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Towards shared innovation – Mechatronics & Manufacturing for High Tech Systems
Overview isostatic design principles • Data-based control • Precision: cost vs value
Cost models for OEM-supplier collaboration • Precision flexure bearing design
Camera requirements for 3D metrology • Electromagnetic pulse forming

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In this issue

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editorial

Craftsmen wanted!

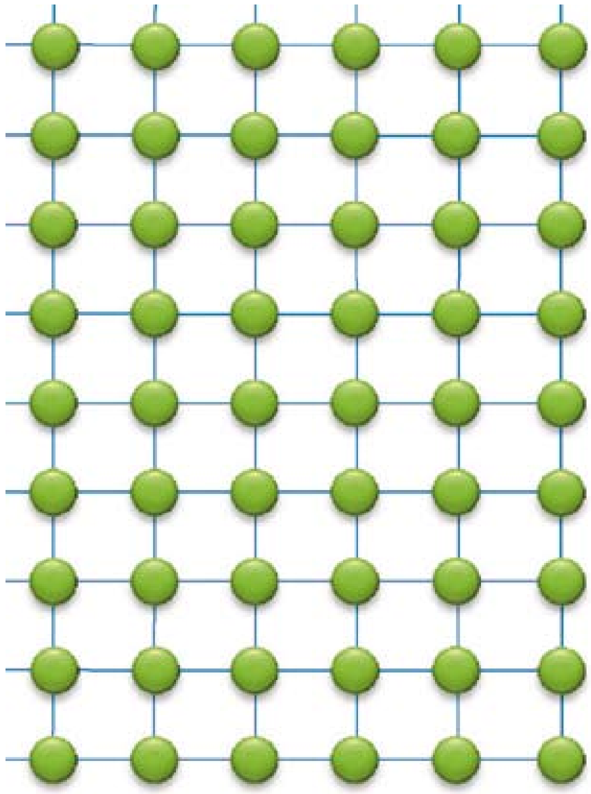
The turnover of a single Dutch citizen – Dutch Gross National Product (640B) divided by the number of Dutchmen (16M) – is 40k euros. Based on 1,400 hours of work at an average 100 euros an hour, a knowledge worker in the Netherlands turns over about 150,000 euros a year. For typical OEMs, turnover per employee is between 250 and 500 thousand euros. About a third of their employees are 'directs', people who actually assemble the products. They are facilitated by all kinds of indirect departments, which would, of course, otherwise not be necessary. So at a rough estimate, a direct employee can realise a turnover of as much as a million euros.
So, it would seem that while a knowledge worker supports himself and two to three others, a craftsman in production can provide for himself and over twenty others: a number of indirects, his family, the baker, the butcher, the teacher, his parents and their nurse.

Conclusion: our prosperity is built on making products, not selling knowledge, something we too seldom realise, unfortunately. Technology hasn't been a sexy subject for years now. Everything we make in the Netherlands that comes under the category high-tech balances on the edge of what's technically possible. And yet there are cutbacks in innovation. Technical education is considered to be too expensive because of the infrastructure it requires. But money spent on education and innovation is an investment; and if we invest well, there will be a huge return in the future.
It is because of the image of industry that parents tell their children that they shouldn't learn a trade. The inflow of students into technical education is so low that for every two technicians retiring in the coming years, there will be only one graduate to replace them. Nowadays, large numbers of knowledge workers are being recruited abroad. Let's hope they stay here, otherwise they will later compete with us from their own home base. As for manual work, the people who assemble the products here, we haven't found the road to recovery yet.
Of course, there's a raft of organisations trying to do something about it. But so far without much progress. Less fragmentation might possibly help. The government could focus efforts by making those academic studies and education programmes whose graduates help ensure the Netherlands' future earning capacity more easily accessible and, conversely, the ones to which that doesn't apply less accessible.
As stakeholders in the chain, we have already launched initiatives in innovation and education, such as CFT2.0 and Centre for Innovative Craftsmanship. And we at Frencken also support the Ontdekfabriek (Discovery Factory) and the Stichting Techniekpromotie (Association for the Promotion of Technology). We realise only too well that technology should become sexy again!

Henk Tappel, Managing Director Frencken Europe

Towards shared innovation

The High Tech Systems industry represents a major asset for the Dutch economy and establishes a unique ecosystem of knowledge, suppliers, and OEMs. A previous article described some of the future challenges for High Tech systems and possible directions of innovation to address these challenges. Now, from the perspective of the Dutch Top Sectors policy, this article describes how to move towards programming and implementation of shared innovation in Mechatronics & Manufacturing for High Tech Systems.



• *Gregor van Baars* •

As a follow-up to the previously published article “Getting High Tech Systems in Shape and Fit for the Future” [1], this article provides some basic explanation of the Top Sectors policy and plans, and more specifically the Mechatronics & Manufacturing roadmap, as well as information on the progress that has been made recently to pave the way for public-private shared innovation in the Top Sector setting. In parallel, and more on the content side, progress has been made towards the thematic programming of such innovation programmes for Mechatronics & Manufacturing.

Previously developed initiatives, such as the CFT2.0 business plan of Brainport Industries [2] have turned out to

Author’s note

Gregor van Baars is a senior system engineer/project manager at the applied scientific research organisation TNO. As TNO’s liaison, he was involved in drafting the mechatronics/manufacturing roadmap within the framework of the High Tech Systems and Materials (HTSM) top economic sector.

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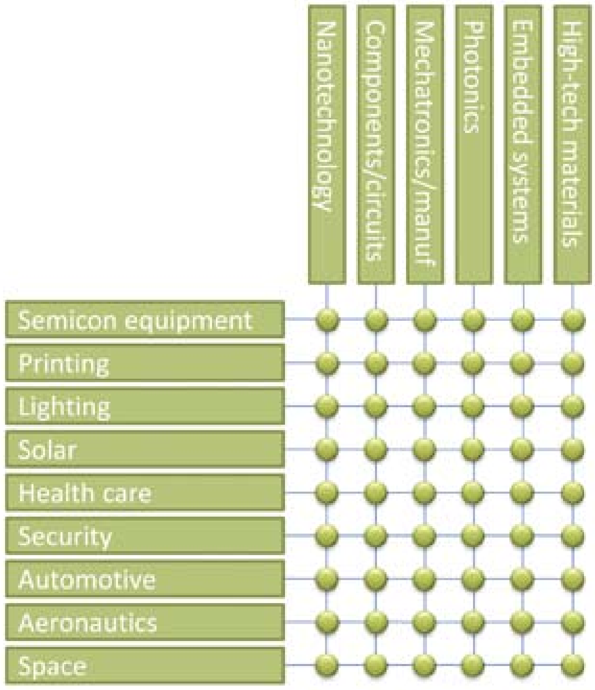

Figure 1. HTSM roadmap matrix. (Source: [4])

be a useful starting point, and Top Sector plans have been developed in close cooperation over the last six months. More on the mechatronics side, similar cooperation has been established with the Point One Mechatronics working group, which is a strong representation of the various players in the High Tech Systems ecosystem.
Even while writing this article, developments continue at a rapid pace. This presents a complication in the sense that progress that will be made between writing and publishing will not be captured in this article. We recommend that interested readers contact the author for more up-to-date information.

Top Sectors – HTSM – M&M roadmap

The previous article [1] emphasised the importance of joining forces. This means joining all the necessary competences and technologies into integral system solutions that enable realisation of future High Tech roadmap needs, but also joining all links in the chain from academia to industrial innovation and realisation in the supply and integration chain, or analogously from idea to volume.
The Top Sector initiative provides an excellent opportunity for letting such collaborative innovation take shape in consortia for the benefit of all. For general information about the Top Sector policy of the Dutch Government, the reader is referred to [3].
The Top Sector relevant to this article is HTSM (High Tech Systems and Materials). See [4] and [5] for background information. The HTSM scope is built from a set of roadmaps as illustrated in Figure 1.

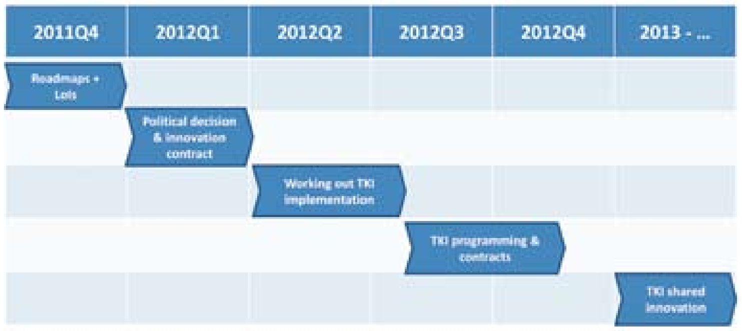

Figure 2. Implementation schedule from roadmap to shared research.

The business- and application-oriented roadmaps are listed in a horizontal direction (from semiconductor equipment to space), while the technology- and competence-oriented roadmaps are envisioned in a vertical direction across the applications.
The scope of the remainder of this article is narrowed down to Mechatronics & Manufacturing (M&M). See the leading link [6], where a pdf version of the most up-to-date version of the roadmap can be downloaded.
To roughly outline the phasing in the process of Top Sector implementation, see Figure 2.

Last year in September, the roadmapping process within HTSM was kicked off with the aim to arrive at a final version before the end of 2011. The roadmaps have been used to get a good view on the intended industrial commitments to engage in public-private innovation programmes within the Top Sector policy. To measure the potential size of the innovation programmes within a specific roadmap, invitations to submit letters of intent (LoIs) were sent out across the known networks in the High Tech ecosystem. By summing up the intended commitments (expressed in euros), the HTSM Top Sector was able to compile the so-called innovation contract proposal [7] and submit it to the Dutch Government (Ministry of Economic Affairs, Agriculture and Innovation).

By the end of the first quarter of 2012, the government reached a positive political decision and signed the innovation contract, and a start could be made by working out structures, funding schemes, and guidelines for implementation of the public-private partnerships. These are denoted by the abbreviation TKI, which stands for 'Topconsortia voor Kennis en Innovatie' (Top consortia for Knowledge and Innovation).
As the rules of the game are becoming increasingly clear, TKI programming and the drafting of contracts can be implemented. This is the phase we are currently in, and while writing this article developments are progressing further, hopefully resulting in powerful innovation

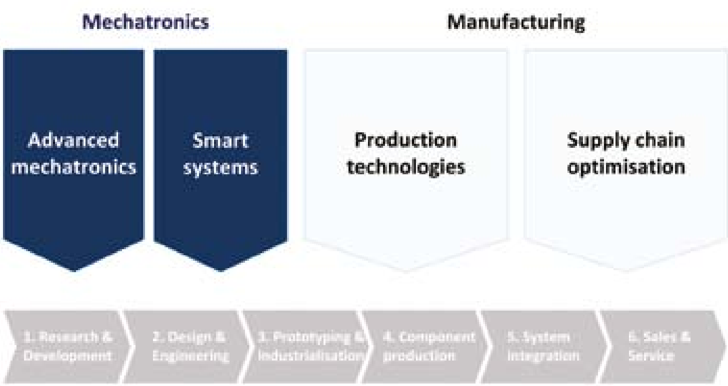

Figure 3. Overview of Mechatronics & Manufacturing themes.

programmes. Although the timing is tight, it is our intention to have all contracts signed on time and implementation prepared such that the shared research programmes can be launched at the beginning of 2013.
It is worthwhile mentioning in this context that the HTSM position in the Netherlands is also promoted internationally via the 'Holland High Tech' branding campaign, see [8].

Organising and programming a M&M TKI

The first initiatives originate from Brainport Industries and were aimed mainly at manufacturing. More than a year ago, 'CFT2.0' was used as a working title for Brainport Industries business plan development [2], with the mission of strengthening the position of the High Tech chain through precompetitive knowledge development and sharing. (CFT was the renowned Philips Center for Manufacturing (fabrication) Technology.)

The focus of the initial CFT2.0 plan was on production technologies and supply chain optimisation, which obviously fits in with the M&M roadmap in the HTSM Top Sector. Based on this, discussions started on further development of the CFT2.0 plans in the M&M TKI context. Brainport Industries mobilised the support of Boer & Croon (who already wrote the CFT2.0 business plan) to work this out in close cooperation with the M&M roadmap representatives, to safeguard compliance with HTSM Top Sector guidelines and boundary conditions. This resulted in organisational proposals in line with the CFT2.0 business plans.

Already at an early stage of these discussions, the extension with Mechatronics innovation programmes was proposed by representatives of the Point-One Mechatronics working group. In line with the M&M roadmap, two themes for innovation were proposed: Smart systems and Advanced mechatronics. Figure 3 provides an illustration of combined M&M innovation set against the well-known development chain. In fact, an extended CFT2.0 scope was proposed.

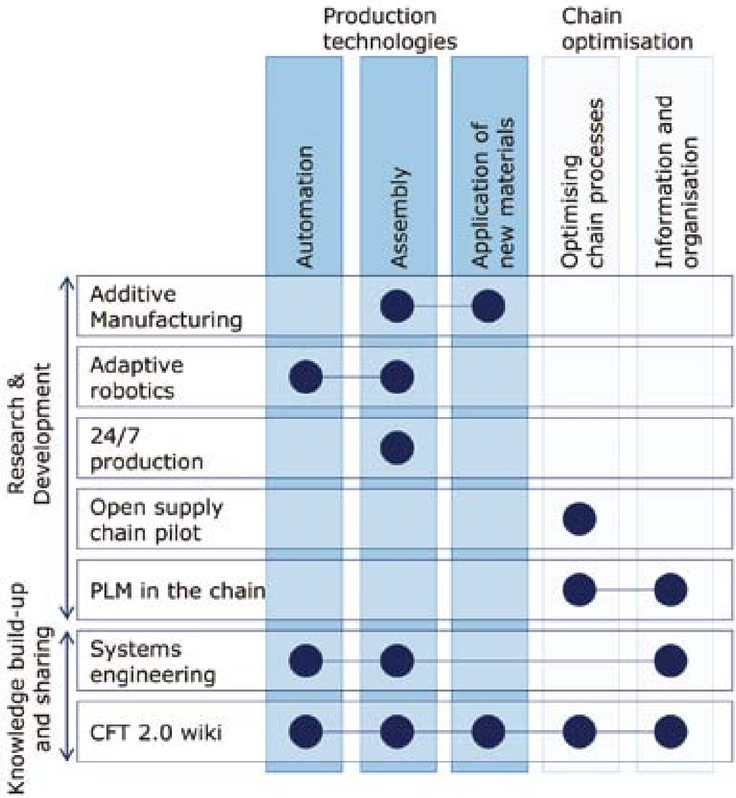

Figure 4. Intended Manufacturing innovation programme (draft, September 2012).

The following sections outline the intended M&M programmes (please note, however, that these are currently under development).

Manufacturing TKI programme proposal

In order to define a more detailed manufacturing TKI programme, several roundtable sessions have been scheduled and facilitated by Boer & Croon, with broad participation from knowledge institutes, suppliers/ manufacturers, and OEMs. The results are schematically summarised in Figure 4.

At the highest level, the above-mentioned main themes are shown: production technologies and supply chain optimisation. One level below, these are split into sub-themes, denoted by blue vertical bars.
The proposed project titles are shown in two clusters in a horizontal direction. The first covers R&D-type activities, while the second covers build-up, conservation and sharing of manufacturing-related knowledge. It is no surprise that upcoming technologies such as Additive Manufacturing and flexible robot-assisted production ('adaptive robotics') are prominently presented in this overview. Further definition of these projects is currently under intensive development and should be finalised before the end of 2012 to allow kick-off at the beginning of 2013.

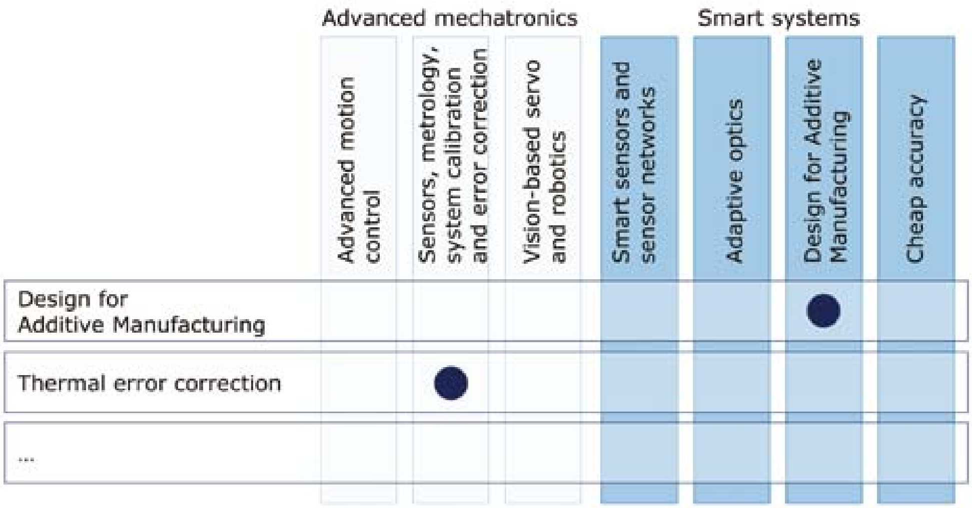

Figure 5. Intended Mechatronics innovation programme (draft, September 2012).

Mechatronics TKI programme proposal

Similar to Manufacturing TKI programme development, the definition of the Mechatronics TKI programme is also taking shape. The current status of Mechatronics innovation is presented in Figure 5.

Advanced mechatronics encompasses well-known competences such as dynamics, thermo-mechanics, motion control, sensing, and robotics. The aim is to expand these technologies, methods and tools into the next generation of Mechatronics competences. Decisive subthemes (shown as vertical light blue bars in this figure) are seen in:

- Advanced motion control
- Sensors, metrology, system calibration and error correction
- Vision-based servo and robotics

Smart systems (nodes/surfaces/structures) means combining actuators, sensors, data, opto-mechanics, and design into high-tech system architectures. This theme is driven by the continuous demand for higher accuracy and production speed. In addition to the quest for ultimate performance, low-cost accuracy is also needed to allow cost-effective equipment solutions for less-stringent accuracy applications. Decisive subthemes (shown as vertical blue bars in this figure) are seen in:

- Smart sensors and sensor networks
- Adaptive optics (smart optic systems)
- Design for additive manufacturing (including topology optimisation)
- Low-cost accuracy

The definition of further projects involving these themes is currently under intensive development and should be finalised before the end of 2012 to allow kick-off at the beginning of 2013.

Next steps

As mentioned above, the main next steps are the further definition of programmes and detailed projects and preparation for practical implementation of the TKI programme. Emphasis will be placed on obtaining commitment for the M&M programme, finding shared innovation themes, and combining available strengths in the High Tech eco-systems into powerful innovation consortia. TNO has offered to host the shared research programme at the Eindhoven site, including office space, infrastructure, and facilities, such that real cooperation in co-located teams can take place when desired and practically feasible.
Although organisation, programming, and preparations are well underway, there is still an open and urgent call for potential partners to submit proposals, join the shared research programme, etc. Please contact the author for any questions or suggestions in this context.

Acknowledgements

As mentioned throughout the text, the current state of M&M innovation development is the result of intensive collaboration and stimulating discussion with many parties involved. The author makes no claim to be the sole contributor to this article and therefore would like to acknowledge the following individuals explicitly: Henk Tappel (Frencken Europe) and John Blankendaal (Brainport Industries), who represent a large number of suppliers/manufacturers and encouraged the CFT2.0 initiatives in HTSM TKI format; Daan Kersten and Imke Reunis (Boer & Croon), who were assigned to work out CFT2.0 implementation formats and organisation structures; Hans Vermeulen (Point-One Mechatronics working group) encouraged the combination of Mechatronics with Manufacturing, and joining forces with Point-One Mechatronics; and finally Edwin Beckers

(TNO), who will set up the Manufacturing TKI programme.

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[3] www.rijksoverheid.nl/onderwerpen/ondernemersklimaat-en-innovatie/investeren-in-topsectoren

[4] www.top-sectoren.nl/hightech

[5] www.htsm.nl

[6] M&M roadmap: www.htsm.nl/Roadmaps/Mechatronics_Manufacturing

[7] Innovation Contract HTSM: www.htsm.nl/dsresource?objectid=7180&type=org

[8] Holland High Tech branding: www.hollandhightech.nl

Ultrastable bonded optical mounts for harsh environments

Over the years, a number of stable optical mounts have been designed, analysed and tested at TNO. This paper provides an overview of the isostatic design principles used. Various examples are presented together with verification test results. The use of adhesives in combination with an isostatic mount design allows mounting of optical components in a limited volume with limited deformation of the optical surfaces due to thermal and mechanical loads. Relatively large differences in thermal expansion over wide temperature ranges can be overcome using a simple and predictable design at a reasonable cost. Although adhesives have limited dimensional stability and loadability, stable optical mounts can be realised when proper design principles are used.

• *Joep Pijnenburg, Martijn te Voert, Jan de Vreugd, Amir Vosteen, Willem van Werkhoven, Jeroen Mekking and Bjorn Nijland* •

Optical mount design for harsh environments is demanding because of the conflicting requirements. On the one hand, the mount with bonded optics must be robust and strong to survive the launch loads and space environment. This is complicated because, in general, optical components are made of glass. The strength of the glass depends on the random distribution of surface flaws in relation to regions under stress. Fractures in the glass occur due to an uncontrolled crack growth of these flaws under tensile stresses. This causes failure stresses that are much lower than those for metals. The adhesives used to bond the optical component to the mount have a nonlinear material behaviour combined with a low strength level compared to metals. On the other hand, the mount must not damage or distort the optical components. This limits the forces and moments that the mount can exert on the optical component. As such, requirements for optical mount design can be divided into strength and performance requirements.

Strength requirements

The mount must be designed in such a way that the optics survive:

- A quasi-static design load (usually in the order of 50 to 90 g) accompanied by a random base PSD (power spectral density, from 20 Hz to 2 kHz) with levels up to 30 g RMS.
- A survival temperature range. A minimum range found in space applications is –50 to +50 °C. For cryogenic missions, the temperature goes down to 100 K or lower.
- An operational temperature, which can be far below the assembly temperature for cryogenic instruments.

Performance requirements

Mount performance requirements are driven by higher-level optical performance requirements on the instrument and include:

- Allowable wavefront error (WFE) of the optics, typically in the order of tens of nanometers. Bending moments and forces on the component must be minimised to avoid deformation of the optical surfaces.

Authors' note

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

The TROPOMI mount was developed for NSO and ESA as part of the ESA GMES Space Component Programme. The GAIA WFS was developed for Astrium Toulouse and the LISA PAAM for ESA.

In the forthcoming November issue of Mikroniek, a TNO article will elaborate on improved stress prediction in adhesive-bonded optical components.

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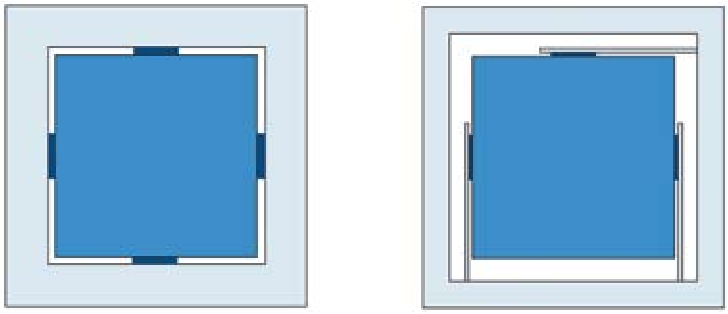


Figure 1. Athermalisation by CTE matching of the bond thickness (left) versus athermalisation by applying elastic elements.

- Stability of the optical component relative to the mount interface. This includes the temporary or permanent change in position of the optical component after initial alignment due to changing gravity direction and temperature. Residual effects due to hysteresis or interface slip after vibration loads or thermal loads are also important. For stability under changing temperature and/or changing gravity conditions, a well-placed thermal centre and high natural frequency are important.
- Limited induced stress in the optical components to avoid stress birefringence (only critical for polarisation-sensitive instruments).

As demonstrated in [1], the stability and WFE of mounted optics depend greatly on the mount design. In this paper, a simple and predictable design approach is demonstrated that shows excellent stability and low WFE while it is still capable of surviving severe loads. Examples are given, supported by analysis and test results.

Isostatically bonded optical mount design

Optical components usually have a different coefficient of thermal expansion (CTE, or α) compared to the mount. For example, fused silica has a CTE of 0.5 ppm, while aluminium has a CTE of 23 ppm. To overcome the survival and operational temperature differences with respect to its assembly temperature, the mount design must be insensitive to a change in temperature (athermal design). Two different design approaches are commonly followed. An athermal design can be achieved by dimensioning the bond thickness so that expansion of mount, adhesive and optical component is matched, or it can be achieved by introducing elastic elements in the mount. Both approaches are shown in Figure 1.

