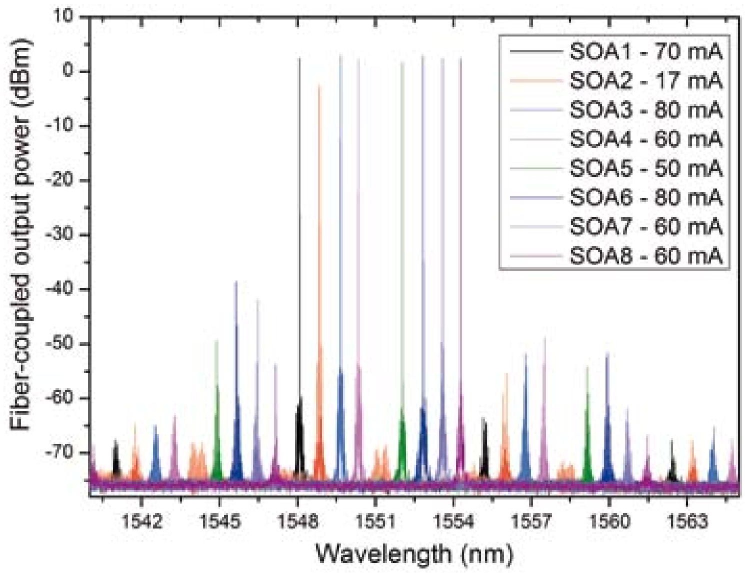


Figure 5. Photograph and emission spectrum of an 8-channel multi-wavelength laser with a booster amplifier [7].

switch. In this case the phase change in one of the arms causes a continuous flow of the power from one output port to another. Under digital modulation with a proper voltage it will discretely switch the signal between the output ports.

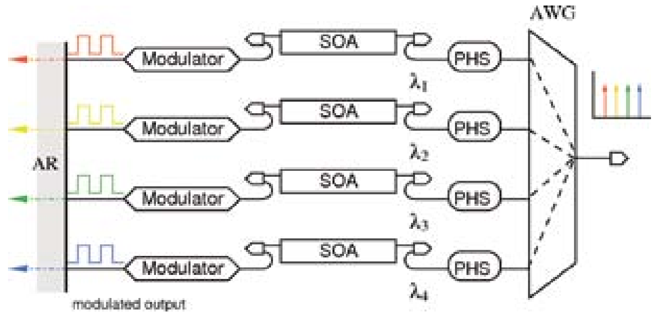
Selected examples of ASPICs

One of the most important applications for InP-based PICs are laser sources of different functionalities. Again, the major drivers for the development of such Application Specific PICs (ASPICs) are the WDM telecommunication systems, which require tunable light sources compliant with the ITU grid. Photonic integration helps with providing lasers that can generate several wavelengths simultaneously and can be (discretely) tuned. Such lasers exist in various configurations, described briefly below.

AWG-based WDM lasers
The simplest structure forming a WDM laser source is an array of semiconductor optical amplifiers (SOAs) combined with an output multiplexer [7,8]. The resonator is formed by the Fresnel reflections at the chip-air interface. The AWG acts also as an intra-cavity filter so that the generated wavelengths depend on its passband. The discrete tuning is obtained by turning on and off the selected SOAs. The device can operate both in a single- and a multiple-wavelength mode, depending on the number of simultaneously biased SOAs. Figure 5 presents an example of an 8-channel multi-wavelength laser together with a measured lasing spectrum [7]. An alternative solution is shown in [25]. The gain section is on the other side of the AWG (in the place of the booster), and the SOAs in the array are very short – they are not used to amplify the signal, but as optical gates to turn on and off the individual laser channels.

A more complicated configuration has been proposed in [26]. The resonator is formed by an N_1xN_2 AWG with N_1+N_2 amplifiers (in this specific case, $N_1 = 5$, $N_2 = 8$). As a result forty (N_1xN_2) wavelengths can be generated, depending on which combination of two amplifiers is biased at the same time.

Ring lasers
AWG-based lasers may also operate in a ring resonator architecture. In [8] a WDM ring laser is described, formed by a 4x4 AWG and four SOAs placed in loops connecting the inputs and outputs of the AWG. The power tapping is done by using two of the arrayed waveguides – one for clockwise and the other for counter-clockwise laser signals.



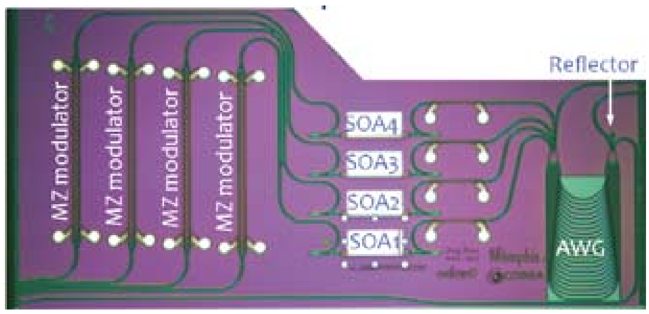


Figure 6. 4-channel, filtered-feedback WDM laser/transmitter [11]. It uses a Fabry-Perot-type resonator with extended cavity, where additional filtering (by AWG) and tuning (by phase shifters) is applied. Mach-Zehnder modulators are for digital signal generation. (Acknowledgement to Jing Zhao for the picture)

Filtered-feedback lasers
A standard Fabry-Perot cavity equipped with some additional components for locking the laser at the specific wavelength, like an AWG and a phase shifter, enables filtered-feedback operation [11]. Figure 6 shows a schematic and a photograph of a filtered-feedback laser. Apart from the laser itself, there are four Mach-Zehnder modulators added for generation of digital signals.

WDM transmitters
The AWG is not the only way of longitudinal laser modes filtering. In the Infinera transmitter chip [10] the operating wavelengths are determined by distributed feedback resonators, while the AWG is a multiplexer combining all

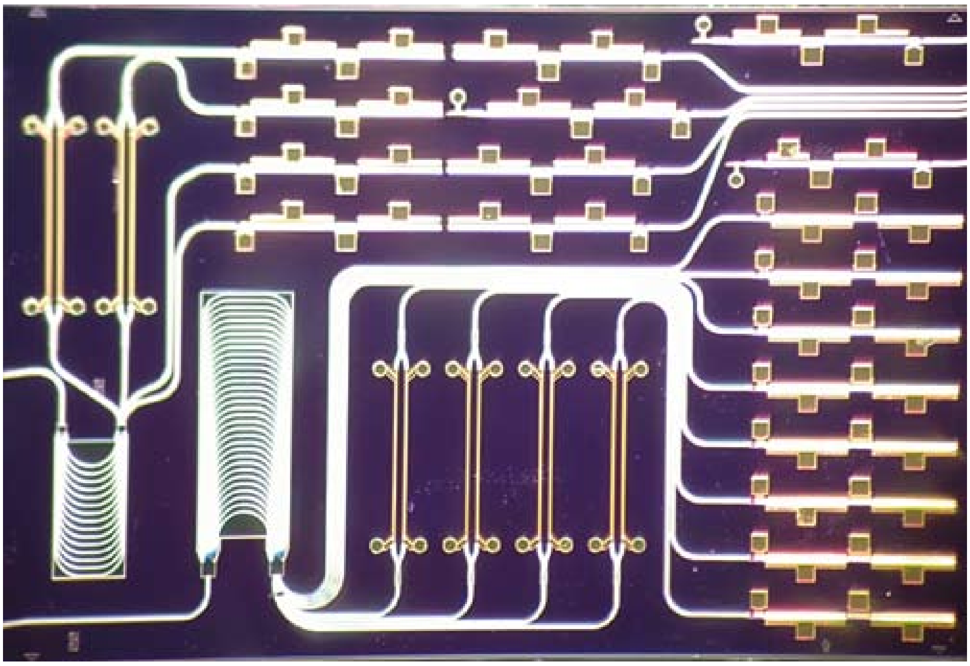


Figure 7. FTTH (fiber-to-the-home) transmitters [9]. The 8-channel circuit comprises an array of eight DBR lasers (right side of the chip). Four channels are digitally modulated by Mach-Zehnder modulators (downstream), four channels provide CW (continuous wave) power for the upstream signals.

