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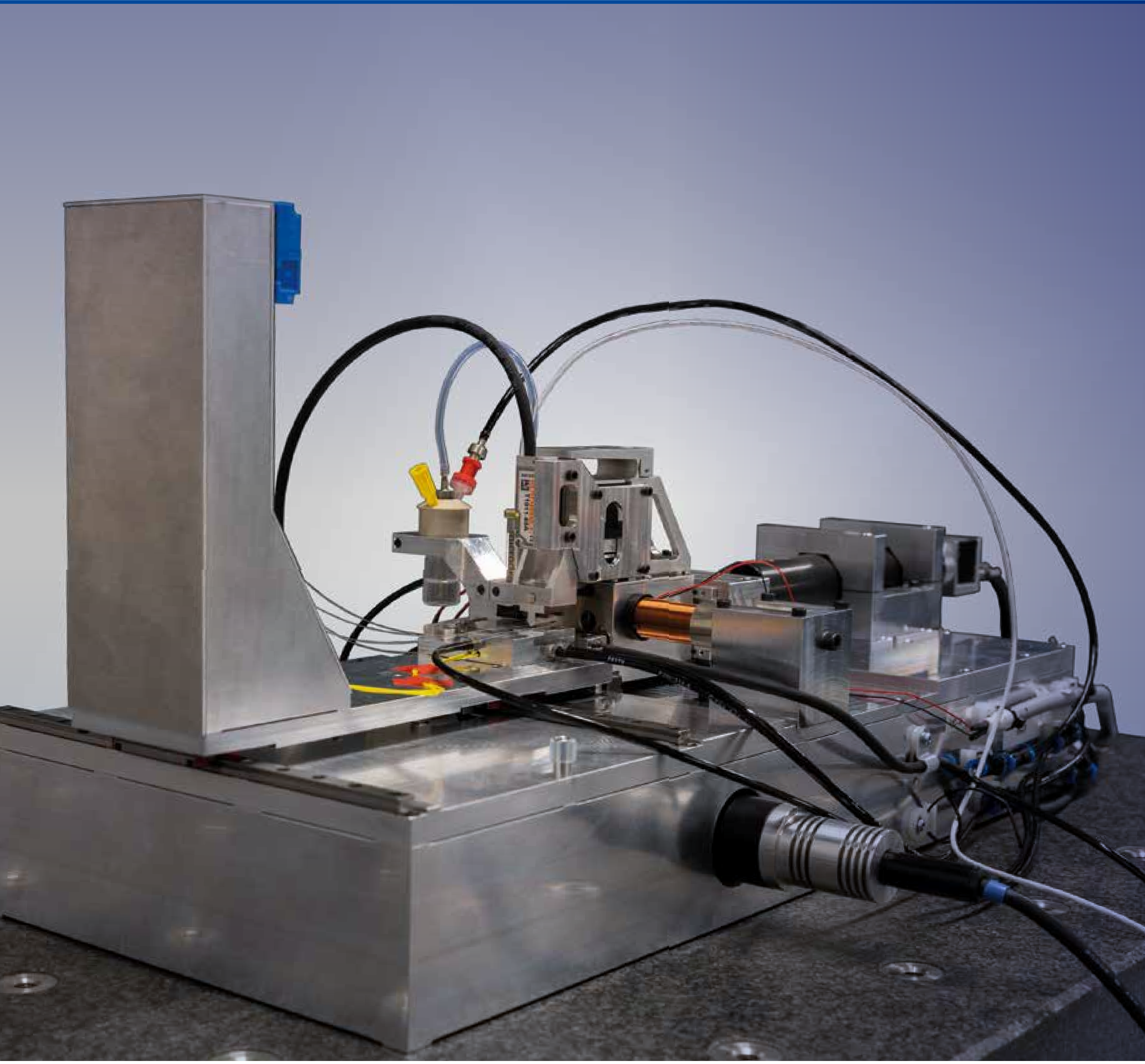

■ THEME: PRECISION MECHATRONICS
■ AUTOMATED SUB-MICRON-ACCURATE OPTICAL FIBRE ALIGNMENT
■ DSPE CONFERENCE 2021 PREVIEW
■ LIFELONG OPTICS LEARNING

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

DSPE
YOUR PRECISION PORTAL

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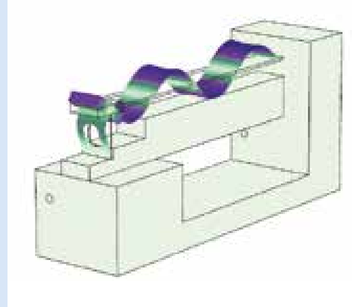
The cover image (featuring a fibre-array assembly machine) is courtesy of Matthijs van Gastel. Read the article on page 5 ff.

IN THIS ISSUE

THEME: PRECISION MECHATRONICS

18



36

FEATURES

SYSTEMS ENGINEERING AS THE DRIVER FOR CONTINUOUS GROWTH

The Brainport region continues its growth, also during a global pandemic. With around five big OEMs, a strong supply chain, and a successful start-up and scale-up climate, we're able to create new products and ventures, make the most complex systems, and pick up new challenges every day. This success is based on a strong fundament in systems engineering and a secret sauce, which I call social innovation.

One thing Brainport has learned, also from transitions in the past, is the ease with which we can find and strengthen each other. That's also something that makes us unique, that's part of our culture, and can't be copied. It's the grease in our systems engineering approach, by which we can make the most complex systems together. That's also why we call Brainport the Champions League of Technology and Innovation.

Nowadays, challenges need a systems engineering approach; they can't be solved alone anymore, we need to perform together, regionally as well as globally. Challenges like climate change, the need for new mobility and the Dutch nitrogen crisis require this systems engineering approach more than ever, and thus Brainport is the place to create the new future.

Although we are the champions in systems engineering, I strongly believe we continuously need to learn more, stay open for different views and keep building on our strengths. This is why we took the initiative in 2019 for a business trip to key centres in systems engineering in North America: Waterloo University, MIT and Stevens Institute of Technology. For this initiative, Brainport Development, HTSC, TU/e, VDL ETG, TNO-ESI and Holland Innovative joined forces.

Thanks to the strength of our network (Holland Innovative's scientific director Jeroen de Mast is also a professor at Waterloo University), the invitation was quickly organised and our main OEMs were connected to the initiative. This was crucial, as they have achieved the competitive systems engineering position of the region. We can build on their strong shoulders and become even stronger by the possibility to jointly work on the most complex challenges. You only can learn and develop if you get the opportunity to work and play in this champions league.

The initiative has already resulted in a stronger focus as well as the awareness that a systems engineering approach is necessary. We opened up the initiative to all stakeholders in the ecosystem, from educational institutions to the industry (with an important role for SMEs) and government agencies. In the long term, the results will also improve the competitive position of Brainport and the Netherlands.

The main focus is on strengthening our knowledge around systems engineering in a sustainable way in education as well as in lifelong learning. We focus on the educational process through challenge-based learning, sharing of cases, and talent development in general. This way, we expect to attract more new employees from abroad in order to not only fill the gap in the human capital need for our projects but also to achieve the diversity mix that is needed to solve all our complex challenges. We know we have to bring together knowledge from all over the world; this initiative is to organise the blind spots as well as our strengths and facilitate the career paths of talents.

As I said, social innovation is the grease that's needed to become agile and develop our leadership and social skills. That's why I'd like to invite everyone to work on this part: build your network, have a balance with activities besides your corporate projects, and use initiatives like our "Drinks, Pitches & Demos" to connect to others, practice your pitching capabilities, and share insights. It enriches you as a professional – and moreover, it's fun!

Hans Meeske
Managing director at Holland Innovative
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PRECISION FOR PHOTONICS

The adoption of photonic chips is currently held back by the considerable cost involved in their production. In particular, optical fibre alignment and fixation have been a bottleneck in terms of product performance, cost and production volume. A new optical fibre array has been developed to couple multiple fibres to a photonic device with sub-micrometer accuracy. To assemble this fibre array in an automated manner, a fibre-array assembly machine has been designed and realised. This machine is able to assemble a 16-fibre array within four minutes with a 100 nm alignment accuracy, which is both significantly faster and more accurate than currently employed methods can achieve.

MATTHIJS VAN GASTEL

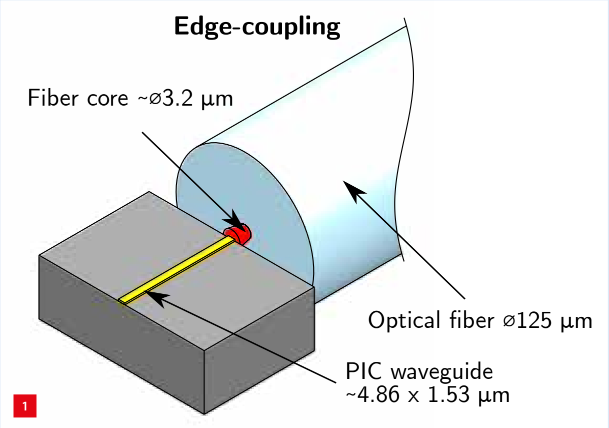
In today's society, the need for data transmission is growing exponentially. Photonic chips show great potential for energy-efficient data transmission with high bandwidth. These chips rely on information transfer based on light as opposed to electrons in the conventional electronic chips.

Photonic chips enable many new applications such as sensors for autonomous driving cars or new medical imaging techniques. An increasingly important issue for enabling large-scale adoption of photonic chips is their assembly and packaging. These processes are currently estimated to account for more than 50 percent of the total cost of a photonic device.

Especially the coupling of optical fibres, which are used to guide light in and out of the photonic device, is critical as they require sub-micrometer alignment. Current fibre alignment methods can either not cope with these alignment requirements or are not suitable for large-scale production. Furthermore, current methods are often labour-intensive and time-consuming.

Current methods

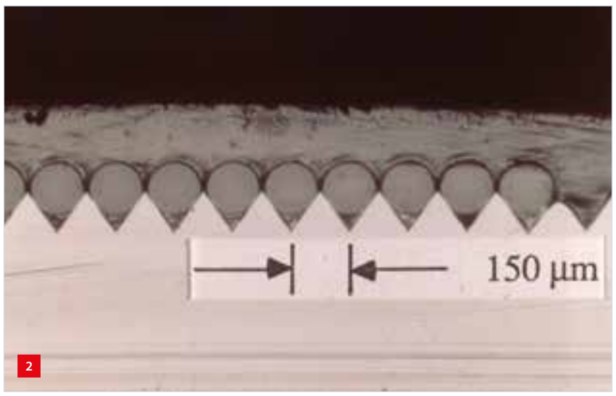
A typical optical fibre is composed of a very thin strand of silica glass with a diameter of 125 μm. The silica glass strand consists of two parts with a different refractive index to enable light guiding: the core and a surrounding cladding. A core as small as Ø 2-10 μm is embedded in the middle of the fibre. This core guides the light, and the surrounding cladding material with a slightly lower refractive index confines the light within this core. To couple light in and out of a photonic chip, the fibre core needs to be aligned with respect to the coupling channels or waveguides present on the chip's side. Figure 1 shows a schematic representation of a fibre-chip coupling. Since a typical photonic waveguide is small (~1-5 μm), a precise fibre alignment is required to ensure efficient operation of the optical components. Especially the alignment in a lateral direction is critical, with a desired alignment accuracy of typically < 200 nm.



1

Schematic rendering of a fibre-to-waveguide-edge coupling.

Nowadays, V-groove fibre arrays are typically used for multi-fibre alignment. Figure 2 shows an example of such a V-groove array. For these arrays, multiple optical fibres are placed into V-grooves that determine the position of the fibres with respect to each other. After the assembly of a fibre array, it can be aligned with respect to the waveguides of a photonic device. A major downside of these arrays is the inability to compensate for the manufacturing tolerances of optical fibres and the V-groove array itself, typically resulting in lateral alignment errors of > 2 μm.



2

Passive alignment using a V-groove fibre array.

AUTHOR'S NOTE

Matthijs van Gastel is currently working as a mechatronic system designer at MI-Partners, located in Eindhoven (NL). He obtained his Ph.D. in the Control Systems Technology group at Eindhoven University of Technology. This article is based on his dissertation work.

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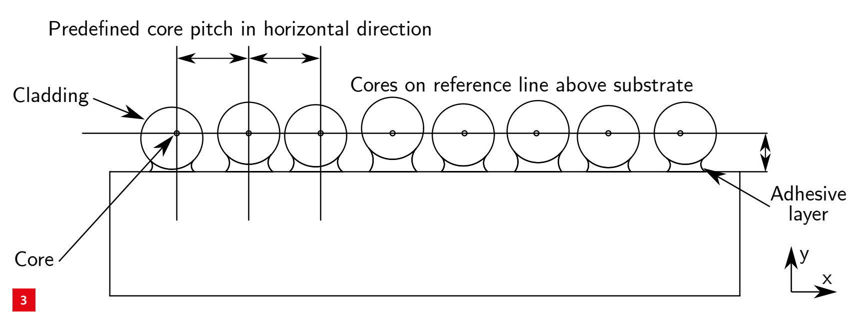


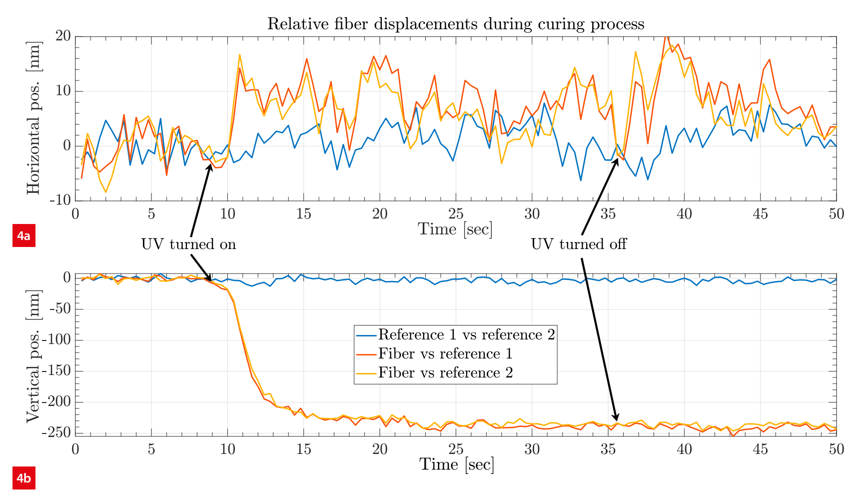
3

The proposed concept of the optical fibre array.

Active alignment methods that use optical feedback to optimise the waveguide alignment are able to compensate manufacturing tolerances of the fibre, enabling sub-micron-accurate alignment. Current active alignment methods, however, are time-consuming, with alignment times of multiple minutes per single fibre connection, and are therefore expensive and not suitable for volume production.

Optical fibre array concept

The main challenge to obtain a low-loss coupling for photonic devices is to overcome the accuracy bottleneck due to the manufacturing tolerances of the individual fibres. In the proposed concept the alignment is split up into two steps. First, a fibre array is assembled with a mutual lateral alignment accuracy of < 0.1 μm between the fibre cores. Later on, this fibre array is assembled in one step to the photonic chip. Since this step is not within the scope of this research, it will not be discussed further. A perfect alignment of the channels/waveguides on the photonic chip is assumed since these chips are made using a lithographic process. In reality, some small chip warpage is present due to the dicing process.
With our decoupled approach we eliminate the risk of having to discard an entire chip when a single fibre alignment has failed. Additionally, this allows for dedicated assembly equipment, resulting in faster and more economical production.



4a
4b

Measured fibre displacements during the adhesive curing process. The displacements are shown relative to fixated reference fibres.
(a) Horizontal (lateral) direction.
(b) Vertical direction.

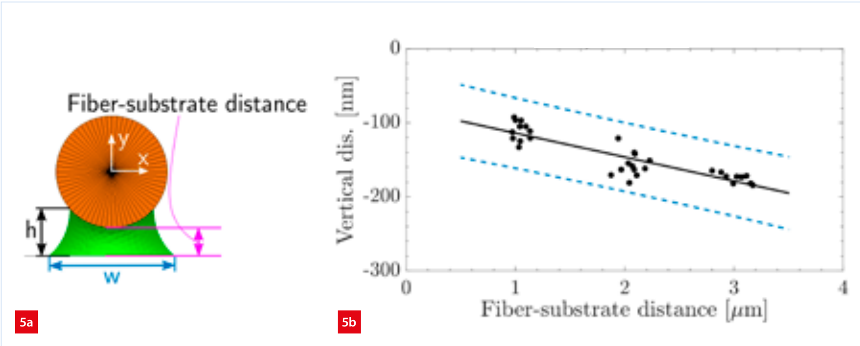
The array, shown in Figure 3, consists of multiple fibres, which are fixated to a flat quartz carrier substrate using UV-curable adhesive. Each fibre is individually actively aligned with respect to the already fixated fibres using a high-precision manipulator before curing. The adhesive layers are used to overcome differences in manufacturing tolerances of the fibres. During the alignment process the cores of the fibres are positioned so that there is no variation in the vertical direction on a horizontal line above the substrate and with a predefined pitch in horizontal direction. By using an adhesive as fixation method, the achievable distance between the fibres can be kept to a minimum since the adhesive only needs to be present on a small portion of the fibre diameter. The usage of a simple flat carrier without the need for any electrical connections or mechanical adjustments results in a cost-effective solution, where the number and pitch of the fibres can easily be varied for specific chip designs.

Adhesive fixation

Adhesives are prone to shrinkage due to curing, which can disturb the fibre alignment. As a result, not the alignment process itself but rather the fixation process forms the bottleneck in reaching the required sub-micron alignment. Simulations and experiments have been performed to investigate the shrinkage-induced fibre displacement for multiple selected types of adhesives. Figure 4 shows the typical fibre displacement due to adhesive shrinkage during the curing process. This figure presents the displacement of the fibre to be cured relative to the two reference fibres that are already fixated. When the UV-curing head is turned on, a clear vertical displacement is observed while simultaneously negligible horizontal drift is observed.

Capillary action results in the formation of a symmetrical bond profile around the fibre when the fibre is brought into contact with the adhesive, which explains the negligible observed horizontal drift.

To measure the shrinkage of selected adhesives, the fibre-to-substrate distance (indicated in Figure 5a) was varied between 1 and 3 μm. This range is sufficient to overcome the most typical fibre tolerances. Larger adhesive layer thicknesses are unfavourable due to a lower bond stiffness and an increased sensitivity for temperature-induced displacements. Figure 5b shows the results of one of the selected adhesives. A negative linear trend can be observed for the shrinkage as a function of the fibre-substrate distance in the examined range of 1 to 3 μm.



Measuring adhesive shrinkage.
(a) Schematic front view of the fibre-adhesive bond geometry (not-to-scale).
(b) The vertical fibre displacement due to adhesive shrinkage as a function of the fibre-substrate distance for one of the investigated adhesives (Nordland Optics 61).

The magnitude of the vertical fibre displacement upon curing lies between 100 and 200 nm, which is in general too large to achieve the required alignment accuracy. The repeatability of the process is however quite good, with a maximum 3σ-prediction bound of approximately –35 nm to +35 nm for the linear least-squares fit through the shrinkage measurement points, which is more than sufficient for the most critical fibre alignment applications. This linear fit is used to apply an offset to the position of the fibre before curing, in order to reach the desired alignment.

Environmental tests have been performed to evaluate the long-term stability of the adhesives since these are prone to mechanical creep and stress relaxation over time. The results of these tests indicate a sufficiently dimensionally stable adhesive bond for photonic fibre alignment with a 3σ position reproducibility of 110 nm.

Fibre-array assembly machine

To assemble the proposed sub-micron-accurate optical fibre array in an automated manner, a fibre-array assembly machine has been designed and realised; see the overview in Figure 6a. By automating the assembly process, a repeatable process is possible for volume production while the assembly costs are simultaneously reduced. The design of the alignment machine comprises three motion axes: a horizontal x-stage, a vertical y-stage and an axial z-stage. Both the vertical and the axial stage are connected in series to the horizontal stage.

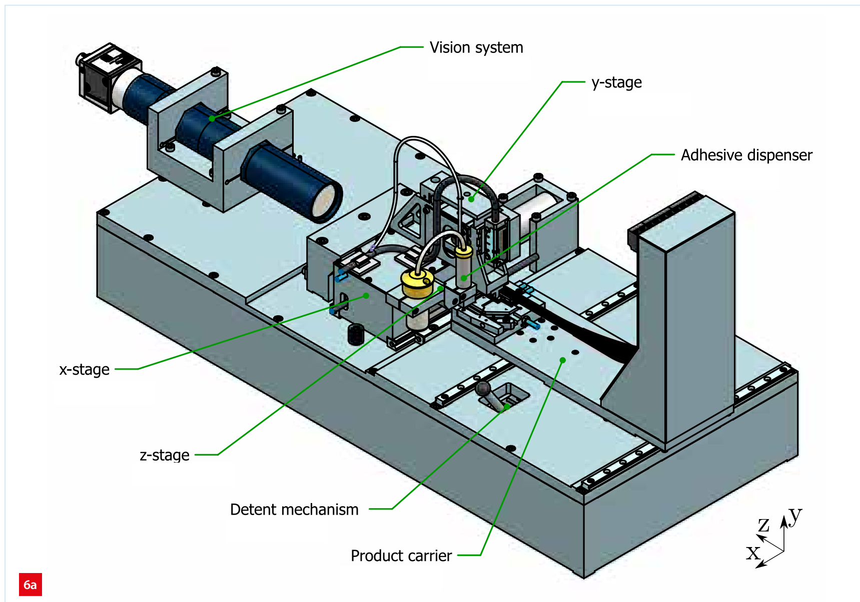
The following main production steps are executed by the machine to assemble an optical fibre array.

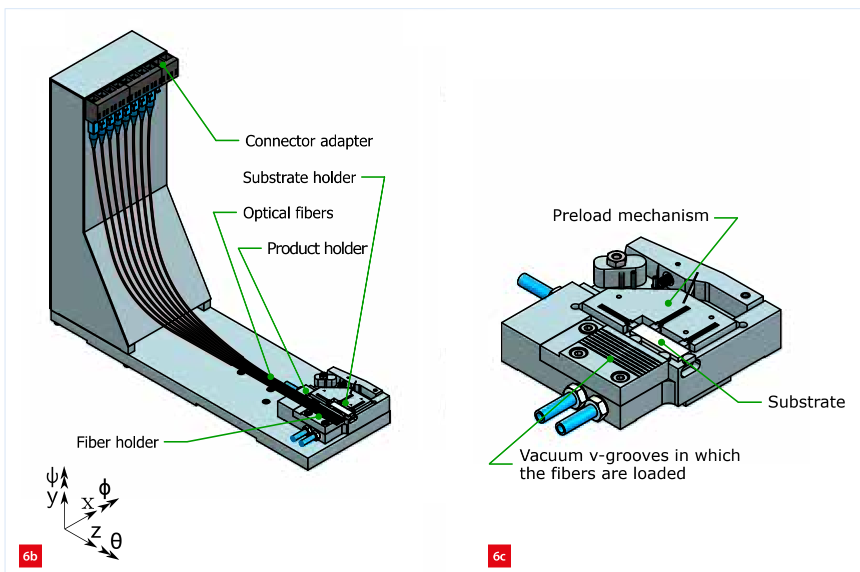
Pre-alignment

As input of the machine, a product carrier (Figure 6b) is used to which pigtailed optical fibres and a quartz substrate are manually loaded into a product holder (Figure 6c). The fibres are held in vacuum V-grooves in a fibre holder while the substrate is preloaded against end-stops and clamped using a vacuum. The product holder is used to determine the position of the fibres and substrate with respect to the other components of the machine. The holder is mounted onto linear guides, which enables loading and unloading of the fibres, substrate and arrays away from the alignment station. A detent mechanism is used to horizontally align the product holder relative to the other components of the alignment machine during a production run.

