Mikroniek

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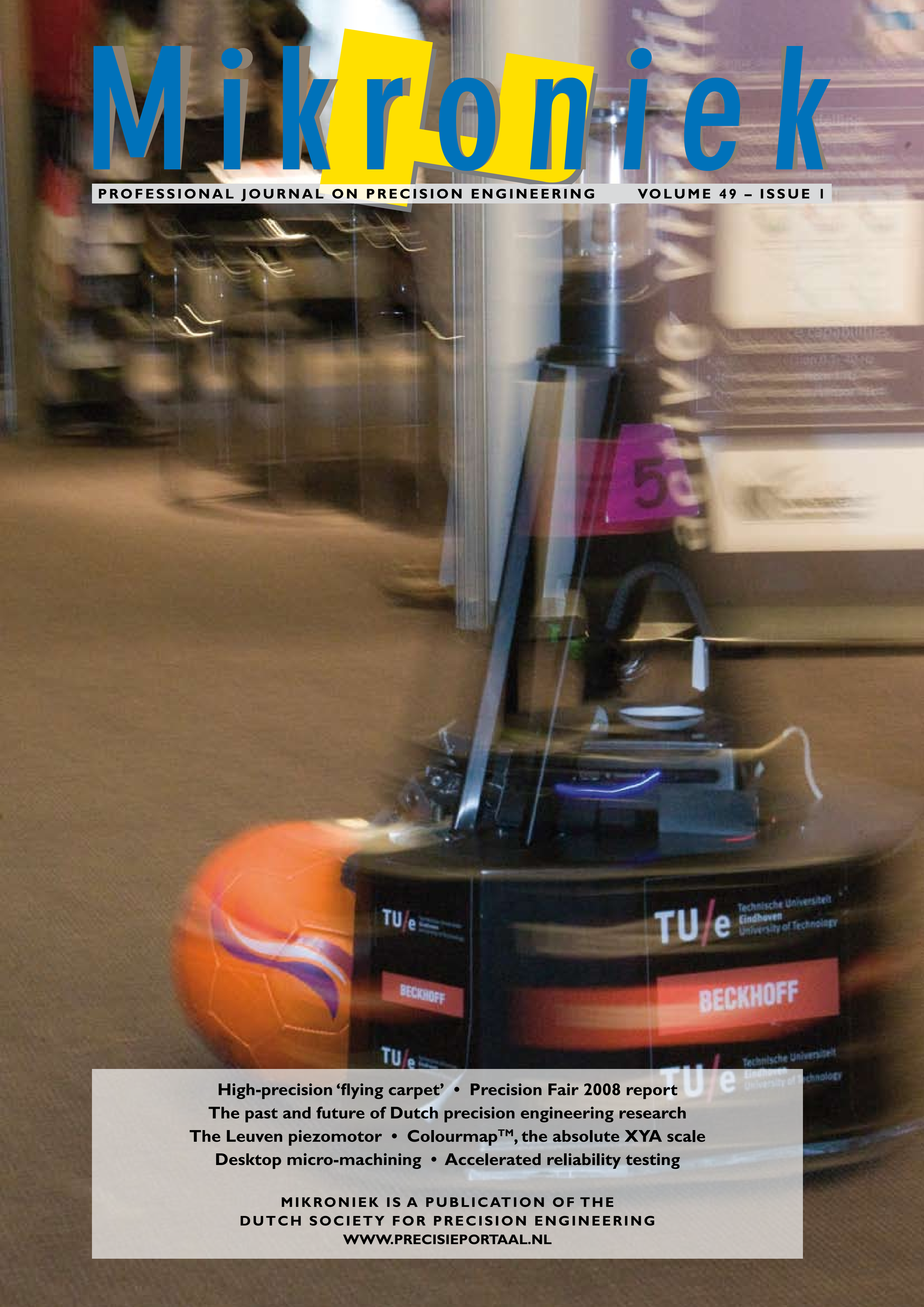

High-precision 'flying carpet' • Precision Fair 2008 report
The past and future of Dutch precision engineering research
The Leuven piezomotor • Colourmap^{TM}, the absolute XYA scale
Desktop micro-machining • Accelerated reliability testing

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The face of ...

TNO Science and Industry

Within the Business Unit Mechatronics Equipment precision technology is a familiar term. What about a highly accurate spectrometer that orbits in space for many years in extreme conditions and can continue to spot the polluted air in your back garden? We can provide solutions for these and more issues with the level of accuracy that is representative not only of our field but also of our customer focus.

In this issue

Publication information

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

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The cover photo (an impression of the Precision Fair 2008) is courtesy Mikrocentrum/Sylvia van der Nol.

editorial

The Dutch precision engineering success story

In Europe, the precision engineering discipline is historically rooted in the need for accurate instruments and machines for astronomy, navigation, surveying, weaponry, metrology (standards), and manufacturing (machine tools). Nowadays the problems are equally challenging: trying to delay the demise of Moore's law in microelectronics by generating ultra-precision lithography machines, providing technologies for the production of structured (nano)surfaces and high-precision microsystems, developing technologies for producing ground-based and space optics, etc.
The high-tech products around us are taken for granted, particularly by youngsters; people do not realize the formidable technological challenges behind those engineering marvels. It is also not realized by society, particularly policy makers and funding agencies, that precision engineering is the enabling technology at the very basis of those products.

The Netherlands have been at the vanguard of the evolution of precision engineering in Europe. The extensive and longstanding research at Philips has been instrumental in spinning out world-leading companies, like ASML (lithography machines), FEI (electron microscopes), Singulus (disc mastering equipment), and many more, turning the Eindhoven region into a future world centre of precision engineering. This evolution is backed by a longstanding tradition of teaching and research (in what was originally called 'fine mechanics') at the Dutch technical universities (now in 3TU context), and by far-sighted actions from Dutch government agencies to massively fund R&D in nanotechnology, embedded systems and mechatronics (Point-One Phase 2).

eu**spen**, the European Society for Precision Engineering and Nanotechnology, has the important mission to increase the awareness of scientific policy makers, funding agencies, and academic authorities of the importance of precision engineering and to assist industry in the development of innovative products that satisfy the needs of society. DSPE/NVPT has the same mission at a national Dutch level. Mikroniek is an excellent journal, unique in its kind, spreading the precision engineering message at a level very well tuned to its readership. eu**spen** applauds their initiative to publish in English and is very happy to distribute these issues to its members. eu**spen** and DSPE consider this as a first step towards a more intense collaboration.

Prof. dr. ir. Hendrik Van Brussel
President of eu**spen**

High-precision 'flying carpet'

Since 2002, Eindhoven University of Technology has been investigating fully contactless *xy*-positioning systems. These magnetically levitated planar actuators consist of a single carrier with permanent magnets that is levitated above an array of coils and can move fast and accurately over long distances in the *xy*-plane. Because the magnets are moving, there are no cables or cooling hoses connected to the moving part. Nevertheless, data and energy can still be transferred, using contactless links. This high-precision 'flying carpet' was one of the subjects in the lecture programme at the Precision Fair 2008.

• *Helm Jansen, Nelis van Lierop, Elena Lomonova and Paul van den Bosch* •

Most multi-degree-of-freedom (multi-DOF) positioning systems are constructed of several single-DOF linear and rotary actuators with air bearings. All these individual actuators are coupled using complex mechanical structures. However, the demand for higher accuracies, higher accelerations, and vacuum compatibility triggers actuator solutions with multiple degrees of freedom and magnetic bearings integrated in one actuator, a concept resulting in a low moving mass.
An example of such a novel actuator is a magnetically levitated planar actuator. This actuator has only one moving body, the translator, which is suspended above a stator with no support other than magnetic fields. The translator can move over long distances in the *xy*-plane and is controlled in six degrees of freedom. There are two options for the planar actuator configuration. The actuator has either stationary magnets and moving coils, or stationary coils and moving magnets. The advantage of the second configuration is that it is truly contactless because of the absence of cables connected to the moving part.

The Electromechanics and Power Electronics (EPE) group and the Control Systems (CS) group of the Department of Electrical Engineering at Eindhoven University of Technology (TU/e), the Netherlands, have been conducting research into these moving-magnet planar actuators since 2002 within the framework of two IOP-EMVT projects (Innovation-directed Research Programme ElectroMagnetic Power Technology, funded by the Dutch Ministry of Economic Affairs). In the first research project, the modeling, design and control frameworks for this type of actuator have been established and proven on a fully operational prototype. Afterwards, it has been demonstrated that data and energy can be transferred to the translator using contactless links. These results were so promising that recently an industrial project was started to investigate whether this technology can be used to construct a single-stage, nanometer-accurate, long-stroke *xy*-positioning system.

Planar actuator

Magnetically levitated planar actuators with moving magnets are coreless actuators that are solely constructed of coils and permanent magnets. A schematic overview of a moving-magnet planar actuator is shown in Figure 1. This planar actuator topology has been patented by TU/e and has 84 stator coils which are arranged in a herringbone pattern. For that reason it is named Herringbone Pattern Planar Actuator (HPPA) [1][2]. Onto the translator, 385 NdFeB permanent magnets are glued in a two-dimensional array with a quasi-Halbach magnetization. Because only the coils below the surface of the magnet array effectively contribute to its levitation and propulsion, the set of active coils (in this case 24 coils) is switched during movement in the *xy*-plane. The stroke of the planar actuator can simply be increased by adding extra stator coils.

The three-dimensional magnetic fields and the lack of symmetries and periodicity in the electromechanical structure of moving-magnet planar actuators, require a different design approach as compared to standard linear and rotary actuators. Moreover, all degrees of freedom are intrinsically coupled. Contrary to many other magnetically levitated systems such as maglev trains, the bearing and propulsion functions are not separated into different parts of the actuator. Only the force production in the *xy*-plane can be physically decoupled by applying rectangular coils as shown in Figure 1.

To design the planar actuator, research in two different directions was carried out. Firstly, an electromagnetic modeling framework was created that can be used for a fast prediction of the force and torque produced by the actuator. Because the actuator is coreless, 3D finite-element simulation turned out to be very slow and time-consuming. Instead, several accurate semi-analytical models were created that can be used for both design and real-time control. These models allow the derivation of simple design rules for the coil and magnet dimensions.

Secondly, research was carried out into commutation and coil switching algorithms. Because all degrees of freedom are intrinsically coupled, standard decoupling algorithms

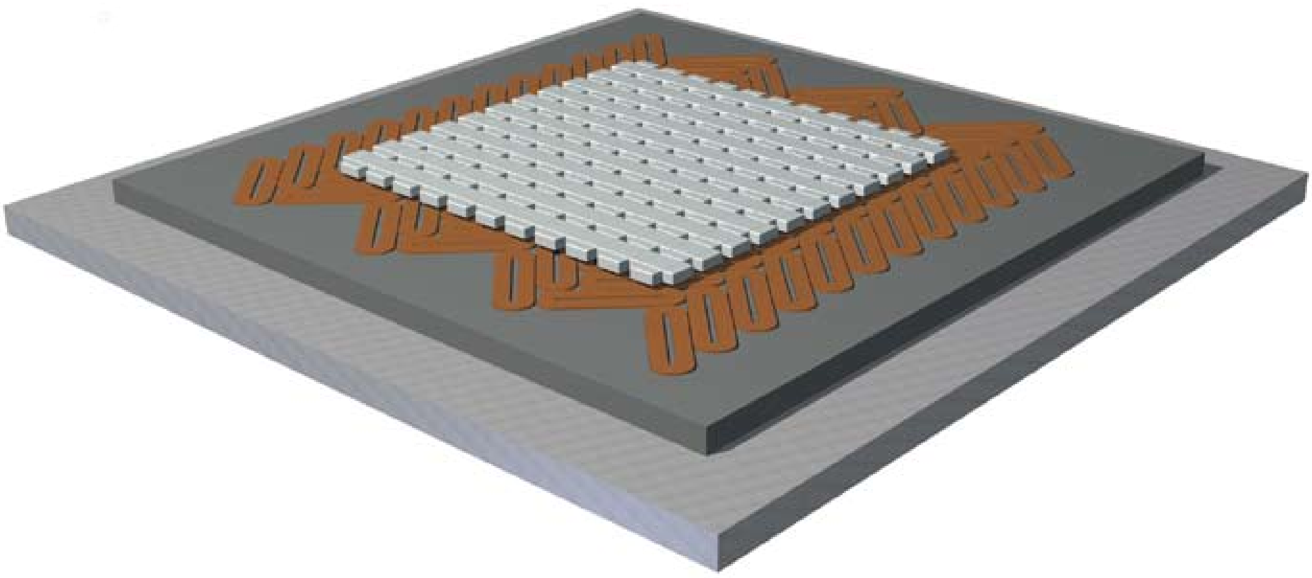

Figure 1. Overview of the Herringbone Pattern Planar Actuator.

for synchronous machines cannot be applied to the planar actuator to decouple the force and torque components. Therefore, a novel commutation algorithm was derived that inverts a fully analytical mapping of the force and the torque exerted by the set of active coils as a function of translator position and orientation. This algorithm guarantees a minimal energy dissipation by the actuator and smooth switching between different sets of stator coils. With this algorithm the controllability of different topologies could be tested. The combination of both the electromagnetic modeling framework and the commutation algorithm turned out to be an excellent tool to evaluate many different planar actuator topologies and to predict performance indicators fast. In several hours, a full planar actuator could be evaluated on thousands of different positions.

Figure 2 shows the prototype that was built to verify the developed theories. Its topology is shown more clearly in Figure 1. The translator has a size of 300 by 300 mm and a mass of 8.2 kg. It consists of an aluminum construction, with mechanical eigenfrequencies of 785 Hz and higher, onto which the magnets are glued. It can move in the *xy*-plane with a stroke of 230 by 230 mm. The maximum velocity and acceleration in the *xy*-plane are 1.4 m/s and 14 m/s^2, respectively.

The position of the translator is reconstructed on the basis of data from eight inductive sensors that are mounted on an external *xy*-robot and from the encoders of the *xy*-robot itself. Because the inductive sensors only have a range of 2 mm, the *xy*-robot follows the same *xy*-trajectory as the planar actuator during long-stroke measurements. However, the planar actuator and *xy*-robot are controlled independently and do not make contact. At standstill the position and angular error of the planar actuator was approximately 0.1 µm and 1 µrad rms, and during high-speed trajectories less than 30 µm and 0.1 mrad. During these measurements, six SISO controllers with a 35 Hz bandwidth were used to control the six degrees of freedom of the planar actuator. The power dissipation for levitating the translator 1 mm above the stator is approximately 40 W.

Planar actuator with manipulator

Although a planar actuator with moving magnets can be applied as a position stage, many applications require sensors on top of the stage. It would be a waste of all the effort that went into creating a fully contactless stage, to install power supply and data cables to these sensors. To demonstrate that both power and data can be transferred without any contact to a moving-magnet planar actuator, a planar actuator with a manipulator on top of it is investigated in the still ongoing second IOP-EMVT project. In this actuator system, three contactless technologies have been combined: magnetic levitation, contactless energy transfer and wireless communication [3].

Figure 3 shows a photo of this system. Below the black surface the stator coils are located. Although rectangular coils are more efficient for a planar actuator, round coils

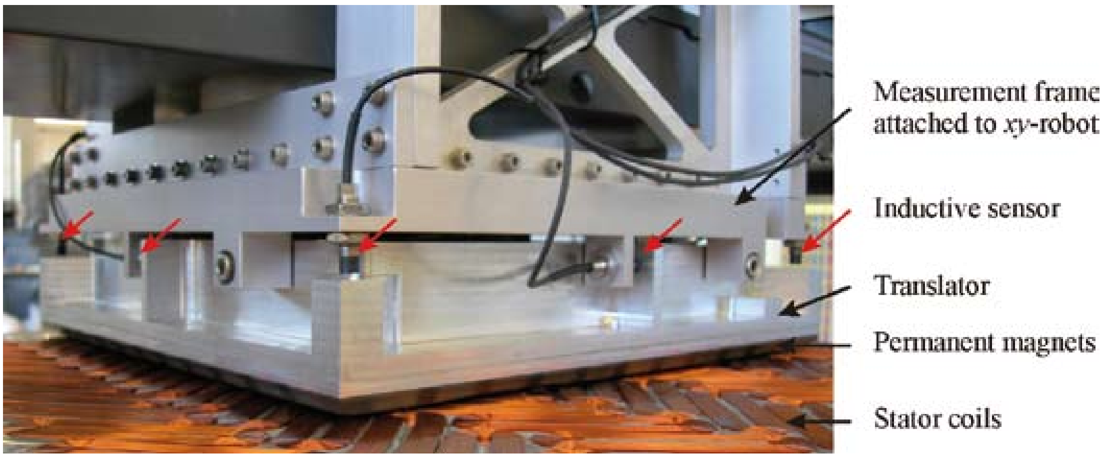

Figure 2. Herringbone Pattern Planar Actuator and measurement frame

were chosen to simplify the contactless energy transfer. Some of these stator coils are wire wound and some are Litz wire wound. The Litz wire coils have two functions. They can be used to produce force for the planar actuator when they are below the permanent magnets, and to transfer power when they are below the secondary coils of the contactless energy transfer system. The inductive energy transfer system is a coreless transformer with multiple primary coils that operates at 158 kHz. The secondary coil of the transformer is the large coil that overlaps several primary coils and is mounted at the side of the planar-actuator translator. The transferred power is rectified and used to drive a two degree-of-freedom manipulator that is placed on top of the translator. This system can transfer 100 W with an efficiency of 72%. The controller of this manipulator is placed on the fixed world. Hence, position data and current setpoints have to be transmitted from and to the current amplifiers on the moving platform. This data is transmitted with a 1.5 Mbit low latency 2.4 GHz wireless link. Because the data transfer is in the loop of the controller, IP-based protocols that are applied for W-LAN could not be used because of their large delays (several milliseconds). Consequently, a new protocol for data transmission was written, having a delay of 0.3 milliseconds. Furthermore, a very fast infrared link (VFIR) was designed, having a data rate of 16 Mbit and a transmission delay of only 7 µs [4]. Also for the VFIR link a custom communication protocol was written. For transmitter-receiver distances smaller than 0.7 m, the optical link is significantly more reliable than the radio link and has a CRC error rate of less than 10^{-7}.