ten channels to a single output. A similar approach has been applied in [9]. However, in this case the lasers are built with SOAs and tunable Bragg gratings. Figure 7 presents a chip that has such transmitters implemented.

Summary

Photonic integrated circuits are definitely one of the most promising solutions for the next generation of optoelectronic devices. Their main advantages are the same as for electronic ICs – compact size, energy efficiency, high-speed operation and low-cost large-scale fabrication. In recent years the fabrication technology of InP-based devices has been significantly developed and nowadays chips consisting of hundreds of elements can be produced. However, lack of a standard fabrication and packaging technology still hampers the commercial application of PICs. In comparison to microelectronics, integrated photonics has not yet penetrated the commercial market on a large scale. The generic integration concept, being developed and tested by the JePPIX platform may bring a significant technological breakthrough and completely change the state of the photonic market. At present, two large European FP7 (Seventh Framework Programme) projects – EuroPIC [27] and PARADIGM [28], which combine the potential of key European players, are focused on establishing a generic manufacturing chain in InP-based photonics. This requires achievement of several objectives – developing and providing all users with unified building blocks (both basic and composite), developing professional software for simulations of the circuits and mask designing, with implemented tools for design rule checking, and, finally, determining the standard for packaging. Then, the foundries have to provide on-wafer verification of the manufacturing process.

One of the means to provide low-cost access to the technology is a multi-project wafer (MPW) run, which allows reduction of R&D and prototyping costs of novel devices, as the users pay proportionally to the occupied area. This idea has been extensively tested and used in microelectronics [29,30] and is now being applied in photonics [17,18]. First MPW runs have already been performed at Oclaro (UK), the Fraunhofer Heinrich Hertz Institute (Germany), and the COBRA Research Institute.

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References

[1] R. Braunstein, “Radiative transitions in semiconductors”, *Phys. Rev.*, 99(6), 1892-1893 (1955).

[2] Z.I. Alferov et al., “Investigation of the influence of the AlAs-GaAs heterostructure parameters on the laser threshold current and realizaton of continuous emission at room temperature”, *Sov. Phys. Semiconductor* 4(9), 1573-1575 (1971).

[3] J. W. Crowe and R. M. Craig, Jr., “Small-signal amplification in GaAs lasers”, *Appl. Phys. Lett.* 4, 57-58 (1964).

[4] G. de Valicourt et al., “High Gain (30 dB) and High Saturation Power (11 dBm) RSOA Devices as Colorless ONU Sources in Long-Reach Hybrid WDM/ TDM-PON Architecture”, *IEEE Photon. Technol. Lett.* 22(3), 191-193 (2010).

[5] G. Keiser, “Optical Fiber Communications”, McGraw-Hill, New York, 2000.

[6] M.K. Smit, “New focusing and dispersive planar component based on an optical phased array”, *Electr. Lett.* 24(7), 385-386 (1988).

[7] K. Lawniczuk et al., “8-channel AWG-based multiwavelength laser fabricated in a multi-project wafer run”, *Proc. 23rd Intl. Conf. Indium Phosphide and Related Materials*, Berlin, 2011.

[8] J.H. den Besten, “Integration of Multiwavelength Lasers with Fast Electro-Optical Modulators”, Ph.D. Thesis, Eindhoven, 2004.

[9] K. Ławniczuk et al., “Photonic integrated multiwavelength transmitters for Fiber-To-The-Home networks”, *Proc. 16th Eur. Conf. Integr. Optics Techn. Exhib.*, Sitges, 2012.

[10] R. Nagarajan et al., “Large-Scale Photonic Integrated Circuits”, *IEEE J. Sel. Topics Quant. Electr.* 11(1), 50-65 (2005).

[11] J. Zhao et al., ”Monolithically integrated filtered-feedback multi-wavelength laser with Mach-Zehnder modulators”, *Proc. 16th Eur. Conf. Integr. Optics Techn. Exhib.*, Sitges, 2012.

[12] X. Guo et al., “Monolithically integrated variable repetition rate mode-locked laser diode”, *Proc. 16th Eur. Conf. Integr. Optics Techn. Exhib.*, Sitges, 2012.

[13] B.W. Tilma et al., “Integrated Tunable Quantum-Dot Laser for Optical Coherence Tomography in the 1.7 μm Wavelength Region”, *IEEE J. Quant. Electr.* 48(2), 87-98 (2012).

[14] R.G. Broeke et al., “An all-optical wavelength converter with a monolithically integrated digitally tunable laser”, *Proc. 28th Eur. Conf. Optical Comm.*, Copenhagen, 2002.

[15] E. Pennings, “III-V integration roadmap”, *MIT Roadmapping Conference*, 2004.

[16] S. Stopiński et al., “Integrated optical serializer designed and fabricated in a generic InP-based technology”, *Proc. 16th Eur. Conf. Integr. Optics Techn. Exhib.*, Sitges, 2012.

[17] M. Smit et al., “Generic foundry model for InP-based photonics”, *IET Optoelectr.* 5(5), 187-194 (2011).

[18] X. Leijtens, “JePPIX: the platform for InP-based photonics”, *IET Optoelectr.* 5(5), 202-206 (2011).

[19] JePPIX platform: www.jeppix.eu

[20] L.B. Soldano and E.C.M. Pennings, “Optical multi-mode interference devices based on self-imaging: Principles and applications”, *J. Lightwave Technol.*, 13(4), 615-627 (1995).

[21] M.T. Hill et al., “Optimizing imbalance and loss in 2×2 3-dB multimode interference couplers via access waveguide width”, *J. Lightwave Technol.* 21(10), 2305-2313 (2003).

[22] M. Bachmann et al., “Overlapping-image multimode interference couplers with a reduced number of self-images for uniform and nonuniform power splitting” *Appl. Optics*, 34(30), 6898-6910 (1995).

[23] E. Kleijn et al., *Proc. 15th Ann. Symp. IEEE Photon. Benelux Chapter*, Delft, 2010.

[24] M.K. Smit, “Progress in AWG design and technology”, *Proc. 4th IEEE/LEOS Workshop Fibres and Optical Passive Components (WFOPC 2005)*, Palermo, 2005.

[25] M.J.R. Heck et al., “Monolithic AWG-based discretely tunable laser diode with nanosecond switching speed”, *IEEE Photon. Technol. Lett.* 21(13), 905-907 (2009).