Athermalisation by tuning the bond thickness

This approach relies on compensating the expansion of optics and mount with the adhesive by tuning the bond thickness. A first-order approximation of the bond thickness t_{bond} as a function of the size of the optics D_{optic}

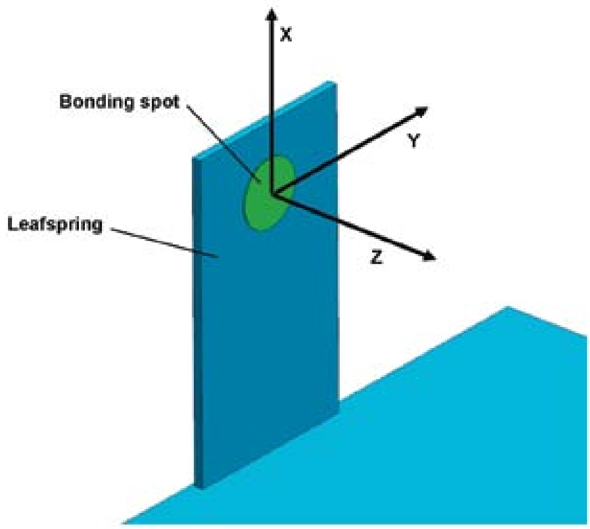


Figure 2. Leaf spring with bonding spot

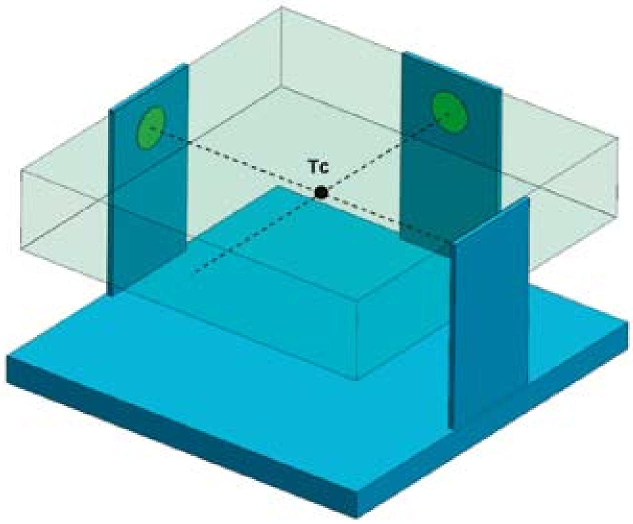


Figure 3. Isostatic arrangement of three leaf springs around a component, showing the location of the thermal centre [6].

and the CTEs of the mount, optic and adhesive is given in Equation 1. More elaborate calculation methods can be found in the literature [2][3].

$$t_{bond} = D_{optic} \frac{\alpha_{mount} - \alpha_{optic}}{\alpha_{bond} - \alpha_{mount}} \quad (1)$$

In subsequent iterations (usually with a numerical model in FEM, finite-element modelling), the effect of the incompressibility of the bond and the dependence of the CTE and Young's modulus on temperature must be included. This design approach often results in thick bond lines. This is not beneficial for strength and stiffness of the bond. Furthermore, it is usually difficult to match the CTEs of all the materials over a large temperature range, especially when considering the lack of reliable CTE data. The stability of this design depends on the symmetry of the adhesive application and on the material stability of the adhesive. If the CTE match is not optimal, internal stresses arise in the bond and optical component, resulting in reduced stability and increased wavefront errors.

Athermalisation by isostatic flexible elements

A better approach to athermalise the mount is to introduce flexible elastic elements in the mount [4][5]. The leaf spring is a very simple flexible element (Figure 2).

Using Equations 2 and 3, dimensioning is straightforward, where k is the stiffness, E is the Young's modulus of the leaf spring and l, t and h are the length, thickness and height, respectively.

$$k_{tensile,x} = \frac{Eth}{l} \quad (2)$$

$$k_{bending,z} = \frac{Eth^3}{l^3} \quad (3)$$

When properly dimensioned, the tensile and lateral stiffness are much higher than the bending stiffness (as a rule of thumb a ratio of 1:1,000 is achievable). The leaf spring can be manufactured with inexpensive conventional milling. Alternatively, it can be manufactured using wire EDM (electrical discharge machining).

A rigid optical component has six degrees of freedom (DoFs). An isostatic design means that each DoF is constrained only once. A leaf spring constrains X, Y and Rz with high stiffness (in the local coordinate system in Figure 2). Given that a bond spot has a high shear stiffness, but a low torsional stiffness, the combination of bond spot with a leaf spring only constrains X and Y with high stiffness. By arranging three leaf springs around the optical component, as shown in Figure 3, the optical component is constrained once in each DoF. The isostatic design means that the mount cannot impose significant forces or bending moments on the optics and deform the optical component. In practice, true kinematic constraints do not exist and bending moments due to parasitic stiffnesses can exert a second-order influence. WFEs introduced by these parasitic forces must be checked using hand calculations or FEM analysis.

The natural frequencies of the mount are high because each DoF of the optical component is constrained with high stiffness. This is beneficial for the stability of the component under inertial loads, such as gravity. The arrangement of the leaf springs determines the location of the thermal centre. If a temperature difference occurs between component and mount, the centre of expansion is at Tc. Because of the flexures, the thermal expansion difference between component and mount can be large

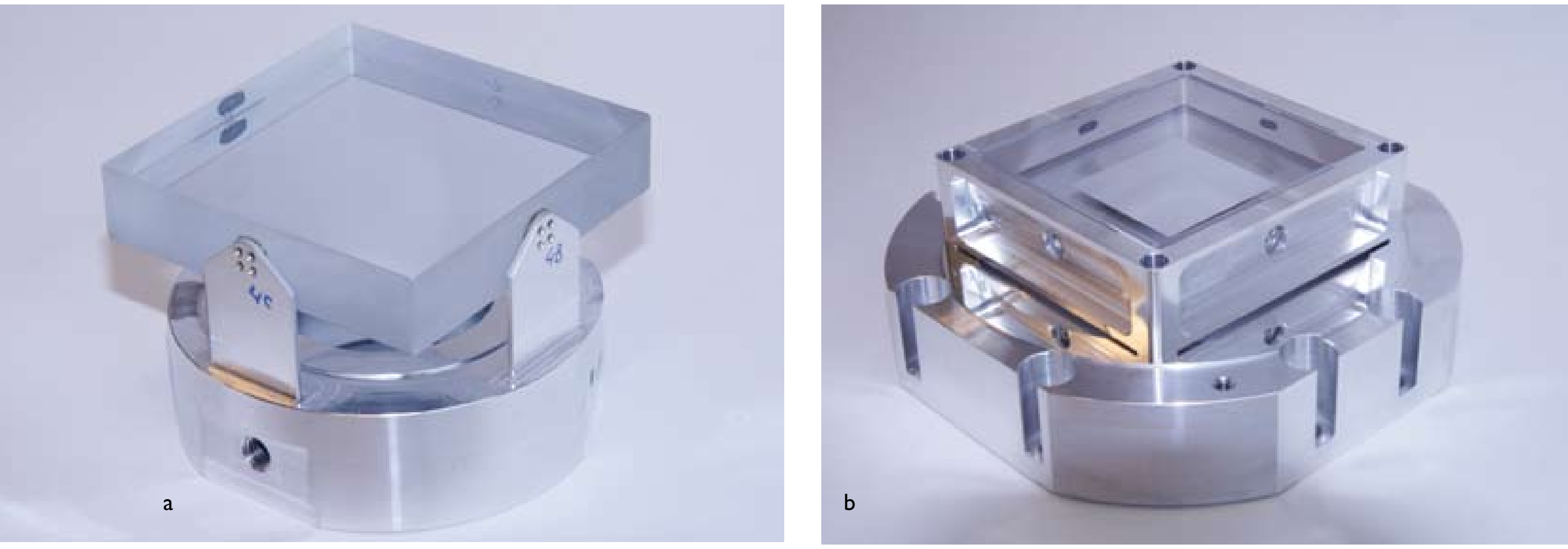


Figure 4. Breadboards of the TROPOMI mount baseline showing aluminium leaf springs bonded to a fused silica component. The thick baseplates contain a diamond turned reference for interferometric stability measurements. The dark bond spots are clearly visible. Please note that the optical components are different in size and that the magnification of both photos is different.
(a) Three leaf springs.
(b) Four leaf springs.

without significant effects. Usually, the thermal centre is located on the optical axis.

The leaf springs decouple thermal expansion of the component in the lateral direction. Only residual local stresses in the glass arise around the bond spots. The effect of these remaining local stresses can be predicted using an FEM model of the bond spot in combination with an accurate material model of the adhesive.

Common adhesives used in optomechanical applications include room-temperature vulcanisation silicones (RTVs) and epoxies. The advantage of RTVs is their compliance, which allows bonding materials with completely different CTEs over wide temperature ranges. Advantages of epoxies are their increased strength and stiffness. TNO developed analytical tools and material models to select the proper adhesive and optimise the adhesive spot geometry. These models and tools are the key to developing highly stable optical mounts with low WFEs. By optimising the bond thickness and diameter, local stresses in the optical component can be minimised [7].

Applications of isostatically bonded optical mounts

A few implementations of the isostatically bonded concept will be described, including test verification results of critical requirements, i.e. stabilities and WFEs. The first application is the mount design for the TROPOMI instrument. Angular stability after launch loads and thermal loads are driving the design in this application.

The second application is a cryogenic mount for the GAIA Wave Front Sensor (WFS). Again, it is stability and WFE that are driving the design. This time, however, it is not only in combination with vibration loads of up to 30.2 g RMS, but also in combination with an operational temperature range from 130 to 200 K.

The last application described is a scan mechanism for gravitational wave detection. Piston stability of the mechanism and mirror mount are driving the design in this application, in combination with microrad stability over its lifetime. It can be seen from the test results that the picometer stabilities of the mount over hours are possible with an isostatically bonded mirror mount.

An isostatically bonded mount is currently being designed for the EUCLID mission; low WFE, high stability and cryogenic temperatures in combination with launch loads are driving the design in this application. Given that no hardware and test data are available yet, this design will not be described in detail.

TROPOMI optical mounts

The TROPOspheric MONitoring Instrument (TROPOMI) is an advanced absorption spectrometer for observing the Earth. It is a push-broom instrument that combines a very large field of view with a spectral range encompassing UV, VIS, NIR and SWIR bands. It is scheduled for launch in 2015 [8].

The instrument consist of an aluminium optical housing which contains more than 20 fused silica and silicon lenses. Most lenses are about 70 mm x 70 mm in size with a mass smaller than 0.2 kg. The compact optical layout of the spectrometer channels limited the design envelope for the mount design. Therefore, all lenses are bonded to three isostatic leaf springs, which are an integral part of the aluminium optical mounts (see Figure 4).

A slightly modified design was chosen for two lenses because of their larger 95 mm x 95 mm size and their high mass. A fourth leaf spring was added to provide a sufficient bond area and to raise the lowest resonance frequency to above 800 Hz. Although this is not a proper isostatic design (because of the fourth leaf spring), analysis showed that the effect of overconstraining the optics can be tolerated for these lenses.

Both mount designs were breadboarded with representative lens dummies. Each breadboard included a diamond-turned reference for measuring the stability of the component relative to the mount. The mechanical integrity and the stability were confirmed by subjecting the breadboards to:

- random vibration testing (with a g RMS level of 14.4 g);
- eight thermal cycles in LN_2 between –50 and +45 °C.

Before and after each environmental test, the bond spots were inspected with a microscope to verify their mechanical integrity. The tip/tilt stability of the component relative to the mount reference was measured with a Zygo Fizeau interferometer. No mount showed mechanical degradation. Measured stabilities for the three-leaf-spring design can be found in Table 1. Testing of the four-leaf-spring design for larger components had not finished at the time of writing this paper.

Figure 5. Flight model of the GAIA WFS. (Photo courtesy of Leo Ploeg)

GAIA WFS cryogenic mount

The ESA GAIA mission is the follow-up to the ESA Hipparcos mission. Its ambitious objective is to create the largest and most precise three-dimensional chart of our galaxy by providing unprecedented positional and radial velocity measurements for about one billion stars in our galaxy. Each of its target stars will be monitored about 100 times over a five-year period, precisely charting their distances, movements and changes in brightness. The expectation is that hundreds of thousands of new celestial objects, such as exoplanets and failed stars will be discovered, and that tens of thousands of asteroids will be identified. GAIA is being built by Astrium EADS. The mount described here is used in the design of the wavefront sensor that TNO has built for this mission (see Figure 5). This wavefront sensor will be used to monitor the wavefront errors of the two GAIA telescopes mounted on the GAIA satellite. The WFEs may be corrected by a 5-DoF mechanism incorporated in the GAIA telescopes, which also functions in orbit. The GAIA WFS will operate over a broad wavelength (450-900 nm) and in cryogenic conditions (130-200 K operation temperature). For details see [9].

Table 1. Tilt stability before and after environmental testing of the TROPOMI three-leaf-spring mount design. Note: the stability measurement "After vibration testing" was performed with a limited accuracy due to misalignment of the samples with respect to the interferometer.

Relative component tilt with respect to the mount reference (µrad)				
Mount #	After bonding	After vibration testing	After thermal testing	Stability over complete test
1	48.76	45.26	48.73	0.03
2	211.03	217.13	211.42	-0.39
3	15.16	11.75	13.89	1.27

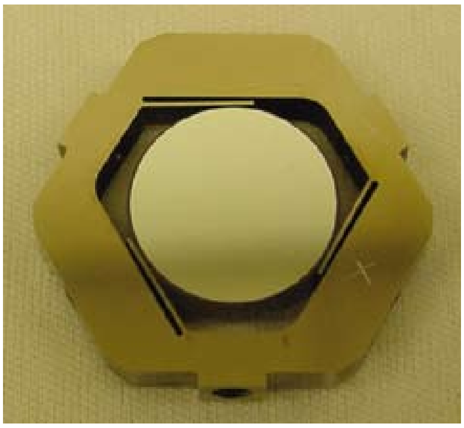


Figure 6. Breadboard of a mirror bonded to three tangential leaf springs as used in the GAIA WFS mount design.

Requirements

The design-driving requirements for the mount:

- Deformation of the surface of the mirror < 3 nm RMS and 79 nm peak-to-valley in the operational range of 130 to 200 K.
- Tip/tilt stability (Rx,Ry) of the mirror with respect to the structure better than 50 µrad over its lifetime. This includes launch loads of up to 30.2 g RMS and thermal cycling in the range of 100 to 350 K.

Mount design

The mirror is isostatically mounted using three tangential leaf springs (see Figure 6). The thermal centre coincides with the mirror's centre of gravity. The leaf springs minimise bending moments to the plane of the mirror, which results in a low global WFE of the optical component. The CTEs of the mount and mirror material are optimally matched (Fused Silica with M93 Invar). The bond between mirror and leaf spring was optimised by tools and material models developed by TNO [7].

Verification by test

Breadboard testing was performed on this and other mount designs (see Figure 7). Based on the low WFE in combination with the high stability, this mount design was selected for the flight models. Test sequence: WFE measurement at 130 K, vibration tests, thermal cycling. The WFE and angular stabilities were measured using a Zygo interferometer before and after all test steps. Table 2 lists the relative tilts between the mount and mirror before and after the vibration testing. The maximum measured instability in pointing is 4 µrad for sample 1 around the X axis.

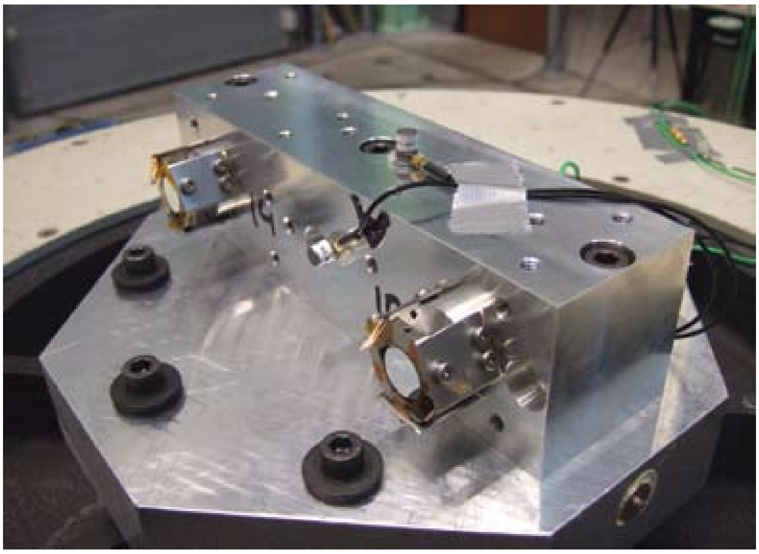


Figure 7. Two breadboards of the mirror mount on the shaker. To avoid misalignment due to the mounting on the shaker interface and to keep the reference plane on the mount flat enough for a reference measurement, the mounts were isostatically mounted on the shaker.

Relative angular stability measurements between the mount and component were performed in ambient temperature and the operational temperature at 130 K. Table 3 shows the measured stabilities and WFEs. The worst-case instability measured was 9 µrad and the maximum WFE measured was 24 nm peak-to-valley. Figure 8 shows the WFE of one of the leaf springs at ambient and cryogenic conditions.

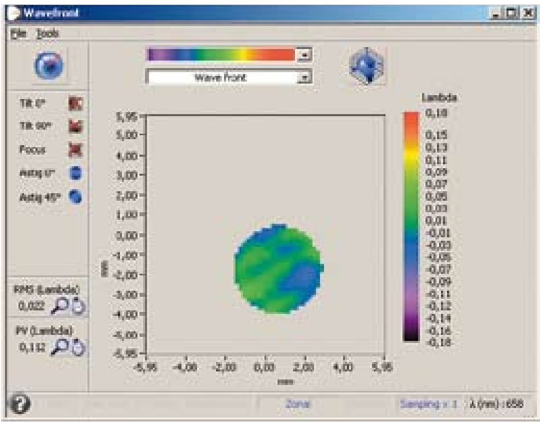
After the breadboard testing, the flight models were successfully built, tested and delivered to Astrium Toulouse, France.

LISA PAAM mirror mount

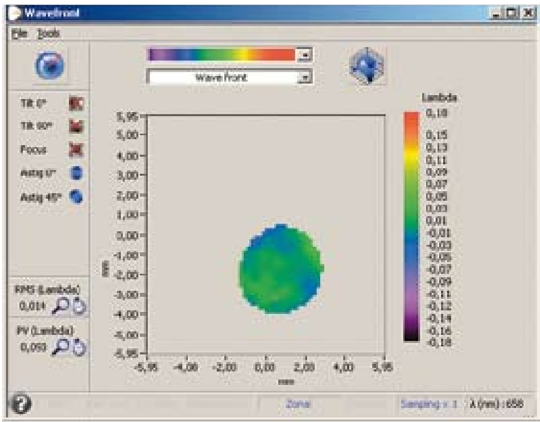
Detection and observation of gravitational waves requires extremely accurate displacement measurement in the frequency range from 0.03 mHz to 1 Hz. The LISA (Laser

Table 2. Tilt stabilities before and after the vibration test with levels up to 30.2 g RMS. All measured values are well within the required values.

Relative component tilt with respect to mount reference (mrad)						
Tangential leaf spring mount #	Rx before vibration tests	Ry before vibration tests	Rx after vibration tests at 17.3 g RMS	Ry after vibration tests at 17.3 g RMS	Rx after vibration tests at 30.2 g RMS	Ry after vibration tests at 30.2 g RMS
1	0.022	0.087	0.024	0.084	0.026	0.084
2	0.001	0.009	0.001	0.012	0.003	0.011



a



b

Figure 8. The WFE of sample 3; peak-to-valley difference < 24 nm.
(a) At ambient temperature and pressure.
(b) At 130 K and vacuum conditions.

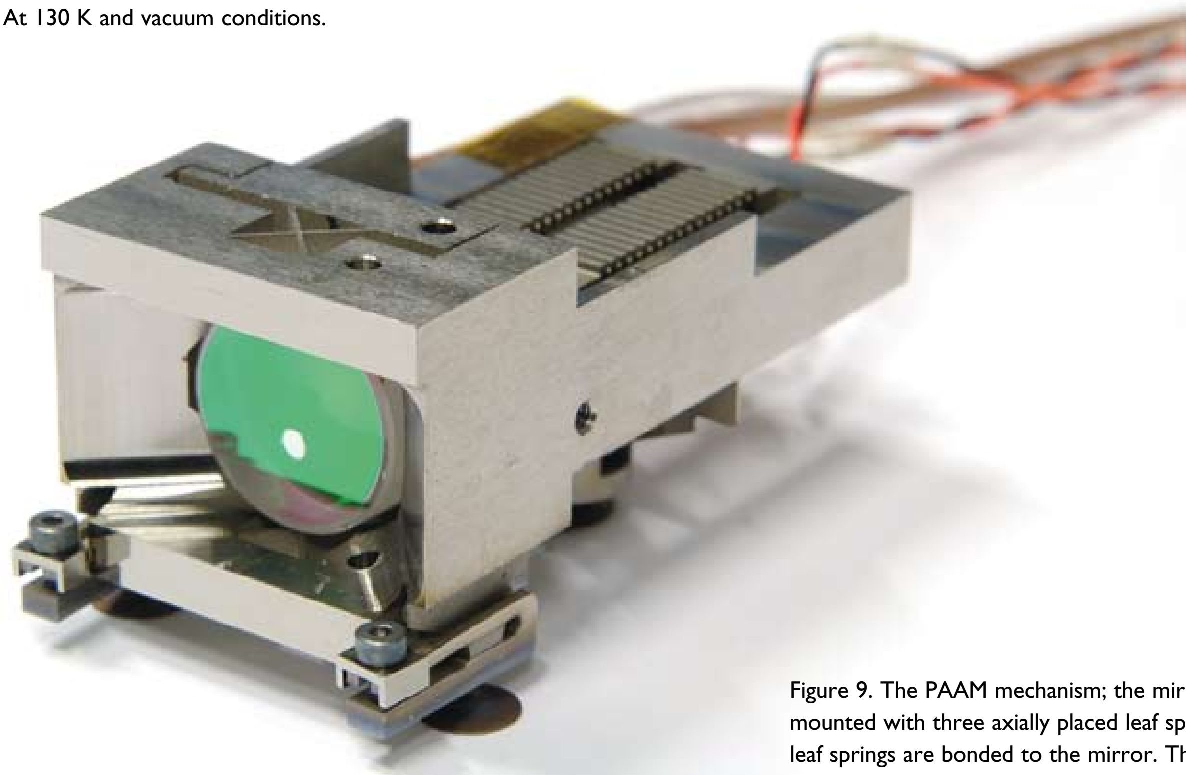


Figure 9. The PAAM mechanism; the mirror is mounted with three axially placed leaf springs; the leaf springs are bonded to the mirror. The axial leaf springs are difficult to see in this photo (for the concept see Figure 4a).
(Photo courtesy of Fred Kamphues)

Table 3. Tilt stabilities and WFEs measured from ambient to 130 K and vice versa. All measured values are well within the required values.

Relative component tilt with respect to mount reference (mrad)					
Tangential leaf spring mount #	Measured Rx ambient to cryo	Measured Ry ambient to cryo	Measured Rx cryo to ambient	Measured Ry cryo to ambient	WFE peak-to-valley [nm]
1	0.007	0.004	0.007	0.008	19
2	0.004	0.002	0.001	0.007	22
3	0.001	0.008	0.001	0.010	24

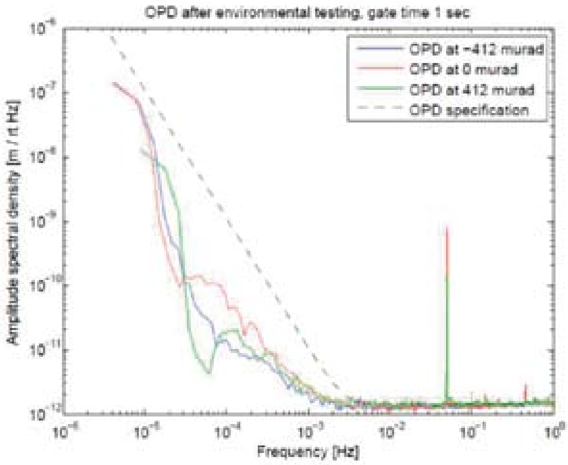


Figure 10. Amplitude spectral density of the optical path difference measurements; the piston stability of the mirror mount is a part of the measured value. Measured values are expected to be dominated by the noise in the measurement set-up. The peak at 50 mHz was introduced to realise alignment in the cavity and is caused by the rotation of the mechanism.

