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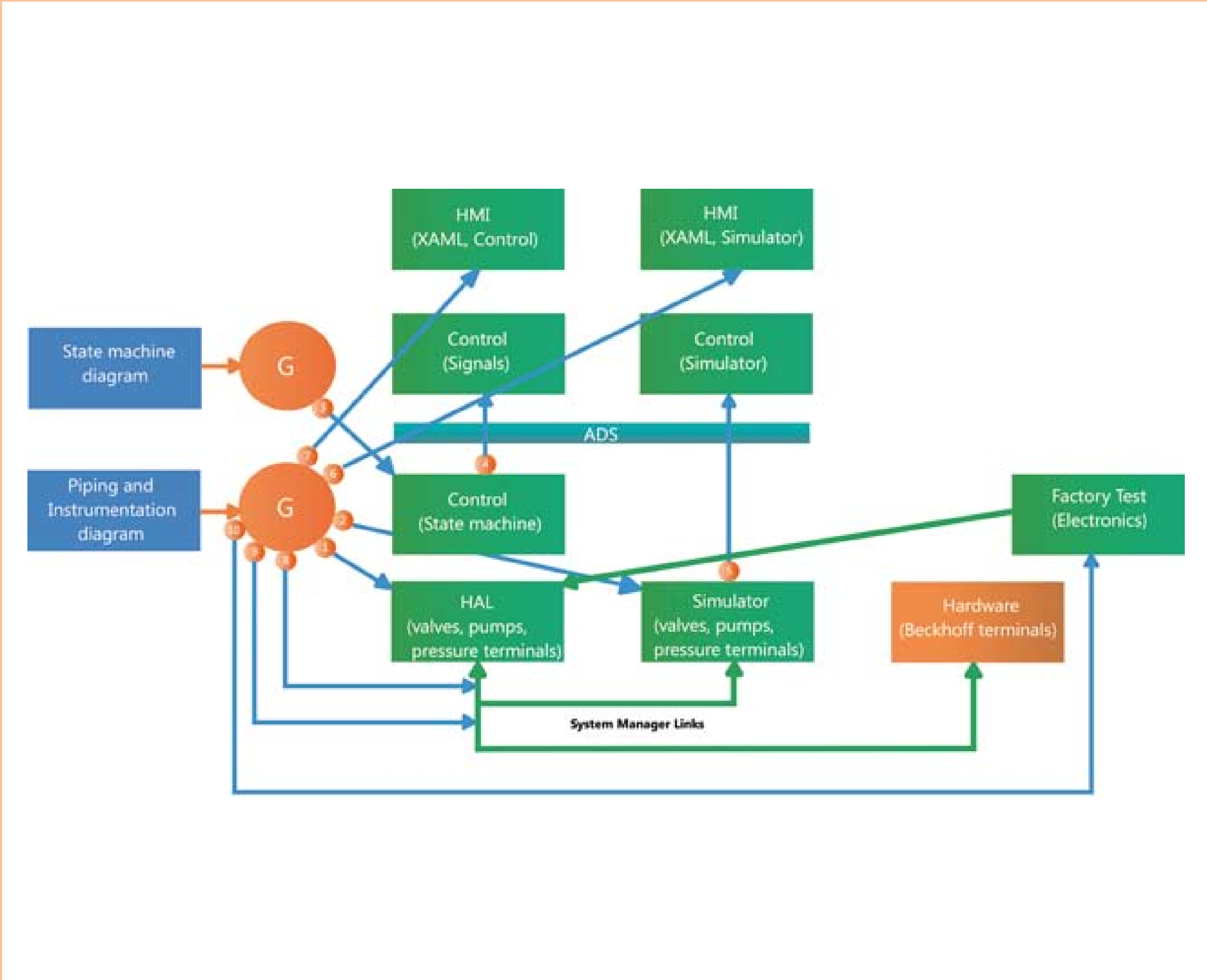

Special Issue Software

DSLs and simulators to improve software quality • Model-Based Design
Automating Dynamic Error Budgeting • Software-aided correction of injection moulds
Machine vision into micron area • Inox and magnetism • LiS's 110th anniversary
Precision Fair and ASPE Annual Meeting reports • Precision Engineering Awards 2011

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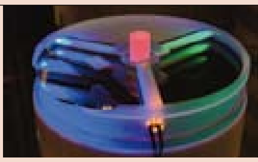
In this issue



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The cover photo (system and simulator from DSLs) is courtesy Robert Hendriksen (Sioux).

editorial

Making the difference

When I was a small kid, my father always told me that it didn't matter what I did for a living as long as I took care that I was the best in it. Later on I realised that this doesn't only apply to individuals but also to organisations or even to whole regions.

We, in the Brainport region, make a difference by creating the most advanced and precise high-tech equipment in the world. Designing and integrating mechanics, electronics, optics, physics, mathematics, electronics and software creates very advanced equipment. For example, ASML's wafer steppers make a difference in creating the world's smallest structures on a nanometer scale. FEI's microscopes make the world's best images at an atomic/Ångström scale. And Océ's equipment is the best in controlling inkjet drops on a picoliter scale.

Mega roadmap innovations are achieved by large companies in the Brainport region. These OEMs are supported by a unique, extensive and local ecosystem of about 200 first-, second- and third-tier suppliers. They must make a difference in their value proposition, determine their own technology roadmaps and compete on a global scale, to be faster, better and more cost-effective than anybody else in the world. The joint ecosystem makes a difference in itself in the way its members collaborate in open innovation and open supply chains. Brainport Industries unites suppliers allowing them to strengthen their forces in the fields of technology, people and market.

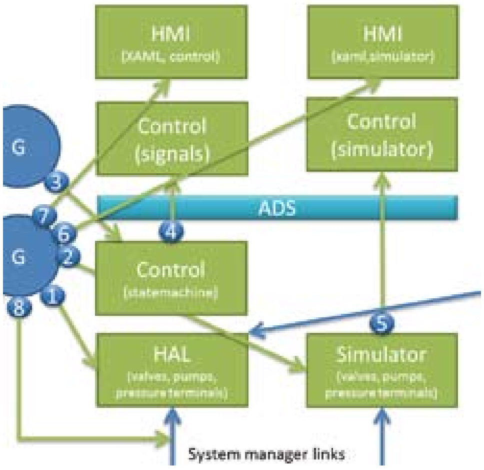
This unique ecosystem also plays a major role in the development of new OEMs that are currently incubated with great speed and progress. In this sense, the innovative performance of Brainport is starting to resemble that of Silicon Valley. Every year, on a smaller scale, Brainport creates new OEMs such as Macawi, MuTracx, Phenom World, SoLayTec, Sorama and many more. These are exciting and promising new companies that each have the potential to grow in 15 years' time towards 100 million euros of revenue.

Building the most advanced and precise equipment in the world and positioning at this scale can only be achieved because of the software that can deal with the high-performance control issues and the laws of physics. But software also plays a major role in the interaction with the user, in the service diagnostics, the quality and speed of the machine, the connection to the factory and the outside world, the application process, the pay-per-use business models, the simulation of the machine, etc. Therefore, I appreciate the fact that this Mikroniek issue is dedicated to this important subject.

Hans Duisters, CEO Sioux Group

DSLs and simulators to improve software quality

Complex high-tech system engineering involves several disciplines, including mechatronics, electronics, optics and (embedded) software. In most engineering projects, each discipline uses its own modelling environment to make an abstract representation of the real system. Integration cycles are often very long due to the variety of approaches taken by the different disciplines.



• ***Robert Hendriksen*** •

At Sioux, we are continuously looking to improve software quality and to make the process of constructing software more efficient. For SoLayTec, Sioux has developed a software system that makes extensive use of DSLs (domain-specific languages) and simulators. Consequently, the software system behaviour is more robust (has fewer bugs) and maintainability is better. Using these methodologies, software systems are created not by coding in a traditional programming language, but by modelling the system at a higher abstraction level. This also makes it possible to simulate the system in a graphical environment, making the software model also available to other disciplines for their engineering purposes. Combined modelling by different disciplines leads to shorter integration cycles and better systems.

Author's note

Robert Hendriksen joined Sioux, which is based in Eindhoven, the Netherlands, in 2006. He has been involved in various projects for Sioux, but at the moment, he works on a full-time basis as software architect for SoLayTec's products. Any time left after this is devoted to the construction and application of DSLs.

www.sioux.eu
www.solaytec.com

Figure 1. Products of SoLayTec: process development tool and high-volume tool.

Atomic layer deposition

SoLayTec is a TNO spin-off and is now an original equipment manufacturer (OEM) for the solar industry. It develops machinery for atomic layer deposition (ALD) on solar cells; see Figure 1. Wafers enter the ALD module where heated gases are applied to one side of the wafer. With each pass, an atomic layer of aluminium oxide is deposited on the wafer; see Figure 2. This ‘passivation’ layer increases cell output, and consequently, SoLayTec has a business case.

Design

When designing and constructing complex, first-of-a-kind instruments from scratch, we are confronted with many changes and uncertainties during a large part of the development process. Extensive use of simulators is one way of mitigating multidisciplinary dependencies.

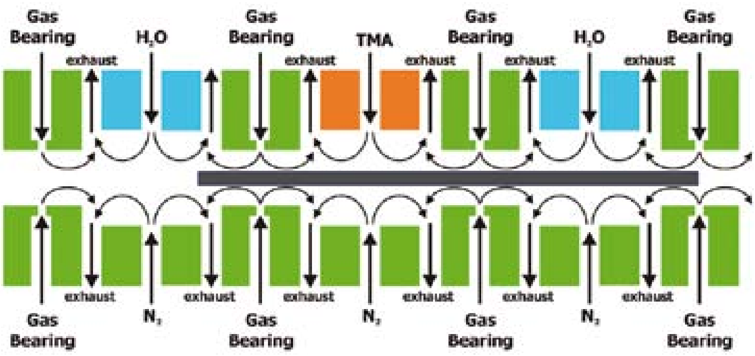


Figure 2. Injector head for Al_2O_3 layer deposition.

Moreover, for SoLayTec’s new high-volume tool, a set of simulators has helped identify bottlenecks early on and as such has influenced the ultimate design to a large extent.

Several incarnations of the system have been tested in simulation before we ended up with a multi-lane setup that was able to provide the required performance; see Figure 3. Each individual variation we tested was constructed using a set of simulation building blocks that are dragged onto a design canvas and connected to each other using a dedicated interface for passing wafers along. Each building block is basically an element of the DSL used for constructing high-volume tools. This simulator enables SoLayTec to evaluate systems with different dimensions and various numbers of deposition units (DUs) and tests our scheduling algorithms.

The high-volume tool typically consists of a number of DUs. The DU is the heart of the system and responsible for the deposition of the gases onto the wafer. The wafer passes the injector head a specified number of times with great precision. To meet this requirement, we opted to use PLC technology from Beckhoff, which provides a real-time environment that is relatively easy to program and turns out to be an almost ideal platform for simulation.

Both simulator and control code run on the same PLC. Twincat provides a dedicated tool (system manager) for connecting PLC variables to electrical terminals of various kinds. The same tool can be used to connect variables to other variables, which makes the configuration depicted in Figure 4 easy to set up. Once hardware becomes available,

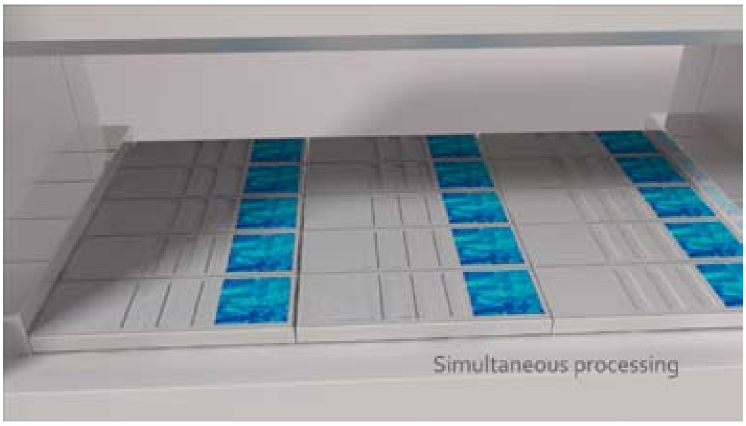


Figure 3. View of the high-volume tool with multi-lane setup.

the links between the variables are replaced with a set of links between control code and electrical terminals. But until that time we use the simulator to develop both control code and simulator synchronously until we have implemented all the requirements.

State machine

The state machine is a typical code construct used for implementing behaviour derived from our requirements. In fact, most of the code consists of state machines. For the development of the SoLayTec process development tool, we already used Enterprise Architect as the tool for documenting all UML diagrams including state machines. Now, for the high-volume tool we translate the Enterprise Architect (EA) state machine diagrams automatically into PLC code. These visual state machine diagrams are first parsed by oAW (openArchitectureWare) using UML's metamodel into an internal representation of all states, followed by the execution of XPAND and XTEXT scripts translating the internal modes into PLC code.

Our investment in the system has brought us several benefits:

- Fewer bugs. Any mistakes in the software system surface quickly. Also, any bugs found are eliminated from all state machines at once on discovery.
- Fewer flaws: the state machine diagram itself can be interpreted by the domain expert, resulting in a very effective review of the design.
- Faster development. Even if you do not take the first two bullets into account, an improvement in development speed occurs because you simply do not have to type as much.
- Documentation is kept up to date more easily. Since state machine diagrams make up a large part of the documentation, it also takes less effort to update the descriptions.

See also the box on the classification of problems in software.

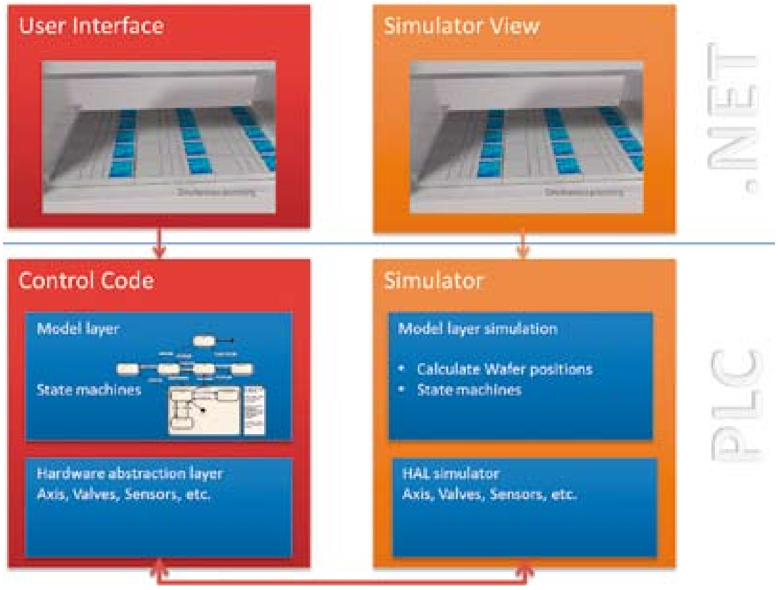


Figure 4. Control and simulator in the PLC.

Evidently, the state machines used to make the simulator work are also automatically created. So far, our focus has been on getting the required functionality working. We are using simulators to verify whether we exert the correct stimuli with the correct timing based on sensory input. By walking through all the use cases we make sure that everything is working as we specified during the requirements process.

FMEA

For us to respond correctly to hardware failures, we need to take a different approach to gathering the correct requirements, and use cases are not the correct tool for that; see Figure 5. A Failure Mode Effect Analysis (FMEA) [2]

Defects, bugs, flaws, and risks

Little research has been conducted on the classification of problems in software, but here are some definitions [1]:

- Defect: Both implementation and design mistakes are defects. A defect is a problem that may lie dormant for years only to surface in a fielded system with major consequences.
- Bug: A bug is an implementation-level software problem. Bugs may exist in code but never get executed. This term can be used for simple implementation errors.
- Flaw: A flaw is a problem at a deeper level. It is instantiated in software code but also present at the design level.
- Risk: Flaws and bugs lead to risks. Risks capture the probability that a bug or a flaw can impact the purpose of the system (risk = probability x impact).

Figure 5. Focus on 'good weather' behaviour (use cases) and 'bad weather' behaviour (FMEA).

focused on the system will find most 'bad weather' behaviour requirements for software; see also the box.

The FMEA should be performed by a multidisciplinary team at the design phase. Typically, you will find hundreds of possible failures, each with a different level of impact and risk of occurrence. You will have to figure out how to detect them and, if detection is possible, determine what the response of the system should be. The solution is always to change the design such that the failure can no longer occur. Such a change can be called a 'Poka Yoke' [3]. But if a system change is out of the question, the software needs to detect and respond to the failure. We have learned that in the case of our systems, only a few different kinds of responses are needed when failures occur. Furthermore, if you cannot detect a failure, its calculated risk and priority will tell you whether or not to add additional hardware for detection or, ideally, future prevention.

The simulator proves to be invaluable when you implement the failure detection and mitigation code. A lot of these failures might be dangerous or destructive to test them on the real hardware, so only the simulator can provide the test bed. At SoLayTec, we perform regression tests for all detectable failures after each software build.

Failure Mode Effect Analysis

- A preventative tool (bottom-up approach) that identifies all potential failures.
- Evaluates all potential risks and current risk control.
- A cross-functional and multidisciplinary team uses the FMEA to evaluate the product or process.

Domain language

A deposition unit (DU) deposits vaporised trimethylaluminium (TMAl) and water (H_2O) onto the wafer. It receives these gases from the gas cabinet. The gas cabinet is responsible for producing the correct mixture of both gases and transporting these to all DUs. For the gas system, we developed a domain language that enables us to create the simulator as well. It also allows us to automatically create a considerable part of the user interface. This DSL is understood by the gas domain expert, so we again shorten the path where flaws might be introduced.

Beckhoff PLCs run in kernel mode and our user interfaces are normal Windows programs running in user mode, both on the same Windows PC. Beckhoff provides an interface called ADS for communication between the two. To prevent a lot of manual coding labour, we have added another DSL for the creation of the model layer in the .NET part of the software. These are depicted as steps 4 and 5 in Figure 6. A simple naming convention helps us to create an object model in the PLC code. When compiled, the resulting type information of the PLC is parsed with a custom-built tool to create the .NET abstraction layer. This layer links directly into the user interface that is also generated.

Hardware abstraction layer

In summary, for the gas cabinet, using the abstract software model (used by many disciplines) we automatically created the:

1. hardware abstraction layer (HAL) for the control code (valves, pumps, sensors, etc.);
2. HAL for the simulator (simulators for valves, pumps, sensors, etc.);

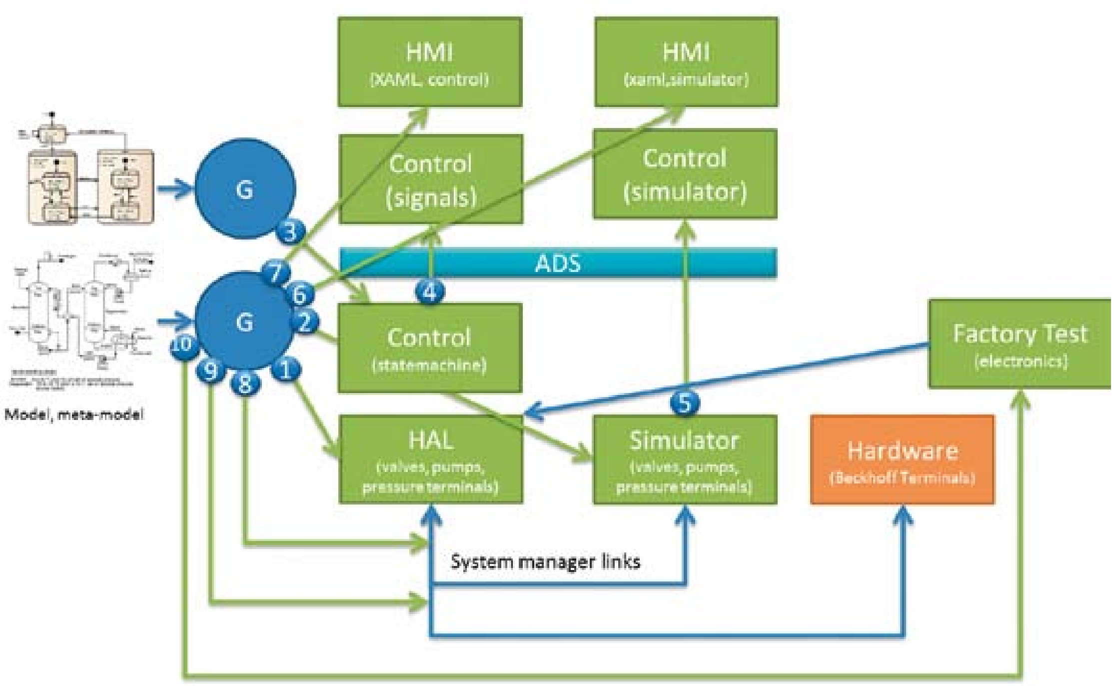


Figure 6. System and simulator from DSLs.

3. control code from state machines operating on the HAL;
4. abstraction layer for the control code;
5. abstraction layer for the simulator;
6. the complete user interface for the simulator;
7. part of the user interface for the gas cabinet;
8. system manager links between the individual HAL components and their simulated counterparts;
9. links with the Beckhoff terminals;
10. software for testing the HAL.

When the gas cabinet has been built up we can test for electrical installation errors. Moreover, the simulator code has been augmented with facilities to support testing the possible failures found by the FMEA process. We have given the simulated HAL-level components the ability to fail. This feature allows the domain expert to implement and test the 'bad weather' mitigation code on the control side in an easy way at his desk.

Software factory
Not everything gets easier when using several DSLs. The system we have built has become more complicated because we need to execute various tools in a strict order because of all the dependencies that have been introduced. Our DSL tooling was built using C#, Java, XTEXT, XPAND and structured text. Basically, we have created a software factory [4] where we use feature-based and graph-like languages, but maintaining it all remains an important challenge and requires an extensive skill set.

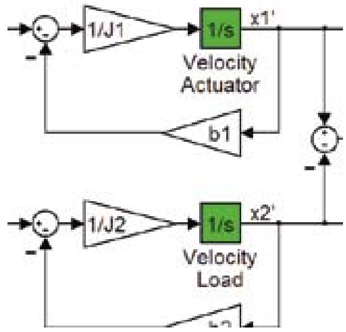
Conclusion
Building a system with use of domain-specific languages understood by domain experts eliminates a vast number of coding phases where bugs and flaws can creep into the software. Automatic creation of a simulator allows the domain experts to iterate design changes relatively quickly, ideally before any hardware is ordered. We found that our investment in simulation software has shortened the normal integration phase considerably and paid for itself. A system-wide FMEA with a software perspective, but executed by the multidisciplinary team, is a great tool for detecting, handling and possibly preventing future system failures. Using simulators to test good and bad weather behaviour of the system is the only way to make sure that the system can degrade gracefully.

References

[1] G. McGraw, "Software Security, Building Security In", Addison-Wesley, 2006.
[2] A.H. Mollah, "Application of Failure Mode and Effect Analysis (FMEA) for process risk assessment", *BioProcess International*, 2005.
[3] S. Shingo and A.P. Dillon (translator), "A Study of the Toyota Production System", Japan Management Association, 1989.
[4] J. Greenfield, "Software Factories: Assembling Applications with Patterns, Models, Frameworks and Tools", Microsoft Corporation, 2004.

Motion control design and verification using simulation

Identifying system level problems early and ensuring that all design requirements are met are two of the top challenges faced in developing mechatronic systems. Model-Based Design is a methodology to address this effectively and efficiently. We will apply this to a classic motion control application where a load must be precisely positioned through a flexible shaft.



• *Paul Lambrechts* •

Introduction

Table 1 presents the results from a survey of 160 companies doing mechatronic product development, asking about their main challenges. Most of the responses, such as "lack of cross-functional knowledge," are associated with the multi-domain nature of mechatronic systems. This shows that it is generally hard for engineers to look beyond their specific area of expertise when it comes to integrating domains and dealing with the complete system. Another significant part of the responses focus on testing, such as finding errors early in the development cycle and testing before hardware is available.

