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**Dynamic Error Budgeting • Design of an active vibration isolation system
High-throughput metrology for lithography • Measurement of 3D microparts
Symposium on difficult-to-machine materials • High-accuracy phi-Z actuator
Piling up technologies against fraud • Focusing on faster high-precision systems**



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In this issue

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- 4 Editorial**
Joep Brouwers (Brainport Development) on high-tech policymaking.
- 5 Dynamic Error Budgeting**
Performance analysis and design of mechatronic systems.
- 13 The “ultimate performance” in floor vibration isolation**
Design of a new 6-DoF active vibration isolation platform, using Dynamic Error Budgeting for predicting the influence of vibrations.
- 21 Mikrocentrum**
Theme day on inexpensive precision.
- 22 YieldStar: entering the picometer era**
High-throughput metrology for lithography.
- 28 Traceable measurements of 3D microparts**
New metrology at Dutch institute VSL.
- 36 Modern materials challenge cutting experts**
Report of symposium on difficult-to-machine materials.
- 43 Design of a high-accuracy phi-Z actuator**
Actuation in Electro Discharge Machining.
- 48 Piling up technologies against fraud**
Company profile: IAI industrial systems.
- 52 Focusing on faster high-precision systems**
Report on a project from the Innovation-oriented Research Programme Precision Technology.
- 55 News**
*Including:
Laser dicing to 12 inches.
Investing in ultrafast ALD.
Philips Innovation Services.*
- 62 Upcoming events**
Including: Euspen 11th International Conference.
- 64 DSPE**
*Including:
International Summer school Opto-Mechatronics 2011.
Introducing DSPE board members – Edwin Bos.*
- 66 Tapping into Each Other’s Expertise**
Ceratec Technical Ceramics.



Momentum

I am honoured to be invited as a non-techie to write an editorial for Mikroniek. Working as such a non-techie at Brainport Development at the forefront of the Netherlands' high-tech systems industry, I am especially inspired by the entrepreneurship of the suppliers in our region. I am sure you must have heard and read about the Brainport 2020 programme that Rob van Gijzel, mayor of Eindhoven, presented to the Minister for Economic Affairs, Mr Verhagen. This programme's key aspect is to foster the Netherlands' high-tech systems manufacturing industries.

The funny thing is that only a few people really understand why this is so important. In the last few years, we have been working very hard to get Dutch politicians to understand this. Every single policy document published in the last two years refers to what we are doing here at Brainport. Nonetheless, a lot of missionary work still has to be done in our own region.

Does this mean that we have convinced everybody of the importance of our manufacturing industry? I'm afraid not. The Dutch government's ideas on innovation and the importance of knowledge and research are not convincing in this regard. Recently, we saw the kick-off meeting of the so-called 'Top Teams'. These teams are going to advise the Minister on the 'Top Sectors'. At least three of these sectors are important to Brainport: the high-tech systems sector, chemistry and food. Other sectors – energy, life sciences, creative industries and logistics – are also closely related to our region.

Our challenge will be to link the policies on the Top Sectors with our Brainport 2020 programme. We already know that this programme has had a great impact on policymakers in The Hague. It was only a few weeks ago that Mr Verhagen advised the chairpersons of the Top Teams to use our programme.

Do we now just have to wait and see? No, of course not. What I learned from all those entrepreneurial (small) suppliers in our region is that we just go out and get them.

Joep Brouwers
Vice Director Brainport Development

Performance analysis and design of mechatronic systems

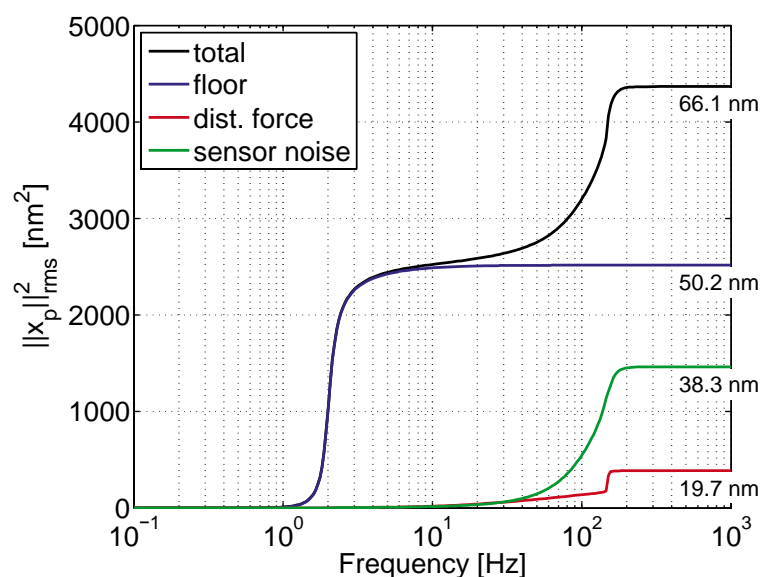
Ultimately, the performance of a mechatronic system is limited by various disturbance sources acting on the system or originating in the system itself. Often these disturbances are of a stochastic nature, or can be interpreted as such. The performance of such a system can be analysed by using power spectrum density models of these disturbances. The great advantage of this approach, called Dynamic Error Budgeting, is that it allows the designer to compare the contributions from various disturbance sources at the performance channel. This is illustrated by the analysis of the performance of a positioning system.

• Leon Jabben and Jan van Eijk •

Authors' note

After having worked in Switzerland, Leon Jabben obtained his Ph.D. at Delft University of Technology, the Netherlands, in 2007. He worked three years at TNO, primarily on space projects. In 2008 he started his own company, Jabius Innovations, for control and design of mechatronic machines. Jan van Eijk is part-time professor of Advanced Mechatronics at Delft University of Technology, and a consultant through his own company MICE (Mechatronic Innovation and Concept Engineering), based in Eindhoven, the Netherlands. The work described here was done in cooperation with Prof. David Trumper of MIT, Cambridge, USA, and Wouter Monkhorst as an M.Sc. student at Delft University of Technology.

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Introduction

In the design and analysis of mechatronic machines, the use of Bode diagrams is widely spread to assess stability and performance. The reason for its widespread use, also outside the control community, is its easy and clear interpretation of the performance when dealing with systems that perform periodic tasks. However, a large class of mechatronic machines have specifications based on their standstill (or constant velocity) performance, e.g., step (or scan) machines for lithography, positioning stages for microscopes and other applications, active vibration isolation and many more. The standstill performance is limited by the noise sources (disturbances) in the closed loop, resulting in a performance measure with stochastic properties.

The difficulty in calculating with stochastic signals and Bode plots is that, instead of calculating with the complex response at one frequency, the influence of the combined signals over a frequency range must be taken into account. For this reason, the use of stochastic calculation tools is less permeated outside the control community. In this article we describe a way of dealing with these stochastic properties and we propose a tool for analysing the performance.

In the design of precision machines, error budgeting is often used to allocate how much each component is allowed to contribute to the total error, see e.g. [1, p. 61]. For the design and analysis of mechatronic systems, one would like to error budget the disturbances acting on the closed-loop system. This can be done by realising that many disturbances in such a system are stochastic of nature and can often be modeled with their Power Spectral Densities (PSD). This allows frequency-dependent error budgeting, which is why this approach is referred to as Dynamic Error Budgeting (DEB).

In [2] [3] [4] the authors use this approach to find the biggest disturbance for the position error in a disk drive. Calculation with PSDs has been used in [5] [6], to determine the optimal preamplifier in a geometer. In [7], the manufacturer uses noise models for the analogue components to analyse the total noise in an operational amplifier. The same approach has been used in [8] to analyse the vibration levels on the International Space Station. In spite of the use of the DEB approach in these

(advanced) applications, we believe that the full potential of DEB in the design and performance analysis of mechatronic systems is hardly recognised in the engineering community.

This paper starts with a theoretical foundation of DEB, as well as the assumptions on which it is based. Next the approach is applied to the analysis of performance for a positioning stage example. The paper ends with the conclusions and recommendations.

Theory

In this section the theoretical background of the DEB approach is given. After covering the assumptions needed for the DEB technique to apply, the connection between performance in the time domain and the frequency domain is made, resulting in an expression of performance in terms of a Power Spectral Density function (PSD). Then it is explained how to predict and analyse the performance using PSDs.

Assumptions

For the DEB approach to apply, the following assumptions should be met:

- All (sub-)systems can be accurately described with a linear time-invariant model.
- The disturbances acting on the system should be stationary, i.e., their statistical properties are not allowed to change over time.
- Only stochastic disturbances are allowed. Signals with sinusoidal and/or dc-components give infinite peaks in their PSDs. If there are deterministic disturbances present, they should be analysed separately with appropriate techniques.

Although DEB does not require the disturbances to be uncorrelated with each other, modeling, analysis and formulas are easier when they are. In this paper it is assumed that the disturbances are uncorrelated. In case the disturbances are correlated, the reader is referred to [9] [10] [11].

The DEB approach makes no assumptions on the probability density functions of the disturbances and the performance channels. However, since a performance channel is the sum of contributions by many disturbances, its probability density function is likely to be accurately

characterised with a normal (or Gaussian) distribution as the Central Limit Theorem [10, p. 95].

Performance in the time and frequency domain

A natural and intuitive measure of performance for systems with a stochastic (and normal distributed) performance signal $x(t)$ is its 1σ value, which is the square root of the variance. The variance is the power of a signal around its mean.

$$\text{mean} \quad \bar{x} = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T x(t) dt \quad (1)$$

$$\text{power} \quad \|x\|_{\text{rms}}^2 = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T x(t)^2 dt \quad (2)$$

$$\text{variance} \quad \sigma_x^2 = \|x - \bar{x}\|_{\text{rms}}^2 = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T (x(t) - \bar{x})^2 dt \quad (3)$$

Since we do not consider dc-components, the Root Mean Square (RMS) of a signal equals its 1σ value. In this article the term power refers to this mathematical definition, Equation 2, of signal power and not to physical power, which is expressed as energy per unit of time [J/s].

Using Parseval's Theorem [10] we can connect the 1σ value to the frequency domain. Parseval's Theorem states that energy in the time domain equals the energy in the frequency domain. Using the definition of signal power and Parseval's Theorem we can link power in the time domain with power in the frequency domain:

$$\|x\|_{\text{rms}}^2 = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T x(t)^2 dt = \int_0^{\infty} \text{PSD}_x(f) df \quad (4)$$

Here, $\text{PSD}_x(f)$ refers to the “single-sided” power spectral density function of $x(t)$.

In a PSD it is difficult to judge whether a small peak at higher frequencies has less or more energy than a broad bulge at lower frequencies. This difficulty is circumvented by calculation and graphical representation of the Cumulative Power Spectrum (CPS):

$$\text{CPS}(f) = \int_0^f \text{PSD}(\nu) d\nu \quad (5)$$

The CPS is always increasing with frequency, starting from 0 at $f = 0$, with an end value that equals the square of the RMS value of the signal up to the end frequency. Due to

the integration the CPS is a rather smooth function, even though measured PSDs are usually noisy, especially at higher frequencies.

Theory of propagation

Key to the DEB design approach is to realise that the final performance of the system is determined by the combined effect of the disturbances that act on the closed-loop system. Examples of disturbances are amplifier noise, ground vibrations, sensor noise, etc. These disturbances act on different locations in the loop, as illustrated in Figure 1. Here one can see three disturbances $w_1 \dots w_3$, applying at different locations, resulting in a performance (error) signal z . The signals are modeled with their PSDs, shown in the blue boxes.

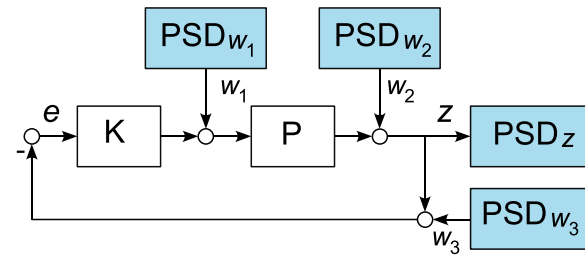


Figure 1. Schematic of a closed-loop system with various disturbances. The disturbances $w(t)$ are modeled with their power spectral density function $\text{PSD}_w(f)$, denoted with a blue box.

Propagation of the PSDs through the closed-loop system of Figure 1, in the case that the disturbances w are uncorrelated, is given by:

$$\text{PSD}_z(f) = \sum_i H_i(f)^2 \text{PSD}_{w_i}(f) \quad (6)$$

Here, H_i is the corresponding transfer function from disturbance w_i to z .

Dynamic Error Budgeting

Having a one-to-one relationship between the performance of the system and disturbances acting on it, the supervising designer can now budget his performance (error) specification over the subsystems. Every subsystem designer gets a part of the total error budget and can now dynamically allocate his contribution to this part using Equation 6. This way, the total machine can be designed in subsystems, while the supervising designer is sure that the specified error budget is met.

Positioning system case

Description of the system

To illustrate the above theory, it is applied to a hypothetical system, schematically depicted in Figure 2. In the system a tool tip is to be positioned with respect to a stator with a positioning error smaller 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 position of the rotor is measured with a sensor and is fed back to a digital controller. The controller commands the actuator, which acts between the rotor and the stator.

The total moving mass (rotor and tool tip) is 2.5 kg, of which the tool tip has a mass of 0.2 kg. The eigenfrequency of the total moving mass with the spring blades is 5 Hz. The tool tip is mounted with limited stiffness to the rotor, which results in a resonance frequency of 150 Hz. The relative damping of the spring blades and the tool tip is 0.01 and $5 \cdot 10^{-3}$, respectively. The stator, with a mass of 500 kg, is supported by air mounts with an eigenfrequency of 2 Hz and a relative damping of 0.1.

The total positioning range of the system is 1 mm, and the range of the actuator is ± 50 N. The command for the actuator is generated by a controller running at 2,000 Hz. The controller has a 16-bit Analogue-to-Digital Converter (ADC), which has electronic noise with a Signal-to-Noise Ratio (SNR) of 80 dB, and a low-resolution Digital-to-Analogue Converter (DAC) with 12 bits. The sensor has

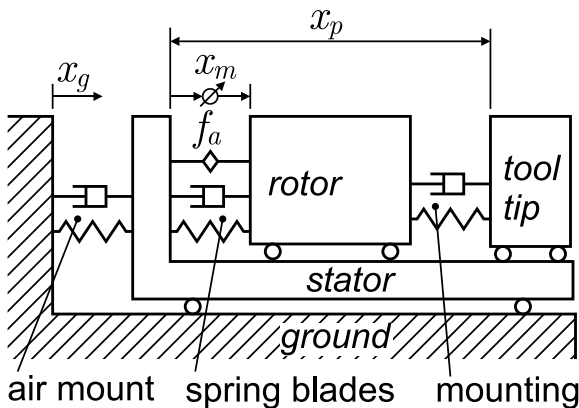


Figure 2. Lumped mass model representation of the positioning problem example. The tool tip is to be positioned with an error smaller than 50 nm (RMS) with respect to the stator.

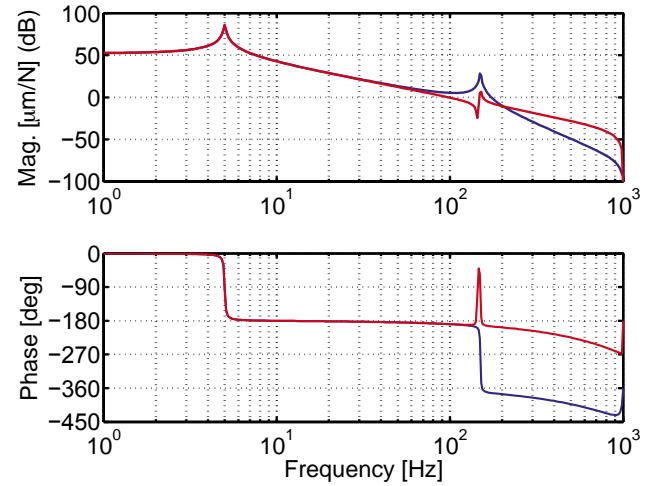


Figure 3. Bode plots of the system, from actuator force input to the position of the tool tip with respect to the stator x_p (blue), which is the performance measure, and to the measured position x_m (red).

(electronic) noise with a peak-to-valley value of $0.1 \mu\text{m}$ up to the Nyquist frequency. It is assumed that the ranges of the converters matches with the ranges of the sensor and actuator. To take into account electronic noise (“ $1/f$ ”) of the amplifier and DAC, as well as low-frequency temperature effects, $1/f^2$ noise is dominant over the DAC quantisation noise up to 5 Hz.

The system can be modeled with the following matrix equation:

$$M\ddot{q} + D\dot{q} + Kq = Ff_a + D_g\dot{x}_g + K_g x_g \quad (7)$$

Here, M , D and K are mass, damping and stiffness matrices and q stacks the absolute positions of the three masses. In [9] it is described how to translate Equation 7 to a state-space representation with force and ground displacement as inputs.

Figure 3 shows the Bode plots of the system. The difficulty in this case is that the allowed positioning error is specified at the tool tip, which has limited stiffness, while the controller controls the position of the rotor.

Sensor noise modeling

If we approximate the valley-to-peak value of $0.1 \mu\text{m}$ of the sensor noise with 6σ , we get a standard deviation of: $\sigma_{\text{elec}} = 17 \text{ nm}$. For simplicity, we shall assume this is white noise.

Noise stemming from the ADC has two sources. First there is the quantisation. Oppenheim [12] treats the quantisation error as uniformly distributed zero-mean white noise. The model describes the theoretical variance of the error and can be written as:

$$\sigma_{ADq}^2 = \frac{lsb^2}{12} \quad (8)$$

Here, lsb represents the least significant bit. Having 16 bits over the range of 1 mm, the standard deviation from the quantization becomes $1/2^{16}/\sqrt{12} = 4.4$ nm. This noise is per definition white and distributed up to the Nyquist frequency.

The SNR gives the ratio of the RMS value of the electrical noise to the RMS value of a sine that covers the maximum range of the ADC. With a range of 1 mm, the RMS of the ADC noise, σ_{ADe} is $354 \mu m / 10^4 = 35$ nm. It is assumed that this electrical noise is white until the Nyquist frequency.

In this particular case, the three sources that contribute to the sensor noise are assumed to be white. Since they are uncorrelated, we can add the variance to a total:

$$\sigma_{sensor} = \sqrt{\sigma_{ADq}^2 + \sigma_{ADe}^2 + \sigma_{elec}^2} = 39 \text{ nm} \quad (9)$$

Then the PSD of the sensor noise can be calculated:

$$PSD_{sensor} = \frac{\sigma_{sensor}^2}{F_{nyq}} = 1.55 \text{ nm}^2/\text{Hz} \quad (10)$$

Here, F_{nyq} is the Nyquist frequency [Hz].

Force disturbance modeling

The floor acceleration is assumed to have a PSD of 10^{-5} [(m/s²)²/Hz] from 1 up to 200 Hz with fourth-order roll-up and roll-off before 1 Hz and after 200 Hz. This spectrum is based on specifications given by lithography stepper manufacturers [13]. The integral of this spectrum results in an RMS value of the accelerations of 47 mm/s². As in Equation 6, the PSD of the vibrations of the table is calculated simply by taking the PSD of the floor multiplied by the Bode magnitude of the table transfer function squared. In doing so, we get the PSD as given in Figure 4 with a resulting standard deviation of 12 mm/s². Note that in our model the input is in ground *displacement*, so for our DEB analysis the PSD of the floor accelerations is multiplied with $1/(2 \cdot \pi \cdot f)^4$.

Finally, the controller output is converted to physical signals by the 12-bit DAC. This results in a quantisation

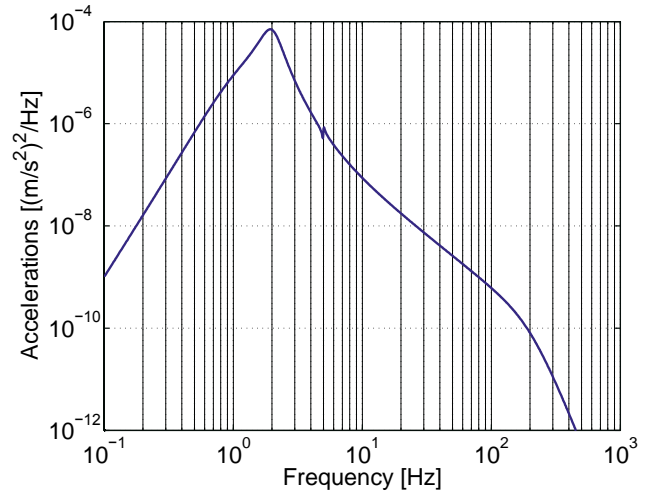


Figure 4. PSD of the accelerations of the stator resulting from the floor vibrations.

noise of 7.0 mN (RMS). As with the ADC, the PSD due to quantisation becomes:

$$PSD_{Fq} = \frac{lsb^2}{12F_n} = \frac{(100/2^{12})^2}{12 \cdot 1000} = 50 \cdot 10^{-9} \text{ N}^2/\text{Hz} \quad (11)$$

To incorporate the $1/f^2$ noise up to 5 Hz, the PSD_{Fq} is multiplied with a filter:

$$PSD_F = \left| \frac{s + 5 \cdot 2\pi}{s + 0.01 \cdot 2\pi} \right|^2 PSD_{Fq} = \frac{f^2 + 5^2}{f^2 + 0.01^2} PSD_{Fq} \text{ N}^2/\text{Hz} \quad (12)$$

Here, s is the Laplace variable. The $1/f^2$ component starts at 0.01 Hz to ease numerical calculations. The total noise of the actuation channel has become 15.6 mN (RMS).

Performance Analysis

Now that we have models of the system and the disturbances, we can apply the DEB approach. To start the process, the loop is closed with a standard PID controller and the bandwidth is such that the error is minimised (an increase or decrease of the bandwidth leads to a bigger error). In Figure 5 the PSD and CPS are given of the error at the optimum bandwidth of 70 Hz. The total standard deviation of the error is 107 nm. From the CPS of the error it is clear that the sensor noise is the biggest contributor and that this is due to excitation of the resonance at 150 Hz. Predicting the effect of preventing this excitation is straightforward. The magnitude of the increase around 150 Hz is about 8,000 nm², hence the performance could become: $\sqrt{(107^2 - 8000)} \approx 60$ nm. Note also that the “ $1/f^2$ ” component in the force disturbance is completely attenuated by the integral action of the controller.

To improve the performance, a notch at 150 Hz is added to the controller. Figure 6a shows the resulting CPS. Indeed, the performance has improved to 66 nm (which is not as good as predicted due to the phase lag from the notch). We

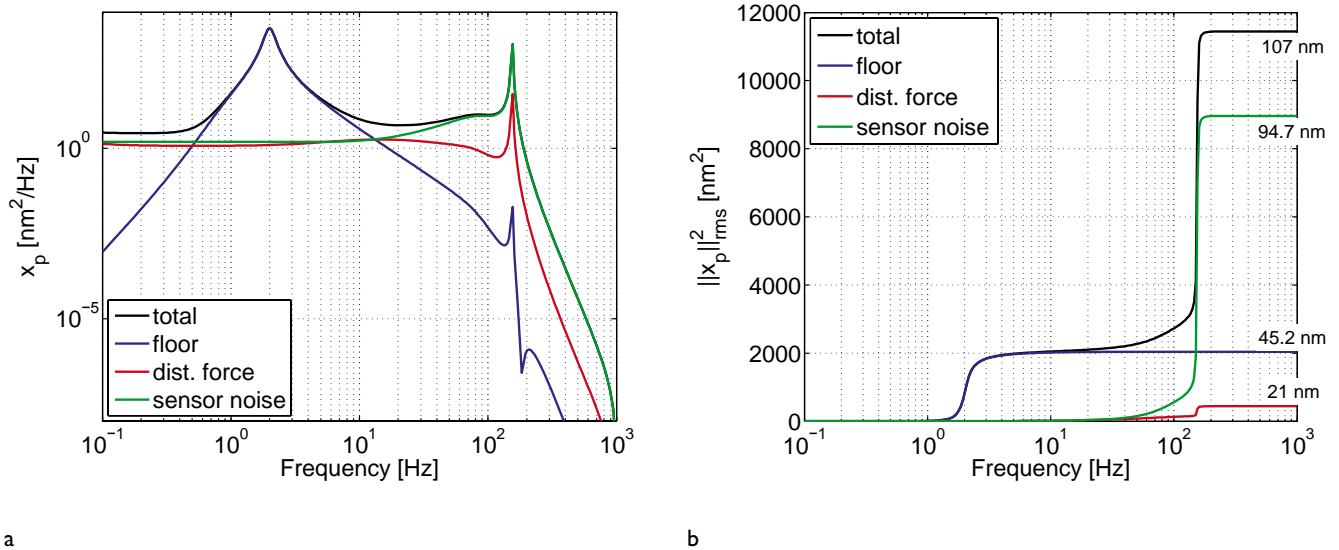


Figure 5. Analysis of the performance.