Interferometer Space Antenna) or NGO (New Gravitational wave Observatory) missions will achieve this by creating a giant interferometer in space, based on free-floating proof masses in three spacecraft.

Due to orbit evolution and time delay in the interferometer arms, the direction of transmitted light changes. To solve this problem, a picometer-stable Point-Ahead Angle Mechanism (PAAM) was designed, constructed and successfully tested. The PAAM concept is based on a rotatable mirror; see Figure 9. The critical requirements are the contribution to the optical path length (less than 1.4 pm/√Hz) and the angular jitter (less than 8 nrad/√Hz). As a part of the mechanism, the mirror mount has to be stable up to picometer level for hours. A bonded axial leaf-spring design was implemented for this mount. Interferometric measurements with a triangular resonant cavity in vacuum proved that the PAAM and thereby the bonded radial leaf-spring mount meets the requirements. For details on the PAAM see [6].

Requirements
The design-driving requirements for the mount are:
- Mirror piston stability of < 0.7 pm1SHz in the LISA measurement band (0.03 mHz to 1 Hz).
- Tip/tilt stability (Rx, Ry) of the mirror with respect to the structure better than 4 µrad over its lifetime. This includes after-launch loads of up to 25 g RMS and thermal cycling in the range of –60 to +80 °C.

Mount design
The mirror is mounted isostatically using three axial leaf springs. The thermal centre is located in the centre of the reflective surface of the mirror. The CTE difference between the structure material and mirror material is decoupled by the leaf springs. The component is bonded to the leaf springs (for the concept of the mount design, see Figure 4a).

Verification by testing
The complete mechanism was tested by the Albert Einstein Institute in Hannover, Germany. A dedicated test set-up was developed within the context of the LISA mission. Figure 10 shows the optical path difference measured by the Albert Einstein Institute [10]. The piston stability of the mechanism including the bonded axial mirror mount is half of the values shown. Figure 11 shows the mechanism on the vibration facility.

It can be concluded from the measurement results that, with a proper design, a bonded isostatic mount can be stable for hours up to the picometer level. Instabilities introduced by the adhesive can be minimised by proper design and dimensioning of the mount.

The mechanism is currently ready to be integrated into the LISA Optical Bench EBB. For details see [11].

Conclusions
TNO has built up a lot of experience with the bonded isostatic mounting concept by implementing it in several applications. Thanks to extensive verification campaigns, excellent knowledge of this mounting concept in terms of strength, stability and wavefront errors has been acquired. This knowledge was developed together with refined material models which have been implemented in design tools developed by TNO. With these design tools and its extensive test experience, TNO is able to predict the performance of mounting concepts in the preliminary design phase.

This was accompanied by further developing the infrastructure for environmental testing and experimental

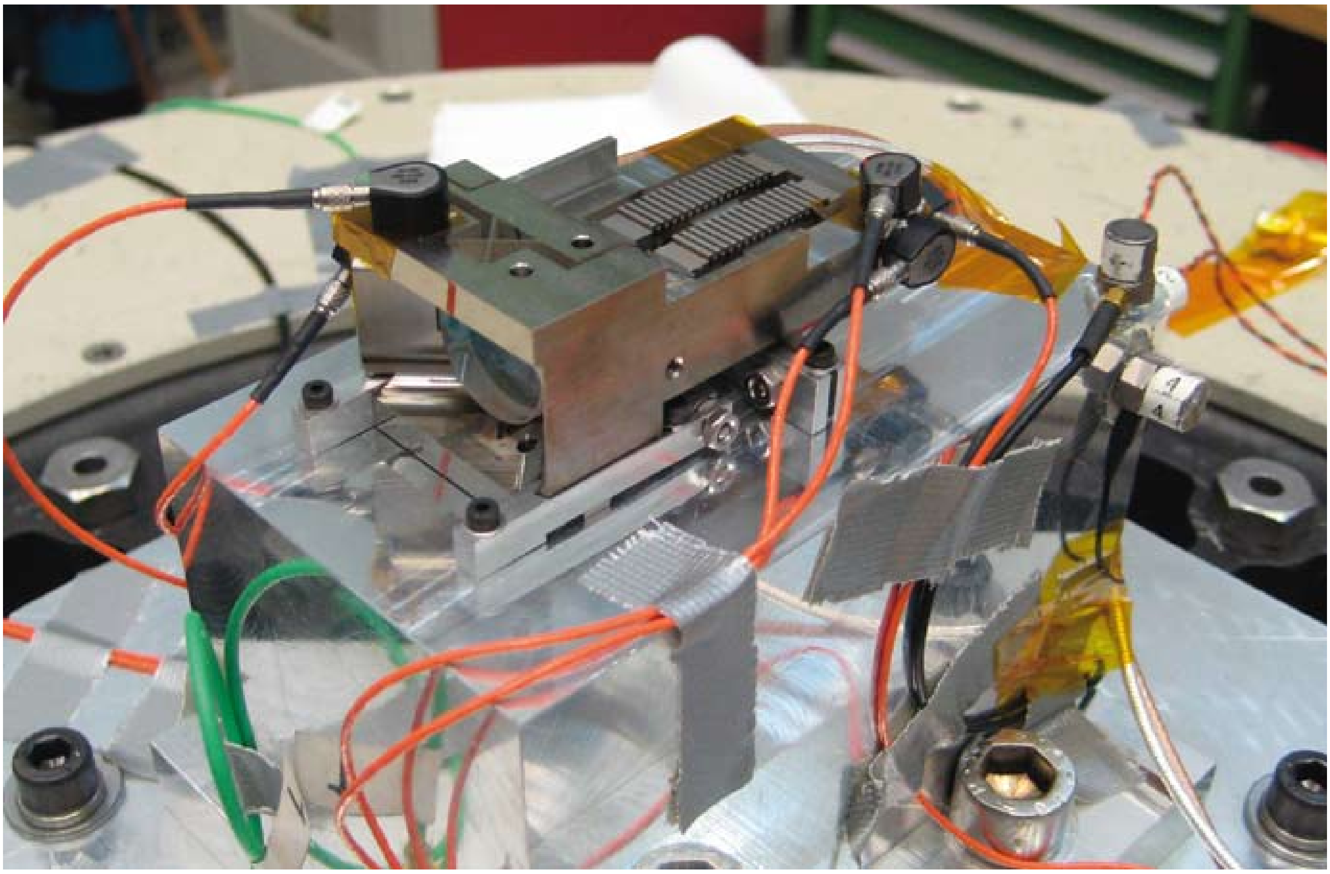


Figure 11. The mechanism on the vibration facility. Tilt stabilities well below 4 μrad have been measured before and after the vibration test (25 g RMS).

validation of stabilities and WFEs which is available from TNO. Over the years, a more or less standard way of testing has been developed. This has led to a relatively inexpensive way to validate stabilities during and after extreme environmental loads. For recent developments in the testing infrastructure at TNO, see [12].

The extensive experience with bonded isostatic mounts in combination with the design tools and the experimental validation infrastructure developed in-house have given TNO the opportunity to develop extreme stable mounts at a low cost, with few risks and within a short space of time

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The driving force behind the manufacturing industry: precision cutting companies 2.0

In the current recession, the idea that we can increasingly make money with services is losing ground. Industry, and manufacturing in particular, is crucial for the Dutch economy now more than ever before. Especially because of its contribution to exports, but also because it is part of a knowledge-intensive manufacturing chain that ensures our (future) prosperity and the related secondary jobs in the service sector.

Within the knowledge-intensive chain, we see that more and more OEMs no longer regard the in-house development of specific and specialised production technologies as a core activity. That is why they are appealing to the supply partners in the manufacturing chain. It is there that the opportunities lie. In that regard, it is important that the suppliers, including precision machining companies and toolmakers, continue to innovate. Technological, social and sustainable innovations and innovations in production, processes and organisations as well as sharing knowledge are key. Another condition is that OEMs and suppliers in the high-tech chain seek to establish mutual, long-term, consistent and predictable relationships.

It is smaller SMEs in particular that often don't know where to start. As an advocate of precision machining companies within the Koninklijke Metaalunie (the royal Dutch association for SMEs in the metal industry), the Dutch Precision Technology trade group sees an important role for itself and for other trade associations. They excel at initiating collaboration and innovation between branches of industry and professional groups such as DSPE, the Dutch suppliers association NEVAT, the Dutch association of purchasing management NEVI, and technological and other knowledge and research institutes, but above all, between the actors in the chain.

Dutch Precision Technology provides its members with insight into new manufacturing and processing technologies which can then be applied in technology fields such as mechatronics, embedded systems and nanotechnology. The starting points are collaboration, using each other's production capacity, joint (international) marketing, sharing networks and knowledge. This has turned them into precision cutting companies 2.0 and made them the driving force behind the Dutch manufacturing industry.

Tom Kusters
Chair of Dutch Precision Technology
www.dptech.nl

Data-based control high-precision

Lightweight high-precision motion stages pose a challenge to the control design. Due to the low-frequent resonances, conventional control techniques can no longer be applied. Transfer function data, obtained from frequency response data, can be used as an extension of loop-shaping techniques. As an example it is shown how a root-locus can be drawn for an experimental set-up, without the use of a parametric model. The root-locus is then used to optimise the gain of the controller such that the settling time is minimised.

• *Rob Hoogendijk, René van de Molengraft and Maarten Steinbuch* •

The trend that the number of transistors on a chip increases while the cost of a chip decreases leads to increasing performance requirements for high-precision motion systems that are used in the chip manufacturing industry. To satisfy the specifications on the throughput and resolution, higher accelerations and improved accuracies are required. The current motion stages are designed to be very stiff to achieve the required accuracy. This makes these stages relatively heavy such that strong actuators are required. Following this design principle, increasing the accuracy would require even stiffer and consequently heavier stages. Especially for the future stages that will carry the larger 450mm wafers this will be a problem. Achieving higher accelerations with heavier stages is not feasible anymore because the high-power actuators that would be required would be inaccurate and very expensive.

Therefore, the next-generation positioning systems are designed to be lightweight to enable high accelerations using limited actuator force. At the same time, however, the system becomes less stiff causing flexible dynamics to shift to lower frequencies. Figure 1 shows typical Bode magnitude plots for a conventional system and a lightweight motion system. It can be seen that for the lightweight system resonances appear below the target bandwidth (BW). This has major consequences for the control design.

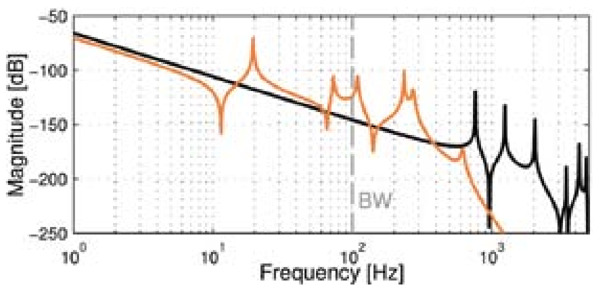

Figure 1. Typical Bode magnitude plots for a conventional high-precision motion system (black) and a lightweight motion system (orange).

# of lightweight motion systems

Rigid-body assumption

The current generation of stages is controlled in six degrees of freedom (DoFs) using multiple actuators and sensors, which makes a stage a multiple-input, multiple-output (MIMO) system. The system is decoupled by using transformation matrices in the input and output channels, such that each DoF can be controlled independently of the other DoFs. In that way, the control design of this MIMO system can be made using single-input, single-output (SISO) techniques. The computation of these transformation matrices uses the assumption that the system behaves as a rigid body. When all resonances lie above the target bandwidth, this is a valid assumption and an acceptable decoupling can be achieved. PID controllers in combination with low-pass and notch filters are used to control these systems. The notches prevent the excitation of the resonances that are present at high frequencies. Active control of these high-frequent flexible dynamics is not necessary for conventional stages, since the resonances lie well above the target bandwidth.

Advanced control

The future lightweight systems that have flexible dynamics at low frequencies cannot be decoupled by the same techniques, because they cannot be assumed to be rigid. The low-frequent resonances cause the system to display a lot of interaction between the DoFs. Furthermore, the resonances will have to be actively controlled because they lie under the target bandwidth. Therefore, advanced control techniques are required to control the future lightweight motion stages. In academia, many advanced control techniques are available, but most of them rely on an accurate model of the system. Finite-element models (FEM) are often inaccurate and computing an accurate, low-order MIMO model from frequency response measurements is also not straightforward. Therefore, the research described here focuses on data-based techniques that lie close to the loop-shaping techniques that are currently used.

Poles for performance

One of the aspects currently under investigation is how the pole locations can be computed without a model of the system. Each resonance in the Bode diagram corresponds to a complex pole pair. For a future flexible motion stage, some of these open-loop poles of the system will lie at low frequencies. Furthermore, these resonances will have a very low damping due to the use of materials with low damping such as metals and ceramics. Without proper control, the settling time of these systems would be very long. Therefore, controllers are required that can add damping to the poles to improve the settling time. Conventional loop-shaping, however, does not incorporate analysis of pole locations, since these are not known when only frequency response data of the system is available. This calls for novel control design and analysis techniques.

Experiment set-up

The techniques that have been developed will be explained by means of the experiments that were conducted on a benchmark motion system. Theory that was used will be explained along the way. The system depicted in Figure 2 consists of two inertias connected via a rotational spring. A motor is used to drive one of the inertias and the angle of

Authors' note

Rob Hoogendijk is a Ph.D. candidate at Eindhoven University of Technology, the Netherlands, in the group of Professor of Control Systems Technology, Maarten Steinbuch. His research, supervised by Associate Professor, René van de Molengraft, is part of the XTreme Motion project, which focuses on the development of high-precision positioning systems for the semiconductor industry.

This article was, in part, based on a presentation at the DSPE Conference, which was held on 4 and 5 September 2012 in Deurne, the Netherlands.

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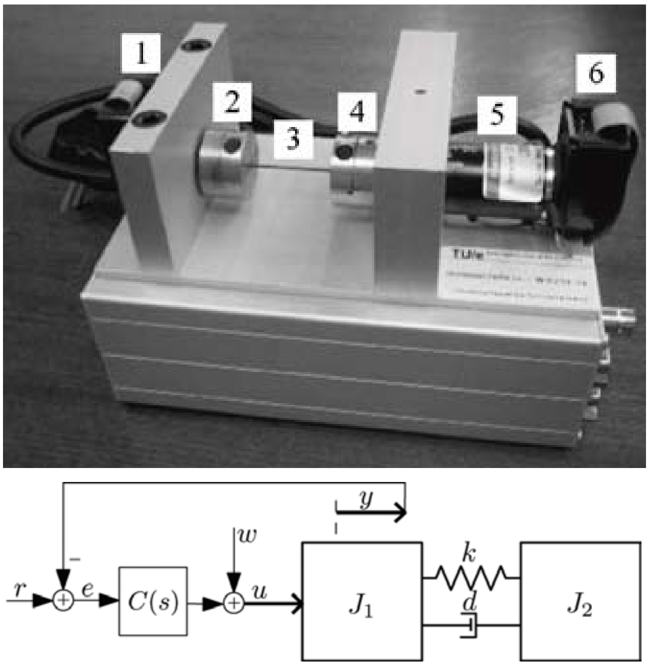

Figure 2. Top: Experimental set-up consisting of load encoder (1), load side inertia (2), rotational spring (3), motor side inertia (4), motor (5) and motor encoder (6).
Bottom: Schematic representation of the system and the feedback loop.

the inertias is measured by encoders. For this experiment, a feedback loop is closed over the motor encoder, creating a collocated control scheme as schematically depicted in the bottom part of the figure.

The feedback controller $C(s)$ consists of a gain, a lead-lag filter and a low-pas filter. The lead-lag filter creates phase lead which will add damping to the poles. Frequency response measurements have been conducted on the set-up to obtain frequency response data $H(j\omega)$. Figure 3 depicts the open-loop Bode plot of the system with controller. Three choices for the gain are shown; the low-gain case is plotted in blue, the medium-gain case in green and the high-gain case in red. But which of the open-loop transfer functions that are shown gives the best closed-loop performance? This question cannot be answered from this figure. Information on the damping of the closed-loop poles is necessary to answer this question.

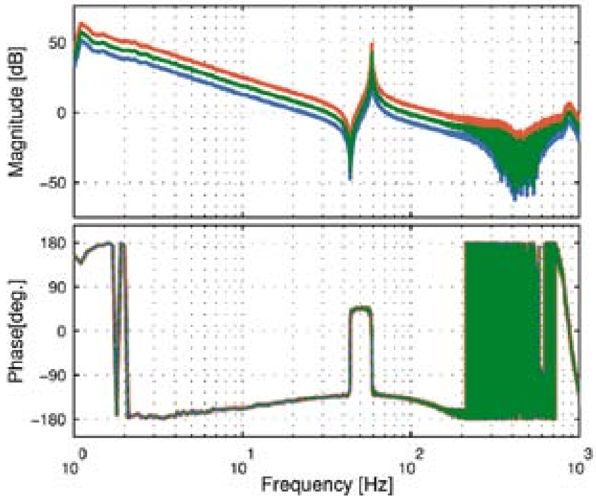

Figure 3. Bode diagram of the open loop of the experimental set-up. Three possible choices for the gain are depicted: low (blue), medium (green) and high gain (red).

Transfer function data

Closed-loop transfer functions all share the same denominator, $1+H(s)C(s)$. Consider for example the sensitivity function $S(s)$ or complementary sensitivity function $T(s)$ of a system $H(s)$ with controller $C(s)$,

$$S(s) = \frac{1}{1 + H(s)C(s)}, \quad T(s) = \frac{H(s)C(s)}{1 + H(s)C(s)}. \tag{1}$$

This shows that the closed-loop poles lie at the points s where the denominator equals zero

$$p_{cl} = \{\, s \mid 1+ H(s)C(s) = 0 \,\} \tag{2}$$

Note that at these points $H(s)C(s) = -1$, which is of course the well-known "–1 point" of the Nyquist plot. The transfer functions are denoted as a function of s and not $j\omega$, since solutions to this equation are not likely to lie on the imaginary axis. Solutions on the imaginary axis would mean that there are closed-loop poles that have zero damping, which is of course very undesirable. This means that information on $H(s)$ and not $H(j\omega)$ is required to solve this equation. This leads to the concept of transfer function data. While frequency response data $H(j\omega)$ only gives information on the transfer function $H(s)$ for points $s=j\omega$ that lie on the imaginary axis, transfer function data $H(s_i)$ gives information on the transfer function for points $s = s_i$ that can lie anywhere in the complex plane. Thus

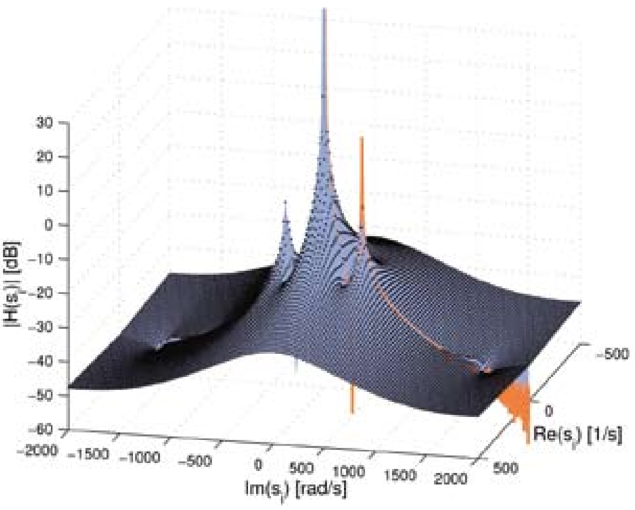

Figure 4. Transfer function data (black dots) and frequency response data (orange) of the experimental set-up.

$$s_i = \sigma_i + j\omega_i, \qquad (3)$$

where σ_i denotes the damping and ω_i the frequency at this point. The subscript i emphases that s_i is a single data point in the complex plane. For lightly damped mechanical systems there is a technique to compute a point $H(s_i)$ from the measured frequency response data $H(j\omega)$ using the following Cauchy integral

$$H(s_i) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \frac{H(j\omega)}{(s_i - \omega)} \, d\omega, \qquad (4)$$

where s_i is a point in the right half plane. The integral (4) can only be computed for points that lie in the right half plane, because the right half plane does not contain open-loop poles. Fortunately, the systems under consideration are very lightly damped such that the open-loop poles lie almost on the imaginary axis. This makes the system symmetric in the origin such that points in the left half plane can be computed from points in the right half plane according to

$$H(s_i) = H(-s_i). \qquad (5)$$

In this way it is possible to compute the value of a transfer function at any point s_i in the complex plane. More details on the computation of transfer function data can be found in [1]. By computing $H(s_i)$ on a grid of points s_i, the value of the transfer function is obtained on the whole complex plane.

Transfer function data has been computed for the experiment set-up. Figure 4 shows the 3D-Bode magnitude plot of the transfer function data of the set-up. In a 3D-Bode magnitude plot, the magnitude of the transfer function $|H(s_i)|$ is plotted as a function of both the real part σ_i and the imaginary part ω_i of s_i. The measured frequency response data is also shown in the figure in orange. Unlike the frequency response data, the transfer function data is very smooth, almost as if they were obtained from a model, which is of course not the case. This smoothness is caused by the integral (4), which has an averaging effect on measurement noise. From the figure it can also be observed that the open poles of the system (the peaks) lie on the imaginary axis, showing that the open-loop system is highly undamped such that the transfer function data is symmetric with respect to the origin of the complex plane.

Data-based root-locus

The transfer function data is obtained for the open-loop system. Next, the influence of the controller is discussed. The controller adds damping to the poles, placing the closed-loop poles somewhere in the left half plane. It is desirable to know the locations of the closed-loop poles such that the settling time and dominant frequencies in the response can be predicted. One approach is to evaluate (2) in a data-based way using the computed transfer function data of the system $H(s_i)$ and the value of the controller $C(s_i)$ yielding

$$p_{cl} = \{ \, s_i \mid 1 + H(s_i)C(s_i) = 0 \, \}. \qquad (6)$$

A numeric algorithm could be used to perform a search over all computed grid points s_i to look for points s_i that satisfy this equation. This would give the closed-loop poles for one specific controller. For SISO systems, however, it is even possible to compute a root-locus in a fully data-based way. The root-locus gives all possible closed-loop pole locations as a function of the gain of the controller. The controller gain k is extracted from (5) according to

$$p_{cl} = \{ \, s_i \mid 1 + kH(s_i)C(s_i) = 0 \, \}. \qquad (7)$$

$$p_{cl} = \{ \, s_i \mid H(s_i)C(s_i) = -\frac{1}{k} \, \}. \qquad (8)$$

This means that points s_i for which $H(s_i)C(s_i)$ is negative and real, belong to the root-locus. In other words, a search for points s_i where the imaginary part of $H(s_i)C(s_i)$ is zero must be performed. Moreover, the corresponding root-locus gain is given by

$$k = \frac{-1}{H(s_i)C(s_i)}, \tag{9}$$

which immediately gives the gain of the controller that is required to achieve these closed-loop pole locations.

This computation is performed for the experimental set-up, see Figure 5. The orange and purple colour indicate the sign of the imaginary part of $H(s_i)C(s_i)$. Points that belong to the root-locus are those points where the imaginary part crosses zero *and* where the real part is negative as well. These points are indicated by the black dots. Along the lines formed by these dots, the gain of the controller goes from zero at the open-loop poles to infinity at the zeros of the plant. From the root-locus it is obvious that the optimal closed-loop pole locations are indicated by 'b', since for this choice the poles lie the farthest in the left half plane which will give the fastest settling time. At 'b' the gain k = 8.58, which is computed using (9). Apparently, there is a certain optimal gain in terms of settling time. Increasing or decreasing the gain will deteriorate the response. To show this, the closed-loop pole locations 'a' and 'c' are analysed as well. At 'a' and 'c' the gains are half and twice the value of b. Thus at 'a' k = 4.29 and at 'b' k = 17.16. These are also the three values for the gain that were shown in Figure 3, hence the corresponding colours.