Author's note

Dr. ir. Paul F. Lambrechts, Senior Application Engineer, MathWorks, Eindhoven, the Netherlands, has a background in mechanical engineering and specialises in MathWorks tools for control design and physical modeling. After his PhD on advanced control design methods for servo systems he became research engineer in various industries, including Corus and ASML. Before joining MathWorks he also completed a two year Post Doctorate period at TU Eindhoven. He has been with MathWorks for almost eight years.
MathWorks is the leading developer of mathematical computing software. MATLAB is a programming environment for algorithm development, data analysis, visualisation, and numeric computation. Simulink is a graphical environment for simulation and Model-Based Design of multi-domain dynamic and embedded systems.

Table 1. The top six challenges of mechatronic product development [1].

Challenge	Response (%)
Difficulty finding and hiring experienced system engineers / lack of cross-functional knowledge	50
Early identification of system level problems	45
Ensuring all design requirements are met in the final system	40
Difficulty prediction / modeling system product behaviour until physical prototypes exist	32
Difficulty implementing an integrated product development solution for all disciplines involved in mechatronic product development	28
Inability to understand the impact a design change will have across disciplines	18

The importance of early testing can be further illustrated by a NASA study that analysed the relative costs of fixing errors based on what phase of development they were introduced in, and what phase they were first detected [2]. From Figure 1, it is evident that detecting errors early in the design cycle, or as soon as possible after they are introduced, can have a dramatic impact on the cost of a project.

Model-Based Design is considered to be an important methodology to help address the challenges of multi-domain design and early testing. This paper describes how to use Model-Based Design for a motion control application to perform system-level simulation and combine electrical, mechanical, and control engineering in a single software environment where testing can be done throughout the design process.

We will use the example of a precision motion system that moves a load from one position to another and back again within a given amount of time. The system consists of a DC

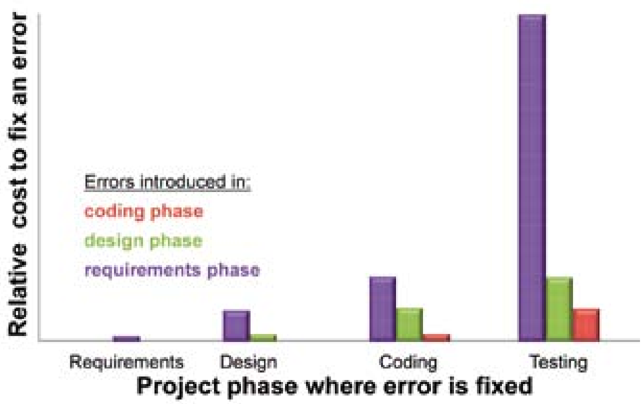


Figure 1. Graph of the relative cost to fix an error based on project phase [2].

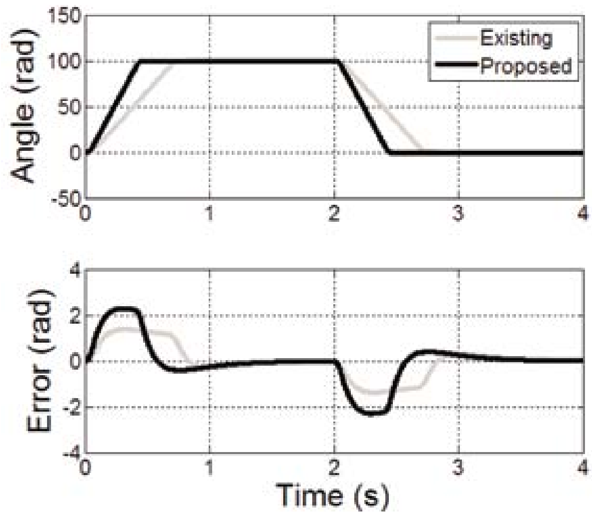


Figure 2. Position and position error for a point-to-point movement. The original performance is shown in gray; the performance for a more aggressive move is shown in black.

motor driving the load through a flexible shaft. This mimics a direct drive system as you may typically find in many sorts of mechatronic machinery. The original design moves at a maximum speed of 150 rad/s and a maximum acceleration of 2,000 rad/s^2. The goal is to increase throughput of the machine by increasing the speed to 250 rad/s and the acceleration to 5,000 rad/s^2. Figure 2 shows that this will not work without losing positioning accuracy. The faster profile only gives larger errors and the machine takes longer to settle: in the end, the net effect is almost zero.

By making use of the Model-Based Design software environment based on MATLAB and Simulink we will learn to understand and model the behaviour of the physical system, optimise design parameters, develop an improved control algorithm, test it, and qualify the produced controller before connecting it to the real plant.

Plant modeling

The plant, or the physical system we are trying to control, is pictured in Figure 3. It consists of a power amplifier driving a DC motor with two optical encoders for measuring the position of the motor shaft and the load. The motor is connected to the load through a small flexible shaft causing a resonance frequency of about 50 Hz.

To improve the controller, we must first develop a model of the plant. Generally this can be done in two ways: data-driven or first-principles based.

Data-driven modeling involves generating input signals to send into the actual system and then measuring the resulting output. These measurements can be used to derive a dynamic representation of the system, such as a transfer

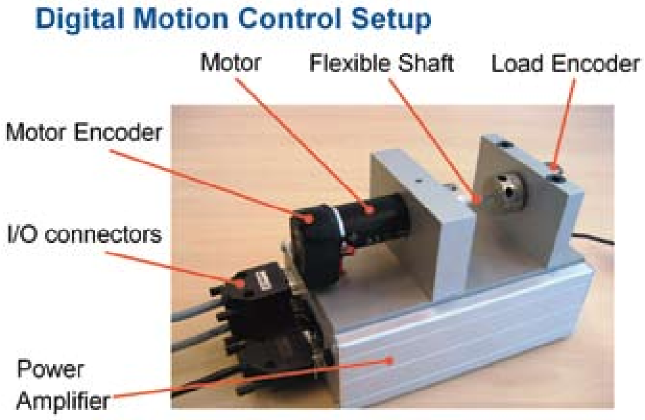


Figure 3. The controlled system.

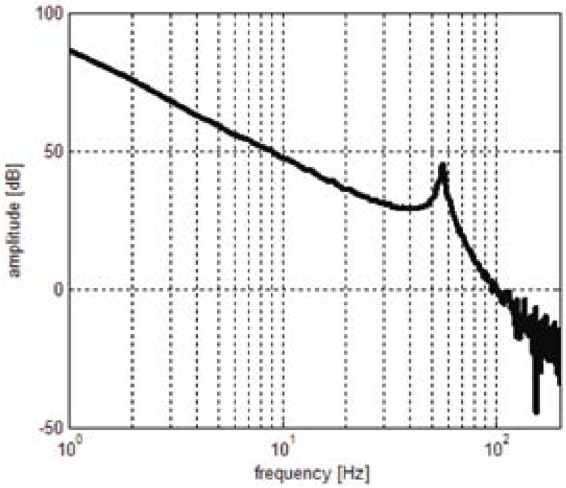


Figure 4. Measured frequency response of the open-loop plant on logarithmic scales.

function. Because it requires measured data you cannot use it before the actual system exists. But because it does not require any insight into how the system is constructed, it can be a quick way to develop an accurate model. Disadvantage is that the parameters in the model have no connection to physical model parameters, such as the stiffness of the transmission shaft. It can be used to help design and test control algorithms, but cannot be used to investigate making changes to the plant design.

First-principles modeling involves building up a model based on the individual components of the system. It generally takes more effort than the data-driven approach, but provides insight into the plant and how various parameters can affect the overall system behaviour. For a new design with no physical prototype, this is the only available path.

In the motion control example, we are improving the performance of an existing system, so we will start by using the data-driven approach. After that we will investigate a first-principles modeling approach.

Data-driven modeling – "The existing system"

To carry out the system identification and generate the model, we first need to collect data from the plant. Typically, this requires sending test signals into the plant's actuators and measuring the responses from the available sensors. In general this is not simply possible without some form of preliminary feedback control; otherwise the plant may drift away from its intended operating range. Fortunately, we can precisely determine the transfer function of the feedback controller from its known structure and parameters and calculate the behaviour of the "open-loop" plant by taking out the effect of the controller. By ensuring the test signals are independently generated and sufficiently affecting the plant dynamics, we can derive the measured frequency response of the plant given in Figure 4.

Here we see one resonance peak associated with the compliance of the shaft that is around 55 Hz. This frequency response data cannot be used directly in a time domain simulation, so we need to convert it to a transfer function model using system identification. For this we used the System Identification Toolbox as shown in Figure 5, which is largely based on the original work of Ljung [3].

The frequency response data is imported into the tool, a model structure is chosen, and then the model estimate can be evaluated. For this example, a fourth-order state-space model was chosen. The model frequency response and the measured frequency response are both plotted in Figure 6, which shows that the resonance peak in the estimated model closely matches the measured data. This state-space model can now be used directly in Simulink to design and tune the controller.

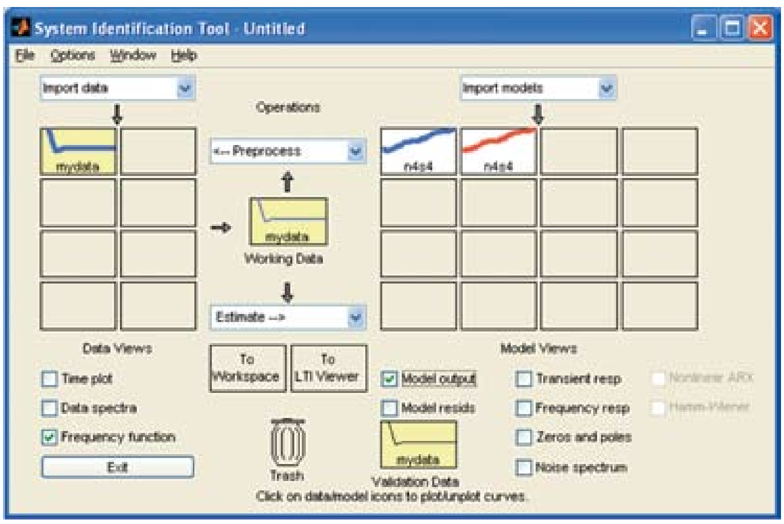


Figure 5. Graphical user interface for the System Identification Toolbox.

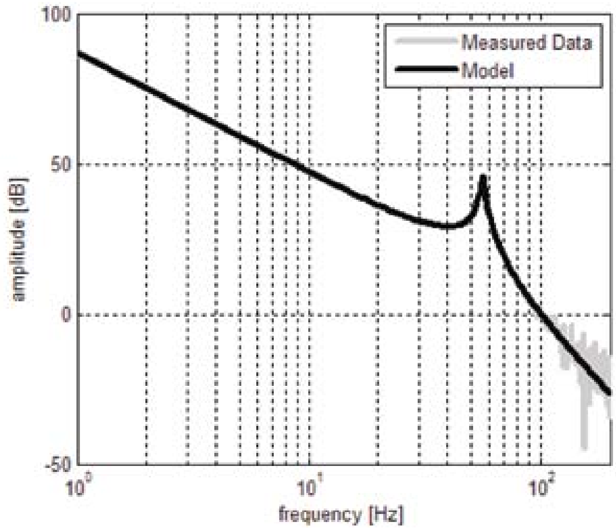


Figure 6. Measured frequency response and the model developed using system identification techniques show good correspondence over the frequency range of interest.

First-principles modeling – "The new design"

Another approach to model the motion control system is to derive dynamic equations for the system based on the physical components. Assuming there is only one dominant resonance mode, the core dynamics of the transmission system can be simplified to the schematic in Figure 7.

T represents the torque from the motor, x_1, J_1 and x_2, J_2 represent the angular position and inertia of the motor and the load respectively, b_1 and b_2 represent the damping of the bearings, and *k* and b_{12} represent the stiffness and damping of the transmission shaft. For this simple system it is fairly straightforward to use Newton's laws to derive the equation of motion for the two bodies:

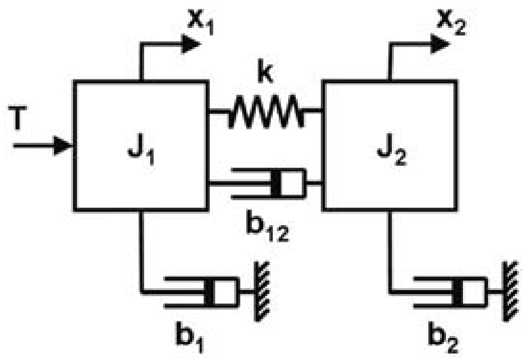


Figure 7. Schematic of the major mechanical components in the motion control plant.

$$J_1 x_1'' = -b_1 x_1' - k(x_1 - x_2) - b_{12}(x_1' - x_2') + T$$

$$J_2 x_2'' = -b_2 x_2' + k(x_1 - x_2) + b_{12}(x_1' - x_2')$$

These equations can then be implemented in Simulink as the block diagram given in Figure 8.
This block diagram can be evaluated with different torque inputs to simulate the behaviour of the system. Note that we treat the power amplifier as a simple gain.

For this example, deriving the differential equations to describe the system dynamics was relatively straightforward. In many cases the systems are more complex and deriving those equations can be a challenging and time-consuming task. An alternative first-principles modeling approach is to leverage advances in modeling tools to build up the plant from basic physical component blocks. Rather than the signal-based blocks that were used to model the differential equations, physical modeling blocks have energy-conserving ports that represent physical connections.

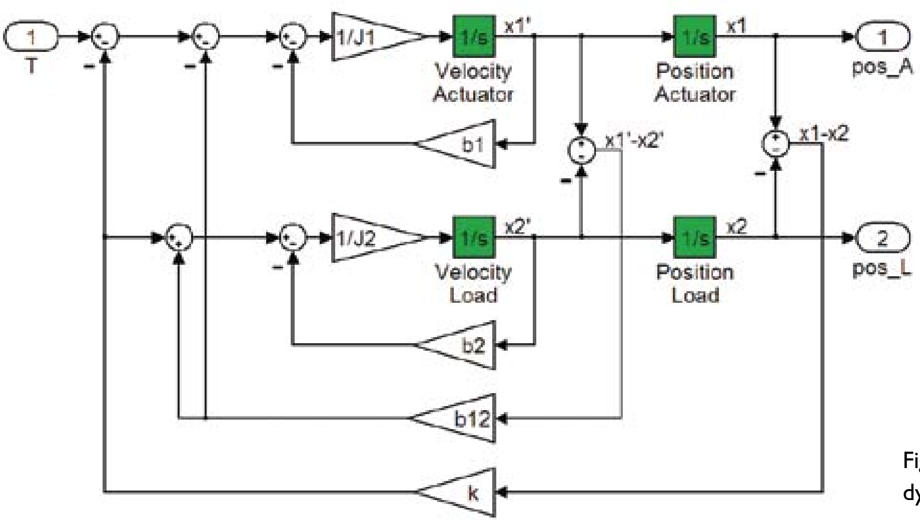


Figure 8. Simulink model representing the dynamics of the flexible transmission shaft.

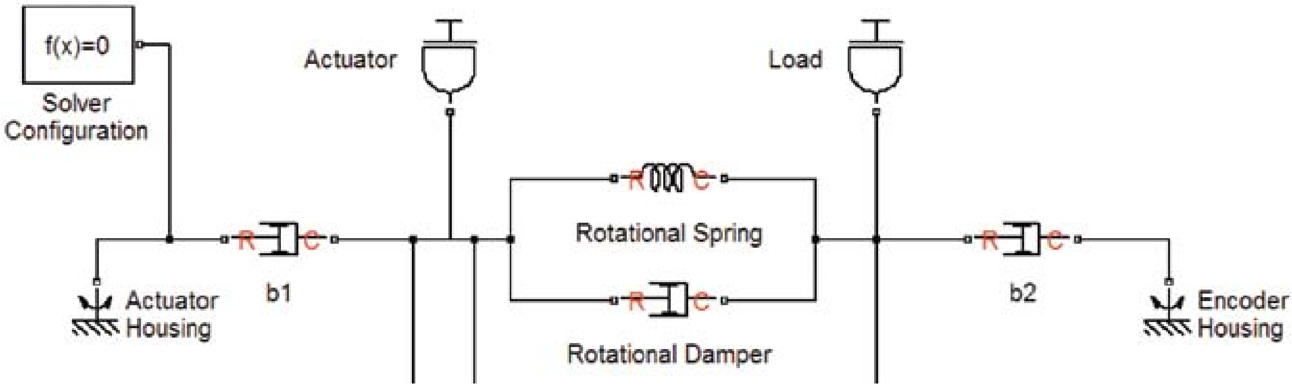


Figure 9. Physical modeling representation of the motion control plant using Simscape blocks.

Within Simulink this technology is provided by Simscape. It provides blocks for several different physical domains including mechanical, electrical, hydraulic, magnetic, pneumatic, and thermal. There is also the ability to extend existing blocks or create blocks from scratch using an object-oriented authoring language. Using physical modeling tools, the model of the motion control system can be created directly from the schematic in Figure 7 without deriving any equations. The block diagram for the physical model of the motion control system is shown in Figure 9. Not shown in the figure are additional sensor and actuator blocks that you can connect to the physical components to make the transition from the signal domain of Simulink to the physical domain of Simscape and vice-versa. These translation blocks allow you to apply the control system defined in Simulink to the physical model in Simscape in an integrated environment.

Yet another option to obtain an accurate model of the mechanics of the motion system is provided by SimMechanics. This method is especially useful if a CAD design of the system already exists. Using a CAD translator tool, which is available for a growing number of CAD environments, it is possible to automatically create a model of the rigid bodies in a system and connect them through appropriate joints. This saves even more time in developing the model and can also provide an animated visualisation of the plant. Figure 10 shows an example of this for the motion control system considered here.

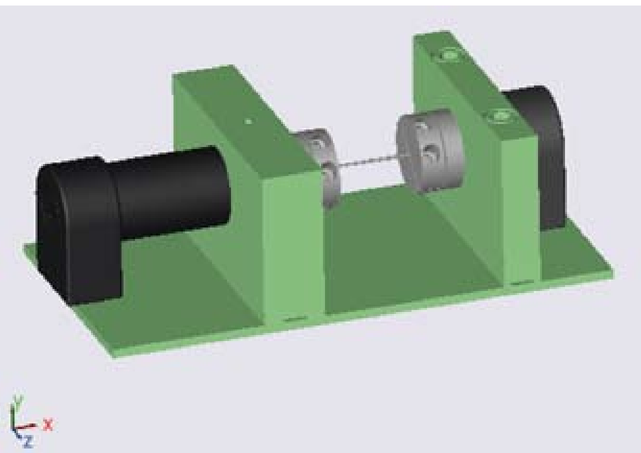


Figure 10. Visualisation of the motion control system after importing from a CAD environment.

This establishes three different methods for creating a first-principles model: deriving differential equations, modeling using physical components, and importing from an existing CAD design. In all of these methods we are using parameters, like stiffness and damping, which correspond to real physical properties.

In some cases the values for these parameters come from a data sheet or direct measurements, or they could simply be guesses. The values provide a starting point for design work, but may not have the accuracy that is necessary for finely tuning a control loop. Once the physical plant is available, it may therefore be helpful to validate the used model parameters.

This process, known as parameter estimation, involves acquiring data from the actual plant, choosing the parameters to estimate, and using optimisation algorithms to minimise the error between the simulated and measured responses. Simulink Design Optimisation can be used to automate this procedure.

Control development

We will look at two different types of control algorithms: classic continuous time control and logic, or supervisory, control.

Classic control

Working in a graphical simulation environment makes it trivial to quickly try different control topologies by simply rerouting lines in the diagram. In our example, the control structure already exists and consists of a feed-forward and a feedback controller. The feed-forward control calculates

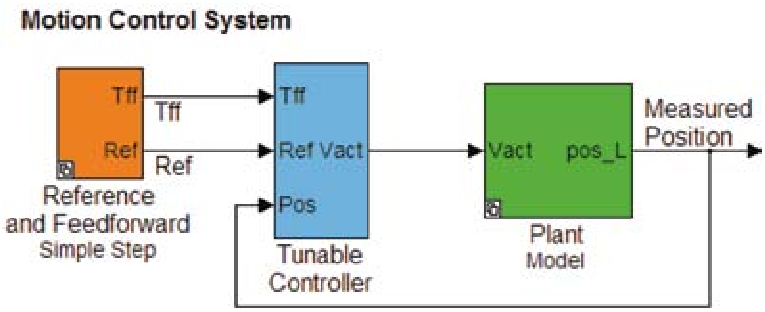


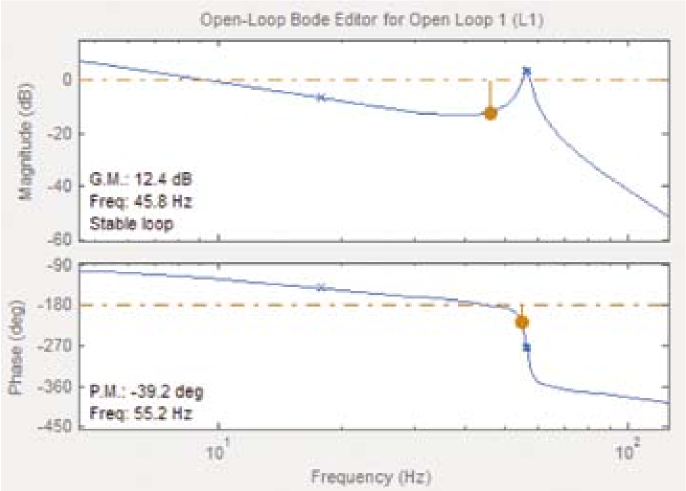
Figure 11. Model of the complete closed loop system.

the required torque to move the motor based on the desired trajectory [4]. Feedback control relies on measurements of the load position to adjust the torque and can compensate for disturbances such as a varying load. For this example, we will focus on the feedback control system and leave the feed-forward system as is. The original feedback control consists of a single discrete PD controller running at a sampling rate of 500 Hz [5]. The input to the controller is the error in the position and the output is a voltage reference for the power amplifier. With this we can construct a complete closed-loop model of our system as shown in Figure 11.

This complete system model now allows us to analyse the change in performance as the controller design is altered. While tuning the closed-loop response, we will look at the response of the load position on a step change in the reference position, disabling the feed-forward control.

A fairly standard approach to improve a motion system that suffers from a badly damped resonance due to structural flexibility is to add a notch filter in the feedback path. The idea is to leave the feedback signal unchanged for all frequencies except the exact frequency at which the resonance occurs. A measure for this is that the open-loop frequency response of the notch filter in series with the plant will no longer show the resonance peak as seen in Figure 6. Although this can be done with calculations, a very convenient and intuitive way to do this is by graphical manipulations, as can be done with Simulink Control Design. Starting point can then be the “open-loop Bode plot”, similar to Figure 6, but also showing the phase delay information. Adding a notch filter then simply amounts to dropping poles and zeros at the right frequency, and fine tuning them by grabbing and dragging. This procedure is illustrated with Figure 12. The updated open-loop Bode plot in Figure 12b has red circles at the resonance frequency. They are the tuned zeros of the notch filter.

Figure 13 shows that the closed-loop step response indeed has reduced oscillations associated with the resonance mode.