- (a) Due to the logarithmic scale of the PSD it is not directly clear which disturbance has the bigger contribution: the high and broad bulge from the ground vibrations or the sharp peak from the sensor noise.
 (b) In the CPS the difference is immediately clear.

now see that the ground vibrations have a significant contribution. This can be reduced by increasing the integral action, which becomes “ $1/s^2$ ” for low frequencies. The result is shown in Figure 6b. The performance has reached 46 nm and the design goal is met. Figure 7 shows the initial and the tuned controller.

Again the sensor noise is the biggest contributor, but now the build up is over a frequency range up to 200 Hz. Further increase of performance could be achieved by increasing the phase lead of the controller, however this would lead to less attenuation of the ground vibrations and force disturbances.

To obtain a bigger safety in the performance, DEB shows one should focus on reducing the sensor noise. Since the sensor noise was mostly due to the electric noise in the ADC, an ADC with a higher SNR is needed.

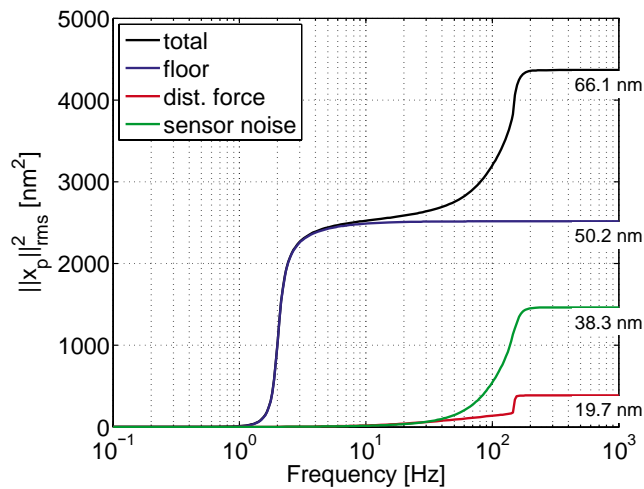
Application of DEB in practice

For disturbances acting on channels of the system, such as DAC, ADC, sensor and amplifier electronic noise and quantisation noise, it is relatively easy to meet the assumptions for applying DEB. Although temperature variations may affect the stability of the statistical properties of the noise, this relation is relatively weak. In well-designed electronics, the channels have a very low correlation between each other, allowing the calculations as shown in this article.

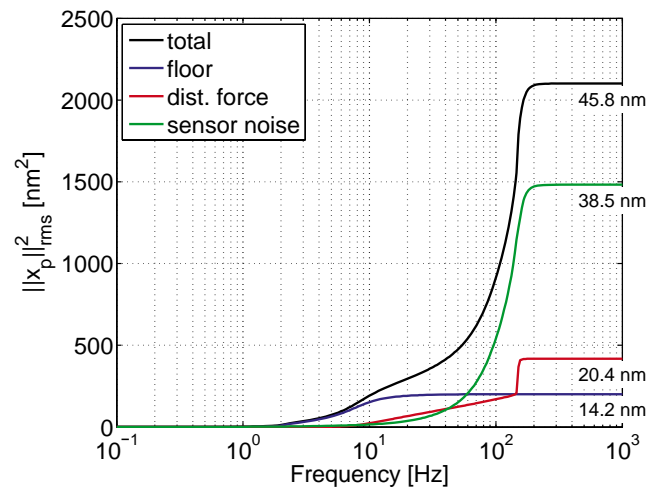
For disturbances acting more globally on the system, such as acoustic noise, ground vibrations and temperature, the

assumptions of DEB require more attention. Typically, these disturbances are non-stationary. One way of dealing with this aspect is to average measurements over longer periods of time. By different means of averaging, a worst case or a typical case PSD can be derived. Furthermore, these global disturbances often contain periodic components stemming from e.g. ventilation. These can be incorporated in practice since a measured PSD contains the energy per frequency bin, and the bin size is taken into account when calculating the CPS. More difficult for multi-input, multi-output systems is the fact that disturbances as ground vibrations and acoustic noise are not uncorrelated in the different directions. Besides the difficulty in modeling the various paths through which these disturbances influence the system, the correlations should be mapped. Here a pragmatic approach is required from the engineer.

For graphical purposes one might be tempted to observe the square root of the CPS, so that the RMS values are directly presented on the y-axis. This is strongly discouraged since this gives a distorted representation. Imagine, for instance, a system with two narrow bandwidth disturbances at different frequencies. The disturbance at the lower frequency has an RMS value of 1, the one at the higher frequency an RMS value of 1.5. The graph for the square root of the CPS will now show two steps; the first with a magnitude of 1, the second of 0.8. As a consequence one will make the erroneous conclusion that the lower frequency disturbance has the biggest contribution! As the power of images is very large, it will be difficult to avoid wrong decisions and costly disappointments.



a



b

Figure 6. Improvement of the performance, visualised by the CPS (Note the different vertical axis scales.).

(a) After adding a notch to the controller at 150 Hz.

(b) After increasing the integral action, which becomes “ $1/s^2$ ” for low frequencies.

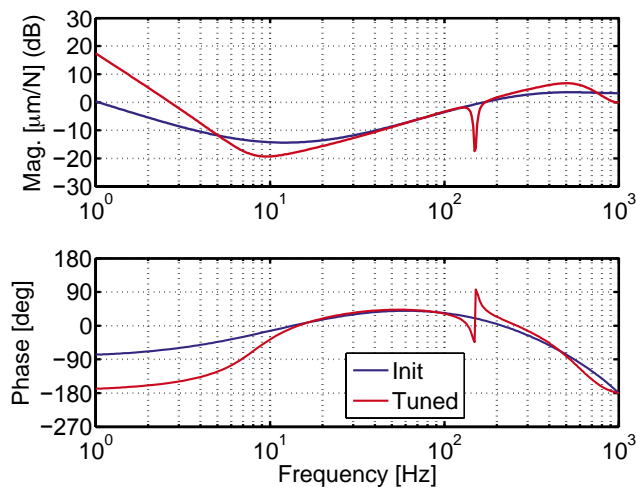


Figure 7. Comparison of the initial and the tuned controller in Bode plots.

Conclusions

The Dynamic Error Budgeting (DEB) approach discussed here is an excellent tool in the design process as well as for performance analysis. It allows the designer to identify the most limiting component in the closed loop. The predicted performance of DEB greatly depends on the models of the system as well as the disturbance sources. In the design phase of a mechatronic system, first-principles model and estimation of the disturbance models can be used to evaluate the design. For performance analysis of experimental systems, one should measure the PSD of the disturbances. Although the application of DEB is an additional effort, we believe it has great added value in the

design of mechatronic machines with standstill or constant-velocity specifications.

The disturbances treated in this article are non-repetitive and not known beforehand. In optimising systems this approach works well for improving performance of the feedback control. For repetitive disturbances and setpoint following, other methods such as repetitive control and model-based feedforward methods can be applied. Independent optimisation of feedback control and feedforward is recommended.

References

- [1] A. Slocum, “Precision Machine Design”, Prentice-Hall, Inc., New Jersey, USA, 1992.
- [2] D. Abramovitch, T. Hurst, D. Henze, The pes pareto method: Uncovering the strata of position error signals in disk drives, in: *Proc. 1997 American Control Conference*, Albuquerque, NM, USA, 1997, pp. 2888-2895.
- [3] T. Hurst, D. Abramovitch, D. Henze, Measurements for the PES Pareto Method of Identifying Contributors to Disk Drive Servo System Errors., in: *Proc. 1997 American Control Conference*, Albuquerque, NM, USA, 1997, pp. 2896-2900.
- [4] D. Abramovitch, T. Hurst, D. Henze, Decomposition of baseline noise sources in hard disk position error signals using the pes pareto method, in: *Proc. 1997 American Control Conference*, Albuquerque, NM, USA, 1997, pp. 2901-2905.
- [5] A. Barzilai, T. VanZandt, T. Kenny, Technique for measurements of the noise of a sensor in the presence

of large background signals, *Rev. Scient. Instruments* 69 (7) (1998) 2767-773.

- [6] P. Rodgers, Frequency limits for seismometers as determined from signal-to-noise ratios. Part 1 the electromagnetic seismometer, *Bull. Seismol. Soc. Am.* 82 (2) (1992) 1071-1098.
- [7] Texas Instruments Incorporated, Noise analysis in operational amplifier circuits – application report, www.ti.com/communitiy/tech_group/analog/tech_paper/21477, last accessed Jan. 2005 (1998).
- [8] B. Tryggvason, R. Redden, R. Herring, W. Duval, R. Smith, K. Rezkallah, S. Varma, The Vibration Environment on the International Space Station: Its Significance to Fluid-Based Experiments, *Acta Astronautica* 48 (2-3) (2001) 59-70.
- [9] L. Jabben, “Mechatronic Design a Magnetically Suspended Rotating Platform”, Ph.D. thesis, Mechanical Engineering, Delft University of Technology, Delft, The Netherlands, 2007.
- [10] M. Priestley, “Spectral Analysis and Time Series”, Academic Press, London, 1989.
- [11] A. Papoulis, “Probability, Random Variables and Stochastic Processes”, McGraw-Hill, 1965.
- [12] A. Oppenheim, R. Schaffer, J. Buck, “Discrete-Time Signal Processing”, 2nd Edition, Prentice Hall, 1999.
- [13] P. Subrahmanyam, “A model approach to precision motion control”, Ph.D. thesis, Mechanical Engineering, Massachusetts Institute of Technology, Boston, USA (1999).

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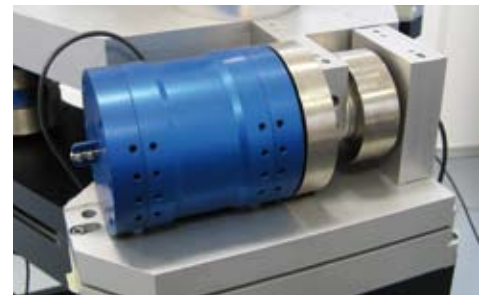
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Accelerating your business

The “ultimate performance” in floor vibration isolation

Commercially available active vibration isolation systems basically are a combination of a passive compliant suspension with active damping of the low-frequency suspension modes. However, with the exception of the semiconductor industry they have not yet found widespread application. Until now performance gain was limited and horizontal-tilt crosstalk demanded for complex control strategies. Therefore, the actual benefits appear not sufficient to accept the added cost. MI-Partners has developed a new 6-DoF active vibration isolation platform with high performance, limited control complexity and high cost efficiency. Fundamental improvements concern crosstalk elimination and noise reduction for better performance. Dynamic Error Budgeting was used in the design phase to predict the integral influence of vibrations.



- *Jan van Eijk, Dick Laro, Jamie Eisinger, Walter Aarden, Tim Michielsen and Stanley van den Berg* •

Authors' note

Jan van Eijk is professor of Advanced Mechatronics at Delft University of Technology, the Netherlands, and director of MICE, based in Eindhoven, the Netherlands. Dick Laro, system architect, Jamie Eisinger, mechatronic system designer, and Stanley van den Berg, project manager/senior mechatronic system designer, all work at Eindhoven-based MI-Partners. Walter Aarden was, Tim Michielsen is an M.Sc. student in the Department of Mechanical Engineering at Eindhoven University of Technology; this article in part draws on their M.Sc. work.

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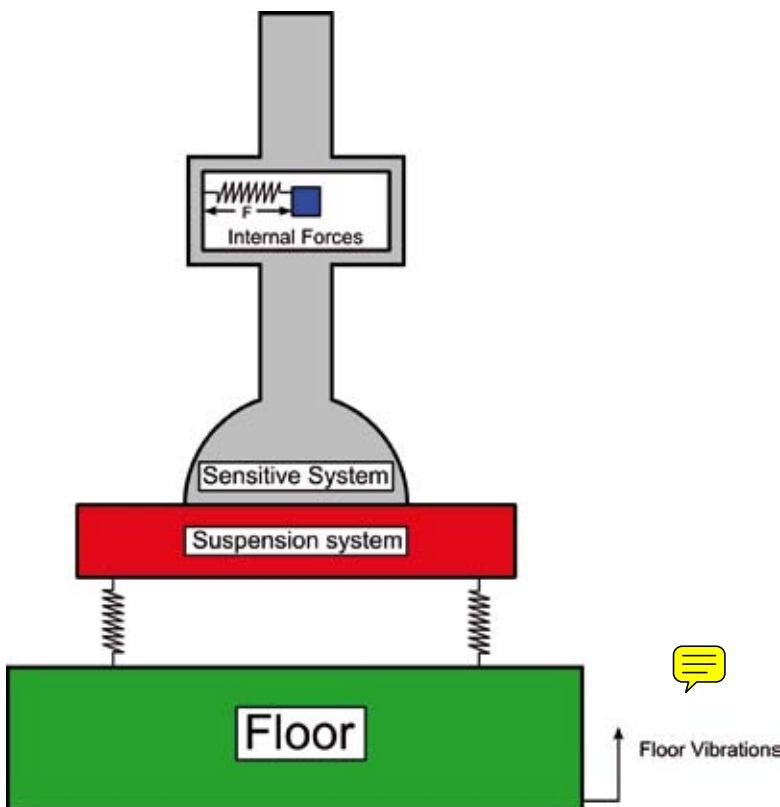


Figure 1. Two disturbance sources for a sensitive instrument: internal forces and floor vibrations.

Introduction

The rise of nanoscale science and technology is creating new challenges in the field of instrument and equipment design. The relative positions of parts of the system must be maintained to subnanometer levels. When imaging at a resolution of 50 pm, the allowable relative motions will be in the order of 10 pm. System vibrations lead to internal deformations – therefore, they must be avoided or sufficiently reduced. The matter has been addressed in recent Mikroniek issues [1] [2].

Figure 1 shows the schematic representation of a sensitive instrument, subject to two types of disturbances. Internal forces may result from driving forces needed to move parts of the instrument. In that case the total system will start to move on the suspension and the resulting forces will lead to internal deformations of the instrument. However, in this article the focus is on the other disturbance source, floor vibrations. These vibrations will be transmitted through the suspension to the instrument and will generate internal deformations.

The design of the suspension system can be aimed at reducing the amount of vibration that is transmitted. In that case, the suspension is designed to be a floor vibration isolator. Both passive and active designs have been proposed and used. To assess the quality of such a

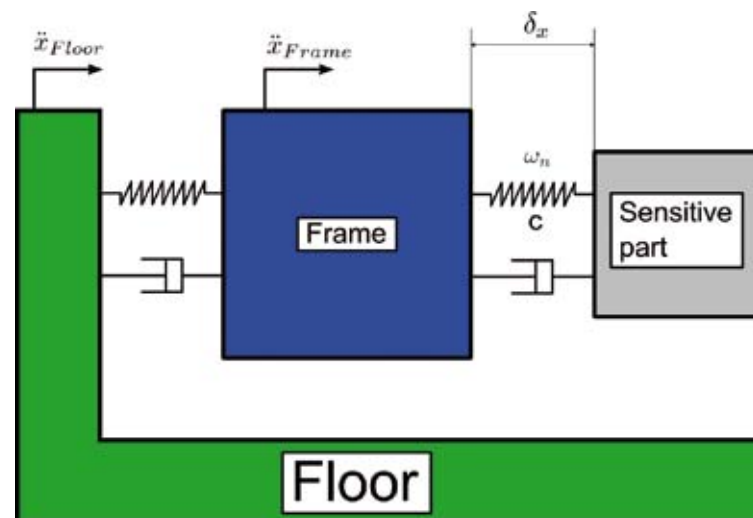


Figure 2. A precision system with a sensitive part connected to a frame by a finite stiffness. Upon force transmission this spring will deform.

suspension system, preferably the final positioning performance of the instrument should be considered.

From vibration to performance

In precision systems the performance is mostly expressed in terms of positioning errors. In an imaging system, however, the mean value of a position error is not as important as the position variations during imaging. Such variations can be characterised using the standard deviation or RMS value of the position error.

Relative motion of parts in a system occurs when forces are transmitted through mechanical parts. Figure 2 shows the schematic of a precision system with a sensitive part connected to a frame. The connection is not infinitely stiff and thus a deformation of this spring will occur when a force is transmitted.

For frequencies below the resonance frequency ω_n of this system the deformation is calculated as $\delta_x = F / c$. When the frame is vibrating with frequencies below the resonance frequency, the force transmitted by the spring is calculated with $F = \text{mass} \cdot \text{acceleration}$. And thus the expression for the deformation becomes:

$$\delta_x = \text{acceleration} \cdot \text{mass} / c = \text{acceleration} / \omega_n^2$$

The ratio between stiffness and mass depends on the natural frequency of the mechanical system. Higher internal frequencies will lead to smaller errors. It can be assumed that system designers have optimised this, within the boundary conditions of the design. Once this is determined, the RMS value of deformation is directly proportional to the RMS value of the acceleration of the frame. Hence, the following statement can be made:

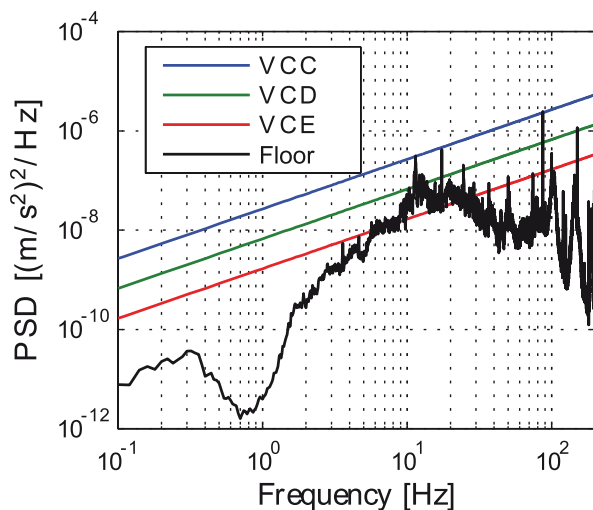


Figure 3. Power Spectral Density presentation of BBN-curves in acceleration units, combined with an actual PSD of measured floor vibrations.

The ultimate performance indicator for an isolated system is the RMS level of acceleration of that system.

Note 1. Of course, the RMS level is depending upon the level of floor vibrations present at a certain location. And comparison of systems must be done using the same external vibration input.

Note 2. This simple derivation is only valid for frequencies below the internal resonance frequency. In high-performance systems such frequencies are higher than 100 Hz. Specifications of floor vibrations are typically determined for frequencies between 1 and 80 Hz, so in many cases it will be acceptable to use this simplification. When interference of internal resonances with vibrations from the environment occurs, more detailed application-specific analysis will be required.

Specifications of floor vibrations

The floor specifications based upon the standards proposed by Bolt, Beranek and Newman (BBN) have been used for many years now. They specified curves with different vibration levels suited for different environments. The curves are indicated as BBN-A to BBN-E, or VC-A to VC-E (VC stands for Vibration Criteria) [3]. The last one is the quietest environment suited for the most sensitive tools. The vibration level is expressed in velocity and the RMS value for 1/3-octave bands is used to assess the vibration level.

In the design of a precision system the integral influence of vibrations can be predicted using the Dynamic Error Budgeting procedure; see the previous article [4], and [5]. Since floor vibrations are of a stochastic nature, the BBN curves can be converted to Power Spectral Density functions, PSDs. As instruments are sensitive to accelerations, using acceleration as the SI-unit is

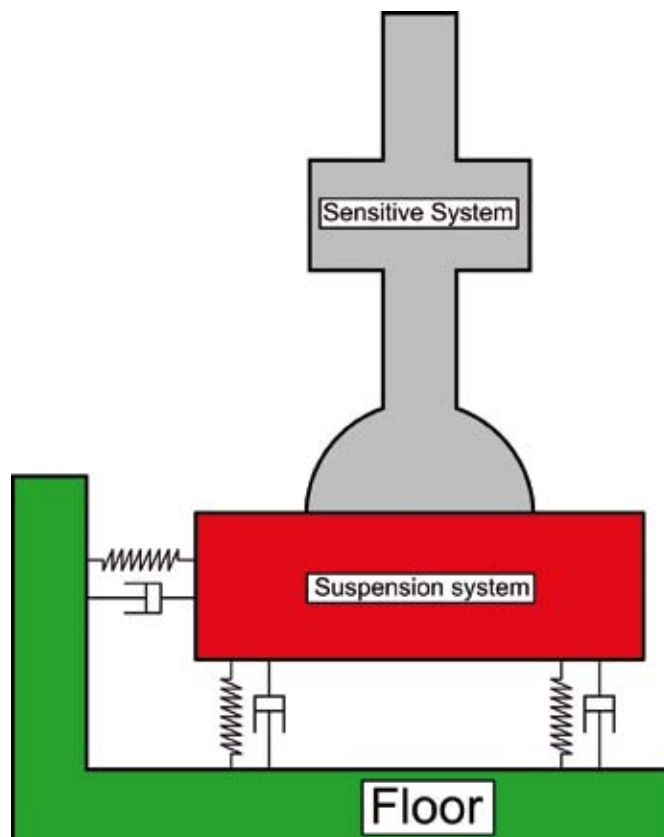


Figure 4. Passive vibration isolation using low-stiffness springs.

recommended. Figure 3 shows such curves together with an actual PSD of measured floor vibrations.

Based upon these graphs, it may be decided that the measured floor can be characterised as a VC-D floor. So, during design the VC-D disturbance level, adding up to about 6 mm/s² RMS for frequencies from 1 to 100 Hz, will be used for performance prediction. The actual level of accelerations in the measured floor, however, is adding up to only 0.8 mm/s². So, during design the influence of floor vibrations will be overestimated by a factor of 8. Therefore, another method of classifying floor vibrations is proposed. For a site, the PSD of accelerations, which indicates the specific frequency content, and the accumulated RMS level of acceleration for frequencies from 1 to 100 Hz must be provided. Then, a fair prediction of the impact of floor vibrations can be made.

Passive vibration isolation

The simplest suspension solution for avoiding floor to machine vibration transmission is to use low-stiffness springs, which in combination with the machine mass creates a mechanical filter; see Figure 4.