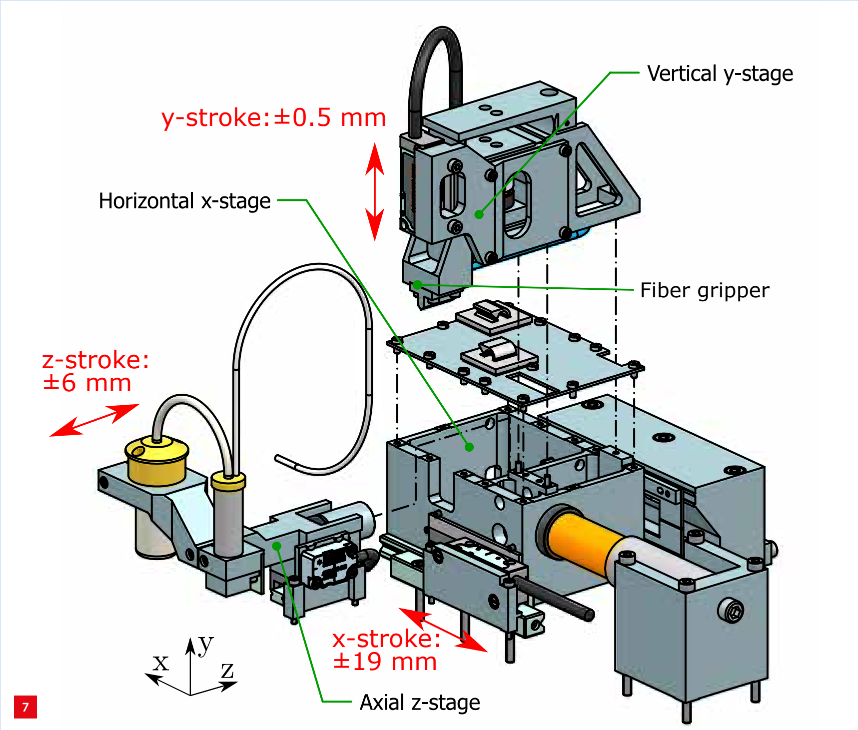
Axial z-alignment

A flat end-face mounted to the axial z-stage is used to mutually align the fibres passively in the axial degree of freedom (DoF). Using the z-stage, the end-face is pushed against the front surfaces of the fibres until all fibres in the vacuum V-grooves of the fibre holder will slip and align axially with each other.





The designed and realised fibre-array assembly machine.
(a) Overview.
(b) The product carrier.
(c) The product holder.

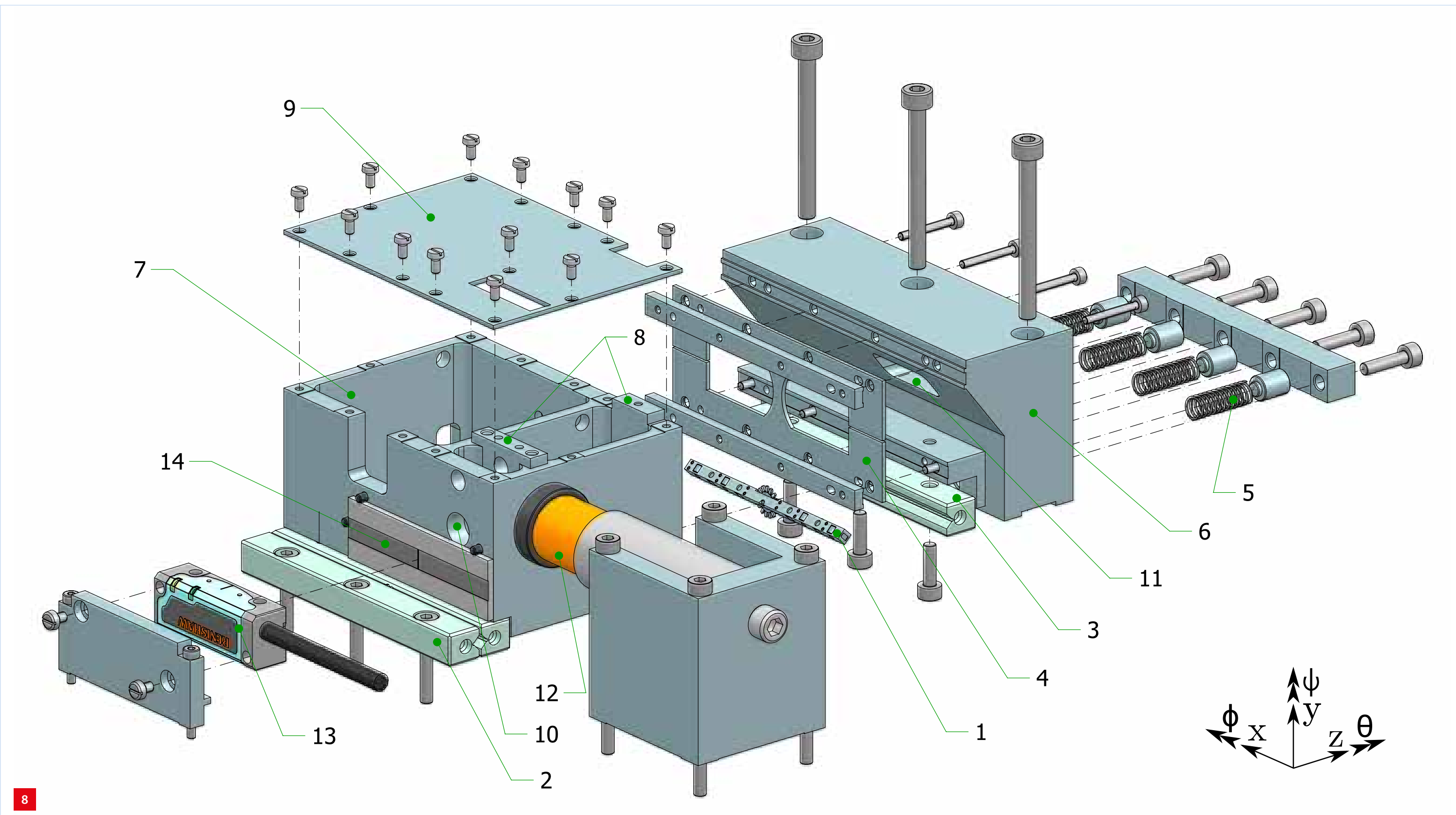


Overview of the motion axes of the fibre-array alignment machine. Indicated in red are the strokes of each axis.

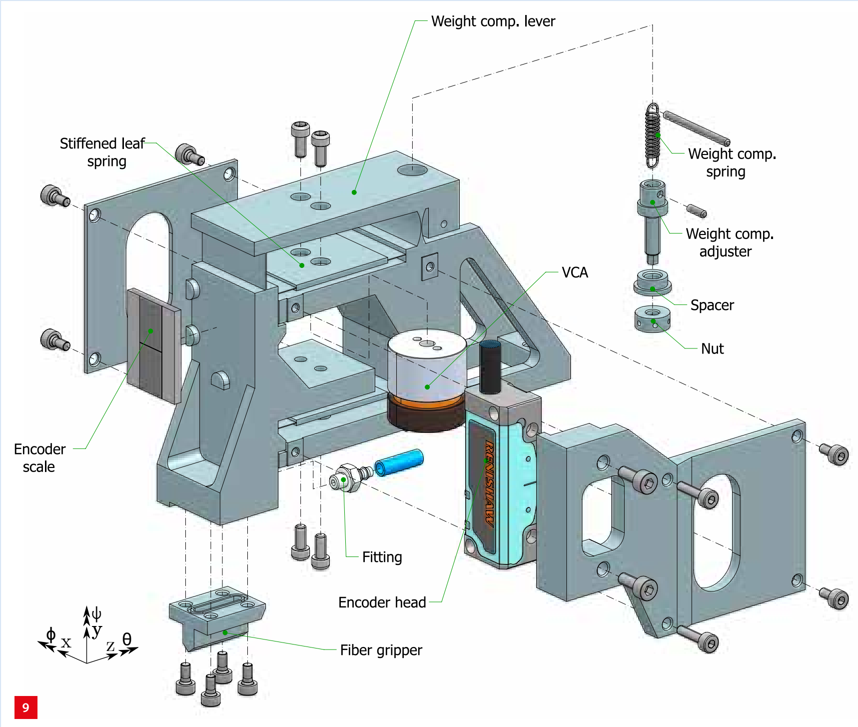
Adhesive dispensing
The fibres are fixated to the substrate using adhesive. An adhesive dispenser, mounted to the axial *z*-stage, is used to dispense multiple droplets in a straight line on the substrate.

Active alignment
The vertical *y*-stage is used to pick up fibres out of the fibre holder using a vacuum V-groove fibre gripper (the high-precision manipulator referred to above and explained in more detail below). Together with the horizontal *x*-stage, the *y*-stage actively aligns each fibre in the *x*- and *y*-DoFs with respect to already fixated fibres and reference fibres present at the product holder. The lateral *x*- and *y*-alignment directions are the most critical ones for obtaining an efficient fibre-chip coupling.

For the active alignment process, light is guided into the fibre connectors. A vision system is used to determine the fibre core positions. Contrary to traditionally used optical power measurements for active fibre alignment, both the current fibre position and the desired target position are instantly known when using the vision system, thus reducing the alignment time. A calibration method has



Partial exploded view of the horizontal x-stage.
1. Crossed-roller cage.
2. Main guide rail.
3. Secondary guide rail.
4. Hinged leafspring.
5. Compression spring.
6. Leafspring support.
7. Carriage.
8. Support point y-stage.
9. Top plate.
10. Carriage vision hole.
11. Support vision hole.
12. Voice-coil actuator.
13. Incremental optical encoder.
14. Encoder scale.



Exploded view of the vertical y-stage.

been developed for the vision system based on error-separation techniques to achieve both a relative and an absolute measurement accuracy of < 100 nm required for the generation of motion setpoints for the fibre alignment. The V-groove of the y-stage's fibre gripper is used to passively determine the less critical and not actively aligned ϕ- and ψ-DoFs.

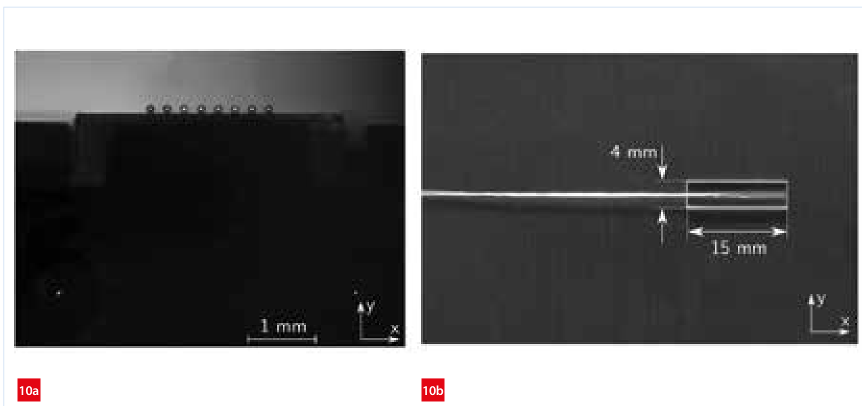
Motion axes

Figure 7 gives an overview of the motion axes including the motion directions. To minimise hysteresis and friction and allow for a high positioning resolution and control bandwidth, all three motion axes are actuated using voice-coil actuators. For position feedback of the axes, optical linear encoders are used, which are placed as close as possible to the output while maximally satisfying the Abbe criterion to minimise measurement errors.

The horizontal x-stage (Figure 8) of the machine consists of a closed box to attain a lightweight and stiff construction and is guided over a stroke of –19 mm to +19 mm using a linear, force-closed, statically determined crossed-roller bearing. The selection of this guidance results in a cost-effective, compact and stiff solution that can be easily maintained while a low friction and backlash is simultaneously attained. The main guide rail of the stage is directly fixated to the frame of the machine. The secondary guide rail is supported on a hinged leafspring and preloaded using multiple compression springs to obtain a force-closed, statically determined guidance. Experiments show that this guidance has a friction of less than 0.015 N, resulting in steady-state positioning errors of 5 nm (limited by encoder quantisation).

The vertical y-stage of the assembly machine (Figure 9) is provided by a flexure-based parallelogram straight-guide mounted to the closed box frame of the horizontal stage. The flexure-based parallelogram results in a backlash-free and frictionless motion over a stroke of –0.5 mm to +0.5 mm with a residual stiffness of 1,100 N/m and a first, bandwidth-limiting eigenfrequency of 865 Hz. A vacuum V-groove fibre gripper is integrated in the bridge of the parallelogram to pick up and place fibres, and simultaneously provide a passive fibre alignment in the other, not actively aligned, fibre DoFs, as enabled by the V-groove geometry. Due to this gripper geometry, only a fraction of the fibre circumference is retained by the gripper, allowing for a minimal fibre pitch of 127 μm (fibre diameter is 125 μm). To reduce power dissipation by the y-stage and prevent damage to the fibre gripper during a shutdown, a weight compensation mechanism is integrated in the parallelogram flexure.

The axial z-stage, fixated to the bottom of the closed-box frame of the horizontal stage, uses a linear guidance with running crossed-roller cages to move a dispenser head and glass end-face over a stroke of –6 mm to +6 mm. By translating the glass end-face mounted to this stage, the fibres are pushed back in the fibre holder to obtain a mutual axial z-alignment with an, experimentally determined, 50 nm repeatability. A non-contact dispensing system based on inkjet depositing is used to dispense multiple small adhesive droplets (Ø ~150 μm each) over a 10 mm line to enable dispensing near the already fixated fibres for fibre pitches down to 127 μm. After alignment, the adhesive is cured from underneath the substrate using a LED UV head focused by an optical system to obtain a homogenous and fast cure that will not disturb the fibre alignment.



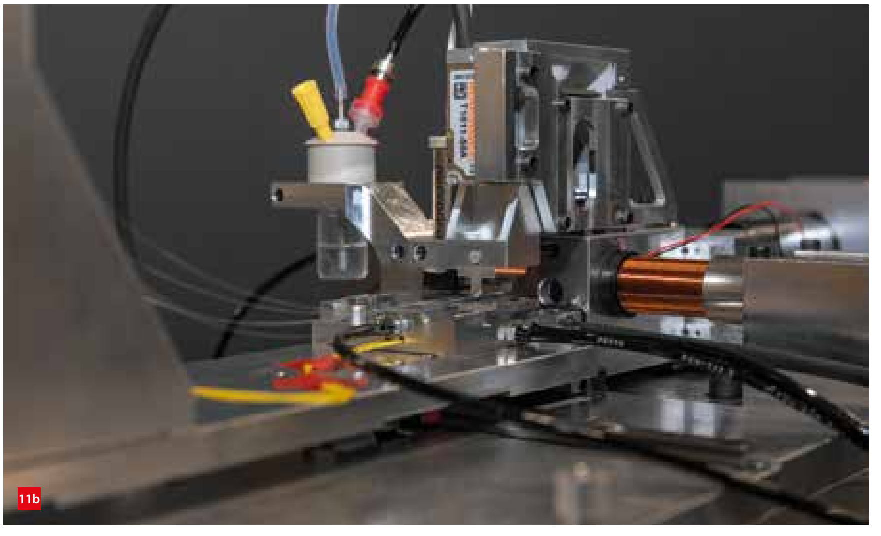
An assembled 8-fibre array with a 250-μm fibre pitch.
(a) Front view.
(b) Top view.

The thermal input to the assembly machine is simultaneously minimised due to the required short curing times and low power dissipation by the LED UV source. The thermal sensitivity of the metrology loop is significantly reduced by employing the two reference fibres located close to the substrate, since thermal drift between the substrate holder and vision system can be detected and compensated for both the lateral (x,y) directions and when rotation occurs around the camera axis. The thermal sensitivity of the metrology loop is reduced further by making the main components of the assembly machine from aluminium (high thermal diffusivity) and using a telecentric lens for the vision system (parallax error elimination).

Results

To assess the performance of the realised fibre-array assembly machine, multiple fibre arrays were assembled, each with a different number of fibres and a different fibre pitch, as small as 127 μm. Figure 10 shows both a front and a top view of an assembled array. The machine is able to assemble a 16-fibre array within four minutes. This is significantly shorter than currently employed active alignment methods can achieve, typically taking multiple minutes per single fibre connection. The curing of the adhesive takes approximately 68 per cent of the required production time and is therefore the major bottleneck for achieving shorter production times. By employing a faster curing adhesive, a significant reduction in the total production time of an array could be achieved.

During the assembly of ten 4-fibre, 250-μm-pitch arrays a maximum fibre alignment error of 81.9 nm was observed in the x-direction while a maximum error of 71.7 nm was observed in the y-direction. This is more than accurate enough for the most critical fibre alignment applications. When compared to traditionally employed V-groove arrays, an approximately eight times smaller alignment error in the x-direction and an approximately eighteen times smaller error in the y-direction was observed for the machine-assembled arrays, demonstrating a clear performance advantage. Figure 11 shows the realised fibre-array assembly machine.



The realised fibre-array assembly machine.
(a) Overview.
(b) The motion stages.
(c) The product holder.

VIEWING ONLINE PRESENTATIONS IN A LIVE SETTING

The DSPE Conference on Precision Mechatronics, which was cancelled last year due to the Covid-19 pandemic, will have a special edition on 14-15 September, 2021 that will combine two elements. Firstly, inspirational presentations, to be given online by invited international speakers, can be viewed at the Academisch Genootschap in Eindhoven (NL) on a large screen in a live, theatre-like setting. This will provide an opportunity for, secondly, the community to meet/network and exchange ideas in a pleasant atmosphere, which will include a BBQ.

Participation in the 2021 edition of the DSPE Conference on Precision Mechatronics is only for members of DSPE, Brainport Industries and the regional mechatronic knowledge exchange groups CGM and MSKE. The international speakers come from adjacent application areas such as bio-inspired mechatronics, robot-assisted surgery, virtual reality, artificial intelligence and more. The Tuesday afternoon and Wednesday morning sessions will feature keynote speakers from the USA and Asia, respectively, as well as speakers from the Netherlands and Europe.

Preliminary programme

Tuesday 14 September

- Facts and fiction about sustainable energy: How can each of us make a real contribution?
  Maarten van Andel
  Director of Fontys University of Applied Natural Sciences, Eindhoven (NL)

- A new generation of nanotechnological devices (to be confirmed)
  Barbara Mazzolai
  Associate Director for Robotics and Director of the Bioinspired Soft Robotics Laboratory, Istituto Italiano di Tecnologia, Genova (IT)
  A new model of a plant robot equipped with artificial intelligence able to have a collective behaviour, to monitor the health of the subsoil; and a new generation of nanotechnological devices for storing solar energy in hydrogen. These two projects, aimed at contributing to the protection of the environment in response to climate change, were successful in the most recent European Research Council's competition.

- Robots with Physical Intelligence
  Sangbae Kim
  Professor of Mechanical Engineering and Director of Biomimetic Robotics lab, MIT, Cambridge (MA, USA)
  While industrial robots are effective in repetitive, precise kinematic tasks in factories, the design and control of these robots are not suited for physically interactive

Prof. Sangbae Kim's research focuses on bio-inspired robot design based on extracting principles from animals. His achievements on bio-inspired robot development include the world's first directional adhesive inspired from gecko lizards, and a climbing robot, Stickybot, which utilises the directional adhesives to climb smooth surfaces, featured in Time's Best inventions in 2006. Recent achievements include the development of the MIT Cheetah capable of stable outdoor running up to 13 mph and autonomous jumping over an obstacle at an efficiency comparable to that of animals. This achievement was covered by more than 300 media articles.

performance that humans do easily. These tasks require 'physical intelligence' through complex dynamic interactions with environments, whereas conventional robots are designed primarily for position control. In order to develop a robot with 'physical intelligence', we first need a new type of machines that allow dynamic interactions. This talk will discuss how the new design paradigm allows dynamic interactive tasks. As an embodiment of such a robot design paradigm, latest versions of the MIT Cheetah robots and force-feedback tele-operation arms will be presented. These robots are equipped with proprioceptive actuators, a new design paradigm for dynamic robots. This new class of actuators will play a crucial role in developing 'physical intelligence' and future robot applications such as elderly care, home service, delivery, and services in environments unfavourable for humans.

- (Title to be announced)
  Patrick Naulleau
  Senior Scientist and Director of The Center for X-Ray Optics at Lawrence Berkeley National Laboratory, Berkeley (CA, USA)

Wednesday 15 September

- Thermal Effects and Precision Systems
  Theresa Spaan-Burke
  Innovation Director at IBS Precision Engineering, Eindhoven (NL)

- Investigating animal locomotion using biorobots and assisting humans with bio-inspired robotics technology
  Auke Ijspeert
  Professor of Biorobotics at EPFL and Head of Biorobotics Laboratory, Lausanne (CH)
  The ability to efficiently move in complex environments is a fundamental property for both animals and robots, and the problem of locomotion and movement control is an area in which neuroscience, biomechanics, and robotics can fruitfully interact. The presentation will focus on how biorobots (i.e. biomimetic robots) and numerical models can be used to investigate the interplay of the nervous system, the musculoskeletal system, and the environment in animal locomotion. Interesting properties for robot and lower-limb exoskeleton locomotion control will also be discussed. Time permitting, a recent project showing how robotics can provide scientific tools for paleontology will be presented.

- Robot Technology for Disaster Response and its Societal Dissemination
  Hajime Asama
  Professor of Service Robotics, University of Tokyo (JP)
  The response to the accident with the Fukushima Daiichi Nuclear Power Plant in 2011 required the utilisation of remote-controlled machine technology including robot technology, to accomplish various tasks in the high-radiation environment. This presentation introduces the robot technologies that have been developed and utilised for the disaster response and the decommissioning, and discusses technologies and their societal dissemination for disaster prevention and disaster response in the future.

- (Title to be announced)
  Tjin Swee Chuan
  Professor at Nanyang Technological University, Singapore; Co-Director of Photonics Institute Singapore; and Chairman of the LUX Photonics Consortium, Singapore

Professor Tjin Swee Chuan's research interests are in fibre-optic sensors, biomedical engineering and biophotonics. Over the years, he has published more than 300 refereed journal papers and conference papers, and has filed 40 patents in fibre-optic sensors, biomedical engineering and biophotonics. To date, he has received more than S$30M external research grants as principle investigator. In December 2000, he pioneered a start-up company that manufactures fibre-optic sensors providing sensing solutions for civil and geotechnical applications. More recently, he started another company with a colleague using the fibre-optic technology for monitoring contaminants in water, which he had developed in his lab.

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FRAGILE AND COOL

A novel design of a retractable imaging device that is able to facilitate a fragile image sensor has been developed. Two major design challenges characterise this design project. Firstly, the designing of a statically determined support for the fragile image sensor that ensures a low thermal resistance to meet the strict cooling requirements. Secondly, designing a non-overdetermined linear retraction mechanism with appropriate pretension and without collision forces at the end of its stroke.

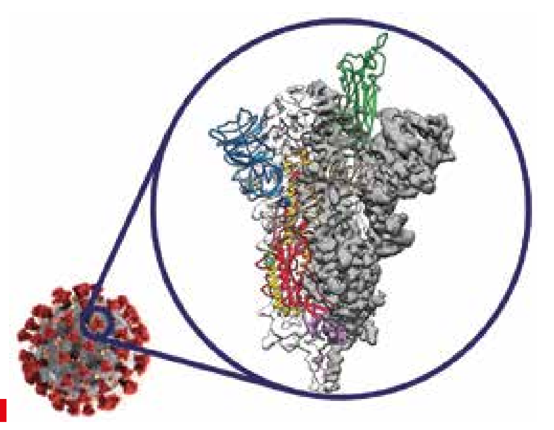
TEUN VAN DE SANDE

Imaging devices are used for capturing samples within, for example, structural biological or fundamental material research. Prodrive Technologies develops and manufactures such imaging devices. Figure 1 shows an example of the importance of the project described here. On the left, the Covid-19 virus is shown with its red crowns on top, depicting the S-proteins. On the right, a 3D reconstruction of an S-protein is shown, which was generated from approximately 3,000 images that were captured by such an imaging device.