Advanced Single-stage Planar Actuator

Nanometre-accurate stages often consist of a short-stroke nanometre stage on top of a micrometer-accurate long-stroke stage. Because of the absence of disturbing hoses and cables connected to moving-magnet planar actuators, the main question after completing the first planar-actuator project was if this technology could be applied to realize a long-stroke nanometre-accurate stage with only one moving part. In April 2008, the third planar-actuator project was granted by the Ministry of Economic Affairs (‘Pieken in de Delta’ programme) to investigate the possibility of an Advanced Single-stage Planar Actuator (ASPA).

In this project several industrial partners, ASML, Prodrive, Tecnotion and VDL-ETG, will participate together with the EPE and CS groups of the Electrical Engineering Department and the Control Systems Technology group of the Mechanical Engineering Department of TU/e, to investigate and realize this nanometre-accurate single-stage

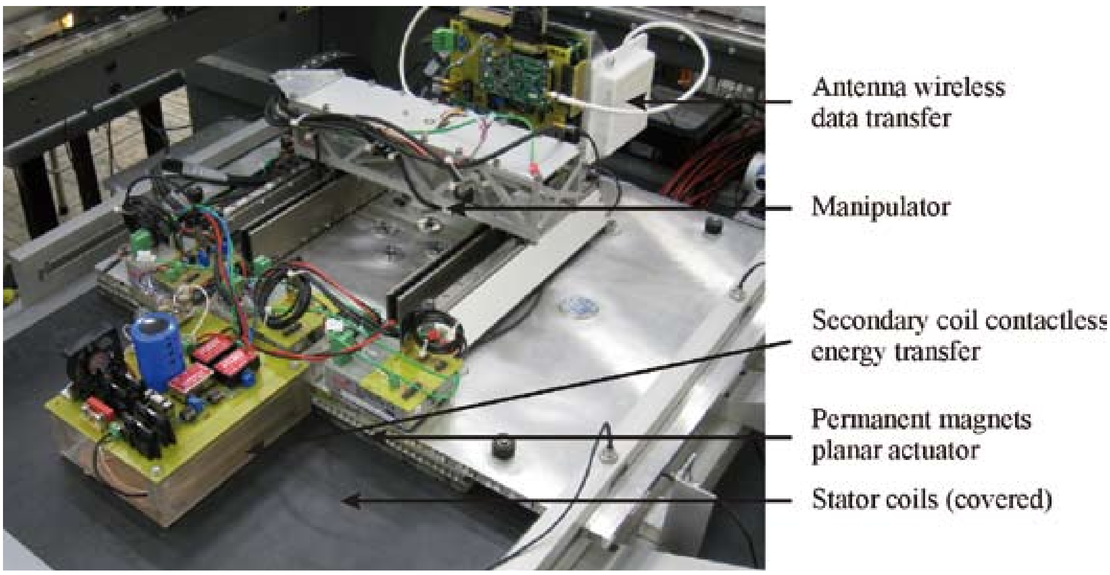

Figure 3. Planar actuator with manipulator and wireless energy and data transfer.

planar actuator. Whereas in the previous projects rigid-body dynamics was assumed, this assumption does not hold in the new project as flexible modes of the moving translator should be actively compensated by over-actuation to achieve the desired accuracy. Hence, the force distribution should be controlled over the surface of the translator as illustrated in Figure 4. Furthermore, the modeling and design of the planar actuator has to be improved and the influence of model inaccuracies and production tolerances on the closed-loop performance has to be investigated and minimized. Another important aspect is the reduction of the number of amplifiers in the system. As only a small part of the stator coils are energized simultaneously, it is not economic to have each coil connected to its own amplifier. In the project an integral design approach will be followed, combining electromechanics, control design and mechanical design.

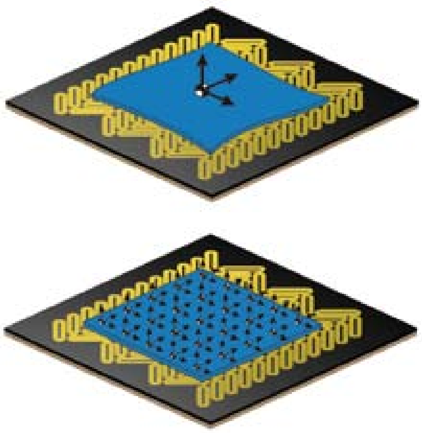

Figure 4. Schematic representation of the use of over-actuation to compensate flexible modes.

Because the measurement system of the planar actuator shown in Figure 2 limits the accuracy of this actuator, it will be equipped with a laser interferometer system to re-measure its performance. These measurements will be the starting point of the research, which will hopefully result in a new generation of highly accurate positioning stages based on moving-magnet planar-actuator technology.

Authors' note

Helm Jansen received his M.Sc. and Ph.D. degrees in electrical engineering from Eindhoven University of Technology (TU/e). He is a postdoctoral researcher in the field of linear and planar actuators in the Electromechanics and Power Electronics group at the same university.
Nelis van Lierop studied electrical engineering at TU/e, where he also carried out his Ph.D. work. Since 2009, he is an assistant professor in the Control Systems group of the same university.
Elena Lomonova was born in Moscow, Russia. She received her M.Sc. and Ph.D. degrees in electrical engineering from Moscow State Aviation Institute (TU). In 2001 she joined the Electromechanics and Power Electronics group at TU/e, where she currently is an associate professor.
Paul van den Bosch received his M.Sc. and Ph.D. degrees from Delft University of Technology. After his study he joined the Control Systems group in Delft, and was appointed full professor in 1988. Since 1993 he has been full professor and chair of the Control Systems group of the Department of Electrical Engineering at TU/e.

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Information

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Precision resists

The best way to resist recession is to ignore it and continue to demonstrate your capabilities. That is what happened at the Precision Fair (Precisiebeurs) 2008 in Veldhoven. The leading theme this year was machining innovative materials, although this item was not so prominently represented at the fair. Nevertheless, the exhibition did offer impressive proof of the know-how in the Dutch precision technology industry. The precision industry is rapidly learning how to beat Asian competition by keeping unmanned machining equipment in operation for 24 hours a day. And not only with the aim of earning back huge investments but also to reproduce extreme precision in complicated product series. Again, the Technology Hotspot showcased the ability of universities and other institutes to assist the Dutch precision industry in its pursuit of a leading edge position.

• *Frans Zuurveen* •

Writing an even-handed report about the Precision Fair 2008 is an almost impossible task within the context of a brief visit and the scope of this article. This is, therefore, a very personal impression coloured by a senior scientist with a metrological, optical and precision-mechanical background, and delighted by seeing the fresh approach to precision technology problems taken by younger people.

Technology Hotspot

Innovation can be seen as a flywheel for making precision technology profitable. That is why research institutes are assisting the precision industry in the selection process for future investments.
A good example of this is an air bearing in a round table shown by K.U.Leuven University in Belgium (see Figure 1). Its special design prompted Leuven Air Bearings to bring a similar bearing onto the market. Stijn Sempels explained that the rotational accuracy of the K.U.Leuven bearing is 50 nm, the reason being that the bearing is to be used in an accurate turntable for grinding components for a miniature gas turbine generator. This generator uses hydrogen as a fuel and will provide 1 kW power output within a very small volume. The diameters of the turbine and compressor wheels are only 20 mm (see Figure 2). The highly challenging specifications prescribe a rotational speed of 500,000 rpm and temperatures up to 930 °C. The Precision Fair 2008 theme was reflected clearly in the material selection: titanium for the compressor wheel and Si_3N_4-TiN ceramic for the turbine wheel. With the extremely high temperature differences inside the turbine, innovative materials such as these are essential.

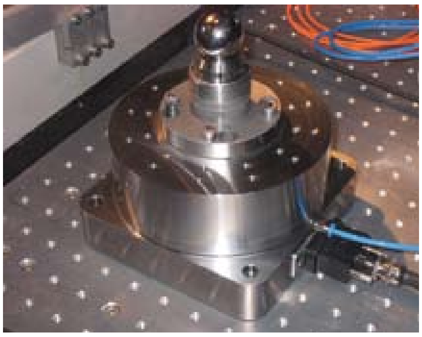


Figure 1. An air bearing designed by K.U.Leuven University, with a rotational accuracy of 50 nm.

Figure 2. The experimental setup for a gas turbine with 500,000 rpm, shown by K.U.Leuven.

Figure 3. A light and stiff balance arm for the James Webb Space Telescope (to be launched in 2013), realised by Astron's patented pocket milling machining technology.

More Hotspot surprises

ASTRON, the Netherlands Institute for Radio Astronomy in Dwingeloo, develops novel and innovative technologies to make discoveries in radio astronomy. Spin-offs in the form of a range of advanced precision technologies have been generated by that mission. Astron's Ronald Halfwerk reported that the institute is taking part in a project for building an IR spectrometer for JWST MIRI SMO, the James Webb Space Telescope that will be replacing the well-known Hubble telescope in 2013. The components in the telescope have to be light and stiff, requirements that are, in most cases, contradictory. Astron has developed an advanced patented technology for milling special pockets in solid aluminium. It leaves thin walls for high stiffness and nevertheless removes more than 95% of the material (see Figure 3). Figure 4 shows the IR spectrometer for the JWST in a one-part aluminium frame with polished gold-coated Al mirrors with a Ti interlayer.
3TU, a partnership between Eindhoven, Delft and Twente Universities of Technology, showed an adaptive mirror made of 0.1 mm thick Pyrex glass. Simon Ravensberger explained that 61 reluctance-magnetic actuators perform local deformations in the mirror, which makes it possible to compensate wavefront aberrations caused by refractive index variations in air. Figure 5 shows a miniaturised prototype developed by the Netherlands Organisation for Applied Scientific Research's (TNO) Science and Industry department (a Ph.D. dissertation by Roger Hamelinck) for later application with many more actuators in EELT, the European Extremely Large Telescope.

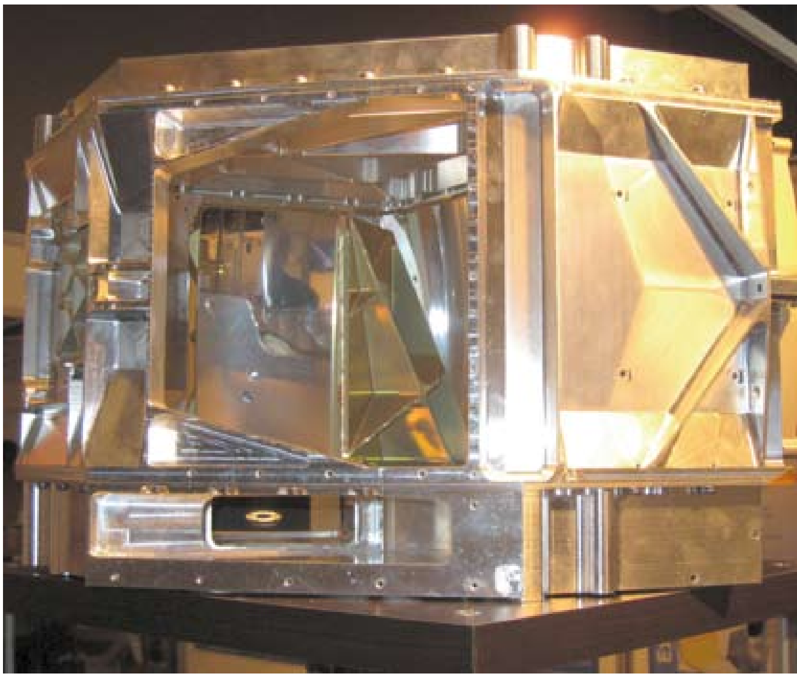


Figure 4. IR spectrometer for James Webb Space Telescope, developed by Astron.

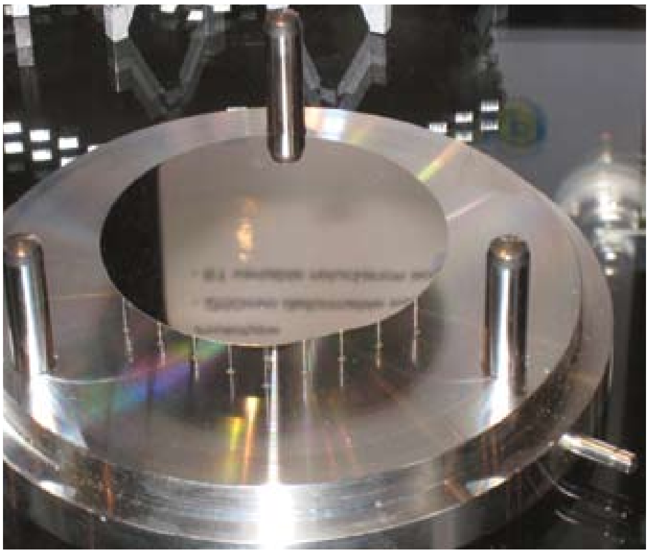


Figure 5. Miniaturised prototype of an adaptive mirror with 61 actuators to compensate for refractive index variations in air.

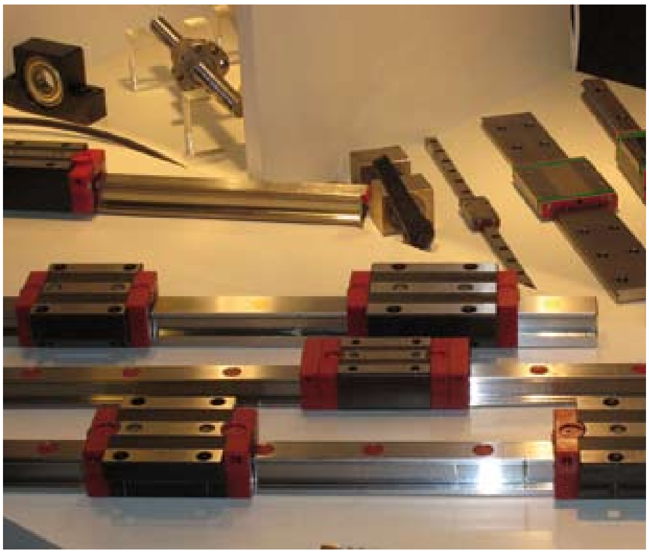


Figure 7. Stamhuis Lineairtechniek showed guiding systems in many variations, with Schneeberger guides prominently in the foreground.

Figure 6. A soccer robot at the 3TU stand.
(Photo: Mikrocentrum/Sylvia van der Nol)

Also at the 3TU stand, soccer robots where shown; see Figure 6. Eindhoven University of Technology for some time has been engaged in international robot soccer competitions, and now a humanoid soccer robot is being developed in a 3TU project.

Guiding and machining

Many sellers of precision guides and makers of precision products were present: business as usual, one might say. Stamhuis Lineairtechniek, for instance, showed a range of small or large guides with or without integrated measuring system and with or without driving system (see Figure 7). The well-known Schneeberger guides were on display at the Stamhuis stand and, of course, at the Schneeberger stand. Stamhuis' motto is 'create and innovate together'.

Many mechanical machining firms showed their high-precision products. No great surprise really but it is always a pleasure to see how mechanical machining pushes its limits (see Figure 8). Figure 9 shows a complicated product machined by Kusters Metaalbewerking.
Lowering costs can become a reality if expensive machines are operated 24 hours a day, 7 days a week. Peter Adema of Wilting Components says that his firm invested both in CNC machines and in handling equipment to move products from one station to an other. Figure 10 shows a complicated precision product that requires long machining times. It can only be produced at acceptable prices if machining can go on continuously, day and night. Figure 11 shows an SMD parts feeder assembly that used to be made in China. Recently, the manufacture and assembly of this complicated product returned to the Netherlands because Wilting Components succeeded in drastically lowering the cost price.

Figure 8. Products machined by Bakker Fijnmetaal. Their specialisation is the machining of copper.

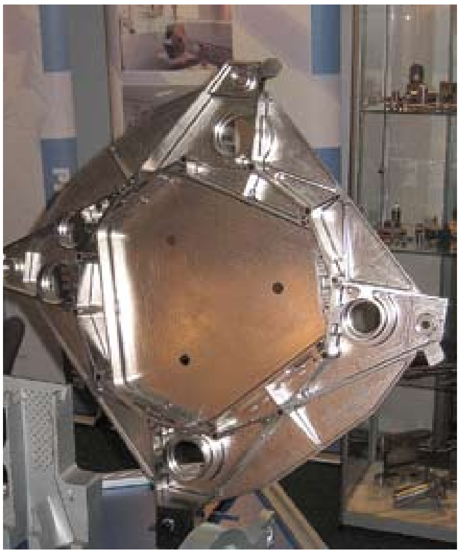


Figure 9. A precision product machined by Kusters Metaalbewerking.

Figure 10. A complicated product that Wilting Components machines in a 24/7 working cycle.