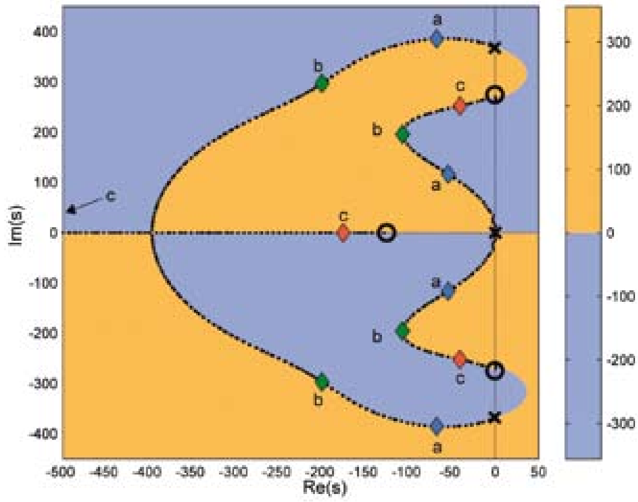

Figure 5. Root-locus computed from transfer function data. The points a, b, and c give the selected closed-loop pole locations. Open loop poles **x** and zeros **o** are indicated as well.

Time domain response

To verify that the controller with gain k = 8.58 indeed has the best response, time domain measurements have been conducted on the set-up with all three controllers, see Figure 6. As predicted, the controller with k = 8.58 indeed has the shortest settling time. The power spectral density of the three responses is computed as well, see Figure 7. It can be seen that the dominant frequencies in the spectra correspond to the frequencies of the predicted closed-loop pole locations. The frequency is in rad/s for ease of comparison with Figure 6. The controller with k = 4.29 shows two peaks; one at 120 rad/s and one at 377 rad/s. This corresponds to the predicted locations in Figure 6, since the imaginary parts of the closed-loop poles at location 'a' have exactly those values. For k = 8.58 only one peak at 207 rad/s can be distinguished in the spectrum, which corresponds to one of the two closed-loop pole pairs at 'b' in Figure 6. The second closed-loop pole pair, at 300 rad/s, is not visible in the spectrum due to its high decay rate. The same holds for k = 17.16, where the peak in the spectrum at 257 rad/s corresponds to the points 'c' in Figure 5.

While it is fairly simple to verify the frequencies of the closed-loop poles via the power spectrum, obtaining a numeric value for the real part of the pole location from the time domain response is not so straightforward. The amplitude of the response should be of the form

$$h(t) = c \cdot e^{-\sigma t} \tag{10}$$

Where c is a constant and σ is the real part of the pole. Fitting this function on so few peaks proved to be very inaccurate. Nevertheless, when comparing the responses it can be said that it is possible to conclude that the σ value of the controller with k = 8.58 is higher than that of the other two controllers. This shows that it is possible to optimise the gain of the controller using this technique.

Conclusions

Lightweight high-precision motion stages pose a challenge to the control design of such systems. Due to the low-

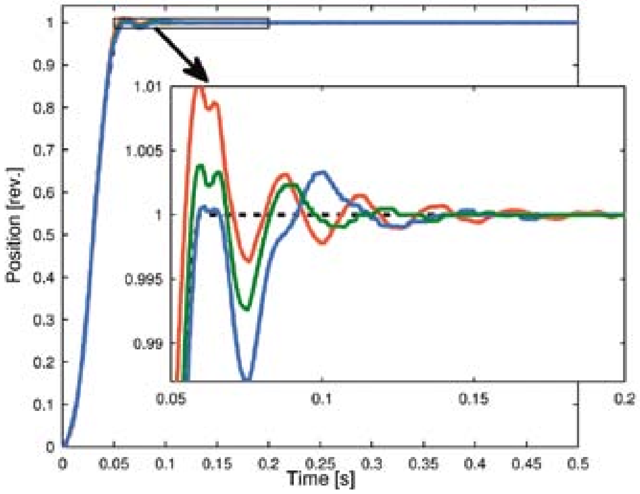

Figure 6. Time domain responses for the three selected gains; k = 4.29 (blue), k = 8.58 (green) and k = 17.16 (red).

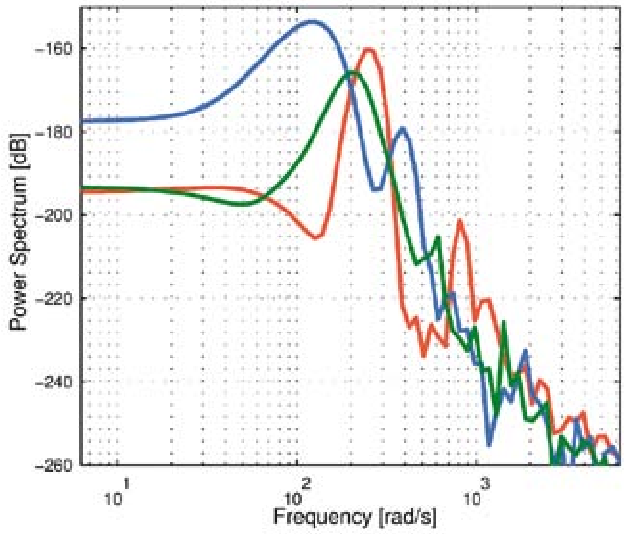

Figure 7. Power spectral density plots of the responses of Figure 6.

frequent resonances, conventional control techniques can no longer be applied. In this article it is shown that transfer function data, obtained from frequency response data, can be used as an extension of loop-shaping techniques. As an example it is shown how a root-locus can be drawn for an experimental set-up, without the use of a parametric model. The root-locus is used to optimise the gain of the controller such that the settling time is minimised. Time domain measurements on the set-up confirm the accurate prediction of the closed-loop poles.

Although the experiments shown here were conducted on a SISO system, extension to MIMO systems is straightforward. In the near future, experiments will be conducted on a 6-DoF high-precision motion system to validate the approach on a MIMO set-up.

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Evolution in the high-tech

The relationship between Original Equipment Manufacturers (OEMs) and their suppliers in the high-tech industry has undergone a major evolution over the last two decades. Both the way of working and the cost models have changed. The route followed by a high-tech supplier – typically a member of Brainport Industries – leads almost inevitably to the position of an OMM or ODM, Original Module Manufacturer or Original Design Manufacturer, respectively. This requires a cultural shift among all parties in terms of focusing, as well as daring to choose, sharing risks and taking responsibility for development.

• *Henk Tappel* •

This is a story about what is called the ecosystem of the Dutch high-tech industry. Typical for the products made in this branch of industry, often from the position of global market leader, is that they are among the most advanced in the world, mostly capital goods, and that they are a blend of high mix, low volume, high complexity and high flexibility. Furthermore, the large majority of these products are being exported and the contribution they make to the prosperity of the Netherlands is therefore invaluable.

Author's note

Henk Tappel is the Managing Director of Frencken Europe, based in Eindhoven, the Netherlands. This article was, in part, based on a presentation at the DSPE Conference, which was held on 4 and 5 September 2012 in Deurne, the Netherlands.

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Dutch ecosystem

Unknown

Unfortunately, the average Dutch person never gets to see most of these products, except perhaps medical equipment, and then usually without wanting to. At best, people recognise the odd few company names, such as ASML, FEI or Vanderlande. Some names are more well-known but mainly because they also market consumer goods as well as capital goods, such as Philips. And if these OEM companies are often unfamiliar, their supplier industries – typically represented in Brainport Industries (BI), the association of leading tier-one, tier-two and tier-three high-tech suppliers in the greater Eindhoven region – are of course even less well-known. You'll never come across names such as Frencken or NTS on any products, even though we sometimes supply very iconic equipment and we're "world famous in Eindhoven". This article is about the way we work with our customers and how earning models evolve.

Making parts

Up until the early 1990s, life was simple for companies like Frencken. You made parts. That meant that your customer gave you a pile of drawings and you were expected to make the parts shown in accordance with specified tolerances, after which the customers often put the parts together themselves to build a functioning system. Thinking about the product itself wasn't really required; the customer did that himself, as well as managing all of the design changes the development group wanted to carry out. A simple life and a simple cost model to go with it. What you could invoice to the customer were production costs and a bit of profit (see Figure 1).

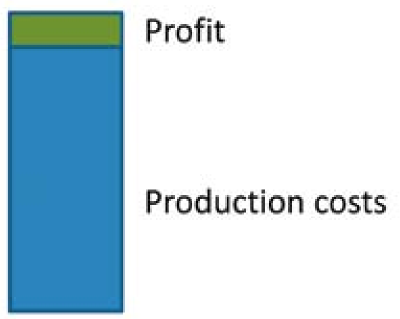

Figure 1. Cost model for producing parts.

Variable costs

When customers started to outsource, thus converting their fixed costs into variable costs in the 1990s, they started to farm out more and more assembly and testing work. Of course that was a steep learning curve at first, so you hardly made money, but gradually the pace picked up and customers and suppliers came to agree on the cost model. It became a recipe of sorts, with five main ingredients: BoM costs, labour costs, logistics surcharge, profit margin and NRE (BoM stands for bill of materials, NRE for non-recurring expense). NRE is the sum needed for making test cabinets, writing assembly and adjustment instructions, constructing special jigs and fixtures and everything else you have to arrange to manufacture the product, but the costs of which are not included in the bill of materials. Figure 2 shows the cost model related to this way of working, referred to as 'build-to-print'.

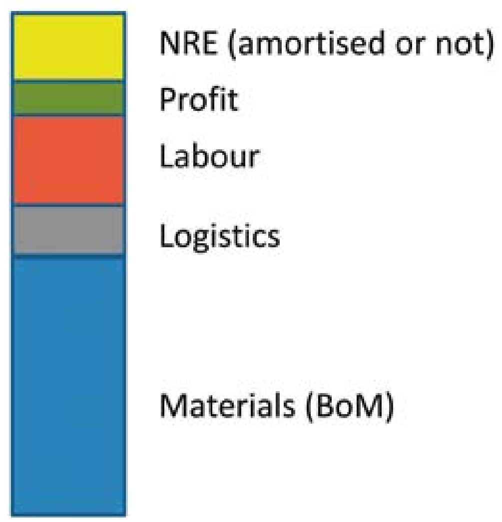

Figure 2. Cost model for 'build-to-print'.

Sometimes, customers settle the NRE in one go, but some customers prefer you to advance the money and then you're repaid a part of the cost for each product. In most cases, it's possible to incorporate an interest component and to agree on the number of products over which the NRE has to be spread out. Because you're a supplier and not a bank, you want to keep the amortisation period down to a minimum, by specifying either a certain sales volume or a period of no more than a few years, after which you settle the remaining sum, in case the product doesn't sell as well as even the customer's most conservative estimate.

In those cases, the customers still assumed the entire risk, which made things reasonably risk-free for the supplier. That made life clear-cut for high-tech suppliers, also in terms of their sales. If you made 1,000 products you didn't need to find 1,000 end customers for them. You left that to your OEM customers who had set up major global sales channels specially for that purpose. They also took care of aftersales.

Disadvantages
There are some downsides to this way of supplying, however. For instance, one major disadvantage is that you can hardly influence your own sales since you don't actively do business with the end customers.You rely on the success of your customer's sales force in the market. Those OEMs really don't order more than they need and because the intellectual or industrial rights are the property of the customers, we can't sell those particular modules to anyone else. Nobody could use them anyway because the interfaces are, of course, very specifically designed by the original customer.

A further disadvantage is that just like the first model, the customer can still give the pile of drawings to your competitor so that they can tender too. The result is often a price that your customer says is well below yours. Arguments that that new offerer has never made that product and therefore can't oversee all the ins and outs don't hold water either. You may be forced to reduce your cost price and put a lot of effort in recouping your margins at some point.

A solution to both disadvantages is, of course, to look for new OEM customers but that's when a third disadvantage crops up: Nobody knows us. The BI companies and their products are hidden in the depths of their customers' machines, and that's why it often takes several years to develop new customers.

Price erosion
That's the way it is; the market is faced with the phenomenon of price erosion and as a result, there is considerable pressure on the costs. So we're faced with a quandary. Let's say that our organisations are already run in a very lean way. The logistics surcharge and labour costs cannot be much lower and of course everyone in the industry is covered by collective labour agreements that ensure that labour costs go up every year. Moreover, customers make higher and higher demands on your organisation, with audits and quality improvement processes so that there is more and more you have to prove and assure in formats that vary from customer to customer. It's only rarely that the customer allows you to charge the resources and the costs that your enlarged organisation entails. So all price increases have to be compensated with increased productivity.

The NRE item cannot be reduced because that money has already been spent and still has to be paid back. Two things are left that you can tinker with, i.e. profits and the BoM. If you as supplier give away your profit margin, you're stuck in a win-lose deal, which is disastrous in the long run. You need your margins to finance growth in terms of investments and working capital and to keep your shareholders happy. Going back on that means risking your own future.

Bill of materials
So that leaves the BoM (see Figure 3), which includes catalogue articles, the vendors of which regularly tell you that they are forced to put up their prices by x% as of 1 January because of rising costs... The customer dictates some of these articles, so looking for alternatives is not an option or the alternatives there are require substantial development resources and endurance testing before the customer releases them. While other articles may not be prescribed, you have to purchase more of them than the average BI member if you want to get a discount on the price of nuts and bolts. As a result, getting a price discount for catalogue articles is not always possible.

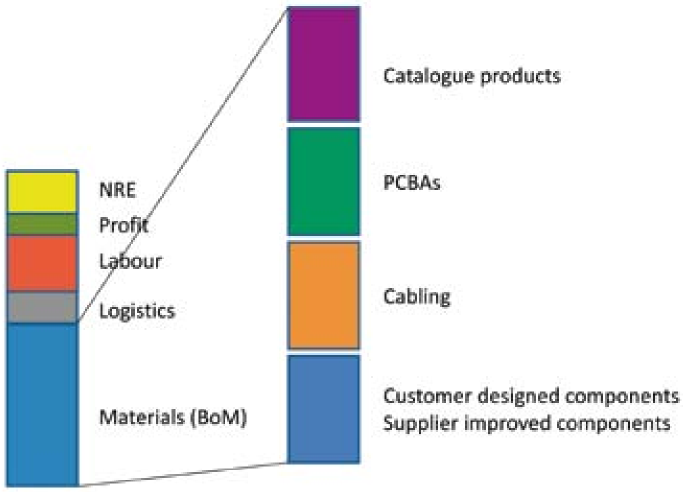

Figure 3. Splitting up the BoM.

In the case of printed circuit board assemblies (PCBAs) and cables, it doesn't make much difference whether you buy them from vendor A or vendor B because it's the components on or in the product that determine the price. I have yet to see a real breakthrough when it comes to how to achieve double-figure percentage savings with an unchanged design and without compromising the quality of the components.

China

That leaves you with the contingent of self-designed parts. It's up to you to decide how much of the BoM that accounts for. How can we achieve price reductions here? Let's say that at some point you'll have completed the learning curve and that the part has reached its lowest price point. Having it made in China is not profitable because of transport costs linked to high quality costs. Moreover, labour costs in Asia are rising much faster than labour productivity. But more importantly, there are few professionals in China with years of experience, and productivity is in any case lower.

If you visit the production divisions of our BI companies, you see people of all age categories operating the machines. Apprentices and experienced specialists work together on processes and products. If you go to Asia, you see lots of young people (too many even) with (too) little experience, who switch employers frequently, so they have no chance of building up experience in the first place. Here in our productive country, by combining processing time and smart configuration, some companies have achieved such a high level of perfection that it's easy to compete with Asia.

The correct specification

By then you'll have hit the bottom line of what a part costs. But the demand for price reductions continues unabated. If you then take a closer look at the design, you'll see that there's a bit more to be had there. You may see that the parts have clearly been devised in a CAD system, and anything goes on a large screen. People add up and subtract cylinders, cones and blocks at will, and of course, the supplier with the multi-axis machine can produce the parts. But there's a chance that the part itself turns out to be way too expensive, a result of the fact that the design fraternity are too far away from the supply chain's lathes and milling machines. And printing the parts, which again opens up all kinds of possibilities (but also gives new design constraints), isn't mainstream technology yet.

You'll only make a real breakthrough in the price of a function if you remake the function, based on your experience but seen through the value engineer's eyes. This means that you redesign the object using fewer and simpler parts. And maybe to the really necessary specification, because it often happens that to be on the safe side, the original specs were rather sharply defined and so they could be eased up a bit here and there. The number of parts is proportionate to the price. And didn't lots of BI companies start out making parts? That's the kind of knowledge we can introduce to the design.

Co-design

That brings us to model 3, 'design and build-to-print', with the supplier engaged in co-design; Figure 4 shows an example. Some BI companies are currently in this phase and not only the tier-one suppliers. The difference between this and the previous model is that the NRE costs go up because they are increased by development costs (see Figure 5). These costs can be settled on an hourly basis, but usually customers want a 'fixed price, fixed time' result commitment. This is a bit strange though, because their own development department often only delivers a resource commitment, and I can't recall any project from my own past that was finished at the originally planned end date. Fortunately, if you are allowed to construct the developed product for a few years, you may get a chance to redress some of the setbacks you suffered.

To redesign a product you need considerable in-depth knowledge, knowledge of the application, of how the product is to be used, and knowledge of the end users. All of this requires that you focus on a number of specialisms. You may even qualify for early supplier involvement,

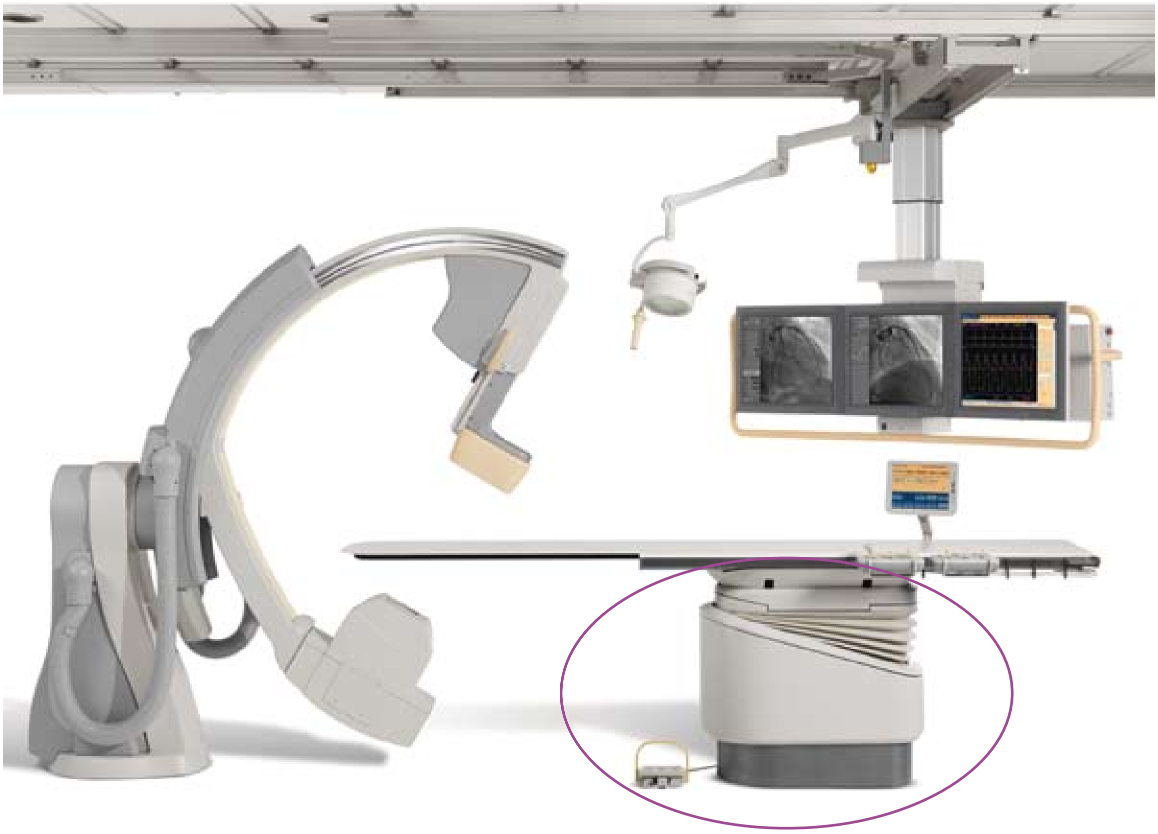

Figure 4. Frencken supplies patient tables for cardiovascular systems to Philips Healthcare, according to 'design and build-to-print'.

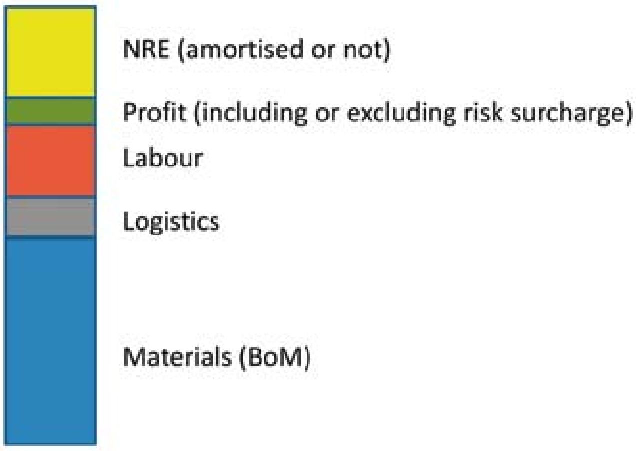

Figure 5. Cost model for 'design and build-to-print'.

which means that you'll be engaging with the supplier from the very start of a new project, but that may cause a little upset. First of all among the developers themselves because you're snatching away part of their specialism and they think you're not good enough anyway. And maybe also in the purchasing department because if they are only permitted to buy the products from you they then cannot enjoy their usual negotiating position. But choosing not to make all the product parts oneself and outsourcing them to a module specialist is a logical choice for senior OEM management.

Next step

But if you're a module specialist it's obvious that you'll be taking the next step, to become an OMM (Original Module Manufacturer) or an ODM (Original Design Manufacturer), selling the same modules or at least the IP therein to as many customers as you can. Possibly with a customised exterior for each customer but with the same content. You bear the risk for the success of the sales yourself. The consequence is that you'll have more developers and engineers working for you than before and that has an effect on the organisation's culture, which will have to change radically as a result. Because you need these people desperately. They are motivated, self-propelled, really smart but unfortunately also very hard-nosed and a real challenge to manage.

That changes the cost model drastically. In the end, the customer pays less because it's you who bears the risk for the success of the sales of your module. Economies of scale are found in the BoM and logistics costs; and by making more, you can configure more efficient processes. Development costs and lifecycle management costs are reduced because they are spread out over more customers

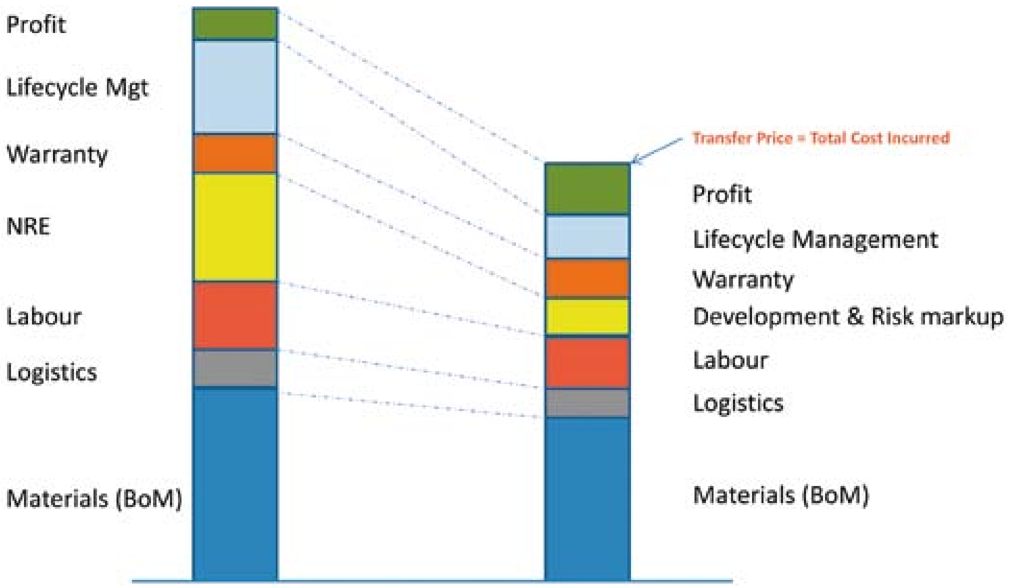

Figure 6. Cost model for the OMM/ODM model (on the right), as compared to the cost distribution for the OEMs if they were to do everything themselves (on the left).

Figure 7. If an OEM outsources to an ODM or an OMM, the non-BoM costs (orange) will suddenly turn into BoM costs (blue), so the share of BoM costs in the total cost for the OEM will increase as a result; operations and procurement don't like that.

even though a risk item is added. But the cost of ownership will drop for the customer. Maybe the advantage for the customer is so great that you can even charge a bit more margin (see Figure 6).