The image sensor considered here is highly fragile, and should be able to withstand extreme temperature differences and thermal cycles while operating in a vacuum environment. Therefore, this sensor requires proper support. Furthermore, the imaging device should be able to insert and retract the image sensor with high repeatability.

Two major design challenges

A system decomposition resulted in two major design challenges to solve. Firstly, designing a statically determined support of the fragile sensor, including its strict requirements on cooling. Secondly, designing a high-precision linear retraction mechanism with a well-defined pretension and without end-of-stroke collision forces.



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A 3D reconstruction of the S-protein of the Covid-19 virus, which was generated from approximately 3,000 images captured by an imaging device [1] [2].

AUTHOR'S NOTE

Teun van de Sande graduated in mechanical engineering from the Eindhoven University of Technology (NL). For his master thesis work, supervised by Nick Rosielle, he received the Wim van der Hoek Award 2020. Currently, he is working as a mechanical system architect at Prodrive Technologies in Son (NL). The author acknowledges the support of Ron Hendrix of Prodrive Technologies.

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For confidentiality reasons, no further details on the design challenge and the specifications can be provided.

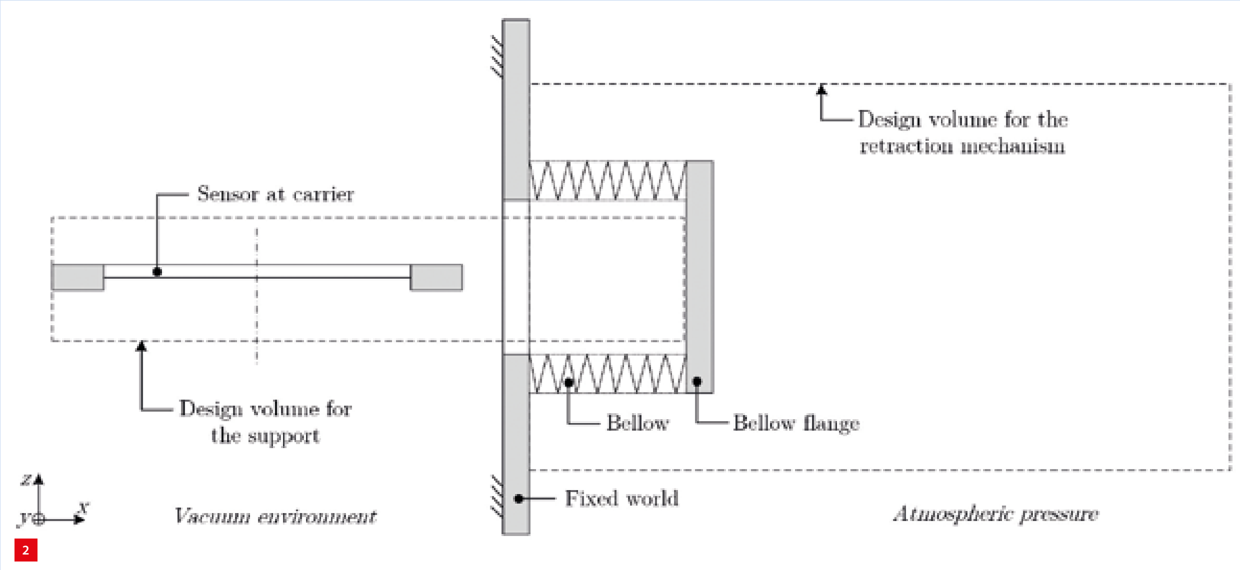
Figure 2 shows a simplified schematic section view of the proposed imaging device. The outer dimensions of the device are 200 mm x 150 mm x 75 mm (x, y, z). The image sensor is attached to a carrier and located in a vacuum environment. A vacuum bellow is used to separate the vacuum from atmospheric pressure. One end of the bellow is connected to the interface flange, which is the fixed world. The other end is closed by the bellow flange. As a result, only a minimal number of components is located in the vacuum, which minimises potential outgassing inside the vacuum environment.

Stress-free support of the image sensor

Minimising deformation during thermal cycling is critical in enhancing the lifetime of the imaging sensor, as this sensor is highly fragile. The induced stress can be minimised by choosing the right material. The image sensor is attached to a carrier with a comparable coefficient of thermal expansion (CTE) value. As the CTE values of both materials are comparable, low relative thermal deformation between the sensor and its carrier will occur. Moreover, the sensor's printed circuit board assembly (PCBA) is thermally decoupled from this carrier.

The carrier is attached to a heatsink that absorbs the dissipated heat. The extreme temperature changes require a stress-free and statically determined mounting of the carrier to the heatsink. Having thermal interface material between the heatsink and carrier ensures low thermal resistance, while allowing stress-free movement of the sensor and carrier.

Figure 3 shows this attachment. Three slotted holes in the carrier construct a thermal centre at the centre of the image sensor, which minimises thermal stresses and pixel movement at the same time. The thermal centre is indicated by the crossing of the dashed lines. The sensor's PCBA contains a flexible part to prevent constraining any degree



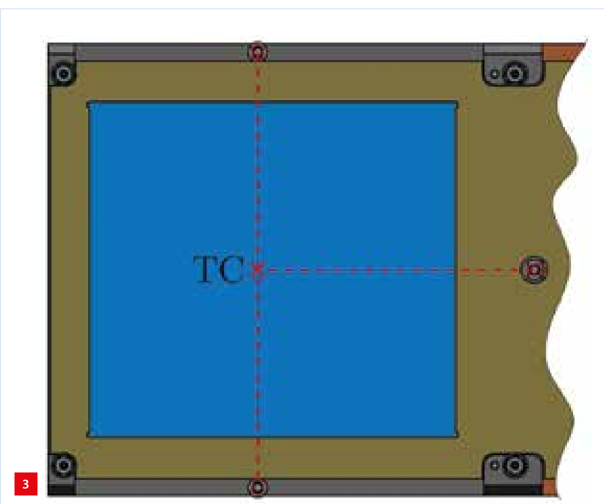
Schematic section view of the proposed imaging device, including the design volumes for the two major design challenges: sensor support and retraction mechanism.

of freedom (DoF) of the sensor assembly. In this way, the position of the sensor assembly is only defined by the support. Compared to, for example, a flexure mechanism for creating a thermal centre, this is a compact and robust design that eases assembly and manufacturability.

The support has a constant temperature during operation, which means that thermal deformation of the support can be considered negligible. Therefore, it is acceptable that the mechanical and thermal paths are not entirely uncoupled within this part.

Statically determined linear guide

Preferably, the motion path is defined mechanically to ensure no collision will occur during the movement. The stroke in x-direction is approximately 100 mm. Moreover, the bellow flange should be supported close to the interface flange at the inserted position to acquire considerable



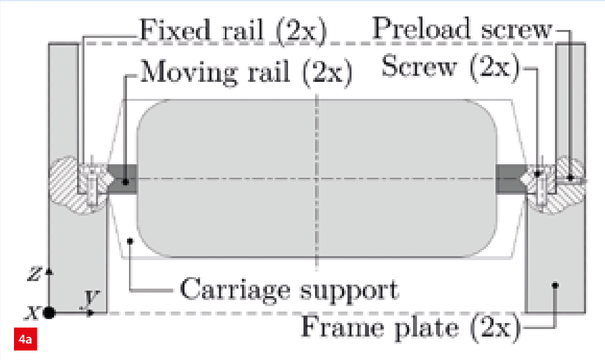
Top view of the cooling assembly. The crossing of the dashed lines indicates the thermal centre.

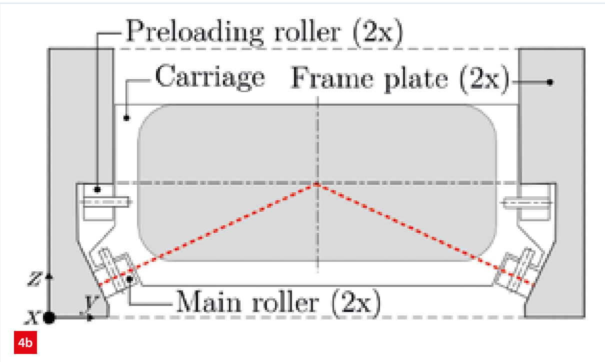
stiffness and to achieve the required repeatability. Figure 4a shows a typical guidance concept based on two conventional linear bearings, preloaded using preload screws. However, this preloading method will establish a form-closed construction, in which misalignment or wear can affect the preloading. This could result in unpredictable preloading with variations over the stroke (or over time), which negatively affects the dynamic behaviour in the inserted position. Moreover, this preloading method could be disadvantageous for thermal behaviour, as the sideways alignment is defined at the left linear bearing instead of at the mid-plane.

The linear bearings are constraining five DoFs each, which is considerably over-constrained. The degree of over-constraint should be diminished by strict manufacturing tolerances. Moreover, this linear guide will over-constrain the bellow as well. The bellow constrains one DoF, namely the rotation R_x around the direction of motion.

Over-constraint is not preferred as it induces internal stresses, which could negatively affect repeatability and result in damage in the long term. The linear guide as proposed in Figure 4b does not have these drawbacks, since it only constrains four DoFs (y, z, R_y, R_z) by pointing crowned track rollers towards the centre of the bellow.

Figure 5 shows the proposed design of the linear guide in an isometric view. The sensor assembly is mounted to a carriage that is guided on the frame plates using two sets of steel rollers, which are mounted to the left and the right side of the carriage. A set of rollers consists of two main track rollers at the bottom and one preloading track roller at the top. The preloading track roller is – viewed from above, along the z-axis – centred between both main track rollers.



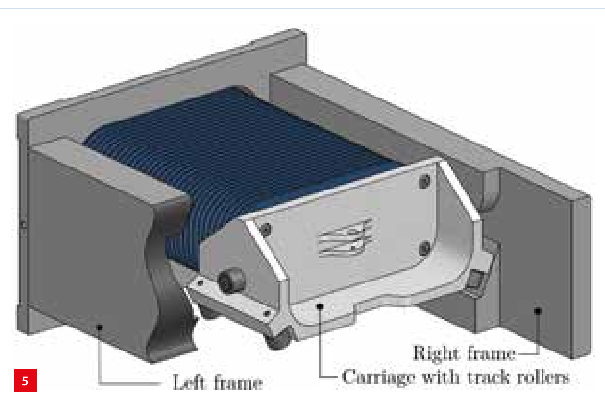


Schematic rear view of the linear guide concepts.
(a) Linear bearings.
(b) Track rollers.

This linear guide is symmetric and free to rotate the bellow in R_x, which minimises internal stresses. The bellow is attached to the linear guide, which is close to the interface flange in the inserted position to provide considerable stiffness at this position.

A bi-stable crank mechanism as drivetrain

The desired motion in the x-direction is performed by a crank mechanism, as shown in Figure 7. The crank is assisted by a compensation mechanism for the relatively high constant force on the bellow flange resulting from the pressure difference between the vacuum and the atmospheric pressure. A motor with a gearbox drives the crank mechanism.



Isometric view of the linear guide based on track rollers pointing to the centre of the bellow.

Personal note: Passion for precision engineering

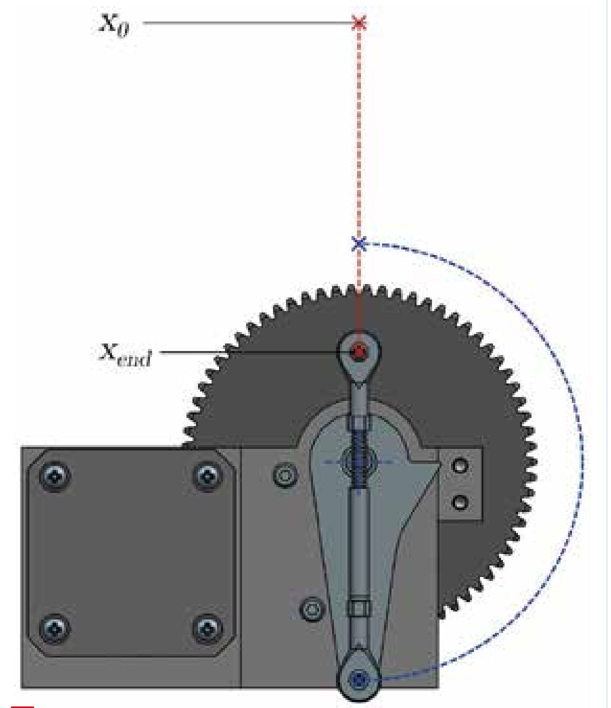
It has been an honour to receive the Wim van der Hoek Award for this work. My already substantial enthusiasm and passion for precision engineering grew extensively thanks to Nick Rosielle's passionate lectures on design principles. Precision engineering inspires me, as it enables us to push the boundaries in high-performance systems within extreme environments, which is the key to creating cutting-edge technologies.

The considerations for the linear guidance concepts presented here are a nice example of different design strategies. The first strategy is based on a commonly used off-the-shelf solution that over-constrains the construction, where the over-constraining should be diminished by tight manufacturing tolerances and assembly procedures. This is acceptable in most situations.

However, what if we create a statically determined design? Another strategy is to use an off-the-shelf solution and add, for example, a flexure to release the over-constrained DoFs. This results in less internal stresses and internal moments, which is beneficial for the predictability and durability of the design.

Nevertheless, what if the released over-constrained DoFs were never constrained at all? I think, that is designing according to Wim van der Hoek's design principles: a design strategy to create a construction or mechanism that exactly constrains the desired DoFs. Thinking one step ahead leads to an even lighter, stiffer and more compact design, while a statically and thermally determined design leads to beneficial dynamical behaviour and low hysteresis effects.

Van der Hoek's lecture notes (in Dutch), titled "Predicting Dynamic Behaviour and Positioning Accuracy of constructions and mechanisms", includes "The Devil's Picture Book", his collection of good designs from a dynamics and positioning point of view.



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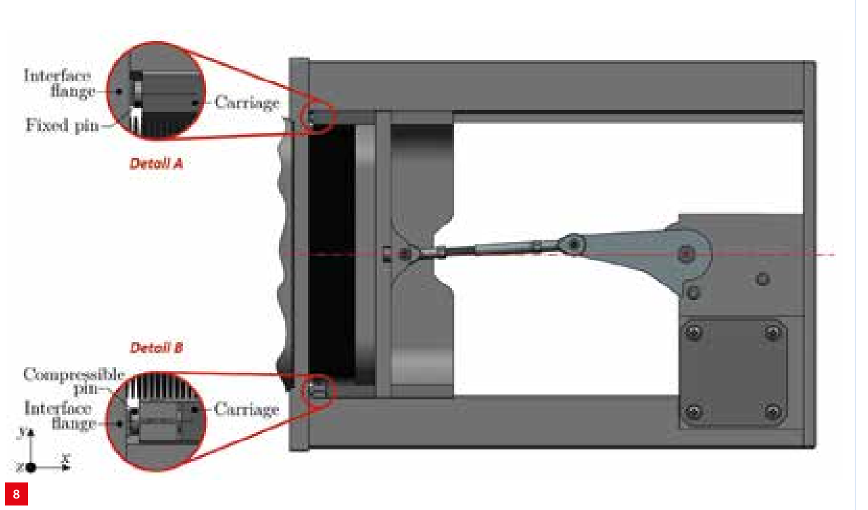
Top view of the crank mechanism and its motion paths, which are visualised by dashed lines. The stroke of the mounting point of the connecting rod is indicated by the red dashed line. The blue dashed line describe the rotational motion of the crank during the stroke.



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Top view of the retraction mechanism slightly before the end of stroke. The landing principle is shown by details A and B.

The crank mechanism has a relatively high stiffness in the inserted and retracted positions, as the connecting rod and the crank are aligned in these positions. This drivetrain design is compact, which enables its placement behind the carriage to correctly align the actuation force and the force acting on the bellow flange. In this way, no internal moments are induced. Despite these advantages, the crank mechanism causes a force perpendicular to the actuation force during the motion. However, this force is fully absorbed by the linear guide in the proposed design.

Landing without end-of-stroke collision forces

The velocity of the crank mechanism at the start and end of its stroke goes to zero by design, which ensures a collision- and shock-free movement of the sensor assembly. Naturally, the mechanism locks the sensor assembly in the retracted position.

At the end of the stroke, adequate landing at the interface is essential for minimising the induction of vibrations to the image sensor and for providing considerable stiffness in the direction of motion. Figure 8 shows a top view of the retraction mechanism slightly before the end of stroke, to explain the landing principle. Depending on the actual manufacturing tolerances, it is possible that the carriage has already landed at the interface, while the crank mechanism still needs to rotate a few degrees. In that case, the crank mechanism can finish its stroke by compressing the connection rod, without inducing internal stresses. During the stroke, the connecting rod is able to endure the tension stresses.

As a result, the collision velocity is not exactly equal to zero. However, the velocity of the carriage is sufficiently low if the crank mechanism is a few degrees before the end of its stroke. Therefore, the collision force will be within the order of 1 N, which is considered low enough.

The carriage has two rounded landing pins at the front end, which are able to land on a hardened surface of the interface flange. Both landing pins provide a point contact. The pins at the carriage should copy the (potentially misaligned) angle information of the interface flange in R_z to not over-constrain the linear guide, which significantly minimises internal stresses during landing. This is realised by one fixed landing pin (Figure 8, detail A) and one compressible landing pin (detail B), which are both placed symmetrically with respect to the mid-plane. The compressible pin needs to be fixed with a screw after installation to copy the angle information of R_z.

In conclusion, the sensor assembly support is statically determined while ensuring a low thermal resistance. At the inserted position, the landing interface provides considerable stiffness to the sensor assembly in the direction of motion (x), as close as possible to the interface flange. The bellow constrains one DoF (R_x), and the linear guide with track rollers stiffly constrains the other four DoFs (y, z, R_y, R_z).

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A PIVOTAL TECHNOLOGY

Scanning mirrors are widely used in optical systems to direct reflected light. Existing products such as galvanometers and resonant scanners are intended for accurate positioning at a low-frequency range and for fast scanning at a specified high frequency, respectively. However, when a wide frequency range is involved, these devices may not be able to fulfil the requirements. In this project, carried out at Hittech Multin, a novel solution was proposed, by tuning the resonant frequency of a scanning mirror and exciting higher-order modes to cover a wide frequency range of 500 Hz to 5 kHz. A test set-up has been developed, of which the results demonstrate that this frequency range can be covered, with a scanning angle range of 1 mrad for the reflected beam.

JIAJIN LI

Introduction

A scanning mirror is an important device in many optical systems for changing the direction of the beam in a scheduled manner [1]. It is widely used in applications for optical communications, material processing, microscopy, etc. [2, 3]. A conventional scanner usually has a galvanometric configuration with a closed-loop control system such that it can achieve the desired angles with high accuracy and resolution [4]. However, when operating at high frequency, high driving power is often needed, which means high energy consumption. Furthermore, due to a large rotational moment of inertia and nonlinear effects at high scanning speed, especially outside the control bandwidth, distortion of the output can be expected [5, 6].

Resonance

To achieve stable high-frequency scanning, a resonant scanner can be used. This has distinguishing features such as high stiffness, low mass and high *Q*-factor [7]. By making use of resonance, it is easy to achieve high-frequency oscillation with low power input and a simple electrical circuit [8]. However, most of these resonant scanning mirrors are designed to operate at the specified frequency. In some applications, such as live-cell imaging and high-resolution imaging in a scanning microscope, both high-frequency scanning (at a few kHz) and low-frequency scanning (at a few hundred Hz) are required [9]. Therefore, resonance should be used to achieve a high frequency, and tuning to cover a certain frequency range.

For generating mechanical resonance, mechanisms can contain elastic elements to provide a certain stiffness. One example is a resonant scanner in a clamped-free cantilever beam configuration, where a mirror is mounted at the tip, orthogonally to the axial direction [10]. But the scanning motion does not have a fixed rotational axis. Resonant scanning can be achieved by a torsional beam, with the rotational axis at the twist axis [11, 12]. In a resonant scanning device with a crossed-flexure configuration, the resonance can be generated by the crossed flexure itself [13]. A crossed flexure can also be used as a guiding, where the resonance is provided by an extra torsional resonator [14]. Even the rotational axis of the crossed flexure can shift during scanning, but this is rather negligible for small deflections [13].

All of these resonant scanners, however, are not tuneable, which means that they can only be operated at one intended resonant frequency. Some designers have attempted to make the resonant frequency adjustable, but this was only intended for error correction in a small range, in order to cope with manufacturing errors, mechanical wear, change of working conditions, etc. [15].

Application background

In the application of a scanning microscope system, a scanning mirror is needed. The basic principle is shown in Figure 1. A biological sample marked by a fluorescent substance is placed on a sample plate. On top of that, there are multiple scanning electron beams, each of which can

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Hittech Group

Hittech Group is a first-tier system supplier in mechatronics and optomechatronics. Within the framework of its technology programme, Hittech carries out research on laser scanning. In the quest for new technologies, Hittech defined a research project together with the Opto-mechatronics research group at Delft University of Technology. This concerned the development of a tuneable resonant scanning mirror, as described in this article. The project was carried out at Hittech Multin, a system supplier that combines development, value engineering, supply chain management and assembly.

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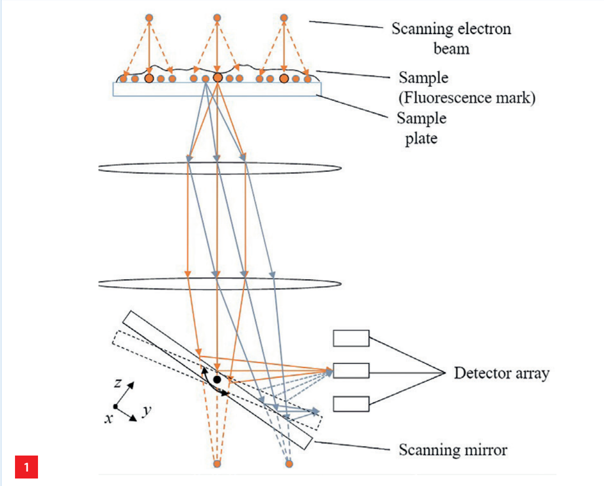

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Basic system principle and application background of a tuneable resonant scanning mirror.

scan its corresponding region. Once an electron beam hits the sample, fluorescent light is generated, captured by an optical system and focused on the corresponding detector in the detector array. It can be seen that the scanning motion of the electron beam modifies the optical beam path (from the orange one to the grey one), and therefore the mirror should rotate to compensate for this beam motion such that the focal point will always remain fixed at each of the detectors during scanning. To be able to achieve both high-resolution scanning and live-cell imaging, a wide frequency range needs to be covered.

Objectives and design requirements

- Frequency range: the resonant frequency of the scanner can be tuned in the range of 500 Hz to 5 kHz.
- Range of motion: the reflected beam is able to scan an angle in the range of 0-1 mrad; note that this means 0-0.5 mrad for the rotation R_x of the mirror.
- Beam size: the scanning mirror is able to cope with a beam size of 11 mm in diameter.
- Size: the device fits within 70 mm × 70 mm × 150 mm.

Note: no specific requirements on accuracy and resolution were set at the start of this 'proof of concept' project. These will be addressed in a subsequent control design phase.