Through increasing the relative damping, the magnification at the resonance frequency can be reduced, although more damping will lead to more transmission above the

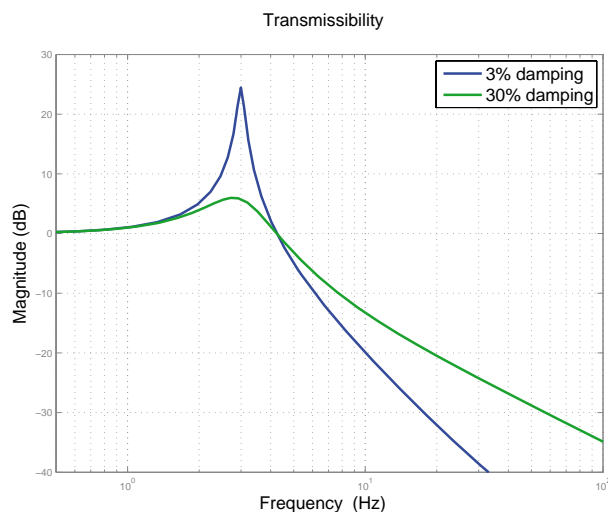


Figure 5. Transfer function describing floor to machine vibration transmission. Relative damping is 3% (blue line) and 30% (green).

resonance frequency. Figure 5 shows the effect of damping for a suspension having a resonance frequency of 3 Hz.

At different frequencies, this passive vibration isolation exhibits a different performance. When we consider the RMS value of acceleration in 1/3-octave bands around specific frequencies we can see the effect. Table 1 presents the RMS vibration of a VC-E specified floor and the resulting RMS level of machine vibration for two suspension solutions. Performance is mainly poor at low frequency. Therefore, active damping of the low-frequency suspension modes is required.

Another setback of passive vibration isolation using low-stiffness springs is the large static deflection at low frequencies due to gravity. This puts serious design restrictions on a passive system and once again calls for active vibration isolation.

Table 1. RMS vibration ($\mu\text{m/s}^2$) of a VC-E specified floor at three frequencies and the resulting RMS level of machine vibration ($\mu\text{m/s}^2$) for two suspension solutions.

	3 Hz	20 Hz	100 Hz
VC-E floor	60	360	1,800
3% damping	600	3.6	5
30% damping	120	36	30

Active vibration isolation

Active damping, or in general active vibration isolation, means incorporating a loop with sensor, control and actuator into the vibration isolation system. The principle, in comparison to passive vibration isolation, is shown in Figure 6.

The noise introduced in the control loop by the various electromechanical elements affects the actual accelerations

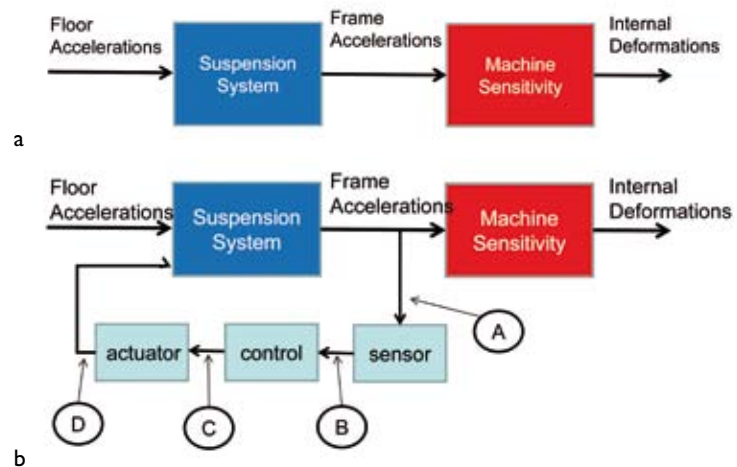


Figure 6. Principles of vibration isolation.

(a) Passive: floor vibrations are transmitted through the suspension; no additional disturbances are considered.

(b) Active: the frame motion is measured and the signal is used in the controller to create a counteracting force; noise present in the control loop causes additional disturbances (A-D).

and deformations. Now the “clean” transfer function from floor to frame accelerations does not completely cover the system performance. Especially for high-precision systems, placed in rather quiet locations, this becomes important. It may even turn out that adding active vibration isolation does not improve system performance as compared to the passive case; see the box on noise generation in active suspensions. It can be concluded that better sensors (and actuators) have to be available to obtain significant improvements.

Sensor and actuator

For active vibration control, MI-Partners developed dedicated sensors and actuators in collaboration with Magnetic Innovations [7]. Often geophones are used as sensors in active vibration control as a cost-efficient solution. A geophone comprises a permanent magnet that is suspended to the geophone casing; the magnet can move within a coil that is also fixed to the casing. The relative motion between magnet and coil induces a voltage proportional to the relative velocity. Hence, a geophone acts as a velocity sensor and its signal can be used as input for velocity-based feedback. It can be shown that the damping obtained is proportional to the absolute payload velocity; this is called sky-hook damping. Figure 8a shows a schematic of a geophone.

As a result of the joint development, geophones have become available that display excellent small signal behaviour down to frequencies as low as 1 Hz. For actuation a moving magnet actuator is used, which has a very low parasitic stiffness; Figure 8b shows a schematic set-up.

Noise generation in active suspensions

Generally the vendors of isolation systems are specifying performance through the transfer function for floor to payload vibrations. To measure such curves, excitation of the floors or internal excitation with the actuators is used. Then the signal levels are large enough to obtain clear curves showing large vibration suppression at specific frequencies.

For the actual system no external excitation is present and signals are generally very small. In such cases the noise from sensors and actuators may well become dominant. Figure 7 shows the PSD of acceleration of an isolated platform placed on the floor presented above, both for a 3 Hz and a 1 Hz passive system.

For the system on the 3 Hz suspension, the RMS value for acceleration is predicted to be about 0.5 mm/s^2 , only a slight improvement compared to the level in the floor. For the 1 Hz system this RMS value reduces to about 0.02 mm/s^2 , a significant improvement.

For active systems, noise generated in different elements will lead to forces exerted on the platform. Such forces will lead to accelerations that must be added to the acceleration due to

floor vibrations. It has been indicated [6] that the noise of the sensors used for active suspension systems is between 0.05 mm/s^2 and 0.1 mm/s^2 RMS. As these levels are above the level obtained with a 1 Hz passive system, active systems would not improve matters. For the 3 Hz system an integral improvement of a factor of 5 to 10 would be the limit. Unless better sensors turn up.

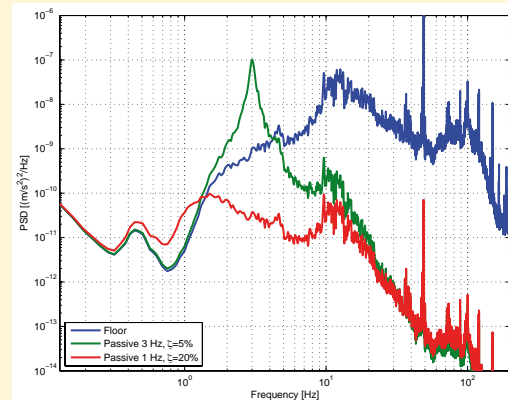


Figure 7. PSD for acceleration of a passively supported platform.

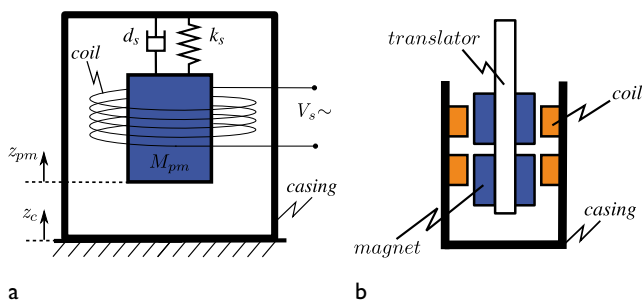


Figure 8. Schematics of sensor and actuator.

(a) Geophone.

(b) Moving magnet actuator.

In practice, the sensor and actuator are integrated in one module (collocation), so mutual inductance can occur. If this effect is large enough it can cause stability problems in the control loop. In the present case these problems were ruled out, but with very large payloads sensor-actuator crosstalk may arise.

To achieve vibration isolation for all six degrees of freedom (DoFs), a total of six sensor-actuator modules is required, which in a practical arrangement are divided into three horizontal and three vertical units.

Elimination of horizontal-tilt crosstalk

The drawback of geophones lays in the fact that a horizontal geophone measures displacements caused by tilt of the payload as horizontal displacements, introducing

measurement errors and the need for complex control actions to compensate. Independently, two parties (TNO [1] and MI-Partners) each developed a patent-pending solution to eliminate crosstalk and hence the need for control complexity [8]. Figure 9 shows a schematic of MI-Partners' solution. It encompasses a mechanical guide which constrains tilting motions of the geophone by connecting these to the fixed world using elastic elements; while the Stinger transfers the horizontal motion of the payload to the geophone assembly.

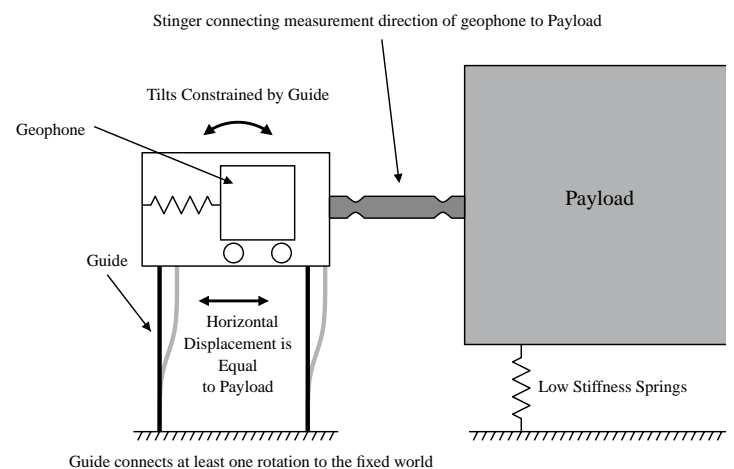


Figure 9. The guide stiffness allows a horizontal motion of the geophone, while constraining tilting motions. In the measurement direction the geophone is stiffly connected to the payload.

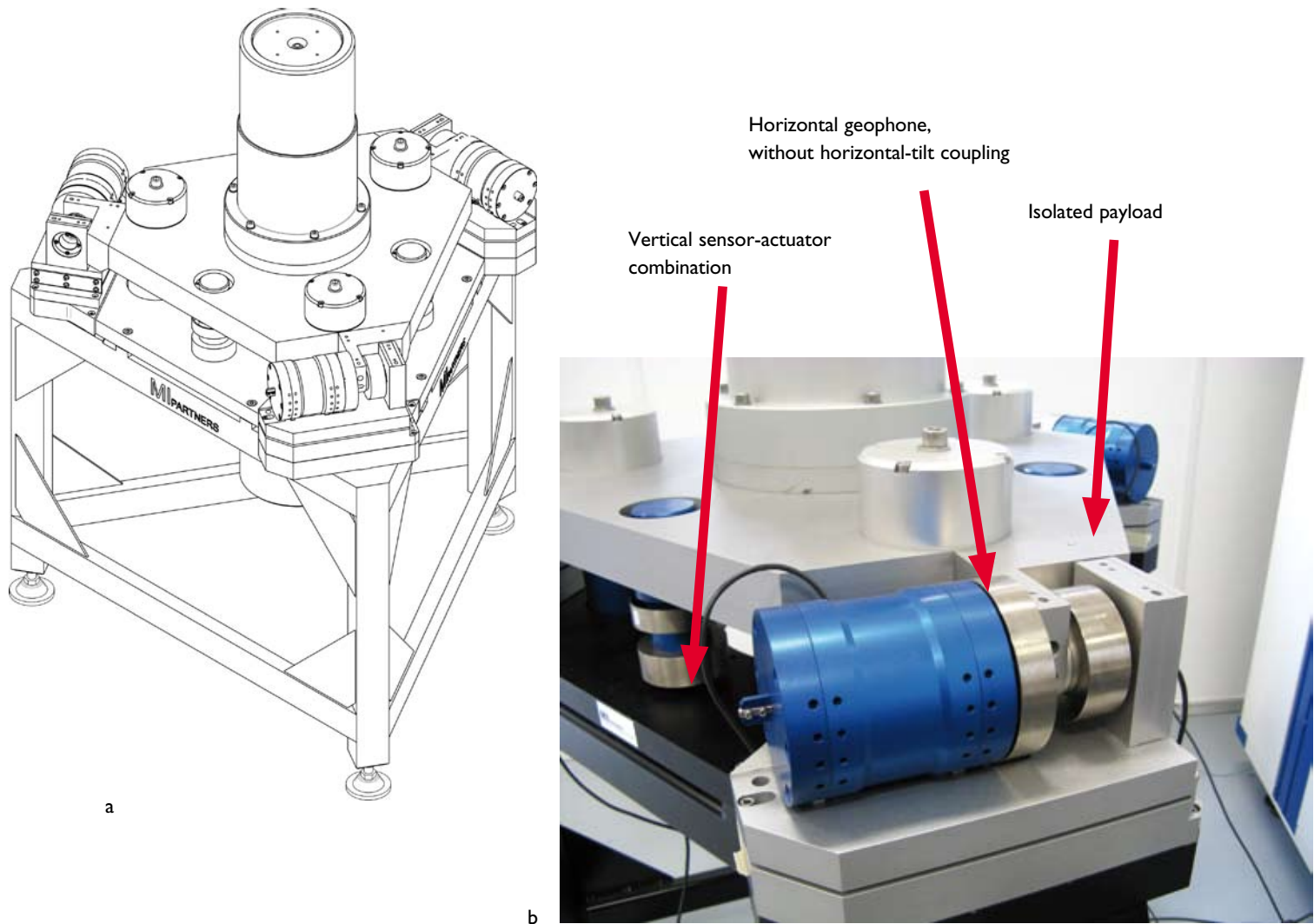


Figure 10. The MI-Partners Active Vibration Isolation system.

(a) Schematic of the design, showing the payload, the frame, the six sensor/actuator modules (not all visible) and three isolator mounts.
 (b) Close-up showing the positioning of horizontal and vertical geophones (the blue elements).

Design

Based on the above considerations, an Active Vibration Isolation system was designed; Figure 10 shows the mechanical design.

From the DEB analysis it was concluded that the signal-to-noise ratio of the geophone signal to the noise level of the AD-converter that generates the control input was insufficient. This limits the effective bandwidth for the active control and hence the performance of the system. Several solutions were considered and the most cost-effective one turned out to be incorporating a preamplifier in the loop, between the geophone and the AD-converter.

Assessment of the “ultimate performance”

In the final analysis all contributions were considered, including floor, sensor, preamplifier and AD-converter. Figure 11a shows the respective PSDs.

A closed-loop vibration suppression in 6 DoFs has been achieved between 0.3 Hz and 30 Hz, with > 40 dB reduction at 3 Hz, see Figure 11b. The measured cumulative noise level in the frequency range of 0..100 Hz in horizontal direction is $37 \mu\text{m/s}^2$ RMS, while in the vertical direction $24 \mu\text{m/s}^2$ RMS has been achieved. Floor vibrations with a cumulative content of 1.2 mm/s^2 RMS (in the order of magnitude of a VC-D floor) in the frequency range of 0..100 Hz can be reduced with a factor 50 in this frequency band.

Conclusion

An active vibration isolation system (AVI) with a high bandwidth and low-noise components was developed. Using DEB (Dynamic Error Budgeting) methodology all components of the active control loop were analysed in terms of PSDs (Power Spectral Densities). Based on the specifications derived from this analysis, improved sensor

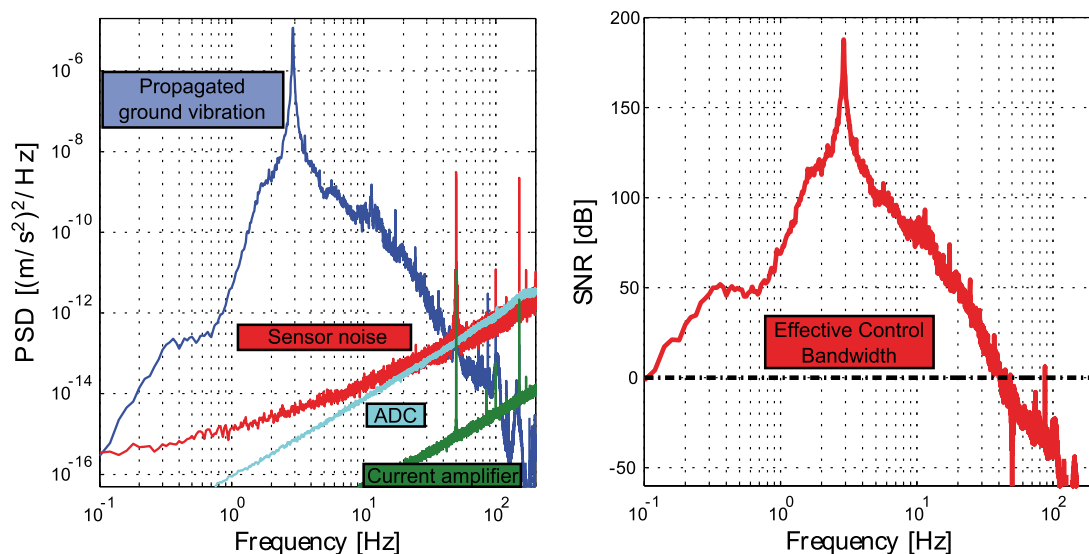


Figure 11. PSDs of all contributions to system performance and resulting signal-to-noise ratio in vertical direction.

Vibrations induced by driving forces

In many cases, active systems yield only limited improvement of floor vibration isolation. For precision systems with mechanical resonances at about 100 Hz one can estimate the position errors due to the accelerations. The 0.5 mm/s² RMS for the 3 Hz passive suspension (see the previous box) will lead to deformations of about 1.5 nm. With the 1 Hz suspension only 70 pm will result. These levels are quite low for most applications and hence the passive systems are quite sufficient in most cases and active systems will not be needed.

Still, in the semiconductor industry active systems are widely used in, for example, advanced lithography systems. To understand why, we have to take into account the acceleration caused by the driving forces for the stages. Accelerations of 10 m/s² and more are quite normal. After settling, the suspended frame, which typically has a 50 times larger mass, will display an acceleration of 200 mm/s². This acceleration is 400 times larger than the acceleration due to floor vibrations. With such acceleration, errors of 600 nm would occur. To eliminate this effect, direct cancellation of the stage forces can be applied. Therefore, an active element is introduced in addition to the passive vibration isolation system. This actuator can also be used to generate damping for the isolation system and hence the total system has all the characteristics of an active vibration isolation system. The main function in this case, however, is the reduction of drive force induced vibrations. An additional advantage of active over passive control is much improved settling behaviour; in the passive case the settling transient is dominated by the (low) suspension frequency.

technology with extremely well small-signal-behaviour was developed and integrated in the new high-end vibration isolation platform. As a result, a platform performance below 40 µm/s² was achieved on a standard production floor.

In this article, the focus was on reducing the transmission of floor vibrations. However, internal disturbances can have a large impact on system performance as well. Here active vibration control can also help; see the box on vibrations induced by driving forces.

References

- [1] B. Bakker and J. van Seggelen, "The revolutionary Hummingbird technology". *Mikroniek* 50(2): 14-20, 2010.
- [2] T. van der Poel, J. van Dijk, B. Jonker and H. Soemers, "Smart mounts". *Mikroniek* 50(3): 10-15, 2010.
- [3] H. Amick, M. Gendreau, T. Busch and C. Gordon, "Evolving criteria for research facilities: I – Vibration". *Proceedings SPIE Conference 2005*.
- [4] L. Jabben and J. van Eijk, "Performance analysis and design of mechatronic systems". *Mikroniek* 51(2): 5-12, 2011.
- [5] T. ten Dam and R. van der Kruk, "Towards the practical application of dynamic error budgeting". *Mikroniek* 50(5): 52-56, 2010.
- [6] G.W. van der Poel, J. van Dijk, H.J.M.R. Soemers and J.B. Jonker, "Selection of motion sensors for active vibration isolation of hard-mounted payloads", *Proceedings MOVIC 2008*.
- [7] www.magneticinnovations.com.
- [8] TNO patent EP2 261 530 A1, and MI-Partners patent N2005549.

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On Thursday, 19 May, Mikrocentrum in Eindhoven, the Netherlands, is holding a theme day on inexpensive precision. Lecture subjects include component placement, design principles, mechatronics, determining position using computer vision, sensor commodities and rapid manufacturing.

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Henk Kiela (left) and Erik Puik, associate professors at Fontys University of Applied Sciences and University of Applied Sciences Utrecht, respectively, will be two of the speakers at the theme day on inexpensive precision.

Vision & Robotics expands with 'Automation Solutions'

On Wednesday, 25 and Thursday, 26 May, Mikrocentrum will be holding the tenth edition of Vision & Robotics in Veldhoven, the Netherlands. This anniversary year will not only provide a review of the familiar vision and robotics subjects, but also serve as a platform for related automation solutions.

Vision and robotics have been on the up for some time now, which is not surprising given the increasing flexibility that is being demanded of automation, including daunting quality requirements. However, rather than being self-contained technologies, vision and robotics tend to be part of an integrated solution. For handling applications, for example, the gripper is an indispensable extension of the robot and there are numerous combinations with other types of sensors and high-grade drives.

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Atmospheric plasma breaks through in industry

Surface activation is a crucial process step in the plastics industry. Not only is attaching glues and topcoats to plastic surfaces, technologically speaking, not self-evident, the rise of hybrid products or multi-material constructions also requires flawless connections between metals, plastics and rubber. Atmospheric plasma is an innovative technology for plasma activation, with a number of clear industrial advantages, including the fact that the technology can be easily incorporated into continuous production processes. The investment costs are considerably lower than those for vacuum plasma technology. On 12 May, Mikrocentrum is holding a theme day at VITO in Mol, Belgium, with lectures, practical examples and live demonstrations in VITO's plasma laboratory.

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YieldStar: entering

A new metrology tool, YieldStar, offers high-throughput measurement of crucial lithography parameters, overlay, focus and uniformity of printed line width. It paves the way for complete in-track wafer quality control and constitutes an essential ingredient for “holistic lithography”. Total measurement uncertainties in the sub-nanometer region have been reported. Lithography control has entered the picometer region.

In just over a quarter of a century, ASML, based in Veldhoven, the Netherlands, has grown from a Philips spin-off into the lithography world market leader. Lithography is the art of optical patterning of integrated circuits (ICs) onto silicon wafers. ASML conducts research and develops and manufactures lithography machines,

called scanners, to meet the semiconductor industry's continuing demand for shrink. Shrinking IC features makes them smaller, for enhanced processor performance, higher memory capacity and improved yield, following Moore's law. To improve the resolution (the smallest feature, usually a line width, that can be “printed”), several options



Figure 1. The NXE 3100, ASML's EUVL pre-production tool.

the picometer era

are available. One is to increase the numerical aperture (NA) of the projection lens; this has resulted in the so-called immersion scanners, as immersion of the lens in water increases the refractive index of the optical system, and hence the NA. Currently, another option (lowering the wavelength of the “light” that is used) is being capitalised by the market introduction of EUV (Extreme Ultra Violet) lithography; see Figure 1. The challenges include vacuum operation and a transition from lens to mirror optics.

Holistic lithography

Another, complementary approach in the “race for shrink” is to improve the performance of the entire manufacturing process, using the scanner as one of the control elements. This is the concept of holistic lithography, which was introduced by ASML a few years ago. In this concept, actual wafer lithography is considered as a part of the total IC manufacturing process. Optimisation of the output of this process requires control of the various process steps. To fulfil its role as a stabiliser in the overall manufacturing process, the scanner has to be very stable, achieved via the BaseLiner scanner stability software, and must offer

adequate control possibilities. These control possibilities are incorporated in other ASML products such as GridMapper and DoseMapper. Underlying these tools are computational models of the lithography process, from which control parameters (the “knobs” that can be turned in the process) can be derived. These models require vast amounts of precise, accurate and robust wafer data (either gathered on product stacks or on so-called monitor wafers). Figure 2 shows a schematic of BaseLiner acting in the holistic lithography control loop. Holistic lithography is considered to be indispensable for the latest generations of immersion scanners (such as the NXT:1950i) and the upcoming EUV scanners. Figure 3 shows an example of scanner stability improvement with BaseLiner.

