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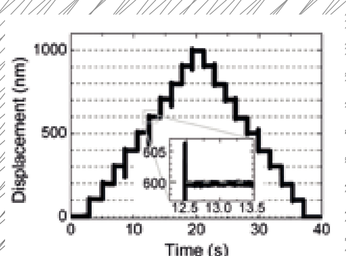
- **SYSTEMS ENGINEERING**
- **ULTRA-COMPACT** INTERFEROMETERS
- HIGH-TECH **MECHATRONICS** SYMPOSIUM
- EU **ROBOTICS** FORUM 2015



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IN THIS ISSUE

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FEATURES

TREND: SYSTEMS ENGINEERING

"Systems engineering is the science of analysing and designing technical and organisational systems, and is based on thinking in systems, processes and closed-loop control systems."

This is one of the definitions you will find if you search for the term Systems Engineering (SE) on the Internet. So it is about the correlations and patterns that occur. Can you identify, describe and control them? Further searches reveal that the definition is not limited to the product (or system) alone. SE effectively relates to the complete delivery of a product or service that meets a need based on a customer requirement. Naturally, functionality must always be weighed against difficulty and investment related to the customer request, budget and market requirements/desires.

The application of SE goes back generations and is certainly not limited to the High Tech market alone. The first Systems Engineer may have been Egyptian, Greek or Roman. These SEs *avant la lettre* delivered large, complex projects such as aqueducts, wastewater disposal, roads, irrigation, medicines, education, and so on. In short, a complete society with all the provisions designed and matched to the necessities of life – and that without computers or clean rooms. Their achievements served them well for a long time.

The great adaptation of SE took place after WWII in the defence industry as a way of tackling large complex systems in a more holistic manner. More and more technical educational institutions started incorporating it into their teaching programmes and an increasing volume of documentation, processes, manuals, procedures and courses was developed. Eventually, SE became an institute. In 1990, INCOSE (the International Council on Systems Engineering) was founded. Today, it has nearly 9,500 members – quite a few, but on the other hand still far too few. For years, SE remained limited to the large industrial firms within the defence and aerospace sectors in particular.

In the Netherlands, SE is becoming increasingly in vogue. There are lots of opportunities for applying SE within SMEs. What helps is the development of ever more powerful tools and methods that simplify an integrated approach. Models, many of them non-linear, which realistically reflect reality support systems thinking and enable trade-offs to be made quickly. The key terms are multidisciplinary, manufacturable, installable and serviceable. We are able to develop more cheaply and quickly, something the market has long been calling for. A trend, in other words!

Educators in the Netherlands have also discovered this trend, an interesting and positive development. For instance, the 3TU Federation (of the three Dutch universities of technology) offers a Systems & Control study programme. However, we still lag behind other European countries, with France and the UK leading the way.

As an industry, we are hungry for specialists in this field. A real systems engineer has broad training, preferably in multiple technical disciplines, is a good team player, is able to translate customer wishes into designs and make smart choices. That pretty much describes the ideal employee. And who wouldn't want to have one of those?

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MERGING PROCESS STRUCTURE AND DESIGN FREEDOM

Systems Engineering (SE) is a methodical approach to the development of new (high-tech) products. For a long time, SE has been considered too complex and unnecessary for application in small & medium-sized enterprises (SMEs). That is now rapidly changing. In 2012 a group of Dutch universities of applied sciences and companies started a so-called RAAK-MKB project to make the tools of SE more accessible for SMEs. At the same time these tools can be used for multidisciplinary student projects, to teach students how to approach the development of a new product.

RINI ZWIKKER AND JOS GUNSING

Introduction

Developing a new product is a beautiful but at the same time almost intangible cooperative process, in which customer, technology and business meet. Various fields of expertise speaking different languages must be merged. In this process there is a continuous alternation between creativity and analysis. A discussion or creative idea can lead to an entirely new solution. But a thinking error or simple miscalculation can make a nice idea fall flat. Cooperation is essential, but also a source of misunderstandings.

There is a common interest: realising a new product which successfully fulfils a customer's needs, and at the same time takes into account a number of constraints. But there will also be contradictions between the project contributors. One member wants to control processes and avoid risks, both financial and technical. Another member would like to keep on changing and improving, preferably up to the end of the design.

Systems Engineering (SE) can contribute to this process. It aims to provide sufficient structure, without limiting the design freedom unnecessarily. It can assure that all those involved, from manager to designer to marketer, start speaking the same language in order to unite the different interests. And it can assist in defining the functions, requirements and peripheral conditions in such a way that the new product really fulfils the user's needs.

This article gives an overview of the fundamentals of SE and its benefits, using a RAAK-MKB project as an illustration (see the box). Special attention is paid to the difference between the structure of the process, which is more or less unidirectional, and the actual way of working of the participants, which is more iterative.

AUTHORS' NOTE

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They both acknowledge the input and critical review by Henk Kiela, professor of Mechatronics and Robotics at Fontys UAS in Eindhoven, Erik Puik, professor of Microsystems Technology at HU UAS in Utrecht, and Joris van den Aker, Programme Manager at TNO-ESI.

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Furthermore, this article is a call to teachers involved in SE at universities of applied sciences to participate in the topic group that is now being formed, and to SMEs to come up with interesting cases for projects to be executed together with teachers and students, at the same time introducing the methods and tools in the organisation. Because only with the correct application of SE structure and innovation can combined – and serious – mistakes be prevented (see the box on page 7).

Definition

The INCOSE handbook 2004 [2] defines SE as: "An interdisciplinary approach and means to enable the realisation of successful systems." With 'systems' we mean complex machines, with 'engineering' the complete process of specification, design, manufacturing and test. In order to achieve that success the approach must fulfil a number of conditions.

The INCOSE handbook continues with: "It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements and then proceeding with design synthesis and system validation while considering the complete problem: operations, costs and schedule, performance, training and support, test, manufacturing and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs." The 'customers' include all stakeholders having an interest in the system, not only the users.

Where does SE fit?

A project consists of several sequential and parallel processes with various interactions in budgets, people, facilities, planning, risk mitigation and market information (Figure 1). Moreover, there are two different but highly complementary viewpoints on these same processes: project management (PM) and systems engineering (SE). PM primarily aims at controlling the process, while SE aims at steering the content of (design) choices.

The primary overlap between PM and SE is the planning. The project manager controls the planning and the budgets. The systems engineer gives input on the costs, the quality (requirements and verification of requirements) and the translation to the planning. The common interest of both

The RAAK-MKB project

RAAK-MKB is a Dutch government funding programme for universities of applied sciences to carry out applied research projects with – preferably – SME companies, teachers and students [1]. The acronym RAAK stands for Regional Attention and Action for Knowledge circulation, and MKB is Dutch for SME.

The RAAK-MKB project Systems Engineering for SMEs aims to contribute to the development of a toolkit with practical tools for the product development process, strongly connected to the (im)possibilities within SMEs. A second goal is to raise the knowledge level of teachers in the universities of applied sciences and as a spin-off the development of educational materials. The so-called V-model will be used as a basis, including the iteration loops.

Initiating partners of this project were the Research Centre for Robotics & Mechatronics (part of the Expertise Centre for Sustainable Innovation) of Avans University of Applied Sciences and Embedded Systems Innovation by TNO (TNO-ESI). Apart from Avans, leading the project, also active are the Fontys, HU and Saxion Universities of Applied Sciences and the companies CE Masters, Ceratec, CSi Industries, Demcon Advanced Mechatronics, ESWE Technics, Fontijne Grotnes, Focal Meditech, Holmatro, Hotraco, IBS Precision Engineering, Irmato Jentjens, LAN Handling Systems, MA3 Solutions, Mecal, MTA, Nieaf-Smitt (Mors Smitt), Philips Innovation Services, Q-Sys, Tegema, Vanderlande and Wijdeven plus the industry organisations FEDA and Brainport Industries. Contacts are meanwhile also being made with the universities of applied sciences of Arnhem and Nijmegen, The Hague and Windesheim plus several newly interested companies.

The project started in September 2012 and will end in September 2015. Introduction of SE in companies had a much bigger impact on the organisation than originally expected. The board, directly involved employees and other departments must be included in the process. Within universities of applied sciences, convincing teachers and boards, and setting up educational material in combination with suitable projects, is also taking more time than anticipated, but progress is there.

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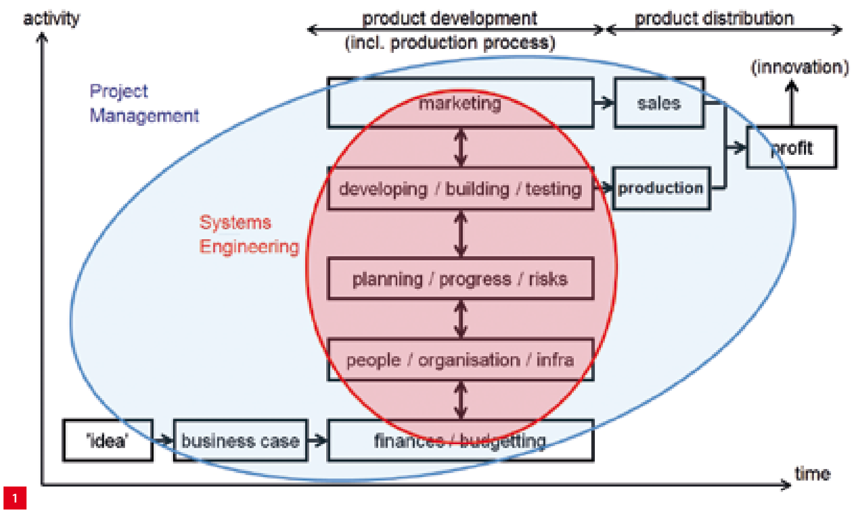


1 *Systems Engineering and Project Management as complementary processes.*

the project manager and the systems engineer in this process is to minimise project risks at the earliest possible stage.

PM includes more aspects than SE: business case, support staff, (after) sales, advertising and production. Setting up the production process is again a complementary interest of PM and SE, because of choices on production facilities, manufacturability and production costs. PM is not (or should not) be leading over SE or vice versa. Both are equally important to achieve a good result, commercially and technically.

Benefits and limitations

SE can be a powerful tool that creates clarity and understanding for the different phases of the product development process. It can increase its efficiency and effectiveness. It can support the development of a helicopter view for important decisions.

Examples of recent projects where serious and expensive mistakes were made

- The French aircraft carrier which was too short.
- The Fyra train (photo) which could not cope with snow.
- The French regional trains which were too wide for the platforms.
- The small Mercedes A which failed the moose evasion test.
- The Ariane 5 (photo) that crashed due to software copied from Ariane 4 without adaptation.
- The O-ring of a Space Shuttle booster fuel tank which could not cope with low temperatures.
- The iPhone antenna shielded by user's hand.
- Numerous car recall actions to correct errors with airbags, brakes or electronics.

The Fyra train. (Photo: Maurits90/Wikipedia)

Ariane 5 launch. (Photo: ESA/CNES/Arianespace)

2 *Examples of complex products that required multidisciplinary engineering from RAAK-MKB participants.*
(a) Palletizer (CSi Industries).
(b) Robot food packaging handler (LAN Handling Systems).
(c) Bead optimisation system (Fontijne Grotnes); the bead is the edge of a tire that sits on the wheel.

But SE is no substitute for solid technical knowledge, experience, understanding and creativity. It cannot match a close-knit team of professionals fully overseeing their assignment without documentation. It does not transform an engineer into an architect. It is no guarantee for a good cooperation. It is no cure for a lack of time, money, people and means. It does not automatically lead to an innovative and successful result.

Why SE?

Related to product development, there are a number of well-known trends that increase the need to explicitly use methods from SE, also for SMEs. Products have become more complex and multidisciplinary over the last decades (Figure 2). Requirements on functionality, safety, environment and energy increase. In contradiction, the time and costs of development must be reduced. Series become smaller, with product variants created by reconfiguration: from build-to-order (BTO) via engineer-to-order (ETO) towards configure-to-order (CTO). This fits well in Industry 4.0 / Smart Industry trends. Products are being developed by various cooperating teams, in parallel or in series. A chain of companies is often involved. Direct integration of standard modules must be possible. The legislator demands traceability of the development process. All these trends require a common information structure with associated data flows.

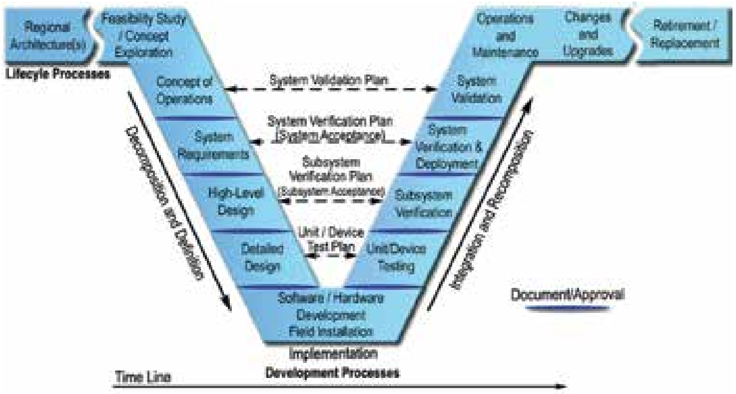
These issues were more than enough reason to step into the RAAK-MKB project for companies like CSi Industries, LAN Handling Systems and Fontijne Grotnes. Some of them have already been working with the SE concept for some time. One of the main conclusions in the early stage of the project was that organisational changes were necessary as well, such as setting the projects for module development (for CTO) more apart from the customer-specific system integration projects.

Even with a strong belief in SE, which most of the product engineers /developers involved have, it takes quite some time to set up SE-based ways of working. It has the character of a culture change. All the companies involved have a strong belief that adopting SE will give them a stronger position in the market, more employee work satisfaction (less reinventing the wheel, more time for real innovation) and as such will become more future-proof.

Different methods – one umbrella

Systems Engineering includes many different methods and tools to support the development process. The most well-known are Plan-Do-Check-Act (PDCA), the V-model, Agile, Spiral Design, Unified Modelling Language (UML), Methodical Design, ISO 2221, CAFCR, and the 3-Cycles Model; see Figure 3.

The methods available all have their own advantages and disadvantages, and are either more or less suitable for specific application areas, because all development projects are different: from simple to complex, from evolutionary to disruptive, from hardware-driven to software-driven. For software-driven projects the structure is often more cyclical, for hardware-driven projects more sequential: in software it is easier (and better for managing complexity) to add



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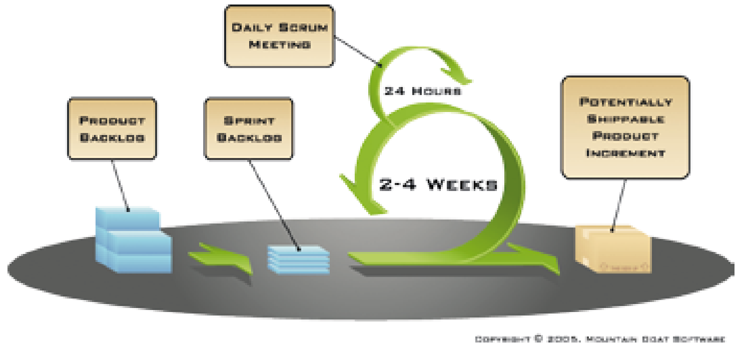

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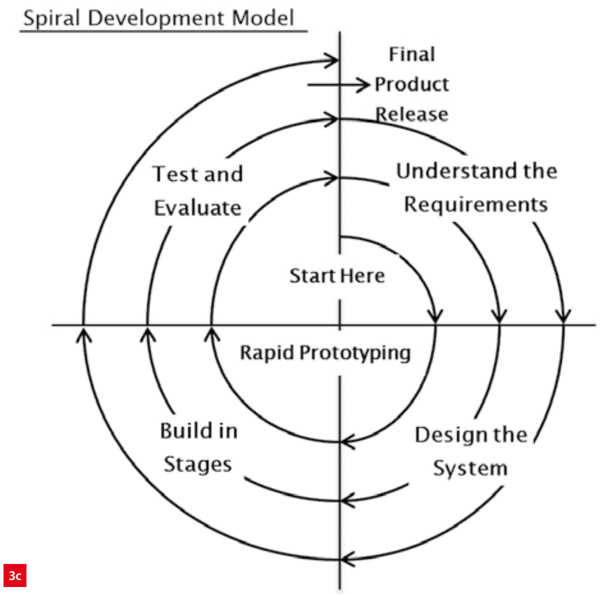

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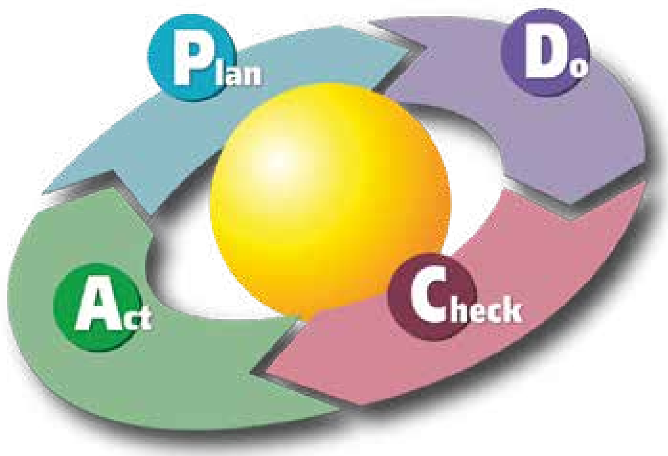

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3 *Various methods for Systems Engineering.*
(a) V-model [3].
(b) Agile [4].
(c) Spiral Design [5].
(d) PDCA [6].

modules or functions during development than in hardware.
This stepwise addition of functions is the basis of the Agile method. But all SE methods must allow a combination of sequential and cyclical processes, as will be explained below. Especially for multidisciplinary (mechatronic!) systems the challenge is to merge and align the different approaches.