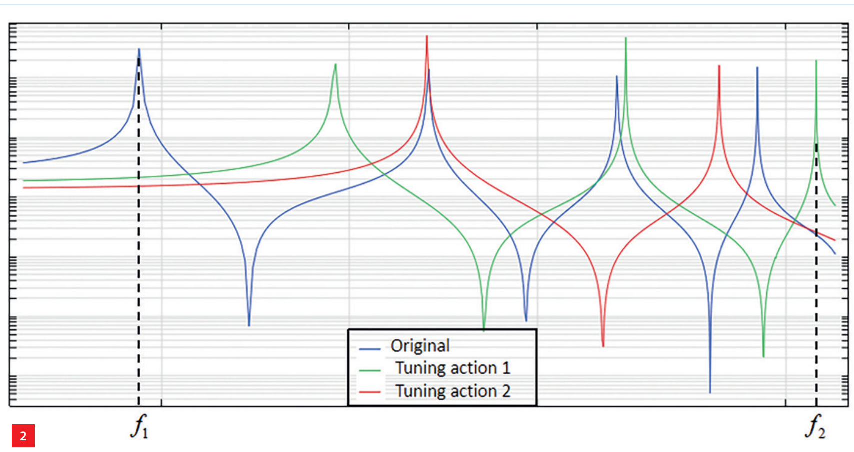
No literature has been found about resonant frequency tuneable devices for such a wide range in macroscale applications. Here, a flexure-based mechanism is presented that meets all the above criteria, as well as a new way of tuning the resonant frequency for a wide range. The end application of this device is to be integrated into a scanning microscope system (Figure 1).

Design and analysis

Concept

The desired frequency range is an order of magnitude (i.e., a factor of ten), which corresponds to two orders of magnitude change in the stiffness if the mass is unchanged. This is quite difficult when only one resonance mode is considered. Therefore, the basic concept to cover a wide frequency range is to combine the tuning action with exciting higher-order modes. Figure 2 shows a non-specific example of frequency tuning for a given range between f_1 and f_2. By applying the tuning action, the system response curve shifts from the original one (blue) to the right. It can be seen that the second and third peaks of the green curve have passed the third and fourth peak of the blue curve, and that the first peak of the red curve is coincident with the second peak of the blue curve. Therefore, the entire intended frequency range, f_1 to f_2, can be covered from the original curve to tuning action 2.

The design of a tuneable resonant scanner consists of two parts, a resonant scanner to provide one rotational degree of freedom (DoF) in resonant motion, and a frequency-tuning mechanism. The resonator inside the scanner mechanism is a cantilever beam, and the tuning action changes its effective length by clamping at different positions.



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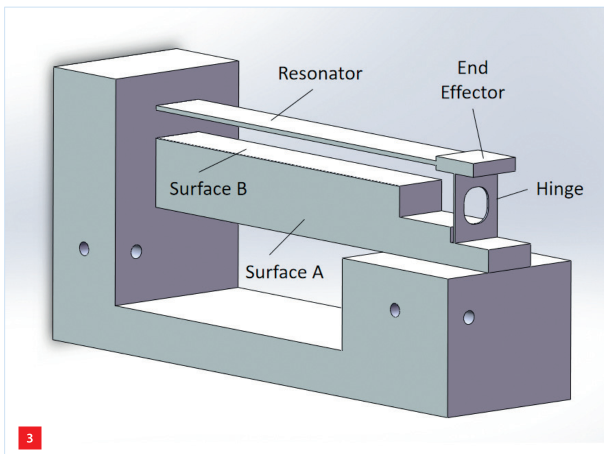
Concept of using higher-order modes for wide-frequency tuning.



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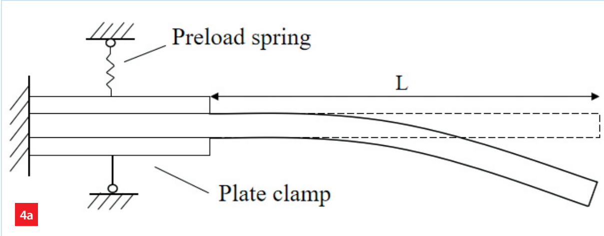
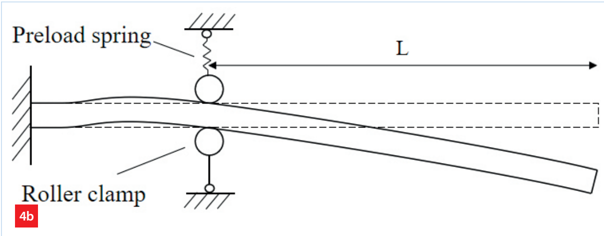
Design of the resonant scanner mechanism.





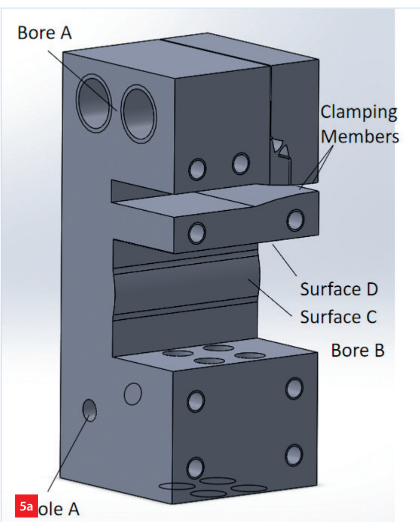
Schematic of a cantilever with clamping.
(a) Plate clamping.
(b) Roller clamping.

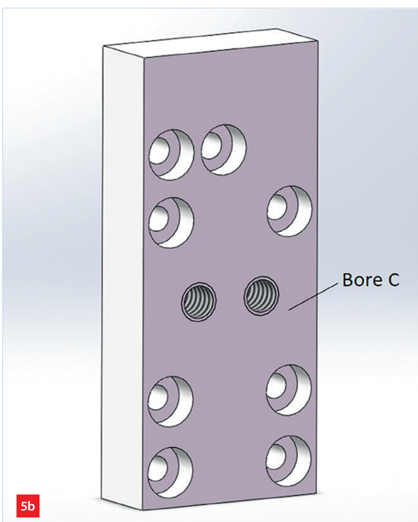
Resonant scanner mechanism
To achieve 1-DoF resonant scanning, use can be made of guiding mechanisms that have one rotational DoF, such as a crossed flexure or a notch flexure that has low rotational stiffness and high stiffness in other DoFs, while resonance is provided by a separate 'resonant actuator'. However, based on the resonator configuration and chosen tuning method, this design scheme may lead to a complicated mechanism. Alternatively, the cantilever can be treated as a leafspring that constrains three DoFs, and a mechanism can be synthesised using the freedom and constraint topology (FACT) method [16, 17]. The mechanism is then equivalent to a clamped-hinged cantilever.

The proposed design model is shown in Figure 3, where the hinge is a leafspring. A cut at its middle decreases its mass and hence further increases its first eigenfrequency, so that it will not interfere with the resonance motion of the cantilever. At the same time, this can reduce the rotational stiffness of the hinge guiding (and hence the required actuator force) as well as reduce the over-constraining effect of the entire mechanism; both effects are beneficial. The cantilever beam resonator is designed with dimensions of 12 mm × 1 mm × 90 mm such that the eigenfrequencies of the 1st to 4th bending modes are close to or remain in the range between 500 Hz and 5 kHz.

Frequency-tuning mechanism
To change the effective length of a cantilever, two clamping members can be used to clamp at different locations of the cantilever, with one fixed and the other preloaded by a spring; if the reaction force at the clamping position is less than the preload force, clamping members will stay in position. To make sure the clamping will function well, Hertzian contact must be considered as well; it is preferable to have a high Hertzian contact stress (< yield stress of the material), as it gives low-hysteresis clamping [18] and high contact stiffness. This means a small contact area with a high preload force will be favourable, and a large radius of curvature if a curved surface is involved. In this sense, using a clamping plate (Figure 4a) is intuitive to predict because the effective length L is well defined as the distance between the clamping end and the end effector, but this may lead to unwanted microslip. Clamping with a Hertzian line contact (Figure 4b) will be more suitable; a standard roller bearing can produce a line contact, but this will require tight tolerances in assembly. Furthermore, a large radius of curvature can lead to a bulky device.

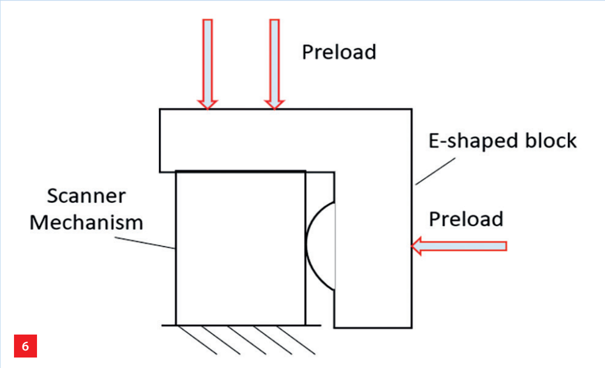
The proposed design has two parts, the first one being an E-shaped block, as shown in Figure 5a. It comprises two clamping curved surfaces with a large radius of curvature, provided with a diamond-like carbon (DLC) coating to enable sliding. A preload of clamping is applied by two springs (bore A) through a notch flexure, which is oriented in accordance with the direction of the reaction force. Between the second and third arm of the 'E', there is a curved surface C, which will be in contact with the plane surface A at the side of the scanner mechanism, whereas the plane surface D will be in contact with the surface B. In this way, these surface contacts constrain five DoFs of the E-shaped block, with a preload from the bottom (bore B) and side (bore C) to keep the block in position. This configuration is exactly constrained, as shown in Figure 6. After tuning, the block is locked by a flexible strut through hole A. It is therefore mounted in a statically determined manner. The second part, shown in Figure 5b, is designed to close the E-shaped block and strengthen it.





Clamping design.
(a) E-shaped block.
(b) Closing unit.

Finite-element modelling
The design has been analysed using finite-element modelling, with aluminium alloy 7075 T6 selected as material. A mirror



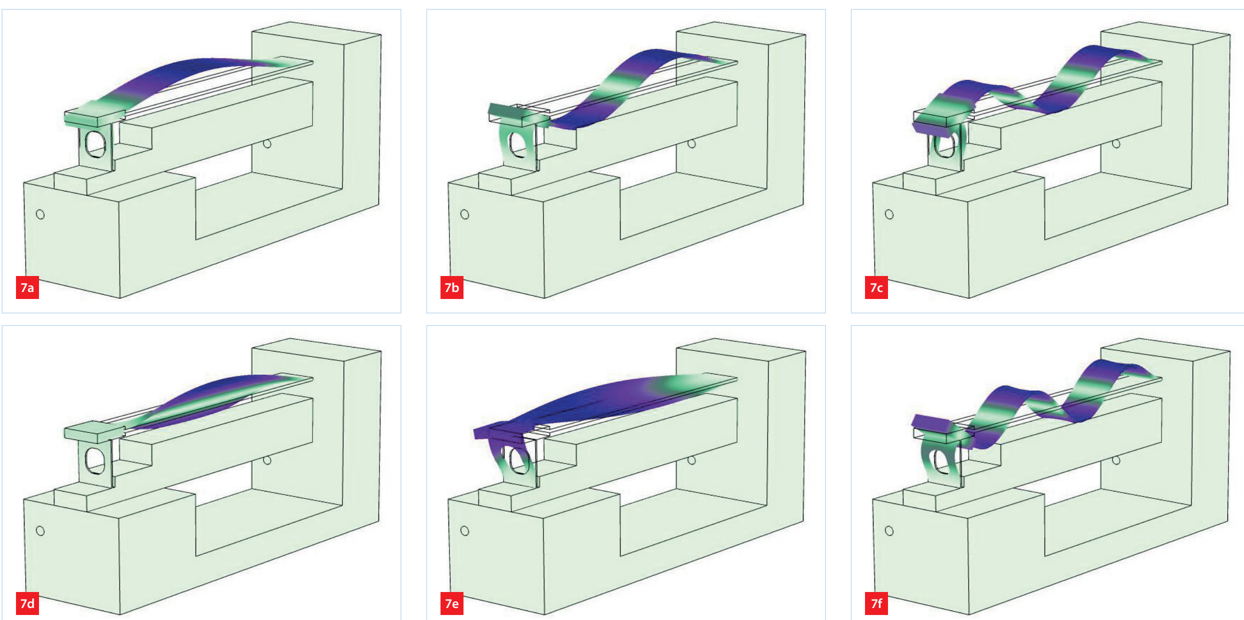
Exactly constrained contact configuration between scanner mechanism and E-shaped block, for defining the clamping position.

is placed at the end effector, with fused silica as material and dimensions of 10 mm diameter and 2 mm height. Modal behaviour and dynamic performance have been simulated. The first six eigenmodes of the scanner are shown as Figure 7, where Figures 7a, 7b, 7c and 7f show the 1st, 2nd, 3rd and 4th bending mode of the resonator, respectively. It can be seen that there are other unwanted modes, which are a torsional mode (Figure 7d) and a transverse mode (Figure 7e). Therefore, it is important to eliminate modal coupling so that the scanning motion can be relatively pure.
It will be difficult to eliminate the transverse mode and torsional mode (and their higher-order modes) of a cantilever in the range of 500 Hz to 5 kHz while its bending modes are in this range, especially when starting the tuning of the bending modes, when other unwanted modes will be tuned as well. To avoid modal coupling, modal behaviour with respect to the clamping position has been studied by modal analysis (the cantilever resonator has a length of 90 mm).

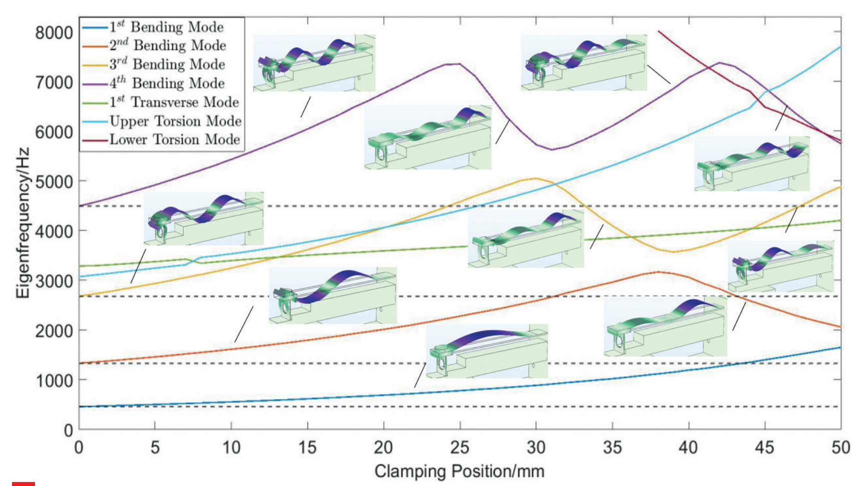
Figure 8 shows an estimation of the modal behaviour of the bending and unwanted modes. It can be seen that by moving the clamping block to around 45 mm, all four bending modes can connect or overlap with their higher ones. Drops of the eigenfrequency occur in some particular ranges of the clamping position, due to the elastic mode of the beam between the clamping block and the base, of which the eigenfrequency decreases with increasing length, as realised by moving the clamping block further from the base. These regions can hardly cause any amplitude at the end effector, and therefore should be avoided.
The 1st transverse and the upper torsional mode (between the end effector and the clamp) start from around 3,000 Hz, and couple into the 3rd bending mode at a clamping position of around 13 mm and 20 mm, respectively, as denoted by intersecting lines in Figure 8. When the clamping block is near 45 mm (halfway the cantilever), the lower torsional mode (between the clamping block and the base) starts to appear close to the working frequency range. At this clamping position, coupling between the transverse and the 3rd bending mode is seen again. It is therefore necessary to be aware that modal coupling between bending and unwanted modes will take place in the range between 3 and 4 kHz, and larger input power can be expected, since unwanted modes will consume energy. To minimise this coupling, accurate alignment of the actuator should be realised such that the force acts at the centre line in the bending direction. In addition, to ensure that the resonance generates a scanning amplitude, only regions with positive slope could be considered as usable ones.

Test set-up

The scanner mechanism and E-shaped block of the frequency-tuning mechanism have been monolithically



Vibrational modeshapes at the first six eigenfrequencies.
(a) 457.61 Hz. (b) 1,321.5 Hz. (c) 2,638.7 Hz.
(d) 2,993.6 Hz. (e) 3,195.6 Hz. (f) 4,413.3 Hz.



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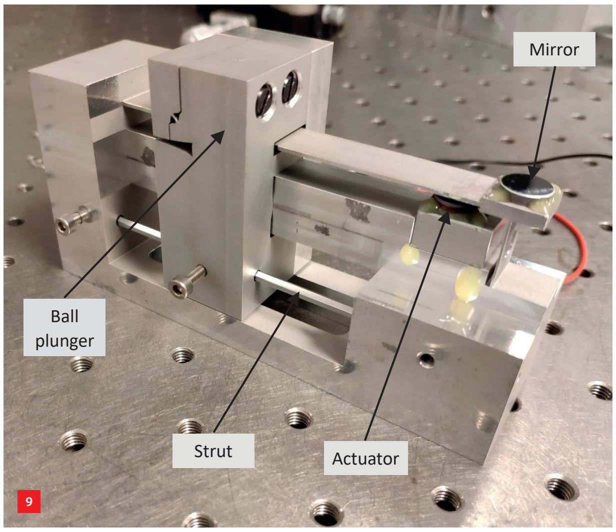
Modal behaviour with respect to clamping position.



9

The scanner and test set-up, showing the mirror, the ball plunger, the strut and the electromagnetic actuator (magnet plus coil).

machined by spark erosion. The assembled system is shown in Figure 9. A mirror is glued to the end-effector stage, and a magnet is glued to the bottom side of the resonator beam. A coil is aligned underneath according to the magnet position. Preload is applied by a ball plunger; its tip is a ball connected to a spring, and the outside is threaded. After tuning, a strut is used with screws perpendicularly tightened in order to lock the frequency tuning mechanism.

To measure the scanning angle, a power meter is placed at a distance L away from the mirror, and a knife-edge is placed in front of the power meter to block part of the reflected light beam. During the scanning, the displacement d of the reflected beam spot at the power meter is obtained from the detected power change, and the scanning angle is calculated as $R_x = d/(2L)$.
During the measurement, firstly, a chirp signal is applied to locate the resonant frequencies. The frequency response function is measured from actuator current (input) to scanning angle (output), and then normalised by the first peak at the 0-mm clamping position. Secondly, an excitation is applied at resonance such that the scanning angle is equal to 0.5 mrad, and the corresponding amplitude is used to locate frequencies with half that gain to determine the Q-factor, which is calculated as $Q = f_r/\Delta f$, where f_r is the resonant frequency and Δf the difference between the two frequencies corresponding to half the gain at resonance. Then, the clamping position is changed and the two steps are repeated.

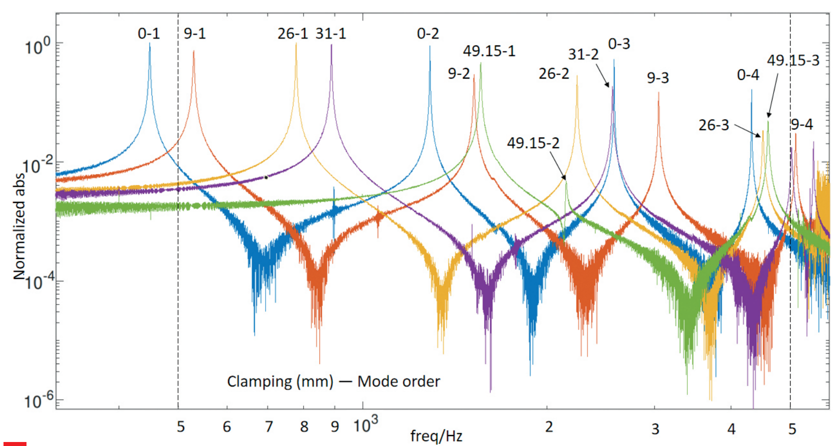
Results and discussion

Figure 10 shows the frequency response within the 500 Hz to 5 kHz range at clamping positions of 0 mm, 9 mm, 26 mm, 31 mm and 49.15 mm (maximum stroke) from the base; the gain is normalised by the gain of the first peak at the 0-mm clamping position. This is the 1st bending mode of the resonator beam itself. At 0-mm clamping, the measured current for a 1-mrad angular movement of the reflected beam at modes 1 to 4 is around 20 mA, 24 mA, 64 mA and 224 mA, peak-to-peak, respectively. For various (practical) reasons, not all modes at the other clamping positions could be measured.

It can be seen that the frequency range of 500 Hz to 5 kHz can be covered by moving the frequency-tuning mechanism within its range. At around 26 mm, 31 mm and 46 mm clamping position, the 3rd, 2nd and 1st bending mode can connect to the 4th, 3rd and 2nd bending mode of the resonator beam itself, respectively, and at the 9-mm clamping position, the 4th bending mode is at 5,102.3 Hz.

The measured Q-factor stays within the range of around 200 to 500, but no clear regular pattern (for example, a decay with increasing mode order) can be found. It can be pointed out that starting from the 2nd peak of the resonator itself, amplitudes of the frequency response drop by a certain negative slope, and this may be partly due to the cut-off frequency of the actuator, because of the limited accuracy and a relatively large gap between the coil and the magnet that remained after hand alignment. An improvement can be achieved by adding an iron core inside the coil to strengthen the magnetic field and reduce the magnetic reluctance, while the air gap between the magnet and the coil can be reduced by a more sophisticated alignment.

Figure 11 compares measurement (circular dot) and simulation (line) of the resonant frequencies of the bending modes 1 to 4. At the 0-mm clamping position, the measured resonant frequency of the first four bending modes is 448.8, 1,288.8, 2,577.6 and 4,324.1 Hz, respectively, with an error (difference between t measured and simulated value) of 1.93%, 2.47%, 2.32% and 2.02%, respectively. This error is mainly due to manufacturing tolerances. With manual



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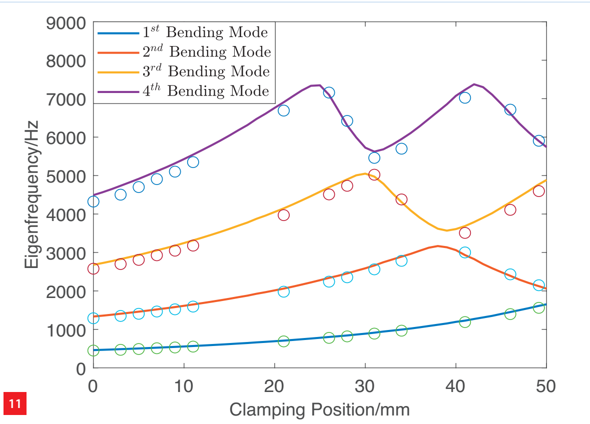
Normalized current-to-angle frequency responses at several clamping positions in the range of 500 Hz to 5 kHz. Gain normalised to the first peak at 0 mm clamping. The numbers at each peak indicate the clamping position (0, 9, 26, 31 and 49.15; all in mm) and the mode order (1, 2, 3, 4).

positioning of the frequency-tuning mechanism, a clamping position accuracy of 50 µm can be achieved. Regarding the error, this can be bounded within 5%.

Conclusion

A flexure mechanism design of a tuneable resonant scanning mirror has been presented. The scanner mechanism contains a bending cantilever as resonator and a cut-leafspring as hinge guiding to provide one rotational DoF. The tuning method is to change the effective length of the resonator beam, and this is realised by two clamping surfaces with a large radius of curvature, one of which is fixated and the other is preloaded. This provides a large contact stiffness and low hysteresis clamping. Sliding is enabled by DLC coating and therefore the clamping position can easily be changed. A novel tuning concept has been proposed, based on exciting higher-order modes of the resonator, so that the scanner can achieve resonant motion over a wide frequency range.



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Comparison between the measurement (circular dots) and simulation (curve) resonant frequencies with respect to the clamping position.