There is a bone of contention in this cost model though (see Figure 7). The blue section on the left shows the BoM costs for the OEM, for which operations and hence procurement are held accountable. The orange costs are from other funds: the engineering change budget, the development funds, the guarantee facility that lots of customers take from the gross margin and that is not included in the cost of goods. If the OEM has to purchase the product – which until then was self-developed and procured from a system supplier at a price that was taken for granted – from the same supplier who is now operating as an ODM or OMM, the BoM costs are going to go up. That is quantifiable and bad for key purchasing performance indicators. That the total cost of ownership drops is an ongoing discussion, but it'll be a few years yet before we're used to this idea.

Conclusion

The route that the high-tech supplier industry follows leads almost inevitably to becoming an OMM or an ODM. That requires a cultural shift. All parties will have to wake up to the fact that it's in everyone's interest that customers are successful. Suppliers have to take a few steps, they have to assume ownership, be prepared to take calculated risks, take on responsibility for development processes, think globally, but they especially have to dare to choose and focus on what they want to excel in. Understanding what it is the market wants and go for it, together with their customers.

On the use of Freedom Constraint

The fundamental principles of the Freedom and Constraint Topologies (FACT) synthesis approach are reviewed and applied to the design of precision flexure bearings. FACT provides designers with a comprehensive library of geometric shapes from which they may conceptualise a multiplicity of flexure bearing concepts that achieve a desired set of degrees of freedom. In this way, designers may rapidly consider and compare every practical flexure bearing concept before selecting the concept that best satisfies the design requirements. Two case studies are provided – a parallel and a serial flexure bearing system. Both of these bearing systems may be used to guide the tip and tilt motions of a light-directing mirrored surface.

• *Jonathan B. Hopkins* •

Flexure bearings are important to precision engineers because they enable highly repeatable mechanical motions due to the fact that they generate almost no friction or hysteresis as they deform [1]. Compared with magnetic or air bearings, which perform with similar repeatability, flexure bearings (i) tend to be smaller and more manageable, (ii) require minimal or no maintenance, and (iii) are easier to fabricate and assemble. As such, the cost of flexure bearings is typically orders of magnitude lower than the cost of their competitors. Unfortunately, however, flexure bearings are difficult to design and analyse because of their complex and often non-linear kinematic, elastomechanic, and dynamic behaviour. This difficulty is a primary reason why flexure bearings are not more widely used in precision machines today.

Author's note

Jonathan B. Hopkins holds an M.Sc. in Mechanical Engineering. From the Massachusetts Institute of Technology, Cambridge, MA, USA, he obtained his Ph.D., on the subject of "Design of flexure-based motion stages for mechatronic systems via Freedom, Actuation and Constraint Topologies (FACT)". He is currently a postdoc at Lawrence Livermore National Laboratories, in Livermore, CA, USA.
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and

Topologies

The Freedom and Constraint Topologies (FACT) synthesis approach [2-4] offers designers an intuitive design and analysis tool for overcoming this challenge. FACT utilises a library of geometric shapes, which embody the combined conceptual rules and principles of constraint-based design [5-7] and the rigorous mathematics of screw theory [8-9], to help designers visualise every way flexure constraints may be placed for guiding motion stages in their intended directions. In this way, designers may rapidly consider and compare a multiplicity of concepts before selecting the concept that best satisfies the particular design requirements without undue complications that arise when using complex mathematical treatments or expensive software packages. Furthermore, FACT provides designers with rules for effectively utilising or avoiding exact-, over-, or under-constraint while synthesising flexure bearing systems.

This article will review the fundamental principles of FACT in the context of two design case studies, which are shown in Figure 1. Both of these case studies involve flexure bearings that guide a mirror with tip and tilt degrees of freedom (DoFs), shown as lines with circular arrows about their axes in the figure, for various light-steering applications such as optical switches [10], projectors [11], and optical-tweezers-based nano-manipulators [12].
The first case study, shown in Figure 1a, utilises a parallel flexure configuration to guide each mirror within an array of tightly packed mirrors, whereas the second case study, shown in Figure 1b, utilises a serial flexure configuration. Parallel flexure systems consist of flexure constraints, which directly connect their motion stage to a fixed ground. Serial flexure systems consist of multiple parallel flexure modules stacked together in a chain-like configuration. As such, serial flexure systems typically possess intermediate rigid stages as is the case with the flexure system from Figure 1b. Similar to this system, serial flexure systems may be designed in a compact way to enable large ranges of motion compared with the overall size of the machine in which they are applied. In this article, the principles of FACT will be discussed for synthesising both parallel and serial flexure systems.

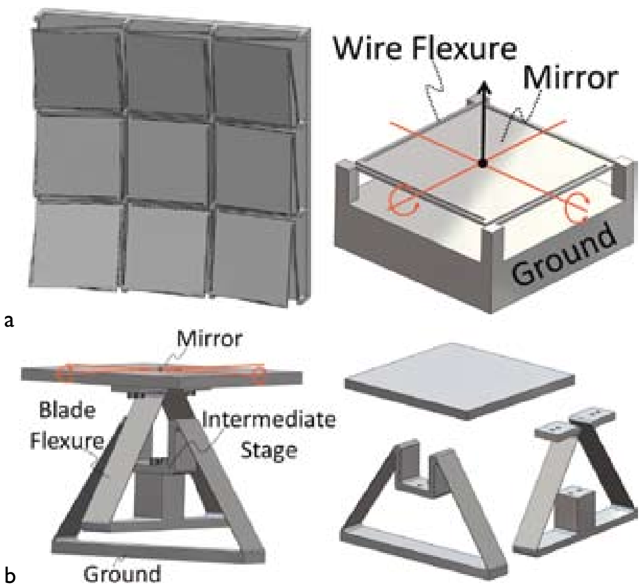

Figure 1. Design case studies.
(a) An array of tip-tilt-piston micro-mirrors.
(b) A large-range tip-tilt mirror.

The geometric shapes of FACT are visual representations of screw systems [13-14]. Originally, screw systems were most commonly applied to the design and analysis of spatial mechanisms and robotic manipulators [15-18]. Only recently, however, have screw systems been applied to the design and analysis of flexures and compliant mechanisms [19-20]. Prior to FACT, screw systems were difficult for most novice designers to use because screw systems were not packaged as intuitive visual shapes, but rather as complex mathematical concepts. FACT enables novice and experienced designers to visualise screw systems and thereby rapidly consider every flexure concept for achieving any desired set of DoFs.

FACT fundamentals

To demonstrate the underlying principles of FACT, the concepts of freedom and constraint spaces are introduced as geometric shapes that help designers visualise desired sets of DoFs as well as the flexure constraints that enable them.

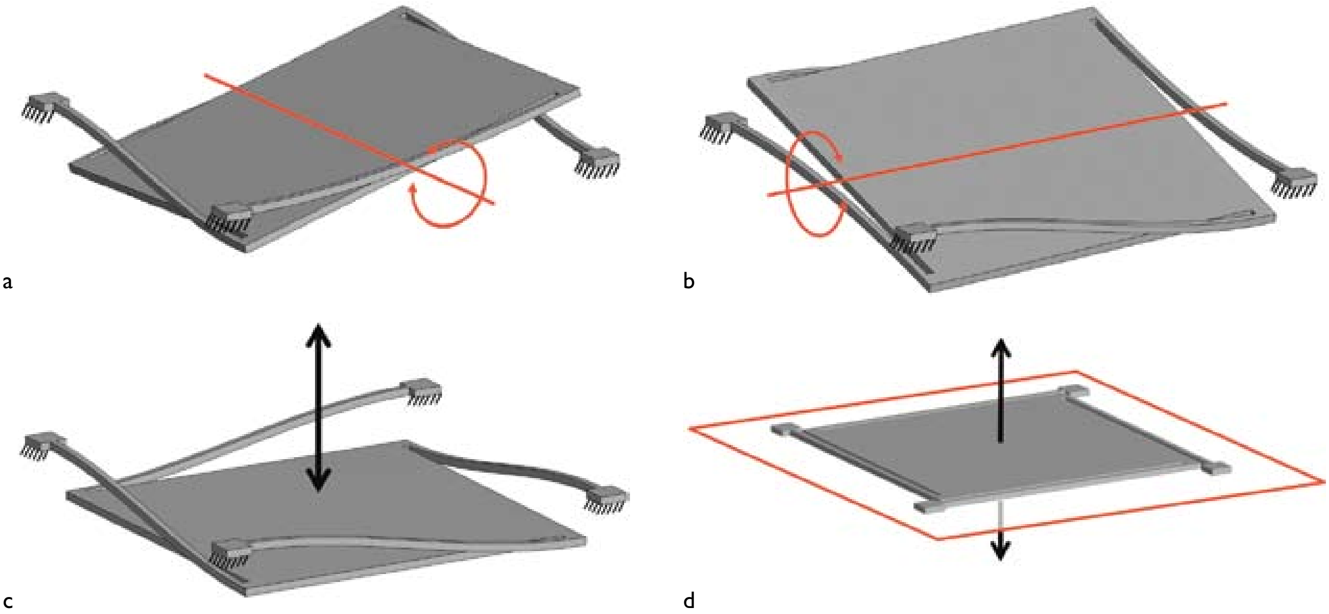

Figure 2. Mirror that possesses two rotational DoFs (a-b) and one translational DoF (c). The mirror's freedom space is a plane of rotation lines and an orthogonal translation arrow (d).

Freedom Space

Consider the flexure bearing system from Figure 1a shown again in Figure 2. Four wire flexures constrain the square mirror such that it possesses three DoFs – two rotations shown in Figures 2a-b and one translation shown as a black arrow in Figure 2c. Although these three motions represent the system's DoFs, they do not represent all the motions permitted by the four wire flexures. If, for instance, all three DoFs were simultaneously actuated with various magnitudes, the mirror would appear to rotate about lines that lie on the plane of the wire flexures. This plane of rotation lines and the orthogonal translation arrow shown in Figure 2d constitute the system's freedom space [2-4]. Freedom space is the geometric shape that visually represents the complete kinematics of a constraint system, i.e., all the motions that the system's constraints permit.

Constraint Space

Every freedom space uniquely links to a complementary or reciprocal constraint space [2-4] according to the rule of complementary topologies [2] or the principle of duality [15-18]. Constraint space is the geometric shape that visually represents the region where all the flexure constraints exist for permitting the desired DoFs within the freedom space.

Consider the complementary freedom and constraint space pair shown in Figure 3a. Recall that this freedom space is the mirror's freedom space from Figure 2d. Its complementary constraint space is another plane that lies on the same plane as the freedom space. Any system with flexure constraints that lie only on this plane will permit the motions within the freedom space. Note from Figure 3b that the mirror's four wire flexures lie within the planar constraint space of Figure 3a. Note also from the other parallel flexure system shown in Figure 3c that its two blade flexures also lie within the planar constraint space of Figure 3a. Although the design of this system will possess different elastomechanic and dynamic behaviours from the system of Figure 3b, the system of Figure 3c will possess the same DoFs and, therefore, the same freedom space, because the constraints of both systems lie within the same constraint space. From a synthesis standpoint, the concept of constraint space is very powerful. If a designer knows which constraint space uniquely links to the freedom space that represents the desired DoFs, he/she is able to very rapidly visualise every concept within the constraint space that satisfies the desired kinematics.

Although constraints selected from within a system's constraint space will always permit the desired DoFs represented by its complementary freedom space, the correct number of independent flexure constraints must be selected to assure that the system does not possess extra DoFs as well. If only a single wire flexure had been selected from within the plane of the constraint space of Figure 3a, for instance, the mirror would not only possess the DoFs within the desired freedom space, but it would also possess other, unwanted DoFs. A comprehensive list of qualitative rules exists for guiding designers in selecting independent flexure constraints from within any constraint space. These rules are embodied by shapes called sub-constraint spaces and are found in [19].

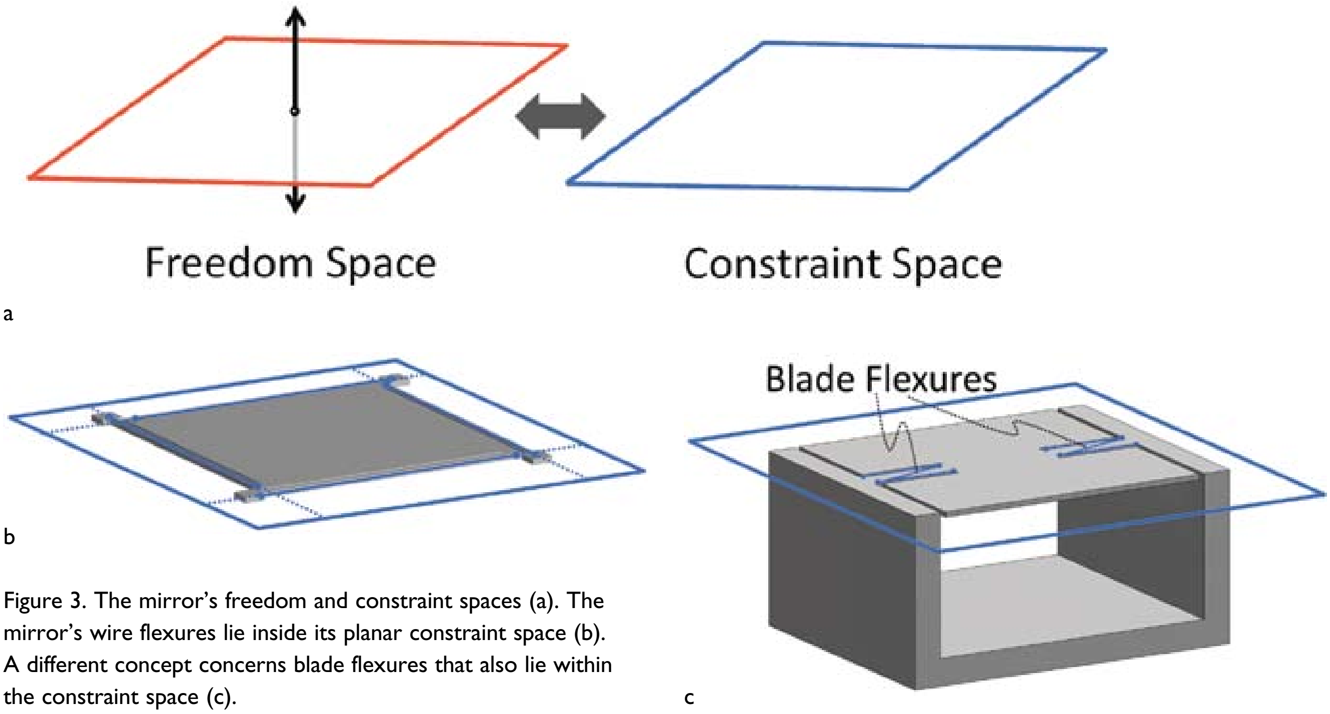

Figure 3. The mirror's freedom and constraint spaces (a). The mirror's wire flexures lie inside its planar constraint space (b). A different concept concerns blade flexures that also lie within the constraint space (c).

Once the appropriate number of independent flexure constraints has been selected from a constraint space, any other flexure constraint selected from the same space will be redundant and will not affect the system's kinematics. Although redundant constraints do not affect the system's DoFs, they do affect the system's stiffness, load capacity, dynamics, and symmetry. Constraint space is, therefore, not only important for helping designers synthesising constraint systems that achieve any desired set of DoFs, but it is also important for helping designers visualise the regions where each redundant constraint exists for optimising other design parameters without affecting the system's desired kinematics. Systems with redundant constraints are said to be over-constrained. Both systems shown in Figure 3 have been over-constrained to increase their stiffness, natural frequency, load capacity, and symmetry and to reduce their parasitical motion errors.

Finally, it is important to recognise that there is a finite number of freedom and constraint space pairs and all of them have been graphically represented and described in [19][21]. Using this complete library of geometric shapes, designers may rapidly visualise all the ways a system may be constrained for achieving any set of desired DoFs.

Synthesising parallel flexure systems

Combining the previously discussed principles, now the systematic steps of the FACT synthesis approach are established for synthesising parallel flexure systems. The parallel flexure system from Figure 1a is designed using these steps as an example.

- Step 1: Identify the desired DoFs.
  For the case of the micro-mirror array from Figure 1a, the desired DoFs are tip, tilt, and piston motions as shown in Figures 2a-c.
- Step 2: Use the complete library of freedom and constraint space pairs to identify the correct freedom space that represents the desired DoFs from Step 1.
  For the 3-DoF micro-mirrors, the correct freedom space is the plane of rotation lines and the out-of-plane translation arrow shown in Figure 2d.
- Step 3: Select the appropriate number of independent flexure constraints from within the complementary constraint space of the freedom space from Step 2.
  The complementary constraint space of each micro-mirror's freedom space is shown in Figure 3a. Three wire flexures with axes that are not all parallel and do not all intersect at the same point, or one flexure blade must be selected from the constraint space to insure independence of the system's flexure constraints. Such instructions for insuring independence of constraints are provided in the sub-constraint spaces discussed in [19].
- Step 4 (optional): Select redundant flexure constraints from the system's constraint space to control system symmetry, load capacity, stiffness, and dynamics without altering the desired DoFs.
  A fourth and, therefore, redundant wire flexure can be selected from the system's constraint space as shown in Figure 3b for the sake of symmetry.

Synthesising serial flexure systems

This section explains how the principles of FACT may be applied to the design of serial flexure systems like the

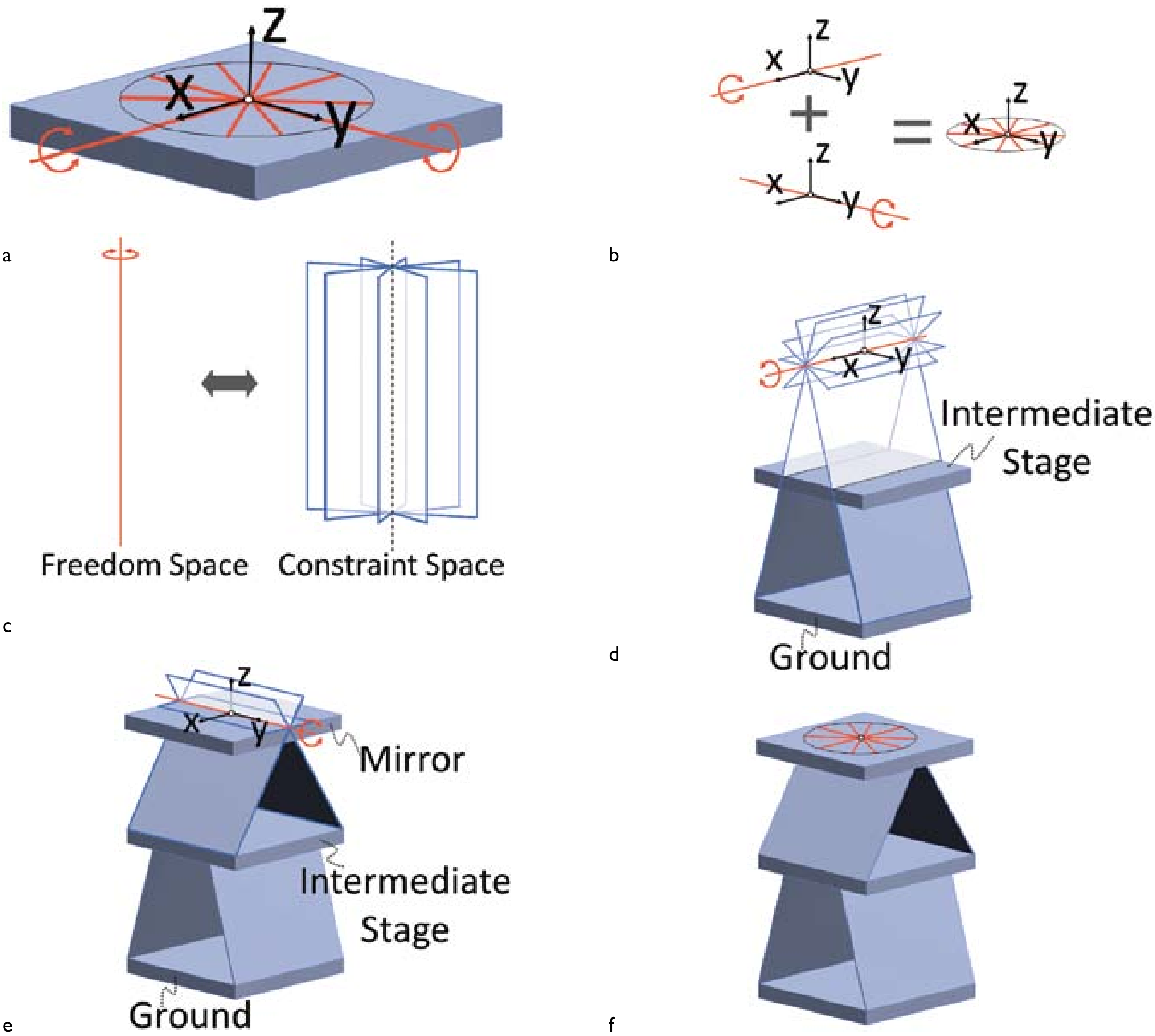

Figure 4. The mirror's desired freedom space (a). Two rotations combine to form the freedom space (b). The constraint space of a single rotation (c). Selecting constraints from within these constraint spaces (d-e). The final serial flexure system that enables the desired freedom space (f).

system from Figure 1b. Consider the 2-DoF tip-tilt mirror shown in Figure 4a. If this mirror's two rotational DoFs were simultaneously actuated with various magnitudes, the mirror would appear to rotate about other lines that lie in the disk shown. This disk of rotation lines is, therefore, the mirror's desired freedom space. If we wished to synthesise a parallel flexure system that possessed this desired freedom space, we would need to identify its complementary constraint space and then select the appropriate number of flexure constraints from within that space, which connect the mirror directly to a fixed ground.

Recognising, however, that the disk-like freedom space results from the combination of two independent rotations as shown in Figure 4b enables the designer to synthesise a serial version of the flexure system. The complementary constraint space of a single rotation line is every plane that intersects that line as shown in Figure 4c. By selecting blade flexures that lie on any of the intersecting planes of the constraint space of the first rotation line along the x-axis and connecting these blade flexures from an intermediate stage to a fixed ground as shown in Figure 4d, the final design will possess that single rotation about the x-axis. By selecting another set of blade flexures that lie on any of the intersecting planes of the constraint space of the second rotation line along the y-axis and connecting these blade flexures from the mirror to the intermediate stage as shown in Figure 4e, the final design will possess that y-axis rotation as well.

This final design is shown in Figure 4f. It will possess the desired disk-like freedom space of rotation lines because each parallel flexure module stacked together contributes part of the freedom space's motions. This principle is fundamental to understanding how the shapes of FACT may be used to consider every way serial flexure concepts may be synthesised for achieving any desired set of DoFs. Note that the serial flexure system from Figure 1b has the same topology as the system from Figure 4f, but its blade flexures have been organised in a more compact way so as to increase the system's stroke-to-size ratio. Furthermore, note that the design from Figure 1b could also be arrayed like the design of Figure 1a because all of its flexures only occupy the space below the mirror.

Conclusion

The principles of the FACT synthesis approach have been applied to the design of flexure bearings, which guide the precision motions of tip and tilt mirrors for various light-steering applications. Rules have been provided for using FACT to synthesise both parallel and serial flexure systems for achieving any desired set of DoFs.

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Camera requirements

As the objects to inspect/measure in high-tech manufacturing become smaller, higher-resolution cameras with better spatial resolution can improve accuracy and precision. This does require a high-quality machine vision camera design, however. 3D measurements in particular pose increasing demands on camera performance and reliability. This article discusses critical camera parameters, depending on the specific application.

• *Jochem Herrmann* •

Nowadays, the ever increasing demand for smartphones and tablets requires state-of-the art production with high-speed inspection for high yield. These devices require smaller and more complex printed circuit boards (PCBs) and electronic components, resulting in a need for more accurate manufacturing and measurement. This is all happening on an aggressive time scale as consumers expect new improvements quickly, resulting in fast innovation cycles. Not surprisingly, this is driving innovation in supporting industries, including machine vision.

High-resolution cameras combined with high speeds that make full use of select image sensors provide the images required for inspection and metrology of the latest generation of devices that go inside smartphones and tablets. This includes supporting the move from 2D to 3D measurements.

Author's note

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There are camera parameters to consider in addition to resolution and frame speed for accurate 3D metrology. A few applications will be described in detail to demonstrate how to determine the most important inspection camera parameters for specific applications.