Common phases

The goal of all methods is a more structured course of the development process, by dividing it into a number of phases with well-defined interactions. Four phases can be found in almost all methods.

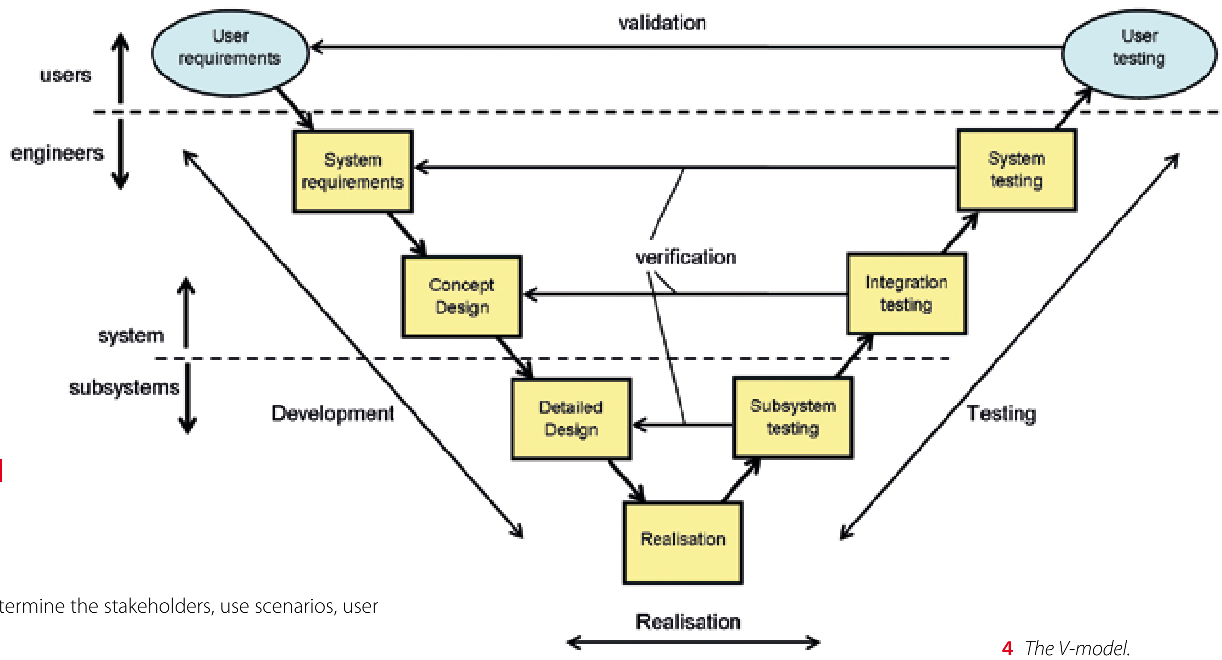
Phase 1 – Compilation of a consistent set of requirements

This starts with the user requirements: "What does the customer need?" These are the functions for the user process. Customers can often not yet formulate this precisely at the start of a new development. It is a time-consuming and iterative process with experiments, interviews, simulations and look-and-feel models to arrive at a consistent set of user requirements that is accepted by the customer and technology and business stakeholders. It is important to uncover the real user requirements together with the customer, and to formulate them at the right level of abstraction.

Partly in parallel with the formulation of the user requirements, the translation and extension to the system requirements needs to be done: "What must the product do?" This is also the transition from marketing to engineering. This set of requirements must be complete and consistent. Make sure they are formulated as SMART (Specific – Measurable – Attainable – Relevant – Time-bound). Formulate the constraints to the design as well: costs (of product, tools & project), legislation, conditions of use, production process, standardisation, design, etc. This is a very important phase in the development process, which strongly determines the result. Adaptations to the requirements still have a low impact on budget and planning, while the effect on the design can be high.

Phase 2 – Generation of a number of concepts

Several concepts are generated in a creative process and compared against a limited list of primary requirements.



4 *The V-model.*

- User requirements:
  What does the user need? Determine the stakeholders, use scenarios, user functions and constraints.
- System requirements:
  What must the product do? Determine system functions and constraints with testable requirements.
- Concept design:
  Generate and evaluate possible concepts; choose and elaborate best concept to proven feasibility.
- Detailed design:
  Design and dimensioning of chosen concept to component level of hardware, and module level of software.
- Realisation:
  From drawings, diagrams and software architecture to testable subsystems.
- Subsystem testing (verification):
  Test the behaviour of separate subsystems at their interfaces. Subsystems are often mono-disciplinary: mechanical, electronic, software.
- Integration testing (verification):
  Do the subsystems work together as intended?
- System testing (verification):
  Test functions and constraints of integrated system against requirements.
- User testing (validation):
  Are the needs of the user in his/her application fulfilled? This is also called acceptance testing.

Tools that can be used in this phase are a morphological overview and a table of comparison. Some calculations are often needed to prove the feasibility of a concept. The compliance with the other requirements needs to be checked. From this follows the choice of the most promising concept. This phase is closed by a concept design review, where the results are presented and discussed.

Phase 3 – Realisation of the design

The chosen concept is elaborated to a detailed design, and documented in models, drawings, diagrams and purchase specifications. The parts are purchased or produced with this documentation. All hardware is assembled. If something does not fit properly this is modified and the documentation is updated. Parallel to this hardware process, the software is developed and implemented, from modules to code.

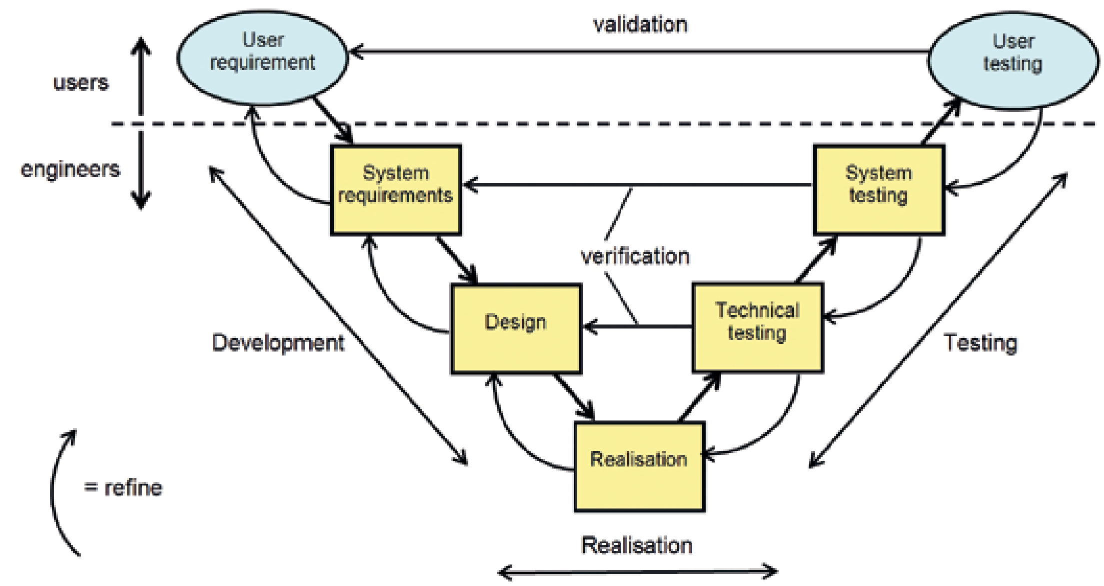
Phase 4 – Testing of the system with respect to the requirements

The subsystems are often verified first, then the complete system, and finally the validation in the customer process is done. Validation means determining the value of the system for the user.

The V-model

The V-model is a much-used and well-structured method for the development of products in which hardware (mechanical or electrical) plays an important role, like mechatronics. Figure 4 makes the name V-model directly clear. The left leg of the V is development, the lower end is realisation, and the right leg is testing. Moving downwards in the V means decomposition from system to subsystem to part level. The four basic phases mentioned above are included, with ‘Requirements’, ‘Design’ and ‘Testing’ divided into several blocks.

A strong advantage of the V-model compared to other methods lies in the horizontal relationship between the development of decomposed system elements and the acceptance criteria that are derived from the subsystem specification. These acceptance criteria will determine the acceptance of the subsystem before it is admitted in the next-level assembly. The other methods leave acceptance criteria more or less open. Practice of development of complex systems teaches us that anything that can go wrong on a subsystem level will be found once the system is assembled. Debugging at that stage can be costly, time-consuming and eventually disappoint the customer.



5 *V-model, with iteration loops between subsequent phases.*

Figure 4 shows nine blocks, with a separation line between the system and multiple subsystems. These subsystems are developed in parallel in the lower part of the V. Horizontal arrows indicate verification and validation. These compare the results at different levels with the requirements (verification) and the use (validation). In Figure 4, the arrows are drawn to the left to indicate the reference for the testing. INCOSE draws them either to the right or bi-directional (Figure 3a), but the meaning is the same.

The V-model has proven to be a successful method and is well-suited to get acquainted with SE for both SMEs and higher education. Every phase results in a specific intermediate product, which is very useful for planning and assessment of educational projects. However, there is a significant risk that the process becomes document-driven, which could hamper creativity and therefore innovation. The documents are a means, not a goal!

Sequential or iterative?

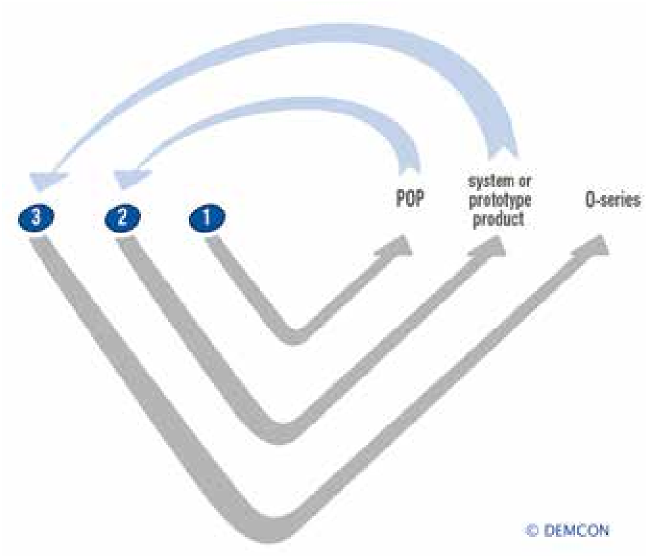
Here, a distinction has to be made between the structure and the way of working. The structure of the process described above appears to be sequential. It has a direction and a goal: from user need to product. It can be divided in a number of well-defined steps. This is the way of thinking of the manager. But the actual way of working of the engineer is more iterative. There must be room for an alternation between creativity and analysis. This especially applies to more innovative developments, where the outcome is more or less uncertain.

All SE methods must allow and merge this sequential and iterative thinking, to unite manager and engineer. In some methods, like Spiral Design (Figure 3c), iterations are the core of the process. An objection sometimes made against the V-model is that it is (too) sequential, which is actually not true: the V-model was initially conceived as a combination of the linear 'waterfall' model and the spiral model.

The validation and verification arrows form several inner loops, as shown in Figure 4, but actually doing a redesign must be avoided where possible. The smaller the loop, the better it is. Most loops even take place within a phase: one must often elaborate a solution to some extent to be sure it will fulfil the requirements. If not, one must take a step back and try something else. But iterations may also take place between subsequent phases, as shown in Figure 5:

- While determining the system requirements, it may be discovered that more information is needed from the customer.
- During concept design, it may be concluded that the system requirements are incomplete.
- During detailed design, flaws in the concept may be discovered and fixed.
- While documenting, it may be necessary to improve the detailed design.
- During production and assembly, the product documentation may have to be corrected.
- During testing, the assembly and integration may have to be optimised (also of the software).

A special note can be made on the fusion of Agile software development, which is a stepwise incremental approach [4], and the V-model. The subsystem development in Figure 4 consists of three steps: detailed design, realisation and subsystem testing. For hardware development the



6 *Triple V-model (Demcon [7]).*

'verification' arrow does not imply that a loop is made. This would happen only when such a large error was discovered during subsystem testing that it necessitated a (partial) redesign.

For a software subsystem these same three steps are named design – implementation – testing. And these can be very well repeated in a number of incremental loops according to the Agile principles, adding functions one by one, in parallel with one 'pass' of the hardware development. This is the way in which mechatronic development with the V-model is implemented at the mechatronics company Demcon [7].

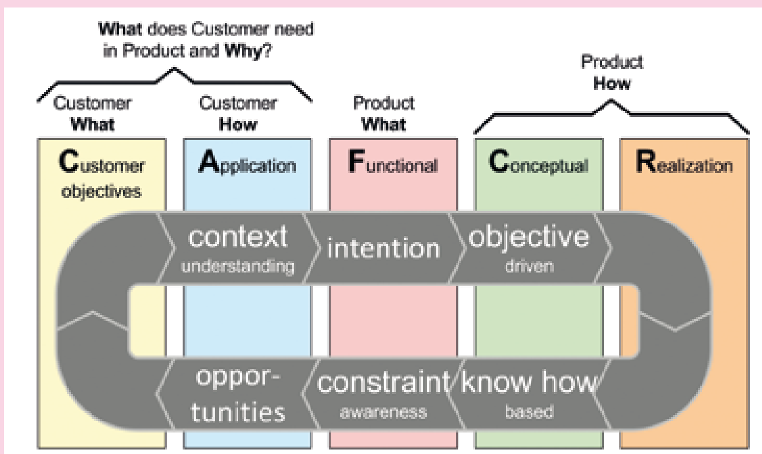
Taking the combination of iterative and sequential approach one step further, the complete V can be passed through several times (Figure 6). Especially for more innovative products this leads to the triple V-model [7], with proof-of-principle, prototype and 0-series. These can also be characterised as research – development – engineering.
In the first (inner) 'proof-of-principle' loop of the triple V-model the main goal is to prove the feasibility of the main function(s), in order to reduce the technical risks. Usually this is done with a laboratory set-up using standard components where possible.
When this has been successfully tested the second loop is entered: to build a prototype that incorporates all functions, requirements and design features of the final system as much as possible.
In the third and outer '0-series' loop some modifications from prototype testing may be made, changes may be made to improve manufacturability, and tooling for production and calibration is developed.
During the three loops the risks decrease, the number of requirements increases, the design freedom is reduced. This process can be depicted as three nested Vs for compact visualisation.

CAFCR

CAFCR is a method that has been developed by Gerrit Muller [8], connected to TNO-ESI. It is the acronym for the steps Customer – Application – Function – Concept – Realisation (Figure 7). It is, again, an iterative process that needs to be repeated a number of times during the definition phase to achieve a valuable, usable and feasible product. The functions defined in this loop are the pivotal point between the user (What?) and the product (How?).

It does not matter what the starting point in the loop is, as long as the correct chain of questions is asked. Who is the customer? What is his application? What is the function of the product in the application? With what concept(s) can this be achieved? Is this concept feasible? What are the constraints? Are there new opportunities?

This iterative CAFCR-process is a good method to determine a complete and consistent set of functions of the product that is to be developed, together with the customer. It also aims to find a set of key drivers for the use of the product. It uses techniques like interviewing, storytelling and creating use scenarios.



7 *The CAFCR-model (Gerrit Muller, TNO-ESI [8]).*

The aim must be to limit the amount of iterations as much as possible, and also the number of phases involved. Iterations between the loops in the triple V-model from outside inwards are certainly not desirable. It sounds contradictory, but a way to achieve this is to go through the complete development process up to the realisation several times in the mind during the determination of the system requirements. This is the essence of the CAFCR model of TNO-ESI; see the box.

SE in education

What becomes more important in enterprises must also get more attention in education. Working together in projects can only be learned in practice. Therefore the execution of group projects is becoming an increasingly important part of student training. Preferably, these projects should be performed by multidisciplinary teams, with students from different disciplines. This accounts in particular for students in mechatronics, who often form the link between mechanics, electronics and software engineering. SE will become a competence just as important as knowledge of, for example, machine components, programming and control engineering.

At all universities of applied sciences involved in the RAAK-MKB project, educational tracks are being set up in which working in projects is an important learning goal. This includes both Systems Engineering and Project Management. Tutorial material is being developed. By using this in student projects it can be improved iteratively. But the importance of this educational track is not yet recognised everywhere; better integration is necessary. ■

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"SCIENTIST, DESIGNER AND ENTREPRENEUR"

In late 2013, Henny Spaan received the Rien Koster Award under the auspices of DSPE for his work in precision engineering as a scientist, designer and entrepreneur. Anno 2015, his company IBS Precision Engineering, a specialist in metrology, keeps on developing and growing. This growth is autonomous, but at the same time Spaan is constantly looking for collaboration with researchers all over Europe, educational institutes and industry organisations. Meanwhile, he bemoans the demise of metrology as an academic discipline in the Netherlands.