[26] C.R. Doerr, C.H. Joyner, and L.W. Stulz, “40-Wavelength Rapidly Digitally Tunable Laser”, *IEEE Photon. Technol. Lett.*, Vol. 11, No. 11, November 1999

[27] EuroPIC: www.europic.jeppix.eu

[28] PARADIGM: www.paradigm.jeppix.eu

[29] The MOSIS service: www.mosis.org

[30] Europractice: www.europractice.org

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Sioux is an engineering group with 300 specialists in Technical Software, Electronics, Industrial Mathematics and Remote Solutions. We help high-tech companies with new ways to innovate or improve their product or services in order to stay or become leading in their industry. We either support the R&D or we act as the R&D department. Either way we help you to shorten the time to market at a better price/performance and to develop a sustainable competitive advantage. We are committed to delivering results and can even help you with funding your innovation.

For more information: www.sioux.eu

Source of your Technology

High Tech represented

The twenty-seventh annual meeting of the American Society for Precision Engineering was held in San Diego from 21 to 26 October 2012. The conference offered educational tutorials, discussion venues, interesting technical sessions, networking opportunities and exhibitions. The Dutch were well represented in the tutorials and lecture programmes.

• ***Funda Sahin*** •

The Annual Meeting continued the tradition of offering two full days of tutorials presented by some of the foremost precision engineers and scientists in the world. The technical sessions and poster presentations offered the latest research results in ultra-precision machining, metrology, controls, precision grinding, micro-positioning, materials processing, design, precision transducers, surface profilometry, and error compensation. The commercial exhibits provided the attendees with the opportunity to view and discuss the latest precision engineering equipment, products, and services.

As inventor of the touch trigger probe and co-founder of Renishaw, Sir David McMurtry received the 2012 Lifetime Achievement Award from the conference committee. The electronic touch trigger probe has transformed the field of contact metrology, producing dramatic improvements in measurement precision and accuracy.

800 ton scale

The conference started off with an unexpected keynote by Elie Homsi, who holds a civil engineering degree from the University of Texas, and has thirty years of experience in the construction industry. His presentation, entitled “Precision on an 800 ton scale”, was about geometry control in the precasting and erection of large bridge components in precast segmental bridge technology. He

The 2012 ASPE Annual Meeting was held at the Hyatt Regency La Jolla at Aventine in San Diego, California, USA.

explained how different factors, such as the heat from the sun or wind, affected the individual shape of each component as well as the final shape of the completed structure. It involves the large-scale application of precision engineering to concrete components weighing 80 to 800 tons and assembled in 100 to 1600 foot-long spans. For the audience who were more familiar with nanometers, it was surprising to hear the accuracy requirement of

Author’s note

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Netherlands
well in USA

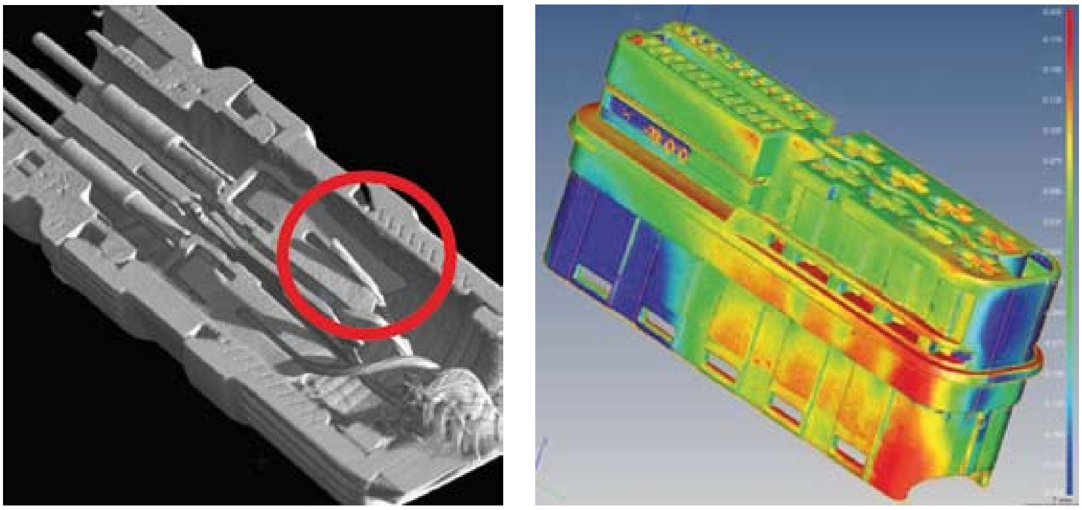


Figure 1. Assembly analysis of an electrical connector showing the potential point of future failure, and colour-coded CAD comparison.

0.3 mm tolerances for a segmented bridge weighing hundreds of tons and spanning many meters.

Progress in precision

After this fascinating keynote the first session, "Progress in Precision", started with the presentations by R.K. Leach of the National Physical Laboratory in the UK explaining the latest improvements in areal surface topography measuring instruments, and by J.S. Taylor from the Lawrence Livermore National Laboratory in the US on the "Production of Large Optics Supporting Experimental Campaigns at the National Ignition Facility".

M.B. Bauza from Carl Zeiss Industrial Metrology explained the recent developments in Computed Tomography (CT) in the field of metrology. With the aid of interesting examples, he showed how over the past ten years CT scanning has migrated from medical to industrial applications. A CT image provides a three-dimensional representation of an object assembled from a series of two-dimensional images. While the first CT image took nine days to be produced, today it may take only seconds to collect the data and reconstruct a 3D image. With the rapid increase in computing power, it will only get faster. Complex parts with several thousands of features can be measured and analysed in hours instead of weeks. The obtained data can be compared with nominal dimensions, and colour-coded deviation maps can be created. In addition, complex assemblies can be analysed and defective processes can be adjusted based on qualitative data. Points of potential failure can be detected and operational failure of an assembled component prevented, see Figure 1.

However, metrological instruments require quite a different design and data analysis approach to produce measurements that are repeatable and provide a useful uncertainty budget. Metrological CT clearly has different requirements for accuracy than standard imaging methodology.

Design of precision machines

In the "Design of Precision Machines" session, J.B. Hopkins, from the Lawrence Livermore National Laboratory, presented an approach utilising the geometric shapes that helps designers to rapidly visualise and consider every flexure topology that can be used to decouple any set of displacement-based

Figure 2. Air Turn air-bearing test set-up.

actuators (e.g. setscrew, piezo, thermal, and magnetostrictive actuators).

Drew Devitt from New Way Air Bearings gave a presentation entitled “Viscous Shear in Air Bearing Gaps for Precise Web Tension and Temperature Control”. His research explores the use of flexible films flowing over “Air Turns” rather than contact rollers (see Figure 2), and the use of viscous shear in the air films for motion control, cleaning, drying and precision temperature control. This system aims to satisfy the demands from the printed electronics industry for non-contact precision manufacturing of flexible displays, OLED lighting, PV (photovoltaic solar cells), smart packaging and printed batteries.

Precision metrology

The “Precision Metrology” session included a wide variety of presentations covering topics such as nanometer precision coordinate measurement, NASA’s precision mass property measurements with five-wire torsion pendulum, and error budgeting of the design of an international X-ray observatory.