“Parameter explosion”

In early scanner generations the projection lens was fitted with one axis for focus control, representing one control parameter. Over the years, increasing scanner complexity required more control parameters and hence more data to be generated by metrology. So, the TwinScan was devised, in which one wafer is exposed on a table under the lens,

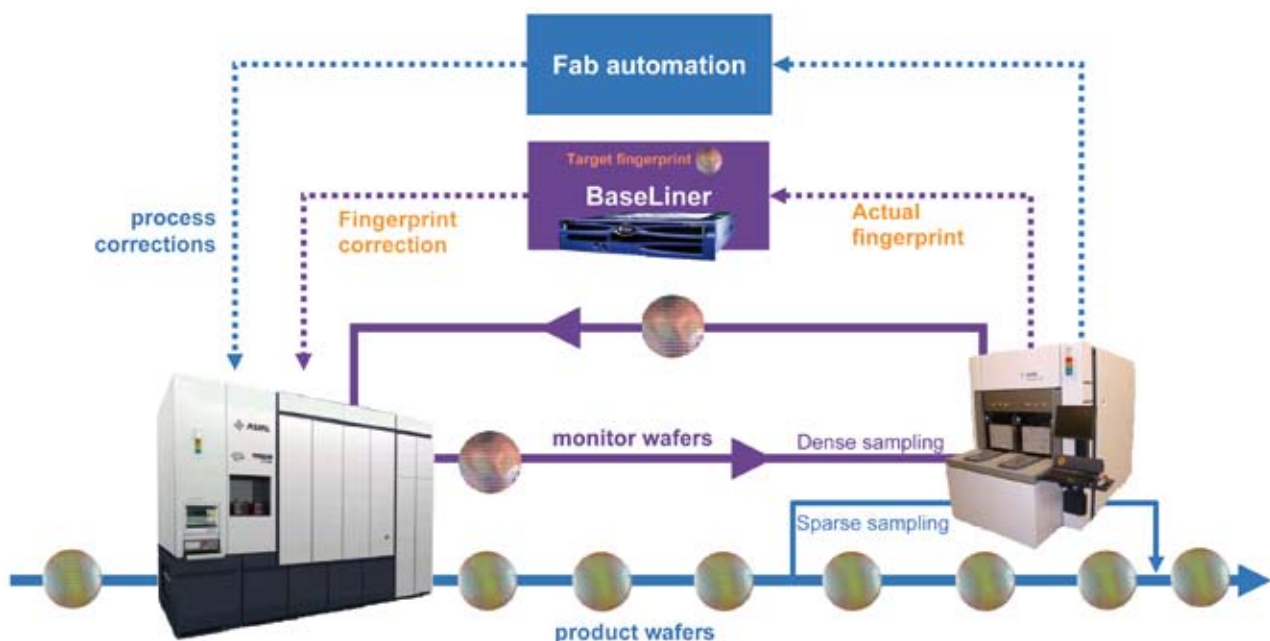


Figure 2. In the holistic lithography control loop, BaseLiner corrects scanner-induced process effects by measuring the scanner’s impact on monitor wafers.

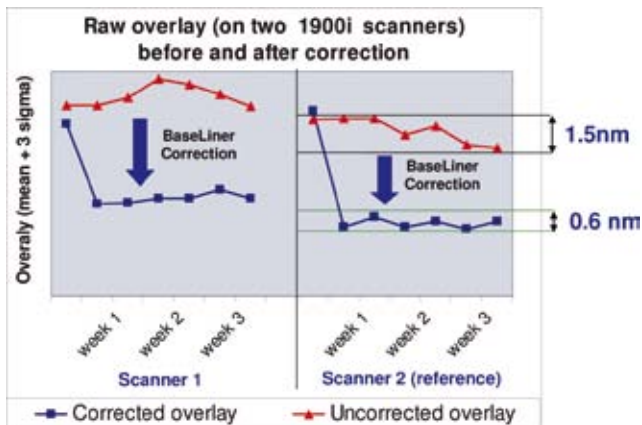


Figure 3. Scanner stability improvement (in terms of overlay, as explained below) with BaseLiner.

while – on a second table – the next one is measured in parallel by on-tool metrology. This avoids a slowdown of the process due to measurements taking up too much time. Recently, FlexRay was introduced, a fully programmable illuminator with thousands of degrees of freedom, for optimising the light path and offering a high degree of flexibility in scanner control. To keep up with the associated ever-increasing number of parameters, the “parameter explosion”, the information input to the computational models had to increase. The necessary metrology for this input could not longer be fitted in the available volume of the machine, and would also reduce its overall efficiency. Therefore, it was decided to take part of the metrology out of the scanner and embody it in an “external sensor”. ASML started development in 2004, in collaboration with Eindhoven University of Technology and suppliers, for software as well as hardware.

YieldStar

This external sensor is called YieldStar and it can be incorporated in the control loop, either as a stand-alone

tool, offering delayed feedback, or as an in-line tool integrated in the complete process track, allowing “real time” feedback and control. YieldStar can be used for scanner qualification and control and for inspection purposes using dedicated monitor wafers, as well as for checking random production wafers. Ultimately, the in-line version may be used for 100% quality control of every individual production wafer. YieldStar was designed to allow the high-throughput measurement of the essential lithographic parameters: overlay, focus and CD Uniformity (CD is critical dimension, or resolution, as explained above).

Up to now, the standard technology used is mainly SEM (scanning electron microscopy). SEM is ideally suited for extensive process characterisation, with a precision of down to 1 nm, but not for high throughput and in-track integration. Next to SEM for CD measurement (CD-SEM), OCD (optical CD measurement) using scatterometry is already in use. As an alternative, YieldStar uses high-NA angle-resolved scatterometry to measure overlay, CD Uniformity and focus in one run using a single sensor. This approach makes YieldStar a very versatile metrology tool, which is several times faster than SEM per measurement point.

Scatterometry

Light that is projected onto an irregular surface will be scattered in all directions. However, if a regular (periodic) structure is present, reflections of a light beam can be

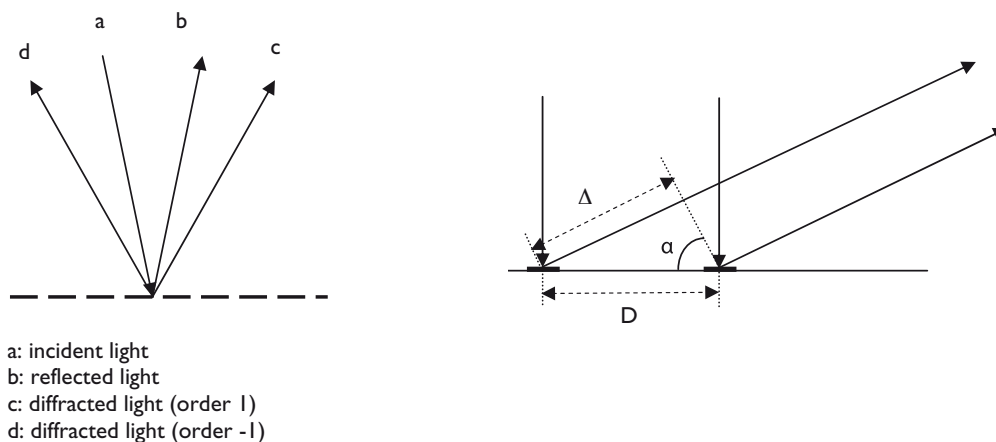
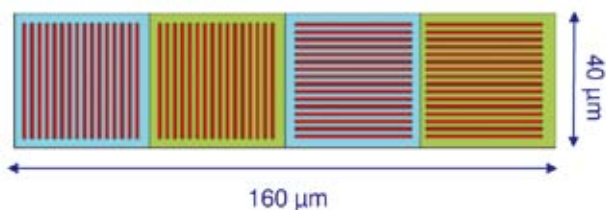


Figure 4. Schematic of diffraction by a grating, showing the 0th order reflection and the two 1st orders. For both 1st orders, the path length difference Δ ($= D \cdot \sin \alpha$) as shown on the right for the case of normal incidence should be 1λ .

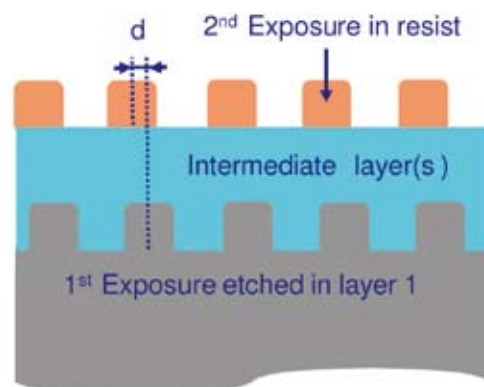


a

Figure 5. Diffraction Based Overlay measurement principle.

(a) Scribe-line target for DBO.

(b) Markers with a deliberate overlay error d after two printing and processing steps.



b

observed in specific directions. This is called diffraction. The dominant direction is determined by “angle of incidence = angle of reflection”. This is the so-called 0th order, with each individual light ray traveling the same path length. When rays of monochromatic light of wavelength λ are reflected by adjacent elements of the periodic structure, for example a simple grating with pitch D , a diffraction pattern is observed. Constructive interference occurs for light traveling in a direction (angle α) satisfying the diffraction equation $n \cdot \lambda = D \cdot \sin \alpha$, where n is the order; see Figure 4. So, by varying the angle of measurement, or the wavelength, a full “picture” can be taken of a test structure (called a target) on a wafer produced by lithography. YieldStar does not provide the real image, in contrast to SEM (“what you see is what you get”), but an angular intensity map, from which information on the (quality of the) structure can be retrieved.

YieldStar can perform up to several ten thousand individual measurements per hour, due to the use of a high-NA objective lens, which captures the maximum of available photons to reduce measurement time. On the other hand, without increasing measurement time the size of the targets (and hence their diffracted intensity) can be reduced, so that they can be incorporated on production wafers in the scribe lines, that is, the space between the individual dies. Due to developments in laser dicing (the separation of the dies), these scribe lines are becoming smaller as well.

Diffraction Based Overlay

In lithography, a complex pattern is printed in several layers. Every layer represents a run of the wafer through the scanner, and in theory the patterns printed in all the layers should match perfectly to form one full 3D pattern – they should exhibit perfect overlay. In practice however, there always is an overlay error, the so-called miss-registration. As a rule of thumb, the overlay error should be controlled to less than 10% of the CD, which for current

scanner generations means 3-4 nm. In turn, the measurement precision should be better than 10% of the acceptable overlay control, hence 300-400 pm. The overlay measurement principle of YieldStar encompasses the detection of first (or higher) order diffraction of gratings subsequently exposed in two different layers. This is often referred to as Diffraction Based Overlay (DBO). If the two gratings are displaced with respect to each other the two signal intensities become asymmetric. Taking the proper calibrations into account, the overlay error can be retrieved from the intensity difference, assuming a linear relationship. Figure 5a shows a typical marker layout, with a total of four gratings used to calculate overlay in the x- and the y-directions. The calibration can be obtained by introducing a two-layer pattern with a deliberate overlay error d (introduced with high precision and accuracy in the reticle used for the patterning); see Figure 5b. The intensity difference measured in this case can be linked to the known overlay error d . This makes DBO a self-calibrating technique.

A single colour is used, which is selected based on the grating properties. Polarisation can be added to make reflection direction-dependent in order to retrieve more information.

Diffraction Based CD & SWA Scatterometry

Measurement of CD Uniformity (CDU) is more complicated. CD is represented by the smallest line width that can be printed reliably. Features that are printed vary

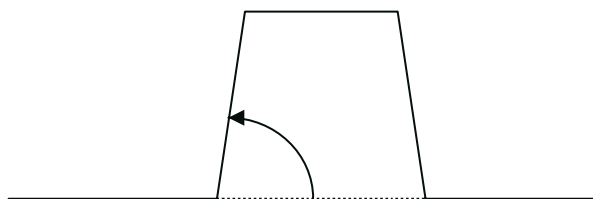


Figure 6. The side-wall angle of a printed feature.

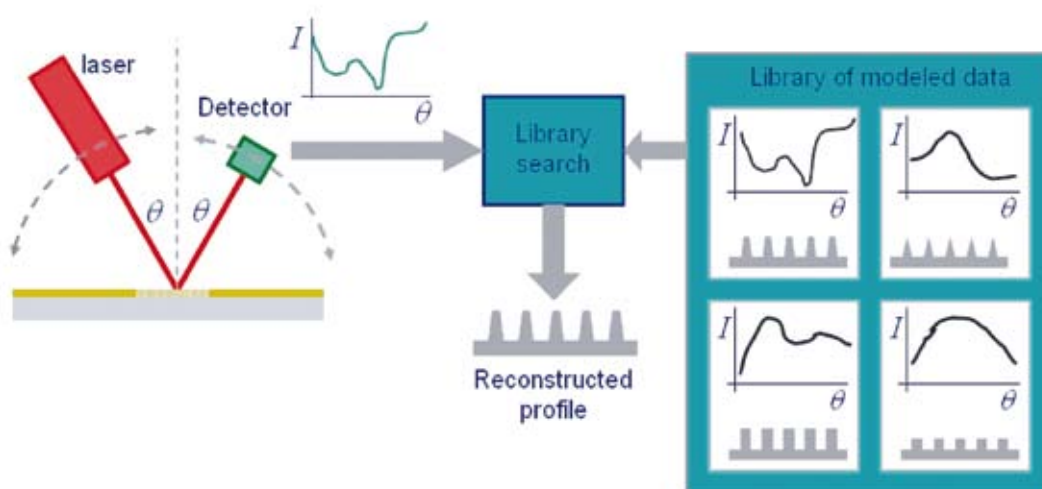


Figure 7. Each specific grating, as characterised by SWA and other parameters, generates its characteristic diffraction intensity profile.

in width, becoming smaller or wider than required, and may become fuzzy when the scanner projection system is out of focus. Hence, the CDU is related to the degree of “out of focus”, which is designated as the focus number of a scanner; this parameter is extremely important for scanner control. Direct determination of this focus number is notoriously difficult. However, it can be related to the so-called side-wall angle (SWA) of features that are printed, as defined in Figure 6.

All kinds of techniques have been developed to reduce focus sensitivity in lithography operation, such as OPC (optical proximity correction) and elimination techniques. In the design of the YieldStar CDU measurement principle, these same techniques were used in reverse to increase the focus sensitivity of the target on a monitor wafer in order to enable reliable detection of a change in focus number. When a test grating is printed, it will exhibit specific values

of CDU and SWA. However, the angle-resolved profile (diffracted intensity as a function of incident wavelength) from this grating can not directly be translated into CDU and SWA values. This problem is solved computationally by taking the inverse route, through rigid coupled wave analysis (RCWA). For a large variety of theoretical gratings each having a specific structure (characterised by parameters such as height, CD and SWA) the Maxwell equations are solved to calculate their diffracted intensity profiles. These results are stored in a library; see Figure 7.

When YieldStar is in Diffraction Based CD & SWA Scatterometry mode, a diffraction intensity profile is measured. Then, by variation of the parameters using library profiles, an optimum fit between measured and calculated profile is obtained, yielding the corresponding values of SWA (focus number) and CD (width of the features printed). Finally, a CDU value typically is

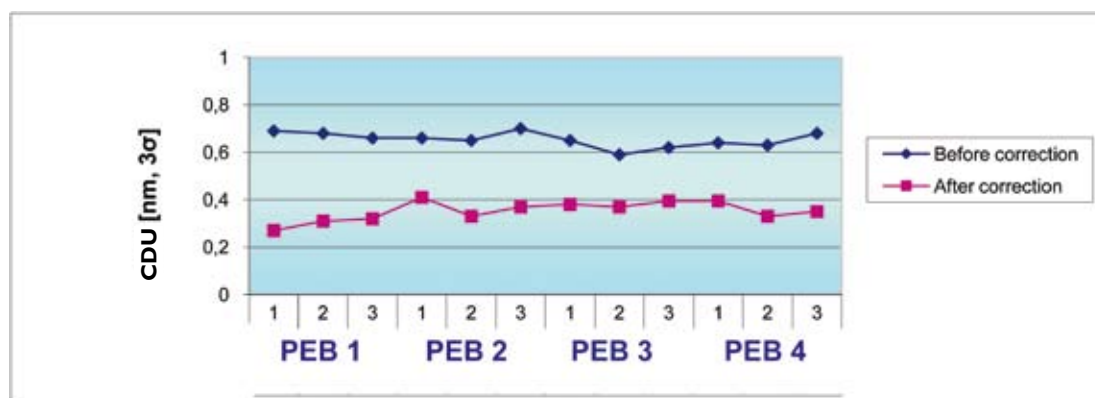


Figure 8. 40% CDU improvement on monitor wafers, achieved by YieldStar through hotplate temperature correction in the track on an XT:1900. The Post Exposure Bake (PEB) step is an important contributor to wafer-to-wafer CD variation. For throughput reasons there are several PEB plates (hotplates), each with their own cross-wafer CDU fingerprint. The results shown represent week 1, 2 and 3, for four different PEB plates.

computed as 3 times the standard variation (sigma) of the CD values measured across the wafer. This requires extensive calculations; a lot of algorithm and software development went into the reduction of computational time. As a result, YieldStar CDU measurement frequency can be as high as 2 Hz, with 0.1 nm precision. Figure 8 shows an example of CDU improvement through YieldStar improving the stability of the scanner in the control loop.

Design

As an enabler for the measurement principles described above, the YieldStar module was designed.

A key issue in the YieldStar design was the stage technology. Stages have to enable measurement of selected spots all over the wafer, variation of the measurement direction as well as control of the sensor focus. Because of the limited space (1 m² in the process track) it was decided to separate the x- and y-movement by introducing a sensor as well as a wafer stage. An additional advantage of the dual-stage design is flexibility in defining calibration protocols. The sensor stage takes care of y- and z-movement (the latter for focus control), whereas the wafer stage is in charge of x and Rz. Rx and Ry are fixed by design, as tilting of the wafer is not required. In the first design of the stand-alone version, custom off-the-shelf stages were incorporated, to facilitate rapid market introduction. However, eighty percent of processing time was spent on stage movement. Subsequently, proprietary ASML stage technology was introduced. The high precision that can be achieved with YieldStar is possible due to the effective use of the information contained in the scattered light. With the next-generation wafer stages incorporated in YieldStar, acquisition times were reduced by half while maintaining the same measurement precision. Figure 9 shows the stand-alone version of the next-generation tool, which can handle up to 200 wafers per hour.

Results

The performance of the YieldStar can be evaluated in numerous ways. One is in terms of the total measurement uncertainty (TMU), which can be defined as the root of the sum of squared contributions such as short-term precision, long-term precision (drift), and tool-induced shift (TIS) as well as TIS variation. Note: measuring the same markers at 0 and 180 degrees wafer rotation must provide the same



Figure 9. The YieldStar S-200 stand-alone tool.

outcome; the systematic difference between the two orientations is called TIS.

In experiments with an S-200 YieldStar in combination with BaseLiner, TMU values of 70 and 100 picometer were found for overlay in the x- and y-direction, respectively. When applicable, tool-to-tool matching can be included in TMU assessments. In another test, the YieldStar tool-to-tool overlay matching (S-100 to S-200) was shown to be as good as 250 pm – for comparison: in a Si crystal the bond length between two atoms is 234 pm. It can be concluded that lithography has definitely entered the picometer era.

Acknowledgement

The collaboration of ASML is gratefully acknowledged. Special thanks to Arthur Becht, product manager, Hugo Cramer, Tom Hoogenboom and Reinder Plug, all system engineers, and Jos Maas, director product marketing.

Reference

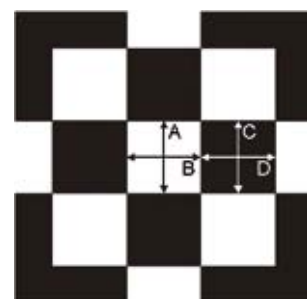
Jos Maas et al., "YieldStar: a New Metrology Platform for Advanced Lithography Control". European Mask and Lithography Conference 2011, Dresden.

Information

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Traceable of 3D

The rise of miniaturised, complex parts poses new challenges to the international measurement community. To address these challenges, the European association of national metrology institutes, EURAMET, undertook a project on truly 3D metrology for advanced microparts. The project, coordinated by the Dutch national metrology institute VSL, has produced valuable insights in the possibilities and limitations of micro-CMMs (Coordinate Measurement Machines), especially with regard to traceability, both for tactile and optical measurements.



• **Rob Bergmans, Ancuta Mares, Henk Nieuwenkamp and Marijn van Veghel** •

Introduction

The use of miniaturised parts leads to larger functionality in a smaller volume. One can think of small freeform lenses, such as are used in mobile phones, where the use of a freeform limits the number of optical elements. Another very interesting application are small devices in the human body. Think of ear implants or eye-optics, but also devices for local administering of medicines and diagnostics. For these medical purposes, safety and reliability are an absolute necessity. Another example is the car industry. Due to miniaturisation more sensors can be applied, which for instance monitor the road holding and CO₂ exhaust, without adding to the weight of the car. Other examples still are small gears and inkjet nozzles. All of these miniaturised parts are commonly referred to as microparts. In size they can range from some 10 mm to sub-mm, and the local features to be measured demand submicrometer uncertainty. They can be made with various production techniques, materials, shapes and surface features.

In order to underpin the quality of these products, reliable measurements are required. Besides increased demands on the tolerances of these objects, they have in common that they are quite complex. Traditionally, conventional 3D Coordinate Measurement Machines (CMMs) have been used to perform measurements on complex objects. The

Authors' note

The authors work with VSL, Rob Bergmans and Ancuta Mares in the Research and Development department, Henk Nieuwenkamp in the Calibration and Reference Materials department, and Marijn van Veghel in the Customized Applied Metrology department. They acknowledge the financial support of the Dutch Ministry of Economic Affairs.

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measurements

microparts

uncertainty of conventional CMMs is however no longer satisfactory for these advanced products, and furthermore, there is an accessibility problem.

To fulfil the increased accuracy demands, about ten years ago the development of micro-CMMs was started and the first micro-CMMs are currently operational. However, the traceability, and therefore the reliability of the measurements performed with these CMMs, are a challenge. Another problem is that the development of small tactile probes for these micro-CMMs is lagging behind. Small probes are necessary to access the small features of the objects.

Besides tactile there are optical measurements, which have the advantage that they are contactless and can therefore be applied to delicate or easily deformed surfaces, such as optics and plastics. Also, the measurement speed is much higher than for typical contact measurements. Therefore, in recent years, there has been a large increase in the application of optical measurement techniques. Especially for microparts, a wide variety of measurement principles and technical realisations of optical sensors is available. However, the influence of the sensor used, in connection with the specific measurement task (material and surface characteristics), on the measurement result is much stronger and more difficult to assess for optical sensors than for tactile ones.

Besides micro-CMMs, Computed Tomography (CT) is an emerging and very promising field in dimensional measurement technology, especially for the non-destructive characterisation of complex components and hidden structures. For many applications, the feature of CT to yield complete geometry information without holes, i.e. to perform high point density measurements, is very important.

To address the challenges above, the European association of national metrology institutes, EURAMET, undertook the project “Towards truly 3D metrology for microparts”, coordinated by the Dutch national metrology institute VSL. Partners included PTB (Germany), NPL (United Kingdom)

and METAS (Switzerland). This article features part of the work done at VSL.