HANS VAN EERDEN

AUTHOR'S NOTE

Hans van Eerden is a freelance text writer in Winterswijk, the Netherlands. He also is the editor of Mikroniek.

The Rien Koster Award is given to a mechatronics engineer/designer who has made a significant contribution to the field of mechatronics and precision engineering. In 2013, this award was presented to Henny Spaan (Figure 1). The jury valued the close collaboration with knowledge institutes and measurement institutes both in the Netherlands and abroad that Henny Spaan seeks when developing concepts for top-end measuring machines and calibration tools. They also valued his entrepreneurship creating jobs at both IBS and associated suppliers. Also, the jury set great store by Spaan's evident professionalism and commitment. Finally, he was a co-initiator of the Precision Fair, and has been actively involved in euspen (European Society for Precision Engineering and Nanotechnology) for many years.

1 *Henny Spaan (right) receiving the Rien Koster Award from the award's namesake. (Photo: Jan Pasman/Mikrocentrum)*

Mechanical engineer

Henny Spaan was educated in mechanical engineering and specialised in metrology. Although this discipline has some highly abstract features, he has preserved the practical application-oriented focus that characterises the true mechanical engineer. "I will always be a 'fietsenmaker' (a bicycle repair man, which is in Dutch the nickname for a mechanical engineer). At IBS we can give a rigorous theoretical substantiation of the measurement uncertainty, but we will also translate a client's measurement problem into a practical set-up. Over the years we have invested a lot in electrical and software engineering, but the majority of our engineers are still mechanical; in fact all our metrology experts are mechanical engineers by education who then specialised in metrology."

Networking

Besides 'application-oriented', other characteristics of Henny Spaan are 'open' and 'collaborative'. Throughout his career, he has been a keen participant in industry organisations such as DSPE, euspen, ASPE (American

Society for Precision Engineering) and CIRP (International Academy for Production Engineering), and networking events like the Dutch Precision Fair, of which he was a co-initiator, and euspen events such as the international conference and Lamdamap.

"It's inspiring for my people to attend such meetings and it brings us a lot of contacts. For example, without the contacts in our worldwide precision engineering network we would not have been able to construct our showpiece, the Isara coordinate measuring machine. Just think of the ceramic products, the zerodur material, or the lasers. In the Netherlands alone we would not have succeeded. The same applies to new developments such as our optical inspection tools. Their realisation requires a worldwide supply and co-development."

Education

Henny Spaan also sets great store by collaboration with educational institutes. In 2014, he instigated a partnership between IBS and Teclab, the Eindhoven-based supplier of specialised engineering training courses at Intermediate Vocational Training level 4. Through this partnership Teclab teachers and instructors learn about the latest in advanced measuring techniques, which they then pass on to the students.

2 *Demonstration by Henny Spaan during the joint IBS-Teclab seminar in September last year. Photo: Teclab*

In a joint effort Teclab and IBS organised a workshop that took place in September 2014 on 5-axis machine tool accuracy and compensation, ISO standards & CAD/CAM software (Figure 2). The day had an international character with participants from Japan, Korea, China, USA and Canada. This in addition to guest speaker Eric Marsh from Penn State University in the USA. The seminar provided the participants with key knowledge and understanding on how to measure and improve their machine tool precision and ultimately improve product quality and reduce costs.

Metrology in academia

The Teclab case shows that Spaan does not limit his educational contacts to academia. Talking about universities, he is worried about the status of precision engineering at his alma mater, the TU/e: "With the Brainport Eindhoven region being the heart of the Dutch high-tech, high-precision ecosystem, it shouldn't have happened that the TU/e shifted its focus to nanotechnology while leaving precision engineering practically uncovered." IBS has continued to collaborate with the TU/e on areas such as the initiative for an Advanced Thermal Control consortium and wireless communications. Further, they hope that the new High Tech Systems Center will provide a renewed focus on precision engineering challenges.

Of even greater concern to Spaan is the future of 'his' discipline, metrology, at the (three) Dutch universities of technology. "With IBS we are one the few companies in the Netherlands involved in metrology, besides Mitutoyo (the Research Center Europe in Best, near Eindhoven, ed. note) and the national metrology institute, VSL. When Piet Schellekens, my dissertation advisor, left the TU/e, the

Henny Spaan

Henny Spaan (Eindhoven, 1967) graduated from Eindhoven University of Technology (TU/e) with a measurement technology project. He went on to do doctoral research with Prof. Piet Schellekens into improving the precision of a milling machine by way of software compensation, and he obtained his Ph.D. in 1995. Two years earlier, he had founded IBS Precision Engineering to market this software compensation.

His company was originally located in TU/e offices, but moved to Best in 1998 and settled in Eindhoven in 2004. Using milling machine software as a starting point, Spaan developed software for measuring machines. This led to him developing and producing complete measuring machines and eventually precision modules building a customer base all over the world. On the way, a range of products for precision measurement and motion control emerged.

In accordance with Spaan's business philosophy this growth has been realised autonomously, without takeovers, so that IBS can remain financially independent. For international sales IBS works via its own offices in Germany and France and sales agents in multiple countries.

For six years Spaan was a member of the executive board of euspen (European Society for Precision Engineering and Nanotechnology). As president of euspen from 2009 until 2011, he put a lot of effort into bringing precision engineering professionals from industry and academia closer together.

IBS Precision Engineering

"Zonder nauwkeurig meten geen realisatie van een nauwkeurig ontwerp" – Without precision measurement, no precision design can be made real. This was the statement of the Rien Koster Award jury in their accreditation to the 2013 winner, Henny Spaan.

At the heart of all that IBS Precision Engineering does is the central belief that many precision engineering challenges depend critically on metrology expertise. For over 20 years, IBS has been delivering customers ultra-precision measurement and engineering solutions built on such expertise. Today, IBS products and custom solutions can be found at leading companies and institutes all over the world in a variety of industries, ranging from data storage and semiconductor equipment to printing and aerospace systems.

As a strategic engineering partner to the world's best manufacturing equipment and scientific instrument suppliers, IBS has maintained a focus on proven and robust precision solutions. IBS delivers custom measurement machines, tailor-made tools and test rigs and ultra-precision modules, with a focus on world-beating design and build. Where large-volume production is required, transition to tier-1 suppliers is also managed by IBS.

IBS products focus on ultra-precision measurement and motion control (Figure 3a). Components, such as porous media air bearings, are increasingly used in ultra-precision production and research systems. They enable enhanced image resolution in computed tomography through to contactless transport in roll-to-roll manufacturing. Measurement sensors with picometer resolution is another example; applied from servo controls for scanning electron microscopes to production quality controls for the latest disk drives.

With a long history in machine tool products, IBS today delivers measurement systems that have transformed the speed and measurement capability for the quality control of machine tool geometrical accuracy (Figure 3b). Leading manufacturers, from aviation to the medical market, have adopted this as their standard, for up to 5-axis.

WWW.IBSPE.COM

3 *IBS products.*
(a) The Isara 400 ultra-precision coordinate measuring machine features a traceable measurement uncertainty proven to within 11 nm.
(b) One of the family of six machine tool inspection and analyser solutions, the Rotary Analyzer, for analysis and diagnostics of 5-axis machine tools.

3a

3b

university did not continue the metrology chair. As a consequence we shifted the focus of our collaboration to Delft University of Technology (TU Delft). But now that Rob Munnig Schmidt has gone into retirement from TU Delft as professor of Mechatronic Systems Design, specialising in metrology (read the report of his farewell symposium in this Mikroniek issue, ed. note), there is no professor of metrology left in the Netherlands."

"It's downright outrageous", Spaan continues. "Our country is leading in high-tech, but without metrology a company like ASML cannot build any machines. The accurate measurement of positions, velocities and accelerations and the smart feedback of this information to the control unit is a key competence of our high-tech systems industry. As an entrepreneur, I enjoy working with academics and I hope to see a new metrology-focused professor in place soon with whom we can collaborate."

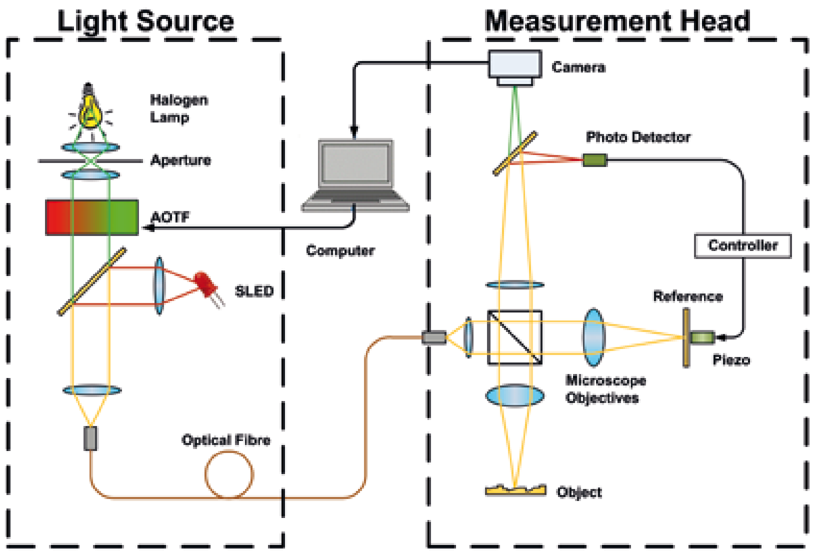
International research

Because of the limited academic basis for metrology in the Netherlands, IBS has primarily been engaging in international research projects, for example within the framework of the European Metrology Research Programme, which is coordinated by the European Association of National Metrology Institutes. Within this platform, they still have been able to continue partnering with the Dutch metrology institute VSL.

IBS has close ties with foreign universities, for example in Germany with the RWTH Aachen and the Friedrich-Schiller-Universität Jena, and in the UK. One recent result of IBS's international research collaborations is a wavelength scanning interferometer (WSI) for fast areal surface measurements of micro- and nanoscale structures, which was developed in a joint project with the University of Huddersfield (UK).

In the WSI (Figure 4) a broad-band light source combined with an acousto-optic tuneable filtering technique is used to generate a sequence of filtered wavelengths, from which a sequence of interferograms is measured. By using this set of interferograms, a height map of (discontinuous) areal surfaces can be produced by using the known phase shifts. Excluding the need for a mechanical scanning process makes the system more suitable for integration.

An active servo system is used to control the optical path length difference between the object and reference. This serves as a phase-compensating mechanism to eliminate the effects of environmental noise. Using this vibration compensation, the requirements on construction and environmental conditions can be relaxed. This makes it



4a

4b

4 *Design of the wavelength scanning interferometer (WSI).*
(a) Schematic layout of the set-up.
(b) Prototype of the measurement head.

possible to use a high-end system for online or in-process measurements on a shop floor. Measuring traceable step height specimens, the system achieves uncertainty within the nanometer range. The measurements, under mechanical disturbance, show that the system can compensate for environmental noise.

Trends

As an entrepreneur, Spaan has always enjoyed the challenge of new directions. According to him, next generation manufacturing provides opportunities for IBS to bring their engineering skills to new platforms. A good example is their work on the European project Clean4Yield. This project

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5 *A contactless web cleaning system developed by IBS.*

targets contamination and defect control in roll-to-roll organic electronics production – ensuring high enough yields for cost-effective manufacturing. To this end, the partners are developing new technologies for inspecting, cleaning and repairing moving foils, and detecting and preventing defects in large-scale roll-to-roll production of OLEDs and OPVs.

As a consortium member, IBS has been responsible for the novel development of air bearing technologies for contactless roll-to-roll transport with ultra precision positioning control. IBS has also developed a contactless web cleaning system for particle removal from foils for next-generation printed electronics (Figure 5).

For in-line detection, IBS developments in optical interferometry aim at fast and high-precision areal surface measurements suitable for particle measurement on foils as well as stepped and freeform micro-nanoscale structures. Examples include films used in the production of packaging materials, flexible solar panels, lighting, digital signage and displays.

As the complexity and precision of machine tools has increased, traditional methods of measuring their performance are failing. Meanwhile, demands from customers for qualification of the machine within the manufacturing chain are increasing. IBS is pioneering new technology to address the four limitations of current techniques: automation, dynamic measurement, speed and continuous monitoring. In a joint project with high-tech supplier KMWE, IBS is introducing a machine tool inspection system which tackles each of these roadblocks while allowing for machine certification.

These examples just go to show that Henny Spaan, the 2013 Rien Koster Award winner, still has much he wishes to do in his chosen field, high-end manufacturing and metrology. ■

THE CONNECTING POWER OF SYSTEMS ENGINEERING

The development of a tool for installing connectors on optical fibres, which is a delicate task, posed a number of challenges. The tool will be used by unskilled operators and many of the processes that were previously performed manually had to be reinvented completely for automated operation. The case of the so-called Light Plug Tool demonstrates the power of the Systems Engineering approach.

SJOERD LIGTHART, OTMAR KLAAS AND MARTIJN DE WITTE

AUTHORS' NOTE

Sjoerd Ligthart is Mechatronic Systems Engineer, Otmar Klaas is Industrial Design Engineer, and Martijn de Witte is Project Manager. They all work with Demcon, a high-end technology supplier with headquarters in Enschede, the Netherlands.

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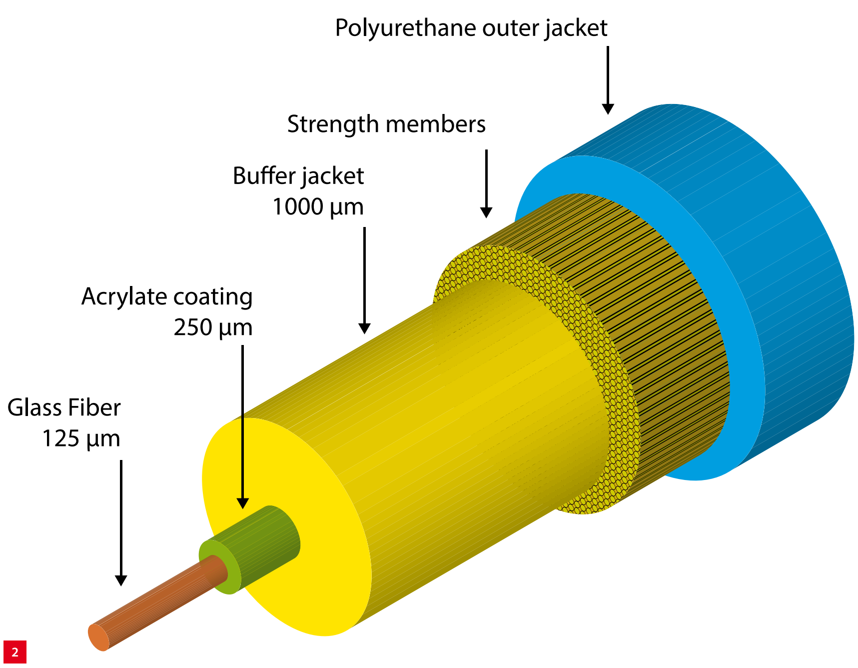
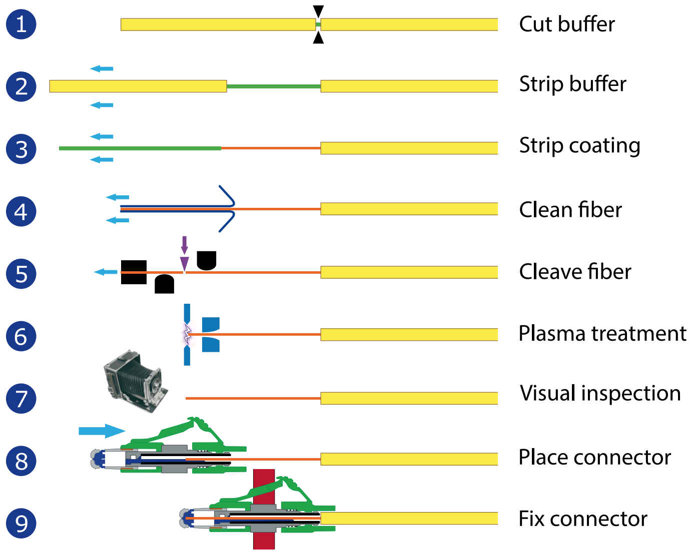
Installing connectors on optical fibres is a delicate task. Operators need many tools and advanced skills (see Figure 1), and the process is very sensitive to errors. Therefore, TE Connectivity took the initiative to create an EU subsidised consortium named VECTOR for development of an optical connector which allows for automated installation in the field. Within this consortium, Demcon Advanced Mechatronics is responsible for developing a tool that installs these connectors on optical fibres.

The development of the tool posed a number of challenges, namely (i) the tool has to be used by unskilled operators and (ii) many of the manual processes had to be reinvented completely for automated operation in the tool. Different fields of expertise, such as system design, mechanics, electronics and software needed to be very closely integrated.