Comfortable measuring

Not that long ago you had to write down two numbers and subtract them to measure diameter. Mahr and Mitutoyo demonstrate that computer-controlled machines make measuring much easier today by automatically focusing on both sides of a hole in transmitted light. Automatic edge detection is the name of this trick in a MarVision MM 320 measuring machine with a zoom lens and a measuring accuracy of 3 + L/100 µm (L in mm) (see Figure 12). The Mitutoyo Quick Image (see Figure 13) is comparably easy to use thanks to the same feature. It provides 2D measurements using a 1.4 megapixel CCD camera. The Mitutoyo has a double telecentric objective with a high depth of field as an extra advantage.

Aart de Raad established MuRaad, a firm that specialises in geometric measuring techniques. He showed the Schneider WMM 300 shaft measuring machine for pieces of up to 300 mm in length (see Figure 14). Schneider also supplies WMM machines for 600 and 1000 measuring ranges, designed for measuring lengths, diameters, radii and angles of long rotationally symmetric work pieces in one working cycle. Using a CCD camera, the machine works rapidly and precisely with an accuracy of 2 + L/200 µm (L in mm).

Peter Schmidt of T&S Gesellschaft für Längenprüftechnik showed the ConturoMatic, a machine that measures both

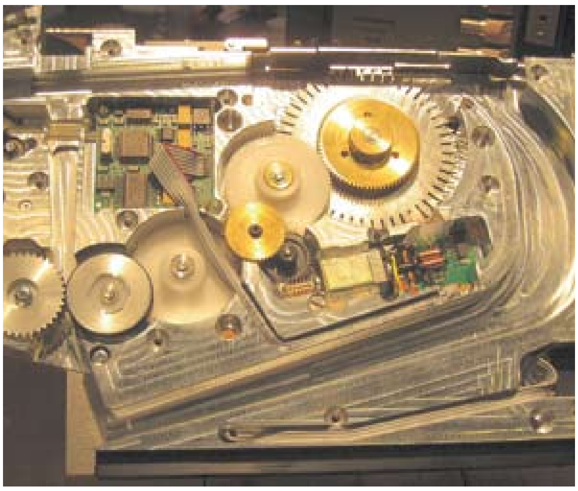


Figure 11. An SMD-parts feeder assembly formerly produced in China, now by Wilting Components.

Figure 12. A MarVision MM 320 measuring machine, part of the VIBA product range.

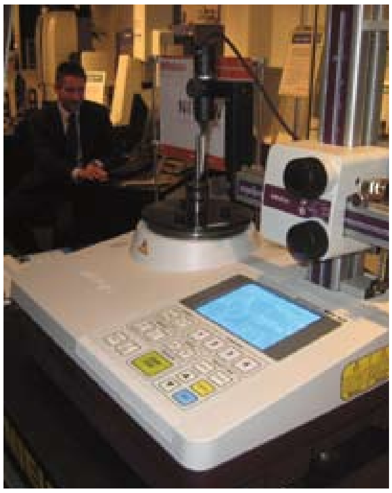


Figure 13. A Mitutoyo Quick Image measuring machine for easy 2D measurements.

Figure 14. A Schneider WMM 300 shaft measuring machine, shown by MuRaad.

Figure 15. Marcus Fabich explained the many features of the Olympus LEXT confocal laser scanning microscope.

surface roughness and form with an accuracy of 1.5 + L/100 µm (L in mm). Its speciality is that it is provided with a high vertical measuring range, with the advantage that the vertical distance of two profiles is easy to determine. A ConturoMatic T3 with air bearings will be available in a few months, with an accuracy of 1 + L/100 µm (L in mm) within a 320 to 300 mm measuring range.

Miscellaneous items

Olympus exhibited its LEXT, a confocal laser scanning microscope (see Figure 15). It provides two different images, a normal light-microscopic image and an image resulting from scanning the specimen surface with a fine laser spot. It can function as a roughness tester, an image microscope, a 3D measuring instrument and as an alternative for a scanning electron microscope at low magnification. For this last application, it has the extra advantage that no specimen preparation is needed. The resolution in vertical direction is no less than 10 nm, and 120 nm in horizontal directions.

At the Heidenhain stand, an interesting set-up showed the influence temperature has on measuring scales made from three different materials. All three scales have a resolution of 0.1 µm (see Figure 16). This makes it clear that selecting the right scale material is crucial. In general, it can be concluded that choosing a zero coefficient of thermal expansion only makes sense in climatised rooms.

Hans Ott of IBS showed a frictionless gravity compensator (see Figure 17) to be integrated into IBS' new measuring machine ISARA 400 with a measuring range of 400 to 400 to 100 mm. The compensator is provided with air bearings and a linear motor to deliver the vertical force required to equilibrate gravity.
The large number of Vision Engineering stereo microscopes on display at the Sondag Optische Instrumenten stand presented a beautiful picture (see Figure 18).

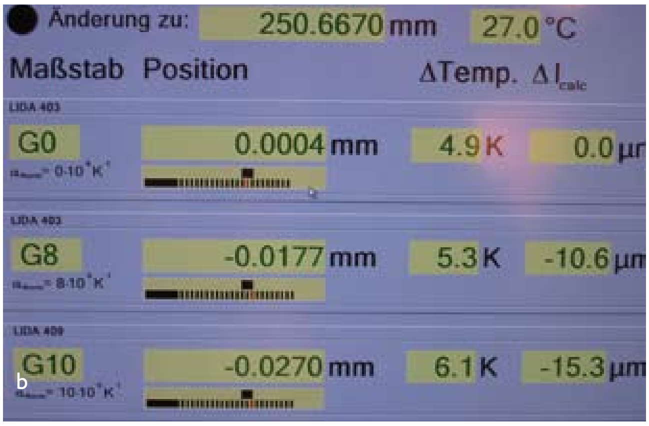


Figure 16. The influence of temperature on Heidenhain measuring scales from zerodur (α = 0), glass (α = 8.10^{-6}) and metal (α = 10.10^{-6}).
(a) Set-up.
(b) Detail, calculated Δl on the right.

Figure 18. Vision Engineering stereo microscopes represented by Sondag Optische Instrumenten.

Figure 17. An IBS frictionless gravity compensator for the vertical axes of the new ISARA 400.

NTS Mechatronics is part of the NTS Group with a range of companies interfacing precision technology. Emile Asselbergs and Hugo Timmers proudly showed examples of NTS skills, i.e. vacuum assemblies and loading systems for electron microscopes. NTS Mechatronics also manufactures the new FEI Phenom, an interesting mixture of light microscopy and scanning electron microscopy (see Figure 19).

Conclusion

As mentioned before, this selection of Precision Fair 2008 items is coloured by personal preferences, so chances are that some visitors and exhibitors will miss references to their particular interests and contributions. Laser machining, for instance, does not feature in this article, an omission that will probably be corrected in a next Precision Fair review. All in all, judging by the nearly 3K visitors, a visit to this Precision Fair was more than worthwhile – and it is certainly an indispensable event for the Dutch precision industry.

Author's note

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

Figure 19. The FEI Phenom, combining a light microscope and a SEM.

Busiest Precision Fair to date

The eighth edition of the Precision Fair, held on 26 and 27 November 2008 in the NH Conference Centre Koningshof in Veldhoven, the Netherlands, was the busiest to date, organiser Mikrocentrum reports. No less than 2,850 visitors were counted in two days, which is 20% more than in 2007.

With 215 exhibitors, the fair was fully booked up. Forty lectures attracted a total of 1,150 attendants. The next Precision Fair will be held on Wednesday, 2 and Thursday, 3 December 2009, again in Veldhoven. www.precisiebeurs.nl

An impression of the Precision Fair 2008. (Photo: Mikrocentrum/Sylvia van der Nol)

Colourmap™ the absolute XYA scale

Colourmap™ dot scale technology is a patented, absolute XY and angle scale system. A matrix of coloured dots is used to encode both X and Y positions. At any position on the scale the pattern of coloured dots will be unique, allowing X and Y positions and the angle of the sensor to be calculated. Because the angle of the sensor is also measured, there is no need to constrain the moving element orthogonally. This means that the system could potentially revolutionise current thinking with regard to applications that require two-dimensional measurements.

• *Gavin Bailey* •

The idea for a two-dimensional scale came directly as a result of work designing three-dimensional co-ordinate measuring machines (CMMs), which are the core product of Aberlink's business. On CMMs each axis will contain its own independent linear scale, and then to achieve accuracy each axis must be controlled so that its motion is perpendicular to each of the other axes.

The Colourmap scale system provides a method for measuring both X and Y position and angle. This not only eliminates the requirement for two sets of linear scales, but also overcomes the need for the axes to run orthogonally to each other. The sensor can be a simple CCD/CMOS Camera. This moves over and reads a pattern of coloured dots. For each position throughout the range of the scale, the pattern of coloured dots will be unique, from this information, the scale can determine not only the X and Y position of the sensor, but also determine the angular position of the sensor relative to the dots on the scale; see Figure 1.

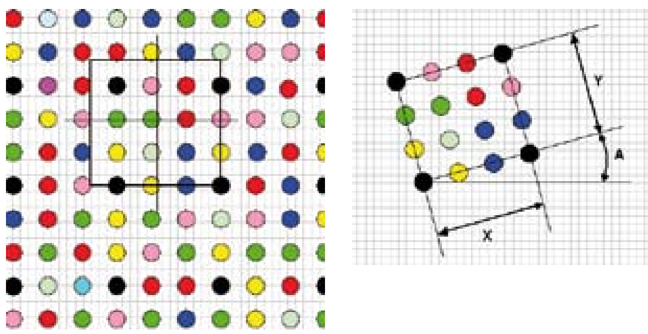


Figure 1. The principle of the Colourmap scale system is that of a sensor looking at a pattern of coloured dots that is unique at each position throughout the scale. This allows the determination of not only the X and Y position, but also the angular position of the sensor relative to the dots on the scale.

Figure 2. Project X is the vision machine that is the first application for the Colourmap scale system.

An important feature of the Colourmap scale system is that it provides an absolute XYA scale. Regardless of whether the scale misses a reading, which may be due to incomplete/damaged scale, excessive speed of movement, power failure or any other reason, as soon as the sensor receives a valid reading from the scale, it will know its X, Y and A position. This means that no reference marks are required.
Coloured dots were chosen as the scale indicators because it is simple for a CCD/CMOS camera to differentiate between colours, although equally any other type of identifiable object or shape could be used to provide the same results.

Applications

Because Aberlink is a metrology company, the first idea for an application of the Colourmap scale system was as the scale within a measuring machine. This lent itself ideally to a vision machine, where the sensor for the measuring instrument was also a camera, and therefore the measurements performed are two-dimensional. The 'Project X' vision machine, which incorporates the Colourmap scale system, is described in detail below. However, the exciting fact about the scale system is that it is completely scaleable. Using standard interpolation techniques the centre position of each dot can be determined to a small fraction of the camera pixel size. Typically the distance between dots can be resolved to around one thousandth of their pitch. Hence the scale system could equally be used on a high precision stage with microscope optics to give a resolution of nanometres, or on an Automatic Guided Vehicle (AGV) with low-cost optics to give a resolution of millimetres.

Because the Colourmap scale is absolute, should such an AGV lose its position temporarily, there would be no need for it to be returned to its docking station in order to regain its position. Moreover, because the angle is calculated, the vehicle heading is always known even when stationary.

The 'Project X' vision machine

Project X is a revolutionary 2D vision measuring machine, and was the first application that used the Colourmap scale system; see Figure 2. Because it was important not to disclose the technology to any third party until the worldwide patent for the scale system had been filed, during its development the machine was referred to as 'Project X'. Then, when a name for the released product was eventually required, this sobriquet was retained.

Within the measuring machine a 'C' shaped bracket is used to float over the Colourmap scale system on an air bearing system. The scale camera is mounted directly below the measurement camera, as in the arrangement shown in Figure 3.

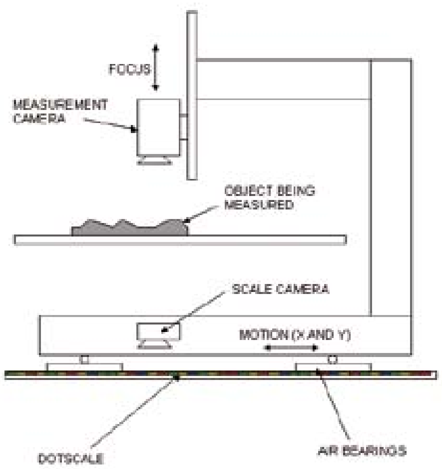
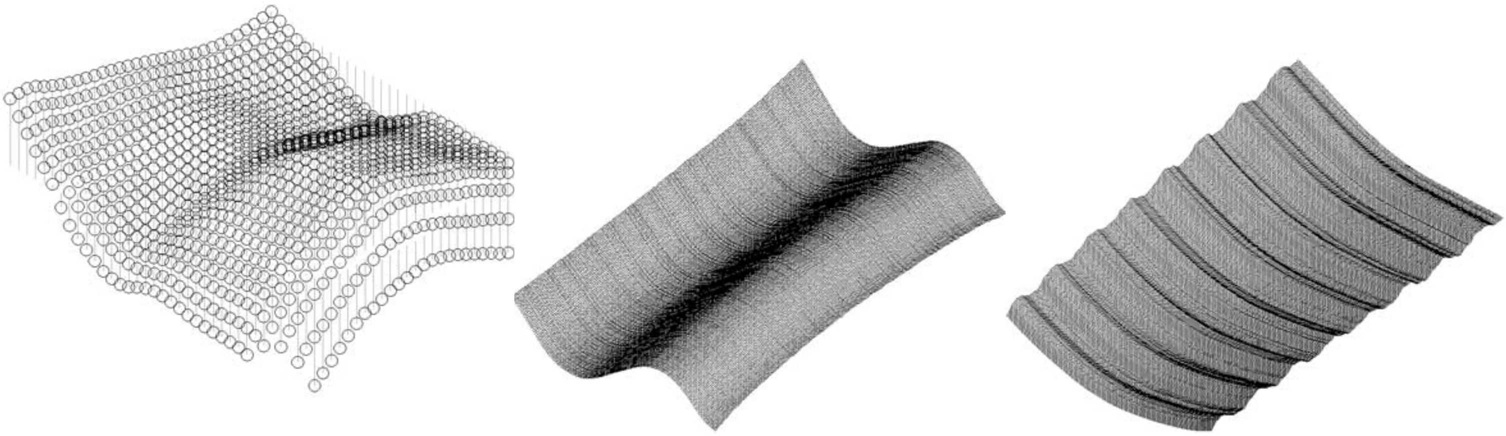


Figure 3. The Project X 2D vision measuring machine as it is equipped with the Colourmap scale system.



(a) Flatness of glass plate. (b) Error of dots in X direction. (c) Error of dots in Y direction.

Figure 4. Calibration of a Colourmap scale.

The scale, which covers an area of 400 x 300 mm, is printed simply using a high quality laser printer onto photographic paper. The dots have a nominal diameter of 0.25 mm on a pitch of 0.5 mm. The photographic paper is then bonded in clear epoxy between two sheets of float glass. The glass then acts as a perfectly smooth, flat and clear surface for the assembly to float over using an air bearing system, allowing the scale camera to read the pattern of coloured dots.

By looking at just nine dots and using seven different colours, over forty million different permutations are possible. By looking at more dots, redundancy is built into the system, ensuring that it is robust against any difficulty in identifying individual dots due to damage or colour fade, etc.

Project X makes use of the Colourmap scale system not only to get absolute X and Y position, but also because the scale measures the angular position of the encoder. This means that the mechanical assembly described above does not have to be constrained along each axis. If the assembly rotates, then the scale reports the angle. Therefore the 'C' shaped frame is simply guided around the scale by a set of pulleys and cables, without the requirement for expensive guideways.

Because the Project X has an accuracy requirement greater than the repeatability of the printing of the dot pattern, each scale must be individually measured in order to produce an error map of the dot positions, which can then be easily applied to any measurements reported by the scale. This is performed on a special-purpose measuring machine, which is able to obtain the results shown in Figure 4.

The measurement camera on Project X is then used to view the component to be measured, and its image analysed to produce dimensions. The scale system is required when the measurement camera has to be moved because the component is larger than the field of view of the camera.

The software written for Project X is a comprehensive vision package that offers a full range of automatic edge detection. The measurement camera is mounted on a motorised Z-axis that offers 125 mm of motion to provide autofocussing on a wide range of different sized components. Also Project X can be supplied with the X and Y motion either under manual or full CNC control.

Future potential

So far the Colourmap scale system has only been used in a metrology application. However, the potential to revolutionise two-dimensional measurement is even more exciting than the innovative and inexpensive measuring machine described above. It is a technology looking to find new applications in other industries away from metrology. Precision stages and AGVs have already been mentioned, but pick & place machines in the electronics industry also require exactly the same feedback.

Author's note

Gavin Bailey is Sales Director and co-founder of Aberlink, the largest UK-owned manufacturer of co-ordinate measuring machines, based in Eastcombe, Gloucestershire, UK. The Colourmap™ scale system is the invention of Marcus Eales, Technical Director and co-founder of Aberlink. Eales formerly worked at Renishaw, the UK-based, high-tech metrology company.

Information

www.aberlink.co.uk

Piezomotors:

A novel type of piezoelectric motor has been developed at the Department of Mechanical Engineering of the Katholieke Universiteit Leuven, Belgium. This 'Leuven motor' can operate in several drive modes by virtue of an innovative symmetrical design. Case studies show that the Leuven motor can be used as a core component of a new generation of stiff, compact and non-magnetic positioning systems with a high positioning resolution, wide speed range and a large stroke, capable of operating in demanding environments, e.g. cryogenic and (ultra-high) vacuum.