Machine vision camera parameters

Several machine vision camera parameters have to be included when analysing the fit of a camera within an automation system:

- Resolution (horizontal x vertical pixels)
  Today, 4- to 25-megapixel cameras are common. Higher resolution allows for larger inspection areas and/or higher accuracies.
- Pixel size
  Whereas consumer cameras have pixels that are less than 1 μm in size, machine vision cameras typically have pixel sizes ranging from 4 to 10 μm. Smaller pixels may result in lower camera costs at the cost of poorer measurement accuracy.
- Frame speed
  System speed is one of the most important selling points for equipment manufacturers; this is directly achieved by increasing camera frame speed.
- Digital interface
  The choices greatly influence system design, as they determine cable length, flexibility and overall system costs.

for 3D metrology

- Functionality and software support
  This is important during design but it also influences maintenance costs during the lifetime of the equipment.
- Spectral response
  The image sensor's spectral response has to match the spectral response of the light source used. A poor match between illuminator wavelength and sensor quantum efficiency (QE) results in poor measurement accuracy due to too much noise in the image, or will lead to the selection of a more expensive light source.
- Read noise
  This determines the noise floor in dark image areas and influences the accuracy of the measurement.
- Full well capacity
  This determines the noise in bright areas of the image and influences the accuracy of the measurement.
- Photo response linearity
  Most measurement methods assume a linear response of the pixel to light.
- Image non-uniformities
  Dark signal non-uniformity (DSNU), photo response non-uniformity (PRNU), striping, shading, and defective pixels, columns and rows all influence measurement accuracy.
- Modulation transfer function
  The MTF determines how 'sharp' the image is and determines the smallest errors that can be detected and the measurement accuracy. Note that the MTF of an image sensor is wavelength-dependent and in general deteriorates at longer wavelengths (such as near-infrared light).

Not all of these parameters can be optimised at the same time and the most important specifications depend on the application. The increasing trend from 2D measurements to 3D results in more stringent requirements for the camera. This makes it even more important to prioritise the key specifications to avoid unnecessary costs. There are several measurement methods commonly used in semiconductor and electronics manufacturing, which provide good examples for this.

Figure 1 shows three often used 3D measurement methods, each with a different measurement range and accuracy level: laser triangulation, fringe projection and interferometry. More accurate measurement methods have higher camera requirements as will be discussed in more

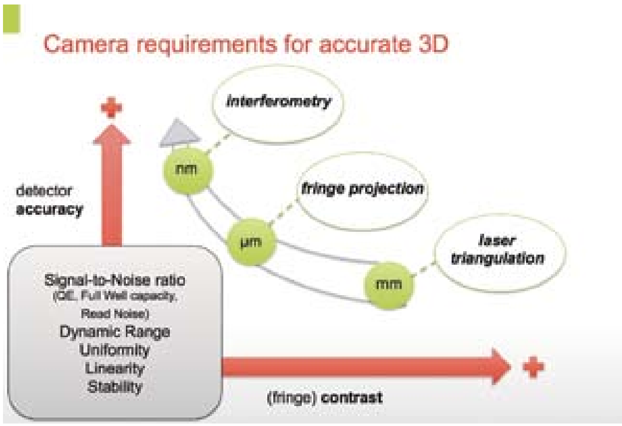


Figure 1. Overview of camera requirements for accurate 3D measurements, depending on the method used.

detail below. The 'simplest' method is laser or LED triangulation. We will not go deeper into this method since it is considered a mainstream application in machine vision and can usually be achieved with standard cameras as they exist today, even for 3D measurements. When increased accuracy is needed in the micrometer and nanometer range, optical measurement methods such as fringe projection and interferometry are used. The following sections describe these methods in more detail.

Semiconductor wafer thickness and flatness measurements

Before any transistor is laid down, the incoming silicon wafer must be analysed for flatness and defects. From this inspection, wafers can be classified to allow the best wafers to be used for the smallest technology node. Typically, measurement techniques such as interferometry are used for this.

Fringe projection is a lighting method that projects a striped pattern with a certain period (e.g. distance between black/white) onto a surface to support phase shift measurements. By moving the pattern over the surface, you can calculate a phase shift out of multiple images. Phase shift measurements can also be obtained via interferometry. With fringe projection you can measure in the µm scale and with interferometry at the nm level.

This technique works because when two waves with the same frequency combine, the resulting pattern is determined by the phase difference between the two waves.

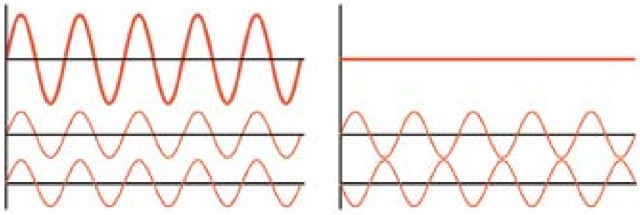


Figure 2. Interference of two waves, with the result depending on their phase difference. (Source: Wikipedia)

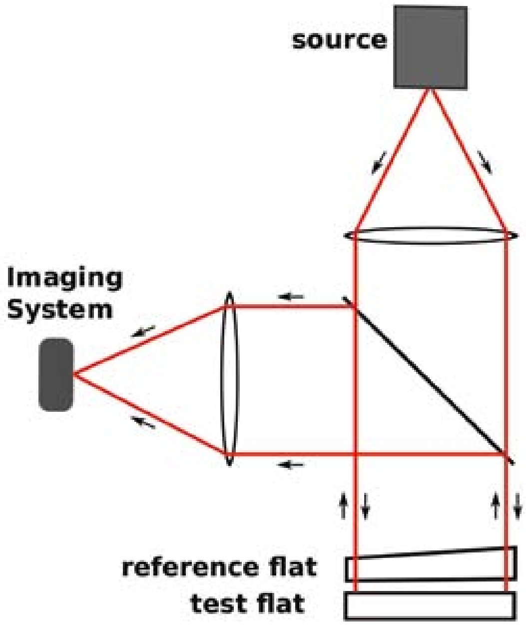


Figure 3. Fizeau interferometry set-up. (Source: Wikipedia)

Waves that are in phase will undergo constructive interference and waves that are out of phase will undergo destructive interference; see Figure 2. In practice, the light beams will have different intensities, so the result will not be true 200% - 0%.

Interferometry measurements would be very difficult and expensive if the entire full-size wafer (300 mm) were imaged in one view. The optics costs alone would be exorbitant. Therefore typical interferometry methods (i.e. Mirau or Fizeau, see Figure 3) use small-size optics to perform many accurate measurements that are stitched together to one flatness map; see Figure 4.

In order to then prioritise the camera requirements for this application, it is helpful to first think of the image or images required for the measurement. For interferometry, several images are required, information in the entire image is used, and there is limited contrast in the images. Therefore, the most important camera specifications to consider are:

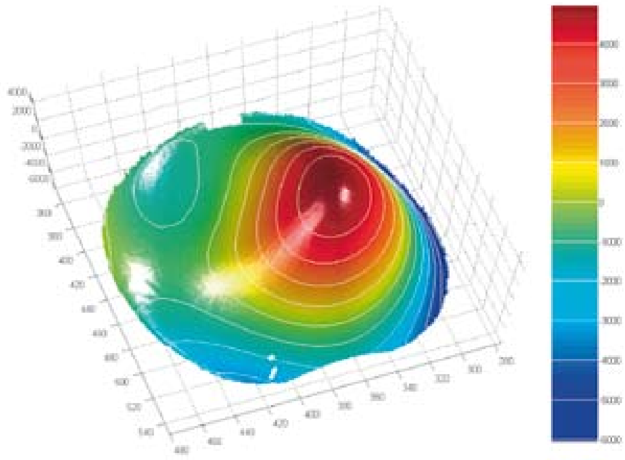


Figure 4. Combined wafer flatness map. (Source: Eindhoven University of Technology)

- Dynamic range to provide detailed information in low-contrast images.
- Image uniformity for accurate data over the entire image.
- Full well capacity, since shot noise is the dominant noise source.
- High frame rate, so that the camera does not limit throughput since many images are necessary for one measurement.
- Image-to-image stability, because multiple images are combined for the measurement.
- Mechanical/thermal stability to support image-to-image stability.

PCB inspection

When the integrated circuit is completed, there are several inspection steps in the packaging process and subsequent PCB manufacturing. Increasing performance while reducing size results in smaller chips, different packages, higher-density PCBs, and multi-layered, more complex boards. There is also a large variety of component sizes.

For years, 2D was dominant and the third dimension with limited accuracy was only used occasionally. With feature sizes continuously decreasing and new packages being introduced (e.g. BGA, flip chip), the third dimension became more important and made improved measurement methods necessary. Modern systems use advanced lighting techniques and algorithms to perform true 3D measurements with high accuracy.

With solder paste inspection, 3D inspection and measurement are also becoming more important because of the changes in the amount of solder paste used. When the solder bumps and balls become smaller, the volume of the solder paste is the important measurement factor and not

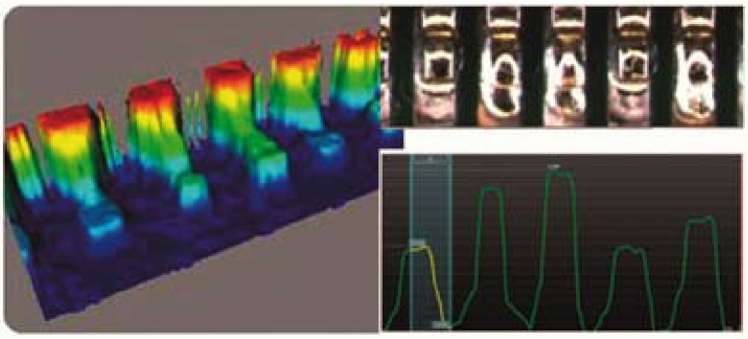


Figure 5. 3D Automated Optical Inspection.

just the width. As the solder provides the connection with the PCB, the correct solder volume is extremely important to achieve a high solder joint reliability. Solder volume and shape are measured both pre-reflow and post-reflow of the solder.

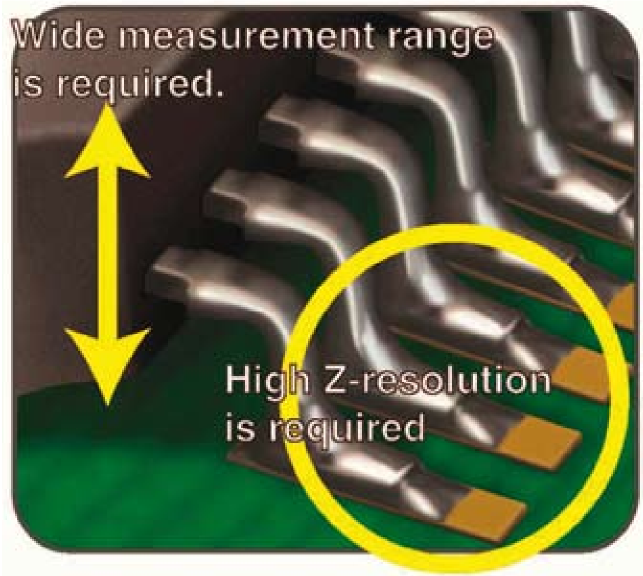
A common technique is 3D Automated Optical Inspection (AOI), which offers significant improvements over 2D, such as full dimensional measurements to verify the exact component information; see Figure 5.

For example, high-speed 3D AOI systems that employ fringe pattern projection (triangulation, multiple directions, multiple colours) need more megapixels to measure the third dimension. With just a 2D view from the top, you can only see defects such as shifts, rotations, and cracks, but not whether components are flat on the board, or the volume of solder paste. With 2D only one image was sufficient to get all of the measurements.

While some 3D measurement systems may use four to five images per inspected region of interest (ROI), more advanced systems use twenty images or even more to increase measurement accuracy and to add colour vision.

The migration from one image for measurement to multiple images results in more demands on the camera-based imaging system. There can be at least two approaches to satisfy these requirements.

Higher-resolution cameras allow for a larger area to be inspected at once and provide more data, which can improve accuracy. But since many images are required to perform quantitative measurements and the overall system throughput must be maintained, the camera frame rate must also be high (for example 4 megapixel at 180 frames per second (fps) or even 25 megapixel at 32 fps and higher).



Another option is to use multiple cameras, although the cameras must be extremely well matched.

With 3D AOI, the most critical camera parameters are:

- Frame speed to maintain or increase throughput.
- High resolution to increase the field of view (FOV).
- QE and Read Noise, as increasing illumination power is expensive.
- Image-to-image stability, as the measurement uses many consecutive images.
- Uniformity, as with higher resolution there can be more defective pixels in the sensor.
- MTF, which determines the smallest details that can be seen.

Conclusion

As the objects to inspect/measure become smaller, higher-resolution cameras with better spatial resolution can improve accuracy and precision. This does require a high-quality camera design, however. As with all measurements, high quality means that the variations in the camera and the images are smaller than the variations of what you are trying to measure, to prevent that you are measuring within the noise of the camera.

Regardless of the specific implementation, 3D measurements mean increasing demands on the performance and reliability of the machine vision camera. By considering the particular needs of an application and measurement method, the most critical camera parameters can be revealed for the best system fit.

Electromagnetic

Innovation of manufacturing technologies is of paramount importance to safeguard future economic prosperity. A specific EMPF (electromagnetic pulse forming) case study is outlined as an example. This manufacturing technology is now the basis for creating new business through a start-up company.

• *Evert van de Plassche and Marcel Grooten* •

In the Netherlands, a lot of attention has been given to innovation and a knowledge-based economy over the past few decades. However, the basis of daily economic value generation is still straightforward manufacturing and product sales [1]. Investments in R&D are below 2% of national GDP and lagging behind. Only in the international high-tech area is 5-10% of revenue related to R&D investments, which will and should result in future manufacturing and jobs (see Table 1).

Companies focusing on a specific product and market are creating today's value by (re)production, sales and service, preferably backed up by an innovative product IP position and specific know-how in manufacturing. This is why manufacturing technology within production processes is at the core of economics. Innovation of manufacturing technologies is of paramount importance to safeguard future economic prosperity. Having smarter and better manufacturing processes and being able to reduce the time-to-market of innovations is key to maintaining a worldwide competitive edge.

Table 1. Manufacturing industry leaders invest heavily in R&D [1].

Company	R&D budget (billion euros)	Percentage of turnover
Bosch	3.80	8.0
ASML	0.52	11.6
Siemens	3.85	5.1
Philips	1.58	6.2
Daimler	4.85	5.0

EMPF technology

An EMPF case study was concluded recently. This manufacturing technology is now the basis for creating new business through start-up company PulseForm [2]. PulseForm addresses the industrial market with tailor-made solutions and applications of EMPF technology and equipment.

A conventional way of connecting tubes is soldering or shrink-fitting. What if there were a method to connect metal and non-metal components without familiar limitations and drawbacks (e.g. toxic gasses, heat-affected zones, or spring-back)? EMPF offers such a possibility.

EMPF technology has been a familiar principle for years, but there have been some straightforward obstacles to implementing this technology in an industrial environment: safety regarding the high voltages and explosive forces used, and the ability to remove the product assembly from the tool. Without that, the technology cannot be applied and is therefore invalid.

The principle of EMPF technology is as follows (see Figure 1): workpieces that need to be connected (at their outer and inner sides, respectively) are placed loosely inside a coil. The capacitor bank is charged and then a large amount of electrical energy is released in the form of an electrical current of up to 1,000 kA. This current flows through the specially designed coil for a very short period of approximately 35 µs. It creates a tremendous magnetic field in the coil, generating eddy currents in the workpiece.

pulse forming

The induced magnetic field in the outer workpiece is opposite to the magnetic field in the coil. This results in repulsive forces large enough to surpass the yield strength of the metal workpiece, causing its plastic deformation.

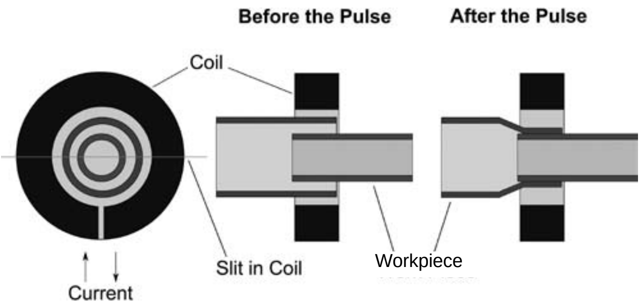


Figure 1. Principle of the EMPF technology (see text for explanation).

As action is reaction, the coil itself is pushed outwards. A simple solution to harness these explosive forces would be to make a strong monolithic coil. Unfortunately, the workpieces can come in many shapes and even form a loop or spiral. Contrary to the requirement of harnessing the deformation forces, the coil needs to be opened for easy discharge of the workpiece.

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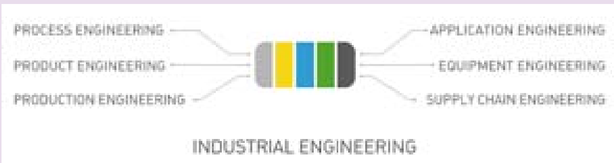

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The solution for both harnessing the deformation forces and allowing easy removal of the workpiece was found in splitting the coil and retaining the parts using a strong hydraulic force. This solution has been designed, built and proven.

Benefits

There are several benefits of this technology, plus it allows specific applications, including:

- Hybrid metal joining.
- Metal/non-metal connections; only the outer workpiece needs to be conductive or has to be surrounded by a conductive sleeve.

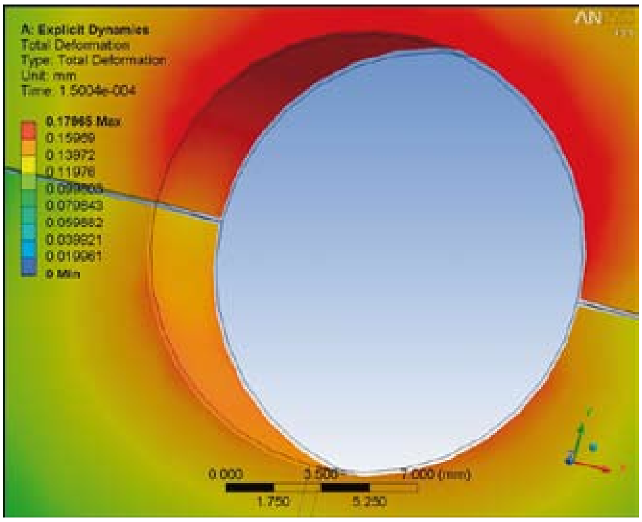

Figure 2. Modelling of forces and deformation during pulse.

Figure 3. Design of the EMPF tool.

Figure 4. The EMPF system; the inset shows a detail of the tool.

- Stable, controlled process.
- No heat-affected zones.
- Green/clean process without precursor, shield gasses or aggressive cleaning agents (flux or gas); no pollution of the workpiece.
- No filler material (e.g. silver solder or welding wire), allowing cradle-to-cradle recycling.
- Contactless connection; no tool print.
- Joining of pre-coated parts; the workpieces that need to connect can be given a surface treatment in advance.

Realisation

To enable this technology, a tool and equipment concept has been designed and implemented. A robust, easy-to-maintain industrial solution was created to implement this new EMPF technology in industry.
The design process started with specification and modelling combined with system engineering, based on choosing the right principles of equipment engineering and control (see Figures 2 and 3).

Realisation was started after several design reviews and considerations, such as DFMA (design for manufacturing and assembly) and FMEA (failure mode and effects analysis) methodology. Typically, sound project management and integration of all aspects and all stakeholders proved essential for success. Following the design, construction, integration and tests with this first prototype, several tests were performed and a lot of interest was raised when this tool was first presented at the Hannover Messe in April 2012.

Figure 5. An example of a connection made with electromagnetic forming.

Figure 6. Cross section of a connection.

A new manufacturing technology opens up new opportunities and applications (see Figure 5). These opportunities go hand in hand with new challenges, as the current design of fittings relies heavily on conventional connection techniques. Process parameters and material characteristics all have their effect on design parameters (see Figure 6). What is the optimal wall thickness? When is the connection water- and pressure-tight? How to design the appropriate coil? This requires a structured approach of modelling and also experimentation and verification (DoE, design of experiments), resulting in new design rules.

Next steps

By creating a new manufacturing technology and supporting a start-up, a new level has been added to high-tech manufacturing technology. Further research and implementation projects for several industries in particular are on their way, depending on specific requirements and applications.

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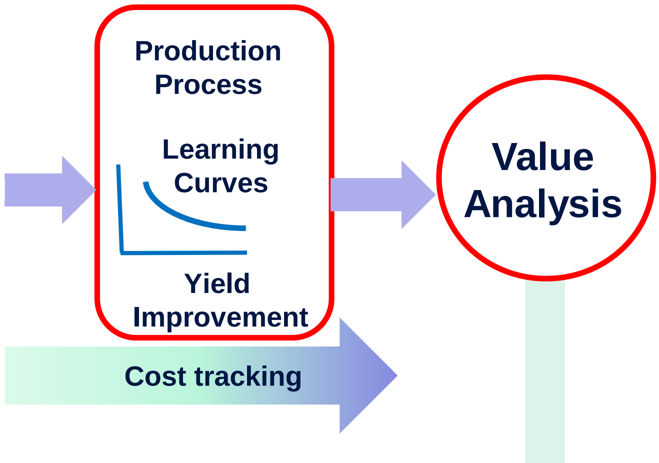
Precision: cost vs value



Value engineering is often synonymous with cost-effective solutions. As such, the word 'precision' acts as a direct trigger to value engineers because, more often than not, precision or high tolerances are identical to high cost or 'cost drivers'. These are best avoided, so: "Stop high precision technology!" That is not the message of course. Precision technology is a very interesting field that is opening up a whole new range of applications. Current developments, including the high-tech and affordable products we use at home or in the office, would be unthinkable without it. This article will show how value engineering can be applied and it will explain that the two fields are not necessarily at odds with one another. On the contrary, the same methods apply in both fields, and it is only the scale of the issue that is different.

• *Goof Pruijsen* •

Value engineering as a method was defined in the early 1950s, when materials were scarce after the Second World War. The basis of value engineering (or value analysis) is functional theory: deconstruct the purpose of a device, existing or in development, into functions, find alternative solutions for each function and then pick the solutions that best fulfil the requirements. As an engineer you may think: "Of course, that's what I always do." And that may be true. However, the difference with applying value engineering during the design process is that, when applied in a systematic fashion and from the very start of the design

Author's note

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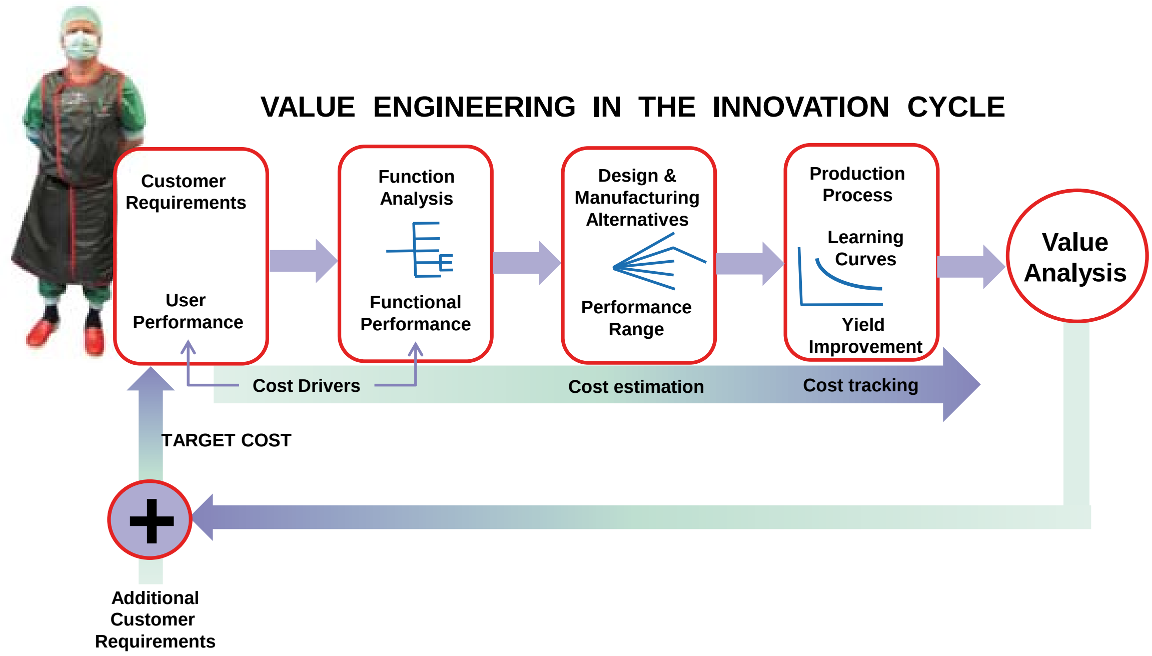


Value engineering in the innovation cycle.

process, the end results are often far better in terms of cost and value to the customer.