1 *Current working conditions for skilled operators to perform optical fibre connector placement.*



2 *Optical fibre layout.*



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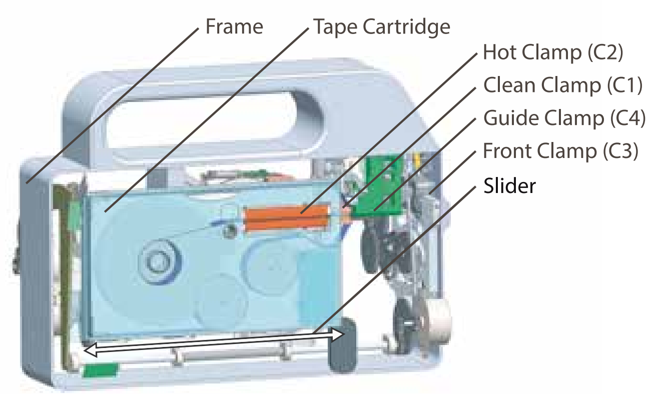

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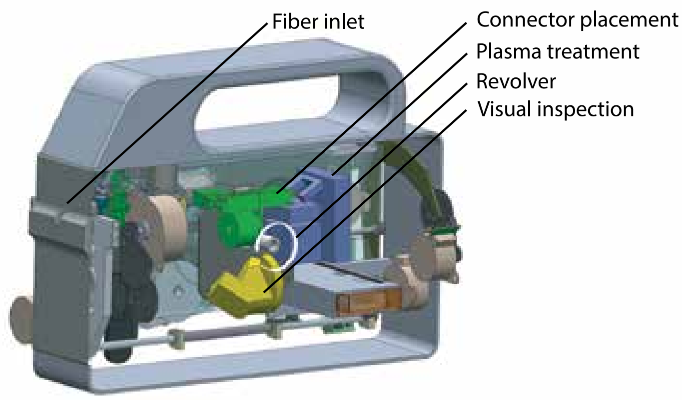

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Fibre connector placement

Current glass fibres consist of a silica core, which transmits the data, surrounded by a silica cladding of a different refractive index, which enables total internal reflection. Several protective outer layers can surround the glass fibre, such as an acrylate coating, a buffer jacket, additional strength members and a polyurethane outer jacket, see Figure 2. The strength members act as strain relief, the outer jacket acts as mechanical protection layer.

Removing the outer layers up to the buffer jacket is relatively straightforward. However, to strip and process the fibre from buffer jacket to the glass fibre requires additional skills and is prone to variability when performed by an operator. The automated tool is therefore intended to handle all necessary process steps from 1,000 µm down to 125 µm. An overview of the process steps involved is shown in Figure 3.

3 *Overview of the optical fibre connector placement process.*

4 *Schematic drawings of the tool with key stations highlighted.*
(a) The slider with tape cartridge for debris removal and four clamps for fibre fixation.
(b) The revolver containing plasma station, visual inspection and connector placement.

First, the buffer and coating are cut and stripped from the glass fibre. An additional cleaning step is integrated to remove any remaining coating particles larger than 10 µm. A cleave process then creates a flat facet on the tip of the 125 µm fibre. After cleaving, the fibre tip is plasma treated. In this process a surface treatment of the bare glass fibre is performed that reduces surface roughness and removes any debris from the cleaving process. Next, an optical inspection is performed to verify correct execution of the above steps. Finally, the connector is placed and fixed to the fibre using heat shrink fixation.

Tool challenges

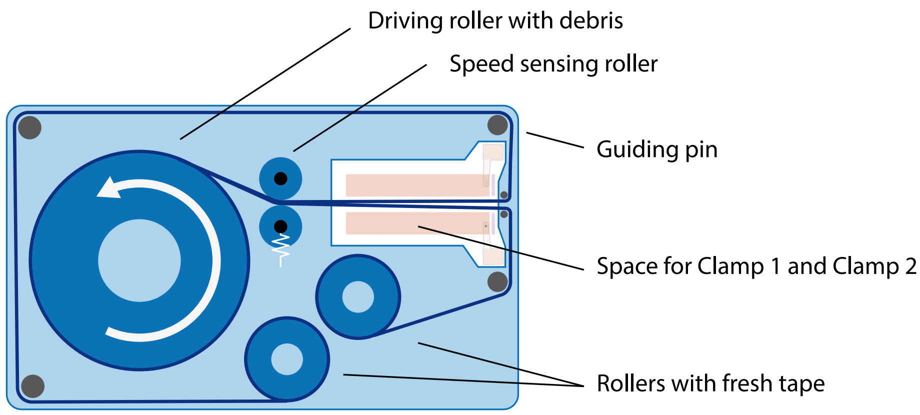
The process described above raises a number of challenges. Apart from the number of functionalities that should be integrated into a tool the size of a small shoe box, the functionalities need to be very tolerant to input variations as well.

In line with the design philosophy for the tool, the process cannot rely on expert user input and is designed to run without prior knowledge about the type of fibre that is inserted. These fibres can differ in diameter from 200 to 1,000 µm. They can have one or multiple layers of coating, which can be tightly or loosely bound to one another. The coatings can consist of different materials and can have different thicknesses.

European VECTOR project

VECTOR (Versatile Easy installable Connector implementing new Technologies for accelerated fibre Optic network Roll-outs in Europe) is a partnership between European universities and the telecom industry with the aim to conduct research activities for development of a field-installable optical fibre connector tool. The tool is intended to be hand portable and has all required processing on board to make an optical fibre connection without assistance by the field engineer. The system will greatly accelerate the deployment of extended fibre optic networks.

WWW.VECTORFP7.EU



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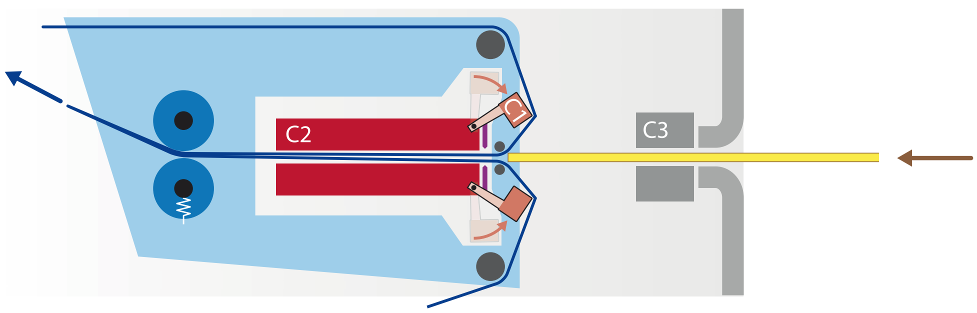

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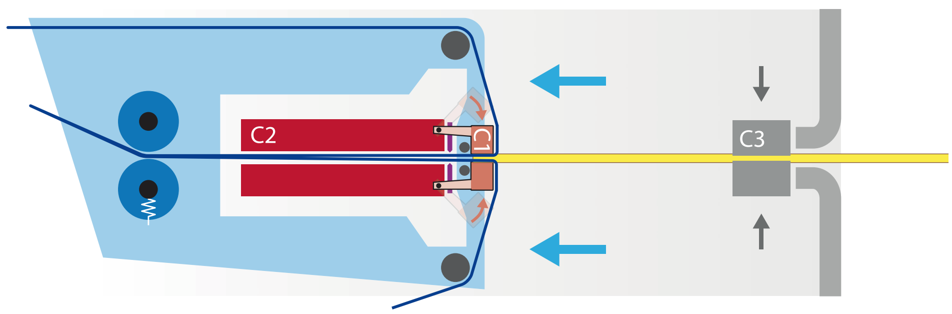

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5 *Schematic representation of the waste bin. Two layers of tape form a tape sandwich that can transport debris to the driving roller.*
6 *Process of fibre insertion.*
7 *Process of fibre infeed.*

Another challenge is to ensure that the exact location of the fibre is always known to guarantee that all processes are correctly aligned with the 125 μm diameter glass fibre. In fact, the total tolerance chain of the different processes should not exceed 100 μm when the fibre is positioned in the connector.

Last but not least, debris is produced in various process steps such as stripping, cleaning and cleaving. Accumulated over the lifetime of the tool (targeted at 20,000 connector placements), this fine glass debris could damage the internal mechanics of the tool and should therefore be disposed of in a controlled manner.

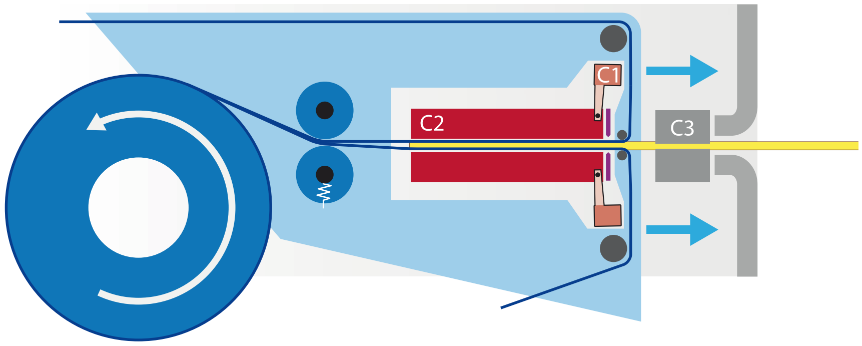
Layout of the tool

The overall layout of the tool is shown in Figure 4. The main processing part of the tool is a slider plus revolver. The slider contains stations for cutting, stripping, cleaning and debris removal. The revolver contains the stations for plasma treatment, visual inspection and connector placement. One station is then still missing, the cleave station, which is integrated in the front of the handle.

The design of the tool required a high degree of process optimisation, mechanical iterations and testing. Each step brought its own challenges and specific solutions, of which a few are highlighted in the next paragraphs.

Fibre debris removal

The chosen solution for debris removal is a consumable that acts as a waste bin, see Figure 5. The waste bin consists of two supply rollers that form a tape sandwich in between a series of clamps. Any debris that is produced is safely transported to the debris roller. Apart from the transportation of waste, the tape cartridge is fully integrated in the different process steps as detailed below.



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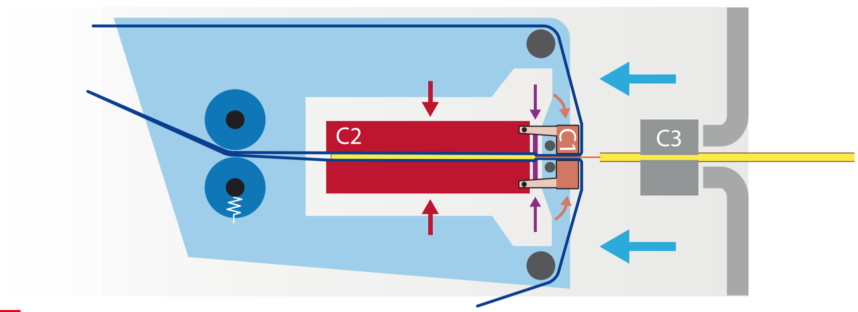

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Fibre processing

The tool features just one button. Once pressed, the process starts with the tape cartridge being positioned in front of the fibre entry clamp C3, as shown in Figure 6. The fibre is inserted by the operator and its presence is detected by the tool.

After the fibre is detected, clamp C1 closes around the fibre. As the fibre is grabbed through the tape, no grease or sand remnants on the fibre can come into contact with the internal mechanics of the tool. The tape cartridge then draws the fibre in, such that the insertion length does not depend on the operator, see Figure 7.

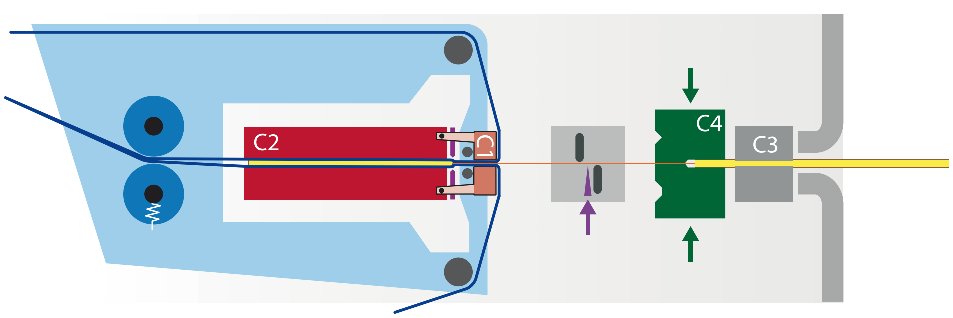
8 *Process of centering the fibre by tape spooling.*
9 *Process of stripping and cleaning. The cutting blades are located between clamps C1 and C2 (purple arrows).*
10 *Process of cleaving. Guiding clamp C4 aligns the fibre (green arrows), which is then cleaved (purple arrow).*

Now, the tool adopts a strategy of "once grabbed, never let go" by closing the front axial fixing clamp C3. This clamp exerts enough force to hold the inner glass fibre through the various layers of coatings and thicknesses. This axial reference is maintained during the entire fibre process; the next time clamp C3 opens, the fibre connector will have been placed.
Next, the tape cartridge moves forwards while the tape continuously moves backwards. This process ensures that the fibre continuously slips within the tunnel of tape formed by the clamps C2. This prevents puncture of the tape by the fibre and straightens it for subsequent steps, see Figure 8.

With the fibre centred in between the series of clamps, the actual connector placement process starts with stripping the outer coatings from the glass fibre. As the unstripped fibre can have any diameter between 200 μm and 1,000 μm, the force required to cut down to 125 μm can vary so much that it could damage the glass fibre. Therefore, the cutting blade is heated to facilitate cutting and melting through the different coating layers, see Figure 9.

During stripping, clamp C2 is also heated to reduce the adhesion force of the coating to the glass fibre and to enable a more homogeneously distributed shear force. Both serve to further improve a safe removal of the coatings without damaging the glass. The tape sandwich prevents molten buffer from coming into contact with the internal mechanism of the tool. In the same process step, a cleaning action is performed by clamp C1 to get rid of any coating remnants and to make sure that the tool gets an immediate hold on the stripped glass fibre once revealed.

Next, a guiding clamp C4, capable of grabbing both remaining buffer and stripped glass fibre, is lowered from the top of the tool to align the fibre (see Figure 10). The cleave station is lowered from the front of the handle and



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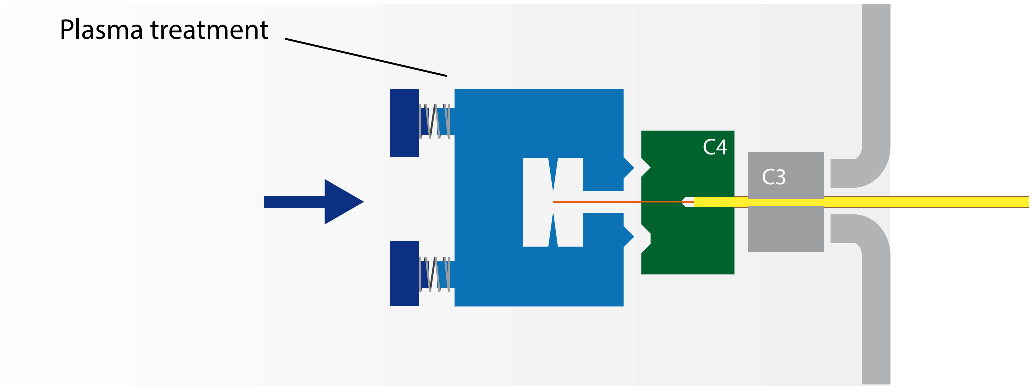

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cleaves the glass fibre in two pieces, hereby creating a flat surface on the tip of the fibre required for good optical transmission performance. The tape cartridge gets rid of the waste glass still between its clamp C1.

Alignment

After cleaving, the fibre tip is hanging free in the air and its location is solely determined by the guiding clamp C4. The next challenge is to carefully align all other functional modules on the revolver (plasma station, optical inspection and connector placement) with respect to the fibre tip.
The chosen solution is a docking principle: the modules are connected by springs to the revolver and are gently pushed against three docking features on guiding clamp C4, see Figure 11. By retracting and rotating the revolver, this principle is repeated for every process station on the revolver.

Connector placement

In the final step of the process, the connector is placed on the fibre by using heat shrink technology. This technique is chosen as it can cope with the entire range of diameters (200 to 1,000 µm) and provides a good holding force on both the bare glass fibre and the coating, which is important if those are loosely bound together.
Once all process steps are completed, the tool signals the operator that the connector placement process has been completed successfully and the fibre may be removed.

Conclusion

Currently, all the different processes have been successfully tested and the first fully functional tools have been realised (see Figure 12). Within the VECTOR project, these tools will be used by the telecom partners to gain experience in the field. ■

11 *Docking principle schematically shown for one of the revolver stations (plasma treatment).*
12 *VECTOR Installation Tool.*

12

UPCOMING **EVENTS**

21 May 2015, Rotterdam (NL)

Aquatic Solutions Conference

The conference, jointly organised by maxon motor and DFKI (German Research Center for Artificial Intelligence), focuses on electrically actuated underwater solutions. Topics include inspection robotics and pressure-tolerant control electronics.

WWW.ASC-CONFERENCE.ORG

1-5 June 2015, Leuven (BE)

Euspen's 15th International Conference & Exhibition

This event will once again showcase the best international advances in precision engineering fields such as additive manufacturing, medical products, micro-biology, nano & micro manufacturing, metrology, mechatronic systems & control, renewable energy technologies and ultra-precision machines.

Topics:
- Important/Novel Advances in Precision Engineering & Nano Technologies
- Nano & Micro Metrology
- Ultra Precision Manufacturing & Assembly Processes
- Renewable Energy Technologies
- Ultra Precision Machines & Control

Euspen Conference venue, the University Hall in Leuven.

WWW.EUSPEN.EU

3 June 2015, Eindhoven (NL)

Bits&Chips Software Engineering

Conference on complex software development, organised by Techwatch.