• *Wim Van de Vijver, Michaël Houben, Hendrik Van Brussel and Dominiek Reynaerts* •

Product design and production technology in general show a strong trend towards miniaturization. Sophisticated positioning devices that realize a controlled motion on a sub-micron level and beyond act as an enabling technology to realize this evolution. Examples of these devices are found in high quality consumer goods (e.g. data storage devices and auto-focus mechanisms for cameras), production machines (e.g. wafer steppers and fast-tool servos), inspection machines (e.g. high-resolution optical microscopes, electron microscopes and surface-profiling tools) and medical instruments (e.g. robotic surgery and tomography).

To understand the evolution of the requirements for positioning devices, the semi-conductor sector can be seen as the leading industry. The technical evolution in this industry is well illustrated by the steady reduction of the line thickness in central processing units. Figure 1 shows an exponential decrease, as predicted by the famous Law of Moore [1]. According to this law, the number of transistors that can be placed at a reasonable price on an integrated circuit increases exponentially in time.

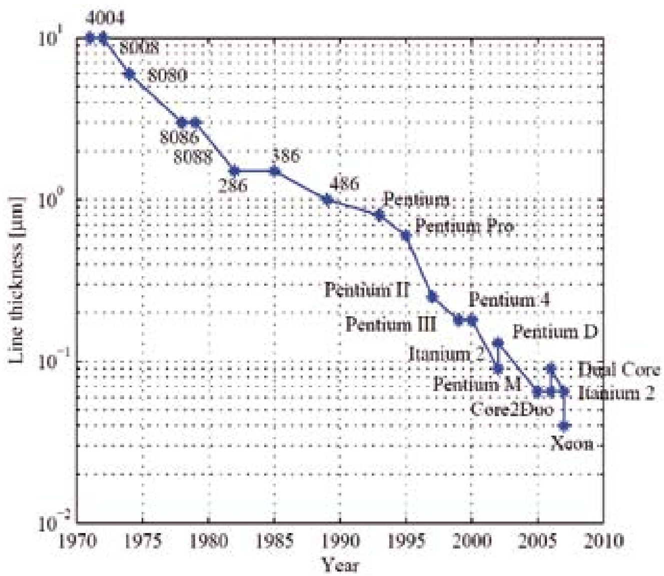


Figure 1. Evolution of the circuit line thickness of Intel processors (data collected from www.intel.com).

an enabling technology

The decrease in line thickness is realized by the evolution of lithography machines. These machines pattern tiny circuits on silicon substrates by exposure to light. Since the construction of lithography machines involves highly accurate lenses, positioning frames, etc., the evolution in line thickness leads to more stringent requirements for precision production machines. Consequently, the evolution of ultra-precise production machines (e.g. diamond turning, micro EDM, micro milling, ELID grinding) follows the pace of the evolution of lithography machines. Taniguchi [2] showed this trend towards higher machining accuracy in his famous graph, depicted by solid curves in Figure 2. However, these curves do not include an economic constraint, while Moore states that the increase in number of transistors is realized *at a reasonable cost*. This cost constraint can be added by a time constraint: the machining time does not increase with increasing precision. This criterion sets two extra requirements for ultra-precise positioning systems: (i) the positioning speed must remain constant, and (ii) the bandwidth must increase [3]. These requirements can be incorporated into an 'extended Taniguchi graph', as shown by the dashed curves in Figure 2.

Figure 2 thus allows extracting specifications for novel ultra-high precision machines: a total machine accuracy of at least 1 nm, and a total stiffness of over 40 N/μm. Moreover, a large travel is needed (over 100 mm) and, to keep machining time down, a high velocity mode with a speed higher than 100 mm/s is required.

Piezoceramic actuators are appropriate candidates to fulfill these specifications [4]. They show a quasi unlimited resolution, possess a high force density and have a short response time. Especially in nanotechnology, piezoceramic actuators offer two key properties that distinguish them from other driving technologies: inherent vacuum compatibility and absence of electromagnetic interference. For this reason, piezoceramic actuators are chosen as actuators for a novel linear piezoelectric motor that has to meet the above mentioned specifications. This motor is called the 'Leuven motor'. The Leuven motor can be used as a core component for a new generation of positioning systems. This article describes the design and the performance of the motor, as well as its implementation into two positioning systems.

Mechanical design

Figure 3 shows a schematic drawing and a photograph of the Leuven motor. It consists of a metal structure, called stator, which is preloaded against a slider at a contact point. The piezoceramic actuators (P1-P4) are mounted inside the stator in such a way that they directly contribute to the stiffness of the Leuven motor. Elastic hinges connect the piezoceramic actuators to the fixed frame and the contact point. A tuning block is connected to the stator via leaf

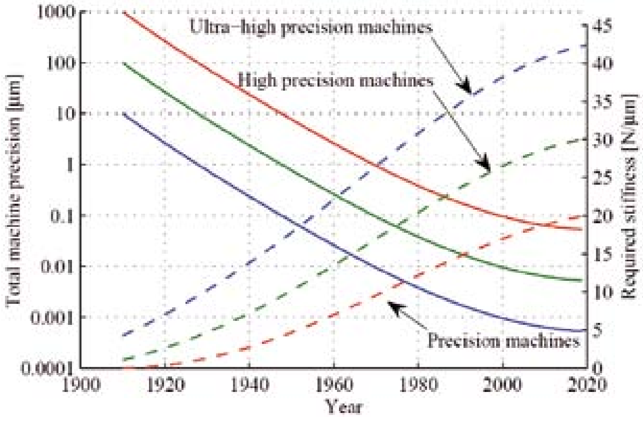


Figure 2. Taniguchi curves (solid lines) and extended Taniguchi curves (dashed lines) to describe trends for required machine accuracy and stiffness.

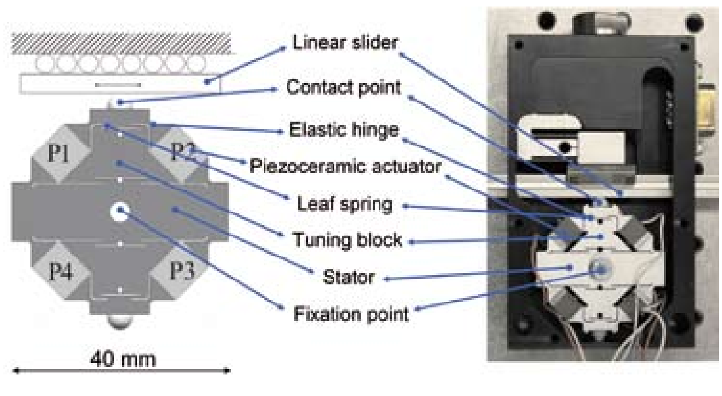


Figure 3. Schematic drawing and photograph of the linear piezoelectric Leuven motor.

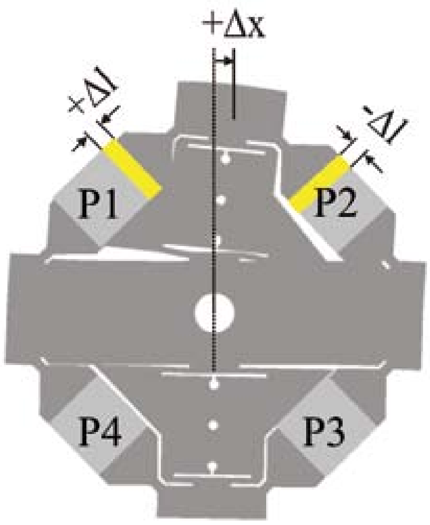


Figure 4. Working principle of the Leuven motor in the direct-drive mode. In this mode, the motor basically imitates piezostack performance.

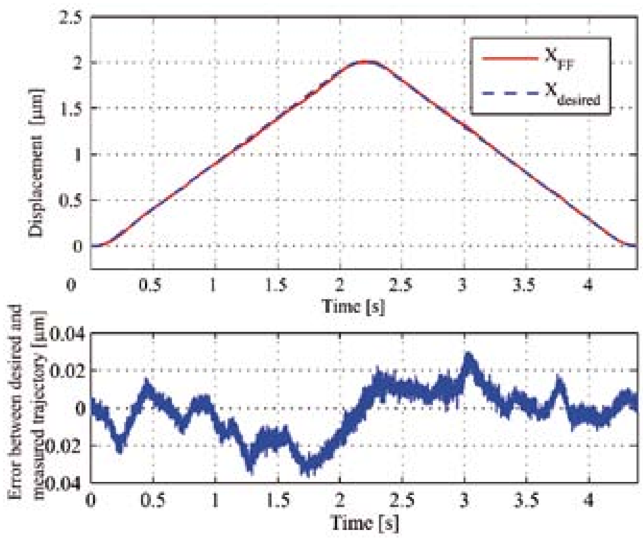


Figure 5. Comparison between measured, open-loop slider displacement and desired displacement for tracking a 1 μm/s trajectory with the direct-drive mode (top). The bottom plot shows the error between desired and measured trajectory.

springs. A bolt connects the stator to a fixed frame at the central point of symmetry.

By applying voltages to the piezoceramic actuators, the drive point shifts and moves the slider by friction. The Leuven motor offers three distinctive operational modes which enable it to drive the slider in a wide speed and accuracy range. The nature of the applied voltages determines which operational mode is active. Principle and performance of each mode is described next.

Performance

Direct-drive mode
The direct-drive mode inherits the advantages of a piezoelectric ceramic: it aims for high positioning resolution and high stiffness. Figure 4 illustrates the working principle. A positive voltage is applied to piezoceramic actuator 1 (P1) and a negative voltage is applied to piezoceramic actuator 2 (P2). The respective piezoceramic actuators are thereby elongated or contracted over a distance Δ*l*. The contact point moves to the right over a distance Δ*x*. If the slider is preloaded to the Leuven motor and the Leuven motor is rigidly attached to a fixed reference, the slider will also move with a distance Δ*x*, supposing no slip. The maximum stroke is limited to a few μm, since it directly relates to the stroke of the piezoceramic actuators.

- Open-loop results
  As is shown by Figure 5, accurate open-loop control can be achieved by identifying a feed-forward system model, and compensating the hysteresis of the piezoceramic actuators. A continuous triangular trajectory with a speed of 1 μm/s is applied. The maximum error is ± 30 nm.

- Closed-loop results
  Closed-loop position control offers both an improved tracking behavior and stability of this tracking behavior in time compared to open-loop control. Figure 6 illustrates the control architecture.
  Figure 7 shows an example of the tracking behavior for a speed of 2 μm/s. The tracking error now remains within the sensor noise, which is a band of about 10 nm.

Resonant-drive mode
For applications requiring a large stroke and high velocity, the resonant operation mode can be used. This principle is based on the generation of an ultrasonic and thus silent elliptical motion of the contact point to drive a slider through a friction interface. This oscillation of the contact point results in a net macroscopic motion of the slider if

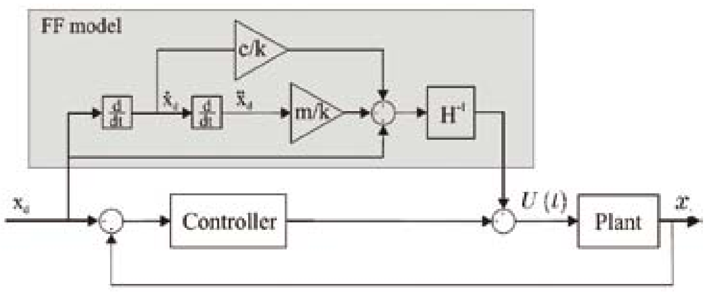


Figure 6. Schematic diagram of the controller for the direct-drive mode.

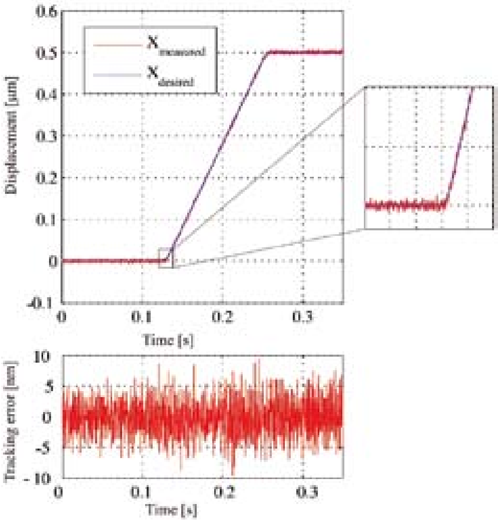


Figure 7. Example of trajectory tracking in closed loop using the direct-drive mode. The bottom plot shows the tracking error in nanometre scale.

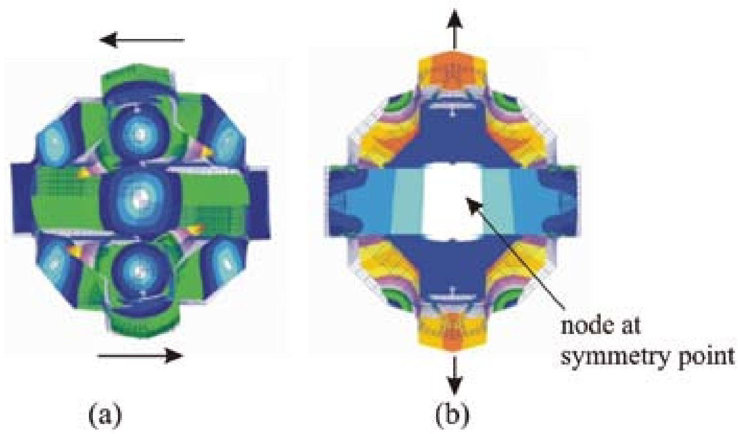


Figure 8. Finite-element calculation of the horizontal (a) and vertical (b) eigenmode of the Leuven motor. Notice the oscillation of the tuning blocks in (a), while hardly any oscillation is noticed in (b).

(i) the drive frequency is high enough, and (ii) a net friction force is present in the positive or negative direction.

To optimize the drive speed and traction force of the slider, respectively, the horizontal and vertical oscillation amplitudes of the elliptical motion of the contact point should be maximized. This is achieved by operating the stator in resonance. Figure 8 shows the results of a finite-element calculation of the horizontal and the vertical eigenmodes of the Leuven motor. Optimal efficiency is achieved when these two eigenmodes coincide. This can be done by altering the tuning mass shown in Figure 3 to compensate for modeling, production and assembly errors. Figure 9 shows how both eigenmodes shift in response to changing this mass.

The importance of tuning is illustrated by open-loop force-speed measurements in Figure 10. A maximum driving speed of over 300 mm/s and a stall force of 12 N are achieved. Careful adaptation of the tuning mass doubles both the maximum driving speed and the stall force in comparison with the same motor right after the production and assembly process.

Figure 11 finally shows the results of a closed-loop position-tracking experiment. To minimize non-linear behavior, a dedicated control strategy is designed. This strategy dramatically decreases the required complexity of the controller. A triangular trajectory with a maximum slider speed of 1 μm/s is applied. The position is measured with a laser interferometer with a resolution of 80 nm. The zoom on the right shows that the reference trajectory is followed within the resolution of the interferometer. A lead-lag controller was used.

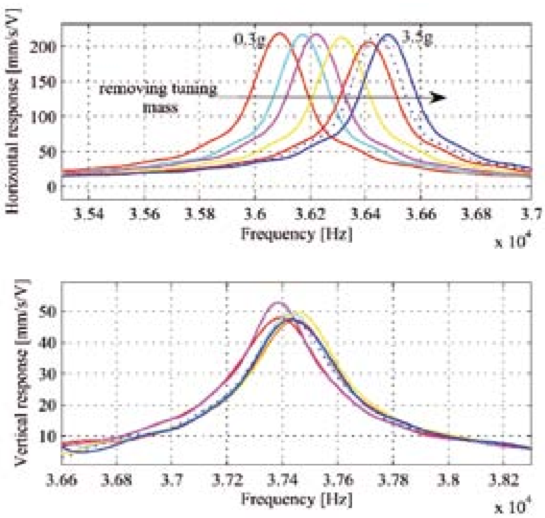


Figure 9. Variation of the horizontal (above) and vertical (below) eigenmode when changing the tuning mass.

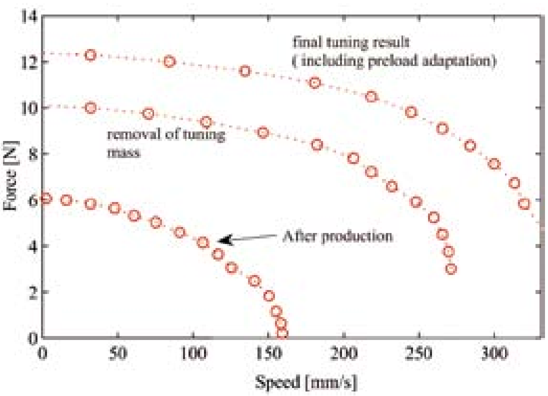


Figure 10. Influence of tuning on the traction-speed characteristic of the Leuven motor.

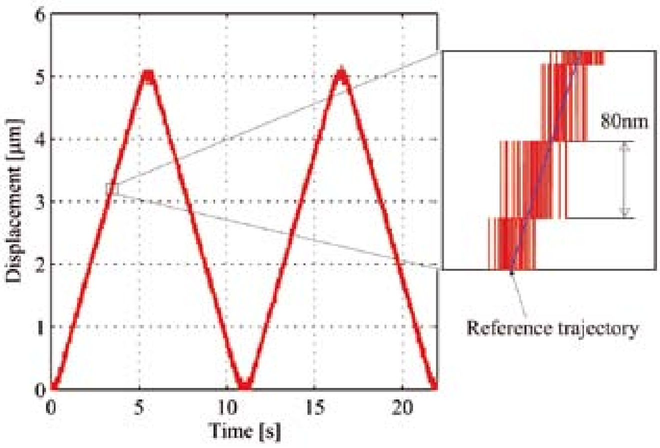


Figure 11. Tracking performance in the resonant-drive mode for a speed of 1 µm/s when a lead-lag controller is implemented.