Finite-element analysis has demonstrated that by clamping from 0 mm to around halfway the cantilever, the first four bending modes can cover the intended frequency range of 500 Hz to 5 kHz. However, it is necessary to be aware that some frequency regions exhibit modal coupling or hardly generate a scanning amplitude.

The design has been realised in hardware. The performance, as specified by the requirements above, has been verified by measurement on a prototype:

- Frequency range: 500 Hz to 5 kHz, achieved by moving the frequency-tuning mechanism from 0 mm to around 46 mm from the base.
- Range of motion: 1 mrad scanning angle, although at high frequency a relatively large current amplitude is needed, which is partly due to the cut-off frequency of the actuator.
- Beam size: end effector of 12 mm × 12 mm, on which a mirror with 12 mm diameter is placed.
- Size: 127 mm × 35 mm × 68.9 mm.

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REDUCING CROSS-TALK

A 4-DoF monolithic decoupled mechanism to be applied as an optical mount and suitable for additive manufacturing (AM) has been designed. It is composed of two 2-DoF parallel stages in series, one for translations and one for rotations. Prototypes were made using AM and numerically and experimentally evaluated and compared. They were shown to be functional and have eigenfrequencies that are sufficiently high for the intended application, although they still exhibited too much cross-talk (parasitic motion), for which the design needs further improvement and optimisation.

NIEK VAN HOEK

Introduction

Optical systems are increasingly applied in industrial processes. In the semiconductor industry, for example, optical systems are required for both the production and the inspection of microchips. An optical system consists of a series of optical components that direct the light going through the system. The decreasing size of details on microchips results in high requirements for positioning resolution and stability of the optical mounts that are used to align the optical components with the light path.

Conventional mechanisms with sliding rigid bodies suffer from hysteresis and (virtual) play, which affects the adjustment resolution when applied for kinematic optical mounts. In addition, coupling between the degrees of freedom (DoFs) makes it difficult for the operator to tune the mount to the desired position by hand. As optical systems can contain a multitude of optical mounts, it can take a significant time to calibrate the complete system. Another issue is that machines with optical systems used in industrial environments are subject to vibrations. Resonance then results in position errors or structural failure and should be prevented by realising a high eigenfrequency of the mount.

Compliant mechanisms have no friction, no backlash and no wear; they are therefore ideal candidates for high-precision applications with a high required adjustment resolution. When the mechanism is manufactured as a monolithic product, there are potentially lower costs as a result of reduced assembly time and effort, fewer spare parts and simplified manufacturing. Cumulative errors in serial compliant multi-DoF mechanisms generally result in more cross-axis coupling and parasitic motion (cross-talk) compared to parallel multi-DoF mechanisms that have no cumulative errors. Also, parallel mechanisms usually have a low inertia and a high stiffness leading to higher eigenfrequencies.

As designing parallel compliant mechanisms often results in complex structures with a significant number of flexure elements, the costs of manufacturing using conventional production methods such as wire electrical discharge machining and milling is high. The progress of additive manufacturing (AM) of metals, however, has resulted in manufacturing methods that are not affected by the complexity of the design. The design freedom of AM also makes it possible to optimise the parameters of the design to increase the stiffness while staying within yield limits at maximum displacements. Furthermore, machining methods such as milling are relatively expensive for the high-performance materials that optical mounts are made of, such as titanium alloys, which is not the case for AM.

Based on all these considerations, in this article the design of a monolithic compliant optical mount with four decoupled DoFs and an eigenfrequency of at least 500 Hz that is suitable for AM production is presented. Prototypes of the optical mount were manufactured from titanium, and evaluated experimentally.

Design

The design objective was a 2-inch concave mirror mount with a 4-DoF adjustment mechanism: two orthogonal translations in plane of the mirror and two tilting rotations out of plane, with adjustment ranges of 1 mm and 1 mrad with a resolution of 1 μm and 10 μrad, respectively. The axes of rotation for tip and tilt have to pass through the optical centre of the mirror. Since the requirements for different applications may be different, a transmission mechanism is needed for each adjustable DoF to allow for adjusting the input stiffness and resolution.

The proposed design of the optical mount is shown in Figure 1. The adjustment mechanism can be regarded as composed of two parallel stages in series: (1) the stage with two translational adjustments that is bolted to the base at the four round holes shown in the drawing; and (2) the stage suspended by leafsprings 1, 2, 3 and 4 (in blue) that enables the rotational adjustments around the two axes of rotation indicated with dashed lines. The mirror

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This article is based on his thesis work in the Mechatronic System Design research group at the department of Precision and Microsystems Engineering in cooperation with VDL ETG. The research was supervised by Gerrit Oosterhuis (VDL ETG) and Volkert van der Wijk and Just Herder, both at Delft University of Technology.

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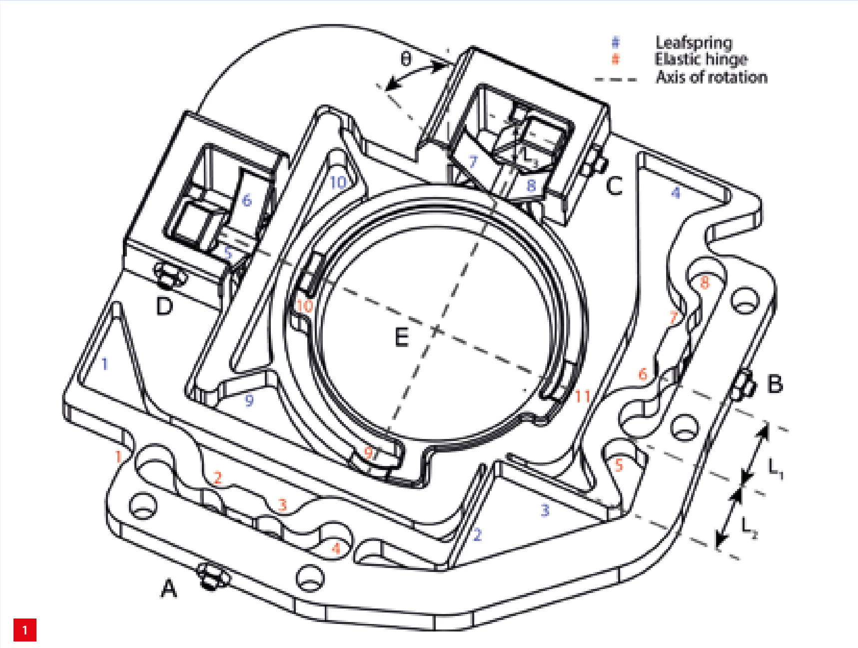

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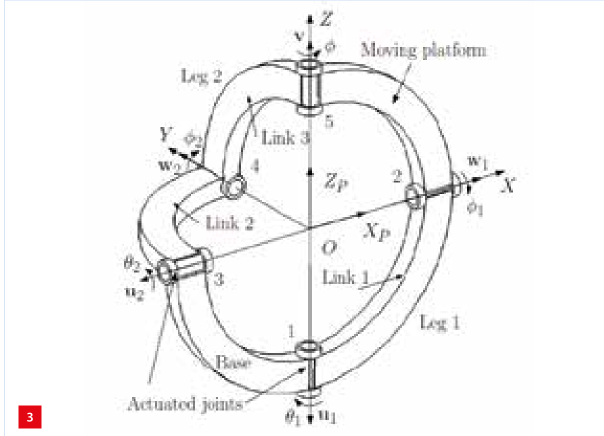
Design of the 4-DoF decoupled monolithic mount with inputs at A, B, C and D, and output at E.



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Drawing of the 5-bar 2-DoF spherical mechanism [2].

is to be mounted in the ring in the middle of the design at E. The DoFs are manually actuated using adjustments screws in A, B, C and D.

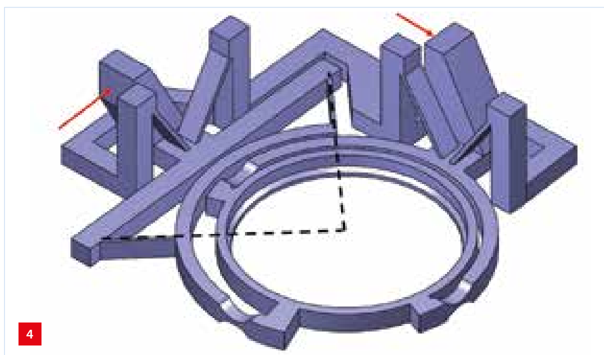
Figure 2 shows the concept of the translational stage which has parallel translational adjustments in X- and Y-direction, indicated by arrows. The rectangular moving platform is suspended by two orthogonal sets of parallel leafsprings These parallel leafsprings allow transverse motion, but have high stiffness in axial direction. An axial displacement is applied with a lever mechanism that is actuated by the adjustment screws pushing them in the direction of the arrows, increasing the size of the gap. This results in a displacement of the motion stage in the opposite direction. The pairs of leafsprings do not perfectly decouple the motions, as the shortening effect of the leafsprings results in a small parasitic motion. This is estimated to result in a cross-axis coupling error of 24 μm at a 1 mm displacement between both translational DoFs. The curved geometry was chosen to prevent local stress concentrations.

On the rectangular moving platform, the tip-tilt stage is placed, which is based on the 2-DoF decoupled spherical 5-bar mechanism [1] shown in Figure 3. Actuation of rotational base joints 1 and 3 results in tip and tilt motions of the moving platform link around the same axes. Joints 2, 4 and 5 decouple these rotations, allowing for parallel decoupled adjustment of the tip-tilt orientation. This mechanism was redesigned to be monolithic and suitable for AM, for the function of an optical mount allowing a free path for the light. This resulted in the new design shown in Figure 4. When printed it does not have floating structures and has limited overhang, which prevents the need for temporary support structures during AM.

The rotational actuation is applied by displacements at the arrow locations by a lever suspended by cross-flexures. Joint 5 is replaced with a notch hinge and joint 2 with two notch hinges on both sides of the mirror mount, which allows rotation about the same axis. This yields improved stability of the mirror mount. The rotational axis of joint 4 has to be perpendicular to the axes of rotation for the tip and tilt motions. This joint with a cross-flexure rotation around the Z-axis is shown with the dashed lines in Figure 4. The two stages are combined by connecting the fixed base of the rotational stage in Figure 4 to the two sets of parallel leafsprings of the translational stage in Figure 2, yielding the design of Figure 1.

2

Design of the 2-DoF parallel decoupled compliant translational stage.



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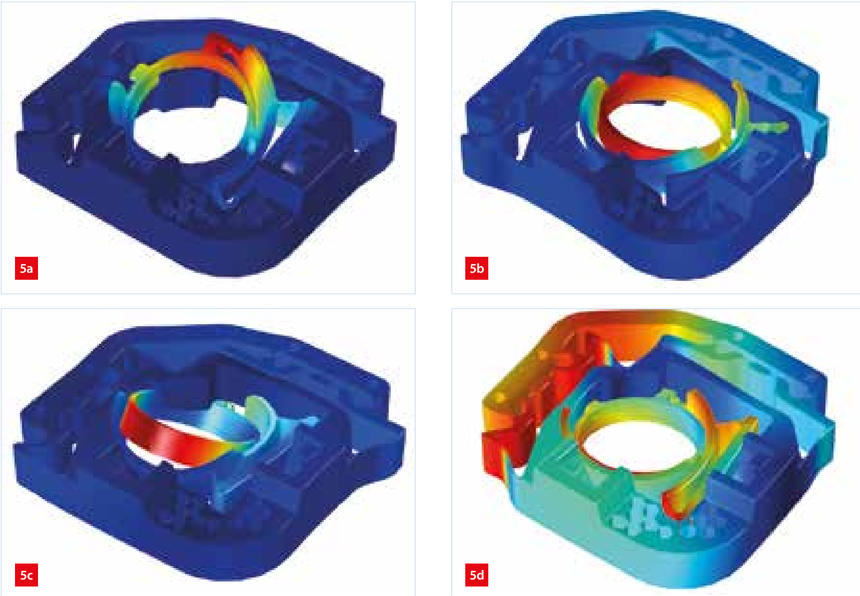
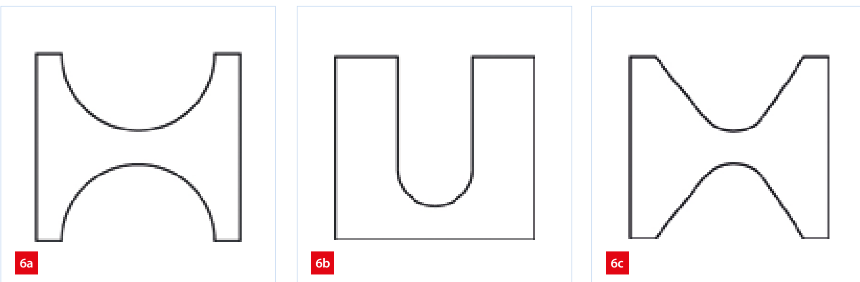
Design of the 2-DoF parallel decoupled compliant tip-tilt stage suitable for AM.



Finite-element analysis of the design.
(a) First eigenmode. (b) Second eigenmode.
(c) Third eigenmode. (d) Fourth eigenmode.

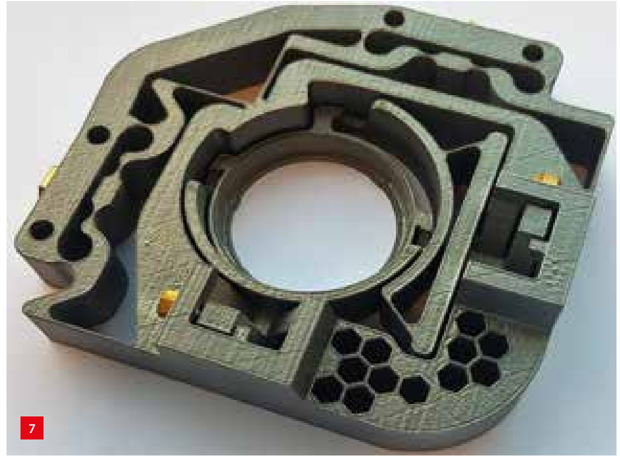


Design variations of notch hinges used in the different prototypes (see text for explanation).

Validation

Modal analysis using the finite-element method

As the optical mount needs to be stable in an environment with high-frequency vibrational disturbances, it requires a sufficiently high first eigenfrequency. With a finite-element frequency analysis the eigenfrequencies of the design were determined. After optimisation, the final design has its first four eigenfrequencies at 772 Hz, 817 Hz, 951 Hz and 1,050 Hz, which is higher than the minimum required 500 Hz. The corresponding eigenmodes are shown in Figure 5.



AM-manufactured titanium prototype 1.

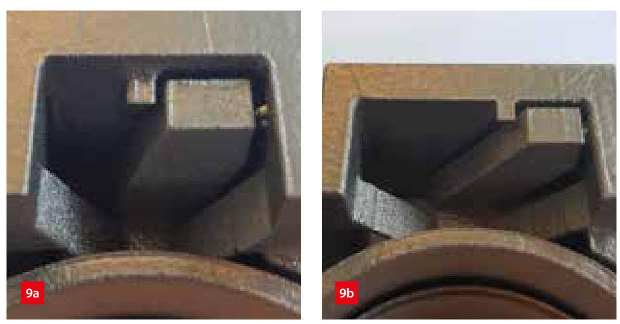
Prototypes

Four prototypes of the design were made in three variations. In these variations, different versions of the flexures with down-facing surfaces were used to investigate the surface quality for different geometries. The following designs were made:

1. Prototype 1: Design as shown in Figure 1, with notch hinges 19, 20 and 21 as shown in Figure 6a, and leafsprings 5, 6, 7 and 8 with an overhang angle of 60º.
2. Prototype 2: Notch hinges 19, 20 and 21 as shown in Figure 6b, where only one side is rounded with half the diameter of the original hinge, and leafsprings 5, 6, 7 and 8 with an overhang angle of 60º.
3. Prototype 3: Notch hinges 19, 20 and 21 as in Figure 6a, and leafsprings 5, 6, 7 and 8 with an overhang angle of 45º.
4. Prototype 4: Notch hinges 19, 20 and 21 as shown in Figure 6c, with V-shapes, and leafsprings 5, 6, 7 and 8 with an overhang angle of 60º.

The prototypes were manufactured of titanium Ti6Al4V Grade 5 using laser beam melting (LBM). They received standard stress-relief heat treatment and a beat blasting treatment. Figure 7 shows the result of prototype 1. Visual inspection showed a good result without any defects, only some roughness as would be expected from LBM. The results for the different notch hinge designs are shown in Figure 8.

AM-manufactured notch hinges.
(a) Design of Figure 6a.
(b) Design of Figure 6b.
(c) Design of Figure 6c.



AM-manufactured leafsprings of the cross-flexures with different overhang angle.
(a) 60º.
(b) 45º.

The down-facing circular hinge in Figure 8a turned out to be slightly collapsed in the middle. The asymmetric hinge in Figure 8b and the V-shaped hinge in Figure 8c do not show any clear irregularities. The manufactured leafsprings 7 and 8 of prototypes 1 and 3 are shown in Figure 9. All sloping leafsprings show a fringe near the top around the upper surface of the main body of the optical mount, which is probably due to the significant change in surface area of the printed layers. The difference in roughness between the two types of leafsprings in Figure 9 seems to be minimal.

Experimental modal analysis

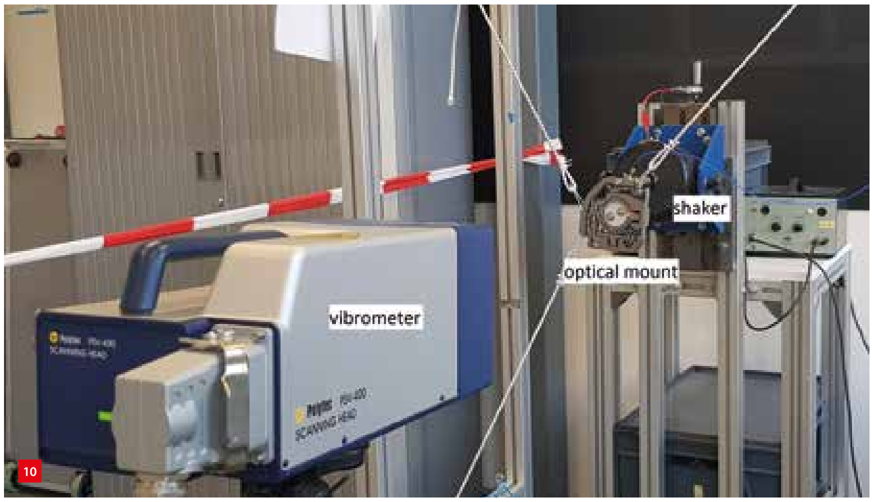
The frequency response of prototype 2 was measured by suspending the prototype with elastic ropes and exciting it by using an electrodynamic shaker, as shown in Figure 10. The excitation force was measured with a mechanical impedance sensor while the resulting displacements were measured with a scanning laser doppler vibrometer that measured the displacements over the entire surface of the optical mount.

Figure 11 shows the measured results of prototype 2; the first four eigenfrequencies are 578 Hz, 653 Hz, 848 Hz and 928 Hz. This is lower than predicted from the finite-element analysis (FEA). The first set of peaks up to 40 Hz are a result of the rigid-body motions of the mount in the set-up, which are not relevant. Figure 12 shows the related eigenmodes.

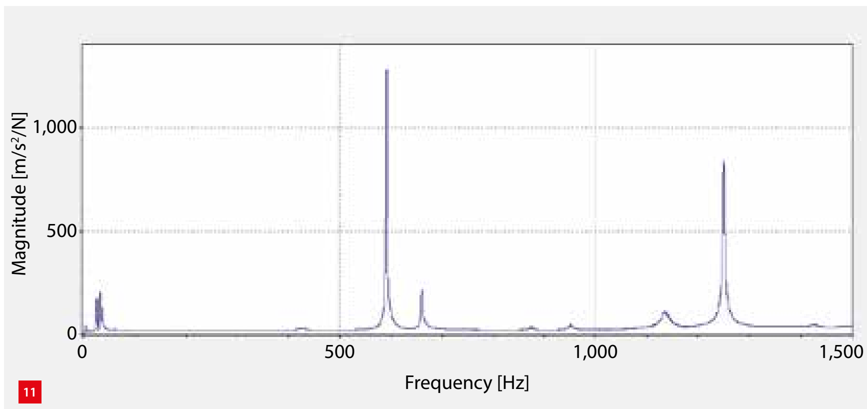
When comparing the results with the FEA results, there are some clear differences. The eigenmode of Figure 5d shows a translational motion of the tip-tilt stage, while the fourth eigenmode in Figure 12d shows a rotation of the stage. This could be due to the set-up for the modal analysis having a single input and the displacement and velocity only being measured in one direction. This means that an eigenmode could be missed when it is not excited by the used input vibration. If an eigenmode results in in-plane displacements, this mode will not show up in the measurement results. Also, since the modes were manually extracted from the frequency response, an amplitude that is very small may not have been visibly recognisable in the Bode plot. Another factor could be that because of simulating the adjustment screw contact as a fixed connection instead of a point contact, the FEA shows higher eigenfrequencies and hence leads to differences between measurement and analysis, such as the 200 Hz difference for the first eigenfrequency.

Cross-talk measurement

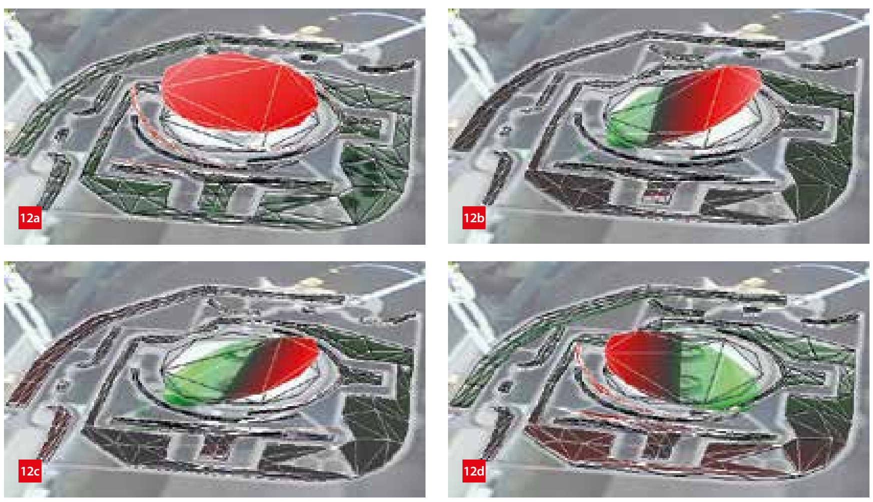
The cross-talk among the actuated DoF and the other DoFs was measured on three orthogonal planes with one, two and three triangulating distance sensors, respectively, as shown in Figure 13. At the location of the mirror a measurement tool was mounted with three orthogonal planes and arms for more distance between the measurement points for increased sensitivity. The resulting measurements were processed to determine the change in position and orientation of the centre of the mirror after actuation of a single DoF. The results showed a significant parasitic rotation of approximately 2-3 mrad/mm around the Z-axis when applying a translation in X- or Y-direction. This could



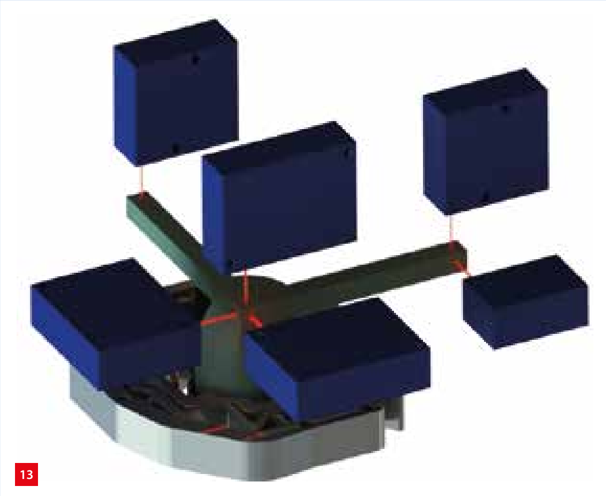
Set-up for experimental modal analysis with the optical mount suspended with elastic ropes.