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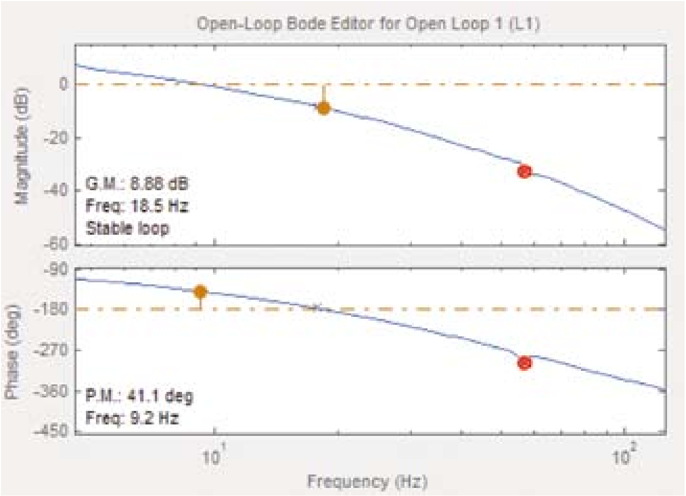

b

Figure 12. Adding a notch filter.
(a) Interactive open-loop Bode plot used for designing the enhanced controller.
(b) The resulting open-loop Bode plot.

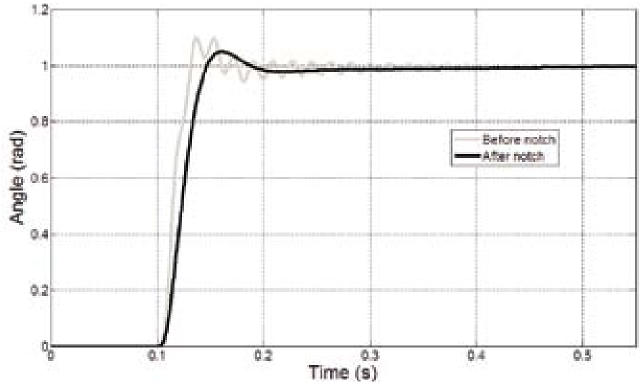

Figure 13. Closed-loop step response before and after adding the notch filter.

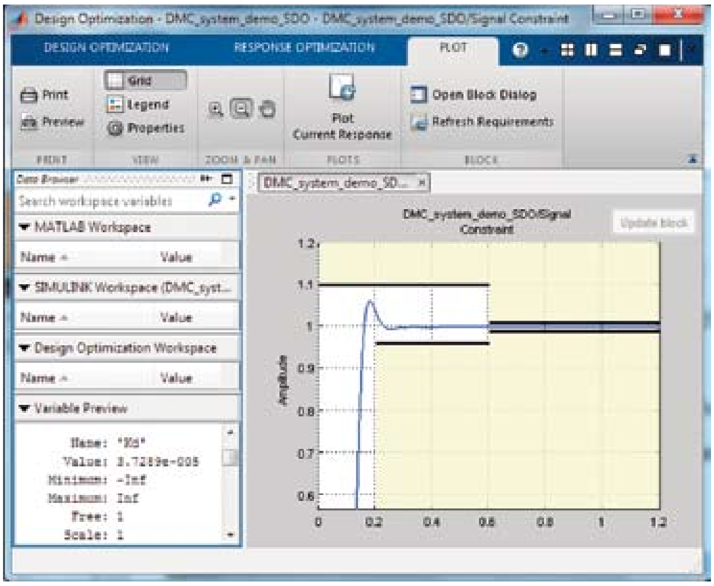

Figure 14. Step response with tuned PD gains.

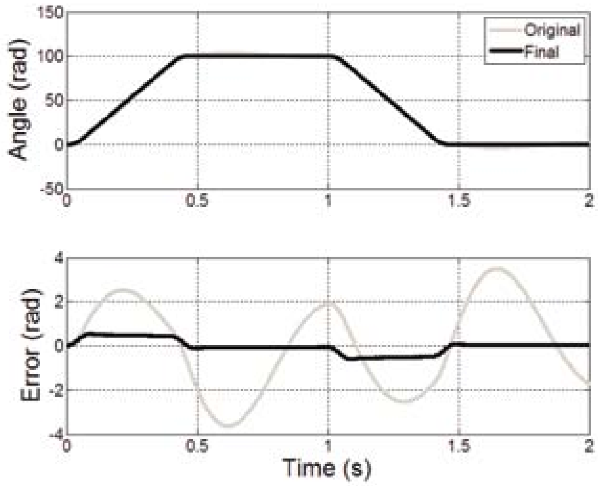

Figure 15. Position and position error with original and improved design.

Design optimisation

Next we can try to further improve the step response by tuning the PD controller gains. We could do this similar to the notch filter design, but as an example we will use a different approach based on numerical optimisation. Since we are in a simulation environment, we can run many simulations quickly and use optimisation algorithms to adjust the parameters to meet a specific goal. We can define the goal as a time-based requirement for one or more signals in the model.

In our case we set a specific set of step requirements for the position signal which can be displayed as boundaries on the step response plot as shown in Figure 14. We can then pick the parameters we want to tune: the P and D gains of our feedback controller. After running the optimisation routine you can see in Figure 14 that the step response has been improved and lies within the design requirements.

Now that we have completed the feedback controller design we can simulate the behaviour of the complete system for the desired point-to-point trajectory already considered in Figure 2. The result, given in Figure 15, clearly shows the position error is well within the desired range allowing the cycle time to be reduced.

Logic control

In addition to continuous control, many motion control applications will also have some logic-based control. Logic control usually changes what the system is doing based on some event. It could be a certain amount of time passing, an alarm going off, or an object reaching a certain position. Once this event happens, the system moves into a different state, perhaps initiating a new motion or going into a shutdown mode.

Figure 16 shows the fault-detection logic for our motion control system in Stateflow. It starts in a normal running state, but if the position goes outside of a safe limit, it switches into a warning state. If the position does not return to the safe limit within 5 seconds, we transition into an emergency stop state. Alternatively, if the position goes too far outside the range it will switch to the emergency stop state immediately.

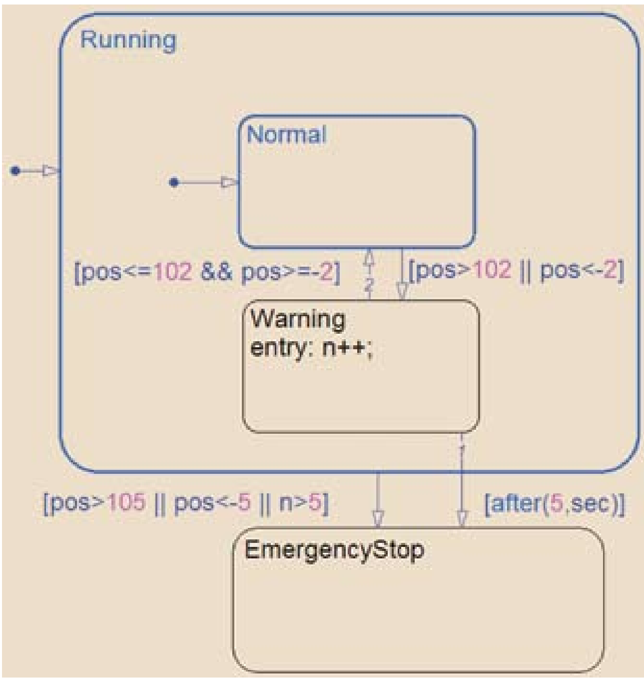

Figure 16. State chart defining the error detection logic.

The system can take different actions depending on what state you are in. In our case, for example, when in the emergency stop state, we will use a backup control system and command the position to a safe location.

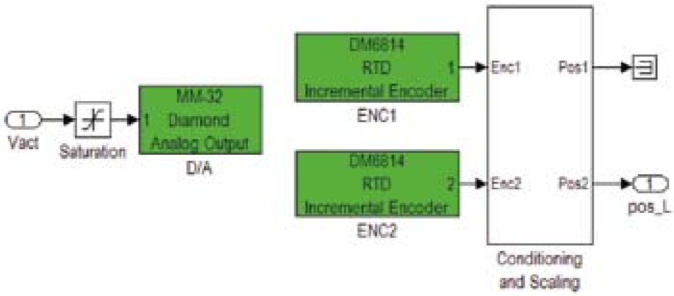

Figure 17. Plant model replaced with a hardware interface for rapid prototyping.

Now this is just a simple example: more realistic state charts may consist of hundreds of states and transitions. In those cases a graphical environment makes it a lot easier to identify and correct problems in the control logic.

Testing

In addition to providing an environment for quickly and interactively designing motion control algorithms, a simulation environment also enables thoroughly testing the motion control system and catching errors before fixing becomes expensive.

Running simulations

The first stage of testing can be done by simulating the system model; the requirements can then be validated very early in the development process. Once the control design is complete, a range of different test scenarios can be run by changing the inputs or the parameters of the simulation. For example, we can run the simulation for a range of stiffness and damping values given a certain distribution to ensure the motion system meets the performance requirements given manufacturing variations in the transmission shaft.

Rapid prototyping

Once the design has been tested in simulation, you may want to ensure that the control algorithms work with the actual plant. Rapid prototyping is testing the control algorithms in real-time with the physical plant hardware, but usually done before deciding on the final controller platform. For this we use an extension of Simulink called xPC Target, which enables the use of PC-compatible computer hardware for real-time testing. In Simulink, the plant model is exchanged for blocks that represent connections to the actual plant hardware. Automatic code generation with Simulink Coder then provides C-code that can be compiled and run in real-time on that separate target computer with the appropriate I/O cards installed.

A connection to the development computer, or host, remains available, so that the signals on the target can be monitored and parameters can be adjusted. With this approach you can use the host machine to run through the same tests that were used in simulation directly on the plant hardware. This verifies that any approximations or simplifications made when modeling the plant do not have a significant impact on the system performance.

In our motion control example, we use a Diamond MM-32 card to send the voltage command to the motor and a RTD DM6814 encoder card to read the motor and load positions as shown in Figure 17.

Figure 18 shows the response of the actual system compared to the predicted response from the simulation shown in Figure 15. Note that there are differences, but the simulated response was a good prediction of the actual system behaviour.

Implementation and HIL testing

In many cases, rapid prototyping can be sufficient to determine the controller or parameters that will ultimately be used in the machine. However, there will often be a need to implement the result in a specific embedded system that requires reprogramming the controller algorithm in embedded code: code that takes the limited resources and other peculiarities of a specific microcontroller into account. In the past this was considered the domain of highly specialised embedded software engineers, but we see that automatic code generation plays an increasingly important role here as well. Instead of rewriting the code, the specifics of the ultimate target are specified in the model using Embedded Coder. This ensures the model to be a true “executable specification,” a precise representation of the embedded code. This prevents manual coding errors and helps to maintain a direct and traceable link to the requirements and tests.

One form of testing that is enabled this way is called Hardware-in-the-Loop or HIL testing. Once the algorithm is embedded in the ultimate controller hardware it is useful to test the result on a simulation rather than the real machine. Typically we can now use the earlier developed plant model as a test environment by, again, using automatic code generation to obtain code running in real-time and suitable to be hooked up with the controller. Test scenarios that are unthinkable to execute in practice, or simply too expensive, can then be analysed extensively in the virtual world.

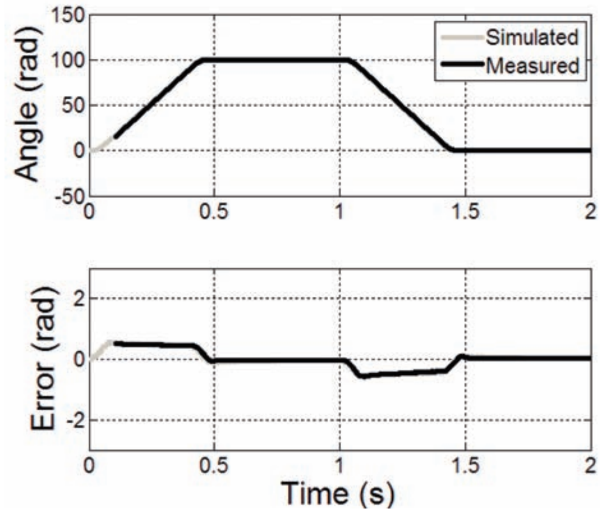

Figure 18. Position and position error for a point-to-point movement, measured from the actual system.

Conclusions

Nowadays it is common practice for mechanical and mechatronic designers to use a computer-aided design (CAD) tool when designing new mechanical components. It is seen as a necessity to prevent small mistakes from becoming very costly when they are not found until the actual assembly of the design. To further reduce (human) errors, there is also a growing use of automatically generated code to machine parts of the design on Computer Numerically Controlled (CNC) machines.

Model-Based Design is the extension of those same principles to the functional behaviour of a complete mechanical, or more often a mechatronic design. It specifically aims to reduce the risk of not meeting the functional requirements by enabling early and continuous verification throughout the entire design workflow. Furthermore, it provides an environment that is rich with numerical and graphical analysis and design tools that stimulate innovation and cooperation within design teams.

All this is combined with automatic code generation capabilities for real-time testing of the design and a growing acceptance of embedded software designers that code generation technology is not only a viable way to deal with the exponential growth in complexity and size of embedded software, but also becoming sufficiently powerful and efficient for actual production use.

This paper illustrates these advances using an admittedly simple, but realistic motion control system, showing a range of software technologies in modeling and control design that are now readily available 'off the shelf.' The initial application of Model-Based Design on a real project within a design team will require investment of time and money, as well as willingness from those involved to do things differently. There are, however, many reported cases where Model-Based Design has been successfully applied company-wide, roughly cutting development time in half.

Acknowledgement

This paper made use of the Model-Based Design environment of MathWorks. The specific tools needed to reproduce the results in this paper are: MATLAB, Simulink, System Identification Toolbox, Stateflow, Simscape, SimMechanics, Control System Toolbox, Simulink Control Design, Simulink Design Optimisation, MATLAB Coder, Simulink Coder, and xPC Target. The models and scripts to reproduce most of the results in this paper are publicly available through MathWorks' user community [6].

References

[1] Boucher, M., "System Design: New Product Development for Mechatronics". Aberdeen Group, Boston, 2008.

[2] Dabney, J.B., Barber, G., and Ohi, D. (NASA). "Estimating Direct Return on Investment of Independent Verification and Validation". *Proceedings of the 8th International Conference on Software Engineering and Applications*, Cambridge, USA, 2004.

[3] Ljung, L., "System Identification: Theory for the User" (2nd ed.), Prentice-Hall Information and System Sciences Series, PTR Prentice-Hall, Upper Saddle River, NJ, 1999.

[4] Lambrechts, P., Boerlage, M., and Steinbuch, M. "Trajectory planning and feedforward design for electromechanical motion systems", *Control Engineering Practice*, Vol. 13, pp. 145-157, 2005.

[5] Franklin, G.F., Powell, J.D., and Workman, M., "Digital Control of Dynamic Systems" (3rd ed.), Addison-Wesley, Menlo Park, CA, 1998.

[6] www.mathworks.com/matlabcentral (search for motion control demo).

Automating Dynamic

The performance of precision machines is limited by the disturbances affecting these machines. These disturbances are mostly of a stochastic nature. Dynamic Error Budgeting (DEB) is a method that allows engineers to calculate the performance degradation resulting from each of the disturbances. Up to now, its application has been limited by the large amount of complex calculations that are required. 20-sim has broken this barrier by introducing a DEB tool that automates the calculations.

• *Paul Weustink* •

This article outlines the application of Dynamic Error Budgeting (DEB) in 20-sim based on the theoretical background and positioning system case described in [1]. It demonstrates how 20-sim can be used to calculate the error budget of the test system, as well as make design changes to optimise system performance. Engineers are now able to take full advantage of DEB by analysing the effects that individual disturbances have on a machine's total output. They only have to concentrate on the disturbance specifications and use the toolbox to calculate the resulting machine performance. This allows them to do quick iterations to find the optimal machine design.

20-sim

Controllab Products' 20-sim modelling and simulation package suits mechatronic system design perfectly. The package contains libraries of physical components and block diagram libraries that allow the user to quickly create models of computer-controlled systems. The package's various toolboxes help to analyse systems in both the time and the frequency domain. The latest 4.2 version of 20-sim, [2], has been enhanced with a DEB tool.

Author's note

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Positioning system case

The DEB tool can be used to analyse the positioning system case, as shown in Figure 1 and as described in [1]. A tool tip is positioned in the system in relation to a stator with a positioning error less than 50 nm (RMS). The tool tip is attached to a rotor, of which the remaining five degrees of freedom are restrained by spring blades. The

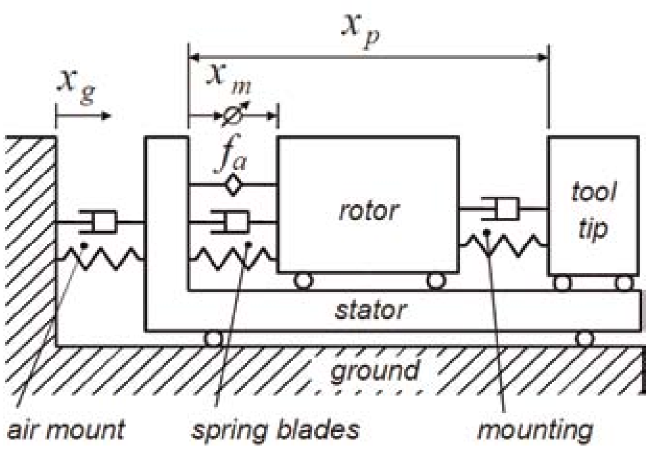


Figure 1. Lumped-mass model representation of the positioning system.

Error Budgeting

rotor's position is measured using a sensor and is fed back to a digital controller. The controller directs the actuator, which acts between the rotor and the stator.

Modelling

Using library blocks from the built-in translation library, the physical parts of the positioning system can easily be modelled in 20-sim. The following blocks are used:

- three masses (for the stator, rotor and tool tip);
- three spring dampers (for the air mount, spring blades and mounting);
- one position actuator (for the ground movement);
- one force actuator (between the stator and rotor);
- two position sensors (for positions *x_m* and *x_p*).

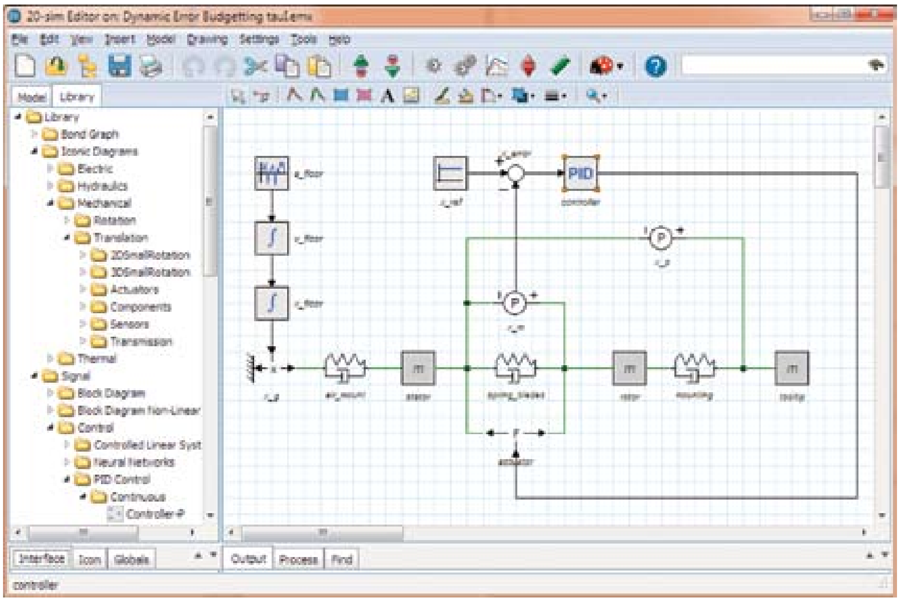


Figure 2. 20-sim model of the controlled positioning system with ground disturbance.

The computer control part of the model is created using blocks from the built-in block diagram library:

- one constant signal (for the position reference);
- one plus-minus signal (for the position error);
- one PID controller (for the actuator force);
- one noise generator (for the ground acceleration);
- two signal integrators (for the ground velocity and position).

These blocks can be dragged from the library and connected according to the outline in Figure 1. The resulting model is shown in Figure 2. A controller measures the rotor position with respect to the stator, and steers the actuator force to get the desired position of the tool tip. The ground movement is added by integrating a noisy acceleration signal.

The next step is to specify the parameters of the system. The physical parameters of the positioning system are given in [1] and shown in Table 1.

The controller is tuned so that the position error is within the desired 50 nm when a noise amplitude of 45 mm/s^2 is used for the ground disturbance.

Table 1. Parameters of the positioning system.

Description	Value	20-sim parameter
stator mass	500 [kg]	stator\m
rotor mass	2.3 [kg]	rotor\m
tool-tip mass	0.2 [kg]	tooltip\m
air-mount frequency	2 [Hz]	air_mount\f
air-mount damping	0.1 [-]	air_mount\b
spring-blade frequency	5 [Hz]	spring_blade\f
spring-blade damping	0.01 [-]	spring_blade\b
mounting frequency	150 [Hz]	mounting\f
mounting damping	0.005 [-]	mounting\b

Simulation

A time simulation is performed to check if the controller works as it should. Figure 3 shows that the tool tip's position in relation to the stator does indeed have a position error less than the desired 50 nm. This position error will, however, increase when other disturbances, like sensor noise and electronic noise from the DA- and AD-converters, are added to the model.

Frequency domain

The next logical step for a mechatronic engineer is to verify the system in the frequency domain. Frequency responses can be generated automatically in 20-sim by

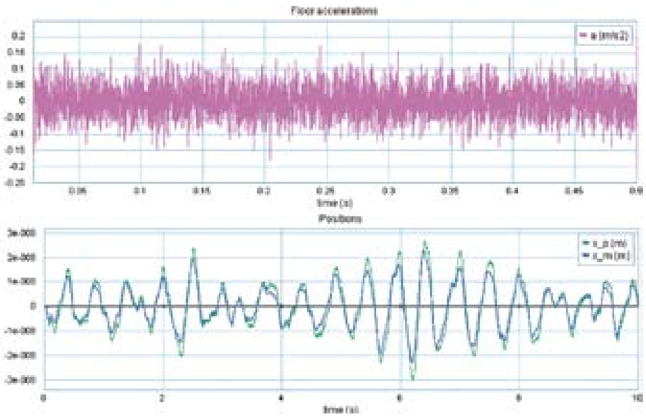


Figure 3. Time simulation of the controlled positioning system.

specifying the desired input and output variables. 20-sim uses symbolic linearisation to determine the resulting transfer functions, and it can present the results in a number of ways, e.g. by using Bode plots. Figure 4 shows the system's Bode plots from the actuator force to the relative position of the rotor (*x_m*) and the tool tip (*x_p*). The resonance frequencies are clearly visible at 5 Hz and 150 Hz.

Dynamic Error Budgeting

There are several disturbances affecting the positioning system, such as the noise of the amplifier, the ground vibrations and the noise of the sensor. The idea behind the DEB method is that it demonstrates how the combined

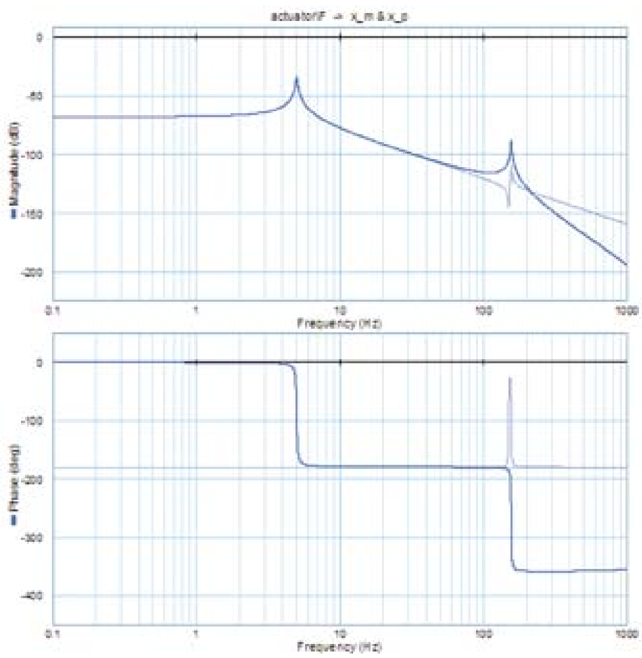


Figure 4. Bode plots from the actuator force to the relative position of the rotor and the tool tip.