WWW.HIGHTECH-EVENTS.NL

3-4 June 2015, Veldhoven (NL)

Vision, Robotics & Mechatronics 2015 / Photonics 2015

Combination of two events organised by Mikrocentrum, featuring the RoboNED conference and the PhotonicsNL conference as parallel events.

WWW.VISION-ROBOTICS.NL
WWW.ROBONED.NL
WWW.PHOTONICS-EVENT.NL

8-12 June 2015, Eindhoven (NL)

International Summer school Opto-Mechatronics 2015

Five days of intensive training, organised by DSPE and The High Tech Institute, with content partner Mechatronics Academy.

Summer school Opto-Mechatronics
Precision Technology

WWW.DSPE.NL/EDUCATION/SUMMER-SCHOOL-OPTO-MECHATRONICS

11 June 2015, Delft (NL)

Dutch Graphene Conference 2015

Second edition of the conference, organised by Mikrocentrum at Delft University of Technology, devoted to the progress in realising graphene technology and graphene-based electronic, sensor and membrane functionality.

WWW.DUTCHGRAPHENECONFERENCE.NL

8-10 July 2015, Golden (CO, USA)

ASPE 2015 Summer Topical Meeting

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

ASPE.NET

17-21 August 2015, Leiden (NL)

LiS Academy Summer School Manufacturability

Summer school dedicated to the manufacturabilty of precision components and targeted at young professional engineers with a limited knowledge of and experiences with manufacturing technologies and associated manufacturability aspects.

The Summer school reader.

WWW.LISACADEMY.NL

18-19 November 2015, Veldhoven (NL)

Precision Fair 2015

Fifteenth edition of the Benelux premier trade fair and conference on precision engineering, organised by Mikrocentrum.

WWW.PRECISIEBEURS.NL

MIXED EMOTIONS – BETWEEN **CONTROL** AND **CREATIVITY**

On Friday 6 March 2015, the auditorium of Delft University of Technology provided the stage for a farewell and a welcome. Rob Munnig Schmidt retired as professor of Mechatronic System Design, whereas Just Herder delivered his inaugural lecture as professor of Interactive Mechanisms and Mechatronics. So the "High-Tech Mechatronics in (e)motion" symposium was a day of mixed emotions, which featured charming demonstrations of music (reproduced by mechatronics-based audio) and mechanisms.

Control

Georg Schitter, professor of Industrial Automation, Vienna University of Technology, kicked off the symposium by recalling his (short) time as an assistant professor in Rob Munnig Schmidt's group in Delft, especially the discussions on the extensive use of mathematics and equations. "Rob was a master in back-of-the-envelope calculations. What I learnt from him was a deep understanding of the physics of the problem at hand. Whenever physics becomes useful, he would say, we call it engineering."

1 *The coming and the going man: Just Herder (left) and Rob Munnig Schmidt. (Photos: Oscar van de Ven)*

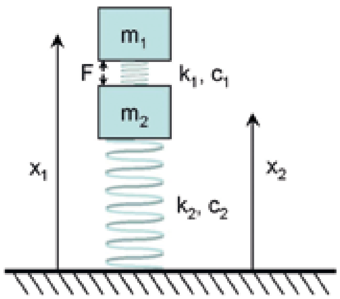
Schitter's presentation was on control in mechatronic imaging systems, such as lithography machines and atomic force (AFM), scanning probe or optical microscopes (see Figure 2). He showed some impressive results of the application of control theory, for example sliding mode control (SMC), iterative learning control (ILC) and model-based filtering. A highlight was provided by the results of 'live' AFM imaging of, for example, biopolymers or a silicon device. Imaging rates of nearly 4,000 lines per second were attained at resolutions in the order of 256 x 128 pixels.

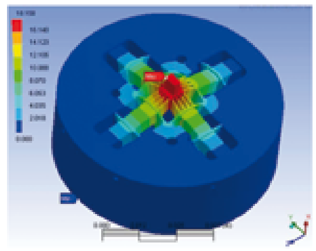
To conclude, Schitter argued that mechatronic system design (to a considerable extent based on conceptual models: 'understanding the physics') and modern control engineering (with its advanced mathematical framework) combine as key factors in achieving high-precision and high-speed performance.

Creativity

Jan van Eijk, founding director of MICE (Mechatronic Innovation & Concept Engineering), also touched upon control theory and its many 'subcommunities' (Kalman filtering, optimal control, PID+, H∞, SMC, ILC, etc.), but his presentation focused on the creative side of system design.

Van Eijk's and Munnig Schmidt's careers show a large degree of parallelism. They studied mechanical engineering in Delft, worked at Philips on topics such as the motion





$$G_{x_1F}(s) = \frac{s^2+2\zeta_2\omega_2 s+\omega_2^2}{m_1(s^2+2\zeta_1\omega_1 s+\omega_1^2)(s^2+2\zeta_3\omega_3 s+\omega_3^2)}$$

$$\omega_1 \approx \sqrt{\frac{k_2}{m_1+m_2}}$$

$$\omega_2 = \sqrt{\frac{k_2}{m_2}}$$

$$\omega_3 \approx \sqrt{\frac{(m_1+m_2)k_1}{m_1 m_2}} = \sqrt{\frac{k_1}{\alpha m_1}}$$

ω_1 ... trampoline-mode
ω_2 ... anti-resonance
ω_3 ... resonance of piezo

2

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control design of the wafer stage of what would become ASML's famous lithography machine, and they were both professors in Delft in overlapping periods: Munnig Schmidt was appointed in 2006, Van Eijk retired in 2012 as professor of Advanced Mechatronics.

They also take a similar 'engineering view' on mathematics, as stated earlier by Van Eijk [2]: "Basically, I'm an engineer, eager to create and realise new designs." Naturally, nowadays that involves a lot of mathematics, but it should not take things over. "You always have to be able to make a simple representation, a model, of the complex system you're studying. You should not just do the maths, but try to gain insight."

Creativity in mechatronics, said Van Eijk (Figure 3), is concerned with describing solutions to relevant engineering problems. But when challenged "to make something new and valuable", the mechatronics designer is faced with serious creativity issues. The first one Van Eijk alluded to as the 'trenches', which he illustrated with the existence of various control theory subcommunities: experts all speak their own language and cannot properly communicate with each other, which makes it hard to find the best solution. Van Eijk urged the (control) experts to 'demystify' their language.

A second 'problem' according to Van Eijk is the solution itself: a solved problem is a 'roadblock' for finding alternative, potentially better solutions. A first solution provides the problem solver with a bias that prevents him from pursuing alternative solutions. Finally, the third creativity issue is 'no problem'. When, for example, a company is successful and it encounters no major problems, it will routinely focus its efforts on improving perfection. It may take a serious (continuity) problem to evoke the creativity that can bring on real (disruptive) innovation and create new business opportunities.

2 An example of Georg Schitter's approach: system level design of the Z-actuation in an AFM [1].

3 Jan van Eijk urges the experts to 'demystify' their language.

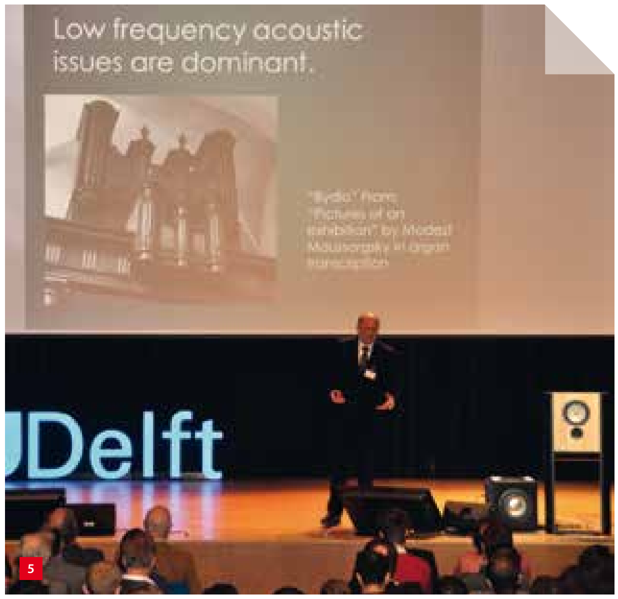
Mechatronics & music

The closing speaker of the farewell part of the symposium was the retiring professor himself. First, Rob Munnig Schmidt dwelled upon the nature of the discipline of mechatronics: a combination of two words (mechanics & electronics) and of two worlds (the abstract, invisible and the concrete, tangible physical domain), yet "a symbol of the inseparable reality of systems".

"I became a mechatronic engineer because of my fascination for music, nature, sound and physics; think about magnetic forces, electricity, radio transmission, power generation, quality of sound, etc. This has always inspired me to create solutions for real-life technical problems. I'm proud to be a generalist. One always needs generalists, people with skills in integrated functional system design." To illustrate, Munnig Schmidt recalled how, at Philips, wafer stage control became based on audio, using audio power amplifiers for driving the stage motion (see the cover illustration in Figure 4).

This pioneering work laid the foundation for the discipline of mechatronic system design that shaped Munnig

4 "Only 1,000 pages." The cover photo shows Philips's audio-based design of a wafer stage for a lithography tool.



5 Rob Munnig Schmidt talking about his fascination for music: "Audio has been an important source of inspiration for high-technology and mechatronics."

Schmidt's career in industry (Philips and later ASML) and academia. Reflecting on his time at TU Delft, he gave an overview of the Ph.D. projects under his supervision, which illustrated his scope of mechatronic system design:

- Microfactory (micro milling, process control, high-speed magnetic bearing).
- Hard disk head fine positioning by means of a thermal actuator.
- Precision positioning using friction.
- Adaptive optics for focal correction at ASML.
- Adaptive thermal control in EUV mirrors.
- Extreme precision laser dimensional metrology.
- Haptic precision robotics.
- Air driven precision systems.
- Deformation estimation using non-collocated sensors.
- 6-DoF Lorentz actuator with gravity compensator.

Just Herder, the 'new' professor, was involved in the haptic precision robotics research. The completion of the project on extreme precision laser dimensional metrology marked the end of metrology research at the (three) Dutch universities of technology, Munnig Schmidt noted with some concern. This matter also worries metrology expert Henny Spaan of IBS Precision Engineering (see pp. 14 ff in this Mikroniek issue).

Besides research, Munnig Schmidt also had fun teaching students. He published the gist of it in a textbook ("of only 1,000 pages", see Figure 4) with his colleagues (and previous speakers at the symposium) Georg Schitter and Jan van Eijk (and with Adrian Rankers for the second, revised edition): "The Design of High Performance Mechatronics – High-Tech Functionality by Multidisciplinary System Integration" (IOS Press, ISBN 978-1-61499-367-4 (print), 978-1-61499-368-1 (online)).

After his retirement as a professor, Munnig Schmidt remains active in the field as director of RMS Acoustics & Mechatronics, the company devoted to his lifelong fascination for music and audio. So he concluded his talk with a treatise on HiFi audio and the design of speakers based on mechatronic principles (Figure 5). "Audio has been an important source of inspiration for high-technology and mechatronics."

To conclude, Rob Munnig Schmidt looked back on his career with pleasure: "To be among the first to work in something as great as the Dutch high-tech industry is wonderful!" ■

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Inaugural: fundamental design

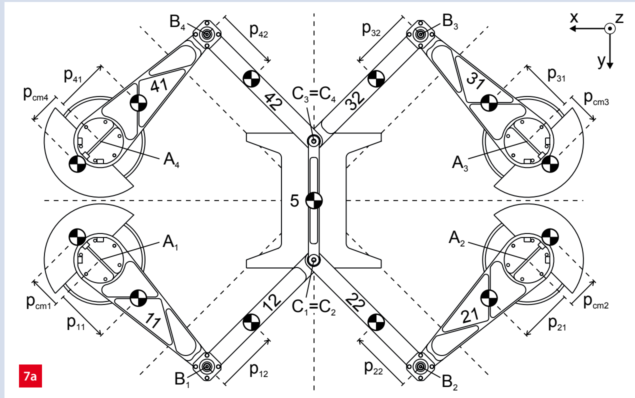
Just Herder's inaugural lecture as professor of Interactive Mechanisms and Mechatronics at TU Delft, which closed the "High-Tech Mechatronics in (e)motion" symposium, was devoted to the subject of fundamental design. Mechanisms with moving parts are at the heart of many mechatronics designs incorporating machines (mechanisms + motors) and their control. According to Herder, it's not just theory that lays the foundation for designs, but on the other hand new designs may also provide inspiration for new theory.

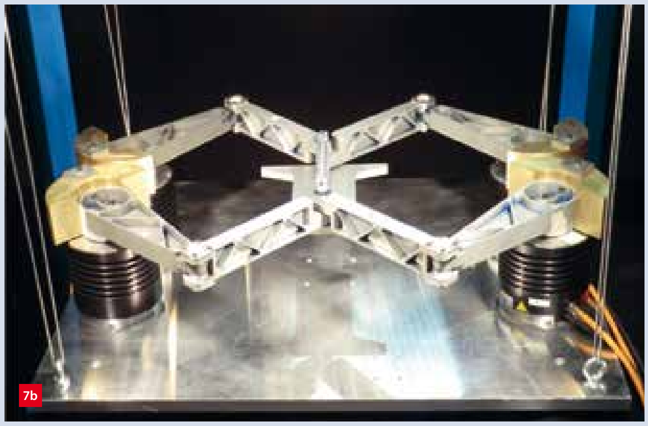
6 *Just Herder demonstrating a statically balanced mechanism.*

To illustrate, Herder elaborated on the essence of grasping a delicate object, like a light bulb. When the number of degrees of freedom for controlling a finger with several joints is increased, performance will not necessarily improve. The reason is that grasping is not about position control for accurate positioning of the joints, but about force control for the (equal) distribution of the forces over the joints. This observation led to the concept of underactuation: employing less actuators in a design than the number of joints it contains.

Underactuation is one of the 'tools' in the design toolbox Herder introduced. Other design tools are static balancing (Figure 6), useful for reduction of the work required for mechanism movement, and dynamic balancing (see Figure 7), for the prevention of disturbing vibrations induced by reaction forces in (precision) machines with moving parts.

The final tool Herder discussed was the compliant mechanism, a mechanical device that accomplishes motion through the deformation of slender segments instead of relying exclusively on rigid links with relative motion lumped in joints. Such mechanisms can be compact and cheap in production, they require no assembly and maintenance, and they exhibit no friction or backlash. Herder showed a number of examples, some of them in combination with underactuation or static balancing. The planar compliant mechanism of Figure 8 was designed as a static balancer in the direction along the ruler, and is slightly stable in the lateral direction. It works well, but no application was found to date.



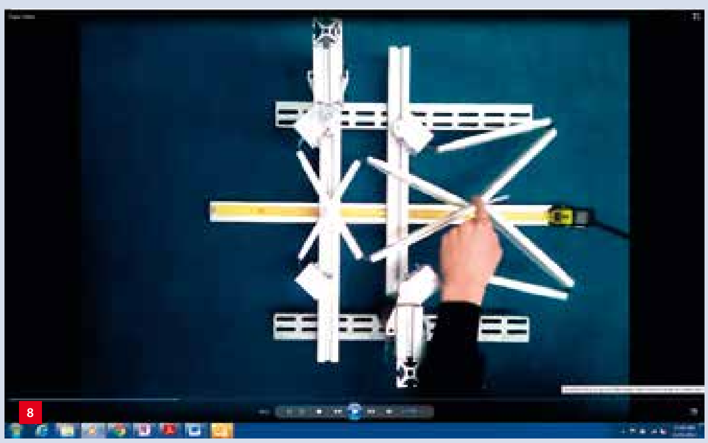


Just Herder concluded his inaugural lecture with a plea for curiosity-driven research, with a mind open to changing perspectives and unexpected applications.

WWW.PME.TUDELFT.NL (see research group Mechatronic System Design)

7 *A so-called DUAL-V balanced manipulator with counter-masses about fixed pivots [3].*
(a) Design.
(b) Realisation.

8 *A planar compliant mechanism, which was designed as a static balancer in the direction along the ruler, and is slightly stable in the lateral direction.*



OPTIONS IN PRECISION METAL MANUFACTURING

Photo-etching is no longer the misunderstood and wrongly categorised (prototyping only) metal processing technology that it was, but is now considered by numerous OEMs as the 'go-to' process for the volume manufacturing of complex, feature-rich metal parts in a variety of metals. A benchmark against alternative metal working technologies.

ALBERT TSANG

For OEMs involved in the design of new metal products the choice of the right fabricating technology will be affected not only by the type of metal being processed, but also by its thickness, the required quality of cut, and the speed with which the manufacturing operation needs to be completed. Ultimately, there are some givens in process selection. Cost per part and quality are key and fairly universal drivers.