One particularly interesting presentation was by Xiaodong Lu from the University of British Columbia in Canada, who presented a 6-axis vision-based position sensor. He reviewed the previous calibration methods and presented a high-accuracy camera calibration method using a CMM (coordinate measuring machine) and active LED marker. Experimental results have demonstrated that after the camera calibration, a 3D position measurement accuracy of 19.5 μm can be achieved over a measurement range of 400 mm by 400 mm by 15 mm. Moreover, he showed a clip of their novel planar motor drive working with this 6-axis measurement system.

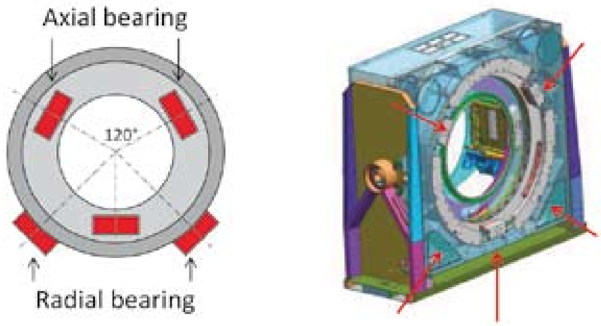


Figure 3. Air-bearing configuration of Philips Brilliance iCT.

Dutch contributions

During the two days of tutorial sessions, the Dutch contributors attracted a fairly large and interested public. The author and Herman Soemers (Philips Innovation Services) presented a full-day tutorial entitled “Design of Electromagnetic Actuation and Levitation Systems in Mechatronic Precision Applications”. Jan van Eijk (MICE) and Adrian Rankers (Armunus, HTI) gave a full-day tutorial on “Active and Passive Vibration Isolation”. Theo Ruijl (MI-Partners) delivered a tutorial entitled “A System Approach to Thermal Modeling”.

Hans Soetens (Philips Innovation Services) presented a lecture on “Air bearing for next generation CT scanners”. He paid particular attention to explaining to the audience the safety aspects of the system. The proposed air-bearing architecture together with the induction motor drive can achieve 300 rpm within 64 μm accuracy at a 20 Hz suspension frequency. The air-bearing system (Figure 3) is part of the recent Philips Brilliance iCT (Intelligent a

b

Figure 4. TriNano N100, the 3D coordinate measuring machine from Xpress Precision Engineering.
(a) Artist impression.
(b) Photo of the probe measuring an artefact.

Computer Tomography) diagnostic imaging system, which currently is among the best performing CT scanners.

Another very interesting contribution came from Edwin Bos (Xpress Precision Engineering). He explained their novel 3D coordinate measuring machine Trinano N100, which has nanometer repeatability (Figure 4). The TriNano N100 design allows a 3D measurement uncertainty of 100 nanometers in a measurement range of 200 cubic centimeters, while greatly reducing manufacturing costs.

Another Dutch contribution, by Gerrit van der Straaten and Piet van Rens (Settels Savenije van Amelsvoort) and Ton Peijnenburg (VDL Enabling Technologies Group), was entitled “System Engineering to Meet Contradicting Requirements”. High accuracy, high thermal loads and high-vacuum environment seem to be contradictory requirements for the design of a system. By separating functions, so the team explained, they found solutions to meet these requirements. They designed and built a vacuum system (D x h = 1.5 m x 1 m) for a light source for EUV lithography with mechanical tolerances that are within 100 μm absolute and less than 10 μm at the local level.

2013 Annual Meeting of ASPE

At the end of the conference, the organising committee announced that the 28th Annual Meeting will be held from 20 to 25 October 2013 in St. Paul, Minnesota. The Twin Cities of Minneapolis and St. Paul provide a fitting backdrop for the meeting, as the metropolitan area is leading in many established and growing technology sectors. The Twin Cities are home to world-renowned micro and nano manufacturing and technology companies, including 3M, Medtronic, Boston Scientific, Seagate Technology, and Hutchinson Technology. Since Minnesota is recognised as one of the world’s largest medical device clusters, the organising committee will make an effort to address the precision engineering needs of the medical device industry.

For inspired and enthusiastic precision engineers, it is certainly something to look forward to.

American Society for Precision Engineering

ASPE, a non-profit organisation founded in 1986, promotes the future of manufacturing in America by advancing precision engineering. It does this by supporting education, encouraging the development and application of precision principles, and organising various meetings. ASPE members represent a variety of areas – from engineering (mechanical, electrical, optical and industrial) to materials science, physics, chemistry, mathematics and computer science – and are employed in industry, academia and national labs.

www.aspe.net/technical-meetings

Course	CPE points	Provider	Starting date (location, if not Eindhoven)
Basic			
Mechatronic System Design (parts 1 + 2)	10	HTI	10 December 2012 (part 1) 4 March 2013 (part 2)
Construction Principles	3	MC	to be planned (Utrecht) to be planned
System Architecting	5	HTI	11 March 2013
Design Principles Basic	5	HTI	29 May 2013
Motion Control Tuning	6	HTI	17 April 2013
Deepening			
Metrology & Calibration of Mechatronic Systems	2	HTI	to be planned
Actuators for Mechatronic Systems	3	HTI	18 March 2013
Thermal Effects in Mechatronic Systems	2	HTI	11 March 2013
Summer school Optomechatronics	5	DSPE	24 June 2013
Dynamics & Modelling	3	HTI	3 December 2012
Specific			
Applied Optics	6.5 6.5	MC HTI	7 March 2013 29 October 2013
Machine Vision for Mechatronic Systems	2	HTI	21 March 2013
Electronics for Non-Electronic Engineers	10	HTI	8 January 2013
Modern Optics for Optical Designers	10	HTI	25 January 2013
Tribology	4	MC	6 March 2013 (Utrecht) 27 November 2012
Introduction in Ultra High & Ultra Clean Vacuum	4	HTI	4 March 2013
Experimental Techniques in Mechatronic Systems	3	HTI	9 April 2013
Design for Ultra High & Ultra Clean Vacuum	4	HTI	8 April 2013
Advanced Motion Control	5	HTI	7 October 2013

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.dsperegistration.nl/list-of-certified-courses

Course providers

- The High Tech Institute (HTI)
  www.hightechinstitute.nl
- Mikrocentrum (MC)
  www.mikrocentrum.nl
- Dutch Society for Precision Engineering (DSPE)
  www.dspe.nl

To High Tech Campus Eindhoven

DSPE has changed address to
High Tech Campus Eindhoven:
High Tech Campus 1
5656 AE Eindhoven
PO Box 80036
5600 JW Eindhoven

High Tech Campus Eindhoven is the smartest square kilometer in the Netherlands with more than 100 companies and institutes, and some 8,000 researchers, developers and entrepreneurs working on developing future technologies and products. The Campus helps companies accelerate their innovation by offering easy access to high-tech facilities and international networks. Campus companies (a.o. Philips, NXP, IBM, Intel) strategically decide what knowledge, skills and R&D facilities they share in order to achieve faster, better and more customer-oriented innovation in the application fields Health, Experience and Energy. Located at the heart of Brainport Campus companies are responsible for nearly 50% of all Dutch patent applications.