Objective

The main objective of the EURAMET project was the development of traceable 3D metrology for microparts, addressing the following topics:

- Realising true traceability of micro-CMMs. This includes improved calibration of geometrical machine errors given the uncertainty level. New and improved methods of probe calibration, such as 3D characterisation of probing spheres.
- Development of new probes, their characterisation and integration. A challenge here is the realisation of probes with probing spheres much smaller than 100 μm with small form deviations and sufficient stiffness. Furthermore, multi-styli probes to improve accessibility of regions to be measured. Different probing principles, such as vibrating probes in order to reduce the effects of probe-sample interactions and contamination, and to speed up the measurement process when scanning.
- Research into the overall instrument behaviour, platform, probe and probe-surface interactions, to estimate the task-specific uncertainty of measurement.
- Scanning and probing behaviour.
- Research on application of optical probe systems.
- Achievement of higher measurement accuracy for industrial CT measurements (e.g. measurement of injection nozzles or microgears) by the use of calibrated micro-artifacts with a very low calibration uncertainty. This includes modeling of the measurement process.
- Development of guidelines for standardised procedures for dimensional measurements with CT and micro-CMMs.
- Comparison measurements between micro-CMMs on five artifacts: two balls of different size, a ring, an invar ball plate and a tetrahedron made of four ruby spheres. This first ever micro-CMM comparison is near completion and results will be published shortly. Furthermore, the project included comparison measurements between micro-CMMs and micro-CT, and micro-CMMs and visions systems.



Figure 1. F25 micro-CMM with the optical probe and the tactile probe shown on the right.

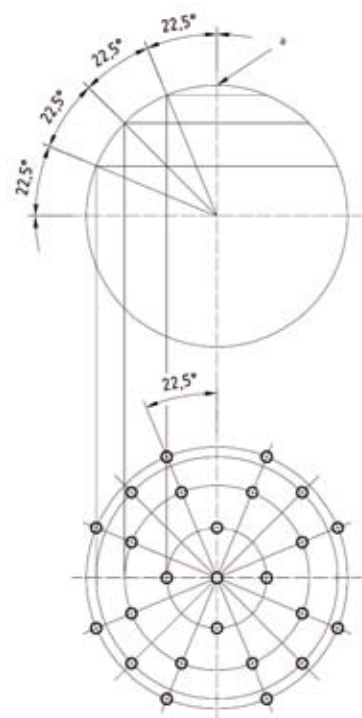


Figure 2. Probing points according to ISO 10360-5.

The F25 micro-CMM

The VSL research within the above mentioned project was mainly performed using the F25 micro-CMM, see Figure 1. The F25 has an aluminum platform that can move in x- and y-direction on a granite table using air-bearings. The pinole carrying the probe systems is suspended in this platform and can move in the z-direction. The measuring volume is $100 \times 100 \times 100 \text{ mm}^3$. The position of the platform and the

pinole is measured by line scales. More detailed information can be found in [1] [2].

The F25 has two different types of probes, a tactile probe and an optical vision system. The tactile probe consists of a stylus with a small sphere of 120 or 300 μm diameter at the end. The probe deflection is measured with piezo-resistive elements incorporated into the silicon membrane to which the probe stylus is glued. The probing force is set at a low level of 500 μN , to avoid deformations of the measured object by the small probe sphere. The optical vision system consists of an objective with a 10x magnification and a CCD camera with 768 x 576 pixels. During the measurement, the object is placed on the measurement table that can provide white light for transmission measurements. The vision system has also the possibility of measuring with reflected light coming from a circular light source of green LEDs.

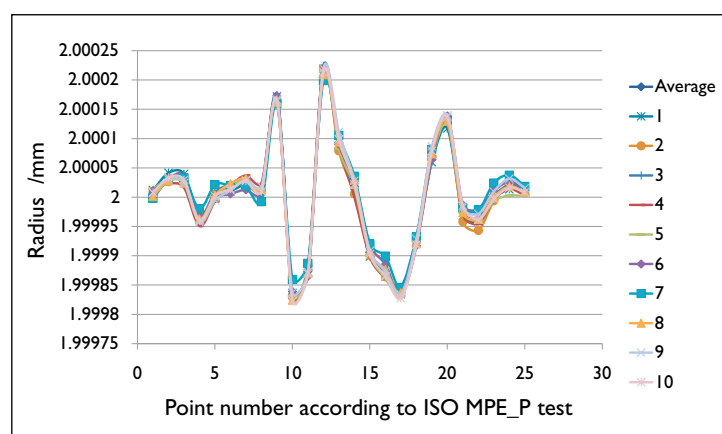
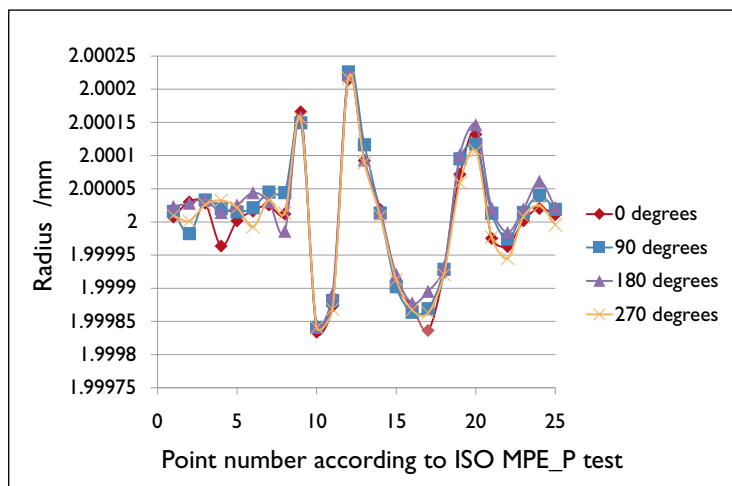
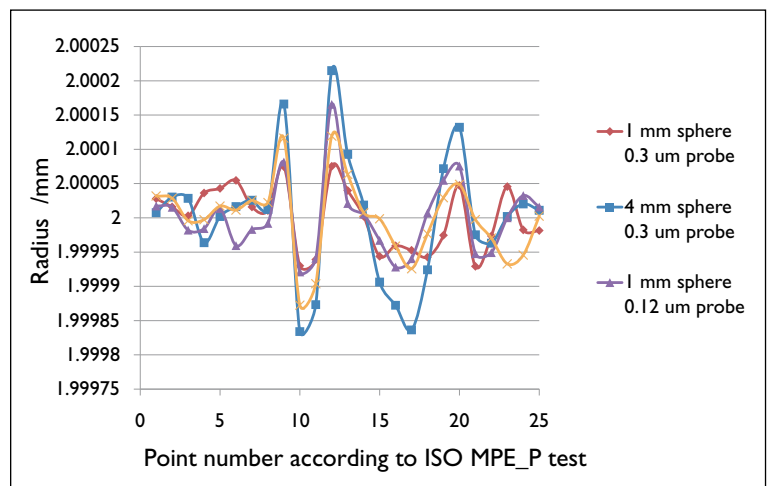


Figure 3. Repeatability of the MPE_P test on a 4 mm sphere.



a



b

Figure 4. The MPE_P test on various spheres.

(a) A 4 mm sphere at different rotations.

(b) Different spheres with different probes.

Tactile probing behaviour

To investigate the static tactile probing behaviour of our F25 we have used tests similar as those used for the conventional type of CMMs, namely the MPE_P (Maximum Permissible Error Probe) test, according to ISO 10360-5. This means probing a sphere on 25 points, see Figure 2. Different size spheres (1 mm, 4 mm, 6.35 mm and 8 mm) and different probes with sphere diameters of 0.12 and 0.3 mm were used. The test spheres are somewhat smaller than prescribed by ISO 10360-5, because the smallest size of 10 mm prescribed by ISO 10360-5 is too large to be accessible by the F25 micro-CMM. This shows the necessity of new guidelines, aimed specifically at micro-CMMs.

The average MPE_P value, being the difference between the measured maximum and minimum radii, of 14 measurements was 189 nm with a standard deviation of 60 nm. All values but one comply with the instrument specification of < 250 nm. Looking more closely at the 25 individual data points, see Figure 3, we found that the observed deviations at each individual point are highly repeatable.

To see if this might have been caused by the form deviation of the reference sphere, we rotated the reference sphere in steps of 90 degrees. Still the results are highly comparable, see Figure 4a. Some differences were observed in the order of 50 nm, which are probably caused by the form deviation of the test sphere; this agrees with the roundness deviations typically found for these spheres when measured on a roundness tester. So the form deviation of the reference sphere is not the main contribution.

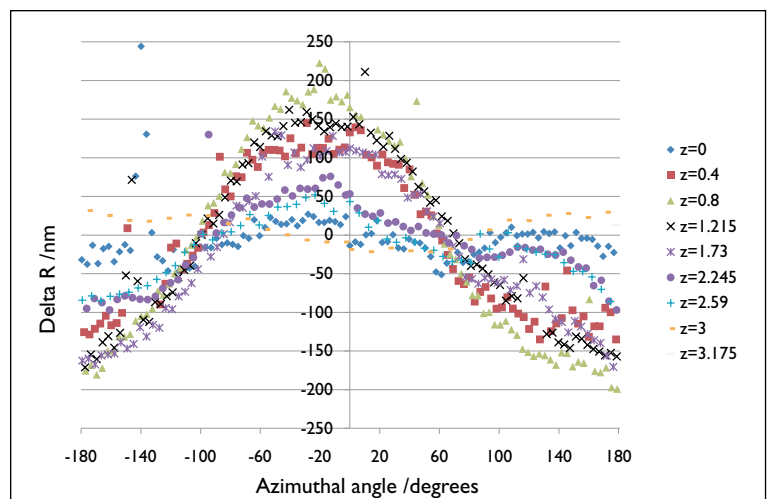


Figure 5. Radius deviation as function of azimuth and height on the reference sphere.

Comparing data on different artifacts and with different probes, see Figure 4b, the same pattern is still clearly visible. Since it is highly unlikely that all the probing spheres have an almost identical form deviation, there must be another cause. The only common factor is the silicon chip membrane to which the stylus is attached. These membranes are produced on wafers by a well-reproducible process. Therefore, it is likely that they exhibit similar behaviour.

To investigate this matter further, we measured a few hundred (668) points on a 6.35 mm test sphere. For this we increased the number of points on the circles of the MPE_P test, see Figure 2, and added additional circles in between. So, measurements at nine instead of five heights were obtained. Again a very repeatable pattern was observed. The radius deviations as function of the azimuth and the

z-coordinate (height) are plotted in Figure 5. It can be clearly seen that the variation in this deviation on a particular circle depends on the height and the maximum variation is found at a height of 0.8 mm.

It was shown that the signals from the sensing elements of the F25 boss probe are dependent on the deflection in the other directions. There are several possible reasons for this: the large anisotropy of the stiffness between x, y and z, potential crosstalk between the piezo-resistive sensors and the stress distribution. For example: when sensing in x and z simultaneously there is additional stress on the x-element compared to the situation where there is no z-deflection. Since the sensitivity coefficients in x and y are somewhat different, also their z-dependency will be different. This explains that when measuring an almost perfect sphere above the equator, an ellipse is observed.

The maximum deviation is observed at an angle of 22.5 degrees with respect to the plane through the equator. The deviations are systematic and reproducible. The current probe calibration, taking points at three different heights (on top, on the equator and in-between), does not or at least not fully correct for these deviations. To reduce the uncertainty contribution of the probe, a more extensive probe calibration is needed to better correct for these deviations.

The more extended MPE_P test with a few hundred points gives a similar value as the normal MPE_P test with 25 points. Therefore, the standard MPE_P test is sufficient for a good estimate of the probe uncertainty of the F25 tactile probe.

The uncertainty of the F25 for 3D measurements of small objects (< 10 mm) will be dominated by the MPE_P value. A possible way to partly compensate for it is taking an additional measurement at 90 degrees rotated and then averaging the measurement data. When doing only planar

2D measurements with the F25, the uncertainty is significantly better and estimated to be about 50 nm.

Optical probing

Measurements on vision systems performed by different industrial users present variations of several μm , as revealed by a recent comparison [3]. The most commonly used transfer standards for calibration of vision systems are line scales, where the pitch distance is calibrated, and chessboard standards, where the absolute feature width is calibrated. Therefore, we have analysed the capabilities of our F25 micro-CMM for measurement of these types of standards, to assess the limits for contactless measurements with this instrument. A comparison against dedicated, but less versatile, calibration set-ups was also made.

Uncertainty budget

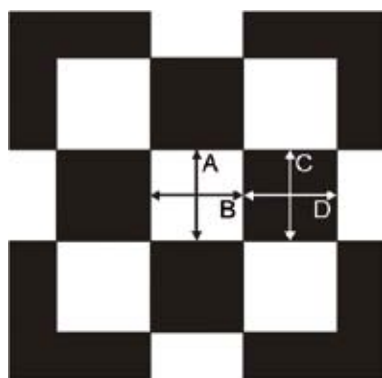
A feature imaged by a vision system is analysed by detecting its edges using the intensity profile and establishing a certain threshold criterion. We have used the following procedure for calibrating line width: first we detect the edge points on both sides of the graduation line. Next we fit the edge points with two line segments. The line width will be calculated as the length of the perpendicular from the center of one segment to the opposite one.

One significant contribution to the accuracy of line-width measurement comes from the edge detection. The line-edge image has a complex intensity profile and is broadened due to scattering at the edges. The uncertainty includes contributions coming from the resolution of the optical system, edge geometry and linearity of the signal of the optical sensor, in our case a CCD camera.

We have performed an extensive investigation into the quantification of the uncertainty sources and their dependence on the measurement parameters of the F25 vision system. A summary of the uncertainty sources is

Table 1. Estimation of the uncertainty budget of the F25 vision system.

Quantity	Uncertainty [nm]	Distribution	Uncertainty contribution [nm]
Repeatability feature (STDA)	16	normal	16
Focus	50	rectangular	14
Geometrical errors F25	50	rectangular	29
Homogeneity image field	100	rectangular	58
Edge influence	400	rectangular	231
Linearity CCD	100	rectangular	58



Mitutoyo

Figure 6. The standard used in the experimental investigation. It contains groups of squares as the one shown here of several widths between 1 μm and 4 mm.

presented in Table 1. For line distance, taking into account the first four quantities presented, the expanded uncertainty is estimated to be 140 nm, and for line width, including all quantities, about 500 nm.

The main uncertainty for line width comes from the uncertainty in the edge detection, which is a critical issue. Proper edge detection requires numerical modeling that takes into account the configuration of the imaging system and also the exact shape of the mask edge. As an estimation of the edge position uncertainty, we use the difference in width values measured in reflection and transmission, which is typically 400 nm. This difference is expected to be due to scattering events occurring on the edges of the mask and therefore will strongly depend on the edge shape and on the optical configuration. The uncertainty stated here is therefore only valid for high-quality standards, such as the chessboards mentioned above.

Line-scale pitch measurements

We have first investigated the capabilities of the F25 vision system to measure distances between lines (pitch distance). For this we used a line-scale standard that was calibrated by the VSL line-scale facility. The line-scale standard is made of Zerodur, a material with low expansion coefficient, and has graduations up to 300 mm with an increment of 1 mm. With the F25 we have calibrated the scale with an increment of 10 mm up to 100 mm length,

this being limited by the measuring volume of the F25. It was measured in two orientations; along the x- and y-axis of the F25.

For every line we calculate the center position from the left and right edge. The distance from the origin to the line is calculated as the perpendicular from the center of the origin line to the graduation line. Each line position is obtained as an average of ten measurements and for every graduation line the origin line is re-measured to account for possible thermal drift. The measurement results reproduce very well on the two orientations, with the exception of the last measurement position at 100 mm. This is not unexpected, since the line scales of the F25 are calibrated and corrected for a range of 90 mm. The differences with the line-scale facility calibration are well within the combined uncertainty, for the two facilities. From this comparison we can conclude that the estimation of the uncertainty of 140 nm for measuring pitch distance is correct.

Feature-width measurements

To investigate the capability of measuring feature-width standards, we performed measurements on a chessboard calibration standard fabricated by Mitutoyo containing chessboard patterns of several widths of transparent and opaque squares. The standard is made of a chromium pattern on a glass substrate. The widths A, B, C, and D for the opaque and transparent squares for chessboards of nominal width 0.8 mm, 0.2 mm and 0.1 mm are measured, see Figure 6.

For comparison, the chessboard standard was also measured at the calibration lab of Mitutoyo Nederland. This facility used for line-width measurements is based on a modified Quick Vision system using interferometric measurement for the line width. The vision system has a 10x magnification objective. The measurements can be done in reflection and transmission with white light. The uncertainty is 250 nm, only valid for measuring Mitutoyo charts using the Quick Vision system with defined settings. For comparisons between different vision systems also systematic errors should be considered and one expects an uncertainty of the order of 500 nm.

The comparison between the F25 and Quick Vision was done for measurements in both reflection and transmission for the chessboard. The agreement for the reflection

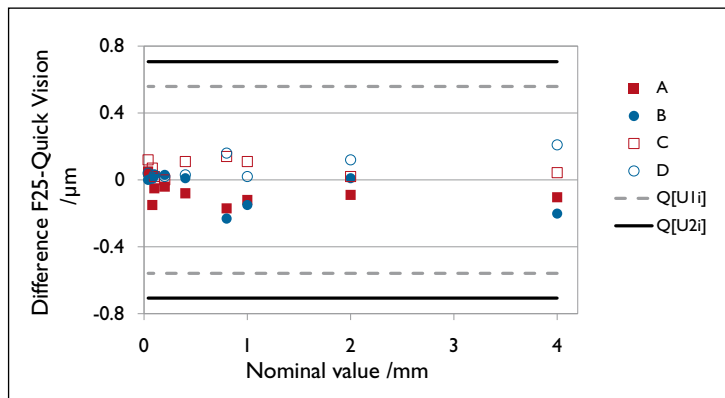


Figure 7. Differences between the results obtained with the F25 and Mitutoyo Quick Vision for the widths A, B, C, D of the transparent and opaque squares for chessboard standard CBMI measured in reflected light. For the combined uncertainties we used an uncertainty of 500 nm for the F25, and for the Mitutoyo Quick Vision values of 250 nm and 500 nm, depending on whether systematic errors are excluded or included, respectively, as explained in the text: $Q[U_{1i}] = \sqrt{(500^2 + 250^2)} = 559$ nm, and $Q[U_{2i}] = \sqrt{(500^2 + 500^2)} = 707$ nm.

measurements is very good, with a maximum difference below 300 nm, much smaller than the combined uncertainty, see Figure 7.

For measurements in transmission the differences are larger, the transparent squares being measured wider on the F25, see Figure 8. We expect that this comes from the different type of light sources on the two facilities. The F25 white table light is a divergent beam with a diffusive front of light. The light coming from below at certain angles can be reflected off the edges and will cause an apparent increase of the transparent squares. In the Quick Vision system the white table light has a parallel beam, thus the reflections on the edges are minimised. Still the differences are within the uncertainty. An additional comparison was made against the VSL line-scale facility. Also these results for line width agreed within the uncertainty.

From the comparisons we can conclude that the F25 vision system is a suitable system for measuring line widths in two-dimensional grating structures. At present we can claim an uncertainty of 0.5 μm for line-width calibrations for high-quality standards. We observed a significant difference between measurements in transmitted and

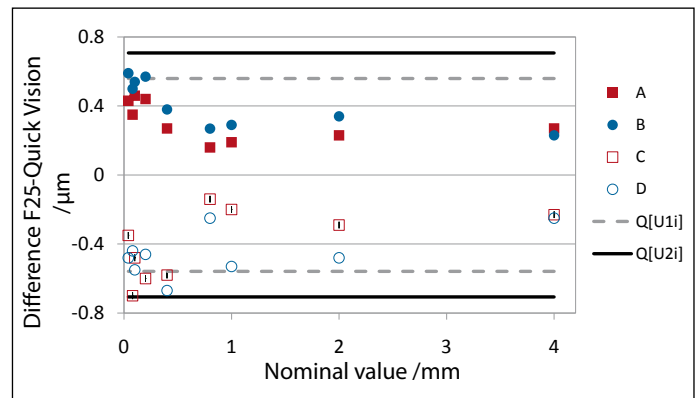


Figure 8. Differences between the results obtained with the F25 and Mitutoyo Quick Vision for the widths A, B, C, D of the transparent and opaque squares for CBMI measured in transmitted light.

reflected light. Therefore, it is important to use the same type of measurements when using these transfer standards for calibrating vision systems.

Conclusion

The EURAMET project “Towards truly 3D metrology for microparts” has produced valuable insight into the possibilities and limitations of micro-CMMs, especially with regard to traceability, both for tactile and optical measurements. Not all of the work has been described here. The work on the calibration of the geometrical errors of the platform and the task-specific uncertainty evaluation for 3D micro-CMMs using Monte-Carlo methods was already published in Mikroniek and elsewhere, [1] [4]. The results on the international comparison will soon be published.

The fact that the EURAMET project has come to a conclusion does not mean that the work on micro-CMMs is finished. New micro-CMMs are becoming available, and it will be interesting to compare their performance against the existing ones. Further research challenges also exist, especially with regard to freeform measurements. These challenges are taken on in a new international project within the European Metrology Research Program (EMRP), called “Optical and tactile metrology for absolute form characterization”. Partners are the national metrology institutes of seven countries, including VSL. In addition, there are five non-NMI partners, of which three are Dutch (TNO, IBS Precision Engineering and Xpress Precision Engineering).

References

- [1] M.G.A. van Veghel, R.H. Bergmans and H.J. Nieuwenkamp, *Proceedings of the Euspen international conference 2008*, Zurich, Switzerland. p.263, V2.
- [2] M. Vermeulen, "High-Precision 3D-Coordinate Measuring Machine", Ph.D. thesis, Eindhoven University of Technology, the Netherlands, 1999.
- [3] S. Carmignato, A. Voltan and E. Savio, "Metrological performance of optical coordinate measuring machines under industrial conditions", *CIRP Annals Man. Tech.*, 59, 497-500, 2010.
- [4] M. van Veghel, "Innovations in dimensional metrology", *Mikroniek* 49(3): 30-35, 2009.

More information

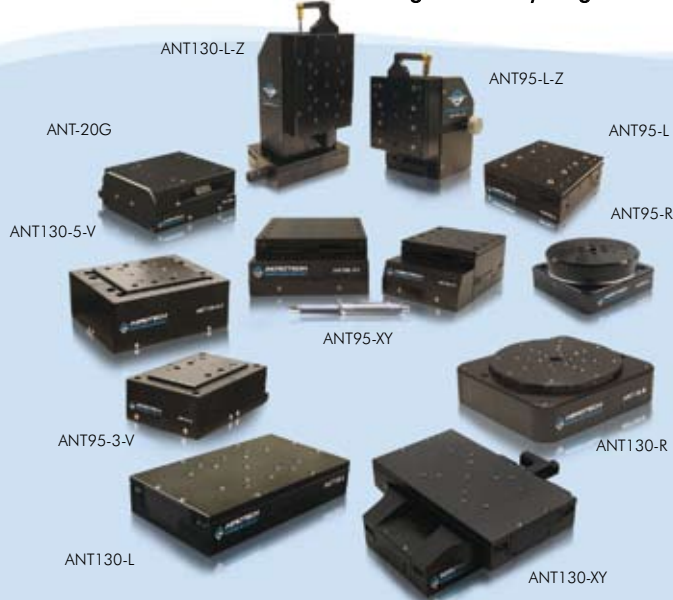
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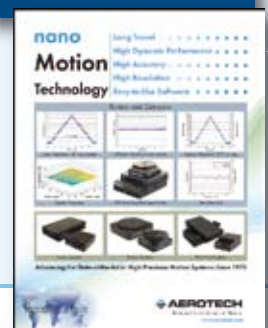
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Modern materials cutting

TNO Science and Industry in Eindhoven, the Netherlands, hosted a Mikrocentrum symposium on materials that are considered notoriously difficult to machine. Exotic materials like titanium alloys, ceramics and super alloys are more and more applied in today's precision technology, because of their excellent properties regarding strength, stiffness and both heat and chemical resistance. This means that cutting specialists can not avoid taking up the challenges imposed by such "difficult-to-machine" materials. The symposium showed that combined process technologies, new machining concepts and better insights in cutting fundamentals give valuable answers to the challenges imposed. And it was very illustrative to hear a surgeon tell about his experiences when applying products made from such materials for solving patients' hip problems.