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The choice facing OEMs

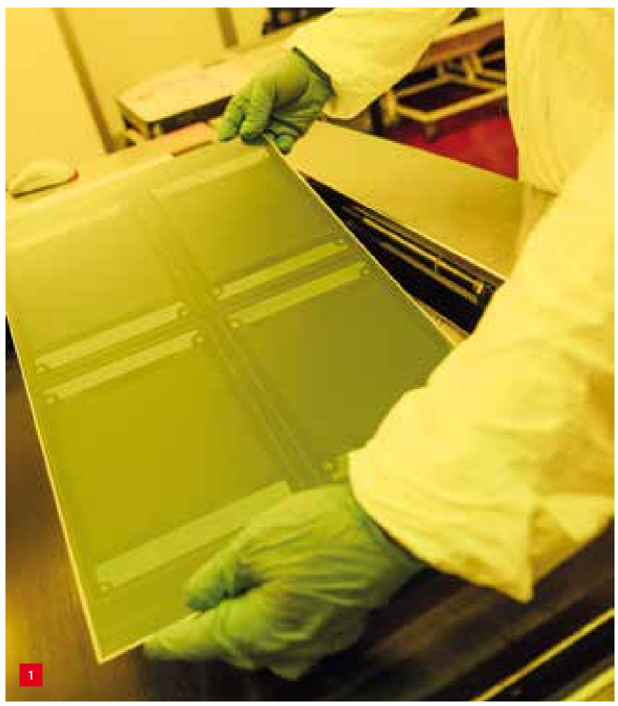
There are numerous metal cutting technologies available to OEMs. These include everything from oxyfuel cutting, plasma cutting, all the way through to laser cutting, punching, stamping, and EDM. Some of the 'less common' metal processing technologies suffer from an inability to process an array of materials, or do not provide the precision that is demanded by industry sectors such as medical, aerospace, automotive, chemical, and electronics.

As such, when benchmarking technologies that are able to produce 'precision' metal parts, the field is narrowed, and most people consider that the viable alternatives are between photo-etching (Figure 1), stamping, punching, and laser cutting. The unique characteristics of photo-etching may overcome many issues associated with the more traditional metal cutting technologies, and as such – in some instances – when looking for a cost-effective solution for the manufacture of precise metal parts, it is the only viable choice.

Traditional metal cutting technologies

Here, the focus of comparison is between photo-etching and stamping, as these metal processing technologies are seen by many engineers as the ones that can produce whole intricate metal parts in volume. Punching is a relatively limited technology, in that it is not used to make 'whole' parts, but is instead used to make specific features – such as holes or slots – on parts. Also, while punching is characterised by its relatively low tooling costs, it is usually only appropriate for low- to medium-volume production runs.

Laser cutting is gaining somewhat in popularity, due in large part to perceived advantages over mechanical cutting which include workholding and reduced contamination of



1 *Photochemical etching starts with applying a photo-resist layer and imaging (under cleanroom conditions) of the pattern to be etched.*

workpiece (since there is no cutting edge which can become contaminated by the material or contaminate the material), enhanced precision as the laser beam does not wear during the process, and there is also a reduced chance of warping the material that is being cut, as laser systems have a small heat-affected zone.

The process also suffers from some inherent disadvantages which limit its appropriateness as a mass-production fabrication process in many applications. First, the thickness of the material affects the quality of the cut of a laser. For thin materials, a very thin kerf – approximately the size of a human hair – is easily achievable.
However, as the material becomes thicker, the cut becomes less clean as when thicker materials heat up, the cut line itself starts to fill with molten metal slag, choking the cut. This can only be overcome through the use of a secondary blowing process to remove the slag which adds to expense. Moreover, adding to the expense of using this technique, laser cutting involves high power consumption in comparison with alternative technologies.

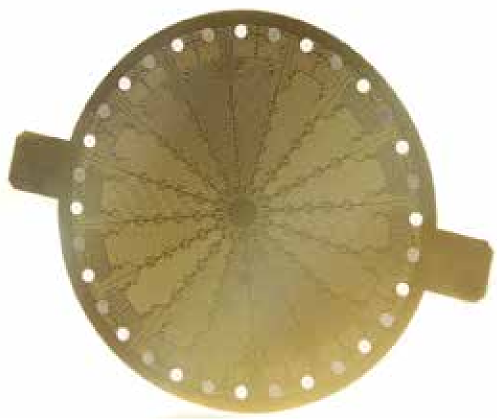
Stamping is an automated, high-speed process suitable for large production runs that make the requirement for initially high tooling costs tolerable. The sheet metal – typically in roll form – is pierced along both edges to create indexing holes that position the sheet during further processing. The location holes are used to advance the sheet metal strip through the stamping machine.

Conventional stamping processes can provide an apparent cost advantage when precision, quality, and repeatability are less critical. However, these savings are quickly lost when secondary operations are needed to achieve flatness, functional edge precision, and exacting size features that are required for component performance in many applications. Stamping is usually utilised for the manufacture of an entire part or multiple whole parts which are produced in one hit.

Photo-etching

Photo-etching is a metal processing technology that produces stress-free, flat components by selective etching through a photo-resist mask. It is especially well suited to the manufacture of precision parts (Figure 2) such as grids and meshes, lead frames for integrated circuit boards, fuel cell and heat exchanger plates, and precision springs.

When compared with the above detailed conventional production processes, it has a number of inherent advantages, key among which are the ability to produce parts without degrading material properties, the fact that there is almost no limit on part complexity, and the ability to process a huge range of metals and alloys. Metals suitable for etching can be both ferrous and non-ferrous, and include austenitic and martensitic steels, coppers, brass and nickels. Hard-to-machine metals such titanium and its alloys, and aluminium can be processed, and also high temperature alloys such as Inconel, and precious metals including silver can also be machined.



2 *Photo-etching is especially well suited to the manufacture of precision parts.*

Eeach of the conventional processing technologies suffers from a number of drawbacks, key among which is the degradation of the material being processed due to high impact, or in the case of laser cutting the use of intense heat. The other key differentiator is in the area of tooling, which can be illustrated by comparing photo-etching to stamping. The tooling for photo-etching is digital, so there is no need to start cutting expensive and difficult to adapt steel moulds. This means that large quantities of products can be reproduced with absolutely zero tool wear, ensuring that the first and millionth part produced are precisely the same.

Also, as the tooling is 'virtual', it can be adapted and changed extremely quickly and economically, making it ideally suited for anything from prototype runs to high-volume production runs. This allows for design optimisation without financial penalty, and helps ensure a low-risk entry strategy as well as facilitating easy product updating. Turnaround time using photo-tools is about 90% less than that for stamped parts. Stamping requires substantial investment in mould fabrication which is not only costly but in some instances can take from six to ten months to complete, compared with a few hours for etching.

The economy and adaptability of the tooling for photo-etching is a key stimulus to design freedom, along with the ability to produce what may seem like impossibly complicated products. As the cost of creating prototypes is so low there is no barrier to entry with the technology, with complex designs being produced in a matter of days and design iterations in a few hours. Perhaps the key drawback for industry in general is that in many instances, photo-etching is not part of some engineers' repertoire, and because of this innovation can be somewhat stunted. Photo-etching opens the door for innovation, and pushes back the barriers that constrain many design engineers and allows for the manufacture of parts many thought impossible.

Many of today's products are extremely complex and also very fragile. In many instances, geometric complexity and the requirement for extremely exacting tolerances and precision (Figure 4) mean that photo-etching is not just 'a' potentially desirable manufacturing process, but is in fact 'the only' technology able to make certain products.

Typically, when stamping, part complexity adds cost, whether in low-, medium-, or high-volume applications. The complexity of a product means the necessity for a complex mould tool, and complex tooling means increased costs, increased potential for tool failure, and increased leadtimes for satisfactory completion. Photo-etching is unaffected by the level of tool complexity, and it makes no difference in terms of costs or leadtime how complex the geometry of the part is.

Moreover, photo-etching has the ability to produce finer detail than is possible with stamping, and all with minimal if any degradation and deformation of the metal being processed, and little to no likelihood of burrs or defects. Failure rates are minute, and unlike in the stamping process, every part produced is absolutely flat.
However, stamping does have its place. Whereas photo-etching's 'sweet spot' is in the manufacture of complex parts in small to medium-sized production runs, in extremely-high-volume runs where the tooling expense is justifiable, and where designs are not overly complex, stamping typically represents a more economic process.

4 *Photo-etching may be 'the only' technology able to make certain products with exacting tolerances and precision.*

Conclusion

The advantages of photo-etching over more traditional fabrication processes such as stamping and laser cutting are its low cost, high speed, flexibility, suitability for complex designs and – most important – its ability to produce burr-free components the properties of which have not been changed by heat or stress.

Standard leadtimes for Precision Micro using the photo-etching technology are around 7 days. For stamping it can take months just to design, build, and de-bug a tool. Photo-etching can be applied to material from 10 microns thick up to 1.5 mm, and from sheets sized up to 700 x 1,500 mm. Perhaps of greatest importance are the possibilities for design engineers to innovate through the use of this versatile and cost-effective metal processing technology. ■

Titanium

Precision Micro recently announced its ability to apply the photo-etching process for serial production of parts from sheet titanium and its alloys (Figure 3), a break-through that will have far-reaching implications for various industrial sectors.
Titanium is fast becoming the material of choice in a growing number of industrial applications, most notably the aerospace, electronics, chemical, and medical sectors (implants). Key among the attributes that make it so attractive is its excellent strength-to-weight ratio, biocompatibility, corrosion resistance, and its extensive temperature range and low thermal expansion coefficients.
However, these attributes make conventional processing methods challenging. For example it can take up to 10 to 100 times longer to shape components made from titanium than those made from aluminium alloys. In addition, production technologies that use mechanical abrasion result in high levels of waste titanium material. Production methods for processing titanium therefore have to be fast and minimise waste to be considered economical.
Applying photo-etching to titanium eliminates stress- and burr-related problems associated with other manufacturing technologies.

3 *A photo-etched titanium heat exchanger.*

REPLACING OPTICAL LINEAR ENCODERS?

Historically, positioning stage designers have integrated optical linear encoders as displacement sensors. Though cumbersome, these have proven robust and cost-effective. Yet with the global trend of miniaturisation, the ever more prevalent micro manufacturing technologies require more compact solutions that offer even better precision, so attocube developed an innovative, compact sensor, which tracks displacements over long range with the accuracy of interferometers. Additionally, it can diagnose complex systems in situ by sensing angular motions and analysing vibrations in real time.

PIERRE-FRANÇOIS BRAUN

The pervasive miniaturisation trend raises extreme challenges, especially in precision mechanical engineering and micro manufacturing. We need new routines to machine or qualify tools and parts. We need new sensors to repeat ultra-precise displacements over ranges of several centimeters and still meet the highest quality standards. We need novel solutions to accurately appreciate and control mechanical vibrations, and thus ensure failure-free production processes.

If we failed in addressing these issues during, for example, a milling process, the workpiece would move erratically with regard to the cutter. This would lead to contouring errors or poor surface finishing [1]. The misshaped component would doubtlessly fail the 'Six Sigma' standard criteria (a state-of-the-art quality process [2]), and would even jeopardise the whole system's assembly or safe operation.

Encoder vs interferometer

Of course, in order to track linear displacements, laser interferometers offer ultimate resolution, accuracy, and versatility. However, they lack the crucial flexibility required to work in confined spaces difficult to access. Moreover, the prohibitive price and rather large footprint of modular commercial interferometers disqualify them for integration in industrial OEM (Original Equipment Manufacturer) products.

Therefore, precision stage designers use optical linear encoders as a back-up solution to read out position. But such encoders require dedicated stage design, prove difficult and time-consuming to align for long-range displacement and necessitate periodic recalibration. Indeed, they measure displacement away from the actual point of interest. Therefore, the output position overlooks misalignments (Abbe errors) or imperfections in guiding accuracy.

Attocube's new non-invasive interferometric displacement sensor, the IDS3010, offers probe compactness (down to only 1 mm in diameter) without compromising measurement accuracy [3]. Its dimensions fit OEM requirements for integration. The system primarily consists of standard optical components, originally developed for mass production in the telecommunications sector (precision laser diodes, photo diodes, fibre optics, etc.). This reduces its manufacturing costs when compared to other commercially available interferometers.

Working principle

The innovative IDS3010 includes up to three sensor probes (Figure 1), either directly integrated or remotely connected through standard optical cables to an electronic unit. It notably embeds a laser diode that emits low-power infrared light and an optical fibre circuit, which routes the invisible and safe-for-the-eye beam to a sensor head (Figure 2). The optical fibre termination reflects part of the light back in the

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Pierre-François Braun did his Ph.D. in the Quantum Opto-Electronics group of the Laboratory of Physics and Chemistry of Nano-Objects at the National Institute for Applied Science in Toulouse, France. In 2008, he joined attocube systems, a high-tech company supplying solutions for ultra-precise positioning and sensing. There, he developed the innovative technology presented in this article.

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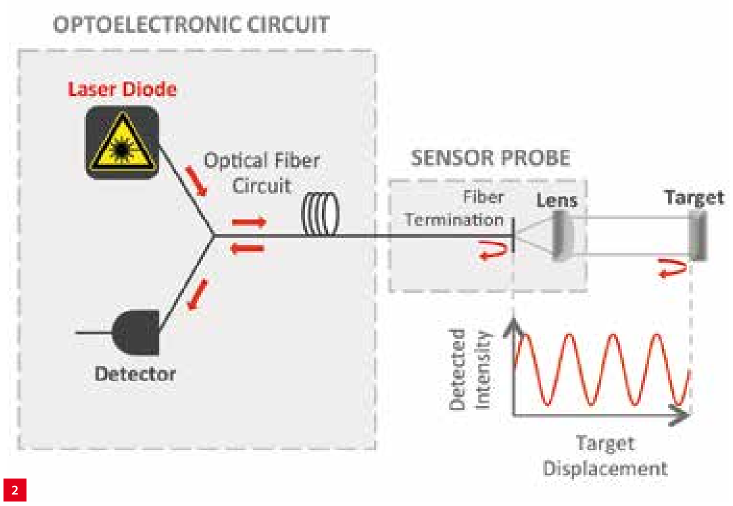

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optical circuit and outputs the rest in free beam toward a reflective target (e.g. a mirror, a polished surface, a piece of metal with low roughness). The light then reflects back into the optical circuit. This arrangement automatically creates a Fabry-Perot cavity: a space between two partially reflecting surfaces in which light rays can bounce back and forth.

The optical fibre circuit then routes both beams (reflected from the fibre termination and the target) towards a detector embedded in the electronics. There, they recombine and generate an interference pattern: the luminous intensity measured on the detector varies according to the target displacement, as sketched in Figure 2. The IDS3010 electronics process this signal and output it in real time through industrial standard interfaces. The innovative and patented probe design [4] allows extreme compactness and unmatched mounting tolerance. Attocube offers various sensor head sizes ranging from 1.2 mm to 22 mm (Figure 3). In the remote electronics version, the sensor head connects by only one optical fibre (compared to optical linear scales, which require up to 11 electrical wires). This ensures robust and easy installation, and eliminates the usual trailing cables' vibration coupling of sensor probe to environment.

Stability and accuracy

In order to perform truly accurate – i.e. metrological – motion tracking, the IDS3010 electronics lock the laser diode wavelength to a gas molecular absorption. Indeed, this process directly references the output displacement to international length standards. Moreover, this technique enables sensing with the highest stability, as shown in Figure 4. The sensor was operated in closed-loop tracking a moving stage over 1 μm in 100nm steps. The figure inset validates the device's sub-nanometer repeatability, proving that the device competes with state-of-the-art interferometers, which, for historic reasons, use expensive helium-neon lasers as light source.

1 IDS3010: a laser interferometer that tracks displacements with picometer resolution over meter ranges, and performs on-the-fly frequency analysis. The sensor includes up to three sensor probes either directly integrated (right), or remotely connected through standard optical cables (left), to an electronic unit.

2 Working principle of the IDS3010. The electronic unit embeds an optoelectronic circuit to generate, route and analyse light radiations. The fibre termination and target reflect the laser light back in the optical fibre circuit to a detector and form a Fabry-Pérot interferometer; the detected intensity fluctuates when the target moves.

Usually, fluctuations of environmental conditions (air temperature, pressure and humidity content) affect the air density and lower the interferometer's accuracy. This Achilles heel was successfully tackled. A simple, tiny electronic box neighbouring the measurement (the environmental compensation unit shown in Figure 5) monitors room temperature, pressure and humidity to enable correction for their variation.

To assess this technique, the national metrology institute of Germany (PTB) qualified the interferometers and ensured their traceability by certifying a displacement tracking accuracy better than 0.14 ppm. This corresponds to a 140 nm uncertainty over 1 meter range. The certified accuracy of the device then matches the theoretical specifications of the best optical linear scales when used in highly controlled conditions (the operator must stabilise the room temperature within only one degree Celsius when using the linear optical encoder). Yet existing optical linear encoders embed electronics, which heat the experimental set-up locally. In contrast, the new interferometer uses low-optical-power and electronics-free probes.

Applications

The novel sensor fits a variety of industrial applications (as shown in Figure 6). It tracks fast linear stage motion with velocities up to 2 m/s (Figure 6e), while preserving the interferometer's ultimate resolution of one picometer. It can also monitor stage guiding accuracy in real time (Figure 6a). Indeed, the system's angular tolerance can exceed several degrees. A simple closed-loop set-up may then control the carrier displacement within six degrees of freedom.

3


4

Likewise, the real-time processing and high-bandwidth interfacing, which follows industry standards, enable on-the-fly diagnosis of part vibrations in a fast and accurate way. Using the contactless sensor avoids changing the mass of the object under study even minimally. This could otherwise induce dramatic shifts in vibration frequency/ amplitude.