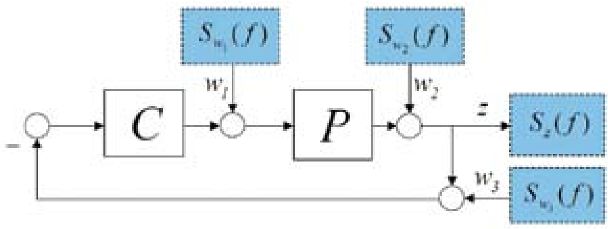
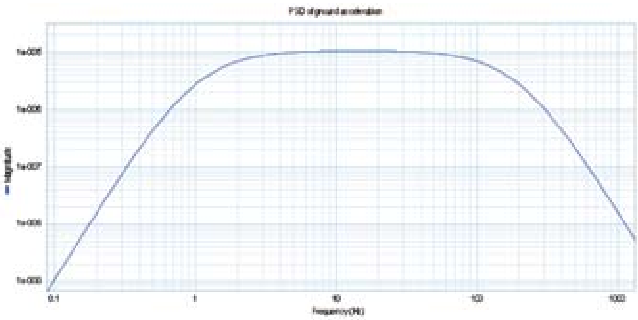


Figure 5. Closed-loop system with three disturbances represented as PSDs.

effect of these disturbances determines the final performance of the positioning system. It presents the relationship between the disturbances and the final performance, which can result in a design tool that can be used to budget the performance specification over the subsystems [1].

a



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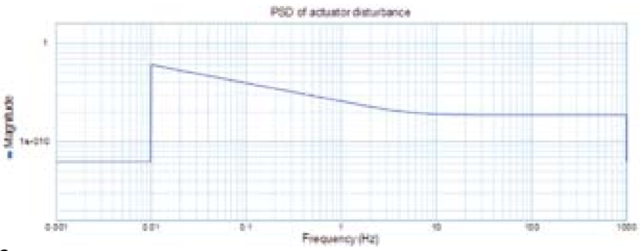

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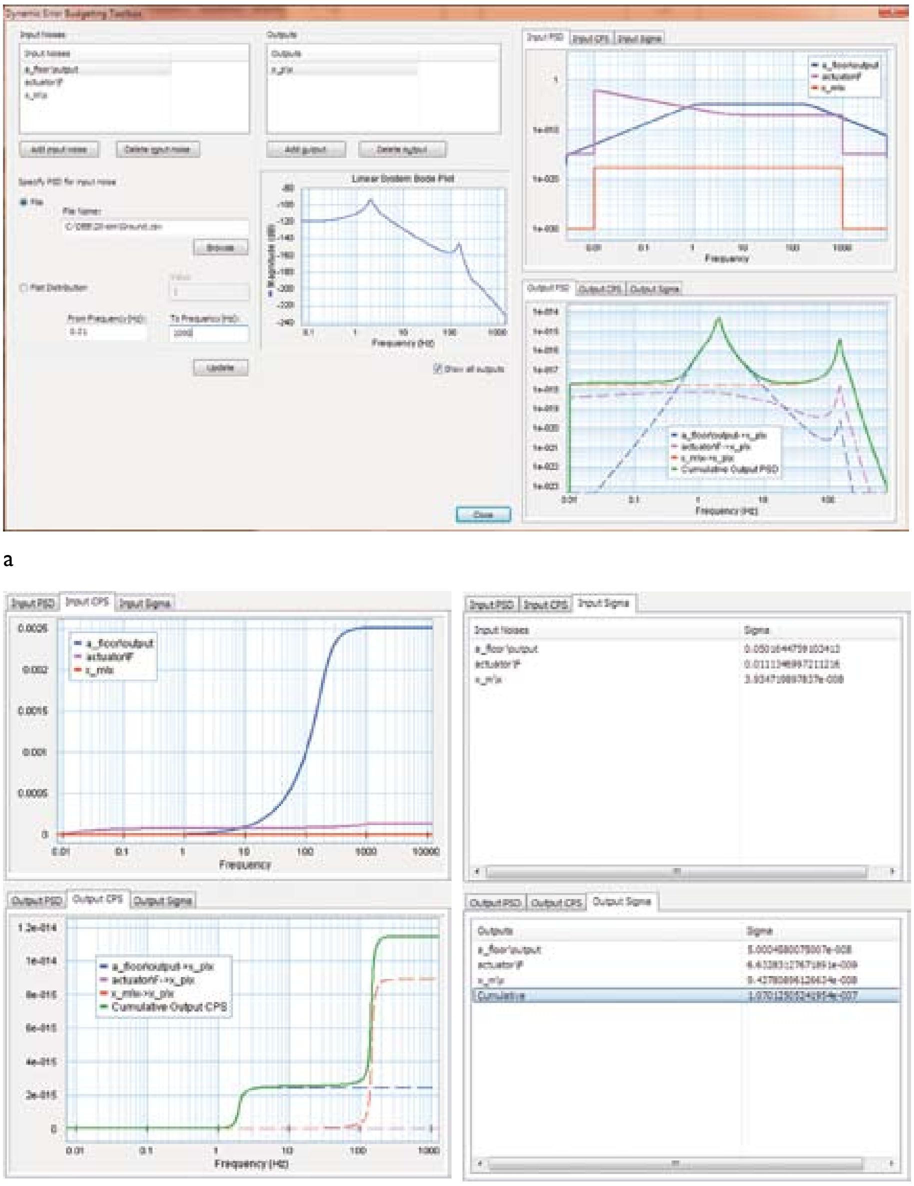
Figure 6. PSDs of the disturbances.
(a) Sensor.
(b) Ground.
(c) Actuator.



a

b

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Figure 7. 20-sim DEB tool
(a) On the right, the first tab, showing the input and output PSDs.
(b) The second tab, showing the input and output CPS.
(c) The third tab, showing the sigmas of the input, the output and the total cumulative output.

The disturbances are specified in the frequency domain as Power Spectral Density (PSD) functions. Parseval's theory presents a relationship between the time domain signal $x(t)$ and the frequency domain $PSD_x(f)$:

$$\|x\|_{rms}^2 = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} x(t)^2\,dt = \int_0^\infty PSD_x(f)\,df \qquad (1)$$

The theory of propagation outlines how the PSD of the output is determined by the PSDs of these disturbances using the transfer function H_i from the disturbances w_i to this output z:

$$PSD_z(f) = \sum_i H_i(f)^2 \cdot PSD_{w_i}(f) \qquad (2)$$

(See Figure 5.)

So, if the disturbances are described as PSDs, and the transfer functions from the disturbance to the output of the system are known, calculating the combined effect of these disturbances on the output becomes an easy task.

Finally, the PSD of the output can be translated into a measure (the performance budget) using the integral of the PSD, which is known as the Cumulative Power Spectrum (CPS):

$$CPS(f) = \int_0^f PSD(v)\,dv \qquad (3)$$

Equation (1) shows that the end value of this CPS equals the variance of x. Taking the square root of the end value results in the 1σ value, which is used as the performance measure of the system:

$$\sigma = \sqrt{CPS(\infty)} \tag{4}$$

Disturbances
In the positioning system example, three disturbances are given [1], for the sensor, the actuator and the ground (see Figure 6):
- The sensor disturbance is considered as white noise with σ_{sensor} = 39 nm and PSD_{sensor} = 1.55 nm^2/Hz up to 1 kHz.
- The ground disturbance is measured as an acceleration signal with σ_{ground} = 12 mm/s^2 and a *PSD* of 10^{-5} (m/s^2)^2/Hz between 1 and 200 Hz.
- The actuator disturbance can be described as a σ_{Fq} = 7 · 10^{-3} N^2/Hz, and a $1/f^2$ filter at 5 Hz starting at 0.01 Hz.

In practice, the disturbances can be calculated as shown in this example or measured on existing set-ups.

20-sim DEB tool
Once the disturbances are qualified, calculating the resulting position error in 20-sim is straightforward. The DEB tool will perform all the necessary calculations. Figure 7 gives an impression of the tool.
On the left-hand side in Figure 7a, the input disturbances have to be specified by selecting corresponding model variables. In this example, the ground acceleration, the force of the actuator and the relative position of the rotor have been selected. The disturbances are specified by their PSDs, either as a flat distribution over a frequency range or by a comma-separated value (CSV) file. The corresponding plots are shown at the top right. The desired output has to be selected at the top middle. In this example, the position of the tool tip relative to the stator is chosen. The Bode plot in the middle shows the closed-loop transfer function of the selected disturbance to the output.

The DEB tool will calculate the effects of the disturbances on the outputs. The results are shown in three tabs at the bottom right: PSD plots, CPS plots, and the resulting sigma values. Figure 7a shows the output PSD as a result of the individual disturbances.
The second tab shows the cumulative power spectrum (CPS) plots (see Figure 7b). The CPS plots provide an insight into the composition of the disturbance to the output (the performance error), as well as an insight into the dominant frequency ranges of the contributions of these disturbances.

The last tab, as shown in Figure 7c, will show the corresponding sigma values (standard deviations) and the cumulative sigma (the performance error). The sigmas are in the same unit as the output variable. In this case, these numbers are in [m], so the performance error here is 107 nm. This is greater than the desired value of 50 nm, so attempts have to be made to optimise the system.

Optimisation
The 20-sim DEB tool helps the designer to optimise a system in a structured manner, i.e.:
- calculate the total performance error budget;
- if the budget is too high, inspect the CPS plots to identify the frequency at which the largest contribution is made to the total budget;
- find countermeasures to minimise this contribution – these countermeasures could be changes to the physical system or modifications to the controller;
- implement these countermeasures in the model, and recalculate the total performance error budget.

The process may require several iterations. [1] outlines how using a notch filter and an increasing integral action will reduce the total performance error budget to 45 nm, which meets the requirements.

The major advantage of DEB is that it allows the engineer to predict the overall accuracy of a system being affected by stochastic disturbances. The method is based on linear systems theory and, therefore, it allows the engineer to implement changes without compromising standard design methods.

Conclusion
Using the 20-sim package and the 20-sim DEB tool, it is possible to quickly apply the Dynamic Error Budgeting method and try out a number of scenarios on a wide range of mechatronic systems. A demo version and trial licence are freely available from [3].

References

[1] L. Jabben, and J. van Eijk, “Performance analysis and design of mechatronic systems”. *Mikroniek*, Vol. 51(2), pp. 5-12, 2011.
[2] C. Kleijn, M.A. Groothuis, and H.G. Differ, “20-sim 4.2 Reference Manual”, Controllab Products, Enschede, 2011.
[3] www.20sim.com.

Software-aided correct

Injection moulding tools rarely start off delivering the ideal product. With shrinkage and distortion, new plastic products show deviations from the tolerances outlined in the technical drawings. Complex high-precision work pieces are particularly susceptible to such deviations. The PointMaster software system developed by the Wenzel Group can compensate for shrinkage and distortion by comparing real and target dimensions in an iterative fault-compensation process. The real dimensions are the measurement results from a Wenzel CT exaCT XS computer tomograph, and the target values are CAD data provided by the product designer.

• *Frans Zuurveen* •

Industrial X-ray Computer Tomography, as used in Wenzel exaCT contactless measuring machines, makes it possible to look inside objects and, therefore, discover dimensional deviations and even internal flaws. The new table-top CT exaCT XS [1] (see Figure 1) has been specially designed to measure small plastic parts.

Starting the iterative chain

Figure 2a shows CAD models of the demonstration product for which Hachtel Werkzeugbau in Aalen has manufactured an injection moulding tool. This German company specialises in the manufacturing of moulds and in multi-component injection moulding. Hachtel Werkzeugbau successfully utilises a Wenzel CT exaCT

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

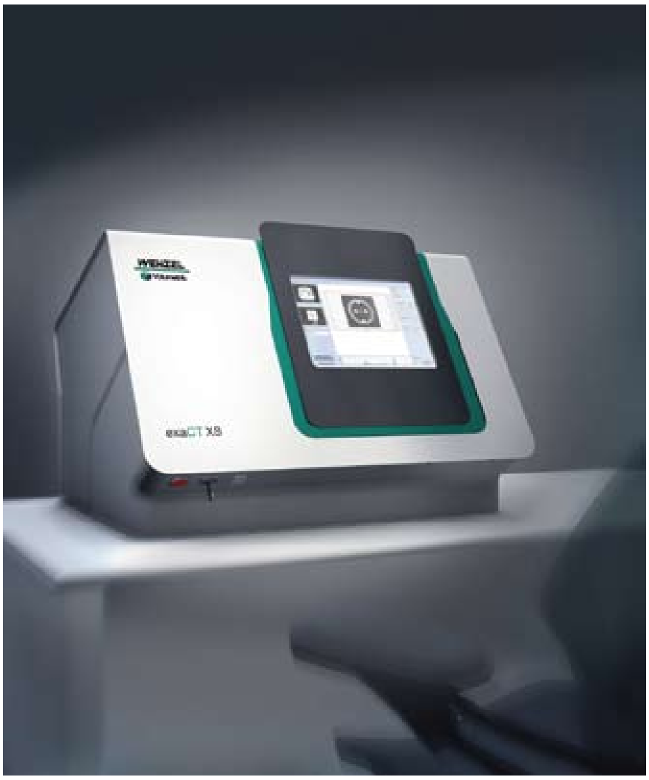

Figure 1. The Wenzel table-top CT exaCT XS measuring machine, designed to measure small plastic components.

CT helps to injection moulds

a b

Figure 2. Demonstration plastic products for which Hachtel Werkzeugbau has manufactured an injection moulding tool.
(a) CAD models.
(b) Result of a contactless scan in the CT exaCT XS.

Figure 4. Reconstruction of the scan data by Wenzel PointMaster software using STL files.

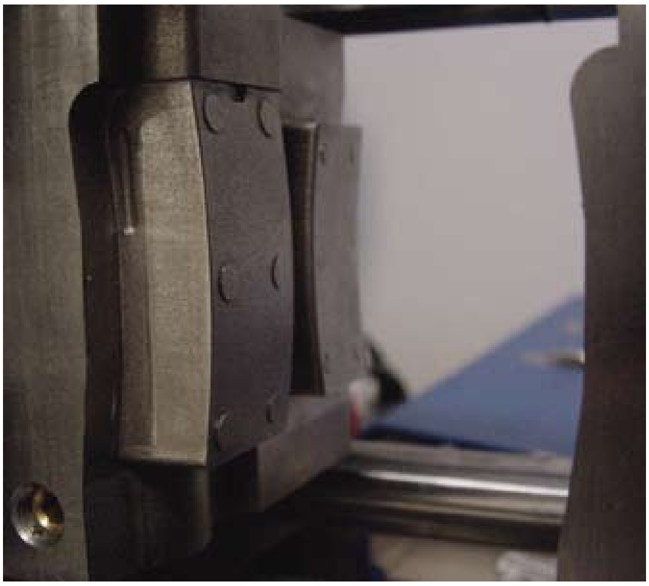

Figure 3. The bottom part of the injection moulding tool manufactured by Hachtel Werkzeugbau. The six product ejectors are clearly visible. (Photo courtesy Hachtel Werkzeugbau)

measuring machine with PointMaster software to optimise and correct injection moulds; see Figure 3. The test product is a small plastic box with the following external dimensions: 9 mm high, 25 mm wide and 46 mm long. The iterative chain of fault-compensation steps starts with the contactless scan of the real injection-moulded product in the Wenzel exaCT XS measuring machine (see Figure 2b). The internal product dimensions are 6 x 20 x 43 mm^3. The small wall thicknesses of 1.5-2 mm imply that the product will most probably be susceptible to distortion.

The next step is the reconstruction of the scan data by the Wenzel PointMaster software program (see Figure 4). This program removes form deviations like engraved text, ejector markings, gas cavities and small injection faults, and smoothes out the data sets per curved plane. It uses STL (Standard Template Library) data to describe the curved plane geometry as a best-fit triangulated surface grid selected from the file library. To determine the geometry, PointMaster needs a larger number of triangles for strongly curved surfaces than for rather flat surfaces.

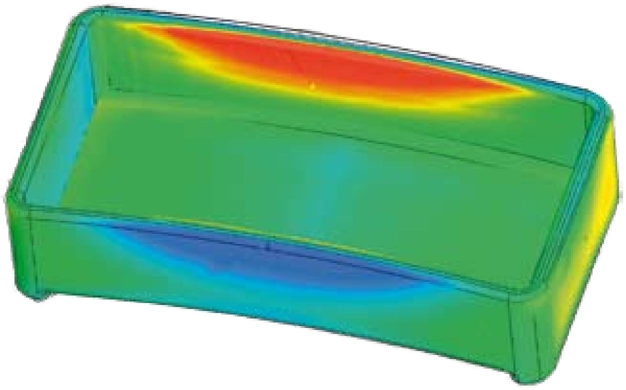

Figure 5. Comparing real and target dimensional data by PointMaster. Red and blue: deviations from tolerances.

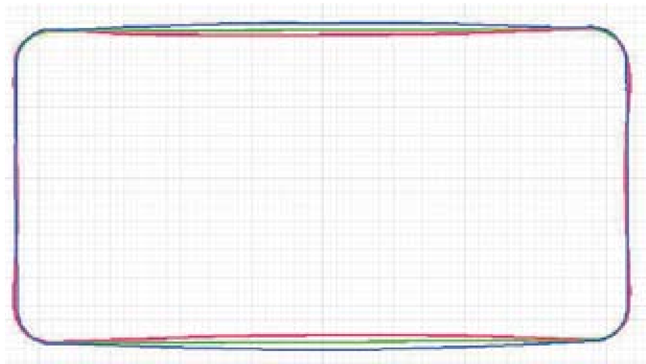

Figure 6. Product cross section illustrating the dimensional compensation strategy. Green: CAD profile. Red: real dimensions. Blue: compensated profile for next test injection.

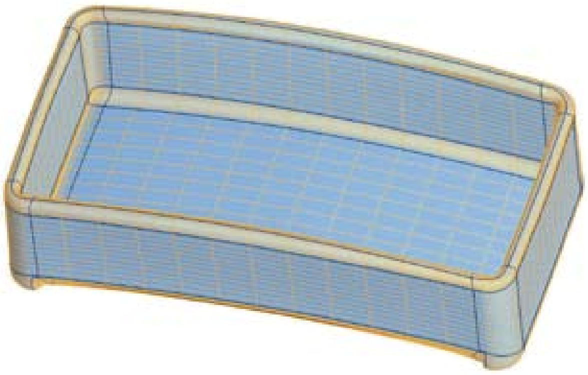

Figure 7. Scan data reconstructed by PointMaster after measurement of the second test product.

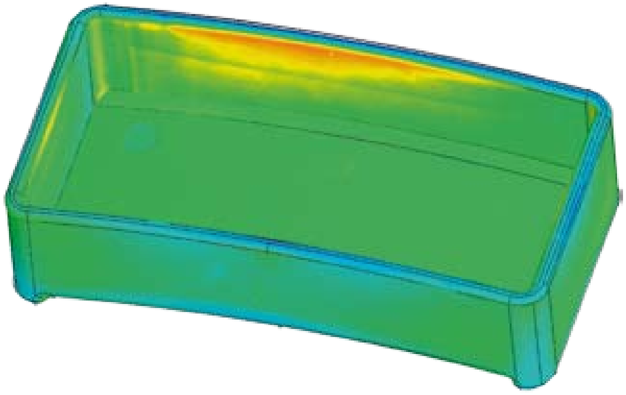

Figure 8. Comparison of real and target dimensions of the second test product, showing tolerances, indicated in red, that have only slightly been exceeded.

Target against real

The most interesting step in the iterative PointMaster chain is comparing the real and target dimensional data of the product. Figure 5 shows the results of this analysis. The deviations in red and blue, which exceed the tolerances, indicate an inward distortion of both long sidewalls. This enables PointMaster to calculate a global compensation procedure. The aim of this procedure is to make local adjustments by bending and transformation based on strategies derived from the knowledge and experience of toolmakers. This tool adaptation algorithm also incorporates the flow properties of the plastic material. The algorithm is based on a broad set of technological parameters collected in cooperation with the Technische Universität München, Germany.

Figure 6 shows a cross section illustrating the dimensional compensation strategy. Red corresponds to the real dimensions, blue to the compensated dimensions as a result of the first iterative step. The toolmaker now has to modify the mould according to the blue line. After a second test injection with the same process parameters, the product should correspond to the green line.

Second test injection

After the injection mould correction as shown in Figure 6, a second test injection is carried out. Figure 7 shows the scan data of the new product reconstructed by PointMaster after measurement in the exaCT XS instrument. The evidence for the successful outcome of the iterative compensation strategy is shown in Figure 8, in which the differences between the real and target dimensions are given again. Nearly all the deviations for the entire product stay within the tolerance of ± 0.1 mm. Only the upper part of one of the side walls shows some of the dimensions exceeding the tolerance limits in red.

An even more convincing result is the statistical analysis of the data in Figure 9. The curve shows that most of the deviations stay within the tolerance limits of 100 μm at

Information

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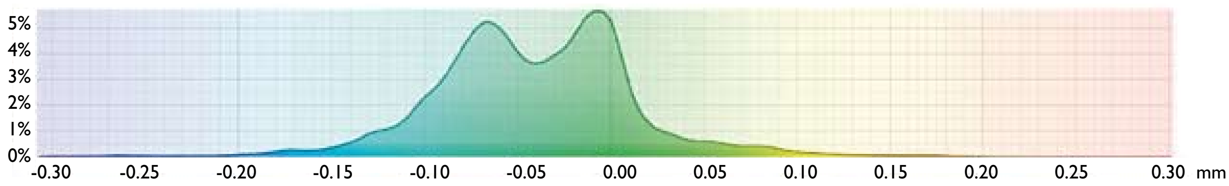


Figure 9. Statistical analysis of the data by PointMaster. The curve shows that the tolerance limits in the negative direction, shown in blue, have been exceeded slightly.

both sides of the nominal dimensions. There are a few values that have been exceeded in the negative direction only. This could be corrected in a third iterative step, if the tool were adapted a little bit further.

To conclude

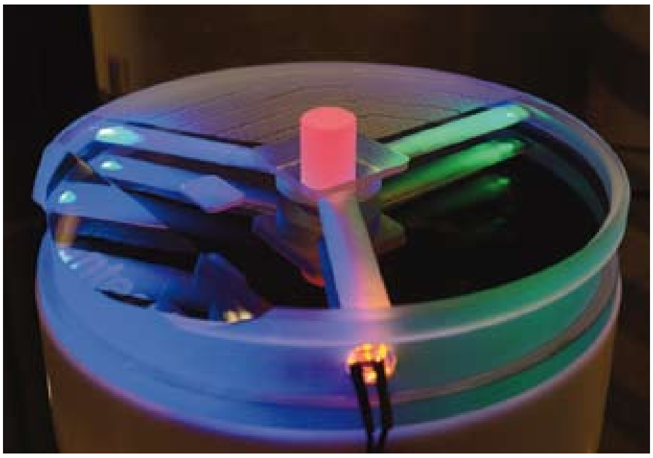
The exaCT series of Wenzel Group measuring machines are very helpful for measurements inside objects, where conventional measuring methods with stylus or optics fail. By incorporating powerful software like PointMaster, the CT measurement procedures become even more user-friendly. Adapting injection moulding tools in a limited number of iterative steps illustrates the power of PointMaster, in terms of reducing measurement time and tooling costs.

References

[1] F. Zuurveen, "X-rays measure inside objects", *Mikroniek*, Vol. 50 (2010), no. 4, pp. 44-47.

More visitors,

The Precision Fair that was held in Veldhoven, the Netherlands, on 30 November and 1 December 2011 attracted a record number of 3,200 visitors and 225 exhibitors. Reporting on the Benelux's premier trade fair on precision engineering, organiser Mikrocentrum said that this eleventh edition had a more international feel than ever before, with more visitors and exhibitors from abroad (12% and 18%, respectively). The lecture programme featured a large number of interesting keynote speakers.