• Frans Zuurveen •

After a short introduction to the symposium on 14 November 2010, chairman of the day Han Oosterling of TNO invites professor Bert Lauwers of the K.U.Leuven University from Leuven, Belgium, to start his lecture on hybrid process technologies.

Hybrid processes

Solutions for problems connected with difficult-to-machine materials may be provided by hybrid processes. For improving conventional machining processes like turning, milling and grinding two strategies are available; see Figure 1. The first strategy is adding an active principle to increase the machinability of the material, for example in laser-assisted turning. The second strategy is adding a

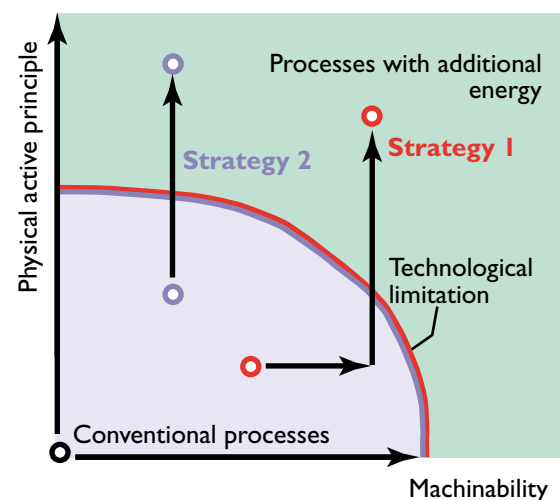


Figure 1. Two strategies for improving conventional machining processes. Strategy I adds an active principle to increase the machinability. Strategy 2 adds a second removal principle [1].

challenge experts

second removal principle, for example in the combination of EDM (Electrical Discharge Machining) with grinding. Both strategies help to exceed the limits of conventional processes.

Another example of strategy 1 is vibration-assisted machining, where a vibration of 10 to 80 kHz with 1 to 15 μm amplitude is added to the tool movement when conventionally turning, drilling or grinding. The advantages are reduced process forces, lower tool wear and improvement of surface finish. EDM also may be assisted by tool vibration, giving shorter machining times due to better flushing conditions.

Laser-assisted machining processes perform better due to the softening of the material by local heating. It is of special interest for difficult-to-cut materials such as high-

alloyed steels. It can also be applied to machine various ceramic materials. However, the composition of the ceramic material is important, because it should include material phases that melt by the induced heat. Chipless processes like sheet forming also may be improved by adding laser heating.

An example of strategy 2 is wire-EDM combined with grinding. This machining process uses a wire in which abrasive grains are embedded. As a result, higher material removal rates are obtained. An improved removal rate is also acquired by adding ECM (Electro Chemical Machining) to grinding processes. Anodic etching then helps to remove material when grinding or polishing.

Media-assisted machining is the name for adding advanced lubrication by high-pressure or cryogenic cooling fluids.

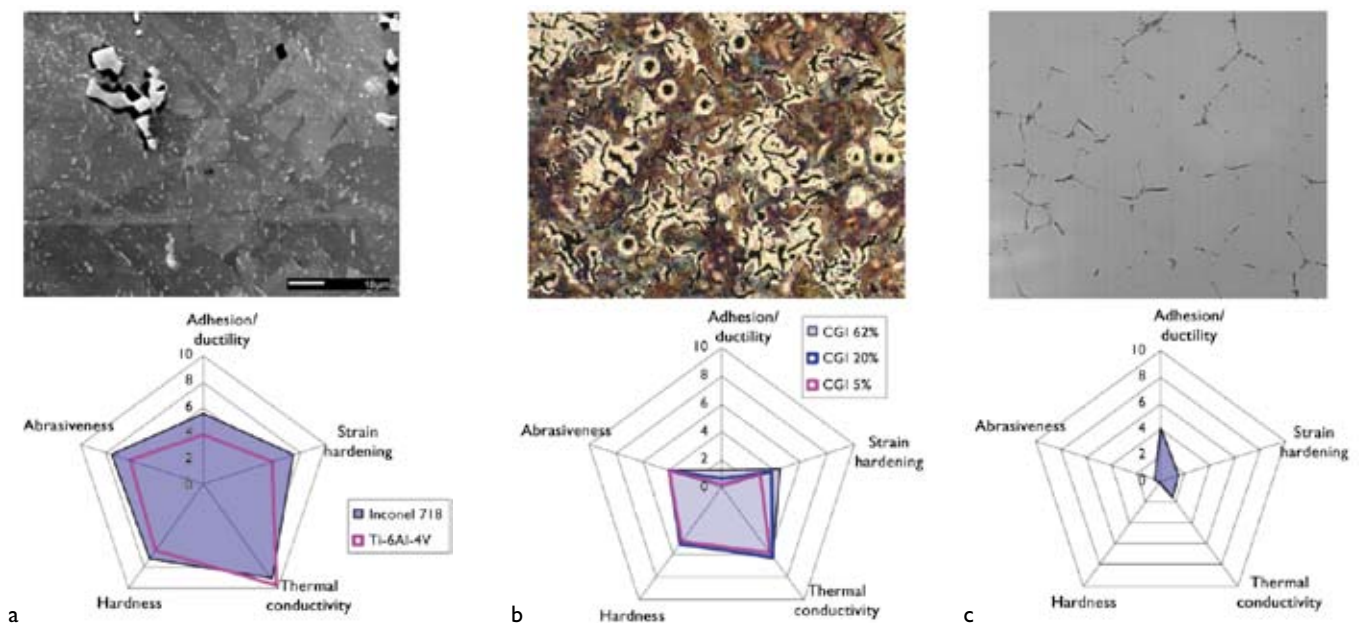


Figure 2. Micro-images and the appropriate polar diagrams. (Courtesy J-E Ståhl, Lund University)

- (a) Inconel 718, showing extremely bad machinability.
- (b) Compacted-graphite iron CGI, showing poor machinability.
- (c) Aluminium alloy 0.7-1.5 Si, showing good machinability.

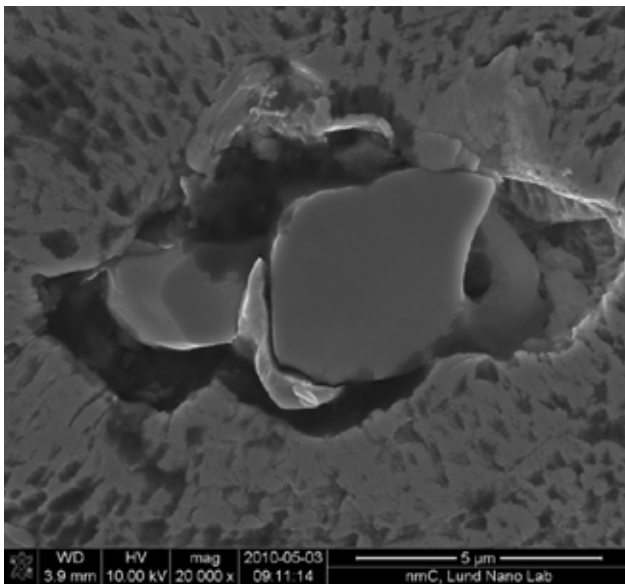


Figure 3. Micro-image of Inconel 718. The bad machinability is demonstrated by the presence of a grain of NbC (niobiumcarbide), which may cause considerable tool degradation. (Courtesy Lund University)

The results are higher cutting speeds, thanks to better chip formation. Through-tool cryogenic cooling gives “difficult” materials like advanced Ni- and Ti-alloys and compacted-graphite iron (CGI) a wider application thanks to longer tool life.

The last mentioned example of hybrid (combined) processes is grind-hardening. In this machining operation local heat from grinding is used for local hardening. Sufficient heat is generated by applying a higher depth of cut at low tool feed. This combination of processes saves costs by eliminating a separate hardening operation.

Polar machinability diagrams

Professor Jan-Eric Ståhl from Lund University in Sweden explains the use of polar diagrams to predict the potential machinability of metals, with simplification of the complexity of metal cutting as a valuable result. In a polar diagram five material properties are each represented along an axis: ductility (elongation at break), abrasiveness, hardness, thermal conductivity and strain hardening. Each property is being characterised by a number between zero and ten, representing a relative value. An outcome in the centre of the pentagonal diagram means best machinability; see Figure 2.

The usefulness of this representation is illustrated by the evaluation of Inconel 718, see Figures 2a and 3. Firstly, the diagram shows the variation in machinability for different material batches. For this alloy the relation between polar diagram and tool wear has been studied by Pajazit Avdovic at Lund University for his thesis. The polar diagram was also used to investigate the potential machinability of CGI



Figure 4. A spur gear, made by turning and hobbing on one machine. (Courtesy MAG IAS)



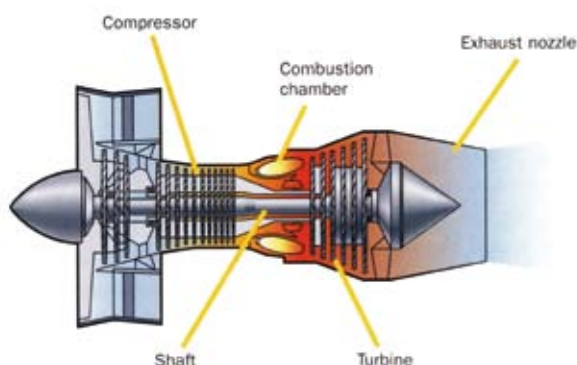
Figure 5. Free-of-twist turning is characterised by machining with a cutting blade that is straight and 10 to 20 mm long. The cutting blade has an angle of inclination between the axial axis of the work piece and the tool blade axis of 15 to 30°. The feed of the cutting blade is 90° across the part. (Courtesy MAG IAS)

and duplex stainless steel in relation to reference material AISI 4041.

Integrated processes in machines

Another approach to meet the challenges of difficult-to-cut materials is integrating processes in one machine. This is highlighted by Heiner Lang from MAG IAS. Key to the integration procedure is the modular design of building blocks with the aid of CORCOM, the MAG in-house technology for cost-effective and flexible communality between units like rotary and linear tables.

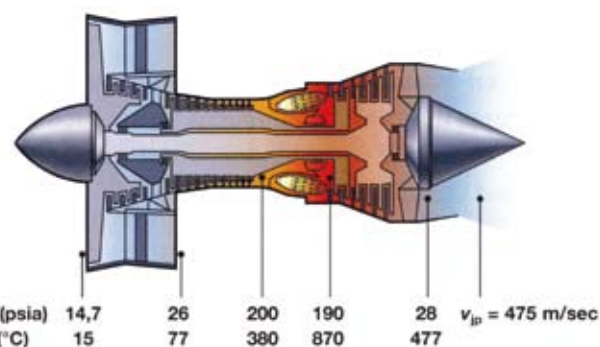
An example is the combination of milling, turning and hobbing (gearing) in one production centre for gear wheels; see Figure 4. Products from a “difficult” material like 18CrNiMo6 can be manufactured with shorter cycle times compared to conventional cutting on separate machines,



a

Figure 6. A turbine engine for airplanes.

(a) Main assemblies.



b

(b) Results of pressure and temperature measurements. (Sandvik)

thanks to minimising non-productive times. When making a gear wheel of 548 mm outside diameter, the setting-up time of 30 min is reduced to 10 min.

MAG also produces horizontal honing units, to be applied on turning machining centres. The honing unit corrects diameter, shape and surface quality of conventionally turned cylindrical surfaces. Automatic tool change facilitates operations and reduces cycle times. In one example cylindricity deviation reduced to 3.5 μm and roundness deviation to 2 μm .

A new process introduced by MAG is free-of-twist turning; see Figure 5. This is an alternative to hard turning or grinding and provides shorter cycle times with longer tool lives. Compared with hard turning, free-of-twist turning provides a much better surface topology: R_a typically reduces from 0.40 to 0.25 μm .

MAG IAS combined hard turning with grinding in a vertical machining centre for large flange parts. Heiner Lang also shows examples of better cutting processes thanks to high-pressure cooling and cryogenic cooling. In the last-mentioned case, MAG applies liquid N_2 or CO_2 in a portable rotary cryogenic adaptor.

Machining titanium alloys

Next, Han Oosterling of TNO explains why titanium and super alloys are being applied in turbine engines for airplanes; see Figure 6a. Temperature measurements in such engines show a variation from 15 $^{\circ}\text{C}$ at the inlet to a maximum of 870 $^{\circ}\text{C}$ after the combustion chambers; see Figure 6b. In the compressor section titanium alloys are able to fulfil the heavy demands of corrosion resistance and high strength-to-density ratio. But in the turbine section the temperature resistance of these alloys is inadequate.

Therefore, engine designers had to rely on super alloys, better called high-tensile heat-resistant metals. Typical examples are hastelloy, waspaloy and inconel. They are characterised by an austenitic face-centered cubic crystal

structure with nickel, molybdenum and cobalt as most important alloying elements.

Oosterling then treats the TNO research programme for cutting titanium alloys. Ti6Al4V is the widest used β -alloy and Ti45Al8Nb1B is an upcoming γ -alloy for heavy-duty space and airplane components. For these materials conventional cutting processes are problematic because of high temperatures at the tool rake face due to low thermal conductivity, vibrations due to segmented chip formation, and crater formation due to chemical reactions on the rake face.

More or less satisfying solutions to the aforementioned problems are the application of sharp tools, low cutting speeds, polished rake faces, high-pressure cooling and vibration reduction by high process stiffness. But these measures involve a “process window” that is difficult to determine.

TNO R&D tries to find answers to demands from industry for higher MRRs (Material Removal Rates) and improved quality and accuracy. By simulating cutting processes with finite-element analysis, see Figure 7, the limits of the process window are being investigated. New coatings on tool bits from CBN (Cubic Boron Nitride) or PCD (Polycrystalline Diamond) reduce tool wear and heat transport. Measures to increase stiffness and damping help to reduce vibrations (chatter). The ultimate goal is to move automatically within the limits of the process window.

TNO Science and Industry is planning an educational project for the transfer of knowledge regarding the machining of “difficult” materials like Ti-alloys, super alloys and duplex steels.

Stable machines

The hydrostatic precision turning and milling machines of Hembrug in Haarlem also help to facilitate the machining of “difficult” materials, explains Bert de Veer. Examples of

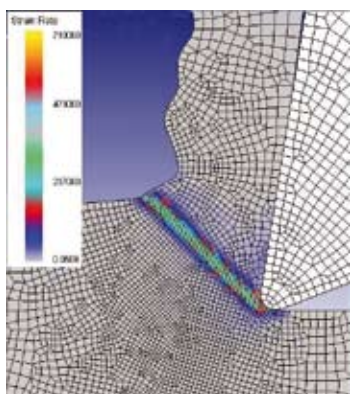


Figure 7. Simulation of the cutting process with finite-element analysis.

Hembrug products are the smallest turning machine 50 CNC with 10,000 rpm and maximum workpiece dimensions \varnothing 150 to 50 mm, and the vertical machine 1400 V4 with 200 rpm, a maximum torque of 1,200 Nm and maximum workpiece dimensions of \varnothing 1,400 to 350 mm, see Figure 8.

For utmost stability, the Hembrug machines are provided with a base frame from granite, which has excellent damping properties, little thermal expansion and a modulus of elasticity about a quarter of the steel value. Despite the low specific gravity, which is half that of steel, the amount of granite in the largest Hembrug machine is not less than 18,000 kg.

All rotational and linear bearings are of the hydrostatic type, to guarantee maximum damping and reproducibility. But regarding stiffness, hydrostatic bearings are exceeded by mechanical bearings with rolling elements. The Hembrug hydrostatic bearings work with a pressure of 30 to 60 bar at a gap width of 15 to 40 μm . Tests on a Hembrug turning machine have shown that a hydrostatic main spindle provides a tool life that is two times longer than for a main spindle with mechanical bearings, when cutting hardened steel with a CBN bit plate.

To reach maximal surface quality the method of workpiece clamping is very important. A Hembrug grip holder with flexible jaws reduced surface roughness with about a factor four, with a much higher tool life as a bonus.

Metal-on-metal hip joint resurfacing

Orthopedical surgeon Frank van den Eeden tells that in 2007 in the Netherlands more than 23,000 artificial hip joints were implanted, of which less than thousand of the so-called resurfacing type. The difference between the "classic" hip joint operation (hip arthroplasty) and hip resurfacing is that in the latter case merely new joint surfaces replace the worn-out cartilage sheet, with the advantage that most of the existing joint is being conserved; see Figure 9. Hip resurfacing therefore can be regarded as a

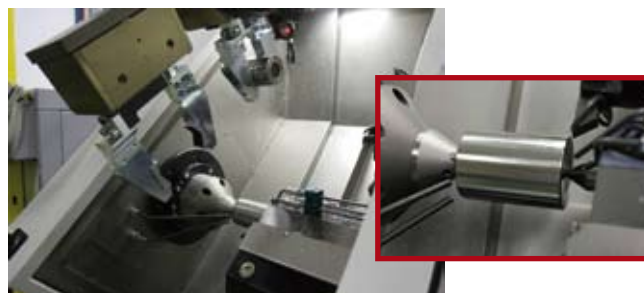


Figure 8. Machining an element for a roller bearing using a Hembrug 100 CNC with Kuka robot. The inset shows a detail.

bone conserving operation, unlike the conventional hip joint replacement; see Figure 10. In the last case a large hole has to be drilled in bone and machined by hand to accurately accommodate the protruding conical and curved stem of the artificial ball head.

In general, younger and active patients with good bone quality are able to undergo a resurfacing operation with little deformation of the hip head. Only a relatively small cylindrical hole has to be drilled after the surgeon has adapted the bone for a precise fit of the new artificial surfaces.

In most cases, titanium is the preferred material for artificial objects, as it is easily accepted by human tissue and bone, thanks to chemical inertness. However, the Corin resurfacing prosthesis is made from a high-carbon CoCr alloy, with better gliding properties. Corin is a major supplier of orthopedic implants and has more than twenty years of experience in machining "difficult" alloys for these purposes. It also participated in research regarding boundary and fluid film lubrication and tribology. For hip joint resurfacing Corin developed the Cormet system, see Figure 9, which consists of a ball-shaped head with small protruding pin, an acetabular cup, and appropriate instrumentation for accurate alignment. The resurfacing heads are available in a diameter range from 40 to 56 mm in 2 mm increments.

The Corin Cormet resurfacing implants have very smooth mating surfaces with an R_a of less than 0.05 μm . The adverse, bone-sided surfaces are roughened to provide better adhesion to human bone. The spherical form accuracy of the joint surfaces is better than 10 μm with excellent precision for the thickness of the film between cup and ball. Therefore, Corin claims to reach lubricated contact in the artificial bearing, which affords patients to leave the hospital after three to seven days following the operation.

To conclude

Today's technology asks for the application of uncommon materials, because of demands like high tensile stress, heat and chemical resistance and high modulus of elasticity. Super alloys, ceramics and titanium alloys provide answers



Figure 9. A resurfacing implant conserves most of the existing human joint. On the right an implanted Corin Cormet resurfacing prosthesis. (Courtesy Corin Group)

to these demands but their bad machinability limits their application. This symposium shows that combining processes or cutting modules in one machining centre, improved insights in cutting processes, media-assisted cryogenic cooling and additive metal manufacturing (the last topic presented at the symposium, but not covered here) all can help to overcome the hurdles in relation to cutting problems.

Nevertheless, much care has to be taken when deciding to apply the aforementioned



Figure 10. A conventional Corin hip joint replacement prosthesis. (Courtesy Corin Group)

exotic materials, because of the narrow limits of the “process window”. A reassuring thought is that TNO Science and Industry is prepared to assist prospective users in discovering those limits. With the outlook that these materials in future will get rid of the adjective “exotic” because of their much wider application.

References

- [1] Bachmann, F., et. al., “Hybride Prozesse – Neue Wege zu anspruchsvollen Produkten”. *Aachener Werkzeugmaschinen Kolloquium - Wettbewerbsfaktor Produktionstechnik*, Eversheim, W., et al. (Ed.), 1999, Aachen, pp. 243-278.

Author’s note

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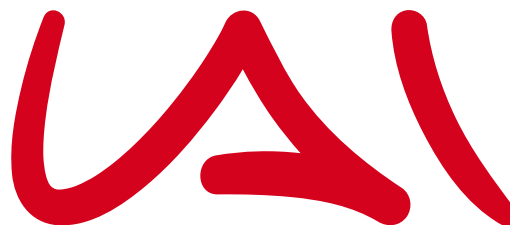
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forward thinking



Design of a high-accuracy phi-Z actuator

The design and development of two generations phi-Z actuators is described. Both types of actuators are being used in EDM (Electro Discharge Machining) production lines of Philips Consumer Lifestyle in Drachten, the Netherlands. In the past, hydraulic actuators were used in these machines. The high energy consumption, the use of cooling water and the space needed for the hydraulic aggregate of these actuators were the main reasons for developing an electrical equivalent.

• Jan Reinder Fransens •

The EDM process

In an Electro Discharge Machining (EDM) process a high pulsed voltage is used to more or less evaporate metal from the product; see Figure 1. During the process, the shape of the tool is copied into the product. Since the EDM process is highly dynamic, the complete system should have a high bandwidth. To obtain an accurate copy, the process gap should be controlled with micrometer precision. In the case of rotationally symmetric products a rotating tool is

preferred to obtain optimal copying results. One of the disadvantages of the EDM process is the fact that material is not only removed from the product but also from the tool. Therefore, the tool should be reworked on a regular interval. In practice this is accomplished using a fixed chisel with an accurate shape.

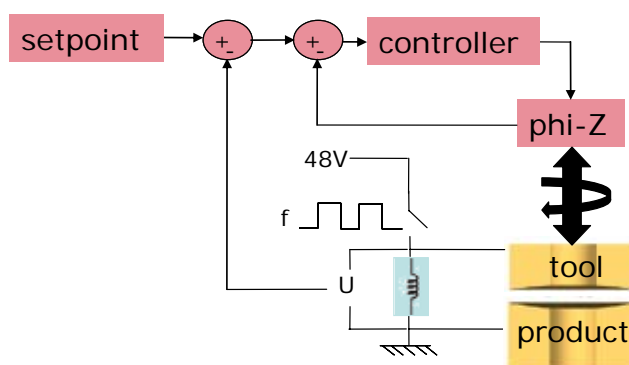


Figure 1. Principle of the EDM process. The phi-Z actuator is controlled by the process voltage U .

Author's note

Jan Reinder Fransens is working as a system architect at Irmato Industrial Solutions in Drachten, the Netherlands. Irmato is an engineering company and employs over 200 engineers divided over eight locations in the Netherlands, Germany and Belgium.

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Figure 2. Old hydraulic phi-Z actuator, which acted as a starting point for the design of electrical phi-Z actuators.

Based on the EDM process description, the main functional specifications for the phi-Z actuator become obvious. The actuator should rotate continuously and translate with very high precision. During the EDM process the force and torque are relatively low. However, during the tool reworking the actuator should be able to deliver a relatively high force and torque to enable the chisel process. Furthermore, the actuator should be highly dynamic, to enable keeping the process gap at a constant value.

First generation

Starting point of the quest for an electrical phi-Z actuator was the hydraulic phi-Z actuator shown in Figure 2. Based on the specifications of this actuator, which were more than sufficient for the application in the EDM machines, the functional specifications for the electrical phi-Z actuator were defined.