Information

www.hightechcampus.com

Precision Fair 2012: bigger, more international

The twelfth edition of the Precision Fair on 28 and 29 November 2012 will be the biggest ever. This year, the venue at Koningshof in Veldhoven has been expanded to include a semi-permanent 1,000 m² hall. Nonetheless, it is again fully booked, with over 250 exhibitors represented, an all-time record. The theme is "Unlimited opportunities in Precision Technology" and the fair will be focusing on business opportunities inside and outside the Netherlands. Besides many foreign exhibitors, particularly from Germany, this year there will be a heavy delegation from CERN in Switzerland, who will give lectures and look for business matches.

The Precision Fair is the largest fair in the Benelux in the field of precision technology. This year, according to the fair's manager Hans Houdijk, Mikrocentrum, the organisation hosting the fair, has done a fair amount of promoting in Germany. "Our publicity highlighted both the fair itself and the exhibitors."

Opportunities at CERN

In addition to the trade fair, there will also be a broad programme of lectures, including presentations by exhibitors and four keynote sessions. These sessions will be dedicated to CERN, high-tech, doing business abroad, and ultra-precision measuring. Scientists from CERN will discuss the current large particle accelerator, the Large Hadron Collider (LHC), and its successor, the even stronger Compact Linear Collider (CLIC). The LHC will be overhauled next year and the tendering procedure for the CLIC hasn't started yet. This presents major opportunities, worth millions of euros, for Dutch companies involved in the development and production of precision parts, optics and electronics, measuring technology and machines, machine parts, and subsystems and subsystem parts. The head of purchasing at CERN will therefore give a presentation in Veldhoven on Wednesday, 28 November, and on both trade fair days there will be an extensive matchmaking session with CERN purchasers that is open only to exhibitioners. Houdijk: "It's certainly not only intended for large companies. CERN is also interesting for SMEs; the average supplier sells about 100,000 euros a year there."

Matchmaking

The session on high-tech will feature the presentation of the roadmap for the top sector for high-tech systems and materials (HTSM). It will also highlight opportunities in the field of nuclear fusion (the international ITER project) and spin-offs from aerospace. The session on doing business abroad will focus on Germany, Switzerland, France and Belgium. In line with this international focus, the fair will again include the International Brokerage Event. Jointly organised by Mikrocentrum, Europe Enterprise Network and Syntens, it is a venue for matchmaking with foreign companies. This year's preparations were very intense, so Houdijk has high expectations for this part of the fair. Mikrocentrum has also partnered up with DSPE, euspen and Brainport Industries, the association of Dutch high-tech suppliers.

www.precisiebeurs.nl
www.mikrocentrum.nl

The CLIC test facility. (Photo courtesy of CERN)

28-29 November 2012, Veldhoven (NL)
Precision Fair 2012

Twelfth edition of the Benelux premier trade fair on precision engineering. This year's theme is 'Unlimited opportunities in Precision Technology'. Some 250 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. The Precision Fair is organised by Mikrocentrum, with the support of DSPE, NL Agency, the Dutch Precision Technology association, and Dutch HTS, the gateway to the Dutch High Tech Systems industry.

www.precisiebeurs.nl

5-6 December 2012, Teddington (UK)
Topical Meeting: Structured and Freeform Surfaces

This meeting of the euspen Special Interest Group Structured and Freeform Surfaces will focus on the technology, needs and design of engineered surfaces. This is the fourth in the series of topical meetings on the manufacturing and metrology issues that modern manufacturing industry faces.

www.euspen.eu

10-11 December 2012, Ede (NL)
Netherlands MicroNanoConference '12

Conference on academic and industrial collaboration in research and application of microsystems and nanotechnology. The eighth edition of this conference is organised by NanoNext.NL and MinacNed. Previous editions enjoyed attendance levels of approximately 450 academics and industrialists, visiting both the exhibition and the conference. See also page 51.

www.micronanoconference.nl

26-27 February 2013, Veldhoven (NL)
RapidPro 2013

The annual event for the total additive manufacturing, rapid prototyping and rapid tooling chain.

www.rapidpro.nl

20-21 March 2013, Milton Keynes (UK)
Lamdamap 2013

Event focused on laser metrology, machine tool, CMM and robotic performance.

www.lamdamap.com

Lamdamap 2013 will be held at Chicheley Hall, home of the Kavli Royal Society International Centre, in Newport Pagnell, near Milton Keynes, UK.

17-18 April 2013, 's-Hertogenbosch (NL)
Mocon 2013

Dutch trade show for motion control, drives and industrial automation. The latest innovations in design, construction, maintenance and use of components and systems will be displayed.

www.easyfairs.com/mocon-nl

24-25 April 2013, Eindhoven (NL)
High-Tech Systems 2013

Brainport Industries, DSPE, Syntens/Enterprise Europe Network and Techwatch (publisher of Bits&Chips and Mechatronica & Machinebouw) have taken the initiative to organise a high-tech event with an international flair in the southern part of the Netherlands. The event builds on Hightech Mechatronica, the trade fair and conference that Techwatch has been organising since 2007.
The revamped event is subtitled International Conference and Exhibition on Mechatronics and Precision Technology. Mikroniek is media partner of the event and will publish the official trade fair catalogue in its April 2013 issue.

www.hightechsystems.nl

27-31 May 2013, Berlin (DE)
euspen 13th International Conference and Exhibition

Conference topics will include:
- Renewable Energy Technologies (progress enabled by precision engineering advancements)
- Nano & Micro Metrology
- Ultra Precision Machines & Control
- High Precision Mechatronics
- Ultra Precision Manufacturing & Assembly Processes
- Important/Novel Advances in Precision Engineering & Nano Technologies

www.berlin2013.euspen.eu

24-28 June 2013, Eindhoven (NL)
International Summer school Opto-Mechatronics 2013

Five days of intensive training, organised by DSPE and The High Tech Institute.

www.summer-school.nl

Slit packages for accurate neutron beam conditioning

Heason Technology, based in Slinfold, West Sussex, UK, has designed and manufactured a range of application-customised and completely non-magnetic four-axis precision 'slit' packages for use in ambient and ultra-high vacuum environments on LARMOR. This is a multi-purpose instrument for small-angle neutron scattering, diffraction and spectroscopy utilising the larmor precession of polarised neutrons. At the Science and Technology Facilities Council's ISIS neutron and muon beamline facility in Oxfordshire, UK, LARMOR is presently under construction and due for completion in 2014. Motion systems specialist Heason supplied similar neutron beam conditioning positioners for other instruments at ISIS, as well as many other micropositioning devices for a number of synchrotron source/particle accelerator applications worldwide.

The slit packages, which all feature piezo-ceramic direct-drive linear motor systems and ceramic bearings, are essentially 4-axis motorised linear blades. These are precisely positioned to sub-micron levels in order to modify the face area and size of the neutron beam to enable the scientists to tune its resolution and divergence to achieve the optimal frequency required for the materials being examined on the instrument.