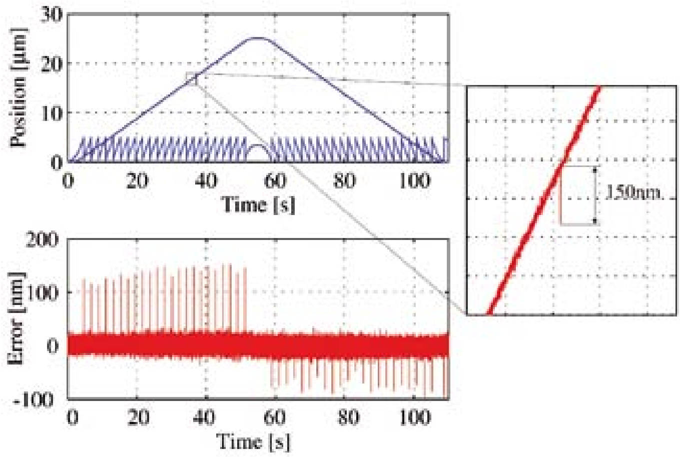


Figure 13. Experimental example of trajectory tracking with the pulse-drive mode.

Pulse-drive mode
The maximum travel for the direct-drive mode equals about 5 µm. Many industrial applications require a much larger displacement, ranging from a few mm to several hundreds of mm. This large displacement range can be obtained by the application of the resonant-drive mode. However, the maximum resolution obtained in this drive mode is limited to 40 nm p-p. Therefore, an alternative operation mode, denominated as pulse-drive mode, is explored. This driving method sometimes is referred to as inertial drive mode [5] or stick-slip drive mode [6].

Figure 12 illustrates the working principle of the pulse-drive mode. A sketch of the driving cycle is given on the right,

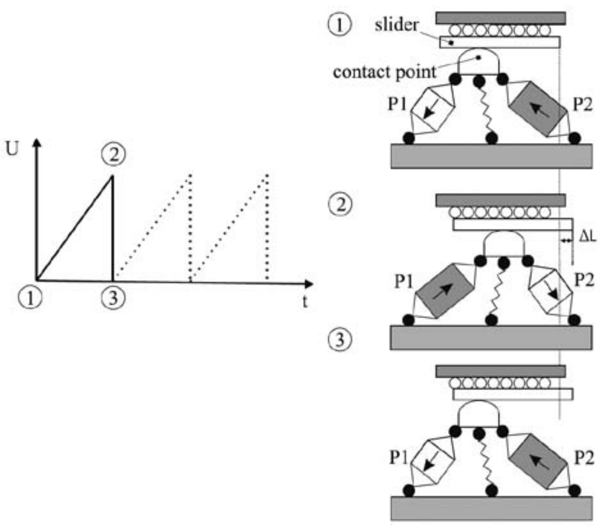


Figure 12. Working principle of the pulse-drive mode.

while the applied voltage to one of the piezoceramic actuators is shown on the left. The voltage *U* represents the voltage applied to the piezoceramic actuators P1 and P2. As the driving saw-tooth signal *U* goes up slowly, the slider sticks to the contact point and moves to the right over a distance Δ*L*. When the driving signal U suddenly drops, the contact point retracts and slips to its original position. At the end of this cycle the slider has made one step Δ*L*. By repeating this, large strokes are obtained.

Figure 13 shows an experiment where the motor is used for tracking a function with a stroke of 25 µm at a speed of 0.5 µm/s. The saw-tooth signal generated at the input of the piezoceramic actuators is also shown. The control architecture is similar to the one in Figure 6. The zoom window at the right of the figure indicates good tracking behavior except for the short spikes generated during the retraction period. These spikes can be as large as 150 nm. The plot at the bottom of Figure 13 gives an overview of the error behavior over the full positioning cycle. The error is limited to the measurement resolution, with exception for the spikes.

Note that the application domain of the pulse mode is limited to relatively low force applications. Indeed, for a high traction force a large preload is needed. This leads to relatively high fluctuations of the slider trajectory, compromising high-precision applications. Moreover, the maximum drive speed is limited to about 1 mm/s.

Case studies

Linear positioning system with a stepping mode
Extending the stroke of the Leuven motor in the direct-drive mode always requires a retraction of the contact point. In

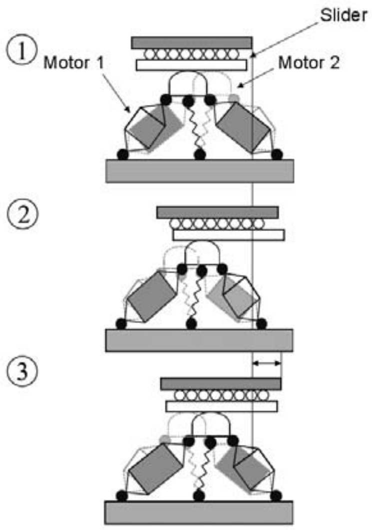


Figure 14. Working principle of the stepping drive. Leuven motor 1 is represented in solid black, Leuven motor 2 in dashed grey.

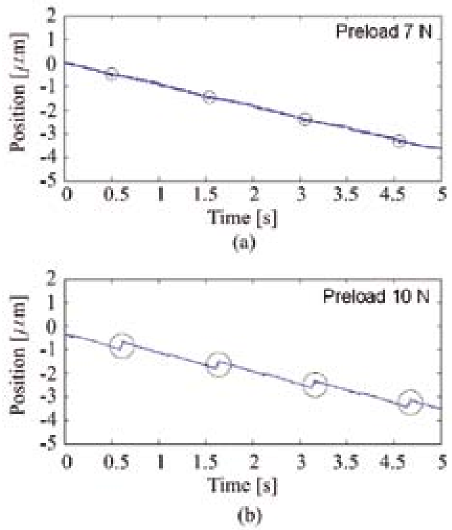


Figure 15. Experimentally measured motion of the slider in the stepping mode.
(a) Preload force = 7 N.
(b) Preload force = 10 N.

the pulse-drive mode, the philosophy is to retract as fast as possible to prevent a distortion on the slider. As discussed above, this retraction causes position spikes. Stepping drives on the other hand are characterized by a form-closed contact strategy. Instead of retracting as fast as possible, the strategy is to retract slow enough to allow corrective actions by the controller. Because slider inertia is not used to prevent retraction of the slider during the retraction period, at least two motors are needed to realize the stepping behavior. One motor is generating the displacement, while the other motor breaks contact with the slider and returns to its original position. Repeating this cycle results in a continuous motion of the stepper. Figure 14 shows the conceptual layout of this drive mode.

Figure 15 shows some first experimentally obtained open-loop results [7]. Figure 15a shows a result for a preload force of 7 N. When the contact switches from one motor to the other, position spikes of 50 nm are observed. For a preload force of 10 N (Figure 15b), these disturbances are already considerably larger. A new suspension design is expected to solve this issue.

Compact and stiff planar positioning system

One of the basic principles in machine design in general and precision engineering in particular is the principle of functional decomposition [8]. According to this principle, each degree of freedom has to be imposed by exactly one machine element. In a classical precision machine, each kinematic constraint is fixed by bearings or imposed by a linear or rotational drive. In order to achieve a multi-DOF positioning system, the bearings and drives often are cascaded. The schematic layout of such a cascaded system is given in Figure 16a. The advantage of this layout is that machine elements can be standardized and the integration of machine elements is facilitated. However, Van Brussel et al. [9] summarized that stacking 1-DOF systems to obtain a multi-DOF system results in a lowered bandwidth and an accumulation of errors. Moreover, stacking leads to a non-symmetric design. In Reynaerts et al. [10], the idea is postulated to combine all motion degrees of freedom into one parallel drive system. This approach is schematically illustrated in Figure 16b. An example of such a system is the Stewart platform. By parallel integration of the various degrees of freedom, the stiffness of the separate actuators adds up.

Figure 17 shows the integration of three Leuven motors into a stiff frame (the rotor), realizing a planar positioning system with parallel kinematics. The Leuven motors both carry

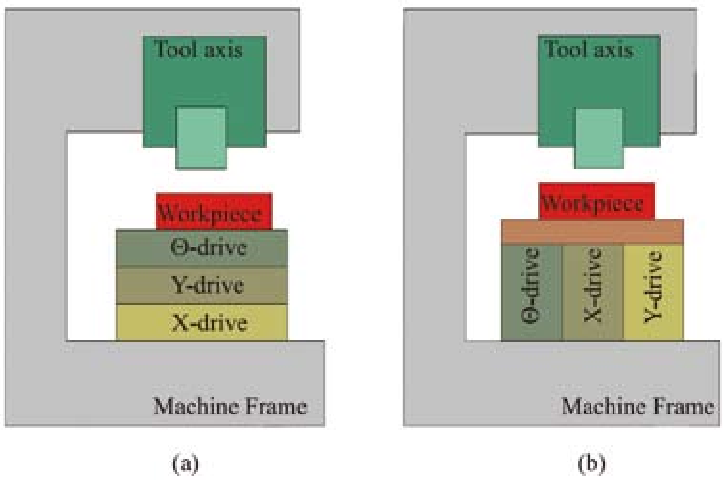


Figure 16. Schematic layout of (a) a classic positioning system, and (b) a parallel system with integrated drive-bearing function.

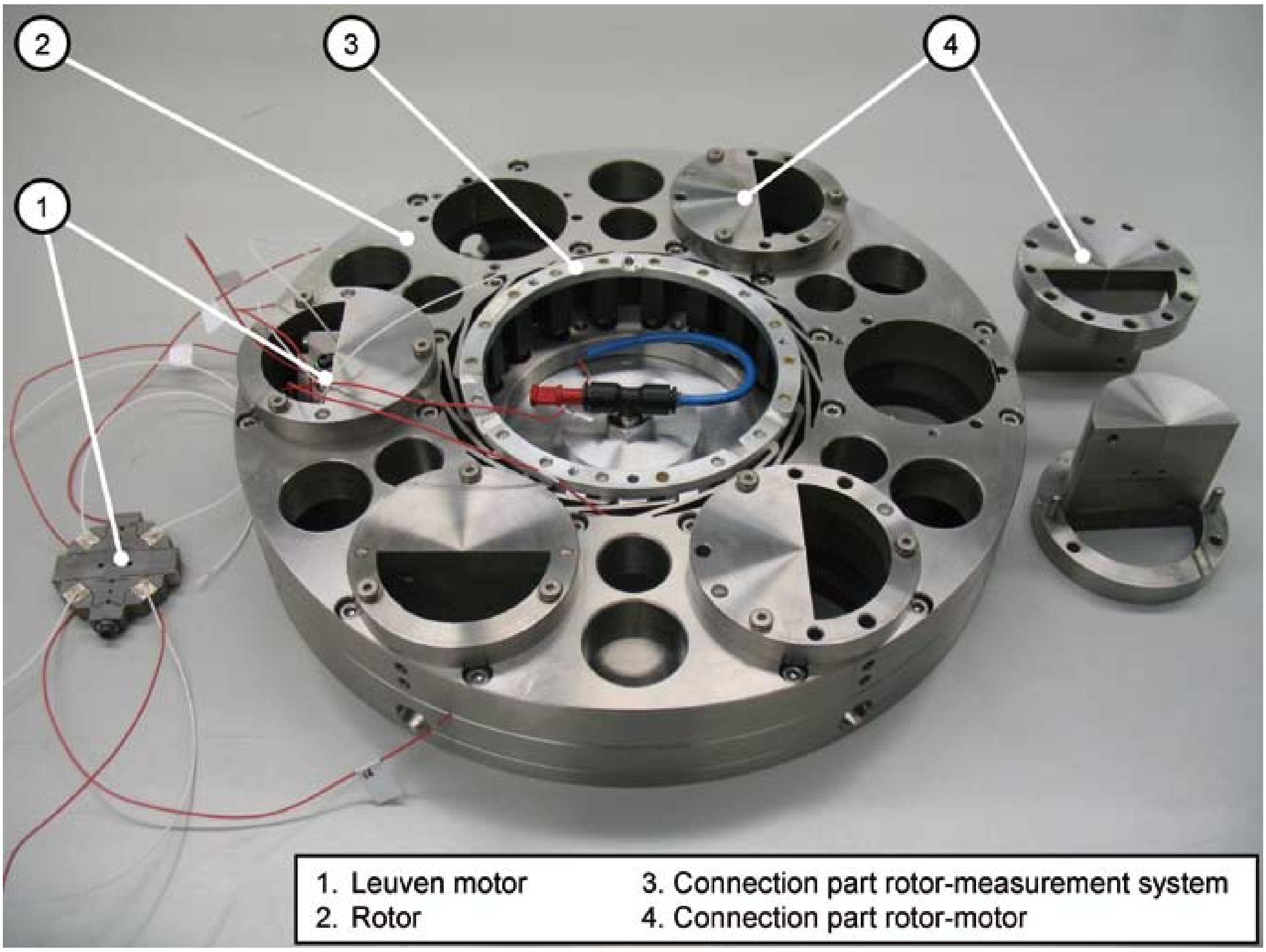


Figure 17. Integration of three Leuven motors into a planar positioning system with parallel kinematics and combined bearing and driving functionality.

and drive the frame, and additionally offer active bearing functionality. A grid encoder is used to measure the position of the frame. Nearly-similar dynamics of the three motors are essential to devise a robust system.

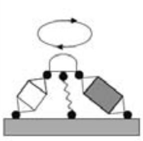
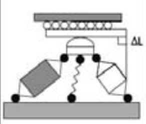
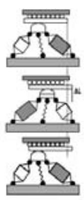
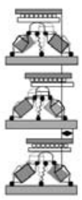
Working principle	Resonant operation mode	Direct drive mode	Pulse drive mode	Stepping mode
				
Stroke	>100mm	5µm	>100mm	>100mm
Speed	300mm/s	50mm/s	1mm/s	1mm/s
Force	12N	>10N	~5N	>10N
Resolution	40nm	10nm	10nm	10nm

Figure 18. Overview of the different operating modes and achieved performance figures of the Leuven motor.

Conclusion

Governed by Moore's Law and pushed by the miniaturization trend, several industrial sectors currently evolve from the micrometre era into the (sub-)nanometre era. In light of this evolution, a novel type of piezoelectric motor has been developed. As elaborated here, this piezoelectric motor – called the Leuven motor – can operate in several drive modes by virtue of an innovative symmetrical design. The direct-drive mode allows imitating the properties of a piezoceramic actuator: high stiffness and (sub-)nanometre resolution within a micrometre stroke. To extend this stroke without compromising positioning resolution, a pulse-mode and a stepping-mode control strategy have been verified. The maximum achievable speed of these modes is about 1 mm/s. Finally, to achieve higher speeds in the order of 100 mm/s, the resonant-drive mode can be used. While being coarser than the direct-drive mode, experiments show that it is still possible to track a reference signal with a maximum error of 40 nm peak-to-peak. Figure 18 summarizes the Leuven motor's characteristics.

As shown in the case studies, the Leuven motor can be used as a core component of a new generation of stiff, compact and non-magnetic positioning systems with a high positioning resolution, wide speed range and a large stroke, capable of operating in demanding environments, e.g. cryogenic and (ultra-high) vacuum. Current research focuses on the tribologic issues related to the friction-drive mechanism [11], and devising control strategies that combine the advantages of the distinctive operating modes.

Acknowledgement
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Authors' note
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Michaël Houben received his mechanical engineering degree from K.U.Leuven in 2006. He is currently making a Ph.D. on contact mechanics and modelling of ultrasonic piezomotors under the supervision of prof. Dominiek Reynaerts and prof. Farid Al-Bender.
Hendrik Van Brussel is full professor in mechatronics and automation at the Faculty of Engineering, K.U.Leuven. He was a pioneer in robotics research in Europe and an active promoter of the mechatronics idea as a new paradigm in machine design. He is president of euspen (European Society for Precision Engineering and Nanotechnology).
Dominiek Reynaerts received his mechanical engineering degree from K.U.Leuven in 1986. He obtained his Ph.D. in mechanical engineering, from the same university, in 1995. He now is full professor and chairman of the Department of Mechanical Engineering of K.U.Leuven.

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Information

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Desktop micro-machining

The University of Manchester has chosen an Aerotech positioning system for desktop micro-machining. Direct-drive linear motor driven positioning stages, ultra-low noise linear amplifiers and software-only G-code motion control system provide a benchmark in high-precision positioning for a major EU-funded research project, so Aerotech claims.

As part of a major research project into high-precision micro- and nano-scale manufacturing and machine design, the Manufacturing and Laser Processing Research Group at The University of Manchester is using an Aerotech-supplied three-axis (XYZ) linear motor driven positioning system that provides a positioning resolution of 0.5 nanometres and a calibrated positioning accuracy to ± 0.3 microns per axis over its 50 mm x 50 mm x 50 mm travel range.

The state-of-the-art system (see Figure 1), currently undergoing extensive testing, includes three ALS130H direct-drive linear stages with Ndrive CL series linear technology servo amplifiers and the PC-based, software-only A3200 motion controller. It will be used as a benchmark positioning system within a new generation of micro-machines to help establish micro-machining accuracy capabilities and develop new design concepts for next-generation ultra-high precision manufacturing.