The development of the first-generation electrical phi-Z actuator started with an idea to use three standard 3-phase brushless rotational motors in such a way that the magnets formed a checkerboard. After a proof-of-principle set-up showed that the principle could work, a development project was started. Goal of this project was to develop the electromagnetic design, the necessary encoder systems and

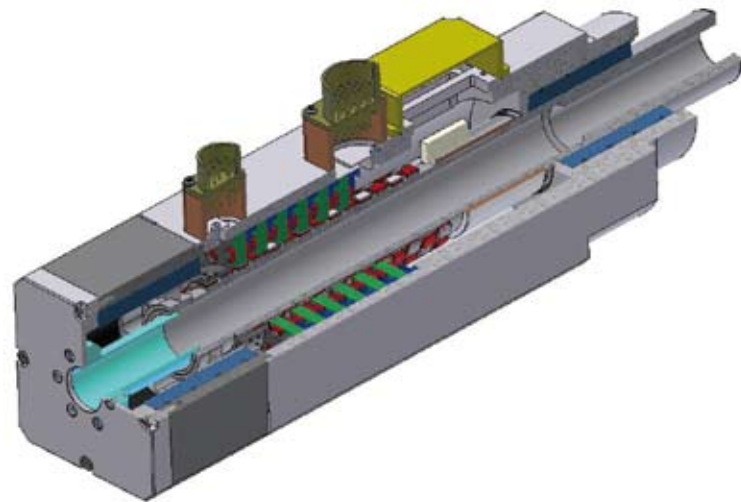


Figure 3. CAD drawing of the first-generation electrical phi-Z actuator.

the control system. The development was a joint effort of the predecessor of Irmato in Drachten (IMS equipment engineering) and the mechatronics group of Philips Applied Technologies (Apptech). The final design is shown in Figure 3.

To deliver the required force and torque, nine standard rotational brushless motors are used. The magnets, visible as a red-white checkerboard, are glued on the central hollow axis of the actuator. Two carbon air-bearings are used for a frictionless and stiff positioning of the axis. Since high resolution and accuracy were demanded for the Z-position, a special encoder bush with a line distance of 20 μm was produced. A standard encoder readhead is used to obtain a resolution of 0.1 μm . To determine the phi-position, a number of Hall sensors is used. The Hall-sensor signals are translated to standard resolver signals by dedicated electronics. The complete phi-encoder system is mounted into a compact sensor ring.

To control the phi-Z actuator, a high-end motion controller is used for the motor commutation and the phi-Z position control. To convert the resolver signals to normal encoder pulses, a converter is needed. Finally, three 3-phase current amplifiers are used to deliver the power for the actuator.

After the first prototype, built by Apptech, performed according to plan, a final version was developed. The final



Figure 4. EDM machines using the first-generation phi-Z actuators.

specifications of the first-generation phi-Z actuator are listed in Table 1. This version of the phi-Z actuator is running 24/7 in a number of EDM machines shown in Figure 4.

Table 1. Specifications of the first-generation phi-Z actuators.

Parameter	Value	Unit
stroke	56	mm
resolution	0.1	μm
absolute axial accuracy	< 2.5	μm
axial speed	> 100	mm/s
axial acceleration	> 20	m/s^2
rotational speed	> 1,500	rpm
axial force	138	N
torque	4.9	Nm
axial bandwidth	150	Hz
phase margin	48	degrees
gain margin	6.3	dB

Second generation

The development of the successor of the first-generation phi-Z actuator was initiated by the request of Philips Consumer Lifestyle to develop a new EDM production machine. The functional requirements for the stroke, torque and force were not met by the first generation of the phi-Z actuator. Simply increasing the dimensions and the number of rotational motors in order to meet the requirements turned out not to be a good solution. This was partly due to the fact that the motor force and torque are coupled as a result of the design. Another drawback of the design is the complicated control of the motor.

After reviewing the different possibilities, it was decided to develop a second-generation phi-Z actuator. Starting point was an actuator with separate phi- and Z-forcers, but with only one moving axis as in the first design. The principle of the encoder for the Z-position could be reused. The encoder for the phi-position needed a redesign. It should have a standard digital encoder output (RS422) instead of the resolver output of the first generation. In this way, the new phi-Z actuator can be controlled as two separate

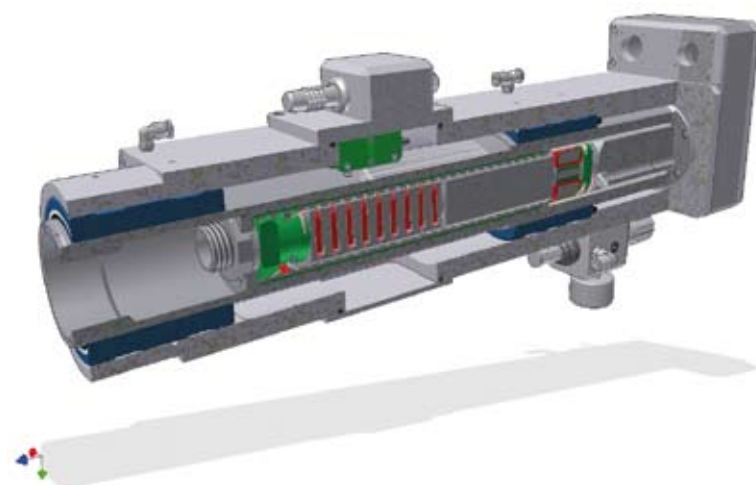


Figure 5. Design of the second-generation phi-Z actuator.

motors. As a result two standard brushless motor controllers can be used to power the new phi-Z actuator.

During the development phase, prototypes of both the phi- and the Z-actuator were built. Main issues were the minimisation of the cogging in the Z-actuator and the stiffness of the complete motor. The design of the second



Figure 6. Central axis during the assembly phase.



Figure 7. Rotating axis of the second-generation phi-Z actuator. The magnets are glued on the inner side of this axis. The encoder lines in the middle of the axis are clearly visible.

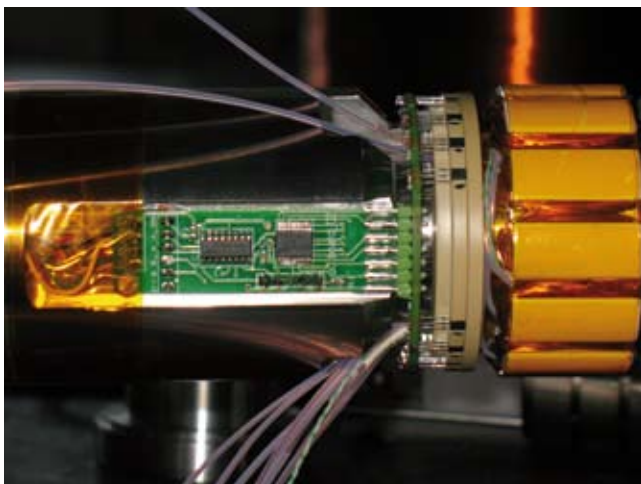


Figure 8. Hall-encoder electronics and phi-actuator during the assembly phase.

generation phi-Z actuator is shown in Figure 5. The forcers for both the phi- and Z-actuators are mounted on a central axis. The magnets of both actuators are glued at the inner side of the moving axis. The lines for the Z-encoder are directly engraved on the outer side of this axis.

As can be clearly seen in Figure 5, the motor consists of separate phi- and Z-motors. This opens the possibility to adapt the Z-force and phi-torque easily. All motor coils and



Figure 9. New EDM production machine during the assembly phase. The phi-Z actuators are mounted vertically.

electronics are mounted on the central axis; see Figure 6. The only moving part is the hollow axis containing the magnets and the encoder lines shown in Figure 7. This axis is mounted in two carbon air-bearings to obtain frictionless movement.

To determine the rotational position and to enable motor commutation, dedicated Hall electronics, shown in Figure 8, was designed.

Compared to the first design, the stroke was increased to 100 mm and the force in Z-direction was increased to 160 N. After some design adjustments the prototype turned out to meet the required specifications. The newest EDM production machine, shown in Figure 9, contains eight of these second-generation phi-Z actuators.

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Reliance provides a **helping hand** to prosthetics industry

Reliance Precision Mechatronics featured the RSL Steeper bebionic hand at the UK's recent Medtech exhibition. bebionic represents the very latest leading-edge technology in the field of prosthetics and demonstrates Reliance's expertise and adaptability in providing customised mechatronic components and integrated assemblies.



Reliance has worked closely with RSL Steeper through the development phase, specifically in the design and manufacture of the finger and thumb actuators. The bebionic hand is fully articulating, with multiple grip patterns, so the challenge has been to achieve the optimum efficiency between speed, power and noise, for the necessary hand flexibility, as well as meeting the weight and size constraints. A thorough technical understanding of the relationship between these requirements has been fundamental to the successful result.

Reliance's design and manufacturing expertise has been called upon to industrialise RSL Steeper's design concept, with rapid manufacturing of development samples to validate the design process. The building blocks have been taken from Reliance's catalogue of mechatronic components, providing the essential gears, leadscrew and nut. These have been adapted to suit the specific requirements of this project, with design engineering to integrate the piece-parts and provide a custom assembly.

Steve Parker, Technical Director of RSL Steeper, is complimentary of the teamwork achieved on the project: "Reliance have a depth of engineering skill and practical knowledge which has really complemented our own design team. We faced extremely demanding timescales for this development programme and I have been impressed by the responsiveness and adaptability of the Reliance team."

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“Piling up techn best remedy

Not so long ago, a passport was merely a paper booklet with a unique number, in which local authorities entered one's personal data and photo, and that one had to sign upon receipt. Forgery was easy and widespread. Modern passports are created with advanced laser technology and contain numerous security features. Forgery has become extremely difficult. Few people know that the technology and machines to make secure passports in the Netherlands and many other countries come from a small company in Veldhoven: IAI industrial systems.

• Jan Kees van der Veen •

The history of IAI industrial systems shows a company that twenty years ago was active in industrial automation (hence its name), but saw a new market and had the boldness and perseverance to gain a share of it. It began in the early nineties with a successful product: a device to automatically write subtitles on celluloid films. The writing was done with a laser and through this the company built considerable experience in lasers and optical technology. Management decided to further invest in this knowledge, as they foresaw new business. Jan Cobben, IAI Managing Director, remembers that soon the expectations came true. “The ING Postbank approached us with an urgent request: could we make their bank cheque more secure, as these were frequently counterfeited and this cost them a lot of money. We solved their problem by perforating – using laser technology – the account number below the printed account number. Effective and simple. It meant our entry in a new market.” See Figure 1.

The word spread and, soon after, a request came in from the Swiss security printer Orell Füssli to design a machine

to laser-perforate the note value as a pattern of tiny holes, that did not disturb the printing work and was only visible



Figure 1. Printed and perforated account number on Postbank/ING bank cheque.

ologies is the against fraud”

when the note was held against the light. The technological challenge was much tougher than for the Postbank cheques: banknotes are printed in arrays on sheets of approximately 800 x 600 mm² that pass the machine with a speed of up to 2 m/s. The time to burn a hole and move to the next one was extremely short, only 25 μ s. The MicroPerf machine that was developed for this application, using six powerful 600W CO₂ lasers to perforate six bank notes simultaneously, was a technical masterpiece; see Figure 2. Fast, crystal-based deflection units made the laser beam deflect perpendicular to the movement of the sheets. To get rid of the heat in-between the perforations – the laser can not be switched off and on that fast – the beam had to be deflected to a water-cooled “dump”. The machine could process up to 10.000 sheets per hour. Cobben: “The development of this machine took a large investment and the decision to do it was not easily made, but we never regretted it. The machine was installed successfully in Switzerland in 1997 and no fraud attempt has been detected since then. Russia followed and machines were installed in Moscow and Perm.” See Figure 3.



Figure 2. MicroPerf machine for perforating banknotes. The long, blue boxes contain high-power CO₂ lasers. The laser beams are led via the six black pipes to the sheet handling machine in front, where the actual perforations are made.



Figure 3. Security perforation in Russian banknote.

Passports

Since security printing had proven to be interesting business, around 2000 IAI decided to go into passport personalisation. Cobben: “We foresaw that in passports we could reuse much of our laser know-how, but it brought new challenges as well. Whereas the printing of banknotes is a high-volume process, passports have to be personalised: each one is unique. Impeding forgery is essential, therefore the owner’s identity has to be brought into the document in several ways, using different technologies. Countries are particularly fond of ‘level-one security features’, meaning that the owner’s identity can be checked just by visual inspection. We developed technologies that met these requirements.”

In modern passports like the Dutch one, the owner’s data page is made of polycarbonate. This material is popular for security documents as it is strong and durable and because tampering with it without leaving a trace is virtually impossible. The page contains a thin, light-sensitive layer. When that layer is exposed to light from a 1 μ m YAG- or fiber-laser, tiny carbon particles are freed, turning the surface grey or black where it was hit by the laser spot. This process is called laser engraving. This way the

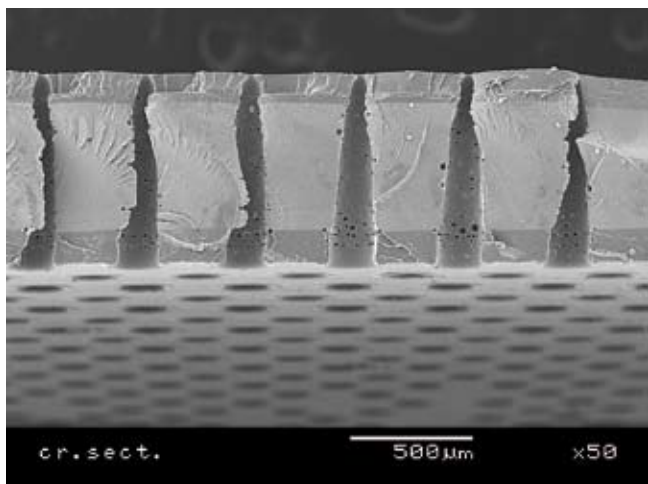


Figure 4. Cross-section of perforated image.



Figure 5. A modern passport data page with two owner's pictures.

owner's personal data, picture and signature are written on the page. To heighten security, the picture is applied a second time with a completely different technology. Using software, the picture is recalculated into a coarser pattern, that is perforated from the backside of the polycarbonate with a CO₂ laser; see Figure 4. The second picture can be seen when the page is held to the light. It can easily be verified visually that the black (laser engraved) and the white (laser perforated) picture represent the same person; see Figure 5. The technology for the laser-perforated picture ("ImagePerf") was invented and patented by IAI.

Piling up technologies

Several more tricks can be applied to make a passport unique and hard to forge. For example, the passport number is not only printed on the data page but also perforated through all visa pages, not mechanically, as in the past, but (again) with a laser, as can easily be checked visually; see Figure 6. Also, most modern passports have a contactless (RFID) chip built in the data page or in the cover, containing biometric data like face image,

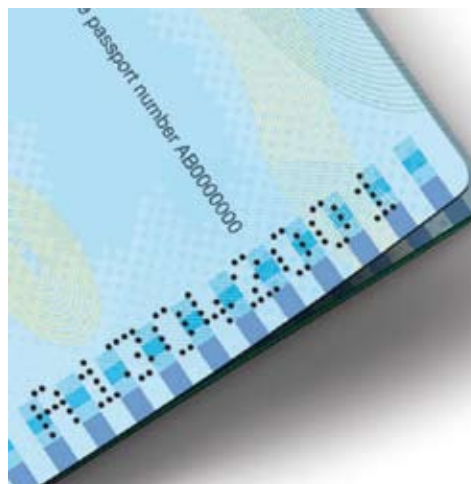


Figure 6. Perforation of the visa pages in a passport.

fingerprint or iris scan information. The piling up of all these different technologies makes counterfeiting passports today extremely hard.

IAI has developed an all-in-one system, the BookMaster One; see the box and Figure 7. Blank booklets can be inserted at one side and fully personalized passports come out at the other side. Processing steps include programming the RFID chip, writing (engraving) data and picture at the frontside, applying the perforated picture (ImagePerf, see

The Bookmaster One

IAI's showpiece is surely the Bookmaster One, that in its most extended configuration is 7.2 meters long and has a weight of 3,000 kg. At one end the blank booklets are clamped and opened at the data page, thereafter they move through the system via one long axis with a hook system that picks up booklets at one station and brings them to the next. The hook is moved up and down pneumatically (0.1 mm accuracy), the horizontal transport is done with an electrical servo system with position feedback from a resolver on the motor axis. The resolver signal is fed to a central Infranor controller that is programmed to accurately accelerate and decelerate the hook to obtain the shortest possible transport time and a position accuracy of 10 μm.

Some modules use additional servo systems. In the ImagePerf/TLI module (TLI is Tilted Laser Image), where a "see-through image" is made that can only be seen at a certain angle, a servo system is used to accurately position the laser angle with respect to the data page surface. In the inkjet printer module (when a paper data page is used instead of polycarbonate) a linear motor is used, as well as a ruler for position feedback.

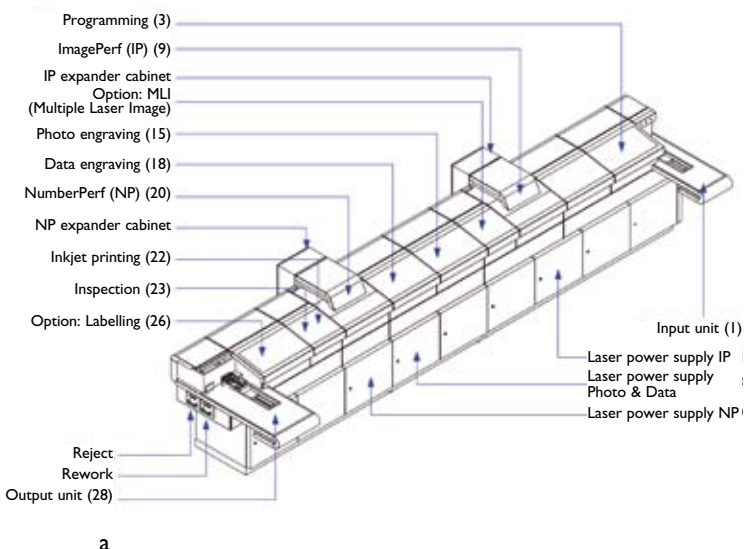


Figure 7. The BookMaster One passport personalisation machine.
(a) Overview of functions.
(b) The system in its most extensive form.

Figure 8), perforating the passport number in the visa-pages and applying a label on the cover to facilitate the distribution of the passports. It is also possible to print data and pictures with inkjet technology, for countries that still use paper data pages. The system is modular: depending on the demands of the country, functionality can be added or removed. The throughput of the machine is approximately 300 passports per hour.

Jan Cobben: “The old decentralised way of personalising passports has, due to its high susceptibility to fraud, been abandoned in most developed countries. Passport personalisation has become high tech, uses sophisticated equipment such as ours and is centralised per country in one or two locations. One of the biggest security risks of

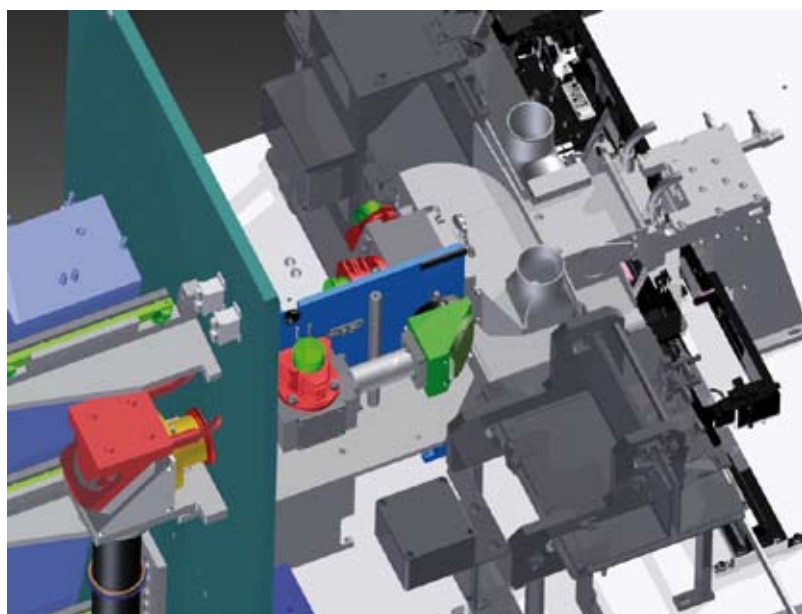


Figure 8. CAD picture of ImagePerf module of the Bookmaster One.

the past, blank passports lying around in town halls all over the country, has now been dealt with.” BookMaster One and similar security systems made by IAI have been delivered to nineteen countries in Europe, Asia, Africa and Northern America.

Finding niches

IAI exploits its laser know-how by constantly looking for new opportunities. In security printing it is a well-respected player with a broad range of products. It is also active in the manufacturing of solar panels, where laser energy is used for soldering contacts. Jan Cobben: “It is not only our laser expertise, it is our laser expertise combined with know-how in precision engineering, electronics, software, and optics that sets us apart. Developing complex mechatronic systems in close co-operation with customers is what we are good at. To extend our success we keep looking for new, attractive niches. Our biggest problem is not to find applications or customers, but to find qualified technical people to do the job.”

Author's note

Jan Kees van der Veen is a freelance technical journalist living in Son, the Netherlands.

Focusing on faster

A high-precision printing or pick-and-place-system, faster, and more accurate than existing machines. Many researchers in the high-tech industry are trying to develop just that. Here, a positioning system is described that is not dependent on an external positioning reference, such as an encoder, but that uses a measurement camera integrated in the operating head for positioning. Integrating solely hardware that is commercially available, a proof of concept was built that can determine the head's position with a 350 μ s delay enabling at least 125 Hz servo bandwidth. This makes camera-based positioning suitable for dozens of real-world applications.

• **Wouter Klein Ikkink** •

In September 2006, TNO and Eindhoven University of Technology (TU/e) started the Fast Focus on Structures (FFoS) project, as part of the Innovation-oriented Research Programme (IOP) Precision Technology set up by SenterNovem (now part of government innovation agency Agentschap NL). In November 2011 the project will officially finish. System architect Rob Snel: "We decided early on in the project to build an actual demonstrator. That is a better way to show people what you've done and is far more interesting to the industry. And it is of course much, much more fun."

Bad vibrations

A demonstrator built by the researchers is more reliable than the systems with external reference for positioning that are commonly used. Project leader Bas de Kruif comments: "An external reference system uses its own position and combines this with assumptions about the position of structures on the substrate to position the operating head." That method has a number of drawbacks. Snel explains: "No matter how stable the surface, there will

always be some vibration, expansion or offset. High-precision printing and pick & place-machines must be placed in rooms with climate control in order to minimise the influence of contraction and expansion of materials. These machines use nanometer-precision interferometers to adjust for those errors. Despite all this, with end products that tend to get smaller and smaller, the accuracy and price of the machines leave a lot to be desired."

A head with an integrated camera can continuously determine its position with the structures on the substrate as a reference. De Kruif: "To make sure such a system is

Note

Wouter Klein Ikkink is a freelance text writer. This article was contributed by TNO. In a forthcoming issue of Mikroniek a technical report on the Fast Focus on Structures project will be published.

high-precision systems

suitable for use in precision systems, such as professional ink-jet printing, accuracy is not enough. It should also be fast. This means that the camera should be able to record images with a high enough frequency, and that the hardware and software process data swiftly.”

The project group started by designing a concept system for positioning an operating head. It then investigated the potential optimisations. The delay with which a measurement becomes available determines the achievable control performance. Vision system designer Kees van den Berg explains: “The camera’s exposure time for a single image was about 100 μ s. The data from the camera was sent to a frame grabber, an interface component that processes images. This took about 800 μ s. Sending the signal from the frame grabber to a PC subsequently took another 200 μ s. The PC then performed calculations on the image to determine the position of the head. These calculations took yet another 80 μ s. So in total, processing time accumulated to about 1,200 μ s. This limits the positional control loop to a frequency of less than 1 kHz. The frame grabber was the bottleneck.”