A unique design feature was the development of the package comprising of ceramic motors and bearings, support frames, housings and feedback encoders assemblies built using completely non-ferromagnetic materials so as not to influence the instrument's measurement capability in any way. With no lead-screws or externally mounted motors, the zero-backlash direct-drive design has reduced the amount of components typically employed in slit packages that use rotary motors – which also require complex magnetic screening and feed-through devices. This has resulted in increased long-term reliability, greater stability, much improved accuracy and positional repeatability, as well as considerable space savings.
The ceramic motor technology used in the packages – from Nanomotion – not only provides the non-magnetic micropositioning element for the application but also benefits from its ability to hold position with no movement whatsoever when power is removed. This feature allows the slit package to be isolated from power at the critical measurement phase, maintaining its exact dimensions but eliminating any potential for movement and heating that could influence the measured results.

www.heason.com

Silicon Europe

Four of the leading European micro- and nanoelectronics regions are joining their research, development and production expertise to form the transnational, research-driven cluster "Silicon Europe – The Leaders for Energy Efficient ICT Electronics". The cluster partners include four national consortia that all have established structures for the close cooperation of research, business and the authorities, thus fullfilling the requirements of a 'triple-helix' consortium. These high-potential mature clusters are Silicon Saxony, centred around Dresden (Germany), Point-One, centred around Eindhoven (Netherlands), Minalogic, centred around Grenoble (France), and DSP Valley, centred around Leuven (Belgium). The partners of Silicon Europe are linked by a common goal: securing Europe's position as the world's leading centre for energy-efficient electronics.

The partner clusters in total have nearly 800 members (297 in Silicon Saxony, 204 in Minalogic, 170 in Point-One, 75 in DSP Valley), more than 75% of which are SMEs. They count for more than 150,000 jobs, thereby covering more than 60% of the respective jobs in Europe. Highly relevant research players such as imec (Belgium), CEA-Leti (France) and Fraunhofer (Germany) as well as large companies such as Philips, NXP, Globalfoundries, Infineon, STMicroelectronics and Thales are active in the partner clusters.

www.silicon-europe.org

LEEP for precision chemical machining

Functional components that use etched channels to transport liquids are becoming increasingly popular in a variety of fluid management applications, such as diffusion-bonded plate heat exchangers, mixers, reactors, heat sinks and fuel cells. Precision Micro, with its head office in Birmingham, UK, has specialised in the design and production of such components using LEEP (Laser Evolved Etching Process), a precision chemical machining process that incorporates laser technology.

Plates are profiled and channels generated simultaneously in a single etch process, before being stacked and laminarly bonded, or simply held under pressure to form a functional matrix. Precision chemical machining imparts no mechanical or thermal stress on the plate that could compromise its planarity (flatness). Alternative manufacturing methods such as CNC milling, stamping or laser machining, can generate thermal distortion and machining detritus that can compromise stack bonding. The versatility of the etching process enables designers to vary the size and shape of channels and incorporate headers, collectors and port features, knowing that they can be produced economically without the need for extra process steps. A further benefit of the process is the ability to control the etchant chemistry, which in turn controls the non-directional surface finish within the channels.

As well as achieving a four-fold improvement in pitch accuracy across an 800 mm x 600 mm sheet of components, the LEEP process guarantees top/bottom side alignment of component features. This enables highly accurate channels to be produced on both sides of the plate, and also simultaneously. In this way high channel densities can be achieved, and by interlacing top and bottom side channels, stack heights can be minimised and thermal transfer improved.

Earlier this year, Meggitt, the international aerospace, defence and electronics group, acquired Precision Micro, a leading high-precision, photochemical machining manufacturer.

www.precisionmicro.com
www.meggitt.com

Reliance receives supplier excellence award

Reliance Precision, with its head office in Huddersfield, UK, provides custom-built gears and geared systems for light actuation and feedback applications, quadrupole mass filters for use in molecular analysis, and a diverse range of electro-mechanical, opto-mechanical, clean and high-vacuum assemblies. In addition, Reliance undertakes in-house research in order to develop technology platforms, specialist techniques and facilities, and to improve processes. In the Netherlands, Reliance serves tens of semicon, opto-mechanical, defense and biomedical companies, as well as their suppliers.

Testing of sub-assemblies at Reliance, using a non-contact CMM.

SELEX Galileo, a Finmeccanica company, has named Reliance Precision the "Laser UK Supplier of the Year 2011". This summer, the award was presented in recognition of Reliance's achievements for exemplary quality, delivery performance, value engineering, innovation and working relationship. Reliance has worked closely with UK-based defence electronics company SELEX Galileo on the outsourcing to Reliance of a range of precision opto-mechanical assemblies. Reliance's activities cover component manufacturing, supply chain management and inspection of the optical components, and finally clean assembly and test of the complete opto-mechanical sub-assemblies, delivering directly into SELEX Galileo's production line.

www.reliance.co.uk

Distinguished speakers on Micro & Nano

Prof. Anja Boisen, Director Department of Micro- and Nanotechnology (DTU Nanotech), Technical University of Denmark.

AMOLF Director Albert Polman.

The Netherlands MicroNano-Conference ’12 will provide participants the opportunity to interact with all the major Dutch micro-systems and nano-technology university groups, institutes and companies, as well as to attend lectures by distinguished speakers from the Netherlands and abroad. This year’s programme will focus on the following topics: Towards a healthy, safe and sustainable society; Innovations in fabrication and instrumentation; Enabling life science; and Photonics, Electronics and Materials.

Prof. Anja Boisen (Technical University of Denmark, DTU Nanotech, Denmark) will present a keynote lecture on molecular recognition using nanomechanical responses. Director David Quéré of ESPCI, Paris Institute of Technology, France, will provide a glimpse into the wonderful world of small droplets and their curious behaviour. Director Albert Polman of AMOLF, the Dutch research institute on nanophotonics and physics of biomolecular systems, will discuss the latest developments in ultra-high-efficiency solar cells. Dr. Jun’ichi Sone, Vice President National Institute of Material Science, Japan, will discuss nanomaterial research directed at solutions of energy and environment issues. Dr. Mostafa Analoui, Head of Healthcare and Life Sciences, The Livingston Group, New York, NY, USA, will address the current state of global R&D and investment, and the future of nano- and MEMS-based therapeutics and diagnostics.

The conference will take place on Monday 10 and Tuesday 11 December in the ReeHorst Conference Centre in Ede, the Netherlands, and is organised by the MinacNed Association for Microsystems and Nanotechnology (www.minacned.nl) and the NanoNextNL consortium (www.nanonextnl.nl).

www.micronanoconference.nl

Robotdalen Innovation Award

Johan Ingvast, chief technical officer at Bioservo Technologies, the winner of the Robotdalen Innovation Award 2012, demonstrates the SEM Glove. (Photo courtesy Terése Andersson)

The winners of the international robotics competition, the Robotdalen Innovation Award, will receive hands-on help from the Swedish robotics initiative Robotdalen, to further develop and commercialise their innovative robotics ideas. The competition targets innovators with commercially valid robotics solutions; it may be entrepreneurs, researchers, inventors, start-ups, robot developers, graduate or postgraduate students.

Winner of the Robotdalen Innovation Award 2012 was Bioservo Technologies, founded by researchers from the Karolinska Institute and the Royal Institute of Technology in Stockholm, Sweden. Their SEM Glove combines their experiences about human needs, with modern robot technology knowledge, creating an innovative, user-friendly and adaptive robotic assistance for people who need extra help gripping things in their everyday life.