One of the big pitfalls in design and improvement processes is devising solutions before you actually understand the requirements, i.e. the problem. For example, if you are in the business of selling drills, you can talk enthusiastically about the type of material used, lack of wear and tear while using it, etc. However, the customer buying a drill does not want a drill; he wants a hole. No, sorry, *she* wants a picture on the wall. Aha! Understanding the final requirement opens up a world of totally different solutions.

Another pitfall is falling in love with a specific technology and turning it into an end instead of a means. For example, you can fit an iron with advanced sensors and wireless technology that automatically messages you on your smartphone if you forget to unplug the iron when you're done with your shirt… A simple bimetal switch will also do the job.

Suppose you have the 'how' (existing solution), keep asking about the 'why' until you reach a sufficient level of understanding. Then start thinking (again) about the 'how' and 'what also does the job?' You will see that this can yield totally different solutions. For the above drill example for instance that would be (re)positioning the picture, using a hook with a double-sided sticker on the back that is detachable and reusable. The added value of this would be less work, no damaged walls, no tooling cost, etc.

Although this sounds obvious, experience has shown that it is very difficult for most engineers to 'think' in terms of functions instead of solutions. And what's worse is that the ones that represent the customers (i.e. sales or marketing) have already defined the solution before development has even started.

Although value engineering was originally a method that focused on 'function', now there is a whole toolkit of methods that we can apply, depending on the case in hand, e.g. designing a new product or improving an existing one in terms of cost and performance. Table 1 presents an overview of methods and application domains, and Figure 1 shows the role that value engineering plays in the innovation cycle. Some of the methods will be outlined below.

Table 1. Overview of value engineering methods and their fields of application.

Requirements and user performance analysis	Functional performance	Basic cost reduction
Voice of the customer	Function analysis	DFMA
Critical-to-quality analysis of performance metrics	Design alternatives	Cost & cost driver analysis
Parameter optimisation		Reverse engineering
		Value stream mapping

Function analysis

When analysing the function of the handle of a coffee mug, most people say that the function (or purpose) of the handle is to hold the mug. That's true, but you could also grab the whole mug. In doing so, however, you may burn your hand if the mug is filled to the brim with hot coffee. Aha, now you understand that the handle of the cup serves another purpose, i.e. to protect the user. Fully understanding the function opens up the solution space in terms of design alternatives. You could also protect the user in other ways, such as creating distance, applying isolating materials, cooling the coffee, etc.

Note that understanding customer requirements, value drivers and required performance is important when it comes to function analysis. Also note that a good function analysis remains constant over longer periods of time. The required performance may change, but the function only changes when the customer application changes.

Design alternatives

Once you understand the requirements, the necessary functions and the required performance, it is important to find a sufficient number of conceptual design alternatives. Drawing up a single overview of the required functions and listing the design alternatives for each into a so-called morphological diagram may be of substantial help. If done well, you can use it to draft different scenarios for total device solutions. It quickly reveals which combinations of solutions are not feasible, but also finds that solutions that at first may not have met the required functional specification may still be feasible when compensated for by other measures. Different scenarios may also imply different product solutions for different parts of the market. Drawing up this overview can prove to be a good investment; the functions (or user jobs) do not vary too much over time. The functional requirements may change however, and with it the solution directions.

DFMA, production technology and process

Early on in the design process, when solutions are being considered, it is important to establish what production technology will be used that can provide the necessary precision, and whether the product can be made. Another matter that should be considered is DFMA (design for manufacturing and assembly). Is it necessary to make separate parts for each function, as a result of which different parts may require different materials, technologies, suppliers and assembly? Or is it possible to reduce the number of parts by integration? Integrating several parts into one is often better as it results in higher precision of the total subassembly, reduced manufacturing costs and less complexity. On the other hand, value engineering and deconstruction into functions strongly favour modular solutions, i.e. one solution for each function.

The right choice between integration and modularisation depends on the type of product and the lifecycle of the product in particular. Short-lived products can provide a high degree of integration at the lowest cost. Long-lived, complex products benefit from architectural considerations, resulting in a platform where a device is deconstructed into separate functions. If the interfaces between the different functions are stable, the solutions can each have their own lifecycle. It must be possible to test them separately against an interface, without the impact of having to retest and redesign a complete product. Finding the right balance in this requires capable system architects.

Cost estimation or modelling

When making these considerations, it is always important to put together cost estimates to check whether the solutions are still within budget. This can be done by using cost experts, known cost models, or simply educated guesses. It is often worthwhile varying a specific parameter to see what happens to the cost. You may sometimes expect linear behaviour, but if there is a step curve it is interesting to find out why. A beam that was designed in a medical system may serve as a good example. The cost was in line with the length up to 3 meters, but beyond that there was a sudden increase. And the reason for this? During installation, parts of the system had to be moved in a hospital elevator. Lengths over 3 meters did not fit in, hence the beam needed to be split and reassembled at the final location. Lengths over 3 meters were the cost driver in this case.

An important topic in value engineering is analysing the cost, its components and, most importantly, what's behind it. Or in other words, what's the cost driver? Again, you can go quite far with this by systematically asking the 'why' question. Why is the cost of a mechanical part X? Is it because of 1) material used (e.g. type, quantity, etc.), or

2) production time (e.g. labour, process type, machine time, etc.)? For production time, why is it time T? Is it because of material hardness, size, complexity, required precision or tolerance, the way the manufacturing process is executed, etc.? Why was this type of material, production process, etc., chosen? ("We always do it like this. Somebody else said to do it like this. We assume that it's the best way. We don't know about other methods. We don't like other methods.")

Now link this to precision engineering, especially in terms of the product cost. Typically, it is the (high) tolerance that is the main cost driver. And since you, the reader, are in the field of precision engineering, you could assume this is just a given in the field and is not something that should be avoided.

But you have to ask yourself:

- Is it really important (i.e. critical to the quality) for the customer to have this tolerance and what happens to the cost if you go easier on the tolerance?
- Does understanding the function lead to other design alternatives that are less critical to the tolerance?
- Application range: is the tolerance necessary over the whole range or only in a part?

The following is what often goes wrong, especially with inexperienced engineers:

1. Solution drive: finding solutions is the most important aspect, without thinking of the cost consequences.
2. Specifying higher tolerances than necessary on the drawing just because they need to be filled in or are copied from other drawing templates, without giving it a second thought.
3. Not being aware of the production process of parts, or thinking that it is not necessary to consider this early on in the design process.
4. Reproduction of prototypes without industrialisation and considering the alternatives.
5. Not being aware of the assembly process.

Consider for a moment the all-too-familiar occasions when components of a device were made by different departments. At first they had long fights on how to divide the responsibility for different tolerances. Then, the tolerances were allocated to the different groups. Hindsight of course shows that had they had an overview of and influence on the whole tolerance budget, this would have led to different, better solutions.

Industry example

A great example of a device that is high precision but avoids high tolerances is the CD player. The digital information on a CD (or DVD or Blu-ray) consists of very small lines that can be read by a laser. Suppose you have to make such a device using mechanics and electronics only. This would require incredibly precise parts to reach the necessary level of precision to make it work. It would also be completely unaffordable. So what did the engineers do to find an affordable solution that consists of low-tolerance, low-cost parts?

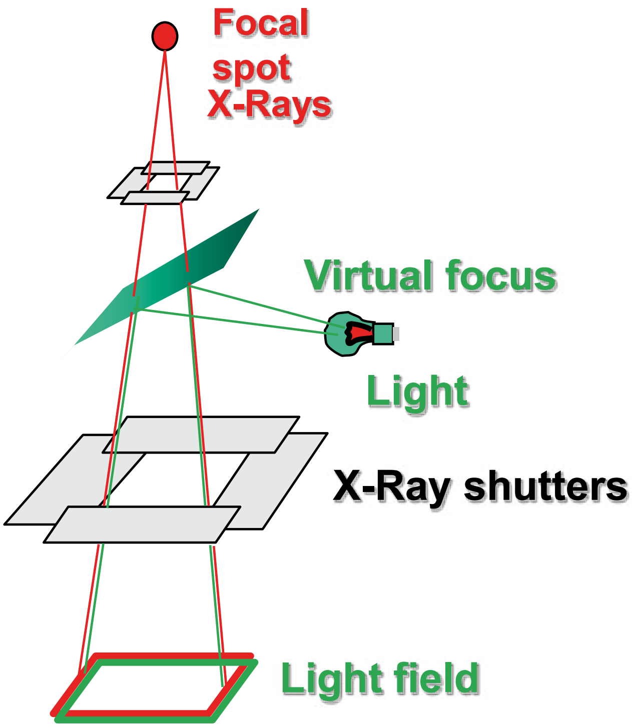
The trick here was a solution totally unrelated to high-precision mechanics, namely software error correction. While reading the information, the CD player produces read errors because of imperfections in the device. In the information read there is additional information for error correction that allows for errors to be detected and corrected. For audio, a certain error level is allowed, causing glitches in the sound that are hard to detect. For CD-ROMs (e.g. installation software), more error correction information is put on the disc to ensure zero read errors.

Thinking about the right level of tolerance required, you could make a zero-error audio CD, but you could also save space on the disc with less error correction information and use the additional space to store more music, e.g. a bonus track. A trade-off between quality (i.e. detectable sound glitches) and other user benefits (i.e. more music) is possible here. In fact, facilitating less mechanical stiffness or lower tolerances by way of other compensation techniques is a whole field of study in itself. What is interesting to note however, is that mechanical designers sometimes think it is not possible to talk to software engineers (language constraints?).

Case study on tolerance

A high-tolerance case the author was involved in concerned an X-ray transparent mirror used in diagnostic X-ray equipment. In a hospital, when an X-ray needs to be taken of a broken bone or a patient's lungs, the operator needs to position the equipment correctly and collimate the X-ray beam to the exact spot on the patient that the doctor needs

a



b

Figure 2. Using 'harmless' light to correct collimation of an X-ray beam.
(a) Clinical set-up.
(b) Light field for positioning.

to check. Using the X-ray for the positioning would expose the operator and patient to a lot of harmful (and pointless non-diagnostic) radiation. As such, medical regulations do not permit this. The simple solution is to put a light in the virtual focus point of the X-ray beam, controlled by an X-ray transparent mirror (see Figure 2). It may not have looked like a high-precision task, but it actually was. Or… so it seemed. Or… so everybody agreed.

On a bad day, the factory called engineering, saying there was a threat of a production stop because of this 'stupid' plastic collimator mirror. The supplier had delivered mirrors half of which were not flat enough. As such, they did not fulfil the medical regulations that stipulated that the light field must simulate the X-ray field with a 5 mm accuracy at a distance of 1 m. This may not sound like a high tolerance, but the mirror was actually specified to a flatness of within 2 μm over the entire surface of the 10 cm plastic mirror with aluminium coating. The (interim) supplier claimed that the mirrors met the specifications and refused to take the blame.

Using an expensive 3D measuring bench, engineering tried to prove that they did not meet the specifications, but it turned out later that this measuring technique was not sufficient to perform the measurement, as the sensor contact resulted in deformation of the weak mirror. In fact, for the entire time the mirror had been in production – which had been for well over ten years – the manufacturers had never measured the flatness, because there was no test designed for the manufacturing process that was economically viable. Nor was there any need, as the mirrors had generally proved to be quite usable until the abovementioned 'bad day'.

The author took this opportunity to get his Six Sigma Green Belt certificate. In the Six Sigma method, tolerances are statistically very important. It is all about being able to manufacture within a specified tolerance with a significantly high process capability. Therefore, he started by thinking about the tolerance of this mirror. After a while he realised that the required specification did not have a lot to do with the flatness of the mirror. What was actually important was that the angle of the edge of the mirror was small enough so that the light rays incident near the edge could still be projected on the patient within the intended light field. Making the rest of the mirror very flat only contributed to the homogeneity of the light field, and this was not a requirement.

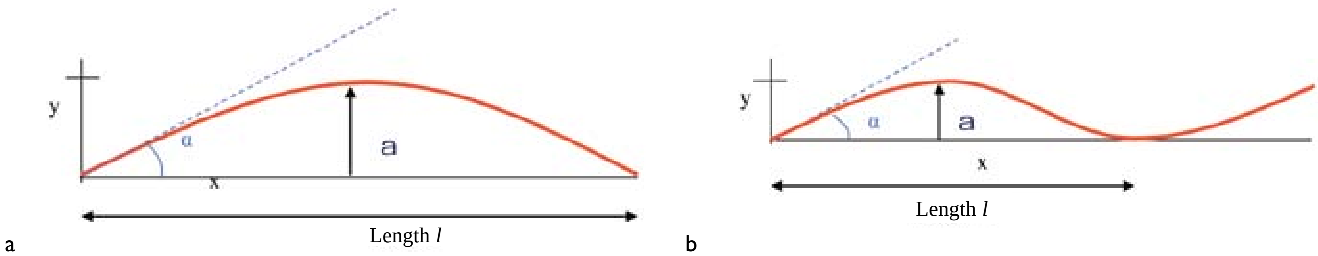


Figure 3. Bending of the plastic collimator mirror.
(a) One bend.
(b) Two bends.

If you model this problem assuming that the mirror always has some kind of bend (see Figure 3), you can calculate that the angle that meets the requirements allows for a 40 μm deviation off the plane in the middle of the mirror. If you then assume that there are *two* bends in the mirror for some reason or another, you can calculate that, with the same maximum angle, the permitted deviation is much smaller. Or vice versa; that a deviation of about 40 μm results in the angle falling outside the required specification.

How did this insight help? There was a guy in the factory who was good at measuring using a knife edge ruler, an inexpensive piece of measuring equipment. Knife edge rulers cannot be used for absolute measurements, but they can be used to easily assess whether mirrors have one bend or two. The mirrors with two bends were actually out of range in the functional test; they were the 'bad ones'.

How do you get two bends in a plastic mirror that is produced via injection moulding? Now it gets easy: thermal stress during cooling. It was noted that the supplier who had done the injection moulding had recently made a change in their organisation and introduced a new injection moulding machine, more operators and a flexible staff roster. The previous operators always manufactured the basic mirrors on the same machine and in the same way.

Now to improve the production process, a lean manufacturing technique was proposed, i.e. visual management. Operating instructions for moulding the base mirrors were placed next to the machine. These clear-cut instructions covered material preparation, machine parameters, the cooling process after the base mirrors leave the machine, packaging instructions, etc., and came with photos.

The problems with the mirrors were resolved almost immediately and the interim supplier was given the boot, because the one thing they were responsible for, i.e. supplying mirrors that meet the specifications, they did not deliver, providing no added value. As a result, mirror yield went up from 50% to 99%, price dropped by 30% (because there was no middleman), and order lead time decreased from 18 to 8 weeks.

Now a new specification for the mirror could be formulated: a 'flatness' of < 0.04/100 mm (20 times less stringent than the previous one, which was ultimately just a ridiculous number) and a maximum of one bend only. The latter specification did the trick. The first was written down to have some numbers on paper; something that you could criticise given that there was still no valid measurement method. The main reason this was done was because omitting it would give a feeling of 'nakedness'.

Learning

Sometimes you think you understand tolerance, but actually you don't. This leads to misinterpretations, drastic upfront measures for problems that do not exist, opinions about who's to blame, time lost problem-solving, additional costs, and in the worst case, a very expensive production stop. Understanding tolerance and dealing with it the right way saves you a lot of trouble. This approach should start early on in the design process, and from that point you should already be looking ahead at whether the production method chosen can provide the capabilities within the required range. Solving it afterwards is expensive. By understanding the 'mirror problem' afterwards, it was also realised that it was pure luck that the problem had not occurred in all those years. So what, you may ask? Understanding also brings with it more exhaustive improvements that you may not have thought of before. And maybe this knowledge will turn into a valuable asset, allowing you to push the boundaries of precision technology even further (and address new challenges).

Conclusion

So is value engineering only applicable to the macro world? No, in fact it is just as applicable to the micro world of precision technology. Methods and metrics are the same, and it is only the scale that is different. Although the focus of this article was on the connection between value engineering and tolerance, do not take precision for

Together with co-author Frank van Dam, the author published the easy-to-read book "Target Costing and Value Analysis" (see www.managementboek.nl). For example, it outlines how to run very effective design workshops with suppliers, early on in development projects.

granted. You must still challenge what's being said or assumed. Insights and overviews of alternative routes lead to new added value. It is important that you create an overview of several things right at the beginning of the development, which would include an overview of requirements, solutions and their applicable ranges, their impact on cost, time, feasibility, etc. It may mean more work at the beginning, but it ensures that a lot of rework can be avoided later on and that products do not fail on the market. Furthermore, by applying value engineering systematically not only do you get better solutions, but you get these solutions faster. And after all, time-to-market is of utmost importance where economic value is concerned.

Advances in design

The ASME IDETC conference on 12-15 August 2012 in Chicago, Illinois, USA covered the latest advances in kinematics, parallel kinematic manipulators, cable-driven robots and design for dynamics, as well as design methodology, design automation and other fields related to precision engineering. This report looks at the tutorials preceding the conference and the advances in mechanism research that were presented, in particular in compliant mechanisms

The ASME 2012 International Design Engineering Technical Conferences (IDETC) were held on 12-15 August 2012 at the Hyatt Regency McCormick Place in Chicago, Illinois, USA (see Figure 1). This event is the flagship international meeting for design engineering and it comprised of several conferences, including "Mechanical Vibration and Noise", "Dynamics for Design", and "Mechanisms and Robotics". Even though ASME (American Society of Mechanical Engineers) sounds similar to ASPE (American Society for Precision Engineering), the ASME conference can largely be regarded as the bigger of the two with a wider variety of subjects. The papers seem to focus on specific parts or methods researching only a limited number of design parameters. The methods and solutions are often more outside the box. ASPE is dedicated more to precision engineering, it has more industrial delegates and it is more into system level solutions.

Figure 1. The Hyatt Regency McCormick Place in Chicago served as the conference venue.

The event started with a variety of tutorials over two days before the conference. The more popular tutorials were: "21st Century Kinematics", "Design for Prescribed Stiffness" and "LEGO® Mindstorms® with MATLAB and Simulink for Teaching Controls, Robotics and Mechatronics".

Mechanisms

The "21st Century Kinematics" tutorial was given by various academic experts. Rather than deliver a straight-up workshop, the aim of this tutorial was to return foundational material that is not present in a lot of current curricula and place it in the context of state-of-the-art

Editor's note

This report was produced by some of the conference delegates from the Netherlands. Ronald Aarts (University of Twente) and Arend Schwab (Delft University of Technology) attended the "Dynamics for Design" conference, Just Herder (Delft and Twente), Nima Tolou (Delft) and Dannis Brouwer (Twente and Demcon) attended the "Mechanisms and Robotics" conference.

engineering

Figure 2. Tutors of the "Design for Prescribed Stiffness" workshop, from left to right Nima Tolou, Dannis Brouwer, Just Herder and Shorya Awtar.

research objectives. The workshop was organised by Prof. Michael McCarthy, who is the editor of the Journal of Mechanisms and Robotics. He highlighted the importance of mechanism synthesis and the challenges that still exist in the analysis of spatial mechanisms and in the conceptual design of mechanisms in general. Prof. Carl Crane showed that seemingly simple mechanisms consisting of a few links and springs yield complex systems of polynomial equations with dozens of mathematical solutions, a subset of which have physical meaning.

The logical question of how to handle more complex mechanisms was addressed by Prof. Charles Wampler, who discussed sophisticated computational tools that are being developed for numerical algebraic geometry that can assist the derivation and solution of these polynomial systems. It is now commonplace for kinematics researchers to derive polynomial systems that dwarf landmark problems of the recent past. Apart from being applied to linkages, kinematic theory has proven instrumental to other fields as well. Prof. Larry Howell demonstrated how the theory can be extended to cover macro and micro compliant mechanisms, i.e. mechanisms that move due to deformation and that cannot be directly described kinematically. Prof. Kazem Kazerounian showed how the movement of large molecules like haemoglobin and DNA can be accurately modelled using spatial kinematics, thus entering the arena of nanomechanisms.

Stiffness

In the "Design for Prescribed Stiffness" tutorial (see Figure 2), Shorya Awtar, University of Michigan, presented closed-form parametric models that capture key non-linearities in beam flexures. These can then be applied to more complex geometries to predict their motion performance (i.e. stiffness, error motions, etc.) without using FEA (finite-element analysis). Dannis Brouwer presented three methods for analysing constraints in a mechanism: Grübler's formula, opening the kinematic loop and a multi-body singular value decomposition method. Bi-stable, multi-stable and zero-stiffness mechanisms were shown by Just Herder and Nima Tolou. Typically compliant mechanisms have a positive stiffness, which may be a disadvantage sometimes as it challenges the mechanical efficiency. Several options were presented to modify the stiffness behaviour.

Figure 3. Early generation LEGO MINDSTORMS NXT. (Photo: LEGO)

The 'feeling' of control

The LEGO® MINDSTORMS® workshop was organised by Prof. James Peyton Jones of Villanova University, who for years has been using the LEGO hardware with Matlab and Simulink for teaching controls, robotics and mechatronics; see Figure 3. He was assisted by Rohit Shenoy from MathWorks, who explained that as of this year Matlab offers full built-in support for prototyping, testing and running Simulink models on LEGO MINDSTORMS NXT. This means that it is now relatively easy to build Simulink models for the NXT processor, to download them via a USB connection and to exchange data with the application using a Bluetooth connection. This software and hardware combination addresses the growing need for hands-on, project-based learning using a low-cost, easy-to-use hardware and software platform that builds on the widely used Matlab & Simulink platform. Prof. James Peyton Jones presented his experience with using the NXT in the classroom to give students the 'feeling' of control, and the conference delegates were invited to join his class during the workshops and build a path-following driving robot.

36th conference

The Mechanisms and Robotics International Conference is organised by the Mechanisms and Robotics Committee of the ASME Design Engineering Division. This year was the 36th edition of this premier international meeting in mechanisms, robotics and related fields, which was first held in 1952. Topics covered are central to mechanical design, e.g. kinematics, dynamics, design, computation, robotics, reconfigurable mechanisms, novel mechanisms and robots, and various applications. The main idea is to have the opportunity to increase international collaboration and understanding and to promote work and disciplines in mechanisms and robotics. The conference programme is developed to share knowledge by presenting research results, new developments and novel concepts.

A special topic in the "Robotics and Mechanisms" conference is compliant mechanisms, i.e. mechanisms that move due to deformation. The main focus here is modelling, analysis, design and optimisation of compliant mechanisms (including parallel compliant mechanisms), compliant joints of all scales and variable compliant devices. New methodologies and applications in robotics, mechanisms and mechatronics are included.

Interactivity

One new aspect of this conference was the way in which the papers were presented in the Compliant Mechanism session. The accepted papers – 26 in total – were divided into two sessions of 13 each, and were presented 'interactively'. This meant that, during a session, the authors first gave a three-minute podium presentation, one after the other, in a so-called fast forward session. This group of 13 authors then presented their papers in a poster-and-demo session with plenty of time to discuss their work (see Figure 4). A second session of 13 papers then followed in the same format. This format allowed all of the authors of an accepted paper to give a brief overview to highlight the key issue of the paper, with plenty of time to discuss this issue during the poster sessions. It combined providing a broad overview with in-depth questioning. Another advantage was that newcomer delegates in particular could easily approach well-established experts, whose attention is very hard to catch in the regular podium-only format.

Figure 4. Plenty of time for discussions at the poster session after the 'fast forward'.

Integration

Dynamics for Design is the integration of recent advances in modelling and system dynamics – including the role of non-linearities, vibration analysis, multi-body systems, and computational dynamics – with current design methodologies, leading to the improved performance of complex, dynamic engineering systems in terms of reduced design cycle times, improved system reliability, and consistent behaviour across operating environments. The 1st Biennial International Conference on Dynamics for Design (DFD) provided a forum to share ongoing work, for example with the aim of developing and demonstrating practical protocols, methodologies and tools used to incorporate dynamics at various stages in the design process.

The models used for this purpose ranged from detailed models to very large, multi-physics, high-fidelity models. The latter models included examples for car manufacturing and aircraft and space applications. Such models involve considerable computing power and time. Modelling may be something that is required at an early stage of the design, e.g. for a component in a system for which many alternatives need to be evaluated in a rather short space of time. Ronald Aarts presented the design of a flexure joint for use in 2-DoF manipulators (DoF = degree of freedom), which has a high support stiffness over a 40° travel range. Arend Schwab presented a new recumbent bike design focusing on handling quality. The passive dynamics of the new design were made identical to a reference recumbent bike by tuning parameters like the head angle and trail.