Smaller-sized machines

The EU grant (I*PROMS, Innovative Production Machines and Systems) funded project includes investigating and optimising the design of 'desktop' micro-machines. Such machines are used to produce small components that require sub-micron to nanometre level linear accuracy and micro-radian level angular accuracy. This could also cover meso-manufacturing for parts having features with a few micrometres. The machine employs currently a milling process but could be extended to include various processes such as electro-discharge machining (EDM) and electro-chemical machining (ECM). Although there are several defined advantages for smaller-sized machines for these applications, including space and energy savings, larger natural frequencies for much reduced vibration and lower mass for higher throughput capability, the current offering of commercially available desktop machines generally does not match the accuracy and finished component quality of larger conventional machine tools that are adapted for micro-scale production.

Micro forces

To address this fundamental issue, the work extends to developing a greater understanding of the micro forces and other micro phenomena that influence precision at these miniscule levels where the laws of macro-scale physics no longer apply. For instance, surface forces are considered negligible at the macro scale but are extremely influential at the micro scale.

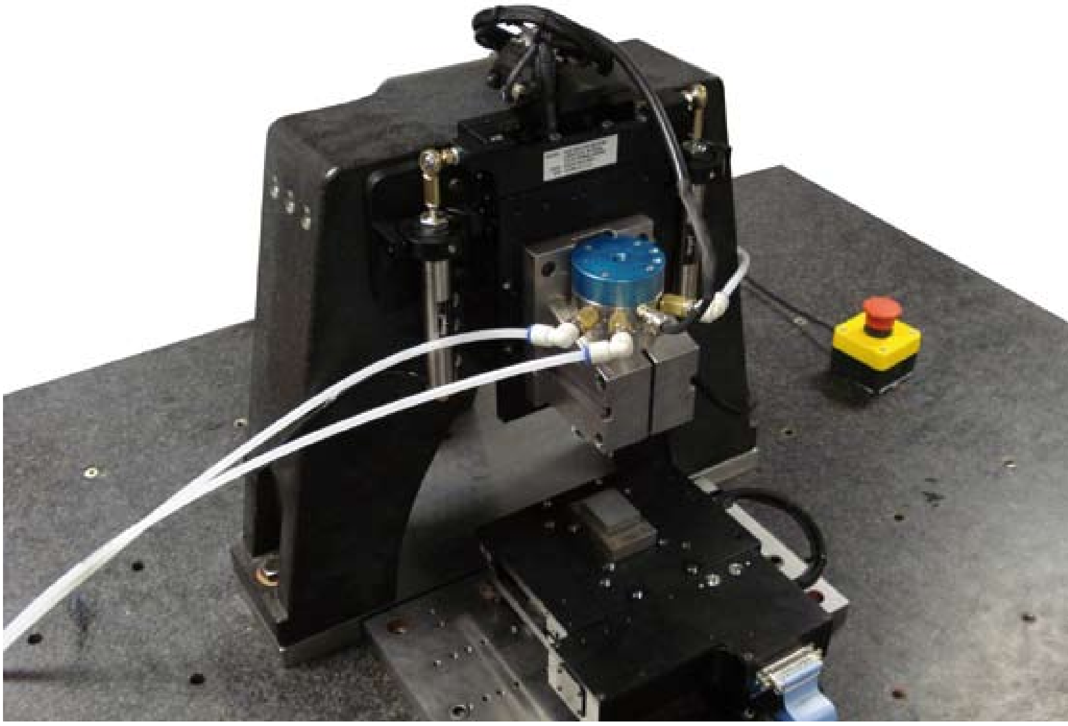


Figure 1. Three-axis micro-milling machine at the University of Manchester.

Within the scope of this project, the measurement of these individual and combined forces requires the development of new sensor technologies. This work is being achieved in conjunction with other major research at The University of Manchester, such as the European Commission funded DYNAMITE, smart-sensing project which aims to develop sensors that will significantly advance the area of predictive maintenance on machines.

Other topics

The project is also studying and innovating solutions for the metrology, robotic handling and the assembly requirements for these small-scale components which are essentially impossible for human handling and are also strongly influenced by other interactive micro phenomena such as electrostatic forces and surface tension. Some of this work centres on a novel vision system based on sub-pixel edge detection for inspecting micro-scale features, and also on new laser-based sensors using the Doppler Effect for in-process inspection and error compensation of components while they are being machined.

There is also a dearth of information available for modelling these micro forces and the research will redress this by developing static, dynamic and thermal models using Finite Element Analysis techniques in relation to actual volumetric dimensional measurements of manufactured test components.

Control

Another fundamental for the project is to develop motion and machine control systems with two different design philosophies. The first is to control a mechanical system which is essentially ‘near perfect’ and will meet specification with conventional servo controls; the second level is a control system that includes error compensation, capable of correcting small-scale errors from a pre-calibrated look-up table or in conjunction with higher-order feedback systems such as interferometry. The machine control system would also take care of the CAD/CAM requirements and advanced G-code programming which are elemental for future high-throughput production systems.

Stage

Aerotech’s ALS130H linear positioning stage features a centre-driven, zero-cogging brushless linear motor with anti-cage creep cross-roller bearings for exceptionally smooth performance and excellent in-position stability; see Figure 2. A 4.0 micron glass scale linear encoder with 40

a

b

Figure 2. Aerotech's ALS130H linear positioning stage.
(a) A single stage.
(b) An XY stage.

MHz encoder processing provides high-speed capability of up to 300 mm/sec with a maximum acceleration to 1g (no load) when used with the A3200 motion controller. Cross-roller technology provides the stiffness and durability required for higher load applications with high resistance to shock loading that is essential for machining applications.

The choice of Ndrive CL series DSP based linear stage servo amplifiers rather than PWM drive stage alternatives guarantees extremely low noise for the application – essential for sub-nanometre applications to minimise stage jitter that would affect in-position stability. The linear amplifier technology also provides a high bandwidth allowing precise feed control from microns per second level speeds through to the high speeds required for fast traverse. The technology also provides zero crossover distortion which is very beneficial for multi-axis contouring – ensuring the highest accuracy interpolation when compound axes are reversed to machine corner details or circular paths.

Automation platform

Aerotech's A3200 Digital Automation Platform is a software-only motion and machine control system that runs on a PC. It provides linear, circular, helical and spherical interpolation, cutter compensation, normalcy, parts rotation, mirroring, path retrace, polar transformations and cylindrical transformations. Electronic gearing functions are also available and advanced features include high-speed registration, multi-dimensional error mapping and orthogonality correction, autotuning, backlash compensation and gantry algorithms.

The complete stages were delivered fully assembled and tested with all set-up and tuning parameters pre-loaded into the controller but could be adjusted according the user's need as in this project. This made the system commissioning straightforward and ensured no time was wasted on this extremely interesting and potentially groundbreaking research project.

Author's note

This article was based on a press release by Aerotech, a key supplier of high-precision, high-throughput motion systems used in manufacturing production, quality control and R&D. Aerotech is headquartered in Pittsburgh (PA, USA) and operates sales and service facilities in the UK, Germany, and Japan.

The collaboration of Dr Samir Mekid (University of Manchester) in writing the press release is acknowledged.

Information

www.mace.manchester.ac.uk/research/groups/manufacturing
www.aerotech.co.uk
www.iproms.org

The end of IOP

For ten years, a significant part of precision engineering research in the Netherlands was organised through the IOP Precision Engineering. This Innovation-driven Research Programme is now coming to an end. The mechatronics part will be continued within the Point-One innovation programme, which also covers nano-electronics and embedded systems. A symposium in Eindhoven last December saw the presentation of past (IOP projects) and future (Point-One) examples of Dutch precision engineering research.

IOP chairman Lou Hulst kicked off the symposium by presenting an overview of the Dutch precision engineering landscape. Following an IOP initiative, the high-tech systems industry was recognised by the Dutch government as a key economic sector. Besides large original equipment manufacturers such as Philips, ASML, Océ, Thales and Vanderlande Industries, there are a great many innovative SMEs, as well as (system) suppliers. Research is concentrated at the three universities of technology, cooperating within the 3TU framework, and in public knowledge institutes such as TNO Science and Industry and ECN. Also, the universities of professional education and institutes for technical training, such as Mikrocentrum, make a significant contribution to technical and theoretical knowledge transfer.
In addition, the chairman mentioned the yearly Precision Fair (see elsewhere in this issue), which plays a pivotal role in the contacts between industry, equipment suppliers and engineering institutes. And finally, he stressed the professional growth of the Dutch Society for Precision Engineering (DSPE), that took the initiative, ten years ago, to negotiate this IOP Precision Engineering to be sponsored by the Ministry of Economic Affairs, through its SenterNovem agency.

IOP themes
The IOP programme has been structured around three central themes:

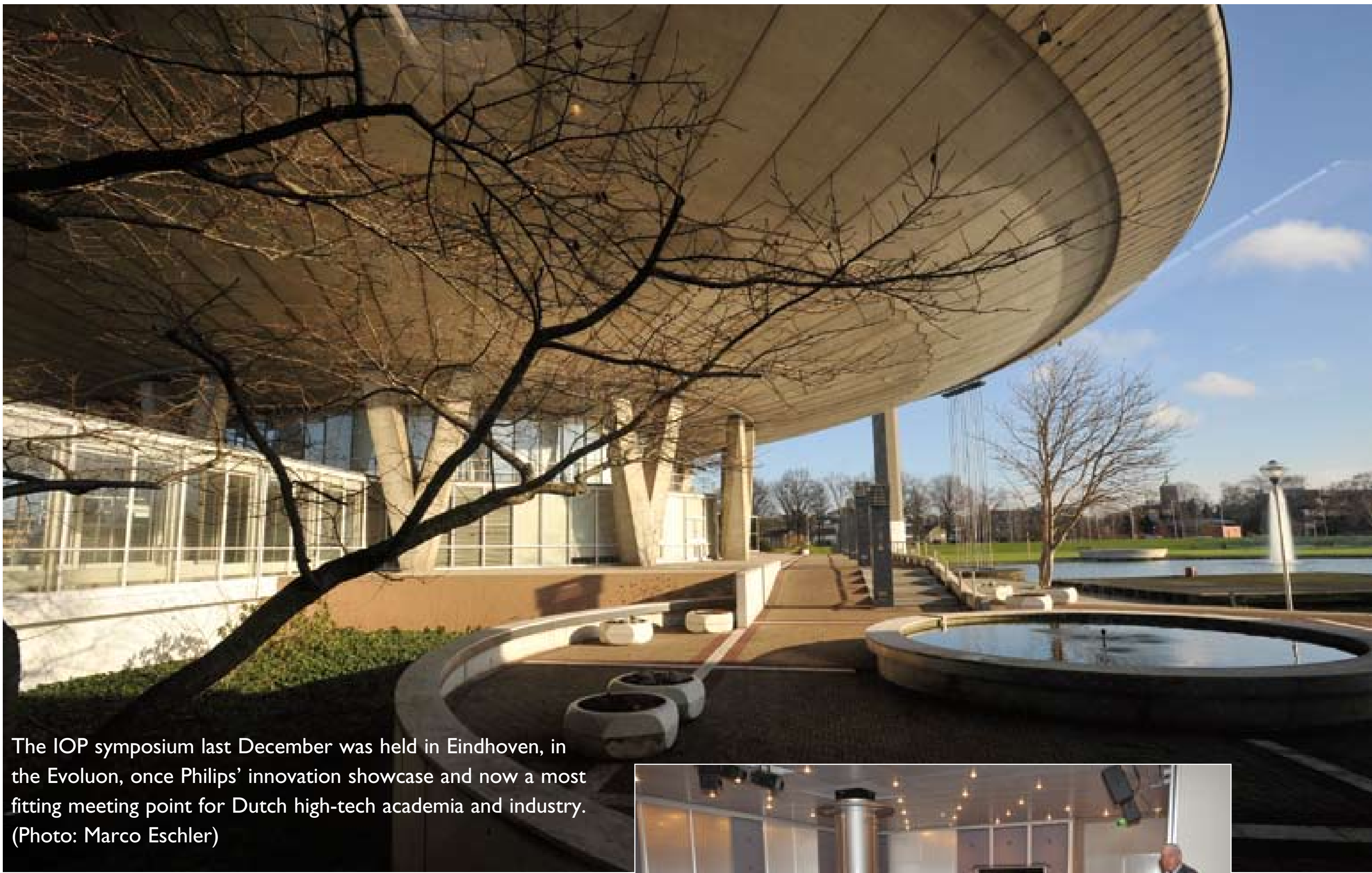
System-oriented design

This theme is concerned with the design and development of products and production systems for creating systems that can achieve high-velocity and high-precision displacements. Dynamic as well as static precision are relevant in compact and stiff constructions. Subjects for study include fast algorithms for mechanics, piezo actuators, precision liquid dosage and in vacuo precision displacements.

The limits of manufacturability

This theme focuses on enhancing the precision of existing manufacturing technologies by means of improved process control and/or the development of new manufacturing technologies that promise a significantly higher precision. This covers classical technologies such as fine turning and more recent technologies such as lithographic etching, laser beam processing and chemical vapour deposition. Micro connection technologies and laser adjustment manipulation for assembly are included as well.

– long live Point-One



The IOP symposium last December was held in Eindhoven, in the Evoluon, once Philips' innovation showcase and now a most fitting meeting point for Dutch high-tech academia and industry. (Photo: Marco Eschler)

Precision in micro systems technology

This theme is concerned with the creation of systems made up of sensors and actuators, linked by a control system and manufactured using semicon technologies. This includes technologies such as wet chemical etching, thin-layer piezo deposition, MST device packaging and micro-mounting techniques.

IOP projects

In the autumn of 2006, a last batch of six IOP projects was started (see next page for an overview of all IOP projects). Various projects have already been highlighted in previous volumes of Mikroniek, while other projects will be presented in more detail in forthcoming issues. IOP research is conducted at universities and research institutes such as TNO Science and Industry. Companies are actively engaged through their participation in review committees. Knowledge transfer activities such as publications and symposia are also organised.

Chairman Lou Hulst opened the symposium by stating IOP's ultimate goal: to make itself obsolete. (Photo: Marco Eschler)

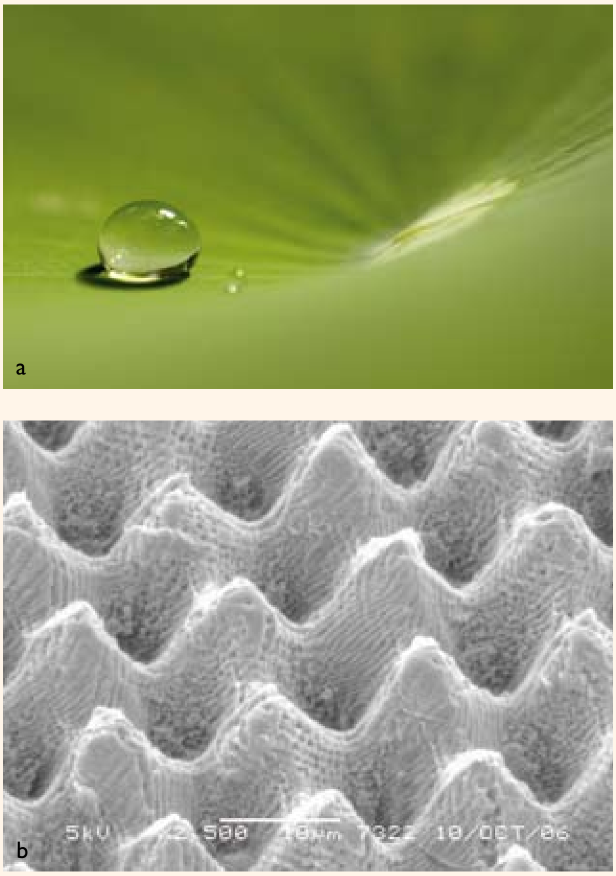
Overview of IOP projects

Started in 2006
- Contactless transport and positioning of vulnerable products
- Pico-drift monitoring device
- Robot for haptic eye surgery
- Precision positioning with vision measuring system (Fast Focus on Structures)
- Active chatter control
- Plastic MEMS structures for microfluidic systems

Started in 2004
- Microfluidic jet systems
- Adaptive mirror with high actuator density and distributed control (Adaptive Optics)
- Non-contact measurement machine for free-form optics (Nanomefos)
- Vibration isolation in precision machinery (Smart Mounts)
- Micro milling of dies and moulds

Projects in 2002
- High-precision cutting of glassy polymers (finished)
- Dressing of super-abrasive grinding wheels
- Lotus texture by laser ablation
- Multi-axis micro stage with sub-nm resolution (finished)
- Fibre-chip coupling (finished)
- MST (Micro System Technology) assembly
- High-speed assembly of micro components (finished)
- Laser die transfer (finished)

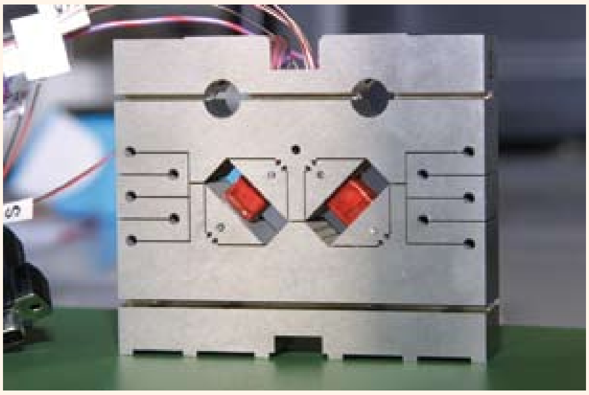
The non-contact measurement machine for free-form optics, developed on the Nanomefos project. (Photos: Leo Ploeg)
(a) The prototype built at Eindhoven University of Technology.
(b) Measurement of an optical flat.