Frequency response of the experimental modal analysis of prototype 2.



Experimental modal analysis of prototype 2.
(a) First eigenmode.
(b) Second eigenmode.
(c) Third eigenmode.
(d) Fourth eigenmode.



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Cross-talk measurement set-up to measure six DoFs with six triangulating distance sensors.

be improved by redesigning the translational stage such that the translational forces in each direction act halfway on the leafsprings instead of at the end, as in the current design; this is a known principle. Both translational adjustments also result in parasitic motion in *Z*-direction. This could be reduced by increasing the out-of-plane stiffness. Both rotational adjustments resulted in a parasitic translation in *Z*-direction and cross-axis coupling to the other rotation. This is since the decoupling elastic hinges 9, 10, and 11 in Figure 1 still have a significant rotational stiffness, for which they do not fully decouple the tip-tilt mechanism.

Conclusion

A new design was presented of a 4-DoF monolithic decoupled mechanism to be applied as an optical mount and suitable for AM. It is composed of two 2-DoF parallel stages in series, one for translations and one for rotations. Prototypes were manufactured and numerically and experimentally evaluated and compared. It was shown that AM was successful and that the prototypes were functional. Although the measured eigenfrequencies were significantly lower than expected from numerical evaluation, with a measured first eigenfrequency of 578 Hz they are sufficiently high for the intended application. Measurements also showed that the cross-talk is not yet excellent, for which the design needs further improvement and optimisation.

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RIGHT AT THE POINT OF INTEREST

In many high-tech applications, piezo-based positioners are the preferred choice for reliable nanomotions, but eventually the achievable repeatability is limited by the integrated closed-loop sensor. Increased positioning performance can only be achieved using sensors with an order of magnitude higher precision, ideally with the ability to measure as close as possible at the point of interest. This calls for a picometer-resolution interferometer in a miniaturised and modular design, allowing straightforward integration in and operation of ultra-precise positioning systems.

GREGOR SCHINDLER AND THOMAS HIRSCHMANN

AUTHORS' NOTE

Gregor Schindler (application engineer) and Thomas Hirschmann (head of business sector Motion & Sensing) are both associated with attocube systems, located in Munich, Germany. This article is based on attocube's Application Note Motion&Sensing 32.

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For applications such as the assembly and alignment of fibre arrays (Figure 1), multi-axis positioning with the highest repeatability and accuracy is key. The array is placed on an xyz-positioner stack and to ensure ideal transmission of light, the signal intensity of each fibre core (diameter less than 100 µm) has to be scanned with an external probe. For enabling a high-resolution image of the detected intensity distribution, the relative movement between probe and fibre core has to be repeatable within 25 nm. Furthermore, to enable the inspection of all fibres in the array, highly accurate movements of up to several millimeters are essential.

A closed-loop positioning system consisting of a piezo-based positioner ECSx3030 in combination with a Fabry-Pérot interferometer (Figure 2) is presented. The IDS3010 interferometer has a resolution of 1 pm and enables precise nanopositioning up to 5 meters, with a repeatability of a few nanometers. The ECSx3030 positioner is designed for industrial applications and offers linear bearings for high stability, a travel range of 20 mm, a maximum velocity of 4.5 mm/s and high loads up to 9 kg.

1

Interferometric closed-loop control of an xyz-positioner stack using attocube's AMC100 position controller and IDS3010 interferometer. The fibre array and a mirror block are mounted on top of the positioner. The three miniaturised sensor heads measure the xyz-displacement close to the point of interest (= fibre array).

2

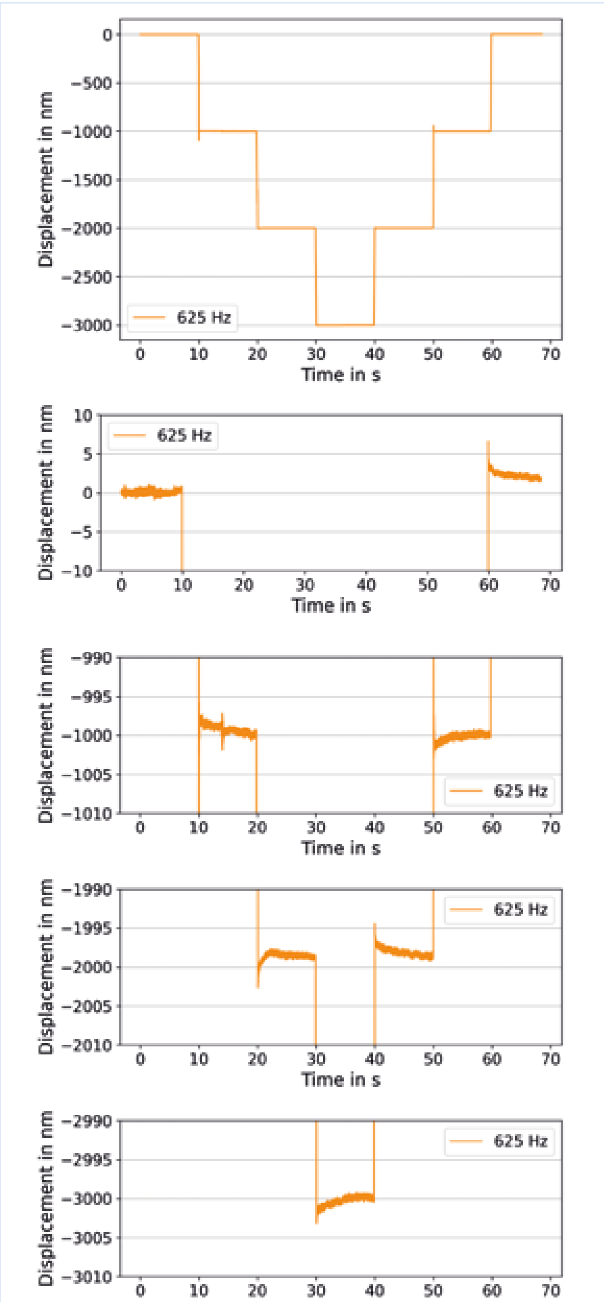
Set-up for real-time position tracking of an x-positioner system, extendable in the y- and z-direction. The grey cube (in the lower right corner) presents the point of interest, where the sample is placed.

Encoder options

The positioners can be used with different encoders. Resistive encoders have a resolution of 200 nm and a repeatability of 1-2 µm. They are often used in low-temperature environments, for example at 4 K. Optoelectronic encoders with a resolution of 1 nm and a repeatability of 50 nm are used for attocube's EC* series positioners and are designed for vacuum and room-temperature applications.

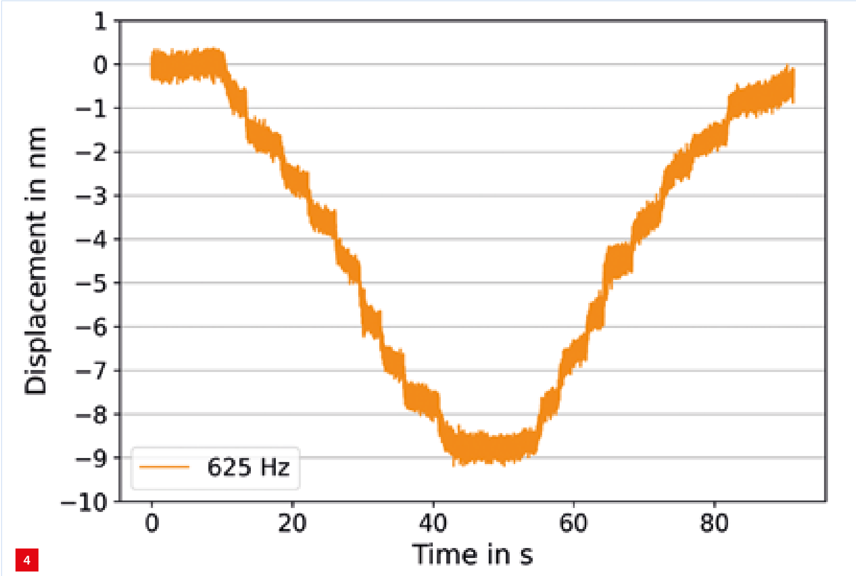
These encoders are integrated into the individual positioner, which simplifies the set-up, but also increases the distance between the point of interest, e.g. sample, and the sensor's measurement point. Using the laser-based IDS3010 as an external sensor, offers the possibility to measure directly on or very close to the sample. This significantly improves the true positioning precision.

Furthermore, in an xy-application the squareness of the motion is no longer limited by the tolerances of the encoder or a positioner mounting. Lateral run-outs and their amplification by a lever can be measured by the IDS and compensated. Moreover, any changes (e.g. thermal drifts)



3

Measurement of three 1-µm steps, back and forth.
See the text for explanation of the various zoom-in results.



4

Measurement of incremental 1-nm steps.

of the set-up are also compensated at the point of interest. Overall, with an orthogonal alignment of the sensor heads, both the repeatability and the accuracy with respect to external references can be significantly improved.

Measurement set-up

The set-up consists of a linear ECSx3030 positioner driven and controlled by the AMC100 position controller.
The closed-loop position feedback is measured with the IDS3010 using a D4/F17 sensor head focusing on a mirror target on top of the positioner. Figure 2 shows the set-up. Measurements are performed at ambient conditions on an optical table. The measurement requires a very stable set-up and good temperature stability in order to prevent mechanical oscillations. To prove the achievable precision, the position of the stage is recorded with a second, independent IDS interferometer with 50 kHz bandwidth. The measured data, sampled down to 625 Hz by averaging, is shown in Figure 3.

Measurement results

The measurement starts at a reference position set to zero. Then 1-µm steps are executed every 10 seconds. Figure 3 depicts all position steps in the top graph. The graphs below show the zoom-in results at each (relatively constant) position. The averaged data shows that a repeatability of 5 nm at ambient laboratory conditions is possible. First, the positioner overshoots the target position in the moving direction up to 100 nm due to the piezo slip-stick movement. Using the fine positioning, the target position is reached.
Next, a nanometer closed-loop measurement is presented. While the AMC100 controller delivers output signals for nine incremental 1-nm steps within ~35 seconds, the IDS3010 detects a total displacement of around 8.8 nm

(see Figure 4). Position steps of around 1 nm in average are visible in the 625-Hz signal.

Conclusion

Using the IDS3010 interferometer as an external closed-loop sensor for attocube's positioners, positioning targets with 5 nm repeatability and 1-nm steps at very stable ambient laboratory conditions can be realised. The systems can also be used in vacuum, which gives the opportunity to realise even higher precision due to the reduction of air and temperature fluctuations. The miniaturised and modular sensor design allows a user-friendly integration into a machine or set-up, which again facilitates measurements close to the point of interest.

Side note

At this level of precision, every external effect can impact the achievable measurement results significantly. To ensure the best performance for a specific set-up, consultation of attocube's application engineers is recommended.

USING AM FOR LED-INTO-FIBRE MODULE

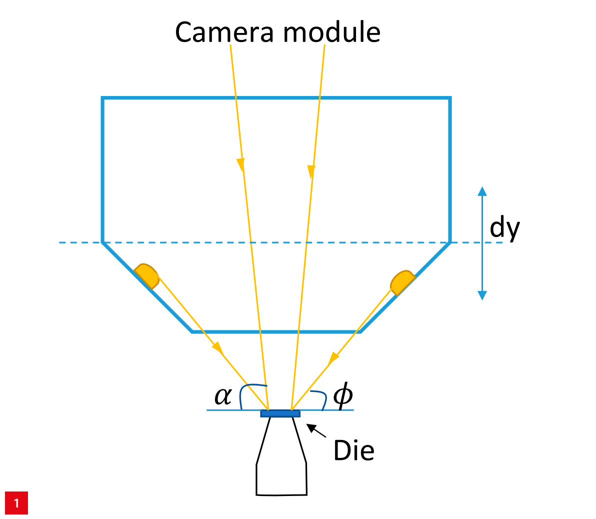
To improve and expand the functionality of a lighting module for die inspection, a multiple-LED ring light design has been developed, which includes a translation to facilitate different illumination angles. Drawing upon the potential of additive manufacturing, a monolithic solution was designed for a bistable mechanism. This mechanism uses negative stiffness to give the mechanism two stable positions: it can switch positions when a load is applied, then snap into the other stable position.

JELLE ELENBAAS

Introduction

Nexperia is a market leader in the production of diodes and other electrical components. In their production line dies are inspected for faults. This inspection is done by the LED-Into-Fibre (LIF) module (Figure 1). The LIF module consists of a LED supply box that is connected to a ring of glass fibre cores by a glass fibre cable. In total, it is a few meters long. Essentially, it is a ring light, and it functions like the flash light on a camera.

The flash is needed to create contrast on the die, and depending on what is being inspected, different types of contrast are needed. The contrast created by the LIF can be adjusted by changing its height manually. This way, the angle under which the die is illuminated can be changed. This is illustrated in Figure 1. The camera module is placed above the LIF and has its own light source, which is limited to one illumination angle, α. It is due to this limitation that the LIF is needed, as the LIF has an illumination angle that is adaptable over a large range. The yellow points in Figure 1 represent glass fibre cores fed by the LED supply box. By changing the height dy of the LIF, the illumination angle φ can be increased or decreased to change the contrast (a smaller illumination angle provides a larger contrast).



1

Schematic overview of the working principle of the LED-Into-Fibre (LIF) module.

Problem and goal

The current design of the LIF had some limitations in its functionality. The positioning of the LIF can be adjusted by hand simply by sliding it up and down and clamping it in place. This makes the settings sensitive to (human) error, and also compromises inspection reproducibility. In addition, the LIF is not capable of producing different colours of light. If a different colour is wanted, another light source (LED supply box) has to be mounted.

The goal was to develop a new design for the LIF that is capable of illuminating dies under four different illumination angles: 60°, 45°, 10° and –10°, where –10° is the background illumination. The design was optimised using the benefits of additive manufacturing (AM), by creating a monolithic construction. Saving costs and reducing the number of parts were secondary goals.

Design requirements/limitations

Given the primary goal, the most basic solution would be to use multiple ring lights stacked on top of each other. Due to a limitation in the power supply, however, only three LED rings can be connected. Designing a complete solution would yield a new module that better fits the needs of Nexperia, while costs could be kept relatively low. Considering the space requirements (80 mm x 70 mm x 30 mm), the new design would look like something that shown in Figure 2. To ensure that all four illumination angles can be provided, one ring must be capable of illumination from two different angles. Logically, this leads to the bottom ring being able to translate, for which a stroke of 10 mm was specified. Figure 3 schematically depicts the working principle.

AUTHOR'S NOTE

Jelle Elenbaas obtained his bachelor degree in mechanical engineering at Fontys University of Applied Sciences in Eindhoven (NL). This article is based on his bachelor thesis, which earned him a nomination for the Wim van der Hoek Award 2020. Currently, he is a master student in science and technology of nuclear fusion at Eindhoven University of Technology.

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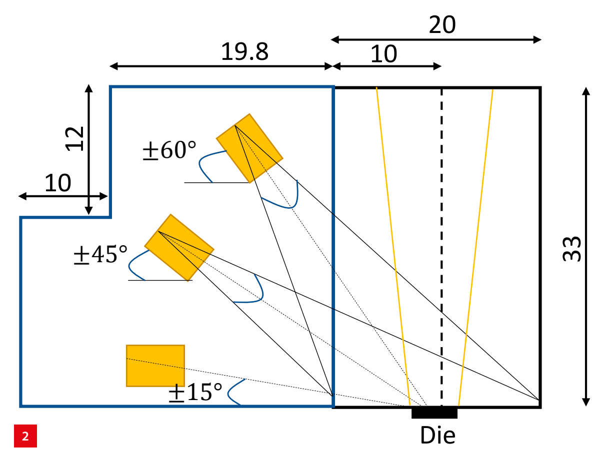


2

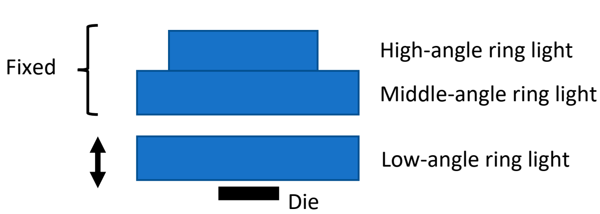
Schematic overview of the new design.

Bistable mechanism

Rationale
While various design solutions were considered, eventually a bistable mechanism was selected as the solution to allow the bottom ring to translate. In this mechanism, the low-angle ring is connected to the middle-angle ring with the use of flexures. These flexures are designed in such a way that they have two stable positions, the top and the bottom positions as displayed in Figure 4. Between these positions the flexures are not stable. This means that the ring cannot be put in an intermediate position. A bistable mechanism offers the possibility of the complete module being a monolithic design, which opens up opportunities for AM – 3D printing of flexures is an area of expertise that Nexperia wants to investigate; a.o., for reducing the number of parts.

Characteristics
As with every mechanism, bistable mechanisms have their advantages and disadvantages; see Table 1.

A literature study provided valuable information about bistable mechanisms. Disadvantage 1 is something that could be used as an advantage. The new design should be less flexible in its settings, because the goal was to give the operator as few settings as possible. Disadvantages 2 and 3 should be considered when designing the mechanism.



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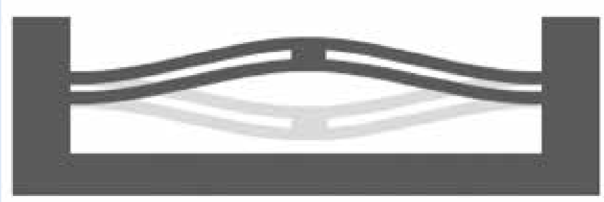
Working principle of the three ring lights.



4

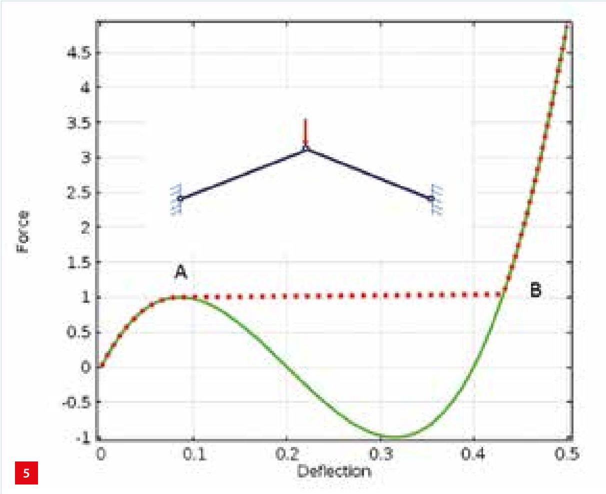
The two stable positions of a bistable mechanism.

The behaviour of bistable mechanisms can be predicted by a stability path. This is a graph in which force is plotted as function of deflection. Figure 5 shows an example of a typical stability path of a bistable mechanism, a two-bar truss structure. Here, when applying a load, the structure will 'jump' from one state to another. When the force is increased, it will reach the peak value at A. Numerically, the stiffness matrix will become singular. Physically, the structure will suddenly invert and jump to the state B along the red dotted line. In real life, this will be a dynamic event. The stored strain energy will be released and converted into kinetic energy.

The indicated points A, B and C in Figure 5 are characteristic of the stability path. Point A indicates the maximum force that is applied before the mechanism is put in motion by itself, i.e., before it snaps. Point C is the second stable point where the applied force is equal to zero. Point C indicates the travelled distance of the mechanism, i.e., the stroke. As seen in Figure 5, between points A and C the stiffness of the mechanism becomes negative. This means the applied force becomes less while the deflection increases [3]. Negative stiffness is characteristic of a bistable mechanism.

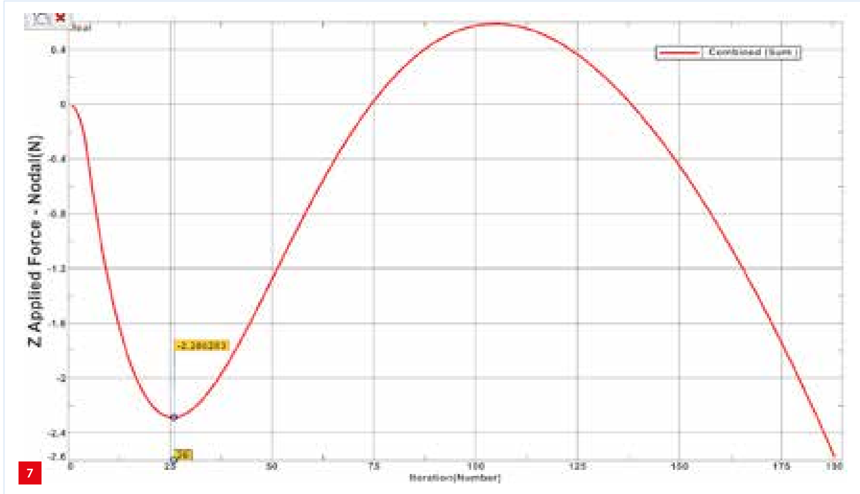
Table 1
Advantages and disadvantages of a bistable mechanism.

Advantages	Disadvantages
1. Mostly used in monolithic designs, hence reduced assembly effort.	1. No flexibility; settings fully dependent on the design.
2. Two stable positions eliminating human error in the settings.	2. Overall higher stiffness than with non-bistable mechanisms [1].
3. No friction between moving parts.	3. Stroke limited by the yield strength of the used material.
4. Lower part count, less weight.	



5

A characteristic stability path (not the specific case described in this article) for a bistable mechanism [2]. The green line is the numerical stability path, the dotted red line describes the physical event. Here, the deflection/displacement is plotted along the horizontal axis and the applied force along the vertical axis, although the force is the input variable.



7

Stability path of the model of Figure 6. Displacement increases linearly with the number of iterations in the simulation. At the second equilibrium point (where the force equals –2 N), the displacement is 10 mm (the required stroke).

The requirements give an indication of how the stability path of the LIF design should look. Point A should be more than the weight of the low-angle ring light with all LEDs and PCBs in place. This is around 6 N, which will be divided between the flexures (three are required to leave only the z-translation unconstrained). If the force at A is lower than 2 N (per flexure), the mechanism moves due to the weight of the design. Point C should be when a displacement of 10 mm (the stroke specified above) is reached.

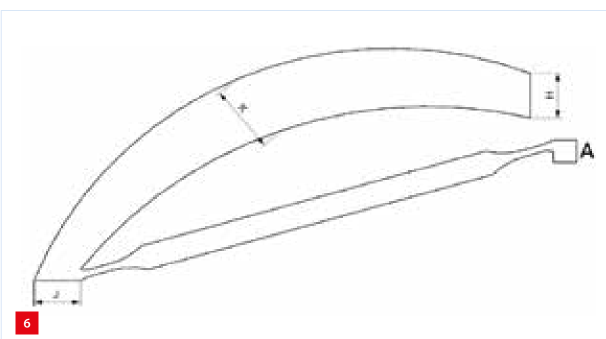
The strength-to-modulus ratio (σ_{yield}/E) is an indication of a material's fitness for a bistable mechanism [4]. This information was used to select the best-fitting material for this application. For this bistable mechanism, which was to be made with the use of AM, nylon was chosen as the most suitable material. This choice means that the stress in the flexures cannot exceed $\sigma_{yield/flexural}$ = 58 MPa [5].