Exhibitor at the Precision Fair 2011 Anteryon specialises in creating solutions using precision glass processing techniques for industrial applications, imaging, telecommunication and microsystems, e.g. CNC lens manufacturing. (Photo courtesy of Jan Pasman, Mikrocentrum)

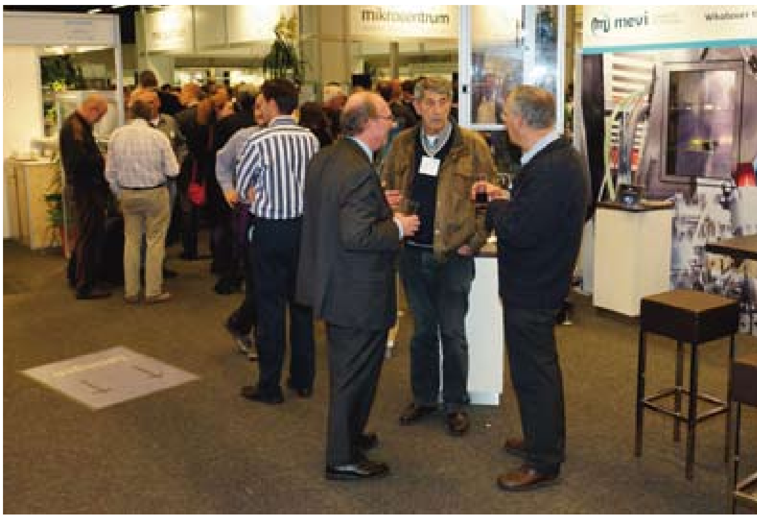
Each year, the Precision Fair attracts exhibitors from over 200 specialised companies and knowledge institutes in a wide range of disciplines, including optics, photonics, calibration, linear technology, materials, measuring equipment, micro-assembly, micro-connection, motion control, surface treatment, packaging, piezo technology, precision tools, precision processing, sensor technology, software and vision systems. The fair is organised by Mikrocentrum, with the support of DSPE and NL Agency. The next fair will be in Veldhoven on 28 and 29 November 2012.

Technology Hotspot

Once again, one of the highlights of the 2011 fair was the Technology Hotspot. This is where students from the three Dutch universities of technology, the universities of applied sciences Fontys, Avans and Utrecht, and the Leiden Instrument Makers School presented their research and technological skills, attracting a lot of attention from the industry. What is also worth noting is that young engineers were well represented among the visitors to the Precision Fair 2011.

Lecture programme

The lecture programme comprised a total of 48 contributions, all of which can be downloaded from the



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

more keynotes

Precision Fair website. As always, most lectures were given by exhibitors, and topics included micro-machining and micro-manufacturing, motion control, measurement, engineering and design. Some of these will be elaborated on and published in Mikroniek, e.g. the lecture on "Mass production using lasers, accurate down to the micrometer day after day" given by Jurgen Adriaensen, a process developer in laser applications at Philips GTDM in Turnhout, Belgium. A more detailed version of the lecture given by Christian Kleijn, the director of Controllab Products, "Tools for Dynamic Error Budgeting", is already included in this edition of Mikroniek.

Keynotes

When compiling the 2011 lecture programme, the Precision Fair organisers took special care to draw up a particularly interesting keynote programme. Topical issues were selected, the number of keynotes increased and keynote lectures organised in four sections of three lectures each:

- Haptic systems
- Micro-manufacturing
- Over-actuation/actuators
- IOP projects

Haptic systems

Herman Soemers, Mechatronics Technology Manager at Philips Innovation Services and Professor of Mechatronic Design at the University of Twente, chaired the keynote session on haptic systems.
Frans van der Helm, a professor in the Biomechatronics & Biorobotics group at Delft University of Technology, talked about optimising shared control between people and the intelligent controller for telemanipulation tasks using force and stiffness feedback. The aim of this approach is to compensate for the sluggish mechanics of the master and slave devices, and to perform much better than the traditional transparent control.
John van den Dobbelsteen, an assistant professor in the Medical Instruments group at Delft University of Technology, discussed haptic feedback in percutaneous interventions, where the accurate placement of the needle tip is essential. Steering the needle by robot could potentially minimise targeting errors and improve patient care.
Michiel Oderwald, a medical devices sales manager at TNO, presented the so-called minimally-invasive force-reflective operation instrument, which uses haptic feedback technology to bring back the feeling of tissue grasping to the surgeon. When compared to open surgery, minimally-invasive surgery benefits patients more, but the surgeon's ability to see and feel during interventions is significantly reduced. New technologies, such as haptics, can give surgeons back the senses taken from them.

Micro-manufacturing

Chaired by Peter ten Haaf, who is in charge of advanced materials processing at Sirris, the collective centre of the Belgian technology industry, the keynote session on micro-manufacturing covered various technologies.
André Hoogstrate, a precision manufacturing research engineer at TNO, discussed the transition of micro-milling from academia to industry. He presented an overview of recent developments and the potential of micro-milling in various application fields and for a range of materials, from relatively soft materials such as graphite and aluminium to hard materials such as hardened steels for moulding applications.

Three-dimensional micro-EDM milling of a turbine impeller (see the article in Mikroniek, Vol. 50 (1), pp. 28-34, 2010).

As presented in the keynote lecture by Rens Henselmans at the Precision Fair 2011, and in the article in Mikroniek, Vol. 48 (5), pp. 5-8, 2008, NANOMEFOS, a measurement machine for freeform optics, was developed in an IOP project.

Following this lecture, Bert Lauwers, a professor in the department of Mechanical Engineering at K.U.Leuven University, Belgium, discussed the integration of micro-milling with micro-EDM (Electrical Discharge Machining). This was part of a presentation on state-of-the-art micro-EDM and its applications, a production technology for manufacturing precise features in conventional as well as more advanced materials such as ceramics.
Hessel Maalderink, a rapid manufacturing research scientist at TNO, gave a lecture on mask projection micro-stereolithography, a high-speed option in the emerging field of additive manufacturing (AM) technologies. AM changes the way some products are designed and manufactured, which is especially relevant for micro-scale systems, in which design freedom and part integration are important factors.

Over-actuation/actuators

The keynote session on over-actuation and actuators was chaired by Hans Vermeulen, a mechatronics project manager at ASML Research. It comprised three presentations by Ph.D. candidates from Eindhoven University of Technology.
Jaron Achterberg talked about the flexible deformation reduction of a moving magnet planar actuator, highlighting the fact that such an actuator generally has more active coils than the number of degrees of freedom that have to be controlled. Reducing flexible deformations of the mover will allow for a mechanical design that is less stiff and can result in less moving mass.
Andelko Katalenic addressed the benefits and challenges of reluctance force in high-precision engineering. Future high-precision industrial motion systems require new actuator designs that deliver higher forces with higher efficiency and less added mass. The popular Lorentz actuators have reached their physical limits, and actuators that are based on reluctance force are a promising new candidate.
Rob Hoogendijk presented frequency-response data-based techniques for high-precision motion systems. The trend towards lightweight systems, causing flexible dynamics to shift to lower frequencies, poses a challenge for control design. Seeing as modelling is not straightforward, frequency-response data-based methods such as the data-based computation of the closed-loop poles to predict the transient behaviour of the closed-loop system are now being considered.

IOP projects

The last keynote session featured three lectures on projects from the Dutch innovation-oriented research programme (IOP) Precision Engineering. Former IOP chairman Lou Hulst chaired this session. Three former Ph.D. candidates presented the results and applications of their projects:

- NANOMEFOS (a measurement machine for freeform optics) by Rens Henselmans, a system engineer in the Optomechatronics department at TNO.
- Adaptive deformable mirror based on electromagnetic actuators by Roger Hamelinck, a mechanical engineer and the owner of Entechna Engineering.

The LMSA integrated inductive length measurement system as demonstrated by Schaeffler in combination with its KUVE-B Rowball Type Profiled Rail Units.

a

b

Exhibitors at the Precision Fair 2011 included:
(a) Irmato – supporting customers in the total product life cycle, from research to development & engineering, project management, supply chain management and assembly/realisation.
(b) Renishaw – a global company with key skills in measurement, motion control, spectroscopy and precision machining.
(Photos courtesy of Jan Pasman, Mikrocentrum)

- Micro-machining and functional surface textures by ultra-short pulsed lasers by Max Groenendijk, CEO of Lightmotif.

These topics have been included in articles in previous editions of Mikroniek, as has an overview of the recently completed IOP programme.

Exhibitors

There were 225 exhibitors at the Precision Fair 2011 – more than ever before. Many of them used the fair to launch product and process innovations. For example, Schaeffler demonstrated its KUVE-B Rowball Type Profiled Rail Units with the LMSA integrated inductive length measurement system. KUVE-B units can be used universally and can absorb forces from all directions and at any point around every axis. The pre-tensioned units have high accuracy, load capacity and stiffness. Given their compact build, combining the units with the LMSA length measurement system creates new opportunities for machine constructors.

Flexibility in motion control

Exhibitor Philips Innovation Services demonstrated improvements on motion control techniques. To keep power consumption and heat dissipation at acceptable levels, system designers are moving away from the traditional paradigm of rigid moving parts and learning to factor in flexibility. Philips Innovation Services recently developed a number of novel control strategies for advanced mechatronic systems that give designers more freedom to incorporate flexibility into their systems, while maintaining or even improving performance. Two such approaches were presented. The first is an advanced feedforward control technique that can compensate for arbitrary system flexibilities, significantly improving tracking, i.e. the component's ability to follow a defined trajectory. The second is a model-based feedback control technique that compensates for quasi-static deformations induced by exogenous disturbances. This increases accuracy at a specified point on the component where the actual process is happening. According to Philips Innovation Services, the improvements could mean a major advance in the performance of high-precision systems.

These presentations, and many more besides, were delivered at the Precision Fair 2011, in the heart of the Brainport high-tech systems region.

Information

www.precisiebeurs.nl

Making smart

Two prizes were awarded during the Precision Fair 2011, under the auspices of DSPE. Edwin Bos, director/founder of Xpress Precision Engineering in Eindhoven, received the Ir. A. Davidson Award for the way in which he made smart precision technology usable and for his enthusiasm for the specialism. Alexander Mulder received the Wim van der Hoek Award for his top-quality graduation project at Delft University of Technology in the field of accurate construction.

On behalf of the DSPE board, Marty van de Ven, the director of The House of Technology in Eindhoven, presented the Ir. A. Davidson Award. The aim of the prize is to encourage young talent and is intended for a young precision engineer who has worked for some years in a company or institute and who has a demonstrable performance record that has been recognised internally and externally. Candidates must also use their enthusiasm to have a positive effect on young colleagues. The biennial prize, which was set up in 2005, is named after the authority in the field of precision mechanics at Philips in the 1950s and 60s. The prize comes with a trophy made by the Leiden Instrument Makers School (LiS), representing the handbook in precision mechanics with which Davidson laid the foundation for the constructors community of Philips.

Entrepreneur

Edwin Bos studied Mechanical Engineering at Eindhoven University of Technology and did his doctorate with professors Schellekens and Dietzel on the subject of high-precision measuring sensors for measuring small 3D objects. He founded Xpress Precision Engineering with partner Ernst Treffers in 2007 whilst still doing his doctoral research. Xpress develops and markets 3D measuring sensors and coordinate-measuring machines for highly accurate applications. As entrepreneur with Xpress, Edwin Bos is responsible for all R&D activities, in addition to which, as a member of the DSPE board, he coordinates DSPE's Young Precision Network.

"Smart tech nerd"

At the prize-giving ceremony, DSPE board member Marty van de Ven described winner Edwin Bos as "a really smart tech buff". "Whilst you were doing your doctorate at Eindhoven University of Technology, you took a close look at a measuring sensor and improved it on several points: in terms of measuring behaviour, assembly and production. You did this so well that you have various patents to your name. This shows how very creative you are. But essentially, you ensured that the sensor is in actual fact usable by closely investigating assembly and cost-efficient production. For that, you have to be able to put yourself in the customer's shoes and, in any case, keep in close contact with them. That's where your strength lies: devising good techniques and making them producible and usable. You demonstrated that as well with your latest brainchild in the field of measuring, the TriNano coordinate measuring machine. I am impressed by the simplicity with which you have been able to capture its accuracy. All in all, you are becoming a true personality in the field of precision technology. At DSPE we have been aware of that for a long time already. Your chairmanship of YPN shows that you hold the specialism dear. That means that you meet all the criteria for the Davidson Award: a good precision engineer, creative, busy producing and actively spreading enthusiasm for the specialism."

precision technology usable

Winner of the Ir. A. Davidson Award 2011 Edwin Bos (centre) has received the certificate from DSPE board member Marty van de Ven. (Photo courtesy of Jan Pasman, Mikrocentrum)

Constructor's Award

The Wim van der Hoek Award was presented by jury chair and DSPE board member Jos Gunsing, business development technology manager at NTS-Group in Eindhoven and Mechatronics lecturer at Avans University of Applied Sciences in Breda. This prize – also known as the Constructor's Award – was set up in 2006 to mark the eightieth birthday of the doyen of construction principles, Wim van der Hoek. The prize is awarded annually for the best graduation project in the field of construction in mechanical engineering at the three universities of technology, and is sponsored by the 3TU Centre of Competence High Tech Systems.

Depth and clear reporting

The prize went to Alexander Mulder, who graduated last summer at Delft University of Technology with a Master's thesis entitled "Design of 6-DOF Miniature Maglev Positioning Stage for Application in Haptic Micromanipulation". Criteria for assessing the submitted theses were quality of subject matter, substantiation and innovation, as well as being able to serve as a model for lecture notes or a book on construction principles. The jury valued Alexander Mulder's reporting, with its clear differentiation between main and side issues, sufficient attention to the role of the specifications, clear motivation and good recommendations, and written in good English. The jury was also impressed with the depth of the mechatronic analysis, the use of various disciplines and the assessment and testing of design alternatives for sensors and actuators.

Winner of the Wim van der Hoek Award 2011 Alexander Mulder talking to the name giver of the prize. (Photo courtesy of Jan Pasman, Mikrocentrum)

Machine vision enters

With increasing quality demands and design specifications regarding precision, manufacturers are facing new challenges in the quality control and qualification of their products. Ad-hoc off-line surveys are increasingly being replaced by 100% inspection, which requires in-line high-speed quality control. Real-time feedback will help to improve manufacturing processes and reduce rejection rates. Focal combines vision, optical and mechatronic expertise to incorporate complex opto-mechatronic systems into the automated inspection solutions that are required, especially in the case of 3D products. Resolutions down to 5 microns can be achieved.

• ***Gerard van den Eijkel and Hans van Eerden*** •

Developments in machine or industrial vision have been facilitated by the ever-increasing availability of low-cost computing power and CCD-enabled cameras. Furthermore, the use of optical measurement techniques and mechatronic design principles benefits the construction of systems for precision (defect) inspection of 3D products as well as surface texture (2.5D) monitoring of features in the 5-50 micron range. Core competences for developing and manufacturing such opto-mechatronic inspection systems are the alignment of optical components, control of their positioning, compensation for the dynamics of the objects inspected, vibration isolation of the mechanical construction, and image processing (software).

Authors' note

Gerard van den Eijkel is co-owner/director of Focal. Hans van Eerden is a freelance text writer in Winterswijk, the Netherlands, working for clients such as Demcon and Focal, and editor of Mikroniek.

3D dynamics

Inspecting 3D products is especially challenging. Traditionally, a CMM (coordinate measuring machine) can be used in off-line inspection for the point-by-point inspection of a product, e.g. checking the dimensions of a cast component. This is time-consuming, however, and therefore not suitable for in-line inspection. Using an optical solution, megapixels of points can be collected instantly. However, when taking a picture of a 3D object from one angle, occlusions will occur: not all surface points of the object will be visible. Scanning the object or a 360° illumination of the object are two ways to prevent these occlusions.

An additional problem associated with in-line inspection is the movement of the products to be inspected. Typically, products may pass under the optical construction on a conveyor belt. As such, the still image of the product has to be retrieved from a moving target image. This requires a smart combination of optics and software.

Software

Product motion is just one of the challenges in designing the software for (in-line) inspection. The heart of inspection software is in image recognition: the use of computer algorithms to analyse images and process them for the purpose of taking decisions or carrying out accurate measurements. Image recognition includes:

- Recognition of products and defects based on template matching.
- Machine learning based on image vectorisation and static pattern recognition.
- Hyper-spectral image analysis.
- Sub-pixel accurate measurements in combination with exposure solutions, such as dark field and telecentric backlight.

MVTec is an internationally recognised open standard in machine vision software. In the Netherlands, Focal is one of the few system integrators that is MVTec-certified. Focal has combined MVTec's Halcon Vision library with its own interface for the PLC that controls inspection and a graphical user interface into the IVI-SYS machine vision platform for very demanding industrial vision inspection applications.

Examples

For quality control of products such as shown in Figure 1, Focal designed an inspection solution using a curved 360° mirror (see Figure 2). Image analysis reveals local deviations from the specifications (see Figure 3).

Another project concerned the inspection of lamp caps in the automotive industry to measure dimensions and check

The Focal brands

Focal Machine Vision & Optical Systems sets itself apart by combining expertise in image recognition and technical optics to supply customers with image recognition systems that are not available off the shelf. Focal's innovative optical systems can measure accurately in 3D by using techniques such as 3D lens calibration, deflectometry, image fusion and 3D stitching. To achieve this, Focal integrates state-of-the art optronics (image sensors, focus systems, optomechatronics and exposure) into image recognition and optics.

In the industry, Focal operates under two brand names:

- Machine Vision: supplies products and services for automated vision inspection of metal, plastic, glass or fabric products at a micrometer level; these solutions can be deployed efficiently in production processes for the purpose of minimising production outages.
- Optical Systems: the engineering agency that provides OEM customers with services for designing, validating or constructing (including first series production) optical measurement and calibration systems that are one-offs or part of an end product.

Focal joins Demcon cluster

In 2010, Focal emerged from the management buy-out of Mecal's Vision & Optronics division. Based in Oldenzaal, the Netherlands, Focal recently joined the cluster of companies in the mechatronic network of high-end technology supplier Demcon, which also has its headquarters in Oldenzaal. With its team of ten experts in optical system design and vision software, Focal will contribute to projects at Demcon, a supplier of complex mechatronic products and systems, primarily in the area of high-tech systems and medical devices. To broaden its scope to include complex optical systems and machine vision, Demcon recently acquired a minority share in Focal. Demcon can also help Focal to address mechatronic challenges in machine vision projects.

www.focal.nl
www.demcon.nl

Figure 1. Typical products for which Focal can design an inspection solution.

for mould defects. The challenges here included the transparency of the material and the complex curvature of the surfaces. Wafers for solar cell or semiconductor production have to be checked for surface defects, such as pitting. And in the coarse materials world, for instance, product pallets have to be scanned for surface flaws, such as sharp nails pointing out. These pallets are supplied for inspection on a conveyor belt. As such, in the analysis the rigid body motion of the pallet has to be extracted from the images that are obtained.

Complex optical systems

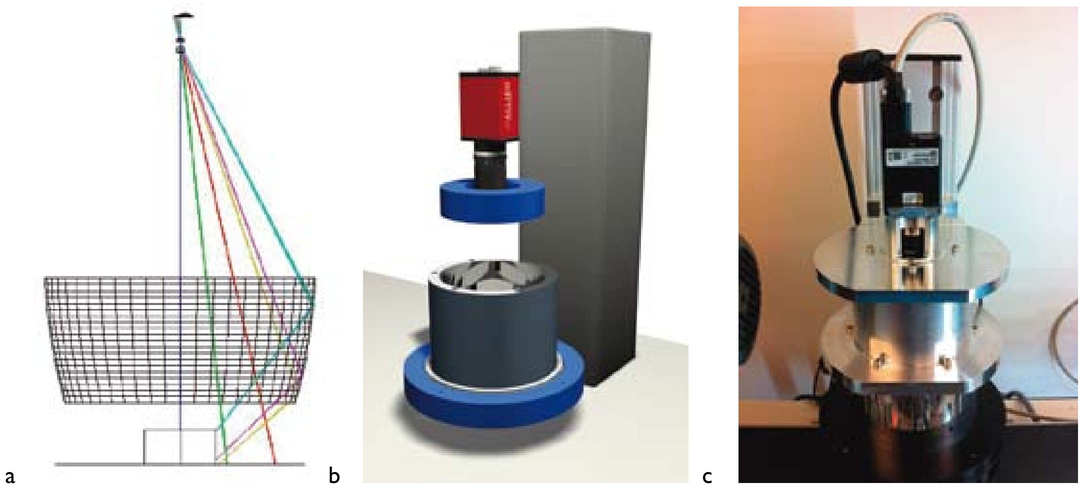
The increasing demands on machine vision have brought the design and construction of an inspection system into the realm of complex optical systems. Typically, an optical system consists of a series of optical components that reflect or refract light rays, ultimately creating a picture (imaging optics) or a desired distribution of light (non-imaging optics).

The human eye is an example of one of nature's optical systems. Focal has been inspired by this natural optical system and contributed to the field of ophthalmology by developing diagnostic equipment for the eye. Projects completed include an inexpensive fundus camera for the

Figure 3. Image analysis reveals local deviations from the specifications.

Figure 4. The low-cost retina camera.

measurement and software-based analysis of the retina for pre-screening campaigns in developing countries (see Figure 4), and an improved corneal topographer. Optometrists use corneal topographers to measure the height profile of the eye to then design such objects as scleral lenses.



(a) Concept showing ray tracing for a 360° curved mirror.
(b) Design showing the system components: above the illumination and sensor unit, below the mirror.
(c) Realisation.

Figure 2. 360° imaging solution for product inspection.

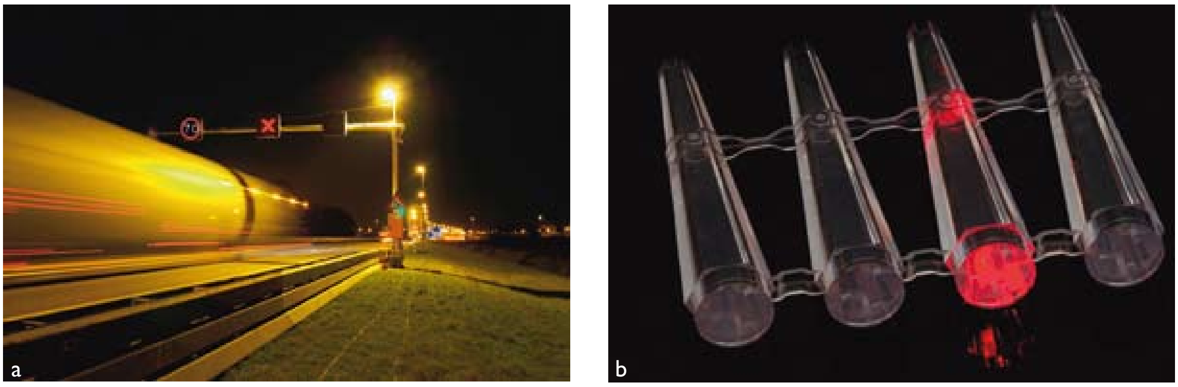


Figure 5. Design of LED optics.

(a) Matrix board application.
(b) Individual LED light guides.

LEDs
Popular non-imaging optical systems include LED applications, which require efficient and homogeneous light emission profiles. Applications with combined LEDs, such as light guides, matrix boards or flat panels, require specific designs for lenses, diffusers and reflectors. Here, form and the materials used play a role. For a matrix board application (see Figure 5), Focal developed so-called catadioptric optics, using both reflection and refraction to achieve the desired reflection profile of the LEDs.