The Robotdalen Innovation Award 2013 is now open for submissions; deadline is 13 January 2013. The winners will be announced at the Robotdalen event Robotics Innovation Challenge in Eskilstuna, Sweden, on 25 April 2013.

www.robotdalen.se/en

European Robotics Week

The European Robotics Week offers one week (from 26 November to 2 December 2012) of various robotics related activities across Europe for the general public, highlighting growing importance of robotics in a wide variety of application areas. The Week aims at inspiring technology education in students of all ages to pursue careers in STEM-related fields, i.e. science, technology, engineering and math. The European Robotics Week is powered by EUnited Robotics, the European Robotics Association. Events are organised locally (by scientists, labs, teachers, schools, robotics engineers, robot makers, etc.), but centrally listed and co-promoted. Activities will take place in Bulgaria, Czech Republic, Germany, Malta, Portugal, Spain and Switzerland. To find out about activities going on in Europe, please check www.robotics-labs.eu.

www.eurobotics-project.eu/eurobotics-week
www.eu-nited.net/robotics

Short-pulse laser optics optimised for UV

Following the successful application of short-pulse laser F-theta lens S4LFT4010 in the infrared and green spectral range, German manufacturer Sill Optics has extended this lens series with a UV version. All optical elements of this lens are made of high-grade fused silica to minimise thermal lens effects. Moreover, this laser lens has no internal ghosts, so no damage can occur due to internal back reflections or reflections from the workpiece. The lens elements are anti-reflection coated with high-durability, low-absorption ion-assisted deposition layers.
The almost perfectly telecentric F-theta lens is designed for a scan field of 35 x 35 mm and has an maximal angle of incidence of 1.4°. With an input beam diameter (1/e2) of 10 mm and a focal length of 100 mm it achieves a spot size of 4 microns over the entire scan field.

www.molenaar-optics.nl

New cleanrooms at NTS-Group

This autumn, NTS Mechatronics in Eindhoven and NTS Systems Development in Wijchen have put new cleanrooms into operation. This will enable the NTS-Group's two operating companies to meet customers' most technologically advanced demands and wishes for the coming years. A growing number of customers require the assembly of critical components for the next generation of their machines under ultra-clean conditions. As a (system) supplier, the technology and competencies of the NTS-Group have to match the evolution of the products of major machine builders (OEMs).

Until recently, the NTS-Group had two cleanrooms in Eindhoven, the Netherlands, measuring 150 and 250 m^2, respectively. Because of the growth in demand, both had become too small. The first has now been replaced by a 900 m^2 facility. Half of the space falls within ISO Class 6, which is necessary to be able to keep up with the latest developments in the semiconductor industry. This is where the modules for customers operating in this market are ultimately assembled. The new cleanroom has enough space to allow thirty people to work at the same time.

The second new cleanroom is located in Wijchen, the Netherlands, where prototypes of modules that are still under development are built. The products and materials used in prototyping also have to comply with increasingly stricter purity requirements. The new 160 m^2 cleanroom qualifies the NTS-Group for the top-level class of purity.

www.nts-group.nl

New training at HTI: Advanced mechatronic system design

A unique training, 'Advanced mechatronic system design' is now offered by The High Tech Institute (HTI) for experienced designers of precision systems. For the first time, this originally internal Philips training is open to all mechatronic system designers and architects who have at least six to ten years of experience.

'Advanced mechatronic system design' launches in Eindhoven on January 23rd, 2013. The training takes place over six days. Participants will gather physical insights, working methods and design concepts for the development of precision systems.

Special attention will be given to lessons learned from the past, in terms of approach and application of specific technical problems and solutions. Jan van Eijk, emeritus professor at Delft University of Technology and course leader at HTI says: "Nowadays, Eindhoven is the smartest, outstanding region in the world because we may have made the most mistakes in the past but we have learned from them. With this training we transfer all these skills and know-how to the future generations of mechatronic system designers, so they can build on this knowledge. In this way, our advance in technology will continue to increase."

Participants will be confronted with aspects on different levels of the global product creation process. These include interaction with the customer and the fact that the customer often consists of multiple persons with sometimes different views. Technical trade-offs on system level and recent insights and developments on module and function level are also part of this course. The training is a mix of presentations and exercises in combination with a conceptual design case study of a precision system, typically for lithography or inspection purposes.

www.hightechinstitute.nl

Start Holland Instrumentation

Holland Instrumentation was officially established in Delft, the Netherlands, this October. This new foundation seeks to combine the capabilities of companies, knowledge institutes and universities from the Dutch province of Zuid-Holland in the field of developing, building and marketing high-quality instruments. Holland Instrumentation aims to double sales and exports by 2030 by developing more high-quality instrumentation activities in Zuid-Holland. Holland Instrumentation plans to achieve this by expanding the regional ecosystem and encouraging entrepreneurship, and through a more focused development and better utilisation of breakthrough technologies. All of this will be done in close cooperation with other regional initiatives and organisations.

Zuid-Holland is a major high-tech region in the Netherlands, second only to south-eastern Brabant, and specialises in instruments. The region is home to over 700 companies and institutes involved in developing and producing instruments for the medical and clinical sectors, aerospace and science, laboratories and the process industry, the offshore and marine industries, and the agricultural and food industries. The development and production of high-quality instrumentation is a healthy and clean industry that provides substantial and diversified employment opportunities and generates relatively high added value and exports, as well as boosting activity among service providers. There is plenty of scope for further cooperation and the development of entrepreneurship, enabling this industry to keep growing. This can take the form of setting up spin-offs as well as supporting initiatives taken by existing successful companies.

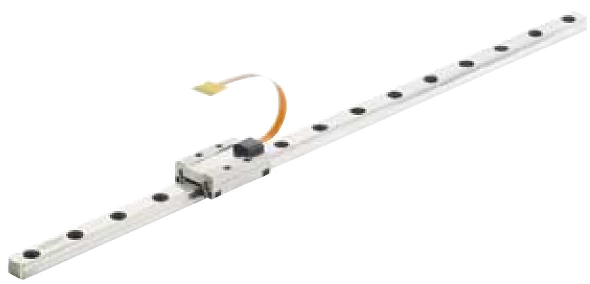
To this end, Holland Instrumentation will be organising public and private meetings, setting up networks for young technicians and entrepreneurs, and lobbying regional governments, chambers of commerce and investors. Holland Instrumentation also aims to create a platform from which joint projects and/or a joint development lab can be set up.

Participants include TNO, Delft University of Technology, Leiden University, Mapper Lithography, Cosine, Science [&] Technology Corporation, Lencon and Hittech.

www.hollandinstrumentation.nl

Miniature guideway with integrated measuring system

Schneeberger has presented the MINISCALE integrated linear measuring system. It combines the proven miniature guideway MINIRAIL, which is stable up to speeds of 5 m/s and accelerations of 30 g, with an optical measuring system. The measuring system features a resolution of 1 µm, an accuracy of +/– 4 µm (over a 30 mm range) and +/– 10 µm (up to 300 mm). The system is ideal for applications where space is limited and a high precision and process



security are required, allowing for a wide range of applications, from semicon and surface finishing to metrology and micro-automation.

www.schneeberger.com

Segula has relocated

Segula Technologies Nederland, a subsidiary of Segula Technologies, an industry leader in engineering and innovation consulting with over 7,000 employees in France and nearly twenty other countries around the globe, started operation in April 2010 in the Bèta building at the High Tech Campus Eindhoven in the Netherlands. From the start Segula experienced a rapid growth and it foresees to continue this growth pace in the years to come. Therefore, Segula has moved to a new office location offering more floor space. The High Tech Campus offers the room for growth, allowing Segula to stay in this inspiring and innovative environment.