Modelling

An important factor when designing a bistable mechanism is nonlinearity. Nonlinear behaviour cannot be taken into account in hand calculations, so modelling is required. The final model configuration is shown in Figure 6. Side H is attached to the middle ring and was, by way of approximation, fully fixed in simulation. Side A is constrained in the horizontal direction and a vertical force is applied, pulling the mechanism down. The result of the simulation is the stability path (Figure 7). It has the same characteristics as the example in Figure 5. The only difference is that the first maximum is negative, as a result of the sign convention used in the simulation. It becomes clear that the force that needs to be applied to get the mechanism in motion is larger than 2 N. This means that the mechanism does not move due to its own weight, thus an external load has to be applied for switching positions. From the simulation it can be deduced that the stress in the flexures does not exceed the yield criterium. So, the model satisfies the design requirements.

Result

The complete design of the new ring light module is shown in Figure 8. In Figure 8a it can be seen that the bistable mechanism is applied three times to the complete design. Figure 9 shows the design as assembled. Here, the RGB LEDs can be seen pointed at the die.

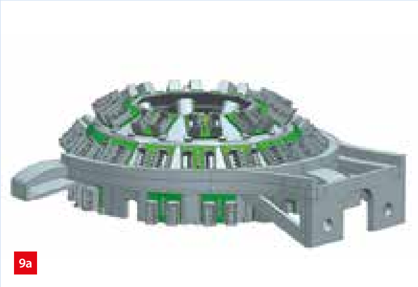


6

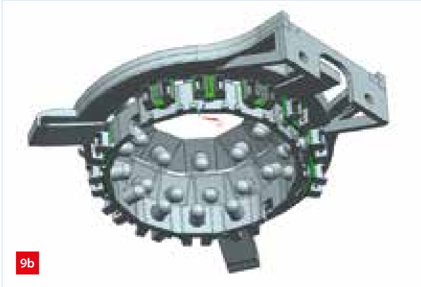
Model used in the simulation.

8a 8b

Complete design of the new ring light module.
(a) Top view, showing that the bistable mechanism is applied three times.
(b) Trimetric view. The part in the lower right corner is a mounting platform.



9a



9b

Two views of the complete design, as assembled.

To conclude

The assignment was to develop a new monolithic design that has an increased functionality and reduced sensitivity to human placement in the height setting for the LED-Into-Fibre (LIF) module. The solution was a bistable mechanism that has only two stable positions. The use of RGB LEDs enabled a multi-colour solution in one design. AM offered the opportunity of designing a monolithic system while reducing production costs; in fact, the costs of the new module were decreased by around 50%. The main advantage of the new design, in reference to cost, is the fact that most parts (LEDs and PCB parts) are cheaper to purchase in great quantities. The next step would be to actually print the design, as prototyping always brings new problems to light and can be insightful.

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DOC, HHS, LiS, TNO, TUD

The Dutch Lifelong Optics Learning initiative aims to provide an optics and photonics training platform for professionals. A practical, testable and modular curriculum is being designed that can be widely used for all SME companies within the optics/photonics domain. Along with the courses available at the various participating educational institutes, which range from secondary vocational training to academic level, dedicated training modules will be developed to meet industrial needs, as determined from a survey that is currently being conducted among interested companies. This autumn, four companies that allow their employees to follow courses will participate in a pilot programme. Next year, the platform will be open to the general industrial public.

LIFELONG OPTICS LEARNING

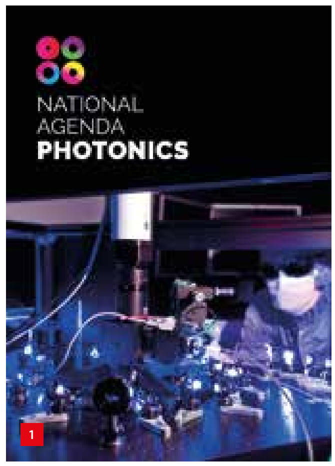
Last year, the Dutch Optics Centre (DOC), a joint venture between applied research organisation TNO and Delft University of Technology (TUD), launched the Lifelong Optics Learning initiative. They were joined by HHS (The Hague University of Applied Sciences, *De Haagse Hogeschool*) and LiS (*Leidse instrumentmakers School*). The project is subsidised by the Dutch Ministry of Social Affairs, under the SLIM incentive scheme for learning and development in SMEs.

The aim is to set up an optics and photonics training platform for professionals, and design a practical, testable and modular curriculum that covers optical training at different levels for professionals from Dutch industry.

Rationale

High-end optics is closely related to photonics, the key enabling technology that uses the properties of light for a wide range of applications such as sensing, data communication and production technology. It comprises ten optical technologies: optical sensors, optomechatronics, quantum optics, imaging, integrated photonics, glass fibres, optical materials, light sources (lasers, LEDs), detector technology, and photovoltaics (for solar energy).

In 2018, the Dutch government and the photonics ecosystem jointly drew up the National Agenda Photonics. Their objective was to intensify and accelerate the application of photonics technologies to solve societal challenges and create new businesses. One of the overarching aims is to strengthen photonics education (at vocational and academic levels) and align it with market needs, in order to resolve the scarcity of skilled staff and improve knowledge transfer and application. This is where the Lifelong Optics Learning initiative fits in (Figure 1).



1 *The Lifelong Optics Learning initiative fits in with the aim of the National Agenda Photonics to strengthen photonics education.*

Pilot and survey

The Lifelong Optics Learning curriculum will include modules (lectures and training courses with self-study) at the secondary and higher vocational education and the academic level, practicals, and an assignment based on a case from the participant's own company. A team of experts will test the acquired knowledge and skills. Currently, the curriculum is under construction, building on the available modules from the participating educational institutes. This will lay the foundation for a pilot programme starting this autumn with the four companies that support the project; Admesy, DJM, Hyperion and Optics11.

In parallel, a survey on the optical training needs in the high-tech industry will be conducted, in companies (primarily SMEs) operating in the optomechatronics, optics and photonics domain. Finally, the mature Lifelong Optics Learning platform will be open next year for all interested parties.

EDITORIAL NOTE

Input by Tijn van Heerden (TUD), Mariët Broxterman (LiS, TNO), Arjan Lock (HHS), Frank Molster (LiS), Bart Snijders (DOC, TNO) and Paul Urbach (TUD) is acknowledged.


At the LiS, Lifelong Optics Learning students can be trained in optics manufacturing. (Photo: Monique Hassink)

Educational partners

Delft University of Technology
TUD offers a mix of optics/photonics courses at bachelor/master level, both theoretical and experimental. Topics range from optical design, light-source theory and (hyperspectral) imaging methods to super-resolution, laser-spot optimisation, nano-optics and optical detectors.
TUD also has developed new optical practicals at bachelor and master levels, and provides training in LabView and 3D printing. In addition, TNO can provide a course on creating free-form optics.

Two years ago, the closely related Optomechanical system design course was developed by TUD and partners.
The course targets mechanical, mechatronic and optical engineers, offering a broad overview of this multidiscipline and helping engineers from the various disciplines to develop a common optomechanical language. The teachers are experienced system architects and designers from TUD, TNO, AC Optomechanix and SRON.

Apply for an assessment

As part as the survey that is currently being conducted, interested companies can apply for an assessment of their need for optical training. A potential outcome of this would be tailormade modules or curricula that match the optical technologies applied and the corresponding knowledge and skills base required by the company concerned.

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The Hague University of Applied Sciences
HHS is the only university of applied sciences in the Netherlands that offers a broad photonics educational specialisation track to (applied physics) students. After a general introduction in geometrical and physical optics, different modules cover specific sub-areas of photonics, including interferometry, fibre optics, spectroscopy, laser physics and optoelectronics. The courses are combined with practicals that make use of advanced facilities at HHS and partners.
In addition, there are general modules on image processing and digital signal processing. HHS also offers a project-based learning module in which students conduct applied photonics research and/or work on problems from companies.

As of this year, the focus on photonics has been further strengthened by the establishment of the research group (*lectoraat*) Photonics. Applied photonics research will be focused on high-tech industry, agri & food, energy & climate, health, and mobility. In all of these areas, digital technology plays a large role, with photonics contributing to digital data acquisition. Central topics of the research are spectroscopy, (fibre-based) metrology and imaging.

Leidse instrumentmakers School
LiS is the only Dutch educational institution that offers training in making optical components. Its contribution to Lifelong Optics Learning is provided by the LiS Academy

and covers combined theory/practice lessons in order to develop knowledge and skills in an integrated manner. The offer starts with a number of basic optics lessons. Subsequently, theoretical topics include laser safety, fibre optics, understanding optical design and aberrations, and qualifying optical components.

The aim is to qualify students for the assembly of optical instruments and to provide them with enough background to engage in serious discussions with optical designers. The theory is supported by practicals, including the manufacturing or adaptation of optical components (Figure 2).

The LiS contribution is to a large extent based on the two elective modules that have recently been developed for its regular curriculum. These two modules are Optical Engineering and Optic Manufacturing. Lifelong Optics Learning students can follow the complete modules or select specific topics. A third elective module, Instrumentation for Space, also has optics-related content. This module aims to train students to specialise in the design and construction of instrumentation for satellites, rockets and astronomical observatories.

Secondary benefits

The Lifelong Optics Learning platform will provide opportunities for knowledge transfer between educational and knowledge institutes mutually and with companies. This will yield valuable information for updating the regular curricula and generate leads for research projects, including graduation projects and internships, based on use cases presented by SMEs. Also, companies will gain easy access to advanced facilities such as production, coating and metrology equipment, cleanrooms, and other lab environments.

All in all, the Lifelong Optics Learning initiative will strengthen the Dutch optics/photonics ecosystem.

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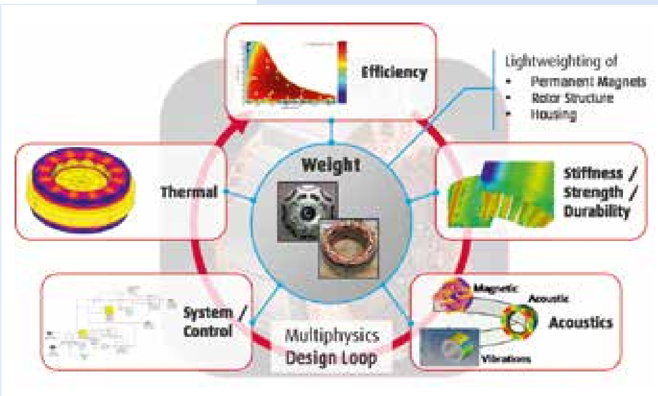
WWW.TNO.NL
WWW.TUDELFT.NL

Altair – Accelerating innovation in mechatronics with simulation software and digital twin

Altair provides simulation software and high-performance cloud solutions to accelerate innovation. Companies specialised in mechatronics are currently facing the complex challenge of shortening their time-to-market, at lower costs and with fewer risks. This can be achieved by organising the product development cycle in a holistic way via the systems engineering method and by optimising design and engineering with a parallel simulation-driven approach. By breaking through the traditional silos between mechanical, electronic and control design with integrated simulations, high-tech companies can still save a lot of time and money.



Multi-physics simulation of a Porsche e-motor.

Integrating and parallelising product development

The mechatronics market has become too complex and is changing too quickly to continue innovating via serial business processes. By performing integral dynamic simulations on a multi-physics-model-based design already in the ideation and first design phases, all components of mechatronic solutions and products can be optimised faster and at lower cost. Altair's solutions Activate and MotionSolve help to close the gaps in product development by facilitating multidisciplinary teams to perform simulations of movements and controls. This can be used to both predict the dynamic behaviour and optimise the performance of moving products and systems.

Digital twin for mechatronic systems

Simulations add more value the more reliable and accurate the underlying model is. Altair helps customers make this possible by creating and optimising an integral digital twin for mechatronic systems using real-time data and machine learning techniques. Enriching a digital twin with real-time sensor data helps high-tech companies increase their understanding of the multi-physical behaviour of dynamic systems, like high-tech production lines, autonomous vehicles and robots. Digital twins also provide opportunities to simulate the risks associated with all possible usage scenarios early in the product development process.

Innovation platform and services

Altair provides a comprehensive platform of simulation applications and complementary engineering services for all phases and application areas during the innovation cycle of mechatronic products and systems. The Altair One Marketplace provides customers with easy access to all available simulation applications from Altair and a wide range of technology partners. This includes a flexible scalable high-performance cloud environment and data-analysis tools. Finally, customers with innovation projects or complex mechatronic design and engineering challenges can also use the simulation knowledge and experience that Altair engineers have gathered over the past decades.

Case 1: design & optimisation of Porsche e-motor

The advanced drivetrain development team at Porsche used Altair Flux, Altair FluxMotor, Altair OptiStruct and Altair Activate to improve the total design balance in e-motor development. As a result, Porsche managed to maximise torque and power under different driving conditions and create a process for multi-physics e-motor optimisation.

Case 2: multidisciplinary design at Schneider Electric

Schneider Electric used the Altair HyperWorks suite and followed a multidisciplinary design approach to evaluate numerous variants and identify the optimal design parameters for the various operating conditions of a miniature circuit breaker. Because they could evaluate the electromagnetic, mechanical, control-strategy and other requirements at the same time, they managed to develop a viable product for a new geographical market within four months.

INFORMATION
WWW.ALTAIR.COM

Please check for any rescheduling, online reformatting or cancellation of events due to the coronavirus crisis.

Face-to-face & online meeting

14-15 September 2021, Eindhoven (NL)

DSPE Conference on Precision Mechatronics 2021

The fifth DSPE conference on precision mechatronics, organised by DSPE, will be a special edition, in view of the uncertain pandemic situation. It will combine two elements: (1) inspirational presentations from multiple invited international speakers from adjacent applications areas like bio-inspired mechatronics, robot-assisted surgery, virtual reality, artificial intelligence and more; (2) the opportunity of the community to meet/network and exchange ideas in a pleasant atmosphere including a BBQ. See the preview on page 12 ff.

WWW.DSPE-CONFERENCE.NL

15-16 September 2021, Den Bosch (NL)

Materials+Eurofinish+Surface

At this event, a combination of three trade fairs, product developers, product designers, engineers, R&D professionals, production staff, materials specialists and researchers can meet the entire materials value chain.

WWW.MATERIALS-EUROFINISH-SURFACE.COM

21-23 September 2021, St. Gallen (CH)

SIG Meeting Advancing Precision in Additive Manufacturing

Special Interest Group (SIG) Meeting hosted by euspen and ASPE, focusing on, a.o., dimensional accuracy and surface finish from AM, design for precision, standardisation, metrology, and integration of AM into an overall holistic manufacturing process.

WWW.EUSPEN.EU

22-23 September 2021, Aachen (DE)

30th Aachen Machine Tool Colloquium

The general topic of AWK'21 (Aachener Werkzeugmaschinen-Kolloquium) is "Turning Data into Sustainability". The focus is on how sustainable development in production can be initiated in order to successfully deal with drastic crises and to sharpen the entrepreneurial view for the future.

WWW.AWK-AACHEN.DE

27-29 September 2021, Eindhoven (NL)

Opto-Mechanical System Design course

The course focuses on the mechanical and mechatronic design of optical systems, and is intended for mechanical, mechatronic and optical engineers involved in opto-mechanical system design. It will also be a very valuable course for any engineer interested in opto-mechanical design approaches and solutions.

WWW.DSPE.NL/EDUCATION

12-14 October 2021, Karlsruhe (DE)

DeburringEXPO

Fourth edition of trade fair for deburring technology and precision surface finishing. Three theme parks will cover "Cleaning After Deburring", "Automated Deburring with Industrial Robots" and "AM Parts Finishing", repspectively.

DEBURRING EXPO

WWW.DEBURRING-EXPO.COM

10-11 November 2021, Den Bosch (NL)

Precision Fair 2021

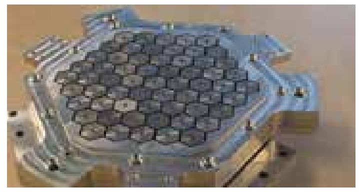
The Benelux premier trade fair and conference on precision engineering, organised by Mikrocentrum. The theme of this 20th anniversary edition will be: Precision technology, the next 20 years. This year, Belgium will be the partner country.

WWW.PRECISIEBEURS.NL

15 November 2021, Düsseldorf (DE)

Gas Bearing Workshop 2021

Fourth edition of the initiative of VDE/VDI GMM, DSPE and the Dutch Consulate-General in Düsseldorf (Germany), focused on gas-bearing components and technology for advanced precision instruments and machines.



WWW.GAS-BEARING-WORKSHOP.COM

17-18 November 2021, Raaba (AT)

SIG Meeting Micro/Nano Manufacturing

SIG Meeting hosted by euspen, focusing on, a.o., micro- & nanomanufacturing technologies and applications, machining technologies for moulds and microparts, metrology & quality control for microparts, microreplication and additive techniques, and assembly & handling.

WWW.EUSPEN.EU

24 November 2021, Utrecht (NL)

Dutch Industrial Suppliers & Customer Awards 2021

Event organised by Link Magazine, with awards for best knowledge supplier and best parts & process supplier, and the Best Customer Award.

WWW.LINKMAGAZINE.NL

1-2 December 2021, Den Bosch (NL)

Food Technology 2021

Knowledge and network event about high-tech innovations in the food industry.

WWW.FOOD-TECHNOLOGY.NL

8-9 december 2021, Eindhoven (NL)

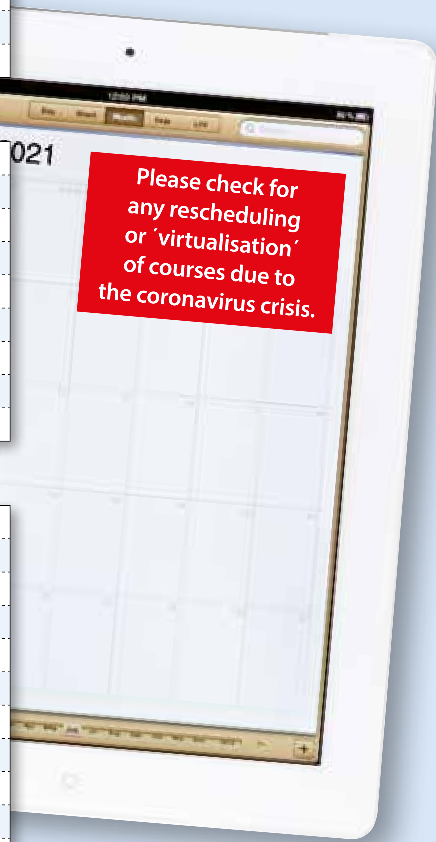
RapidPro 2021

The annual event that showcases solutions for prototyping, product development, customisation and rapid, low-volume & on-demand production.

WWW.RAPIDPRO.NL

ECP² COURSE CALENDAR

COURSE (content partner)	ECP² points	Provider	Starting date
FOUNDATION			
Mechatronics System Design - part 1 (MA)	5	HTI	11 October 2021
Mechatronics System Design - part 2 (MA)	5	HTI	8 November 2021
Fundamentals of Metrology	4	NPL	to be planned
Design Principles	3	MC	22 September 2021
System Architecting (S&SA)	5	HTI	11 October 2021
Design Principles for Precision Engineering (MA)	5	HTI	to be planned
Motion Control Tuning (MA)	6	HTI	13 September 2021
ADVANCED			
Metrology and Calibration of Mechatronic Systems (MA)	3	HTI	2 November 2021
Surface Metrology; Instrumentation and Characterisation	3	HUD	to be planned
Actuation and Power Electronics (MA)	3	HTI	to be planned
Thermal Effects in Mechatronic Systems (MA)	3	HTI	to be planned (Q4 2021)
Dynamics and Modelling (MA)	3	HTI	30 November 2021
Manufacturability	5	LiS	to be planned
Green Belt Design for Six Sigma	4	HI	20 September 2021
RF1 Life Data Analysis and Reliability Testing	3	HI	20 September 2021
Ultra-Precision Manufacturing and Metrology	5	CRANF	to be planned
SPECIFIC			
Applied Optics (T2Prof)	6.5	HTI	1 November 2021
Advanced Optics	6.5	MC	24 February 2022
Machine Vision for Mechatronic Systems (MA)	2	HTI	upon request
Electronics for Non-Electronic Engineers – Analog (T2Prof)	6	HTI	to be planned
Electronics for Non-Electronic Engineers – Digital (T2Prof)	4	HTI	to be planned
Modern Optics for Optical Designers (T2Prof) - part 1	7.5	HTI	to be planned (Q1 2022)
Modern Optics for Optical Designers (T2Prof) - part 2	7.5	HTI	10 September 2021
Tribology	4	MC	26 October 2021
Basics & Design Principles for Ultra-Clean Vacuum (MA)	4	HTI	6 December 2021
Experimental Techniques in Mechatronics (MA)	3	HTI	4 October 2022
Advanced Motion Control (MA)	5	HTI	11 October 2021
Advanced Feedforward & Learning Control (MA)	3	HTI	to be planned (Q1/Q2 2022)
Advanced Mechatronic System Design (MA)	6	HTI	to be planned
Passive Damping for High Tech Systems (MA)	3	HTI	23 November 2021
Finite Element Method	2	MC	4 November 2021
Design for Manufacturing (Schout DfM)	3	HTI	30 September 2021



ECP² program powered by euspen

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

WWW.ECP2.EU

Course providers

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

Content partners

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

New director for LiS

Stef Vink has been appointed director-administrator of the *Leidse instrument-makers School* (LiS) as of 1 June, 2021. Vink has worked in both education and industry, and until recently was domain leader Metal and Process Technology at ROC Da Vinci College in Dordrecht (NL). "We got to know Stef as an experienced teacher and a warm personality, with a great interest in technology and technology education. We have every confidence that he will be enthusiastic and results oriented in leading the school," reports the LiS supervisory board. In a forthcoming issue of *Mikroniek*, Vink will further explain his vision for the future of the LiS.

Stef Vink succeeds Godelieve Bun, who took office as director of the LiS on 1 March, 2019, and was appointed director-administrator on 1 January, 2020. She ran the LiS to mutual satisfaction, but commuting to and from work turned out to be too burdensome, as she lives at a great distance from Leiden (NL). "With pain in my heart, I had to decide for private reasons to step down as director of the LiS. I put my heart and soul into the school and worked on further strengthening the educational organisation and broadening the range of training courses. Now that some 'regular' (multi-disciplinary) Regional Training Centres (ROCs) are abandoning their technology courses due to funding problems, the national importance of the LiS is only increasing."

Stef Vink is the new director-administrator of the LiS.

WWW.LIS.NL

Investment in NFI

Nearfield Instruments (NFI), the leading semiconductor scanning probe metrology equipment scale-up, has raised €17.5 million as part of its Series B funding round. Dutch impact investor Invest-NL contributed € 10,5 million. The other investor was the existing shareholder Innovation Industries, with an investment of € 7 million. This funding round supports NFI to intensify the collaboration with its leading customers and take the necessary next steps in scaling up the organisation to develop new metrology technologies, attract tech talents, and expand their infrastructure. NFI was extensively featured in the February 2021 issue of Mikroniek.

WWW.NEARFIELDINSTRUMENTS.COM

New managing director for Mikrocentrum

Bert-Jan Woertman will be the new managing director of Mikrocentrum. Next August 16th, he will succeed Geert Hellings, who will then have been managing director of the Eindhoven-based knowledge and network organisation for the high-tech and manufacturing industry for over 18 years.