Accuracy
Accuracies down to 5 microns can be achieved in current inspection systems by combining advanced hardware (optics and mechanics) and smart software (image recognition). The physical properties of light limit the resolution to a few microns, i.e. without using interferometry. Therefore, the next step will be to bring interferometry to machine vision by incorporating interferometric principles in the design of optical inspection systems, which will subsequently increase achievable accuracy to a sub-micron level.

From deepwater maskless

The 26th Annual Meeting of the American Society for Precision Engineering took place in the city of Denver at the foot of the Rocky Mountains from 13 to 19 November 2011. The annual meeting started with two days of tutorials, followed by three days of technical sessions and was concluded with a day of company tours. The ASPE 2011 conference featured some 150 oral and poster presentations and over 30 mainly American exhibitors. The conference keynote focused on precision engineering applied to deepwater drilling and completion.

• Ronald Lamers •

Figure 1: The venue for the 26th ASPE conference was the Marriott City Center Hotel in Denver, Colorado.

American Society for Precision Engineering

ASPE promotes the future of manufacturing in America by advancing precision engineering. It does this by supporting education and encouraging the development and application of precision principles. ASPE members work in a variety of technical areas – from engineering (mechanical, electrical, optical and industrial) to materials science, physics, chemistry, mathematics and computer science – and are employed in industry, in academia and in national labs. ASPE was founded in 1986 and is a non-profit organisation. The 27th ASPE conference will be held in San Diego, California, from 21 to 26 October 2012.

www.aspe.net

drilling to lithography

a

b

Figure 2. Impressions from ASPE 2011.
(a) Technical session.
(b) Commercial exhibition.

The American Society for Precision Engineering held its well-attended 26th Annual Meeting in Denver (Colorado), at the Denver Marriott City Center Hotel (see Figure 1). ASPE 2011 comprised a mix of workshops and tutorials, presentations, poster sessions and a commercial exhibition where companies could present themselves and their products; see Figure 2. The conference programme was quite diverse and it was a good opportunity to get to know some interesting and unexpected precision engineering approaches. The technical sessions were all well-attended despite the diversity.
Remarkably, ASME (the American Society of Mechanical Engineers) was holding an international conference in Denver at exactly the same time and there was an opportunity to attend both conferences.

Tutorials

The first two days of the conference consisted of tutorials on various typical precision engineering topics, such as design principles (mainly flexures), thermal aspects and metrology. "Dutch precision" was well-represented on the first day with two full-day tutorials; see Figure 3. Herman Soemers and Dannis Brouwer lectured on "Design principles for precision mechanisms" and Theo Ruijl and Jack van der Sanden on "A system approach to thermal design and modelling". Both tutorials attracted a large number of attendees, which underlines the importance of both subjects in precision engineering and the leading position of the Netherlands in this field. On the second day, the author attended two tutorials: "Measurement uncertainty", by Tyler Estler and Steven Phillips (NIST) and "Precision flexural design", by Jonathan Hopkins (MIT). The level of both tutorials was very high. The tutorial by Jonathan Hopkins presented an interesting approach to parallel flexural mechanism design [1].

Author's note

Ronald Lamers works as a senior mechanical designer/thermal specialist for MI-Partners in Eindhoven, the Netherlands.
He has a keen interest in mechanical and thermal precision engineering topics. Herman Soemers' contribution on the technical tours is hereby acknowledged.

www.mi-partners.nl

Figure 3. "Dutch precision" at ASPE 2011, from left to right: Theo Ruijl (MI-Partners), Herman Soemers (Philips Innovation Services and University of Twente), Jack van der Sanden (Philips Innovation Services) and Dannis Brouwer (Demcon and University of Twente).

After the welcome reception and opening of the conference by chairman Bradley Jared of Sandia National Laboratories, it was time for the keynote presentation on deep drilling technology by John Peters, drilling and completion engineering manager for Deep Water Exploration and Projects at Chevron. Nowadays, deepwater drilling and completion is faced with many technical, safety, environmental and political challenges. It does, however, represent approximately 50% of all new oil discoveries worldwide. Currently, global deepwater oil production exceeds 5 million barrels of oil equivalent a day and is expected to increase with rising global demand and the depletion of "easy" oil reserves.

Keynote

The keynote presentation gave a breakdown of the basic steps of a deepwater drilling operation and the critical components that are used. During such operations, pressures and tensile loads can exceed 1,400 bar and 7 MegaNewton, respectively. The achievements are impressive and it was interesting to learn about the challenges deepwater drilling faces. Overcoming these challenges requires precision engineering in the areas of sensor measurements, data transmission, strength of materials, high-performance mechanical designs, etc. What was missing in the presentation was how the precision engineering community could be linked to the oil and gas community in order to help address these challenges.

Sessions

The conference comprised a total of eight sessions:

1. Interferometry and Optics
2. Precision Manufacturing
3. Multi-axis Machine Design
4. Precision Metrology
5. Nano-Positioning
6. Precision Manufacturing
7. Control of Precision Machines
8. Precision Component Design

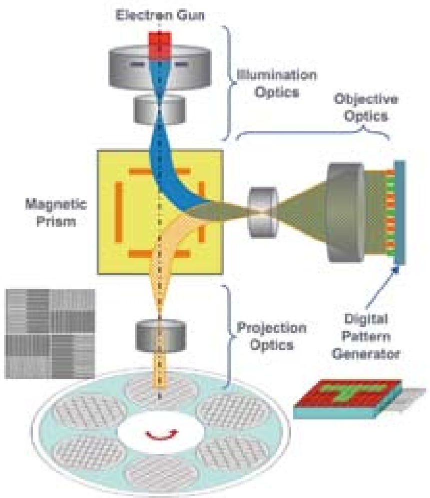
REBL

In sessions 1 and 3, two interesting presentations were given on REBL, by Joseph Di Regolo and Upendra Ummethala of KLA Tencor, respectively. REBL, which stands for Reflective Electron Beam Lithography, is a programme at KLA Tencor for the development of a novel approach to high-throughput maskless lithography [2]. The programme targets 5 to 7 wafers an hour at the 45nm node. A DPG (digital pattern generator) chip, which contains over one million reflective pixels that can be individually turned on or off, is used to project an electron beam pattern onto the wafer.

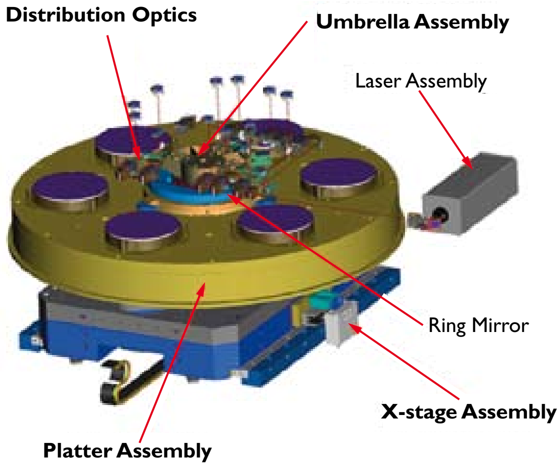
In the machine architecture of the so-called Maskless Nanowriter, six wafers are placed on a contactless maglev rotary stage (mass 120 kg, radius 1 m), which rotates underneath the electron beam (see Figure 4a). This rotary stage can also translate (to one degree of freedom), which enables the electron beam to write patterns on the wafer (see Figure 4b). The contactless maglev rotary stage architecture removes the throughput barriers associated with linear stage architectures where the required aggressive stage acceleration limits throughput. The rotary stage operates quasi-statically (also at high scanning velocities), with extremely low disturbing impacts on the writing process and with highly reproducible and predictable wafer and stage motion. Both papers on REBL contained contributions from Philips Innovation Services.

Elastic averaging

What is interesting to note is the difference between the typical Dutch way of precision mechanism design and some American examples. Where the Dutch "Van der Hoek" school of design is rigidly based on exact constraint design, some American examples showed over-constrained designs based on the principle of elastic averaging. An exact constraint design, as opposed to elastic averaging,



a

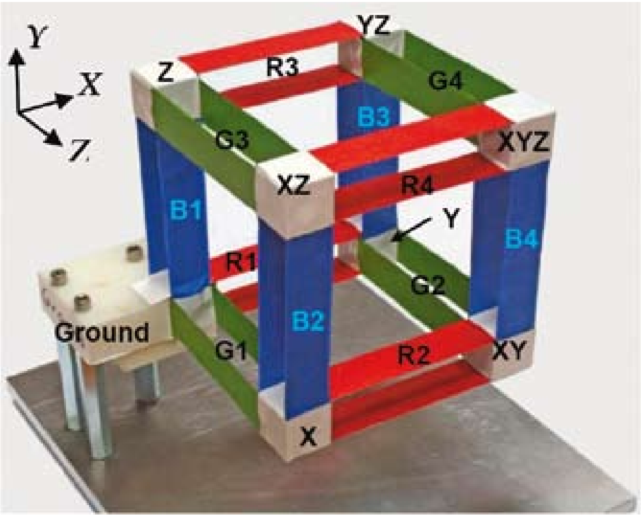


b

Figure 4. The Maskless Nanowriter using Reflective Electron Beam Lithography (REBL).
(a) Overview of the concept.
(b) The maglev rotary stage on a translating linear stage. (Photo courtesy KLA Tencor)

does not require tight manufacturing tolerances and is relatively insensitive to temperature fluctuations. However, elastic averaging can be successful when the stiffness of the structure becomes critical, but these designs are more sensitive to misalignments.
An example of such a design was shown in session 3 by Shorya Awtar of the University of Michigan [3]. He presented a large-range XYZ parallel kinematic flexure design with an XYZ motion range of 10 mm x 10 mm x 10 mm. Figure 5a shows the proposed design, which is clearly over-constrained and would give many “Van der Hoek” designers the creeps, but, according to the presenter, the design is able to work properly due to elastic averaging. Figure 5b shows the experimental set-up. Because of the parallel kinematic nature of this design, a major advantage will be that actuators and sensors can be ground-based, thus preventing moving cables, for instance.

The poster presentation by Dannis Brouwer on “Freedom and Constraint Analysis and Optimization” showed a visualisation method using generalised Von Mises stress to show over-constrained modes. The paper says that a misalignment angle of several tenths of milliradians can be sufficient to provoke bifurcation in an over-constrained parallel leaf-spring flexure. The bifurcation results in a stiffness reduction of roughly one order in the intended stiff support directions. He concludes that exact constraint design promotes deterministic behaviour.



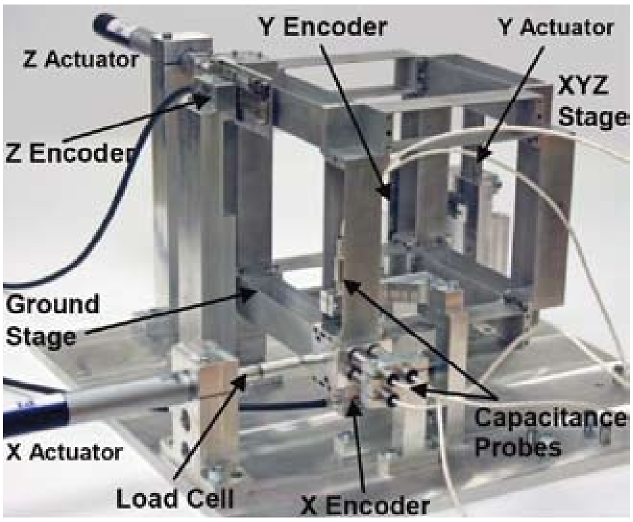


Figure 5. XYZ flexural mechanism.
(a) Proposed design.
(b) Experimental set-up. (Photo courtesy University of Michigan)

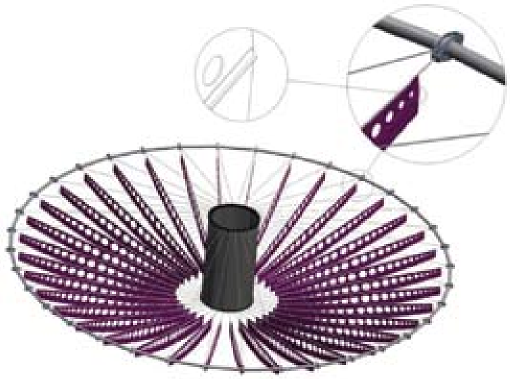


Figure 6. Truss structures.
(a) Traditional design.
(b) Spoke design. (Photo courtesy Solar Systems and Heliocentric Solar Technologies)

Concentrating solar systems

In addition to all high-end precision engineering applications, in session 2 Ben Shelef of Heliocentric Solar Technologies presented the unique engineering challenges posed by the design of optical concentrators for solar systems. Compared to precision optical instruments, solar concentrators are crude devices. However, they are also high-volume systems that are subject to strict budget constraints.

According to Shelef, there are two typical types of dish constructions (see Figure 6a). The basis of both types is a truss structure. In the first case, the reflector tiles are mounted on an inaccurate truss structure and adjusted afterwards. In the second case, the truss structure with dish is accurate enough and no adjustment of the tiles is required. Both designs are relatively expensive. Shelef introduced a kinematic truss, familiar to most people as a tensile-spoke bicycle wheel, as the basis of the dish (see Figure 6b). The advantages are that the structure is cheap, kinematic and rigid, and weighs only 25% as much as a comparable standard truss. Structural alignment is achieved by tweaking the spoke length.

Technical tours

Two technical tours were organised on the day after the conference, one to the National Renewable Energy Laboratory (NREL) and the other, which is described here, to the NIST (National Institute of Standards and Technology) in Boulder, 40 km northwest of Denver. The researchers presented the subjects themselves in their natural habitat (laboratories) and in an informal and enthusiastic way. The NIST lab dates back to the mid-1950s, which explains its “authentic” appearance, which is somewhat comparable to the former Philips Research buildings. The construction of a new lab is to start next year on the same premises. Subjects of the tour: atomic clocks for time standard (see Figure 7), voltage standard, laser power measurement and meta-materials.

The Quantum Voltage Project develops Josephson junction-based superconducting electronics to produce the most accurate DC and AC voltage. The micro-electronics is produced in-house using (Dutch) ASML steppers. NIST Boulder is also researching meta materials with negative refracting indices, among others. Though this seems ground-breaking, applications are still very limited given the high-frequency bands of these phenomena. A practical application is in the field of high-frequency antennas enabling a factor 100 to 1,000 efficiency improvement.

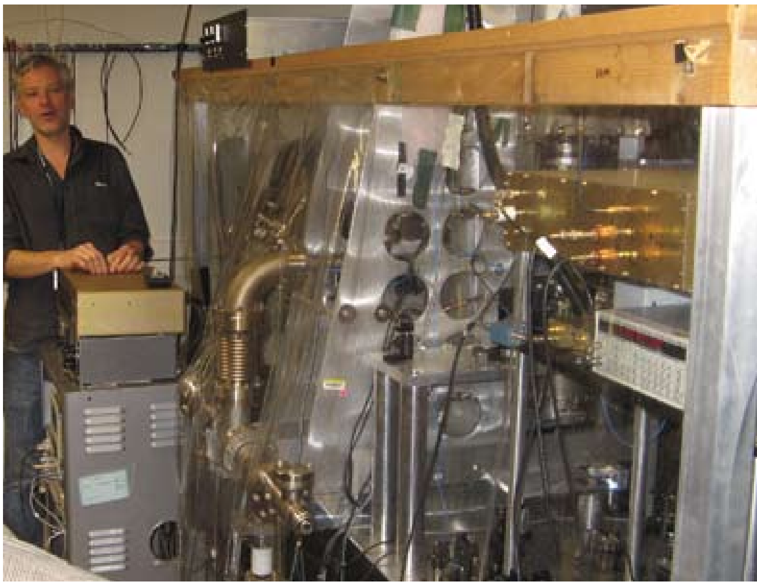


Figure 7. Technical tour: atomic clocks for time standard at NIST laboratories in Boulder.

References

[1] www.jonathanbhopkins.com
[2] www.darpa.mil/Our_Work/MTO/Programs/Maskless_Nanowriter.aspx
[3] awtarlab3.engin.umich.edu

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Note on inox and

The most commonly used, austenitic, type of stainless steel is non-magnetic, so designers of high-tech machines and measuring equipment have been taught. That is an essential property when electrons are involved, as in electron microscopes or other e-beam devices, but the magnetism or non-magnetism of structural steel may also be important in the design of other high-precision equipment. It is good to know, therefore, that austenitic stainless steel can actually be magnetic.

• *Kees van der Neut* •

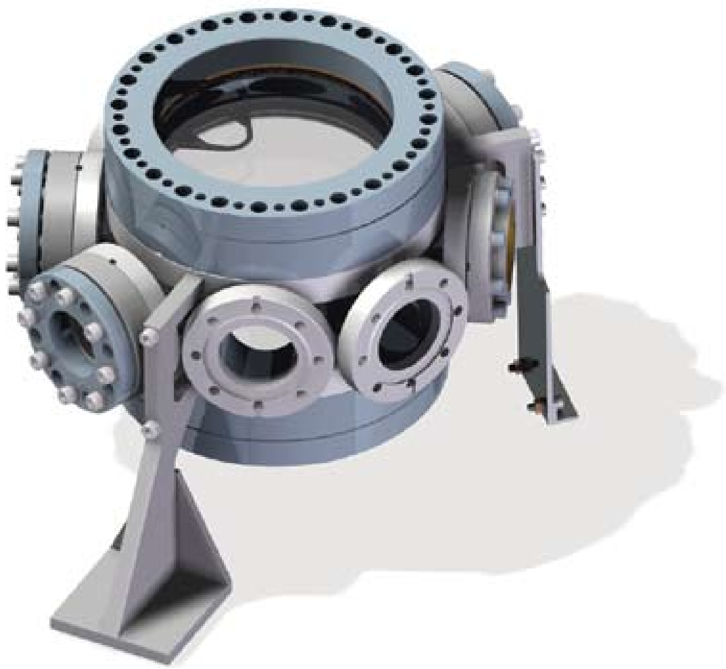

Figure 1. The experimental set-up with the flanges that had to be strictly non-magnetic.

In the past, the Scientific Instrumentation engineers at Utrecht University would opt for inox 304 in vacuum set-ups, while inox 316 was chosen when magnetism was to be avoided at all costs. There was a chance that material would become magnetic after processing, but this could be counteracted by means of heat treatment. With this in mind, when constructing a so-called magnetic optical trap for a project on plasmonic structures, flanges for openings were turned that were absolutely not to be magnetic; see Figure 1. Yet an inspection did show up magnetism. After first having checked the material (which showed that the flanges were indeed made of inox 316), further study was required.

Information

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Stainless

A stainless type of steel has a chromium content of at least 10.5% and is passivated when used in oxidative environments. Stainless steel of this type is not very resistant to reducing substances such as sulphuric acid. Because chromium binds easily to carbon and oxygen, the

magnetism

production of stainless steel was difficult at first. After a great deal of research, a preparation method was eventually found in which low-carbon steel scrap (sometimes with added iron ore) is melted in an electric oven. The chromium is added in the form of low-carbon ferrochromium, a hard but brittle compound comprising approximately 80% chromium and 20% iron. This is still basically the common preparation method, except that other components are added to improve the material's properties.

Austenitic stainless steel

There are ferromagnetic types of stainless steel, viz. ferritic stainless steel and martensitic stainless steel, which contain carbon. The most commonly used types, austenitic stainless steel, are, however, not magnetic. Austenitic stainless steel contains 16-26% chromium and 7-22% nickel. Typical properties include a high degree of toughness and ductility. Upon deformation, some of the material's non-magnetic character can be lost (as a result of ferrite separation). Rolling makes cold-rolled steel ferromagnetic and also results in a slight reduction of the material's excellent corrosion resistance. Because of its toughness, austenitic stainless steel is less easy to machine than regular steel. Special turning grades have been developed to overcome this drawback. Other typical properties of austenitic stainless steels are their large expansion coefficient and poor thermal and electrical conductivity.

In the AISI classification (of the American Iron and Steel Institute [1]), austenitic stainless steel falls in the 300 series, with well-known examples such as AISI 304 and 316, or inox 304 and 316.

Magnetism

Austenitic stainless steel is generally considered a non-magnetic material, but – especially nowadays – this is not necessarily true. When stainless steel was produced in the past, the nominal values of the different elements were taken into account because manufacturers did not want the product to fail the requirements and, besides, it was not possible to determine the contents very accurately at that time. Modern technologies have greatly improved and raw materials are more expensive, as a result of which manufacturers attempt – within wide specifications – to use as little as possible of the expensive raw materials in the stainless steel. This may have changed the properties compared to the 'old' stainless steel; it has been proven by experiment that this is certainly the case for magnetism. Stainless steel is, of course, much less magnetic than regular steel, but the degree of magnetism depends largely on the exact composition of the stainless steel and the production process. Table 1 presents the key elements of stainless steel composition. However, the basis for stainless steel is usually scrap metal, which may contain traces of other elements as well.

Table 1. Composition of inox 304 / 316 [2].

Element	Content (%)
Chromium	16.5-20
Nickel	8-15
Carbon	< 0.03-0.08
Manganese	< 2
Molybdenum	2-3
Silicon	< 1
Sulphur	< 0.03
Nitrogen	< 0.11-0.22
Phosphorus	0.035-0.045

Metastable

The key alloying elements of inox 304 and 316 are chromium and nickel, with chromium being a martensite former (magnetic) and nickel an austenite former (non-magnetic). Silicon and molybdenum are also ferrite formers, while manganese and nitrogen are austenite formers. This makes these types of stainless steel metastable: major changes in the contents of the different elements within the wide specifications may influence the properties.

As is clear from the ternary phase diagram (Fe-Cr-Ni), see Figure 2, when the minimum values of chromium and nickel are adhered to, the alloy in question is close to the martensite and ferrite phase (i.e. magnetic) in the metastable phase. If other contents are also 'unfavourable', the risk of magnetism increases. If, however, more nickel is added, the alloy moves away from the martensitic and ferritic phases and the risk of magnetism decreases.

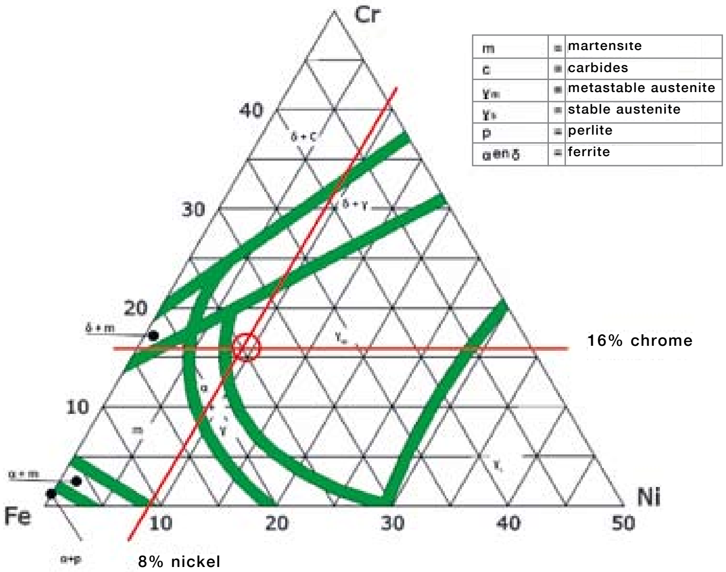


Figure 2. Ternary phase diagram (Fe-Cr-Ni) for stainless steel.

Non-magnetic stainless steel

In addition to the American AISI classification, there also is European standardisation, EN [3]; this is much more accurate in the sense that there are smaller bandwidths for the contents of the different elements. This makes it easier to judge whether a type of inox could be magnetic or not. Inox 316, for example, is divided into different EN alloy numbers. If you order standard inox 316L, you usually receive steel with EN number 1.4404, because this contains the least (expensive) nickel and molybdenum and is, therefore, the most common. If magnetism is important, it is better to opt for a type with more nickel, such as EN 1.4435 or EN 1.4429 (inox 316LN), which contains a fair amount of nickel, and nitrogen as well. Unfortunately, this latter type is more difficult to obtain as a starting material. Flanges, however, are still available in this steel.