Figure 6b shows a typical frequency analysis result obtained by monitoring and recording the displacement of a motor housing. The sensor's remote electronics perform a Fast Fourier Transform (FFT) of the signal in real time. In this example the set-up vibrations are displayed versus frequency in the 5 Hz to 50 kHz range for the motor spindle rotating at 500 or 2,000 revolutions per minutes (rpm). The frequency analysis emphasises that the present motor design couples vibrations at the fundamental frequency to higher harmonics. At 2,000 rpm, these then feed device resonances, which drastically amplify the overall motor vibration amplitude, and even jeopardise the system's safe operation. This crucial information triggered a design modification of the motor, minimising the system response to vibrations and preventing potential system failures.

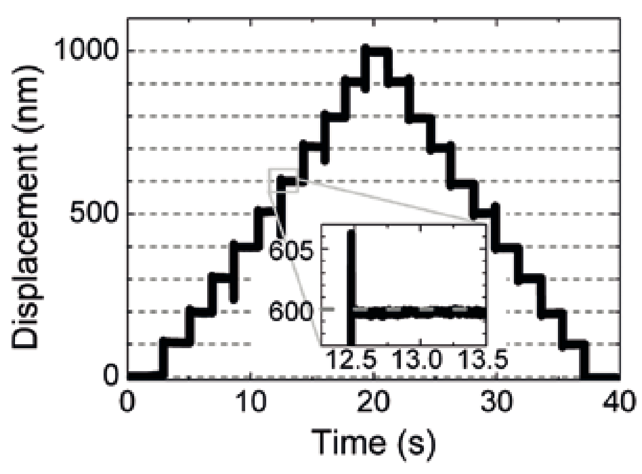
Among other attributes, the novel sensor also tolerates measurements on curved and milled surfaces. It can then directly measure the actual runout of a rotating shaft. As an example, the bearing errors of a standard electromagnetic motor were characterised (Figure 6c en 6d). Likewise, the in-plane motion of a rotating milling machine workpiece was monitored, showing the difference in vibration spectra arising when the milling process takes place as compared to the idle state (Figure 6c).
As opposed to optical linear encoders that designers integrate in the positioning stage holding the actual piece to mill, the new device targets the object of interest directly and avoids any in-between error sources such as stage bearing imperfection or slight angular encoder misalignment.

3 *Ultra-compact and robust sensor probes, the smallest one reaching 1.2 mm in diameter.*
4 *Closed-loop control of a positioning stage, which performs a displacement over 1 µm in steps of 100 nm. Inset: zoom on one step end that clearly shows sub-nanometer position stability.*
5 *Environmental compensation unit used in compensating for any changes of room temperature, pressure, and humidity.*

Conclusion

A new device for ultra-precise linear displacement sensing was presented. Figure 7 summarises its specifications. The new solution either integrates processing and optical components in one system or remotely connects an extra-compact sensing probe to a remote electronics unit by a single and robust optical fibre. These designs ensure easy sensor integration and portability, so the system fits industrial requirements for OEM manufacturing. The IDS3010 tracks motions over the wide DC to 10 MHz range with picometer resolution. Users may benefit from high angular tolerance to characterise a stage guiding accuracy.

In brief, the IDS3010 enabling technology permits a variety of industrial applications: calibrating CNC machine axes, positioning linear stages for example in coordinate measuring machines (CMMs), controlling motions with the most demanding precision (as in semiconductor lithography set-ups), performing vibrometry, etc.
For example, the frequency analysis tool allows on-the-fly diagnosis of machines in a production line without disrupting the manufacturing process. Production teams can then trace back unbalanced, misaligned, damaged or



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loose components and trigger service or maintenance on time. This improves part quality and minimises machine downtime. As this solution remains cost-effective, it matures in a viable solution for complementing or even replacing optical linear scales. Therefore, by complying with standard industrial communication protocols and operating through a user-friendly web interface, the new sensor qualifies for the 'Industry 4.0' challenges.

Up to now, machine tool manufacturers have embedded optical linear encoders in their products and then qualified their machine with an optical interferometer. Yet, by directly using attocube's OEM solution at similar expense, they can eliminate this process, ensure higher system accuracy and even avoid regular instrument recalibration. Additions to this product portfolio will be introduced, for example, a new product line adding absolute referencing to the present displacement tracking feature. ■

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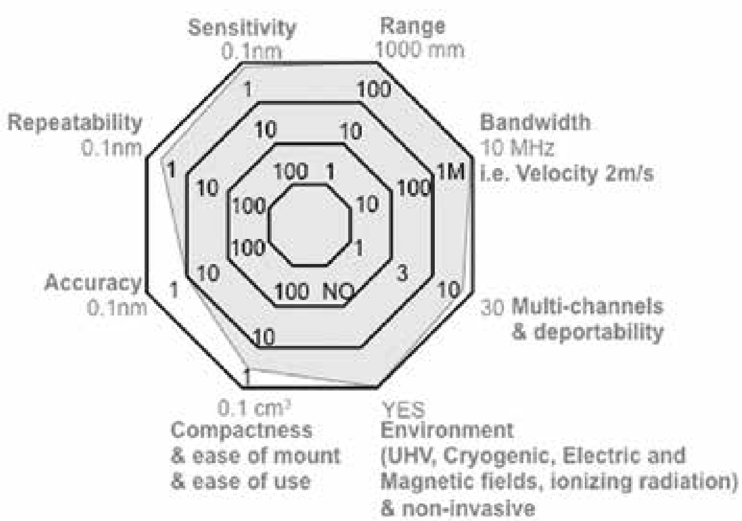
[4] Karrai, K., Braun, P.-F., inventors; attocube systems AG, assignee. "Device and method for acquiring a position with a confocal Fabry-Perot interferometer", United States Patent 2011211199, 2014 July 08.

6

6 *Examples of typical applications targeted by the IDS3010 in a milling machine environment.*
(a) Real-time stage guiding accuracy analysis.
(b) On-the-fly non-contact diagnosis of part vibrations.
(c) In situ monitoring of rotational object motions in plane (such as a milling machine workpiece).
(d) With (c): Direct detection of bearing errors and runout behavior.
(e) Linear stage motion tracking over meter range with picometer resolution.



7

7 *Spider chart mapping the sensor's principal specifications.*

FROM 'FACTORY IN A DAY' TO SOCIAL INTELLIGENCE

The 5th EU Robotics Forum, this year in Vienna, Austria, from 11 until 13 March, provided an excellent overview of European robotics innovation projects and the universities and companies involved. The event covered a wide variety of topics, from 'Factory in a Day' and low-cost mobile robotics for logistics to swarm intelligence and socially intelligent robots.

HENK KIELA

The yearly EU Robotics Forum [1], organised by EU Robotics aisbl, has become a yearly meeting place for researchers, engineers, managers and business people to discuss the European robotics business and research roadmaps. The event provides an excellent overview of various European robotics innovation projects and the universities and companies involved. Moreover, it offers a good opportunity to learn about upcoming project calls.
The ERF 2015 event in Vienna [2] offered a wealth of interesting subjects and trends in European industry and research. Below a few snapshots.

Logistics and internal transport

Institutes such as Fraunhofer, DTI (Odense) and the TU Vienna are working on small low-cost mobile robotics for logistics. Internal logistics will change into decentralised demand-driven logistics via small autonomous vehicles that find their own way around a factory. Safety for humans, proper localisation and swarm intelligence at low cost are

European robotics network

EU Robotics aisbl is a network organisation with members in academia and industry working together to develop and exchange knowledge about robotics and thus push forward the European robotics agenda toward applications. Robotics are at the point of changing our world significantly in all areas of society, from the home to the factory, from care to agriculture. The European robotics programme as organised by EU Robotics intends to develop new knowledge and especially involve companies to put this knowledge to effect.
EU Robotics has developed a multi-annual roadmap through SPARC, its strategic partnership with the European Commission. The European roadmap [3] is covering a broad range of societal challenges and technological aspects, and is updated yearly by approximately 20 topic groups [4]. They cover many relevant aspects and constitute "the place to be" for those who want to be involved in upcoming calls and challenges in the EU strategic research agenda for robotics.

WWW.EU-ROBOTICS.NET

AUTHOR'S NOTE

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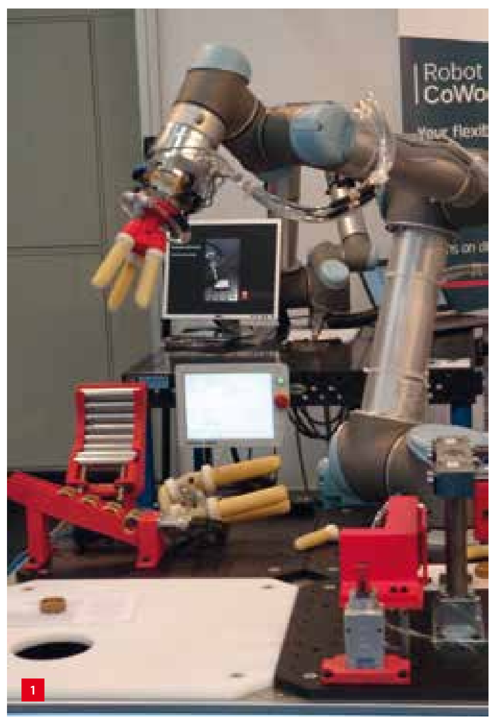

1 *A robot in the Artemis R5-COP project.*

key. The Artemis R5-COP project [5] provides modular robotics for mobile transport and part manipulation (Figure 1), as well as modular control and communication components.

Jobs?

One discussion addressed the political issue of how robotics will change work organisation. Will robots make jobs redundant or do they create new and better jobs? The opinion of the forum was that we have no choice in an international perspective anyhow, and robots will offer a great opportunity for economic growth and strengthened European innovation and job security. Aside the technological and labour aspects, attention is needed for legal and societal issues. More autonomous robots pose a challenge on how to deal with responsibilities.

Factory in a Day

The need for robot systems that can be configured in a short time and instructed without programming is addressed in the European 'Factory in a Day' project [6]. Philips demonstrated a robot cell that can be reconfigured for a new task in a few hours and is equipped with sensor 'skin' able to detect humans within 20 cm (Figure 2). Human workers and robots should be able to share spaces. The RoboPartner project [7] on the other hand showed examples of how to instruct robots and interact with them via natural speech and gestures by mapping.

Socially intelligent robots

The topic of socially intelligent robots is gaining importance in the robot community. We need robots that interact with humans in a natural and understandable way. They should for example be able to understand emotions from speech and facial expressions and they should know how to navigate in the proximity of humans in a convenient and safe way. The French company Aldebaran is very active in this field, as well as the universities of Toulouse, Paris and Eindhoven. While this topic covers a large spectrum of activities, there is a lack of interest from industry at this stage.

Modularity and interoperability

Standardisation is a major subject in robotics research. Modularity and interoperability both in software and hardware are generally seen as key in speeding up application development of robots. Modularity means that for example a robot arm, a robot gripper or a complete robot can be swapped for another one without much effort.

Suppose a robot cell in a manufacturing site needs to be adapted to a new product, that may require a change of the gripper/end effector of the robot arm. The vision system needs to be updated as well to the new part geometries.

2 *Philips demonstrated a quickly reconfigurable robot cell equipped with sensor 'skin'.*

Modularity helps to have the robot operational very quickly with the new gripper because mechanical, electrical and control interfaces are standardised and parts can be recognised.
Several partners are active in international ISO standardisation committees for robot safety and robot modularity. The major robot suppliers are not yet very supportive to this activity. But Asian countries have already adopted this subject effectively as an opportunity to get a foothold in the robotics market. Quite a few small companies are actively developing intelligent components that fit in this philosophy.

Communication of mobile applications

The experience of several projects shows the limitations and flaws in today's (Wi-Fi) communication. As the radio frequencies used for wireless communication become more and more exhausted, it turns out that indoor as well as outdoor communication with mobile robots is difficult and lacks reliability and responsiveness. Increased autonomy and fail-safe behaviour may be part of the answer. New communication technologies might be needed as well.

2016

As this short overview demonstrates, ERF 2015 was a highly informative – and very pleasant – event, which left the participants with a lot of new contacts and inspiration. Next occasion: 21-23 March 2016 in Ljubljana, Slovenia [8]. ■

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[7] www.robo-partner.eu
[8] www.erf2016.eu

“CHECK YOUR COMPETITOR’S IP”

Obviously you know your competitors. You check their website or their booth at a trade show and scan magazines – such as Mikroniek – for relevant news. But what if your competitor is in the process of obtaining exclusive rights for an innovation that you are also working on? This type of information is less visible through the above channels. However, within a few mouse clicks you can be up to date of your competitor’s IP. Surprisingly enough, this opportunity is not used that often.

JOOST NELISSEN

Many databases related to intellectual property (IP) rights, such as patents [1] or design rights [2], are freely and easily accessible. Publications in IP databases are often the very first indication of developments of your competitor in a new technical field. The reason for this is that one has to take steps to protect an innovation well in advance of its market introduction. Applications for IP rights are published shortly after filing thereof. Trademark and design rights applications are normally published within about one month and patent applications within one and a half year after filing. Given this early notice, this information can be very valuable.

With this information, you may manage to steer your innovation in a promising direction, so as to (still) obtain a competitive advantage and to avoid infringement. Patent databases are also a very valuable source of inspiration for solving technical problems. A good question is of course how to implement – at little effort – such IP database-related actions in your organisation?

AUTHOR’S NOTE

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It is advised to set up a process of regular checks – for example at least two times per year – as to the IP-related activities of competitors. From the IP databases you may also monitor activities in a specific technical field or fields of interest. In this way you may quickly act on any relevant IP-related actions. Since your own design engineers have specific, relevant knowledge, they are well able to perform this job. Barely any extra training is required, as the most relevant databases are relatively easy to access and use.

More in general, it is advisable to consider IP information at a very early stage in your innovation process. Not per se targeted at acquiring protection, but at first to do research in the information available. You may entrust one or a few colleagues with this type of research. They will gradually build up experience that can be shared with other engineers. In this way, IP research becomes part of their regular problem solving.

More often than not companies independently work on similar technologies. The sooner you are aware, the better you are prepared to benefit from this information. To alter your developments, but also to seek for cooperation and to safeguard your position on the market. It is a waste of effort to reinvent the wheel. ■

Quick start

One of the most used patent databases is Espacenet [1], the database of the European Patent Office (another large database is Google Patents [3]). In Espacenet, select the Advanced search mode. Then you can search on keywords (in the field ‘Title or abstract’), or on company name (in the field ‘Applicant’). For future updates in any results list use the RSS feed button.

REFERENCES
[1] worldwide.espacenet.com
[2] register.boip.int/designsOnlineWeb/?l=en
[3] www.google.com/patents

SMART INDUSTRY, ROBOTICS AND MORE

The programme of the High-Tech Systems 2015 (HTS 2015) event on 25-26 March in 's-Hertogenbosch, the Netherlands, was well received. Highlights included the lecture track on Smart Industry and the presentation of a robotics market survey by the Brabant Development Agency (BOM).

HTS 2015, featuring a two-day lecture programme and an exhibition, attracted over 1,000 visitors. The exhibition in the pleasant atmosphere of the 1931 Congrescentrum venue in 's-Hertogenbosch counted 46 participants, mostly companies but also a few educational institutes, among them Fontys Hogeschool ICT (see Figure 1), the ICT school of Fontys University of Applied Sciences in Eindhoven, the Netherlands.

Getting smart

A major theme of HTS 2015 was Smart Industry, the Dutch version of the German Industrie 4.0 industrial policy, centred around the ongoing digitalisation of factories. Mechatronica&Machinebouw, the mechatronics and mechanical engineering magazine of HTS 2015 organiser Techwatch, and the FEDA sector organisation for drive and automation technologies, in collaboration with robot suppliers and engineering companies, put together a special lecture track dedicated to Smart Industry.

The digital factory of the future may be regarded as a smart networked high-tech supply chain, in which suppliers not only take care of (mass) production, but may also engage in co-creation. Depending on the specifics of the product at hand, dedicated companies may 'plug into' this supply chain. The inevitable conclusion is that Smart Industry has great potential not only for large companies but for SMEs as well. Other lecture topics were the smart production of high-precision customized components, and the optimisation of logistics performance with automated guided vehicles – which might also be called robots...

Adaptive robotics

The Adaptive robotics lecture track covered a wide range of robotic applications, including flexible automation, medical

1 The Fontys Hogeschool ICT stand at the exhibition of HTS 2015.

2 The market survey presented during HTS 2015.

INFORMATION
WWW.HIGHTECHSYSTEMS.EU

robotics and a laser coating removal robot. The session was concluded with the presentation of a market survey by the Brabant Development Agency (BOM): Solutions for Support, Assistance and Collaboration – Market overview and opportunities for Brabant (the province of Noord-Brabant in the Southern Netherlands).

The survey (Figure 2) distinguishes between five market sectors: Industry, Healthcare, Agrofood, Maintenance and service, and Intralogistics. Growth in these sectors is primarily expected from the new generation of (service) robots which can support and assist people at work. What distinguishes these new (smart) robots from the previous (not so smart) ones is their highly-developed competencies in the fields of perception and navigation.

Brabant, according to the survey, boasts an extensive high-tech ecosystem: renowned research institutions, innovative hardware and software manufacturers, and creative system integrators with a knowledge of the markets in which they operate. They have what it takes to confront the remaining challenges in perception, navigation and cognition, which require increased software and hardware capacity. ■

3 *A NAO robot from Aldebaran.*

4 *Design by ALTEN Mechatronics of a stage for an FEI Small Dual Beam system. (Photos: Bart van Overbeeke)*
(a) *Realisation.*
(b) *Dynamics.*

HTS 2015 tracks

During the two days of HTS 2015, the lecture programme featured eight tracks:

- Adaptive robotics
- Smart Industry
- High-tech materials
- Opto mechatronics
- Software engineering
- Medical systems
- High-level supply chains
- Thermo mechatronics.