Best paper

One of the papers submitted by the Twente Mechanical Automation and Mechatronics group, based on a Master's thesis by Ger Folkersma with supervisors Steven Boer, Dannis Brouwer, Herman Soemers and Just Herder, won the Best Paper award in the category "Compliant mechanisms – applications". The paper presented the design of a 2-DoF stage with high dynamic performance (disturbing frequencies higher than 100 Hz) over a relatively large range of motion (100 mm x 100 mm) with confined outer dimensions of the mechanism (540 mm x 585 mm x 87 mm). The research on flexures is of interest for possible applications in vacuum that can be found in ASML and FEI machines. The Twente representatives acknowledged the recognition of their long-term research into the design (Design Principles) and modelling (SPACAR) of flexures for precision equipment.

Conclusion

The visit to the ASME IDETC conference was an excellent opportunity to present advances in mechanism research, in particular in compliant mechanisms, and to learn about the latest advances in kinematics, parallel kinematic manipulators, cable-driven robots and design for dynamics, as well as design methodology, design automation and other fields related to precision engineering.

Information

www.asmeconferences.org/idetc2012

Successful premiere precision mechatronics

The first DSPE Conference on precision mechatronics, an initiative of DSPE, Brainport Industries and the mechatronics contact groups MCG/MSKE, has been a huge success. The conference was held on 4-5 September 2012 and attracted a full house of about 150 delegates. With nearly sixty presentations, posters and demonstrations, they presented an overview of systems thinking in precision mechatronics. All in all, the conference underscored the leading global position of the Dutch high-tech systems community.

Delegates at the first DSPE Conference on precision mechatronics. (Photos: Vincent Knoops)

showcases Dutch capabilities

The DSPE Conference was organised by DSPE and Brainport Industries, the association of leading tier-one, tier-two and tier-three high-tech suppliers in the Eindhoven region. The target group included technologists, designers and architects in precision mechatronics.

Opening speakers

On Tuesday, 4 September, the conference opened with Harry Borggreve, Senior Vice President of ASML. He discussed the market and technology challenges of EUV lithography and the transition to 450 mm wafers in semiconductor manufacturing. As a guest speaker, Prof. Paul Shore, Head of the Cranfield University Precision Engineering Institute, gave an overview of activities at his institute and its spin-off companies, including Loxham Precision, a manufacturer of ultra-precision production technology. His presentation, “Systems thinking in advancing productivity of ultra precision machines”, provided a British perspective on the conference theme.

Prof. Paul Shore, Head of the Cranfield University Precision Engineering Institute, gave a keynote lecture on systems thinking in advancing productivity of ultra-precision machines.


Harry Borggreve, Senior Vice President of ASML, opened the conference.

Sessions

Following these two inspiring ‘appetisers’, the programme covered five topics in one or two sessions (of three presentations) each:

- Precision Technology
  From 450 mm lithography challenges (ASML) to carbon-nanotube-based constant force mechanisms (Delft University of Technology and Brigham Young University).

Information

www.dspe-conference.nl
www.brainportindustries.com

Full house at the Willibrordhaeghe conference location in Deurne, the Netherlands.

Poster presentations and demonstrations attracted plenty of interest and stimulated lively debate.

A small table football tournament with the Dutch against the world added to the pleasant atmosphere.

- Motion Control
  From motion challenges in a medical environment (Philips Healthcare) to data-based control design methods for lightweight high-precision motion systems (Eindhoven University of Technology; see the article in this issue).
- System Engineering and Design
  From back-end laser scribing and inkjet for thin-film in a solar roll-to-roll production tool (ECN) to systems thinking dealing with contradicting system requirements (Settels Savenije van Amelsvoort).
- Business/System Architecture
  Including mechatronics as a money spinner (Frencken Europe, see the article in this issue).
- New Business
  Including the revolutionary industrial inkjet printing solution for the PCB industry (MuTracx).

As indicated, two of the presentations have already been reworked into an article in this issue of Mikroniek. Forthcoming issues will include other conference content.

To conclude

In between the sessions, over thirty poster presentations and demonstrations attracted plenty of interest and stimulated lively debate. Besides all of the presentations and demos, the conference also provided the ideal setting for networking and technical discussion. The overall pleasant atmosphere of the two-day conference also benefitted from the inspiring Willibrordhaeghe location, the magnificent Indian summer weather, and the small table football tournament that was organised on Tuesday evening.

It's no wonder that the organisers have already announced that a second DSPE Conference will be held in 2014.

Awards

Adjudicated by an independent jury, three awards were presented at the end of the conference:

- Best presentation: Raymond Knaapen (TNO), "Atmospheric Spatial Atomic Layer Deposition in Roll-to-Roll Processes".
- Best demonstration: Eric Hennes (Nikhef), "Passive seismic isolation applied in gravitational wave detection".
- Best poster: Ad Vermeer (AdInsyde) and Ingmar Kerp (TMC Mechatronics), "Carrierless substrate motion concept for spatial ALD reactor".

Fueling the Dutch with the

Each year twenty ASML Henk Bodt Scholarships are available. It's an initiative aimed at attracting the world's top technology students to study in the Netherlands and who may then join one of the country's many high-tech industries. Started by ASML in 2007, the scholarship is named after the man who, for twelve years, was the company's Supervisory Board Chairman.

T"The Henk Bodt Scholarship is a priceless opportunity for me", says Jianglei from China, who is currently studying for a master's degree in Applied Physics. "It's more than money, it's also a training programme. And even better, I have experienced first-hand, as an intern, the truly electric working atmosphere of ASML."

Rigorous selection criteria

"Not all of the twenty available scholarships are awarded each year", says Irene Kroon, ASML Starters Program Coordinator. "The selection criteria are very rigorous and involve psychometric testing and face-to-face interviews. Plus, ASML is looking for the very top talent, and we don't always find twenty people that fit this very demanding profile."
The scholarship fund helps international master's degree students attending either the TU Eindhoven, TU Delft or University of Twente. The scholarship offers full tuition and living expenses for the duration of the two-year master's programme, and, if successfully completed, most of the times the scholar is offered a three-year contract for a high-technology position at ASML.

Editor's note

This article was contributed by ASML.

www.asml.com

Development programme

In addition to the intensive two-year master's study course, each student follows a special development programme run by ASML, which includes an assessment at the beginning and regular coaching sessions. It also provides special support and training for each student's technical mentor at ASML. This way the company can best monitor and develop the student's skill sets – both the 'hard' technical skill set and the 'softer' personal skill set that includes communications, creative thinking and teamwork. These are known to be essential at ASML.

"Initially, the scholarship was intended for overseas students only", says Irene. "But with continuing Dutch government cutbacks in education, it may soon be made available to Dutch nationals." During its five-year history, students from all over the world have benefitted, including those from China, Colombia, India, Indonesia, Iran, Mexico, Pakistan, Rumania, Thailand, Turkey, and Ukraine. It's a truly international mix, and one that suits ASML's own extremely diverse cultural mix of employees.

First impressions

"When I first arrived, it was really great discovering a completely different culture and a new way of living", says

high-tech industry

world's top talent

Miguel from Mexico, studying Mechatronics. "Since I wasn't the only foreign student and since the university has a really well-organised meet-and-greet week we all had a terrific time – the first week felt like one big party."

"The first couple of weeks involved so many activities with other students that I had no time to be homesick", says Vidya from India, who recently graduated in Embedded Systems and will start her job at ASML.

Success to date

Since 2007, 83 scholarship students have graduated, from which 27 have been employed by ASML directly after their graduation. Before 2011, students could also apply for a Ph.D. position at the TU Eindhoven, an opportunity taken by eight scholarship graduates.

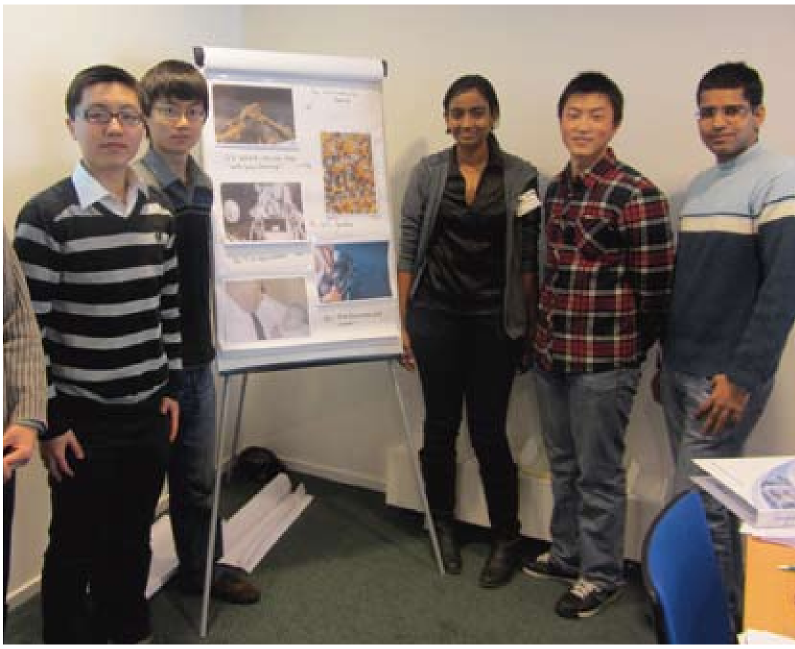
"Without the Henk Bodt Scholarship, the only way of financing my course at TU Delft would have been to get a federal grant from the Mexican government", says Miguel. "But these are usually reserved for doctoral studies, so it is more than likely that I would have needed to stop my student career."

"The first year has been fantastic", says Junnan from China, studying Electrical Engineering. "Especially my internship at ASML. Everyone here is very energetic and committed, and also very helpful. I am definitely learning a lot, and not just on the technical side. The personal development programme is also making its mark and I feel that it is really helping me."

Who can apply?

Students who have already been admitted for a master's degree course in the following subjects can apply for the ASML Henk Bodt Scholarship – either via the university or via the ASML website.

- TU Eindhoven:
  Applied Physics, Chemical Engineering (Molecular Engineering or Polymers & Composites), Computer Science & Engineering, Electrical Engineering, Embedded Systems, Industrial & Applied Mathematics, Mechanical Engineering, and Systems & Control.
- TU Delft:
  Aerospace Engineering, Applied Mathematics, Applied Physics, Chemical Engineering (Molecular Engineering), Computer Engineering, Computer Science (Information Architecture or Software Technology), Electrical Engineering, Embedded Systems, Materials Science & Engineering, Mechanical Engineering, and Systems & Control.
- University of Twente:
  Applied Mathematics, Applied Physics, Chemical Engineering (Molecules and Materials), and Nanotechnology.



Henk Bodt Scholars on their first training day at ASML.

Information

irene.kroon@asml.com

31 October 2012, Utrecht (NL)
RoboNED Seminar

Since the Dutch Robotics Strategic Agenda has been received very positively, the next step of RoboNED is to implement the plans. This seminar will be the kick-off for creating consortia around four societal problems where robotics may contribute to a solution.

www.roboned.nl

8 November 2012, Den Bosch (NL)
Bits&Chips 2012 Embedded Systems

Eleventh edition of the conference on embedded systems and software. Last November, the event celebrated its tenth anniversary with over 600 participants and some fifty high-tech companies and organisations presenting themselves at the conference venue.

www.embedded-systems.nl

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

Twelfth edition of the Benelux premier trade fair on precision engineering. This year's theme is 'Unlimited opportunities in Precision Technology'. Some 250 specialised companies and knowledge institutions will be exhibiting in a wide array of fields, including optics, photonics, calibration, linear technology, materials, measuring equipment, micro-assembly, micro-connection, motion control, surface treatment, packaging, piezo technology, precision tools, precision processing, sensor technology, software and vision systems. The Precision Fair is organised by Mikrocentrum, with the support of DSPE, NL Agency, the Dutch Precision Technology association, and Dutch HTS, the gateway to the Dutch High Tech Systems industry.

www.precisiebeurs.nl

Impression of the Precision Fair 2011.
(Photo courtesy of Jan Pasman, Mikrocentrum)

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

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

www.euspen.eu

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

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

www.micronanoconference.nl

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

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

www.rapidpro.nl

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

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

www.lamdamap.com

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

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

www.hightechsystems.nl

Impression of Hightech Mechatronica 2012, the event on which the new High-Tech Systems event is to build. (Photo courtesy of Techwatch)

Course	CPE points	Provider	Starting date (location, if not Eindhoven)
Basic			
Mechatronic System Design (parts 1 + 2)	10	HTI	10 December 2012 (part 1) 5 November 2012 (part 2)
Construction Principles	3	MC	30 October 2012 (Utrecht) 20 November 2012
System Architecting	5	HTI	29 October 2012
Design Principles Basic	5	HTI	14 November 2012
Motion Control Tuning	6	HTI	20 November 2012
Deepening			
Metrology & Calibration of Mechatronic Systems	2	HTI	to be planned
Actuators for Mechatronic Systems	3	HTI	18 March 2013
Thermal Effects in Mechatronic Systems	2	HTI	11 March 2013
Summer school Optomechatronics	5	DSPE	24 June 2013
Dynamics & Modelling	3	HTI	3 December 2012
Specific			
Applied Optics	6.5 6.5	MC HTI	7 March 2013 30 October 2012
Machine Vision for Mechatronic Systems	2	HTI	27 September 2012
Electronics for Non-Electronic Engineers	10	HTI	8 January 2013
Modern Optics for Optical Designers	10	HTI	25 January 2013
Tribology	4	MC	30 October 2012 (Utrecht) 27 November 2012
Introduction in Ultra High & Ultra Clean Vacuum	4	HTI	29 October 2012
Experimental Techniques in Mechatronic Systems	3	HTI	9 April 2013
Design for Ultra High & Ultra Clean Vacuum	4	HTI	26 November 2012
Advanced Motion Control	5	HTI	7 October 2013

DSPE Certification Program

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

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

Course providers

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

Theme day - Organic and Printed Electronics

The combination of different techniques and materials in the area of organic and printed electronics is facilitating more and more new applications. The various widely ranging results of these new developments will be presented during a theme day to be held at Holst Centre on Eindhoven's High Tech Campus on 23 November 2012.

The examples of techniques, materials and products are only the tip of the iceberg when it comes to the myriad of new options. Increasingly stringent requirements on weight reduction, integration of functions, cost reduction, etc., have prompted the use of new techniques and materials and the development of new products.

Various speakers will present their knowledge and experience during this theme day. Where necessary, the underlying theory will also be addressed. At the same time, they will give delegates a glimpse of current and future developments in relation to techniques, materials and products, and combinations thereof.

More information

www.mikrocentrum.nl

The following innovations will also be highlighted:

- Smart Materials for Conformable Electronics (TNO/ Holst Centre)
- Inkjet / Surface modification (Fontys University of Applied Sciences)
- Organic Photovoltaics (ECN)
- Roll-to-Roll technology (TNO/Holst Centre)

Precision Fair 2012

The twelfth edition of the Benelux premier trade fair on precision engineering will be held on 28 and 29 November 2012 at the NH Conference Centre Koningshof in Veldhoven, the Netherlands. Specialised companies and knowledge institutions will be exhibiting in a wide array of fields, including optics, photonics, calibration, linear technology, materials, measuring equipment, micro-assembly, micro-connection, motion control, surface treatment, packaging, piezo technology, precision tools, precision processing, sensor technology, software and vision systems.

No less than 250 exhibitors will be present in Veldhoven. The Precision Fair also features a highly relevant lecture programme, the Technology Hotspot, with over twenty knowledge institutes from the Netherlands, Germany and Belgium, and an international Brokerage Event.

www.precisiebeurs.nl

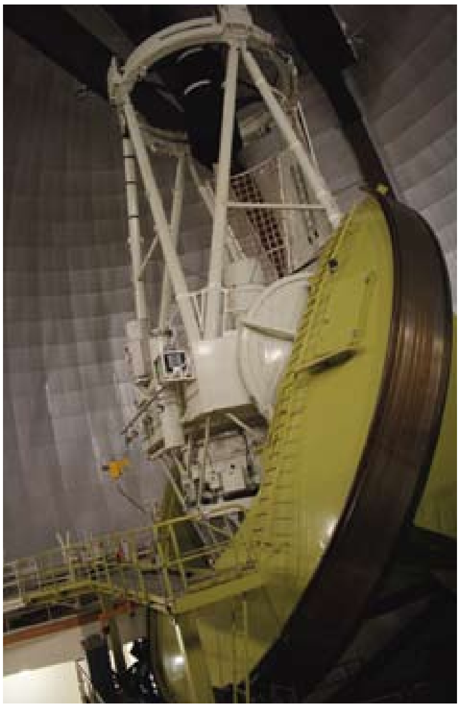
Impression of the Precision Fair 2011.
(Photo courtesy of Jan Pasman, Mikrocentrum)

Erratum Australian Astronomical Observatory

Unfortunately, the article “Tapping into Each Other’s Expertise” in the previous issue of Mikroniek contained an error regarding the concept of dF, degree field of view. The editor’s apologies to the Australian Astronomical Observatory.

The final paragraph should read:
The instrumentation programme has been a key factor in the AAO’s scientific success, producing innovative instruments that have powered the research programmes on the Australian telescopes, the AAT (3.9 metre Anglo-Australian Telescope) and UKST (1.2 metre UK Schmidt Telescope), and has provided access to other large telescopes such as the European VLT (Very Large Telescope) and the Japanese Subaru telescope in Hawaii. Instruments include, for AAT, the 2dF fibre positioner (to feed the light of individual stars into fibre-fed spectrographs, such as the AAOmega VPH grating spectrograph, and the soon to be delivered even larger, 4-channel HERMES spectrograph), and, for UKST, the 6dF fibre positioner (dF = degree field of view).

www.aao.gov.au



The Anglo-Australian Telescope, powered by AAO’s instruments.

Threading hardened ball screw nuts

During the AMB trade fair, Hembrug presented its Mikroturn® 100 Special, which uses a fully hydrostatic integrated torque motor spindle. This main spindle, which has a run-out accuracy of 0.1 μm, has a high torque and extreme stiffness, which generates optimum stability for the threading process.

During the AMB international exhibition for metalworking held in Stuttgart (Germany) from 18-22 August 2012, Dutch machine manufacturer Hembrug Machine Tools presented its latest developments in the field of finish hard turning, with a focus on threading hardened ball screw nuts.

Hembrug specialises in the engineering and construction of hard turning machines for the ultra-precision processing of hardened workpieces up to 68 HRC. Using hydrostatics for the main spindle and slides and constructing its machines on natural granite bases, this machine manufacturer’s Mikroturn® machine series is a cost-saving alternative to cylindrical grinding.
In addition to applications for bearing rings, hydraulic components and automotive parts, Hembrug has years of experience in threading hardened ball screw nuts. With its finish hard turning machines, Hembrug according to a press release, offers many advantages for this application compared to regular threading machines, because both the rough and finish threading of the hardened product can be done in a single clamping fixture with very high precision using the CNC pre-programmed contour. As such, a 1-2 μm pitch can be generated in a 24/7 process.

www.hembrug.com

Frencken extending

Frencken Mechatronics, a subsidiary of the Eindhoven-based high-tech supplier Frencken Europe, has extended its production area considerably. With an increasing demand for cleanroom production, the cleanrooms have been extended and, where necessary, their air quality class was upgraded, while all non-cleanroom activities have been moved to an adjacent building.

Frencken, which is celebrating its 65th birthday in 2012, will organise an open day next spring to present the extension to customers, employees and other interested parties. Optiwa, another Frencken Europe subsidiary based in Reuver, is also working on extension plans.

As supplier to international OEMs, Frencken Europe is active in the field of medical, semiconductor and analytical systems. In addition to the manufacture, assembly and testing of complex and advanced components, modules or even complete products based on fine mechanics, electronics and software, the company is also involved in product development. Frencken Europe is responsible for all business development, marketing, sales, development and engineering activities in the global Frencken Group, which has production sites in China, Malaysia, the Netherlands, Singapore and the United States.

www.frencken.nl

RoboNED Conference with Vision & Robotics trade fair in 2013

The 12th edition of the Vision & Robotics trade fair and conference will be held on 22 and 23 May 2013. The 2012 edition enjoyed a significant growth in visitor and exhibitor numbers and a successful collaboration with the RoboNED conference. According to a press release, the collaboration with RoboNED added more quality to the programme of lectures, resulted in a range of demonstrations and served as an impetus for joint ventures between the business community, universities and knowledge institutes.

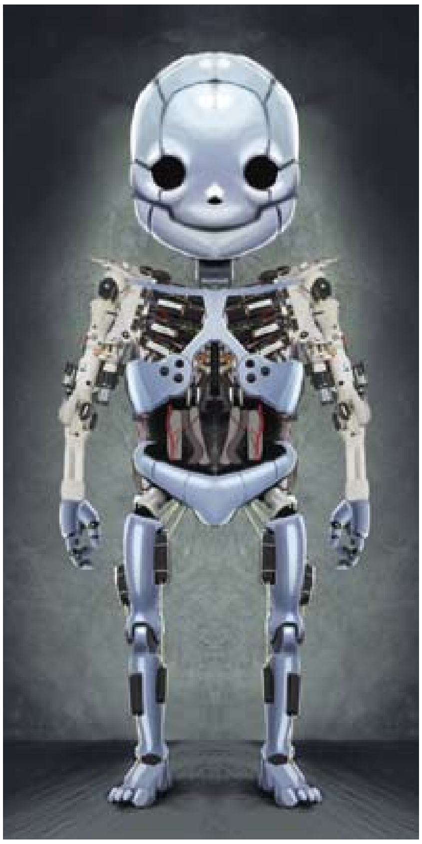
In addition to the existing comprehensive trade fair with industrial exhibitors and an industry-oriented programme of lectures, this makes Vision & Robotics the annual event for everyone in the Netherlands and Belgium active in the fields of vision, robotics and industrial automation. All parties involved, including visitors and exhibitors, saw the collaboration with RoboNED as a positive and valuable development, and this collaboration will be continued in 2013. A survey showed a preference for continuing the event in the same vein, possibly extended to include sensors, motion control, linear motion systems and, above all, mechatronics. The latter is not surprising, seeing as robotics is really a unique form of mechatronics.

In 2013, Vision & Robotics (or perhaps Vision, Robotics, Mechatronics) will focus more specifically on markets such as the agricultural and food industries, mechanical engineering and the metal industry.

www.vision-robotics.nl
www.roboned.nl

Impression of Vision & Robotics 2012. (Photo courtesy of Purple Vision)

Switzerland's first tendon-controlled humanoid robot



Roboy (right) is a further development of the technology used in the famous ECCE Robot (left).

A project team with experts from science and industry, including the drive specialist maxon motor, is developing a new humanoid robot, Roboy. On March 9, 2013, nine months after project start, Roboy will be presented to the public at the "Robots on Tour" international robotics fair that will take place in Zurich, Switzerland, as part of the 25th anniversary of the Artificial Intelligence Laboratory (AI Lab) of the University of Zurich.

Since June 2012, the project team has been busy implementing the latest knowledge in the field of robotics to create a new humanoid robot. Roboy will be 1.30 m big, with an anatomy and motion characteristics that mimic that of humans. With Roboy, the project team wants to show what topics are being researched in the field of robotics and which technologies are ready for series production. Roboy is a further development of the technology used in the famous ECCE Robot. Both robots are equipped with tendon-controlled drive technology, which gives the robots the ability to perform humanoid movements and to react to their environment.
In addition to the scientists of the AI Lab, international research groups from Germany and Japan are participating in the project. Furthermore it has the support of partner companies that are providing cutting-edge Swiss high-tech expertise. As main project partner, maxon motor is supplying numerous DC and EC motors, as well as sensors that enable Roboy to make high-precision movements.

The know-how generated as part of the Roboy project is freely available to researchers, robotics fans and people who are interested in technology. "With Roboy, we are defining a new development platform for humanoid robots that can and should be used and further developed by everybody", explains Prof. Rolf Pfeifer, initiator of the ambitious project. To make Roboy a reality by March 2013, the researchers need the support of partners and robotics fans. At the project website, everybody can take part.

www.roboy.org
www.maxonmotor.com

Third subsidiary: Nobleo Manufacturing

Technical consultancy firm Nobleo established its third subsidiary, Nobleo Manufacturing on 1 August 2012. Eindhoven-based Nobleo ('Noblesse oblige', Talent entails responsibility) has been operating in the market for eighteen months now and currently employs fifty staff. On top of the existing subsidiaries Nobleo Technology and Nobleo Bouw & Infra, the service for businesses has now been expanded to include a proposition for high-quality manufacturing projects. Nobleo Manufacturing focuses on such sectors as Medical, Automotive, Chemical & Materials, Printing & Equipment, Life Sciences, Semiconductors and Oil & Gas.

www.nobleo.nl

Mikroniek guide

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W www.ace.eu

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

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