There are, therefore, different kinds of inox with a high nickel content, which is good in terms of preventing magnetism, but the question is what consequences this has for other properties. Moreover, as an expensive raw material, nickel pushes up the cost price. Table 2 presents an overview of the available non-magnetic types of stainless steel.

References

[1] www.steel.org.
[2] Source: www.inoxexpert.nl.
[3] EN 10088.

Table 2. Non-magnetic types of stainless steel.

EN	AISI	Chromium content (%)	Nickel content (%)	Availability
1.4438	317L	17.5 - 19.5	13 - 16	fair
1.4335	-	24 - 26	20 - 22	poor
1.4429	316LN	16.5 - 18.5	11 - 14	fair
1.4466	310MoLN	24 - 26	21 - 23	poor
1.4361	-	16.5 - 18.5	14 - 16	poor
1.4539	904L	19 - 21	24 - 26	good (expensive)
1.4864	330	15 - 17	33 - 37	fair

New machines and inspiring life science

On 17 November last year, the Leiden Instrument Makers School, abbreviated to LiS, celebrated its 110th anniversary with a symposium entitled "Life Science". A new 5-plane machining station was officially commissioned on this occasion as well. Proof yet again that the LiS is alive and kicking.

• *Dick Harms* •

The LiS is a school for precision technology at senior secondary vocational (MBO) level, where young people are trained to become research instrument makers. The school is unique in the Netherlands and plays an important role in training specialists for roles in high-precision research and the high-precision industry. The gift the school was given in honour of its 110th anniversary highlighted this important role. Thanks to generous donations from various organisations, the LiS now has access to a fantastic 5-plane machining station, a first for an MBO school. This machine was officially commissioned on 17 November (see Figure 1).

Author's note

Dick Harms is Director of the Leiden Instrument Makers School in the Netherlands.

www.lis-mbo.nl

Figure 1. The new 5-plane machining station, a first for an MBO school.

This gift evidently proved infectious, as Zeiss decided to donate a state-of-the-art measuring station to the school (see Figure 2). The LiS was also really delighted with this machine and thanked all of the generous donors.

Figure 2. Advanced measuring station for LiS from Zeiss.

Figure 3. One of Paul Breedveld's slides.

Life Science

Before taking the new machine into commission, the LiS organised a brief symposium to update businesses and other stakeholders on developments at the school. The topic of the symposium was "Life Science" and there were three keynote speakers. Dr Paul Breedveld of the Delft University of Technology took the delegates on a journey into the magical world of "Bio-inspired Technology", demonstrating how the muscle structure of worms and cephalopods can inspire the design and construction of agile, movable tools and probes used in medical operations (see Figure 3). Dr Henk van Zeijl, also from the Delft University of Technology, talked about intelligent implants that perform measurements in the human body and can administer customised medication. Finally, Dr Eric Kaijzel from the Leiden University Medical Centre gave a presentation about technology that uses fluorescent substances to make cancer cells visible. The light sensors used in this research were developed by a group of former LiS students now working at the Erasmus University Medical Centre in Rotterdam.

Job market

The symposium also marked the completion of a two-year project by the Dutch province of Zuid-Holland, the aim of which was to further empower the LiS in terms of the following key lines of action in the precision technology sector:

1. Breaking through the job market for instrument makers and precision engineers by following refresher and further training programmes.
   Intensive collaboration has been established in this field with a partner in the eastern part of the Netherlands. There will be a follow-up to this part of the project in the coming years.
2. Apprenticeship programmes and exploration of a higher professional vocational education (HBO) learning pathway in precision technology for incumbent and future staff, with a continued learning pathway starting from MBO.
   At present, a detailed and unique curriculum is in place for a HBO training course as a 'precision engineer', set up in close cooperation with the Delft University of Technology. The LiS is now looking for partners to deliver this course and, given the scale – we do, after all, operate in the micro and nano fields... – at which this is to take place, this will be a challenge. For some time now, the LiS has been exploring options with the Delft University of Technology and the universities of applied sciences in The Hague and Leiden.
3. Publicising the opportunities for education and a career in the Life & Health Sciences, and increasing the numbers of new LiS students and graduates.
   Much has been achieved in this field. More professional recruitment has led to greater familiarity among secondary school students. This has resulted in a waiting list for the 2010-2011 academic year. Ultimately, the LiS admitted 10% more students than usual, so its popularity is clearly on the increase. At the same time, the LiS is seeing a major rise in graduate numbers, so these developments are running parallel.
4. Forming networks and sharing knowledge by and for the LiS in the field of research instrumentation and precision technology.
   It was clear from the hundred or so delegates at the symposium that this line of action has also been successful.

Van Musschenbroek medal

A medal was presented at the end of the symposium. On special occasions, the LiS presents the Van Musschenbroek medal to those who have made a particular effort on behalf of the school. The medal is named after the renowned 18th-century Leiden instrument maker Pieter van Musschenbroek and was established by Heiko Kamerlingh Onnes, Nobel prize winner and founder of the LiS. The LiS considered its 110th anniversary a good opportunity to honour those who have dedicated themselves to ensuring that the LiS could remain an independent technical school with its own building. The laureates were Prof. Dr Jan Korving and Dr Hans van Duineveldt. The current chairman of the board, Prof. Dr Jan Schmidt presented the Van Musschenbroek medal. Unfortunately, Dr Van Duineveldt had died shortly before the symposium, so his two sons accepted the medal on his behalf.

Prof. Dr Rudolf de Bruyn-Ouboter, former chairman of the LiS board, gave a detailed description of the important work done by the new Van Musschenbroek laureates. It was clear from this that, on several occasions, the LiS had almost been swallowed up by the broad-based Regional Training Centres (ROCs). Thanks to an eagerly embraced loophole in the law, however, the school was able to continue operating independently.

Independent

Earlier that afternoon, Drs. H.J.J. Lenferink, the mayor of Leiden, vividly recalled how the municipality of Leiden had been engaged in the LiS's struggle to maintain the school's independence. Lenferink congratulated the LiS and the city of Leiden on the 110th anniversary of the Leiden Instrument Makers School.

28-29 February 2012, Aachen (DE)
3rd Aachen Precision Days

International conference focusing on precision and ultra-precision manufacturing, addressed at participants from industry and research. The organisers are the Fraunhofer Institute for Production Technology, IPT, and the Center for Precision and Micro Technology, ZPM.

www.ipt.fraunhofer.de

22 March 2012, Eindhoven (NL)
ESI Symposium 2012

The fourth symposium of the Embedded Systems Institute, covering a wide range of applied academic and industrial research topics on embedded systems.

www.esi.nl/symposium

27-28 March 2012, Nieuwegein (NL)
Fotonica Evenement

The sixth edition of the Photonics Event is organised by Mirocentrum and Photonics Cluster Netherlands. The event forms the bridge between new technologies (such as LEDs, microscopy and lasers) and innovative applications, and is targeted at researchers, scientists, entrepreneurs, CEOs, policy makers and science students. Conference themes include Health & Life Science, Information & Communication Technology, Photonics in Daily Life, Lighting, Industrial Photonics, and Solar.

www.fotonica-evenement.nl

29 March 2012, Veldhoven (NL)
Hightech Mechatronica 2012

Techwatch Events organises the sixth edition of this conference and exhibition. Research, development and implementation of mechatronic systems are the main themes.

www.hightechmechatronica.nl

2-3 May 2012, Thoiry (FR)
Precision Engineering at CERN: Future Challenges & Opportunities

Matching industry and science, and identifying potential suppliers, for the electron-positron collider programme (CLIC).

www.cern2012.euspen.eu

9 May 2012, Den Bosch (NL)
Model-Driven Development Day 2012

Conference and exhibition, organised by Techwatch Events, on model-driven development, focusing on high-end engineering with high-level tooling, including finite elements, multi-body dynamics, multi-physics development methods and simulation.

www.hightech-events.nl/mdday

9-10 May 2012, Brussels (BE)
DRIVES & CONTROL 2012

Trade show for transmissions, motion control & robotics, organised by easyfairs, co-located with SENSOR & VISION 2012, and AUTOMATION & ENGINEERING 2012.

www.easyfairs.com

4-7 June 2012, Stockholm (SE)
euspen 12th International Conference and Exhibition

Conference topics will include:

- Precision Engineering of Plastic based Electronics and Optronics
- Scandinavian Precision Engineering and Nanotechnology
- Nano & Micro Metrology
- Ultra Precision Machines & Control
- High Precision Mechatronics
- Ultra Precision Manufacturing & Assembly Processes

- Important/Novel Advances in Precision Engineering & Nano Technologies

www.stockholm2012.euspen.eu

Impression of the euspen 11th International Conference and Exhibition, May 2011 in Italy. (Photo courtesy euspen)

5-6 June 2012, Veldhoven (NL) Vision & Robotics 2012

Knowledge and business network event, organised by Mikrocentrum, on robotics and automation solutions. The focus is on innovations and solutions for vision systems, robotics, motion control, sensors and machine automation.

www.vision-robotics.nl

25-29 June 2012, Eindhoven (NL) International Summer school Opto-Mechatronics 2012

Organised by DSPE and The High Tech Institute. See also page 54.

www.summer-school.nl

4-5 September 2012, Deurne (NL) DSPE Conference

DSPE and Brainport Industries organise this first conference on precision mechatronics. The target group includes technologists, designers and architects in precision mechatronics, who (through their respective organisations) are connected to DSPE, Brainport Industries, the mechatronics contact groups MCG/MSKE or selected companies or educational institutes. The call for abstracts of technical contributions (papers, posters, demos) closes on 1 April 2012. See also page 56.

www.dspe-conference.nl

25-28 September 2012, Besançon (FR) Micronora 2012

The biennial microtechnology and precision trade fair features multiple activities – from assembly, engineering and machining to metrology and nanotechnology – for markets with high technological value, including aerospace, (bio)medical, microelectronics and telecommunications. The event includes conferences and a European technology brokerage event on micro- and nanotechnology. Micronora 2010 attracted over 14,000 visitors and 565 direct exhibitors (200 from abroad), with a further 300 firms or brands represented.

www.micronora.com

Summer school Opto-mechatronics 2012

Following the success of the 2008 to 2011 editions, DSPE and The High Tech Institute organise the Summer school Opto-Mechatronics 2012, from 25 to 29 June in Eindhoven, the Netherlands. Once again, it is the place to be for anyone working in the field of precision engineering and wanting to learn and experience from experts how to design opto-mechanical instruments that are actively controlled, operating in the non-perfect environment.

The Summer school Opto-Mechatronics 2012 comprises five days of intensive course, taught by excellent Dutch professors and scientists in the field of precision engineering, who work at TU Delft, TU Eindhoven, ASML, Philips, TNO, ESO and The High Tech Institute, combined with hands-on training. Participants will come from universities and high-tech large companies and SMEs. The programme includes social events and venue is TNO at the university campus in Eindhoven.

Programme

Monday 25 June: Systems Engineering
Opto-mechanical instruments are always co-existing with other equipment. So, before starting their design, the essence of the systems engineering has to be considered. What is critical and what are the margins? How to approach such a project and how to gain insight in the background of the requirements?

Tuesday 26 June: Optical Design
The case starts with an introduction to the optical design and its use in optical aperture synthesis applications. Next, in teams, several delay line designs will be compared, in order to select the best design with respect to the optical requirements. Also, an effective optical design has to be found for measurement of the optical path differences. Zemax will be used to analyse the optics in the delay line. Further work pertains to wave-front analysis and pupil imaging while moving the delay line, and assessment of alignment accuracy.

Wednesday 27 June: Control Design
Based on the functional requirements of the optical delay line, the challenges for control will be discussed. These include actuation for a high dynamic range, servo behaviour, vibration rejection, sensor noise, closed-loop stability and others. An introduction of suitable control design methods is presented to achieve nanometer positioning accuracy.

Thursday 28 June: Opto-Mechanical Design
The trade-off made for a linear guiding of 66 m, with sub-mm accuracy, will be presented. The students are requested to design and assess, in a team effort, the performance. Emphasis will be put on the interactions with the other key technologies needed (optics, control and electronics) and on the mechanical design itself.

Friday 29 June: Mechatronics
Designing an actively controlled delay line that is stable enough to perform interferometry over large distances, is

far from trivial. Some still missing elements will be presented that are necessary to realise high performance active positioning and control systems for optics. Following an overview on electromagnetic and piezoelectric actuators, optical position measurement systems and capacitive sensors, attention will be given to the performance determining mechanical system dynamics and vibration isolation. The new field of adaptive optics will also shortly be touched upon.

Information and registration:
www.summer-school.nl

Introducing DSPE board members: Cor Ottens

Ever since I was a child, I have been interested in technology. I took a lot of things apart because I wanted to know how they worked, especially the precision mechanics. I repaired bikes, motorbikes and cars, but was also drawn to designing and making new things, such as furniture. I started my technical career at BKL Engineering, where I enjoyed my first experience as a mechanical designer. I worked on several assignments at BKL for DAF Special Products and Philips Optical Fiber. In 1990, ASML hired me from BKL Engineering. I started on a precision mechanical project there for the new PAS5500 wafer stepper. This project was about developing the opto-mechanics of an alignment sensor for determining wafer position. I never left ASML after this, and in 1997, I got an ASML contract. I worked on various projects, such as an XYZ manipulator for positioning a mercury bulb in a parabolic mirror, and an air-conditioning unit with heat exchangers and filters.

I decided to pursue a mechanical engineering programme at a higher vocational training level (HBO), the final project for which I was able to do at ASML. Meanwhile, I started working on developing the opto-mechanics of a new alignment sensor for the Twinscan machine. The challenge here was to keep, after positioning, the optics stable at the nanometer level under the influence of thermal, dynamic and mechanical disturbances. In my final project, I used this experience to draft a manual with guidelines for designing opto-mechanically stable constructions. After this, I worked on the opto-mechanics for a number of other sensors. As a senior designer and team leader, I worked with technology as well as with people, a combination I like. I am currently group leader of the mechanical engineers working on the EUV light sources of the new EUV machine.

I am a member of DSPE because I like developing things, especially precision mechanics. Fundamental knowledge is required to properly understand the mechanics for producing good designs, where the difficulty lies in simplicity. The high-tech industry needs good precision (mechanical) engineers. I joined the DSPE board to contribute to the promotion of precision mechanics in the Netherlands. As a board member, I participate in the CPE (Certified Precision Engineer) program, to give precision engineers the credit they deserve. It is also important that, as an internationally leading high-tech company from the Netherlands, ASML is represented on the DSPE board.

Call for papers, posters and demos for the first DSPE conference

To promote sharing the expertise and experience available in the field of precision and control technology, DSPE and Brainport Industries have taken on a new challenge; they are organising the first DSPE conference on precision mechatronics. The conference will be held at the inspiring conference location of Willibrordhaeghe in Deurne, the Netherlands, on 4-5 September 2012. The target group includes technologists, designers and architects in precision mechatronics, who, through their respective organisations, are connected to DSPE, Brainport Industries, the mechatronics contact groups MCG and MSKE, or selected companies and research/educational institutes.

In addition to demos and paper and poster presentations, the conference will provide the ideal setting for networking, technical discussion and sharing the enthusiasm of working in this challenging field. The theme this year is 'Systems Thinking', which is vital at a system level, but also at a detail level. System performance is determined by the optimal balance between system architecture and mission-critical details. The overall system architecture often determines whether a component is mission-critical or not. However, it also requires systems thinking to work out the optimal solution at a detail level. And, last but not least, it is only using systems thinking that you can question and challenge the requirements imposed on a component, thereby avoiding 'over-specification' and high costs.

The organising committee invites papers, posters and demonstrations to be submitted. To stimulate discussion and interaction, topical issues stemming from current projects – as opposed to successfully completed projects – are encouraged. Areas of interest include, but are not limited to, innovative solutions at a system and detail level, creating value, systems architecture, 450mm challenges, nanometer stability, platforms, thermo-mechanical effects, new materials, design principles, electro-mechanics, power electronics, actuators, sensors, control systems, modelling, instrumentation and measurement, software and hardware implementation, manufacturing, and testing.

Timetable

- 1 April: deadline for submitting abstracts.
- 1 May: notification of acceptance and provisional programme ready.
- 15 May: end of early registration bonus (free copy of "The Design of High Performance Mechatronics" by Robert Munnig Schmidt, Georg Schitter and Jan van Eijk – see the review in this issue of Mikroniek).
- 1 August: deadline for submitting final papers/extended abstracts.
- 4-5 September: the first DSPE conference on precision mechatronics.

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

The DSPE Conference is organised by DSPE and Brainport Industries, the association of leading tier-one, tier-two and tier-three high-tech suppliers in the Eindhoven region.

Producible construction

Because OEMs are increasingly outsourcing production, the knowledge of production techniques in their own development departments is shrinking. This is particularly the case with modern production techniques that only suppliers are familiar with. Mikrocentrum is therefore offering a course entitled "Producible Construction", which is to start again in April, and can be attended either in Utrecht (3 April) or Eindhoven (11 April).

Correctly specifying a product or a system is one of the key tasks of the constructor. The specifications are intended for the supplier who requires input to be able to choose the correct production technique, which does, after all, have a huge impact on such aspects as geometry, tolerances, surface condition, sustainability, cost, etc. Therefore it is essential that constructors are familiar with production techniques so as to be able to use the potential of these techniques in their designs and to avoid impracticalities.

During the course, specialists will provide participants with the necessary insight into various production techniques for metal, with the emphasis on machining, sheet metal working, welding and other joining techniques. Attention will also be paid to the effect of these techniques on the costs. The course can be taken on its own or – under the heading "Constructing Effectively" – combined with "Form and Place Tolerances" and "Tolerance Analysis", in which a single case study runs like a common thread through the various courses.

www.mikrocentrum.nl/opleidingen

Theme day: Measuring in the workshop

The theme day "Measuring in the workshop" will be held at Mikrocentrum in Eindhoven, the Netherlands, on Thursday, 19 April. The individual responsibility that staff have for manufactured products makes heavy demands on their knowledge of measuring techniques. Workshop staff (executive staff, craftsmen, measuring engineers, etc.) have to be able to measure reliably as this helps avoid unnecessary rejections as well as having a cost-saving and quality-enhancing effect.

During the theme day, three lectures will be held on measuring uncertainty and calibration, the effect of machine inaccuracy on workpiece precision, and interpreting form and place tolerances and standards.
Actual practice will be discussed after lunch; six companies will introduce the application, the accuracy and the use of new measuring appliances:

- Clamping techniques combined with off-line programming in MCosmos (Mitutoyo).
- Comparative measuring with Equator (Renishaw).
- Measuring surface roughness with various appliances and how to compare them (Viba).
- Pitfalls when measuring surface layers (Helmut Fisher).
- Measuring uncertainty in contactless measuring (SMS Benelux).
- Measuring with the six-axled TESA Multi-gage arm (Hexagon).

www.mikrocentrum.nl/evenementen

"The Design of Performance

Robert Munnig Schmidt, Georg Schitter and Jan van Eijk, "The Design of High Performance Mechatronics – High-Tech Functionality by Multidisciplinary System Integration", Delft University Press (an imprint of IOS Press), ISBN 978-1-60750-825-0 (print), ISBN 978-1-60750-826-7 (online).

Last July, this comprehensive mechatronic design handbook was published. Written especially for mechatronic designers and architects, it gives an extensive overview of all technical subjects needed for conceiving and creating a high-precision mechatronic motion system. The extensive index provides easy access to any subject the reader wishes to learn about. The 750 pages have been printed with clear, full-colour pictures and graphs.

Mechatronics is a broad multidisciplinary field of engineering and, generally, development projects require teams consisting of generalists and specialists from many disciplines to achieve optimal system performance.

The authors acknowledge the importance of (embedded) software but restrict themselves to the prime functionality, touching only briefly on the role of software in the form of controller algorithms and aspects such as calculation delay. Also, the authors were wise not to write a separate chapter on design principles or precision mechanics, including subjects such as design for stiffness/compliancy, (non-) hysteresis, damping, manufacturability, cost price, accuracy and so on. Instead, they refer to the excellent book "Design principles for precision mechanisms" by Herman Soemers, which builds on and adds to the heritage of Wim van der Hoek and Rien Koster.

The authors intentionally give a lengthy historical overview of high-precision mechatronics in the Netherlands, presenting the first video long players and CD players of Philips. The book underlines the importance of mechatronics for the Dutch industry and outlines its evolution in research and education, especially at the Dutch universities of technology.

The book features the disciplines/elements that are present in any servo-controlled, opto-mechatronics device. They are grouped in the following chapters:

- Mechatronics in the Dutch high-tech industry
- Electricity and frequency
- Dynamics of motion systems
- Motion control
- Electromechanical actuators
- Analogue electronics
- Optics in mechatronic systems
- Measurement in mechatronic systems
- Precision positioning in wafer scanners

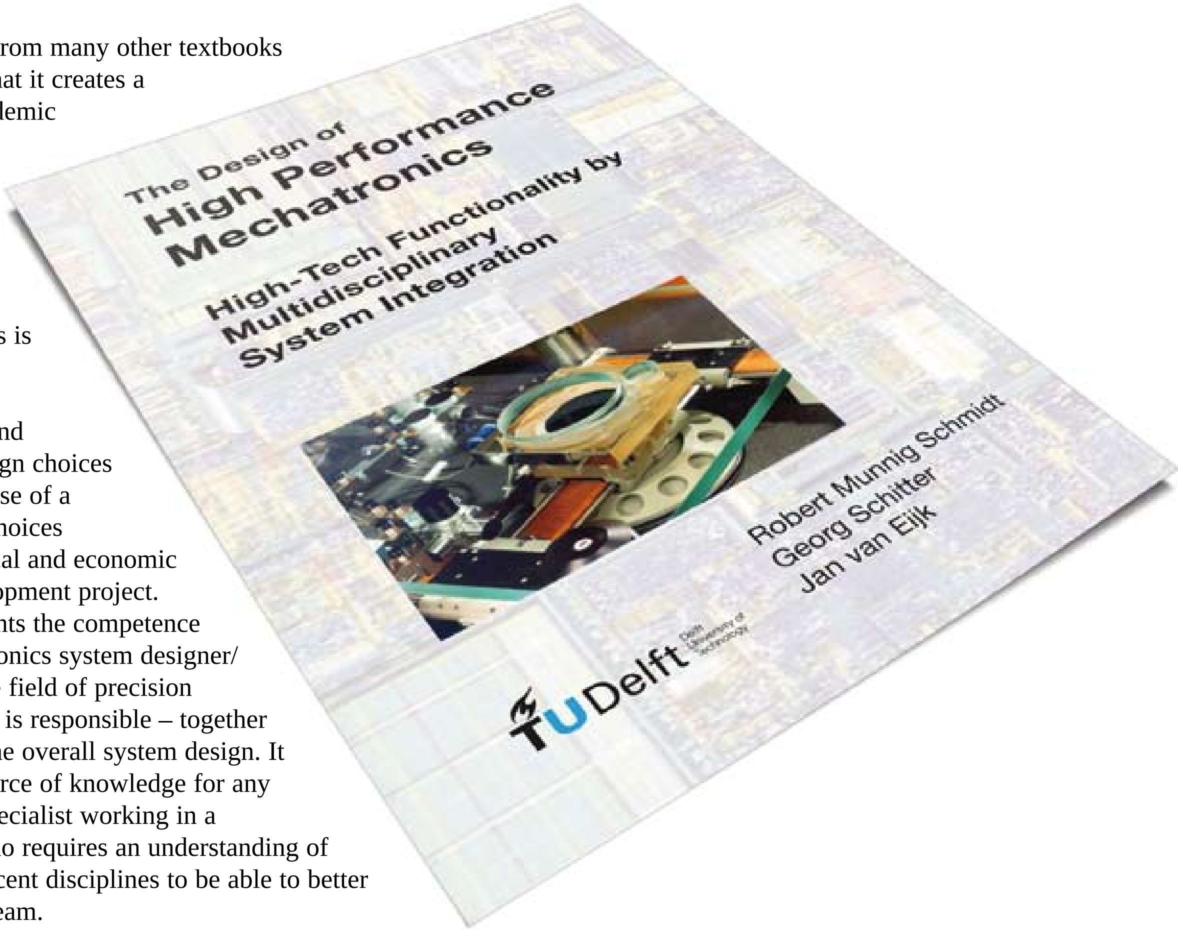
Scanning the chapters, we are given elementary outlines of electricity, electronics, the mathematical understanding of waves and frequencies from mechanical vibrations to electromagnetic waves and light frequencies, and from the foundations of Laplace and Fourier transforms to Bode diagrams, including the usefulness in understanding dynamics, electronics and control. The control chapter deals with feedback versus open-loop control, proportional control versus integrating or differential actions, phase shift, stability, etc. Electromechanical actuators have their own chapter, which includes an explanation of magnetics and Maxwell's equations, how to use and to create magnetic fields, and their application in Lorentz actuators. Also, the use of magnetic fields for the purpose of damping is covered. Finally, various applications of piezo material are presented.