"Now that the organisation is ready in all respects to enter a new phase, I am happy to leave the writing of that new chapter to my team and successor." With these words, Hellings announced his farewell on 1 March, 2021, referring to the repositioning that Mikrocentrum has initiated in recent years. The coming years Mikrocentrum will focus on the further development of the ambition to be the prime meeting place for the high-tech and manufacturing industry, in which "the unique combination of training, meeting and entrepreneurship" is key. In Woertman a successor has been found to further lead this growth process.
For many in the Brainport region, but also beyond, Woertman is a familiar face. He started his career as HR manager at Philips and was subsequently associated with the High Tech Campus Eindhoven for over eleven years. As director of marketing communications, he was responsible for the international expansion of the High Tech Campus brand. As co-initiator, he built the start-up accelerator programme HighTechXL into one of the top-5 high-impact programmes in the world. After his time at the High Tech Campus, Woertman was commercial director of the Eindhoven University of Technology (TU/e) campus and was involved in the start-up of the Brainport Industries Campus as managing director. In recent years, he has used his experience in building innovative ecosystems at the start-ups SocialMachines and AlphaBeats and as liaison manager at TU/e Innovation Space.

Naturally, Woertman is no stranger to Mikrocentrum. In his new position, he can rely on a healthy, stable knowledge and network organisation that has been connecting people in the high-tech and manufacturing industry for more than 50 years. "After 20 years of experience in international innovative environments, I have experienced that working together in smart networks makes the difference. By exchanging people, experience and ideas, knowledge, creativity and entrepreneurship are better utilised. Mikrocentrum plays a central role in this."

In the autumn, Mikrocentrum will organise a meeting to thank Geert Hellings for 18 years of inspiring leadership and to get acquainted with Bert-Jan Woertman.

Bert-Jan Woertman, the new managing director of Mikrocentrum, as of 16 August, 2021.

WWW.MIKROCENTRUM.NL

Horizontal-arm CMMs

To supplement its high-accuracy HC-90 ceramic horizontal-arm coordinate measuring machines (CMMs), British manufacturer LK Metrology has introduced three additional models of technically advanced design based on an aluminium construction. They provide users with multiple affordable alternatives for dimensional inspection of large components typically found in the automotive, land transport and heavy industries.

The new, horizontal arm CMMs are supplied in three ranges – the LY-90T table version, LY-90R rail version with single or twin arms, and the shop-floor-ready HD-90 rail version with single or twin arms, which has been developed specifically for quality control of vehicle bodies and sub-assemblies in car plants. The HD-90R single-rail and HD-90TR twin-rail models offer superior dynamics and accuracy and are designed for use in production areas. They are encapsulated in protective covers to ensure thermal insulation against environmental changes and to protect the system from airborne contaminants typically found in a workshop environment.

Air bearings mounted on both the Y- and Z-axis are the key element of this high-performance measurement solution. For the twin-arm version, the measurement volumes of the two horizontal arms overlap each other by 100 mm to ensure access to all component features. Ten sizes of HD-90 are available with axis travels from 4,000 mm x 1,600 mm x 2,000 mm to 8,000 mm x 1,600 mm x 3,000 mm. A full range of probing options is offered to suit all types of metrology application, including motorised indexing probe heads and touch-trigger probes, infinite-positioning servo wrist heads with long-reach probe builds, scanning probes, and single- or triple-stripe laser scanners.

The new HD-90 horizontal-arm CMM from LK Metrology shown in twin-rail configuration

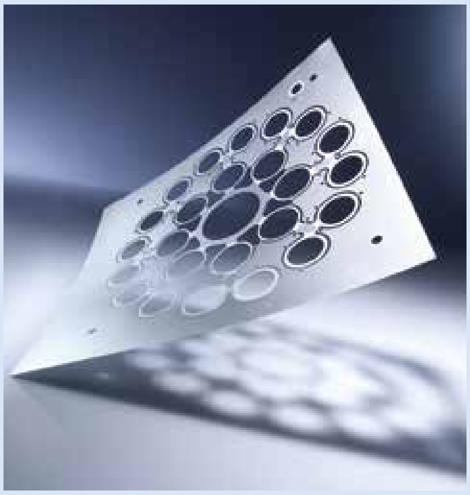
WWW.LKMETROLOGY.COM

Photochemical etching going reel-to-reel

In many applications, photochemical etching (PCE) is seen as the only technology that can achieve the repeatability, accuracy and geometric complexity demanded by OEMs from across industry, so claims PCE specialist micrometal, located in Müllheim (Germany). The process is able to produces intricate parts with tolerances as low as ±7 µm depending upon material and its thickness, this tolerance attainment being unique among all alternative metal fabrication technologies.

The PCE process is further characterised by the fact that it produces parts without degrading material properties, stress- and burr-free parts being manufactured with no limitations when it comes to complexity. It can also be used on a broad range of metals and alloys, the 'art' often being seen as the creation of different etchant chemistries that can manufacture parts from even difficult-to-process metals such as aluminium and titanium, and hardened metals. Etchant chemistries, however, are only one part of the picture when it comes to providing a truly optimised PCE process, according to micrometal. "Our PCE process is very different from conventional PCE processes, laser processing, or fine stamping. Uniquely, we use a special liquid resist system to obtain ultrathin (2-8 µm) photoresist layers enabling a higher degree of precision in the chemical etching process. It allows us to achieve extremely small feature sizes of 25 µm, a minimum hole diameter 80% of the material thickness, and single-digit-micron tolerances repeatably. Our PCE process enables ultra-precise contours to take shape."

In addition, the company's continuous production technology allows for the manufacture of endless strips of components (so-called reel-to-reel production) enabling the manufacture of customer-specific high-precision parts in industrial volumes wound onto reels for ease of further processing post-delivery. Metal strip thicknesses can be between 25 and 400 µm.



A PCE-produced chemical filtration part.

WWW.MICROMETAL.DE

Non-destructive inspection of large components

When using X-ray CT (computed tomography) for non-destructive quality control of larger components like aluminium castings or battery modules for electrical vehicles, the challenge is to shorten inspection cycle times without compromising resolution. One prerequisite for achieving this is high X-ray intensity, or flux. In Nikon Metrology's range of X-ray CT systems, a rotating target can already triple the flux for a given focal spot size, and the flux can be further increased by motorised FID (focal spot to imager distance), which brings the detector closer to the source at the push of a button.

With the release of a new offset CT reconstruction algorithm in the latest version of the manufacturer's Inspect-X software, not only can larger components be scanned but it can also be performed at higher geometric magnification. Offset.CT is a scanning method that allows small or large components to be inspected fully while only part of the sample is within the field of view (FOV) during rotation. The component is placed such that only just over half of the object lies within the X-ray cone beam, allowing a much wider FOV and reconstruction volume.

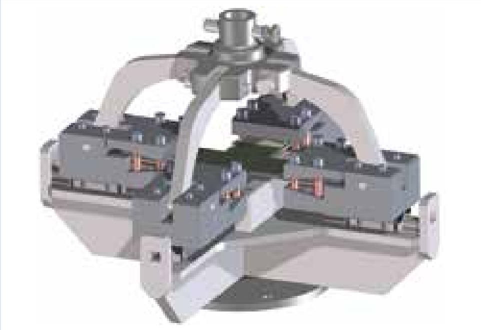
Compared with traditional CT, this has two main benefits for component inspection. First, larger components, even those wider than the detector itself, can be scanned without having to use a larger CT machine. Secondly, it allows the component to be placed much closer to the X-ray source, allowing higher magnification and therefore significantly increased voxel resolution. Consequently, a broader range of sample sizes can be scanned at high resolution.

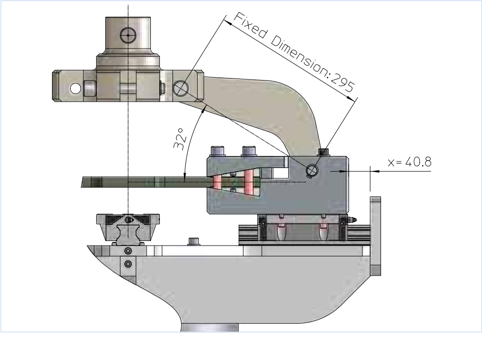
One of Nikon Metrology's X-ray CT systems offering enhanced scan speed and image resolution.

WWW.NIKONMETROLOGY.COM

Biaxial tensile tooling tailor-made for ESA ESTEC

Space structures such as solar panels and rocket motor housings are built from carbon fibre-reinforced composites (CFRPs). To ensure that these materials continue to function properly in space, material tests (such as tensile tests) are performed on them. As fibre reinforcement in CFRP composites is difficult to realise in all directions, biaxial tensile tests have to be performed, at institutions such as ESA ESTEC in Noordwijk (NL), the European Space Research and Technology Centre of the European Space Agency.





Design of the biaxial tooling, with a close-up of the lever.

ESA ESTEC has a servo-hydraulic tensile testing machine that is available for performing uniaxial tensile tests. To extend it to biaxial tensile tests, Enduteq in Westervoort (NL) has developed a compact and innovative tensile test tooling. Its specifications were: maximum biaxial tensile force 100 kN in all directions, maximum stroke 100 mm and material thicknesses of 0 to 20 mm.

The composite material is strong and stiff, which makes it vulnerable to point loads. Therefore, the specimen may not be loaded with bending forces; in addition, the clamping system must ensure uniform clamping. Based on a biaxial tensile test concept developed previously, Enduteq, in close cooperation with the scientists of ESA ESTEC, has developed a tailor-made tool.

The tooling consists of four product clamps, each positioned on its own stage. The clamps are connected to each other by hinged levers in a central pressure point. When the tensile testing machine applies a load to the central pressure point, all the product clamps are pushed apart simultaneously with the same force via the levers. Thus, the specimen is pulled simultaneously on four sides. As the angle of the levers is reduced in this process, the resulting force on the specimen increases while the pressing force remains the same. This is not the intention; the pulling force must remain constant. The control unit of the tensile testing machine ensures this by reducing the pressing force.

WWW.ENDUTEQ.NL
WWW.ESA.INT

New 3D beam deflection system for laser micro-machining

Aerotech has launched the AGV3D, a new 3D beam deflection system for laser micro-machining. The thermally stable three-axis laser scanner is particularly suitable for high-precision manufacturing of complex components for the medical, microelectronics and automotive sectors, including additive manufacturing.

3D laser scan heads are particularly suitable for applications where flat-field objectives (f-θ lenses) cannot be used or the contour of the workpiece requires focus tracking in the z-direction. Most 3D scanners available on the market to date employ a third rotary galvo motor with a tangential arm for tracking the focusing optics. However, these designs can become thermally unstable. This limits the dynamics and precision in continuous operation, which is becoming increasingly important in many markets and applications.

The AGV3D offers a rapid, flexible and high-precision laser scanning solution featuring direct operation of dynamic linear tracking of the focusing optics with high-resolution feedback, according to an Aerotech press release. Positioning errors can be significantly minimised due to the high stiffness and accuracy of the linear module. A DFM (Dynamic Focusing Module) based on a linear focusing axis with a powerful direct drive, enables the AGV3D to provide superior dynamic performance with smooth motion as well as high-resolution positional feedback for accurate and repeatable focusing, Aerotech claims. With integrated water and air cooling, the new scanner also achieves maximum thermal stability.

Thanks to the AGV3D's large field of view, smaller, more efficient movement mechanisms can be used for positioning the workpiece. Depending on the process requirements, the three-axis scanner is available with different apertures for different beam diameters. By synchronising with other motion axes, the AGV3D also offers the unique feature of processing workpieces larger than its field of view, while maintaining high processing quality. The IFOV (Infinite Field of View) feature is available for improving structural accuracy and avoiding errors, for example in 'classic' stitching. Linear or rotary axes are synchronised with the laser scanner, which theoretically increases the scanner's field of view to infinity.

WWW.AEROTECH.COM

Supportless 3D printing

Each time a 3D printer produces custom objects, especially unusually-shaped products, it also needs to print supports – printed stands that balance the object as the printer creates layer by layer, helping maintain its shape integrity. However, these supports must be removed after printing, which requires finishing and can result in shape inaccuracies or surface roughness. The materials the supports are made from often cannot be re-used, and so they are discarded, contributing to the growing problem of 3-D printed waste material.

For the first time, researchers of the USC Viterbi School of Engineering at the University of Southern California (SC, USA) have created a low-cost reusable support method to reduce the need for 3D printers to print these wasteful supports, vastly improving cost-effectiveness and sustainability for 3D printing.

A new dynamically-controlled base for 3-D printing (middle) will reduce the need for printed supports (left), cutting wastage and saving time. (Image: Yong Chen)

Traditional 3D printing prints layer by layer, directly onto a static metal surface. The new prototype instead uses a programmable, dynamically-controlled surface made of moveable metal pins to replace the printed supports. The pins rise up as the printer progressively builds the product. Testing of the new prototype has shown it saves around 35% in materials used to print objects, and 40% in printing time.

The research team's new prototype works by running each of its individual supports from a single motor that moves a platform. The platform raises groups of metal pins at the same time, making it a cost-effective solution. Based on the product design, the program's software would tell the user where they need to add a series of metal tubes into the base of the platform. The position of these tubes would then determine which pins would raise to defined heights to best support the 3D printed product, while also creating the least amount of wastage from printed supports. At the end of the process, the pins can be easily removed without damaging the product.

The researchers claim the system could also be easily adapted for large-scale manufacturing, such as in the automotive, aerospace and yacht industries.

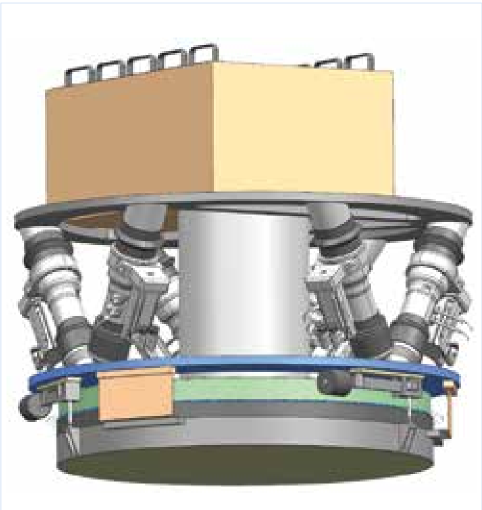
WWW.VITERBISCHOOL.USC.EDU

Adaptive mirror technology for Europe's largest solar telescope

TNO has been selected to start the design of an essential component for the European Solar Telescope (EST), scheduled for construction in the Canary Islands. The telescope will allow detailed investigations of the Sun, in particular its powerful magnetic fields and complex atmospheric dynamics that can have a drastic impact on modern technology, such as satellites, aircraft, GPS and more.

TNO will design the adaptive secondary mirror (ASM) that can rapidly change shape to correct for the distortion of the telescope observations caused by the Earth's atmosphere. Adaptive mirrors are mounted on actuators that enable them to change shape to achieve optimal clarity. But the leading technology for these actuators is fragile, energy-inefficient and difficult to control. TNO proposed revolutionary actuators designed to be precise, robust, predictable and far less power-hungry than the current state-of-the-art. TNO's actuator system is ten times more efficient than traditional systems, and is still ultra-precise and effective, controllable to nanometer precision.

In this preliminary design phase, TNO will provide proof of concept for the EST ASM. TNO will partner with VDL ETG to construct the actuators. This is the second time TNO and VDL ETG together have applied this revolutionary technology to telescopes. As part of a joint investment with the University of Hawaii, in 2019, the team designed a 63-cm-diameter ASM as an upgrade for the UH88 telescope in Hawaii. That ASM, now being assembled, will be actively shaped by 210 actuators. For EST, TNO aims to design an 86-cm-diameter mirror with 2,000 actuators, allowing the most precise movement and control possible.



Impression of the EST adaptive secondary mirror.

WWW.EST-EAST.EU
WWW.TNO.NL

Large-format inspection and metrology system

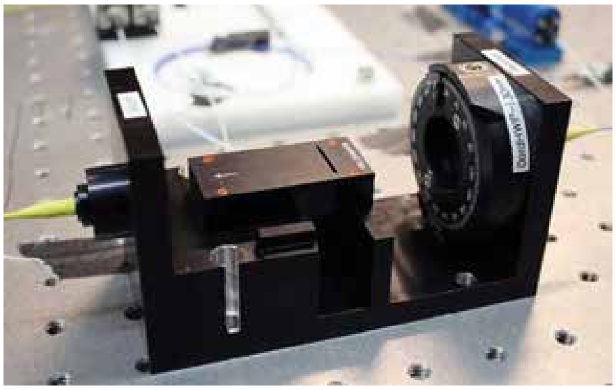
ZYGO has launched the Nexview™ 650, a large-format metrology system designed as an inspection tool for the automated measurement of injection moulding tooling, PCBs, glass panels, and other samples requiring an extended work volume up to 650 mm x 650 mm. The system provides 2D and 3D measurements of a variety of surface features with sub-nanometer vertical precision and sub-micron lateral precision. It is the latest addition to ZYGO's range of 3D optical profilers for precise, quantitative, ISO-compliant, non-contact surface measurement and characterisation of micro- and nanoscale surface features.

At the heart of the new system is coherence scanning interferometry (CSI), a technology that uses specialised optical microscope objectives that not only provide the imaging and magnification of a surface, but also measure its 3D topography. CSI profiling is completely non-contact, which eliminates any chance of the sample being damaged. Also, in contrast with other microscope-based 3D topography techniques, CSI has the distinct advantage that the height resolution of the measurement is consistent across all magnifications, whether the field of view is 20 μm, 20 mm or much larger. With a metrology area that accommodates lateral dimensions up to 650 x 650 mm, a sample load of > 100 kg, a vertical range of 150 mm, and options for a fully enclosed or partially enclosed system, the Nexview™ 650 provides maximum flexibility for large samples that require precision 3D optical profiling.

WWW.ZYGO.COM

Polarisation-entangled photon sources

OZ Optics, represented by Te Lintelo Systems in the Netherlands, has developed a line of polarisation-entangled photon sources to support the growing field of quantum information science. These sources are room-temperature, non-linear-optics-type photon pair sources based on poled crystal technology and poled fibre technology that support all of the common phase-matching scenarios. They are offered in OEM, benchtop and rackmount configurations, and cover a broad wavelength range extending from the near infrared through to the short-wave infrared. Each source can be further customised for niche applications.



WWW.OZOPTICS.COM
WWW.TLSBV.NL

Planetary roller screw on Mars

Ewellix has developed and manufactured a planetary roller screw that recently landed on Mars as part of NASA's Mars 2020 Perseverance Rover Mission that is searching for signs of ancient microbial life. The rover is to collect Martian rocks, and extract and seal samples for testing and onboard storage. The planetary roller screw is housed inside the sealing station on the rover's base and will generate the high force required to hermetically seal the 43 sample tubes on board. It is a fully customised version of a standard SR/HR planetary roller screw product, robust enough to withstand the extreme conditions of outer space and Mars. Adaptations include aerospace-grade materials and heat-treatment operations.

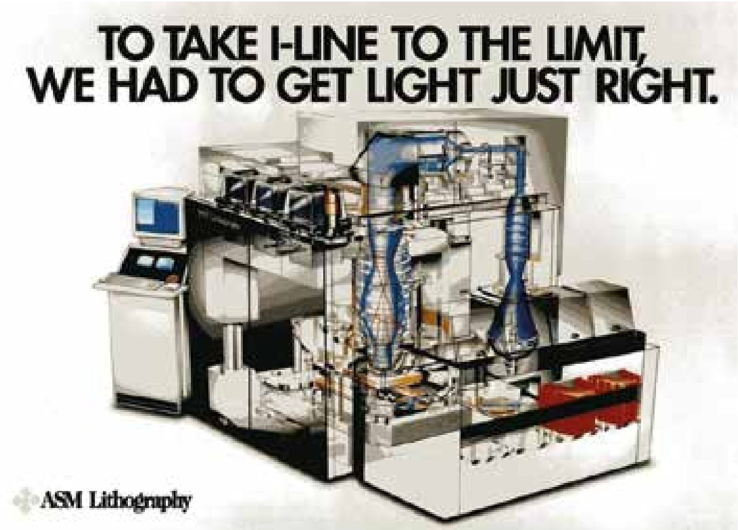
WWW.EWELLIX.COM

Three decades of PAS 5500

May 9, 2021 marked 30 years since the first-ever PAS 5500 platform was shipped by ASML. The PAS 5500 comes from a long line of systems initiated by researchers at Philips in the 1970s, hence its name: the Philips Automatic Stepper (PAS). It has become ASML's longest-lived lithography platform and one of their most versatile product lines. The success of the PAS 5500 platform laid the foundation for ASML's growth to become the global leader in lithography.

Twinscan is now the platform of choice for high-volume semiconductor manufacturing and at the leading edge of Moore's Law. And although the PAS 5500 is no longer made as new, its low cost, small size, simplicity and robustness mean that a refurbished PAS 5500 is often the preferred option in various niche applications. That's why ASML has extended the customer service of its oldest product line to 2030 and beyond.

Micron, one of the world's largest producers of computer memory and storage, in the mid-1990s was ASML's largest customer and therefore instrumental in the PAS 5500 platform's success. They got early access to the latest technology and, in return, provided valuable feedback that would help ASML improve the performance of their systems. Initially, Micron used the PAS 5500/200, which had a resolution of 0.35 µm, to create the critical layers in its cutting-edge memory chips of the day. Through continuous improvement – introducing higher resolution i-line systems as well as krypton fluoride (KrF) and argon fluoride (ArF) systems – even finer resolutions were supported.
As new systems come online in fabs to produce the critical layers of more advanced chips, older systems remain in constant use but migrate to the lithography of choice for less critical layers. This was the case for Micron's PAS 5500/200 systems. However, in 2000, there was a major industry switch from 200-mm wafers to 300-mm wafers to support higher chip outputs and improve cost efficiency. Many of ASML's larger customers decided to migrate their production to the Twinscan platform, which, unlike the PAS 5500, supported the larger wafers.



An early advertisement for the PAS 5500 platform.

Over the next few years, Micron sold off its 200-mm wafer processing equipment base. For example, to manufacturers who are not trying to push Moore's Law, but are active in the so-called 'More than Moore' market. This is a field where digital electronics meet the analog world, like sensor chips for automotive, micro-electromechanical (MEMS) chips such as accelerometers, ultra-low-power chips, and chips for RF identification. As an alternative to direct reselling, some chip manufacturers choose to sell their surplus lithography systems back to ASML, which has refurbished and resold well over 500 PAS 5500 systems.
When ASML refurbishes a system, it can guarantee the original specifications and provide a full warranty. This gives the buyer confidence that they are getting a reliable, high-quality system. Depending on market requirements at the time, when refurbishing a machine ASML may also reconfigure it to higher specifications, upgrade it to a newer model type or even convert it to a new wavelength. More than 90% of the PAS 5500s are still in use. They are still going strong and helping to meet growing demand for sensors, MEMS, chips, photonics and more.

(Abridged version of a story by Sander Hofman, corporate communications manager at ASML.)

WWW.ASML.COM

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

member DSPE

Cleanrooms

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

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

member DSPE

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W www.connect2cleanrooms.nl

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

member DSPE

Development

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W www.tno.nl

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

member DSPE

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TBRM Engineering solutions (previously Segula Technologies Nederland B.V) is part of the TBRM Group. TBRM-ES is an engineering company which operates internationally and aims at supporting customers by providing services from consultancy to complete project solutions including delivery of hardware, which are carried out either at the customer's location or at TBRM-ES.

TBRM-ES aims at providing innovative solutions for both existing OEM companies, as for small start-ups: Together we can create opportunities!
In addition, we aspire to be a company which distinguishes itself with a high degree of commitment, honesty, accessibility, professionalism, customer focus, quality, and an entrepreneurial spirit, where the team element is paramount in the working environment.

member DSPE

Education

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

member DSPE

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maxon is a developer and manufacturer of brushed and brushless DC motors, as well as gearheads, encoders, controllers, and entire mechatronic systems. maxon drives are used wherever the requirements are particularly high: in NASA's Mars rovers, in surgical power tools, in humanoid robots, and in precision industrial applications, for example. To maintain its leadership in this demanding market, the company invests a considerable share of its annual revenue in research and development. Worldwide, maxon has more than 3.050 employees at nine production sites and is represented by sales companies in more than 30 countries.

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