Next to the automotive and industrial vehicles industries, Segula Technologies Nederland serves customers in the high-tech industry, with design, development and system integrations of equipment for various markets. Segula's expertise includes lightweight and stiff design, static constrained design, electromechanical design, dimensioning and tolerances, thermal/mechanical design, and analyses (CFD, thermal and FEM).

www.segula.nl

Mikroniek guide

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W www.ace.eu

ACE has developed into a leading engineering and consultancy firm with a strong focus on mechanics and mechatronics. Services include conceptualization, development, engineering and prototyping.

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Leidse instrumentmakers School

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W www.lis-mbo.nl

The LiS is founded in 1901 by the famous scientist prof. Kamerlingh Onnes. Nowadays the LiS is a modern school for vocational training on level 4 MBO-BOL. The school encourages establishing projects in close cooperation with contractors and scientific institutes, allowing for high level “real life” work.

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Mikroniek guide

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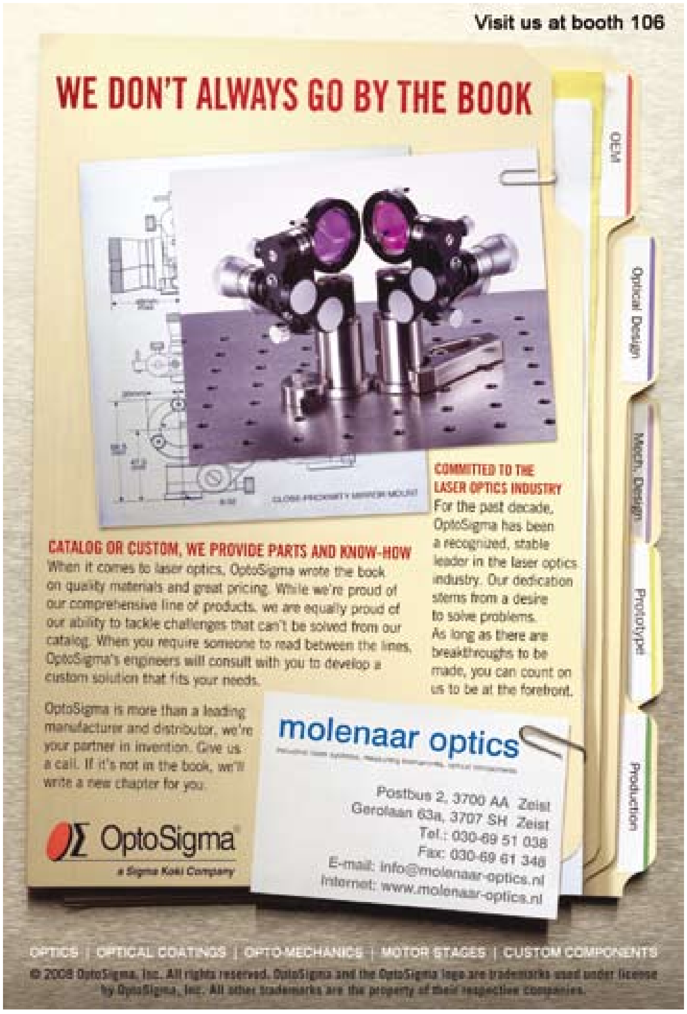

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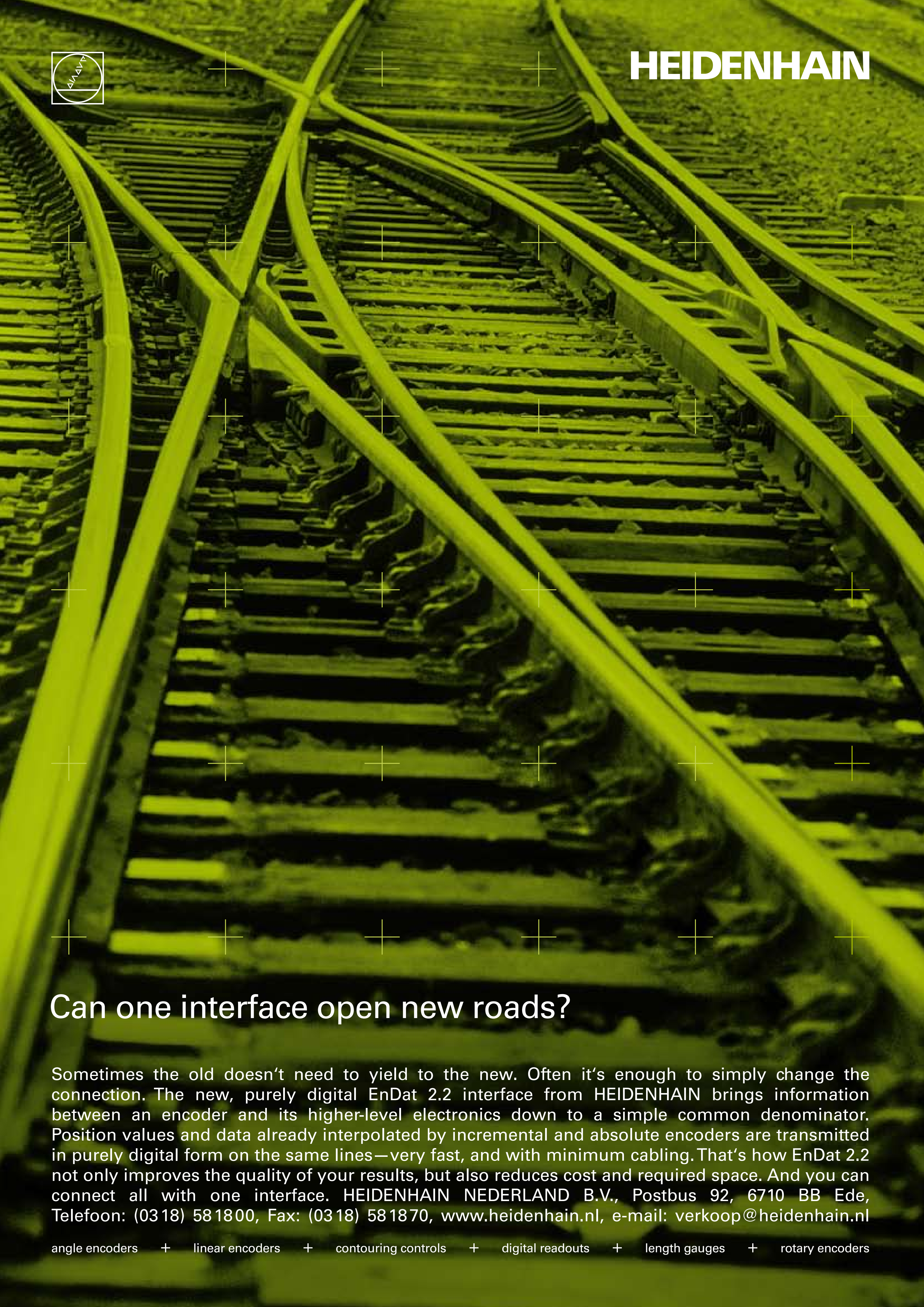
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