Analogue electronics have their own chapter. Both signal processing by means of filters and the basic concepts for power electronics are explained. Various classical circuit concepts are enumerated, explained and placed in a mechatronic context. This chapter provides the mechatronics engineer with (high-level) basics of relevant electronics allowing him to make system-level design decisions and specify his requirements to an electronics expert. Here too, the historical perspective – from vacuum tubes to MOSFET – provides excellent and comprehensive insights.

High Mechatronics”

The chapter on basic optics, related to mechatronic applications such as lithography and optical sensing, describes the fundaments of lasers and Snellius’ law, as well as spherical aberrations, astigmatism and coma errors, followed by chromatic aberrations. Touching further on the history in lithographic systems, the authors elaborate on optical imaging and topics such as telecentricity, optical lenses, and field stops. These are shown in their fundamental use along with diffraction optics and gratings. Measurement systems, including their physical background, receive due attention, and error budgeting and signal processing are also covered.

The book is distinct from many other textbooks on mechatronics in that it creates a balance between academic insights and industrial application, which stems from the authors’ many years of industrial experience. The focus is on understanding the essential basics of all relevant disciplines and making the right design choices in the conceptual phase of a project, since these choices determine the technical and economic success of any development project. Thus, the book presents the competence base for any mechatronics system designer/architect active in the field of precision motion systems, who is responsible – together with his team – for the overall system design. It is also a valuable source of knowledge for any mono-disciplinary specialist working in a mechatronic team who requires an understanding of the essentials of adjacent disciplines to be able to better cooperate in such a team.



The last chapter features the use of the combined technologies in the design of wafer steppers, the field in which the authors have been involved for the past decades. This once again demonstrates the impact of high-performance mechatronics. All in all, the book is highly recommended and is a must-have for those active in high-precision mechatronics and for mechatronics students.

www.dupress.nl

(by Adrian Rankers, Piet van Rens and Frank Sperling)

Aerotech's Motion Simulator GUI

Aerotech's comprehensive precision positioning and motion control range includes advanced motion simulators that provide position, rate and acceleration profiles for testing and calibration of inertial navigation components and instruments such as gyroscopes and accelerometers; see Figure 1. Typically supplied as complete ready-to-run systems, these high accuracy rotary simulators range from economical single-axis units to high-performance three-axis assemblies that use state-of-the-art direct-drive and air-bearing technologies. To complement such advanced positioning mechanics and motion controls, Aerotech has developed an easy-to-use Motion Simulator graphical user interface (GUI) that enables manufacturers and test houses to create the required motion trajectory parameters and analyse the performance data for components or complete inertial systems, with a user interface and programming environment that requires no third-party development software.

Figure 1. High accuracy single-axis motion simulator with tilt axis for testing and calibration of inertial navigation components.

The Motion Simulator GUI runs on Aerotech's A3200 Automation Platform – a 32-axis Windows® software-based machine controller with motion, vision, PLC, robotics, and I/O that utilises the industry standard FireWire® (IEEE-1394) network to provide from 1 to 32 axes of synchronised and decentralised control with no degradation in performance as the axis count increases.

As a part of Aerotech's Motion Composer development environment for the A3200, the Motion Simulator GUI is able to call and integrate a full suite of configuration, status and diagnostics tools and library files within separate and easily discernable screens. The GUI can also integrate highly advanced functions using Aerotech's optional Dynamic Controls Toolbox, which includes a set of controller level algorithms that reduce settling times, eradicate harmonic disturbance, enhance in-position stability and offer many more functions for increased throughput and improved performance.

Manual motion and data collection tools that do not require specialist programming skills are built into the Motion Simulator GUI. Simulating the typical motion characteristics used to test gyros and inertial measurement devices, users can easily set manual motion on up to three axes and individually capture and display the actual analysed motion data on screen. As the duration of the capture is essentially limited only by the PC's CPU memory, exceptionally long capture times are possible. Captured data can also be exported as .CSV files, which can be interpreted by most devices for later analysis.

For external motion signal tracking, the GUI can synthesise an external analogue signal and make the positioning mechanics follow it in position or velocity. The user can call, debug and modify programs and integrate digital or analogue I/O or any other programming functions available on the A3200.
Motion profiles can be optimised within the GUI by calling Aerotech's Motion Designer utility. This is an add-on software component to the Digital Scope that allows the user to build any trajectory from motion blocks (trapezoidal, sinusoidal, sawtooth, etc.) or from imported data using position, velocity, acceleration and time (PVAT) coordinates. By executing the profile over several iterations, Motion Designer's built-in learning control algorithm will minimise the position error for improved path accuracy; Figure 2 shows an example.

The frequency response tool in the Motion Simulator GUI is a utility for characterising the transfer function of sensors or any device under test. With the ability to measure any number of parameters over a range of frequencies, a swept bode plot can be produced. This tool may be used to determine, for instance, the acceleration command as a reference compared to the analogue output from an accelerometer – providing its transfer function. This tool can be configured to compare the transfer function using a combination of several characteristics from drop-down menus. Thus beyond sensor testing, the same tool is also used to test the transfer function characteristics for many other applications. This might include individual linear or rotary stages or a complete positioning system by measuring the magnitude and phase response over a range of frequencies.

Other advanced functions that can be integrated into the Motion Designer GUI include Harmonic Cancellation, which optimises motion position errors generated by sinusoidal motion, and Position Synchronized Output (PSO) for real-time event triggering.

www.aerotech.com

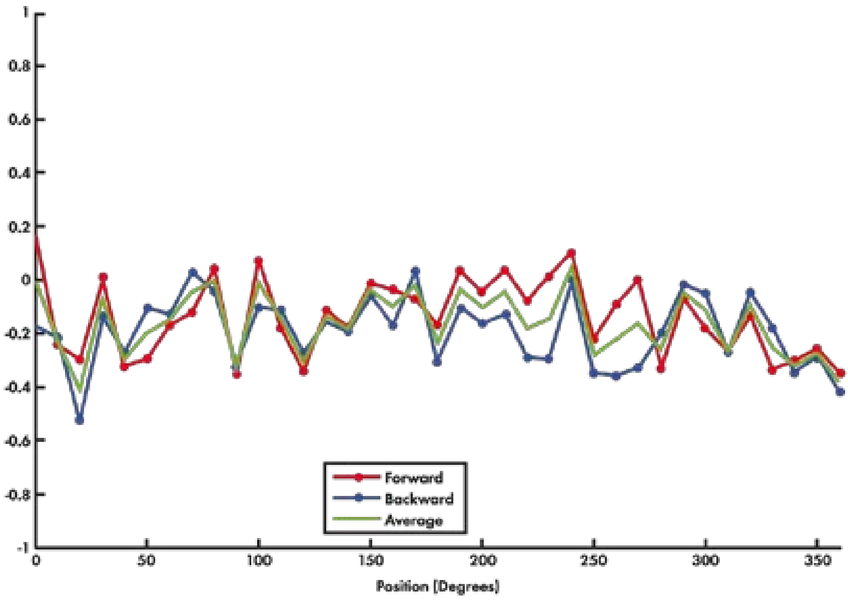
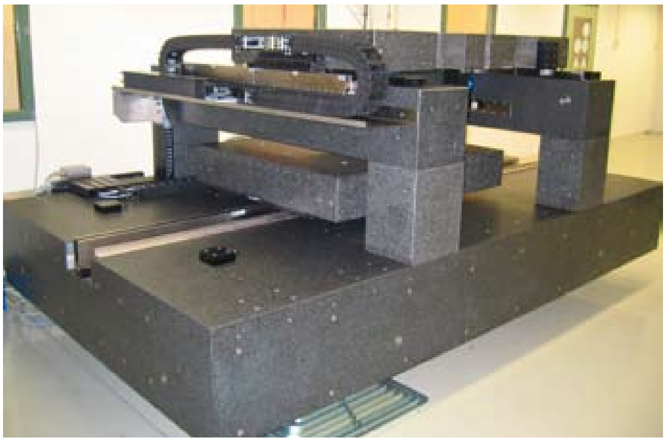


Figure 2. Accuracy plot showing better than 1 arcsec accuracy (4.85 μrad).

NTS-Group takes over BoTech

The NTS-Group in Eindhoven, a supplier of opto-mechatronic systems and modules to international OEMs, has taken over BoTech in Helmond, which will continue as a fully owned NTS-Group subsidiary under the name of "NTS Botech". BoTech's primary products are made of granite, which, given its hardness and stability, is used in a number of different ways in ultra-precision machines. The company also specialises in re-tooling large frames, and it boasts a lot of knowledge and expertise in co-designing and assembling large mechatronic high-precision modules and machine components. All thirty employees have joined NTS.

www.nts-group.com



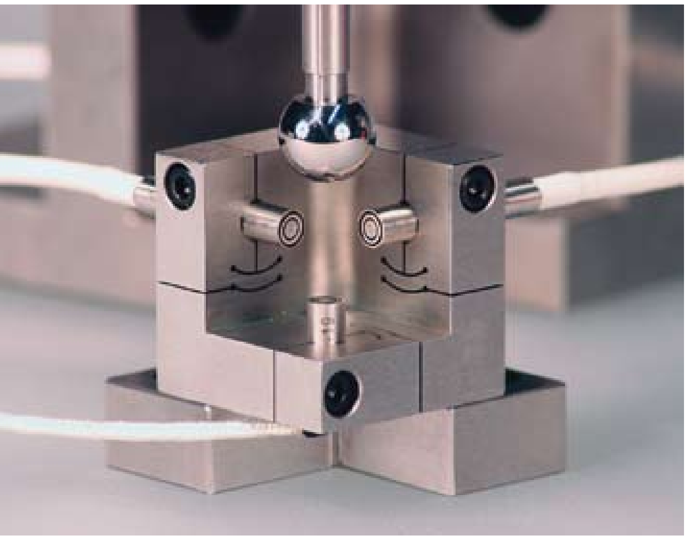
A typical BoTech product.

Alten extending service provision to Mechatronics

Alten provides technical consultancy and engineering services throughout Europe. In the Netherlands, Alten has meanwhile become a household name in technical automation through its subsidiary Alten PTS. In line with the other European countries, Alten is now expanding its operations in the Netherlands to include other specialisms in technical consultancy. From January 2012 on, Alten will also be providing services in mechatronics and installation engineering. The new business unit Alten Mechatronics has been launched under the leadership of Mark Menting, with mechatronics and robotics as the expertise areas.

www.alten.nl

Evaluating micro-machining performance



For over ten years, the industry standard Spindle Error Analyzer (SEA) from Lion Precision, offered by IBS Precision Engineering based in Eindhoven, the Netherlands, has been measuring machine-tool spindle thermal growth and error motions in multiple axes. It has now been adapted for micro-machining. The SEA system includes high-resolution non-contact capacitive displacement sensors, precision probe mounts, precise masterball targets with less than 100 nm of roundness error, temperature sensors and software to acquire and analyse the measurements, including ANSI and ISO standard tests of spindle performance.

Machining problems related to surface finish, feature location and roundness are all significantly affected by spindle performance and thermal effects. The SEA system measures spindles at operational speeds up to 300,000 rpm with resolutions less than one nanometer. With the recent surge in micro-machining spindle designs that minimise error motions, measuring those error motions will continue to present challenges to designers and end users alike. This micro-machining adaptation of a standard instrument may help the micro-machining industry to the next level.

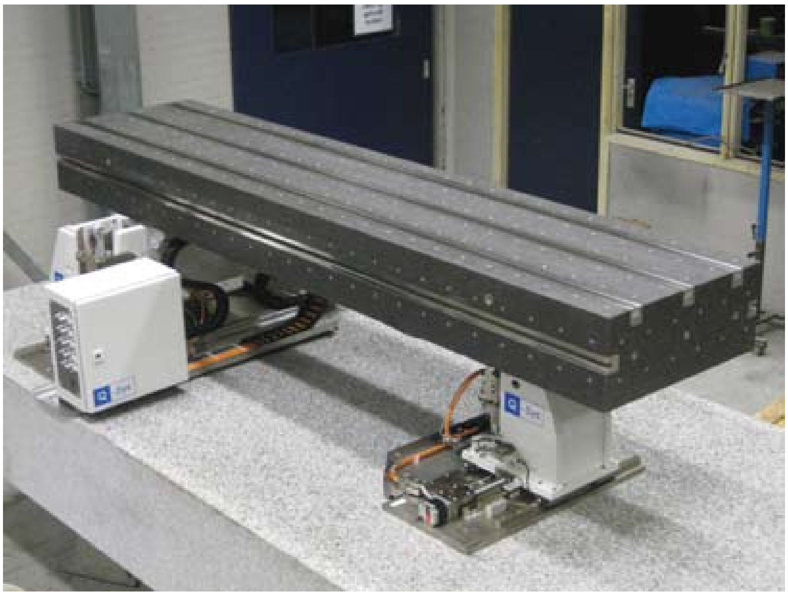
www.ibspe.com

5-DoF optical table

Q-Sys has designed and built an optical platform with five degrees of freedom (DoFs) for precise sample positioning applications at DESY (Deutsches Elektronen Synchrotron). At 2,700 mm long and 800 mm wide, the optical table can accommodate loads of up to 1,000 kg. In addition to a large number of threaded inserts, it has five full-length stainless steel T-slots to give the user total flexibility in the mounting of components.

The granite table is supported on three actuator systems which, according to a Q-Sys press release, by a combination of clever design and ingenious kinematic mounting, deliver controlled motion in five axes. Using specific combinations of moves of the individual actuators, the table is controlled in both horizontal and lateral positions, plus pitch, roll and yaw. The custom-designed actuators also include full protection against overtravel and power loss, including integral dampers and brakes. Precision positioning is available over ranges of 100 mm in the vertical direction and 200 mm in the horizontal. These are complemented by ranges of ±1° in each of pitch, roll and yaw.

www.q-sys.eu



Prizes for professional skills

Last year November saw the 22nd edition of the Ir. Noordhof Award presentation for professional skill, organised by the Stichting Bevordering Vakmanschap, which brings together a great many companies in the manufacturing industry in the greater Eindhoven region. During the event, which was hosted by the VDL Group, 400 guests were able to admire the workpieces and presentations of the 34 nominees from the construction, metal, electronics, mechatronics and other industries.

The winner of the Ir. Noordhof Award 2011 in the Metal and Mechanical Engineering category was Jan van Kroonenburg, employed at Bosch Rexroth in Boxtel. According to the jury, he is a very dedicated colleague, a true all-rounder and an excellent ambassador of his profession. He has unique problem-solving skills, takes on every challenge the profession throws at him, from extreme depths and glow problems to exotic materials and special 'almost forgotten' processes. He is also very involved in schools and training young colleagues and students at local technical schools. The Young Talent Award 2011 went to Thieu Schevers, who combines his education at a Regional Training Centre with work at NTS Mechatronics in Eindhoven. In next to no time, Thieu managed to design and build a project with remarkable craftsmanship and enthusiasm, said the jury.

www.bevorderingvakmanschap.nl

From left to right: Thieu Schevers, winner of the Young Talent Award; Richard Schoenmakers, winner of the Ir. Noordhof Award in the Construction category; Jos Smetsers, Senior Director PACCAR Purchasing Europe and chair of Stichting Bevordering Vakmanschap; Wim van der Leegte, general director VDL Group and event host; Annie Verhoeven-de Bresser, winner of the Ir. Noordhof Award in the Other Professions category; Jan van Kroonenburg, winner of the Ir. Noordhof Award in the Metal and Mechanical Engineering category.

Frencken acquires US Motion

Frencken Europe, a wholly-owned subsidiary of Frencken Group Limited, has acquired the majority of shares in US Motion Inc. The group sees the acquisition as a strategic move to strengthen the position of its Mechatronics Division as a global player in the high-technology sector. Operating from a fully-equipped factory in Spokane, Washington (USA), US Motion is a high-technology solutions provider that designs, engineers and manufactures electro-mechanical products and systems. Besides offering project-based mechatronics services, USM develops its own range of proprietary products which include precision measurement systems, brushless servo motors, optical rotary encoders and integrated systems. USM employs a team of thirty people.

Frencken Group Limited is a global high-tech capital and consumer equipment service provider offering complete and integrated 'one-stop' outsourcing solutions in partnership with its customers in the capital equipment and consumer industries. With facilities in the Netherlands, Singapore, Malaysia and China, the group offers a comprehensive range of product solutions that span the entire value chain – from initial product design, development and prototyping, to engineering, final test and series manufacturing.

www.frenckengroup.com
www.usmotion.com

LEO – Center for Service Robotics makes itself known

One of the LEO projects is Teleflex, a surgical telemanipulation system with intuitive control for minimally-invasive operations.

The year 2010 saw the launch of LEO – Center for Service Robotics in the Dutch region of Twente – led by the inspirational incentive of University of Twente professor in Advanced Robotics Stefano Stramigioli and Demcon director Dennis Schipper. The initiative of knowledge institutes and high-tech companies is geared to robotics application in health care, rehab, (personal) service and industrial inspection. Last spring, Matthijs Roorda was employed as quartermaster to further expand the network of participating companies and organise concrete activities such as workshops, company visits and an annually recurring Service Robotics Congress. The robotics centre has national ambitions. Roorda wants to increase the number of (paying) members of LEO to at least twenty and to initiate projects. Alongside the UT, rehab centre Het Roessingh and Twente-based companies such as Demcon, IMS, Hankamp, Controllab Products and maxon motor benelux, Assistive Innovations (Didam), Focal Meditech (Tilburg) and DVC Machinevision (Breda) have also joined and more new members are knocking on the door. Eventually, LEO is to become a self-supporting ecosystem.

The first congress took place last November. Speakers from renowned companies shed light on a range of different application fields, from agricultural mechanisation and milking robots (Lely) and mobile service robots in the factory of the future (KUKA Laboratories) to space robotics (ESA-ESTEC) and remote handling for remote maintenance of a nuclear fusion reactor (Heemskerk Innovative Technology).
Opportunities for new robotics are to be found in the area of medicine and care, Roorda adds. “Because of an ageing population, we will have to keep the welfare state on its feet with fewer people. Besides, people want to live independent lives for longer. Using robotics, there are plenty of solutions you can offer. Many people are beginning to experience its benefits, the robot vacuum cleaner being a case in point. Not that there isn’t plenty of work still to do, when it comes to accepting robots, from a social perspective.”

www.leorobotics.nl

The Dutch high-tech ecosystem flourishes

The success of the Dutch high-tech industry is driven by the strength of the underlying innovative ecosystem of large companies, SMEs and knowledge institutes. The "Vereniging Point-One" association has worked for years with concrete projects to reinforce and develop this ecosystem, focusing on the competitive edge of the high-tech SMEs and the availability of high-tech knowledge workers (human capital). One example is a project with Mechatronics Partners, a strategic partnership of five industrial engineering and manufacturing companies in the southern Dutch provinces of Limburg and Brabant: Addit and Nedinsco in Venlo, Kleeven Control/Kleeven Medical and GTE in Horst and MMI in Venray.

Outsourcers (OEMs) in the high-tech industry are limiting themselves more and more to their core business and are therefore looking for a one-stop shop for the supply of complex modules at a higher level. This can be a first-tier supplier that turns out to be a system supplier but also a cluster of mutually complementary suppliers such as Mechatronics Partners (MP). "The added value of MP lies in the fact that each partner is highly innovative in their own markets and competences and is able to respond rapidly to questions from OEMs," says Huub Hendrix, Addit's marketing & sales manager. The challenge, however, lies in making that added value transparent and in building trust with OEMs.

To this end, a Point-One project for market development was set up, the aim being to take the collaboration within the cluster to a higher level. The partners defined criteria on which outsourcers can base their choice of a cluster or a classic, first-tier supplier. They also investigated how to make trust – an essential ingredient of partnerships – quantifiable. And finally, the results of this project had to be transferable to other clusters. Taking a concrete assignment, a closer look was taken at the project management, the internal organisation and the commercial approach of the cluster so as to formulate improvement objectives and to make a professional impression on OEMs. It emerged that collaboration could be formalised even more and that documenting milestones, also by customers, could be improved. And there were more of such eye-openers for the partners. As Hendrix said, "We learned a lot from the project and have moved closer together."

Point-One is an open association of and for high-tech companies and knowledge institutes engaged in research and development in the Netherlands in the fields of nano-electronics, embedded systems and mechatronics. The aim of the innovation programme is to allow the Dutch economy to grow by investing in technology. To date, all Point-One activities have been financed by the project participants and Agency NL of the Ministry of Economic Affairs, Agriculture and Innovation, supplemented by a contribution from the European Commission for the international R&D section. This year, under the influence of the Dutch government's innovation policy, Point-One will be steering a new course.

www.point-one.nl

New motion control product locator

The European Power Transmission Distributors Association (EPTDA), the leading pan-European organisation for the mechanical Power Transmission and Motion Control (PT/MC) industry, recently announced its brand new e-tool: the EPTDA Product Locator. The EPTDA Product Locator is a product search engine that increases the accessibility to the products of the EPTDA distributor and manufacturer member companies.

www.eptda.org/product-locator

Course	CPE points	Provider	Starting date (location, if not Eindhoven)
Basic			
Mechatronic System Design (parts 1 + 2)	10	HTI	11 June 2012 (part 1) 5 November 2012 (part 2)
Construction Principles	3	MC	20 March 2012 (Utrecht) 11 April 2011
System Architecting	5	HTI	26 March 2012
Design Principles Basic	5	HTI	23 May 2012
Motion Control Tuning	6	HTI	30 May 2012
Deepening			
Metrology & Calibration of Mechatronic Systems	2	HTI	unknown
Actuators for Mechatronic Systems	3	HTI	8 October 2012
Thermal Effects in Mechatronic Systems	2	HTI	unknown
Summer school Optomechatronics	5	DSPE	25 June 2012
Dynamics & Modelling	3	HTI	3 December 2012
Specific			
Applied Optics	6,5 6,5	MC HTI	1 March 2012 30 October 2012
Machine Vision for Mechatronic Systems	2	HTI	unknown
Electronics for Non-Electronic Engineers	10	HTI	8 January 2013
Modern Optics for Optical Designers	10	HTI	2 March 2012
Tribology	4	MC	29 February 2012 (Utrecht) 28 March 2012
Introduction in Ultra High & Ultra Clean Vacuum	4	HTI	12 March 2012
Experimental Techniques in Mechatronic Systems	3	HTI	3 April 2012
Design for Ultra High & Ultra Clean Vacuum	4	HTI	16 April 2012
Advanced Motion Control	5	HTI	8 October 2012

DSPE Certification Program

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

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

Course providers

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

Mikroniek guide

Bearing and Linear Technology

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Schaeffler Group - LuK, INA and FAG - is a world wide leading company in developing, manufacturing and supplying of rolling bearings, linear systems, direct drives and maintenance products. Applications: automotive, industrial and aerospace.

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