Lotus texture, which causes lotus leaves to repel water in an extreme manner, can be mimicked by micro structuring of surfaces through laser ablation.
(a) The natural lotus effect.
(b) SEM picture of a mould surface structured through laser ablation.

Projects in 2000 (all finished)

- Active vibration damping using intelligent structural elements (Smart Disc)
- Nano-dispensing
- Surface Acoustic Waves actuation
- Magnetic bearings for ultra-precision manufacturing processes
- Free-form polishing with interferometric in-process measurement
- Sub-nm laser interferometry
- Micro-abrasive blasting



The Piezo Active Lens Mount, a result of the Smart Disc project. (Photo: Job van Amerongen)

Symposium presentations

At the symposium last December, researchers, i.e. (former) PhD students, presented results from four IOP projects.
Ron Hendrix and Thijs Meenink showed work on the design of a robot for haptic eye surgery, which is conducted at Eindhoven University of Technology in association with TNO Science and Industry and the Amsterdam Medical Centre.
Paul Verstegen and Paul Goede discussed new concepts for increasing the output of high-speed assembly robots for micro components. They finished their work at the Universities of Professional Education in Eindhoven (Fontys) and Utrecht, while Delft University of Technology was involved as well.
Roger Hamelinck and Rogier Ellenbroek in the Adaptive Optics project worked on the design of an adaptive membrane mirror with high actuator density and distributed control. These actuators are required to position mirror surfaces (for application in astronomy, for example) with nanometre accuracy. This project is a joint activity of the Universities of Technology at Delft and Eindhoven with TNO Science and Industry.
Jia Wei, of the Delft University project on microfluidic jet systems, investigates the design and development of a reliable and robust microfluidic jet system with an accurate picolitre droplet volume, a high droplet placement accuracy and high jetting frequency.

Point-One

IOP chairman Lou Hulst had opened the symposium by stating IOP's ultimate goal: to make itself obsolete. Frans van 't Hullenaar, former manager and CEO of Philips Applied Technologies, sketched the road that was taken to continue IOP-like precision engineering research in the Netherlands, via plans for a new 'precision institute' and the establishment of the Programme for High Tech Systems (which Van 't Hullenaar chaired), to eventually Point-One Phase 2.
Point-One office director Clément Goossens went into more detail to describe Point-One Phase 2. With the inclusion of the Programme for High Tech Systems, Point-One was transformed into an association and its scope of nano-electronics and embedded systems was extended with mechatronics. Until 2012, Point-One will manage an annual investment of nearly a quarter of a billion euros – enabled by the partners, the Ministry of Economic Affairs and the European Committee. The research programme will be determined by the members of the Point-One association, currently consisting of more than 100 companies, universities and knowledge institutes. Approximately 75 percent of the Point-One budget will be invested in European co-operative programmes (Eureka/Medea-Catrene-Itea, JTI/Eniac-Artemis). There is also room for national 'bottom-up' research initiatives, and special attention is given to stimulating university-industry interaction and nurturing SMEs.

Frans van 't Hullenaar, as chairman of the Programme for High Tech Systems (PfHTS), sketched the road that was taken to continue IOP-like precision engineering research in the Netherlands, via plans for a new 'precision institute' and the establishment of PfHTS (which he chaired), to eventually Point-One Phase 2. (Photo: Marco Eschler)

Jan van Eijk is a professor at Delft University of Technology and an independent mechatronics consultant. As a speaker at the IOP symposium, he put Dutch mechatronics into an international perspective. He observed that the Netherlands focuses primarily on high-end applications at the apex of what he called the mechatronics pyramid, e.g. nano-mechatronics for high-tech equipment. But there is more out there than just that. Van Eijk referred to 'consumer mechatronics' (with the US leading the field), automotive applications (Germany and France) and intelligent robotics (Japan). The greatest economic potential is to be found lower in the pyramid. He urged the Dutch mechatronics community to broaden its horizons and focus more on business. From the R&D-oriented Dutch, this will require more 'respect for operations', integrated cost awareness and business acumen. Opportunities identified by Van Eijk include robotics at home, inkjet technologies, solar panel manufacturing and 3D integration of ICs.
(Photo: Marco Eschler)

Agenda and roadmap

The research is directed by Point-One's Multi-Annual Roadmap, which includes an Emerging Technology Agenda. Mechatronic subjects on this agenda are:

- distributed actuation, identification and control,
- precision systems,
- intelligent robotics,
- transient electromagnetics design,
- smart materials,
- smart ultra-lightweight actuators,
- man-machine interfaces,
- mathematical systems theory.

Based on this agenda, a Multi-Annual and an Annual Roadmap for mechatronics research have been outlined:

- health care: reliable and robust robotic manipulators;
- energy & power: green mechatronics designs;
- semicon: new stage concepts (front-end), 3D integration of ICs (back-end);
- industrial printing: electronics, high-tech manufacturing;
- lifestyle & leisure: domotics home care for the elderly;
- transport, logistics & security: robotics for dangerous events/environments.

This agenda and these roadmaps lay the foundation for precision engineering / mechatronics research in the coming years. To start with, the IOP symposium last December included three brainstorm sessions on the subjects of fast and accurate positioning, high-precision, ultra-slow movements and robotics at home. This resulted in inspiring ideas for further elaboration. At the moment, Dutch researchers are drawing up research proposals for submission to Point-One. IOP Precision Engineering is coming to an end, long live Point-One.

DSPE

In the Dutch precision engineering landscape pictured above, the Dutch Society for Precision Engineering (DSPE, also known as NVPT after its name in Dutch) plays a prominent networking role. Actually, as Lou Hulst already pointed out, it was DSPE that in the late nineties took the initiative that resulted in the launch of the IOP programme. In recent years, DSPE has renewed its spirit and grown to become a flourishing society, with an extended board, successful activities such as the Summer school Opto-Mechatronics, its well-rated magazine Mikroniek, a popular website (Precision Portal, soon in English as well) and an active Young Precision Network. At the moment, DSPE is establishing close ties with Point-One regarding such subjects as research, human capital and roadmapping.

Information

www.senternovem.nl/iopprecisietechnologie (in Dutch)
www.point-one.nl
www.dspe.nl (at the moment largely in Dutch)

MEOST,

a jump into the future

Given the demand for shorter development lead times, traditional methods of system and product reliability testing are too time-consuming. The Multiple Environmental Over Stress Testing (MEOST) method appears to be a very strong tool for designing and developing a robust and reliable product.

• *Jan Eite Bullema* •

Companies are often pressured by competitors and by their business environments to bring new products and new innovations to the market as quickly as possible. This rapid introduction of new products increases the risks associated with the reliability of new products. Traditional test methods used to guarantee the reliability of new products are not sufficient to reduce the time of design cycles.

The reliability of a system is often derived from testing its subsystems. Subsequently, the reliability of a subsystem is derived from the reliability of the components of that subsystem. Often these tests are guided by 'mission profiles' that are used to model the practical conditions of use. In practice, it appears to be very difficult, if not impossible, to infer a systems' reliability from the reliability behaviour shown by subsystems and components. As the renowned quality guru Edwards Deming put it, "*you cannot test a battleship*" [1].

It has been known for at least twenty years that traditional methods for arriving at reliable products take too much time and have relatively little predictive value [2]. For example, the reliability handbook of the American military, MIL-Handbook-217, has not been updated since the mid-1990s due to the limited predictive value of the traditional Mean Time Between Failure (MTBF) approach that the handbook uses. The handbook is much too conservative and hence often unrealistic when it comes to failure prediction.

New, modern quality approaches such as Six Sigma [3] offer little in the way of a reduction of the design cycle time. Despite claims that the 'Design for Six Sigma' method leads to a substantial reduction in the development lead time, the method contains no real solutions for the urgent demand for accelerated reliability testing [4].

According to Keki Bhote [4], Multiple Environmental Over Stress Testing (MEOST) is a method that may well lead to robust and reliable complex systems. The MEOST method was developed in the 1960s and successfully applied by NASA in the development of the lunar module, a complex system that placed extraordinarily high demands on reliability.

The main benefits of the MEOST method are (a) that it requires very short development cycles that enable short time-to-market developments, and (b) that the design is very robust.

Critical subsystems

Electronic printed circuit boards are often critical subsystems in mechatronic systems. Failure in a printed circuit board leads to a standstill of the total system. The Netherlands Organisation for Applied Scientific Research (TNO) has worked with the Dutch suppliers association NEVAT EMS (Electronic Manufacturing Services) in a technology transfer project on the subject of the reliability of lead-free soldering [5] [6]; see Figure 1. In particular the relationship between certain choices in the design of the lead-free printed circuit board and the impact on the reliability of the soldered printed circuit board was studied. The lead-free design work was done on a practical printed circuit board design for the production of one of the NEVAT EMS companies.

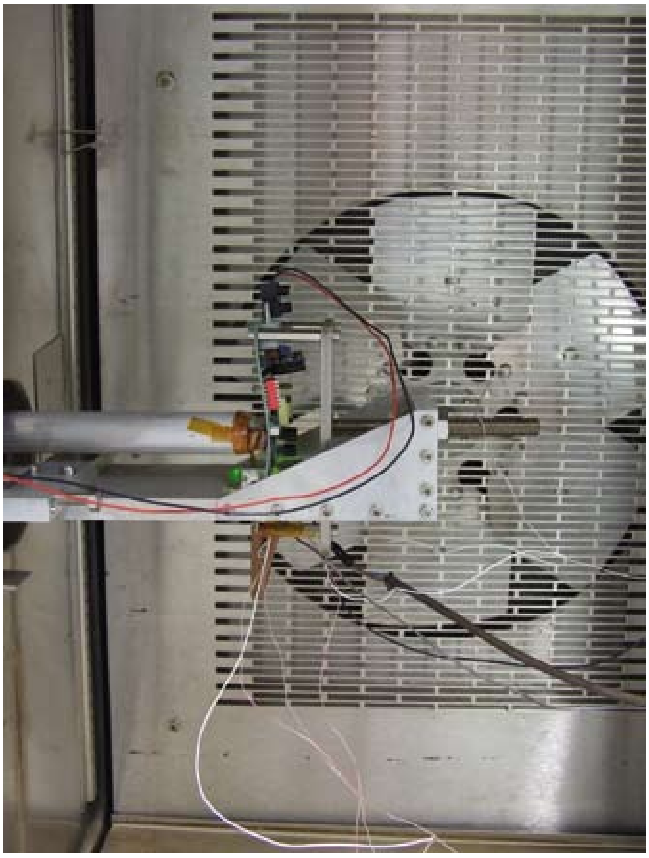


Figure 1. The experimental set-up developed by TNO to test printed circuit boards according to MEOST test plans. Simultaneous bending, heating and electrical bias are applied [6].

Failure modes

If we zoom in on electronic products, and especially on failure modes that are associated with lead-free soldering, we can identify numerous potential failure mechanisms; see Table 1 and Figure 2. These become manifest under specific stressing of a product. This is crucial for the understanding of accelerated testing. It is often very difficult to predict the user profile of specific individual users. Testing product ageing at elevated temperatures does not provide an insight into failure behaviour due to mechanical shock.

Table 1. Frequently encountered failure mechanisms in lead-free soldered electronics.

- Thermo-mechanical fatigue
- Mismatch between coefficients of thermal expansion
- Bulk solder brittleness
- Mechanical shock
- Vibration
- Low-cycle fatigue
- Electro-migration and electro-corrosion
- Warping
- Kirkendall voiding

During the transition towards lead-free soldering in the electronics industry, there have been numerous examples of companies incurring financial damage because of their ambitions to beat competitors. Well-known, in the context of lead-free soldering, are the reliability problems Microsoft encountered with the introduction of the Xbox, which led to an estimated write-off of 1.15 billion Euros in 2007 [5]. The Swiss watch company Swatch reported a loss of approximately 1 billion Euros as a result of ‘tin whiskers’ in lead-free soldered watches [7].

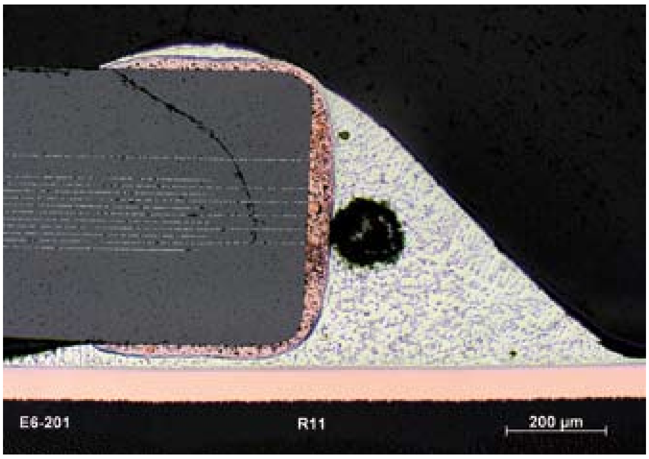


Figure 2. An electrical capacitor crack, the result of a thermal mismatch (mismatch between coefficients of thermal expansion) [5].

A thorough knowledge of material properties is required to design tests that make it possible to assess the reliability of a product. Many lead-free solder alloys are stiffer and less ductile than the traditional lead-tin solders. To be able to predict the expected useful life of a solder interconnect based on a cyclic thermal load, it is necessary to adjust the time that the interconnection is loaded at a higher temperature (i.e. dwell time) [8]. Some lead-free solders lose their ductility abruptly below a certain transition temperature, which can lead to brittle breakages at impact stresses below these temperatures [9]. Specialist knowledge of these material properties is needed to develop and design meaningful tests for lead-free soldered interconnects. This is even more the case for accelerated reliability tests.

Traditional methods

The electronics industry traditionally uses what are known as reliability handbooks for reliability prediction, one very well known one being the MIL-Handbook-217 [10], which was introduced in 1962 by the American military and used to estimate the failure rate (Failures In Time or FIT) or the Mean Time Between Failure (MTBF). This handbook was last revised (revision F) in 1994 and there have been no updates since then. The Handbook-217 is still used by many designers for estimating the reliability of an electronic design.

Arrhenius acceleration model

The most commonly used method of determining the acceleration factors in accelerated testing is based on a method developed as early as the 19th century by Svante Arrhenius [11] and used to determine the effect of increased temperature on chemical reaction rates. The Arrhenius method also can be used to predict the ageing behaviour of products. A quantitative prediction of acceleration factors can be made on the basis of measurements. In turn, these acceleration factors enable a quantitative prediction of the expected life of a specific product. Measurement data is plotted using what is known as an Arrhenius plot, in which the reciprocal absolute temperature in Kelvin is plotted against the logarithm of the reaction rate. In many cases, the plot leads to a straight line. According to the quality guru Joseph Juran, straight lines are very much appreciated by scientists and engineers.

Weibull Statistics

Waloddi Weibull formulated a statistical approach [12] that has become the standard in the field of reliability engineering. In the Weibull method, the cumulative defects are plotted on a double logarithmic scale against the logarithm of time. Again, this leads to straight lines. Depending on the statistical parameters of the Weibull distribution function, a product's life is classified in three phases:

- infant mortality, characterised by a decreasing failure rate;
- useful life phase, characterised by a constant failure rate;
- wear-out phase, characterised by an increasing failure rate.

These phases in a product life lead to the well-known bathtub curve, which graphically represents these three phases of the product life. Aspects such as reliability and expected life can be estimated using the Weibull analysis. With a knowledge of acceleration factors and specific failures, it is possible to predict reliability and expected life on the basis of accelerated testing.

HAST

As mentioned above, traditional reliability testing approaches are time-consuming and often do not correspond to the practical conditions in which the products are used. In the testing of electronic products, methods such as Highly Accelerated Stress Testing (HAST) are already being used. Here, combinations of stresses are applied to accelerate reliability testing. A disadvantage of the HAST method is that a relatively large test series is required to arrive at statistically significant conclusions.

MEOST

A method for testing reliability that differs fundamentally from existing methods for testing the reliability of products and systems is the Multiple Environment Over Stress Testing (MEOST) method developed by Dorian Shainin. This method is based on very small sample sizes and takes a subtle approach to the stressing of a product in that a well-designed combination of stresses is carefully applied. The

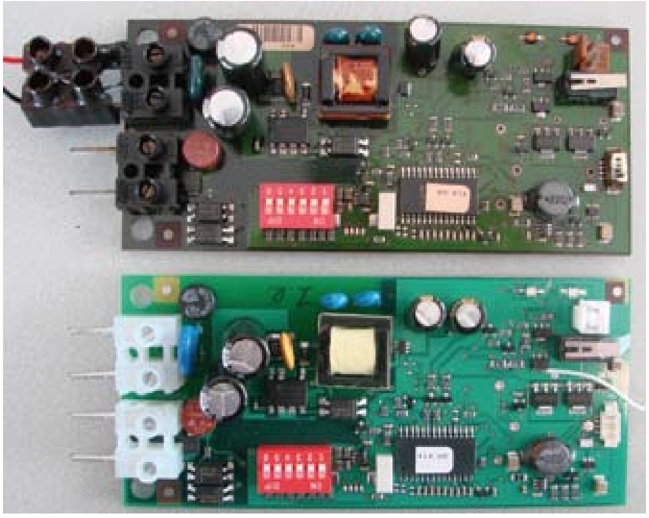


Figure 3. A printed circuit board after 0 hours (above) and after 1,800 hours (below) in the climate chamber at TNO.