3

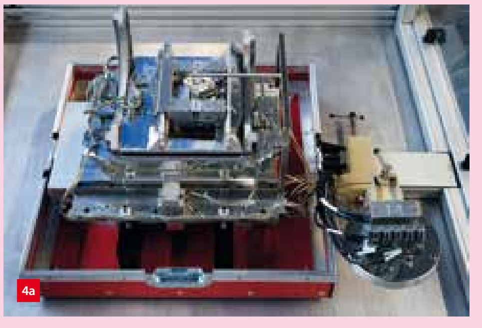
Over 20% of the contributions were from international speakers. Among them, to illustrate the broad scope of HTS 2015, presentations by Hugo Thienpont, full professor at Vrije Universiteit Brussel (Belgium), on optics and photonics essential to manufacturing, and Jon Conroy, of UK-based Claytex Services, on the effects of gearbox preconditioning on vehicle efficiency as investigated using multi-body model simulations.

Several presentations will be elaborated on in articles in forthcoming issues of Mikroniek. This includes "Interferometric CTE measurements of materials and joints and associated temperature metrology", by Jens Flügge, head of the Dimensional Nanometrology department of the German national metrology institute PTB, and "Web-enabled and experience-based cognitive robots performing everyday manipulation tasks, the RoboHow approach", by Hagen Langer, senior researcher in Artificial Intelligence at the University of Bremen (Germany). The RoboHow consortium is coordinated by the Artificial Intelligence Research Group of Michael Beetz at the University of Bremen and consists of academic partners from seven European countries and Aldebaran Robotics (France) as an industrial partner (see Figure 3).

Fast motion planning

At the HTS 2015 exhibition, ALTEN Mechatronics demonstrated a stage which it designed for a Small Dual Beam (FIB-SEM) system from FEI Company. This system incorporates a focused ion beam (FIB) and a scanning electron microscope (SEM). The vacuum chamber of the Small Dual Beam is full of subsystems, including the sample stage. At all costs, collisions of the moving stage (Figure 4) with one of the other (static) objects have to be prevented, without compromising on the speed of positioning the 8-degrees-of-freedom stage. ALTEN Mechatronics used the Robot Operating System (ROS) and applied a smart motion planner for implementing fast, collision-free trajectories by applying simultaneous instead of sequential control of the various axes.

WWW.ALTEN.NL


4a


4b

FIRST GAS BEARING WORKSHOP A SUCCESS

On Tuesday 14 April 2015, some 40 specialists from Germany, Belgium and the Netherlands gathered in the Industrieclub in Düsseldorf (Germany) for the first Gas Bearing Workshop. This workshop was organised on the initiative of VDE/VDI GMM (Microelectronics, Microsystems and Precision Engineering Society) and DSPE, with strong support of the Dutch Consulate-General in Düsseldorf and the help of the Dutch "Bond voor Materialenkennis".

Initiators of the workshop, from left to right: Ronald Schnabel, Executive Director VDE), Ton Lansink, the Dutch consul-general in Düsseldorf), Wolfram Runge (professor at Beuth Hochschule für Technik Berlin) and Jos Gunsing (board member DSPE).

Ton Lansink, the Dutch consul-general in Düsseldorf, emphasised in his opening speech the strength of networks for improving knowhow for innovation and thus business. He made a comparison with the Dutch tulip growing community over the past centuries where everyone knows everyone and the whole community is successfully centred around one subject.

Professor Wolfram Runge, Beuth Hochschule für Technik Berlin (chair for the day), introduced the workshop programme and expressed his wish to start a gas bearing network with help of this event. Together with René Theska, Technische Universität Ilmenau, he had brought up the idea of a Gas Bearing Workshop to be organised by DSPE and VDE/GMM.

First bronze-level CPE certificate awarded

Recently, the first bronze-level CPE certificate within the DSPE Certified Precision Engineer training framework (see also page 44) was awarded to Nikola Vasiljević from the Technical University of Denmark. He successfully completed the 3-day Actuation & Power Electronics course by Mechatronics Academy in cooperation with The High Tech Institute and thus reached the level of 25 CPE points, which corresponds to the bronze level.

The bronze level is a stepping stone towards ultimately reaching a total of 45 points in a well-balanced package of courses, which corresponds to the full CPE certificate and the title of Certified Precision Engineer. Last year, more than 350 students followed one or more certified courses. The CPE program has raised international interest and cooperation with renowned European parties has started to bring the concept to European level.

WWW.DSPE.NL/EDUCATION

Historical perspective

Farid Al-Bender, KU Leuven University (Belgium), had the opportunity to give a historical overview of the gas bearing industry. In his opinion, the first serious attempts related to air bearings are dated in 1864 (Hirn) and through the work of the well-known Reynolds and Mitchell the first patents emerge. The real rise of air bearings application goes back to the mid-40s of the last century when precision grinding machines, high-speed textile equipment and centrifuges for uranium enrichment were constructed. A little later, data retrieval/hard disks were also an area in which gas bearings could very well be applied.

After a somewhat quieter period a lot of knowhow was being built up with respect to dynamic stability and actively controlled bearings; certainly the availability of affordable simulation programs for both fluid dynamics, controls/multi-body dynamics and controllers has played a big role.

Presentations

The presentation of Michael Muth (Aerolas) featured the emergence of gas bearings in hot and aggressive environments, e.g. in atomic layer deposition equipment (for flat panel display and solar applications).

■ *Impression of one of the presentations.*

Nils Heidler, Fraunhofer-Institut für Angewandte Optik und Feinmechanik, presented his work on the static and dynamic properties of gas bearings in a vacuum environment. Both simulated bearing behaviour and the confrontation with the experiments were presented including the test rig set-ups.

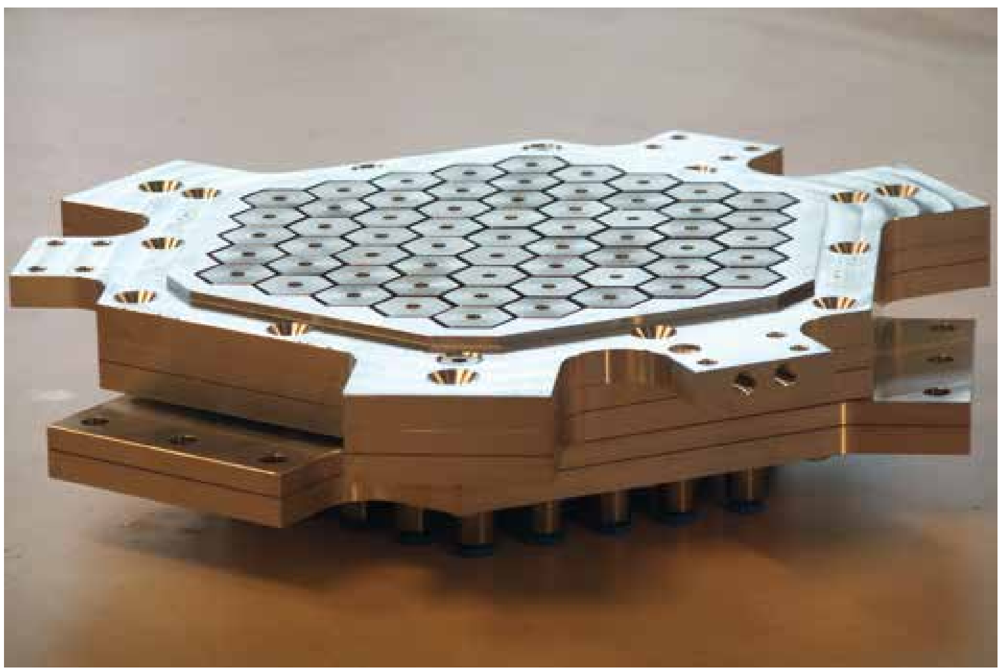
Air bearings where *x*, *y*, *θ* and/or *z*/*θ* combinations were integrated were the subject of Hans Eitzenberger (Eitzenberger Luftlagertechnik). Compactness and the possibility to drive at or close to the centre of gravity are the possible advantages of these concepts.

Tobias Waumans (Leuven Air Bearings) spoke about his work on the predictability and measurement of synchronous and asynchronous motion errors. With help of smart ways of data filtering/manipulation (frequency analysis in several steps), he was able to discern the synchronous and asynchronous errors very clearly.

After these sessions on air bearings and their behaviour from a theoretical/analytical/experimental point of view, Kai Schmidt (LT Ultra) gave an overview of ultra-precision machines with gas bearings as developed and manufactured by his company.
Ron van Ostayen (Delft University of Technology) presented a subject which for many people is really new: precision positioning of, for example, wafers in *x*,*y*-directions (in the future even flat panels may be possible) with help of air only. Currently, the so-called flowerbed actuator (see the figure) is in an advanced stage of development; earlier test set-ups already produced very promising results with respect to potential precision positioning in the near future.

Last but not least, Julien van Kuilenburg (Philips Innovation Services) gave an overview of his work as a tribologist on the seizure resistance of gas bearings. You never want to meet situations of seizure as a gas bearing applicant, but they will inevitably happen. Applied on a CT scanner with gas bearings he showed how affordable and effectively seizure-resistant gas bearings can be designed. A lot of experimental work has been done, looking for the proper material combinations which successfully combine functionality and manufacturability.

■ *The flowerbed actuator.*



Wrap-up

The initiators look back on a successful workshop and the start-up of a network group on gas bearing topics. A small survey will be held in order to improve the organisation, together with ideas for subsequent workshops and to find out if there is interest in having a next workshop in, let's say, two years from now.

The presentations will become available on either the VDE/GMM website or the DSPE website, or through the author. ■

(report by Jos Gunsing, chair, on behalf of the programme committee, which included Wolfram Runge, René Theska, Farid Al-Bender and Ron van Ostayen)

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WWW.GAS-BEARING-WORKSHOP.COM

CPE COURSE CALENDAR

COURSE (content partner)	CPE points	Provider	Starting date (location, if not Eindhoven)
BASIC			
Mechatronic System Design - part 1 (MA)	5	HTI	28 September 2015
Mechatronic System Design - part 2 (MA)	5	HTI	5 October 2015
Design Principles	3	MC	22 September 2015
System Architecting (Sioux)	5	HTI	22 June 2015
Design Principles Basic (SSvA)	5	HTI	to be planned (Autumn 2015)
Motion Control Tuning (MA)	6	HTI	18 November 2015
DEEPENING			
Metrology and Calibration of Mechatronic Systems (MA)	3	HTI	24 November 2015
Actuation and Power Electronics (MA)	3	HTI	to be planned
Thermal Effects in Mechatronic Systems (MA)	3	HTI	29 June 2015
Summer school Opto-Mechatronics (DSPE/MA)	5	HTI	8 June 2015
Dynamics and Modelling (MA)	3	HTI	7 December 2015
Summer School Manufacturability	5	LiS	17 August 2015
SPECIFIC			
Applied Optics (T2Prof)	6.5	HTI	3 November 2015
Applied Optics	6.5	MC	10 September 2015
Machine Vision for Mechatronic Systems (MA)	2	HTI	24 September 2015
Electronics for Non-Electronic Engineers – Basics Electricity and Analog Electronics (T2Prof)	5	HTI	12 October 2015
Electronics for Non-Electronic Engineers – Basics Digital Electronics (T2Prof)	5	HTI	5 September 2016
Modern Optics for Optical Designers (T2Prof)	10	HTI	to be planned (2016)
Tribology	4	MC	3 November 2015 (Utrecht) 5 April 2016
Design Principles for Ultra Clean Vacuum Applications (SSvA)	4	HTI	28 September 2015
Experimental Techniques in Mechatronics (MA)	3	HTI	11 November 2015
Advanced Motion Control (MA)	5	HTI	5 October 2015
Advanced Feedforward Control (MA)	2	HTI	2 November 2015
Advanced Mechatronic System Design (MA)	6	HTI	3 July 2015
Finite Element Method	5	ENG	In-company only

DSPE Certification Program

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

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Course providers

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- Mikrocentrum (MC)
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Content Partners

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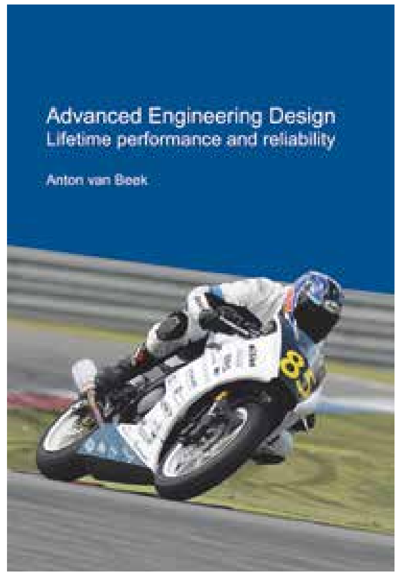
- Settels Savenije van Amelsvoort (SSvA)
  WWW.STTLS.NL
- Sioux
  WWW.SIOUX.EU
- Technical Training for Professionals (T2Prof)
  WWW.T2PROF.NL

Updated and extended: Advanced Engineering Design

This spring, Anton van Beek, an associate professor in the Department of Precision and Microsystems Engineering at Delft University of Technology, the Netherlands, published a revised edition of his book "Advanced Engineering Design - Lifetime performance and reliability".

The objective of this book is to provide guidelines for engineers, helping them to improve machine lifetime performance and reliability. Most machine problems occur with the passage of time, from dynamic loading and interacting surfaces in relative motion. Friction and wear of interacting surfaces in relative motion may take on an unacceptable form, resulting in play, frictional heat or jams. In rolling contacts, surface fatigue is generally the predominant failure mode. Cyclically loaded machine elements may suddenly result in fatigue fracture after a large number of load cycles. It is estimated that approximately 95% of all machine problems are related to fatigue fracture and tribology phenomena such as friction and wear. The science focusing on the management of friction, wear and fatigue consequently deserves due attention.

The purpose of this book is to give insight, through case studies and a wide range of illustrations, into how machine performance deteriorates, how machine elements may fail, how to analyse the cause of performance deterioration and failure and, most importantly, how failures may be prevented and performance improved. The possibilities of pushing the boundaries of load-carrying capacity and motion control are explored. With newly-gained insights the engineer is better equipped to reach innovative solutions to further optimise machine lifetime performance, improve machine reliability and simultaneously to minimise the need of maintenance.
The author discusses numerous design tools, design charts and guidelines, and makes user-friendly PC calculators of the formulae derived in this book available.

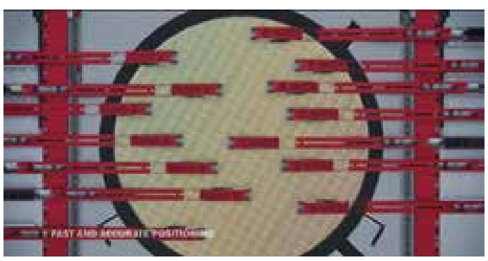


Anton van Beek, "Advanced Engineering Design - Lifetime performance and reliability", ISBN-13 978-90-810406-1-7, full-colour, 472 pages, Tribos, 2015.
Book + CD, EUR 85.00, including postage and VAT.

WWW.TRIBOLOGY-ABC.COM/BOOK

Parallel scanning probe microscope

A multiple miniaturised Scanning Probe Microscopy (MSPM) heads system has been developed by the Dutch applied research organisation TNO. The system can inspect and measure many sites in parallel, featuring an enhancement of throughput in the order of more than 1,000 times the single SPM throughput. It is capable of more than 10 wafers per hour throughput in the semicon and nanoelectronics industry and parallel and simultaneous measurement of biomedical samples to guarantee the same condition of scanning for all samples. Because of the speed and parallel scanning, the conditions during measurement are less likely to change due to variations in temperature, biological conditions, etc. This has numerous advantages, for example if used for statistical analysis.



A parallel SPM system for imaging multiple locations on a wafer or mask. Multiple positioning arms on two sides of the wafer stage, each capable of moving a miniaturised SPM scan head on to a large sample. Many parallel miniaturised SPM heads enable full-area coverage at high throughput.

Scanning Probe Microscopy (SPM) is emerging as an essential nano-instrument in numerous applications where nanometer-resolution imaging and characterisation are required. The ability to accurately measure critical dimensions on a nanometer scale has made it an important instrument in various industrial applications, such as semiconductor, solar, data storage, bio-medical, pharma and food science. Examples are surface roughness, channel height and width measurement, defect inspection in wafers, masks and flat panel displays. In most of these applications, the target area is very large, and, therefore, the throughput of the measurement plays an important role in the final production cost. Single SPM, however, has never been able to compete with other inspection systems in throughput, thus has not fulfilled the industry needs in throughput and cost. Further increase of the speed of the single SPM helps, but it still is far from the required throughput and therefore, insufficient for high-volume manufacturing.

Over the past few years, within the Enabling Technology Program (ETP) Optomechatronics at TNO a revolutionary architecture for a multiple miniaturised SPM (MSPM) heads system has been developed, which can inspect and measure many sites in parallel. The very high speed of miniaturised SPM heads allows the user to scan many areas, each with the size of tens of micrometers, in few seconds. Recent experimental results have confirmed that the time for a parallel SPM has arrived.

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