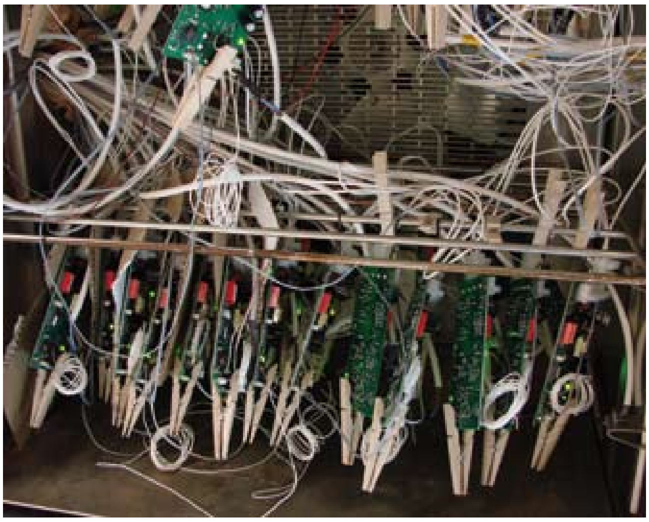


Figure 4. Printed circuit boards in the climate chamber at TNO. The clothes pegs are used for pressing a test switch.

aim is not to arrive at a sound statistical straight line but to develop a product that is robust and can withstand any stress or combination of stresses during its useful life.

The starting points that distinguish Multiple Over Stress Testing from the traditional reliability approach are:

- Failure of the product during testing is a success.
- Stresses are combined, where possible, to create interactions that lead to product failure.
- Stresses are applied preferably as far as possible above the design specifications.
- Stress levels are adjusted as rapidly as possible (steep ramp-up and ramp-down).
- Extremely small test series (three to five products in a test) suffice.

Because of the combination of stresses, an analysis of MEOST data does not lead to straight lines as we have seen in the Arrhenius and Weibull plots, which is probably why acceptance of the MEOST method has been slow.

Experimental work

In the context of the TNO and NEVAT EMS knowledge transfer project, TNO performed a series of classical MIL-STD-883 reliability tests to evaluate design changes in a lead-free soldered printed circuit board; see Figures 3 and 4. Parallel to these traditional experiments, a series of MEOST tests was performed on the same printed circuit boards to evaluate the different designs. The aim was to compare the traditional reliability test and the MEOST test.

One of the variables in the experiments was the glass transition temperature of the printed circuit board material. As lead-free soldering leads to higher soldering temperatures, the material quality of the printed circuit boards becomes more critical. It can also drive costs up.

The conclusion drawn from both experimental studies using traditional and MEOST tests was that the glass transition temperatures in the selected materials had no influence on the failure behaviour of the soldered printed circuit boards. This led to the choice of the most cost-effective material.

A MEOST test lasting ten hours enabled the same conclusion to be drawn as the traditional MIL-883 test where testing time was one thousand hours.

It is clear that successful use of the MEOST test demands a thorough knowledge of product design, material and production technology. Moreover, an understanding of lead-free soldering mentioned in the introduction is needed to design MEOST experiments and to come to meaningful interpretations.

Conclusion

The MEOST method appears to be a very strong tool for designing and developing a robust and reliable product. The MEOST method can be used to assess and improve the reliability of a technical system in very short cycles. More specifically, the MEOST method can be used to test the reliability and robustness of mechanical systems, mechatronic systems and complex software. In short, this method reduces design cycle time (a factor 100 is possible) and enables the design of more robust and more cost-effective systems.

Author's note

Jan Eite Bullema works at TNO Science and Industry in Eindhoven, the Netherlands, on the development and application of microsystems packaging. This article is based on work within the framework of a knowledge transfer project that TNO has conducted for NEVAT EMS, which investigated the reliability of an existing product.

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Information

www.tno.nl
www.loodvrijsolderen.nl (in Dutch)

Vision & Robotics 2009

On 16 & 17 June 2009, Mikrocentrum organizes the eighth edition of the Vision & Robotics trade fair. In Nieuwegein's Business Center, the Netherlands, industrial robot and vision applications will be presented under one roof.

An inspiring lecture programme will guide visitors into a world full of integrated robot and vision applications. Advanced camera and lighting applications allow robots to operate fully autonomously. In times of economic prosperity as well as in the current recession, robots equipped with fitting 'eyes' will enable industry to manufacture products of superior quality at low cost.

Vision system as well as robot suppliers and system integrators, united in the Robotics Association Benelux (RAB), support the event. They also will showcase appealing application examples in the lecture programme, which is directed at end users, original equipment manufacturers, and system integrators. In 2008, the event attracted 46 exhibitors and over 600 visitors.

www.vision-robotics.nl (in Dutch)

VISION
& ROBOTICS
2009

Micro-assembly

On 11 June 2009, Mikrocentrum organizes the interactive seminar 'Positioning systems for micro-assembly'. During the day, examples and applications will be be presented to demonstrate the rationale and potential of using positioning systems and other tools for micro-assembly.

Mikrocentrum

Eindhoven-based Mikrocentrum is an independent competence centre with a 40-year history of supporting companies and institutes. The main objectives are improving know-how and stimulating intercompany networking and co-operation. Mikrocentrum's network extends into government(-related) organisations, as well as into scientific and educational institutes, and its High Tech Platform comprises some 480 high-tech industrial companies. Annually, over 20,000 people participate in events organised by Mikrocentrum, such as 30 to 40 special-interest sessions on topics ranging from technology, product development and manufacturing to quality and management. Mikrocentrum also offers a comprehensive array of short, concise practical courses and workshops in technology and management at all educational levels ranging from the hands-on technical up to the academic. Additionally, Mikrocentrum organises a dozen trade fairs a year in fields such as precision technology, vision & robotics, and health & technology.

www.mikrocentrum.nl

Updated and extended: Advanced engineering design

The website www.tribology-abc.com was designed to support the calculators that were included in the book 'Advanced engineering design - Lifetime performance and reliability'. Although this book originally centred on tribology-related topics, later editions more and more focused on the design of high-precision and high-reliability systems. Now, an updated and extended version has been published.

The main components in these systems are typically the actuator plus controller, the bearings and the supporting frame. The system engineer is faced with the many options available for the subsystems and the combinations of subsystems with respect to the system specification. Selection of the most promising combination of components will be successful when the principle of operation, accuracy, resolution, and repeatability of each component in the system are clearly understood.

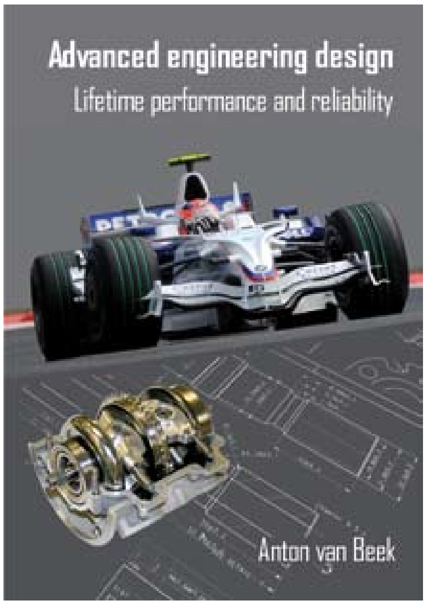
The electrical resolution for stepper motors, as an example, relates to the step size, while the resolution for servo motors relies more on the encoder resolution. The physical limitations of overall system accuracy, however, may be due to transfer mechanisms such as supports, couplings, lead screws and their associated wind-up, backlash or hysteresis. Generating an overview of quantitative data – error budget – makes it clear which factors dominate the system accuracy.

Many books are written about machine design. Most of them are focused on selection and computation of strength and stiffness of basic machine elements. The objective of this book is to provide guidelines for engineers helping them to improve machine lifetime performance and reliability.

The first part of the book concerns the fundamentals of design for lifetime performance and reliability, including design procedures to estimate and improve machine reliability, failure analysis, fatigue strength, static and dynamic load rating of concentrated contacts, friction phenomena, wear mechanisms, machine lubrication, material selection and coatings.

The second part concerns the design of high-performance and high-reliability systems, including the principle of operation, performance and design of hydrodynamically lubricated bearings and sliders, viscous dampers, dynamic sealing systems, hydrostatic bearings, pressurised air bearings and flexure mechanisms. Although the designer using this book is expected to have a good background in mathematics, the objective is that the design tools illustrated by cases will be useful anyhow.

www.engineering-abc.com/book



Anton van Beek,
Advanced engineering design - Lifetime performance and reliability,
ISBN-10 90-810406-1-8,
full-colour, 534 pages, Tribos, 2009.
Book + CD, EUR 85.00,
including postage and VAT.

Motion control trade fair MOCON

8 & 9 April 2009, the next edition of motion control trade fair easyFairs MOCON will be held in Den Bosch, the Netherlands. The large variety of exhibitors will cover all facets in motion control, including the 'high-end' part of drive techniques, and solutions for synchronising movements. The previous edition in Den Bosch, in 2007, attracted 154 exhibitors and over 2,400 visitors. This year, some 2,500 to 3,000 exhibitors are expected.

Among the over 140 exhibitors that have already registered, are B&R, Heidenhain, maxon motor, Minimotor and Siemens.

www.easyfairs.com/mocon-nl

Summer school Opto-Mechatronics

Following the success of the Summer school Opto-Mechatronics 2008, the Dutch Society for Precision Engineering (DSPE) and TNO Science and Industry decided to organize a Summer school again. The Summer school Opto-Mechatronics 2009, in Eindhoven, once again is the place to be for anyone working in the field of precision engineering and wanting to learn and experience from experts how to design opto-mechanical instruments that are actively controlled, operating in the non-perfect environment.


Professors at the Summer school include Maarten Steinbuch (left) and Rob Munnig Schmidt.

The Summer school Opto-Mechatronics 2009 comprises, from 29 June to 3 July 2009, five days of intensive course, taught by excellent Dutch professors and scientists in the field of precision engineering, combined with hands-on training by TNO specialists; TNO is the leading independent Dutch institute for applied research in a.o. high-end technical disciplines. Participants will come from universities and high-tech large companies and SMEs. The programme will include social events. Venue for the Summer school will be TNO Science and Industry at the university campus in Eindhoven, the Netherlands.

Scope

The scope of the Summer school is to learn about the system design of optical instruments based on fundamental knowledge of optical design, mechanical design and actively controlled systems. Typically these systems include semiconductor equipment, metrology systems, microscopes, printers, space instruments and high-tech production equipment.
This international course is hosted by Dutch experts, from Delft and Eindhoven Universities of Technology, TNO Science and Industry, ASML, Philips and Dutch Space.
During the course, students will be working on the design of an optical delay line for the Very Large Telescope, under the supervision of TNO experts.

The preliminary course programme outlined below each day offers a combination of theory and practice.

Summer school Opto-Mechatronics
Precision Technology

Impression from the 2008 Summer school.

Programme

Monday 29 June: Systems Engineering
Opto-mechanical instruments are always co-existing with other equipment. So, before starting their design, the essence of the systems engineering has to be considered.What is critical and what are the margins? How to approach such a project and how to gain insight in the background of the requirements?

Tuesday 30 June: Optical Design
The case starts with an introduction to the optical design and its use in optical aperture synthesis applications. Next, in teams, several delay line designs will be compared, in order to select the best design with respect to the optical requirements. After this, an effective optical design has to be found for measurement of the optical path differences.
In a workshop, Zemax will be used to analyse the optics in the delay line with a focus on tolerancing. Further work pertains to wave-front analysis and pupil imaging while moving the delay line. Also, the accuracy of the alignment is part of the assignment.

Wednesday 1 July: Control Design
Based on the functional requirements of the optical delay line, the challenges for control will be discussed. These include actuation for a high dynamic range, servo behaviour, vibration rejection, sensor noise, closed-loop stability and others. An introduction of suitable control design methods is presented to achieve nanometre positioning accuracy.

Thursday 2 July: Opto-Mechanical Design, statically
The trade-off made for a linear guiding of 66 meters, with sub-millimetre accuracy, will be presented. After this introduction, the students will go through the design. In a team effort they are requested to design and assess the performance.
The finite-element method programme ANSYS will be used to gain insight in the mounting of (aberration-free) optical components, and some smart construction principles. Students will learn the capability of finite-element simulations, the preparation of the required input, and interpretation of the output.

Friday 3 July: Mechanics and Dynamics
Designing an actively controlled delay line that is stable enough to perform interferometry over large distances, is far from trivial. The system needs to operate constantly over long time scales. Temperature changes, ground vibrations, moving systems, acoustic and electrical noise, these all are aspects that will influence its performance. Students will learn to understand these influences and how to deal with them in a smart, constructive way.

Information and registration
www.summer-school.nl

A tour of the TNO laboratories during the 2008 Summer school.

TValley 2009: mechatronics moves you

Mechatronics Valley Twente Foundation will hold its sixth TValley conference on 16 April 2009 on the University of Twente campus, Enschede, the Netherlands. This time, the conference on innovation and business in the high-tech manufacturing industry will feature robotics and mechatronics as attractive options for business, research, study and work. Presentations by industry and academia will show the impact of mechatronics on Dutch robotics. (Former) University of Twente students will demonstrate their appealing work on a humanoid.

The conference is aimed at the (Dutch) manufacturing industry. TValley 2009 will help researchers, study programme directors, technologists, marketeers, (HRM) managers and policy makers to keep moving, searching for the technological potential and the attractiveness of mechatronics.

www.tvalley.nl

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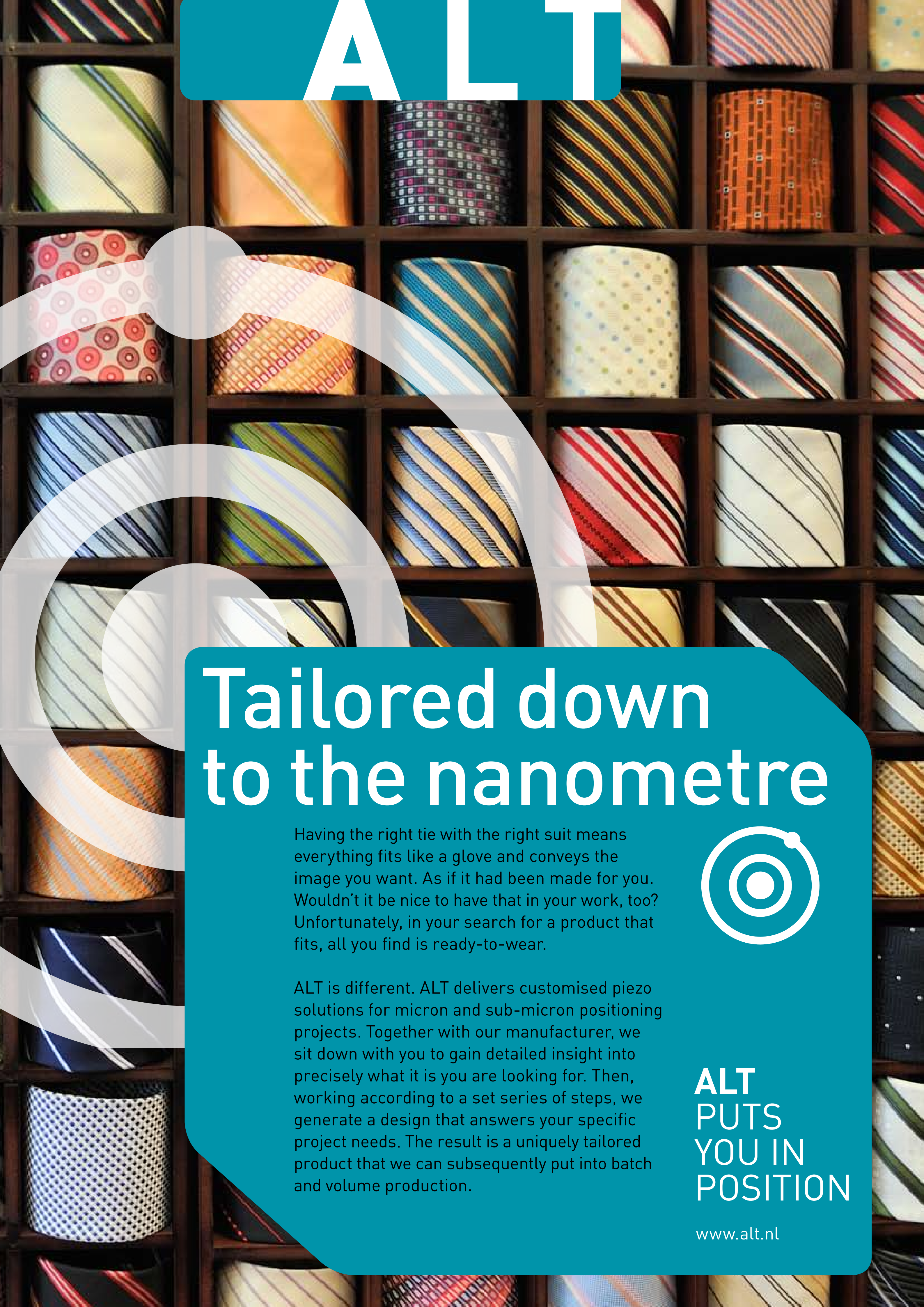
ALT
Tailored down to the nanometre
Having the right tie with the right suit means everything fits like a glove and conveys the image you want. As if it had been made for you. Wouldn't it be nice to have that in your work, too? Unfortunately, in your search for a product that fits, all you find is ready-to-wear.
ALT is different. ALT delivers customised piezo solutions for micron and sub-micron positioning projects. Together with our manufacturer, we sit down with you to gain detailed insight into precisely what it is you are looking for. Then, working according to a set series of steps, we generate a design that answers your specific project needs. The result is a uniquely tailored product that we can subsequently put into batch and volume production.
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