Fingerprint

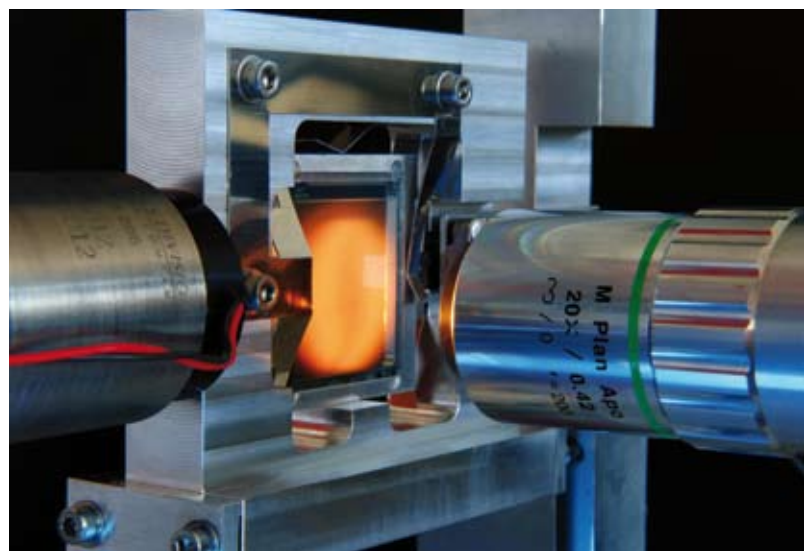
Many researchers around the globe are investigating faster, more accurate positioning systems. Van den Berg: “Most of them try to find the solution in complex algorithms or dedicated hardware. We chose a completely different path. Our starting point was to see what we could achieve with commercially available hardware.” Snel: “Finding the right camera took some time. It not only needed to be fast, it also had to expose all the points in the image at the same time. Eventually we found a camera that did that and was able to record 5,000 images per second.”

The frame grabber had to be replaced as well, says Van den Berg: “We replaced it with another type of frame grabber, containing a Field Programmable Gate Array.” This FPGA not only serves as an interface between camera and PC, Van den Berg explains: “It also carries out an important pre-processing step. Instead of sending the entire 256x256 pixel image to the computer, it sums the pixels of every row and column. This results in a kind of fingerprint of the image, consisting of 512 values. The FPGA can grab

the camera’s image and perform this very simple calculation in about 200 μ s. The calculation decreases the amount of data per image a hundredfold, enabling faster transmission to the PC’s memory as well as faster calculation.”

The calculations could easily be done on a mainstream PC, although the operating system used had to meet some rigorous standards. Van den Berg: “A common operating system is relatively sloppy when it comes to queuing and prioritising tasks. The result is that the time it takes to complete a given task can vary greatly and unpredictably. This so-called jitter is not relevant when you use your computer for common tasks, but in our case Real Time control was critical. Therefore we used RT Linux, an operating system that focuses on consistent task completion time.”

The demonstrator that TNO eventually built, has a 350 μ s delay per image. Snel: “This is fast enough for most real-world applications. Our system is about 25 times faster than earlier vision-based control systems enabling a control



Detail of the vision set-up in which the substrate is moved by a voice coil. The camera system determines the position with a sampling frequency of 5 kHz, allowing for industrial ‘vision in the loop’ applications. (Photo: Fred Kamphues, TNO)

bandwidth of more than 125 Hz, which in turn enables to suppress common vibration spectra from airco or even semicon factory cleanroom floors. This is a step up in the high-tech and scientific instruments industry. And the price has remained low due to the standard components.”

Viable

In developing the FFoS-system, TNO aimed at high flexibility. De Kruif: “The system consists of off-the-shelf parts. The FPGA can be programmed graphically, which makes it very accessible and easy to customise. The computer itself is household stuff. Embedding the software is of course a possibility as well.” The researchers did not make a groundbreaking discovery, Snel admits: “Basically, we did little more than clever integration of parts that were already on the market. Yet, we managed to make a system that is orders of magnitude faster and more reliable than existing machines. We are really proud of the fact that we succeeded in finding the right standard components and connecting them in a way to achieve these specs.”

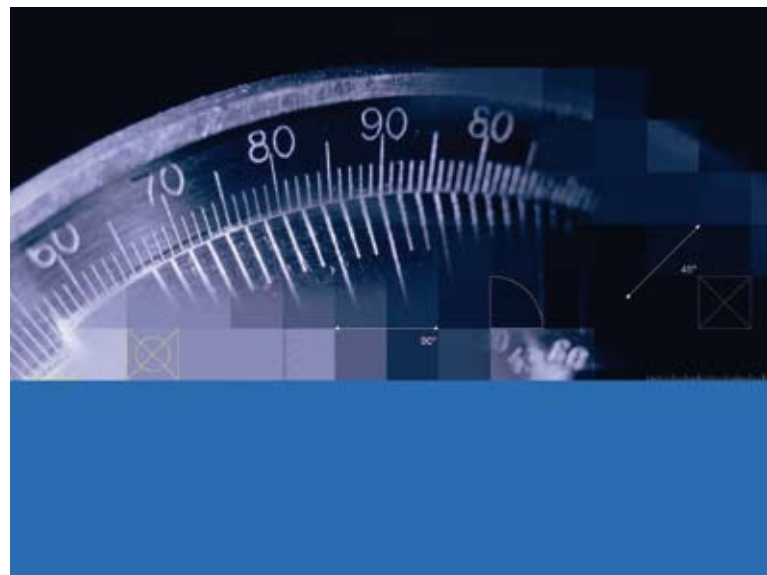
Further software development will probably shave off tens of microseconds, Van den Berg says: “Putting the FPGA on top of the camera will probably significantly reduce processing time even further. But we would have to develop dedicated hardware, which was not within the scope of this project. But it surely can be done.”

The demonstrator that TNO built is currently a ‘vision in the loop’-system. De Kruif: “The current system determines the head’s position and repositions it in one dimension with a sample frequency of 5 kHz. It does however show to the world that vision-based positioning is possible and viable for real-world applications.”

Co-development

While TNO focused on a vision system that measures the position quickly, Ph.D.-students Roel Pieters and Jeroen de Best, from the TU/e-groups of Henk Nijmeijer and Maarten Steinbuch, respectively, work on algorithms for feature tracking and feedback control using visual information for repetitive structures. They use an industrial platform to investigate the benefits of these algorithms for feedback.

During the project, a number of companies, including ASML, Assembléon and OTB, provided feedback to the vision set-up of TNO. Snel: “They are potential customers



The project described here was part of the Innovation-oriented Research Programme (IOP) Precision Technology.

for the system we developed. We updated these companies on our progress. They shared their thoughts with us and advised us on how to proceed and on what aspects to focus.” The project is financially supported by Agentschap NL. Companies, however, have already expressed interest in further development on the basis of the proof of concept, De Kruif says: “We are inviting the market to invest and to co-develop this system with us. The next step will then be to produce a system performing a task which is now carried out by conventional precision systems. In this way we can show the difference.”

The FFoS-system can also play an important role in new technologies like 3D integration. Snel: “Many companies around the world are developing technology to stack multiple chips on a single die. This will result in cheaper chips with higher energy efficiency and less heat production. To produce this kind of chips, we need the kind of precision that our FFoS system can deliver.” The aim was to show that the FFoS system is an enabling technology, Snel concludes: “It can be used to enable all kinds of novel printing and pick & place tasks. There are dozens of applications that will benefit from this development, once it reaches the market.”

Information

www.tno.nl
www.tue.nl
regelingen.agentschapnl.nl/content/iop-precisietechnologie

Investing in ultrafast ALD

The German wet processing equipment producer RENA and Brabant Development Agency (BOM) have invested in SoLayTec, which will commercialise ultrafast Atomic Layer Deposition (ALD). SoLayTec, a TNO spin-off, will apply this technology in equipment within the solar market for the production of solar cells, after independent research organisation TNO had demonstrated the proof of concept. SoLayTec will deliver the first process development tool from the second quarter of 2011. The additional investments by BOM and RENA will help to facilitate the development of a high-volume tool, capable of processing up to 3,600 wafers/hour in 2012.

The next generation of industrial silicon solar cells aims at efficiencies of 20% and above. To achieve this goal using ever thinner silicon wafers, a highly effective surface passivation of the cell (front and rear) using Al_2O_3 is required. With ALD Al_2O_3 can be deposited layer by layer, resulting in a

very dense and uniform layer. SoLayTec's ultrafast spatial ALD principle is significantly faster than traditional ALD, making it suitable for industrial application.

SoLayTec has been awarded a subsidy from the Dutch Peaks in the Delta programme to industrialise the ultrafast ALD technology. Partners in the project are Frencken, Lamers High

Tech Systems, Bronkhorst, TMC, Van Berlo, Sioux and NTS Mechatronics, with co-funding coming from the Ministry of Economic Affairs, Agriculture & Innovation, the provincial authority of Noord-Brabant and the Eindhoven City Region.

www.solaytec.com
www.rena.com



SoLayTec's process development tool and high-volume tool.

Philips Innovation Services combines technologies on a nano- and microsystem scale

As of January 1, 2011, Philips Applied Technologies (Apptech) has continued its mechatronics activities in Philips Innovation Services. This new organisation combines the innovation services and facilities of the Philips MiPlaza and former Philips Applied Technologies organisations. It draws upon a range of technology competences, facilities and process consultancy that for decades have accelerated the innovation activities of Philips and other companies such as ASML, KLA-Tencor, Océ and IMS. Philips Innovation Services' support covers the entire innovation process, from idea generation, system architecture, design, engineering, test and integration as well as prototyping.

Development projects include complex industrial systems with nanometer precision and various modalities in healthcare and consumer lifestyle.

Over the years, competences have been built up in advanced precision systems in various areas such as vacuum environments for Extreme UV applications, charged particle, imprint and inspection tooling as well as robotics. Now combined with the MiPlaza competences and facilities, even more services and facilities can be offered to accelerate innovation. For example, customers can hire multi-purpose clean rooms (2,650 m²), equipped with over 300 machines for deposition, lithography, etching and

measurement, with specialist support if required.

Furthermore, Philips Innovation Services is now able to offer a broad range of trace analysis and contamination control services which can help engineers to improve their processes down to detailed levels. In addition to the physical labs, a Virtual Lab enables customers to follow their analysis by Internet connection, with live interaction & 'look over shoulder' viewing.

In the next issue of Mikroniek, vice president Harry Vaes will disclose Philips Innovation Services' strategy regarding its mechatronics activities.

www.innovationservices.philips.com

Laser dicing to 12 inches

ALSI (Advanced Laser Separation International) in Beuningen, near Nijmegen, the Netherlands, is celebrating its tenth anniversary this year. ALSI, which develops and sells innovative machines for laser cutting chips from wafers, is on the brink of a major breakthrough. Started years ago with machines for small (4- and 6-inch) wafers, the latest model can cut large 12-inch wafers.

The latest development in the semiconductor production process is dicing, i.e. separating individual components, or ICs, from the wafer. Traditionally, this is done by means of sawing, which results in a great deal of material loss, especially for small components. Philips Semiconductors (now NXP) in Nijmegen developed a quick, efficient and clean alternative called laser dicing. The key advantages of cutting with a laser beam: higher speed (increased return), smaller 'saw cuts' (less loss of material) and no mechanical stresses in the usually brittle wafer (less product wastage). At the heart of the Philips design is the multiple beam. The laser beam is split into a 'comb' of parallel beams with the aid of optics. A wafer stage travels underneath the multiple beam in a straight line (parallel to the comb). In this way, a deeper cut can be made in one cutting pass, while the (disruptive) thermal load from each beam remains limited. Furthermore, with a constant total laser capacity, the cut from a multiple beam is narrower than one from a single beam.

Philips spin-off

ALSI was established in 2001 to develop the concept into a fully functioning machine, initially for small wafers of 4 and 6 inches. After all, proportionally speaking, the largest reduction of material wastage can be achieved with the narrower laser cut on wafers full of small, discrete components (such as LEDs, transistors, diodes and power amps for mobile phones). From the outset, ALSI's partners included research and

development firm CCM in Nuenen and the supplier of the engine for the stage, IMMS in Ilmenau, Germany. When Point-One was launched in 2006, the three companies together defined an R&D project entitled '300 mm Integrated Stage Platform'. This project was eligible for an Agentschap NL subsidy. "Our market collapsed in 2009", explains ALSI CEO Peter Chall. "Thanks to the subsidy for Point-One, we were able to continue with the development during this 'quiet' market period. We would have still done that anyway, just at a slower pace, which would have resulted in a later market launch."

Challenges

The biggest technical challenge when upgrading the current state-of-the-art 8 inch to 12 inch was with the wafer stage. This should be driven like a flying carpet across an ultra-thin layer of air with high precision (within 1 micrometer for a saw-cut) by an IMMS planar motor, for which the permanent magnets are housed in the stage. Given the rigidity of the stage required to counter internal vibrations that negatively impact precision, the aluminium used for the smaller versions was no longer sufficient as a construction material. A switch to steel was made, resulting in a structure that weighed 90 kg. That considerable mass should be moved at a speed of 500 mm/s and, at the end of the pass, be able to 'turn' within 0.1 seconds, which in itself is an acceleration of the order of 1 g. The required currents and the high duty cycle demand the utmost of the boosters driving the planar motor.



ALSI's new ICA 1204 platform for laser dicing of 12-inch wafers.

The SAXCS (Smart And Flexible Control Solutions) platform developed by CMM was used for designing real-time processing. SAXCS enables developers to achieve controls that are component-independent, and, therefore, more flexible in a much shorter period of time than before using model-based design tools, such as Matlab/Simulink.

Aim: to zero

ALSI, meanwhile, has very advanced plans to build a new lab for the next development projects. As early as 2009, ALSI started working with various partners on a second Point-One R&D project, ALISS (Advanced Laser-Induced Subsurface Separation), with the aim of reducing the cut to zero during separation: zero dicing width. Focusing the laser beam inside the wafer generates a mechanical stress that can be used to break the wafer into individual components in a controlled fashion and without losing any material.

www.alsi-international.com

Low-profile piezomotor stage for vacuum use

Confined spaces in vacuum chambers require drives and positioning solutions which are particularly compact. With a height of only 21 mm the M-683.2V4 translation stage from Physik Instrumente (PI) is one of the flattest micro-translation stages on the market, and is now also available for use in vacuum environments to 10^{-6} mbar. An encoder resolution of $0.1\text{ }\mu\text{m}$ over 50 mm travel makes this PI stage ideal for tasks requiring a high degree of precision.

For better guiding accuracy the M-683 positioner from PI uses two crossed-



roller bearings, which are mounted on precision-ground aluminum profiles. They are designed for loads up to 5 kg. Its piezoceramic U-164 PILine® linear motors have high holding forces which are greater than the drive forces, even when powered down. They therefore generate no heat when

at rest, nor is there any positional jitter with active closed-loop control, as may occur with conventional motors.

The PILine® piezomotor technology developed by PI requires neither spindle nor gear. The direct drive is integrated in the stage and gives it its high velocity of up to several hundred millimeters per second.

In the Benelux, PI is represented by ALT (Applied Laser Technology).

www.alt.nl

Two-axis “checkerboard” motor

At present, actuators usually count one axis. If a multitude of movements is required, the common solution is to stack multiple single-axis stages. In this way, degrees of freedom can be added but the tolerances of the individual axes also stack up as a result. Therefore, a high-accuracy multi-axis milling machine, for example, requires highly-complex drive algorithms to guarantee its precision.

Recently, Alliance Technologies, based in Leeuwarden, the Netherlands, introduced a motor that has “more than one trick up its sleeve”, as an Alliance press release phrases it. It is called the checkerboard motor, a brushless, tubular servo motor of which the removable, hollow shaft can be driven in both rotation and translation. Both movements are, in contrast to the conventional stacking method, direct driven from a single motor. The linear and rotary positions are fed back with a resolution of $1\text{ }\mu\text{m}$ and 0.01° , respectively. The standard stroke is

150 mm, but this can be adjusted to any desired length.

The checkerboard motor can be controlled by any motion controller. Both axes are independently driven or can be coupled by electronic gearing. The shaft, therefore, can easily make a rotary, linear or screw movement. The focus has been on creating a user friendly and intuitive system. Peripheral hardware can be chosen by the user, the use of industrial standard components like standard brushless servo drives adds to the flexibility of

the solution. The “low-cost” checkerboard motor is suitable for applications in for example pick & place modules, assembly units, precision manipulation and robotics.

www.the-alliance.eu



The new checkerboard motor is named after the checkerboard pattern exhibited by the array of permanent magnets on the hollow rotor.

Vision combined with touch probe

Mitutoyo, a leader in dimension measurement technology, has expanded its Quick Vision series. In addition to an optical system, the new TP versions of the vision measuring instruments comprise touch-trigger probes for contact measurement. Quick Vision 3D CNC vision systems are especially designed for use in metrology laboratories and in a production environment. Here, they carry out fully automatic measurements primarily in medium-sized and large series.

The technological highlights of the system include, on the one hand, the clear-image optical system and the enhanced edge detection by surface structure analysis. On the other hand, there is the triangle-pattern projection for focussing low-contrast surfaces as well as the high drive-speed and acceleration.

Additional models with multi-sensor features provide the series, which so far already comprises 17 versions, with even more areas of use. In addition to the optical measuring system, the TP versions are equipped with a contact sensor. Measurements can be carried out on workpieces that cannot be acquired with a purely optical system alone. Therefore, the user is able to choose the strategy that is appropriate for each measuring task.

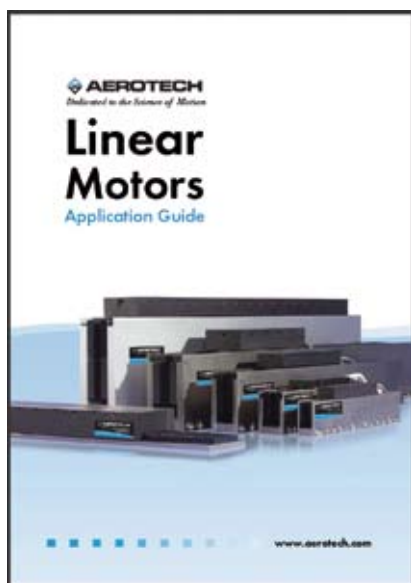
TP versions are optionally equipped with a Renishaw TP20 or TP200 probe and stylus. The TP200 model is shipped with a controller and an interface set. A tool changer is optionally available for both versions.

www.mitutoyo.nl



A Quick Vision system equipped with a touch probe.

Aerotech updates



UK-based Aerotech has released an updated edition of its popular Linear Motors Application Guide including a

new section on applying linear motors as components in servo positioning systems. The new section complements chapters on the basics, types, benefits, selection, and the commutation of linear motors with a detailed overview of the drive technologies, feedback devices, bearing types and cable management systems available. The Linear Motors Application Guide was first introduced in 2002.

Recently, also a new publication was launched. The nano Motion Technology resource guide provides design considerations and full specifications across Aerotech's recently released range of ANT series linear and rotary nanopositioning stages, and the advanced motion controls that together provide high-throughput performance at 'one nm at

a time' displacement intervals and high levels of in-position stability.

www.aerotech.com

Professor Jos Benschop

Jos Benschop, ASML's vice president Research and DSPE Advisory Board member, has been appointed part-time professor at University of Twente, Enschede, the Netherlands, in the NNV chair of Industrial Physics. NNV is the Dutch Society for Physics.

www.asml.com
www.utwente.nl
www.nnv.nl

High-precision inspection for E-ELT

UK-based Cranfield University is in the race for manufacturing 1,000 mirror segments for the European Extremely Large Telescope (E-ELT). Early this year, Cranfield started producing seven prototype mirror segments for “the world’s biggest eye on the sky” with the aid of high-accuracy measurement systems from Hexagon Metrology. Built by the European Southern Observatory (ESO) the E-ELT, a ground-based telescope, will be 42 m in diameter and made up of 1,000 hexagonal mirror segments, each 1.5 m wide and just 5 cm thick.

Production and measurement pose challenges to Cranfield University and Hexagon Metrology. Cranfield has developed BoX (Big OptiX), a specialised grinding and measurement system for realising the mirrors. The ultra-high accuracy Leitz PMM-F 30.20.10 CMM from Hexagon Metrology is used to verify the performance of the Cranfield BoX grinding machine and measures the mirror segments. With this combination it is expected that each mirror segment can be ground within 20 hours, up to ten times faster than the competition.

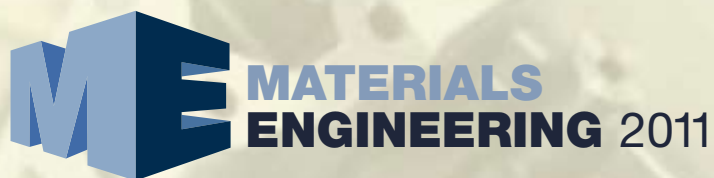
After processing at Cranfield, the mirrors are sent for polishing. The segments are polished utilising error surface maps generated from the Leitz PMM-F. These identify high and low points for initial corrective polishing. The polished quality requirement is a surface roughness of 1-2 nm RMS and form accuracy of 10 nm RMS. To

verify these extreme surface accuracies, an 8 m optical test tower is used, which has a Leica Absolute Tracker AT901 from Hexagon Metrology integrated for accurate alignment.

www.cranfield.ac.uk
www.hexagonmetrology.com



Inspection of a mirror segment.



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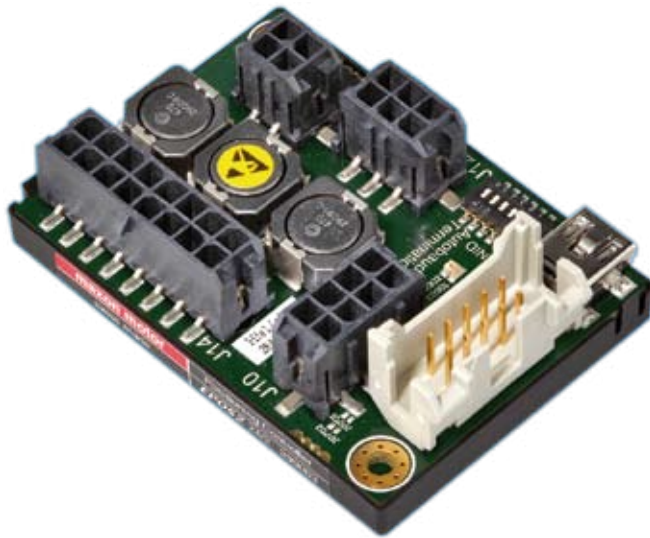
for more information go to www.materialsengineering.nl

Miniaturised positioning controller

Maxon motor's EPOS (easy to use positioning system) is being expanded in a second generation. Several variants of the EPOS2 24/2 positioning controller permit the use

of various brushed DC motors with encoder or brushless EC motors with Hall sensors and encoder up to 48 W. The EPOS2 24/2 quasi represents the synonym for the currently possible

degree of miniaturisation in positioning controller design, according to a maxon motor press release. "More power, more functionality, and more comfort in such a small space are today almost impossible."



As with all other maxon motor EPOS products, the EPOS2 24/2 was developed specifically for commanding and controlling in the CANopen network. USB and RS232 are available as further communication interfaces. Due to the variety of operating modes, such as position, velocity and current mode, they can be used flexibly in automation technology, tool building and mechatronic drive systems.

www.maxonmotor.com

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We are looking for excellent people to strengthen our enthusiastic team. Working at MI-Partners means working on innovative solutions for mechatronic problems with customers from all over the world. Our projects - for markets like semiconductor, automotive, medical, inspection and printing - are carried out in-house, using the latest measurement and analysis tools and cleanroom facilities.

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For engineers who think ahead

10 May 2011, Eindhoven (NL) Engineering Event: Safety 2011

Event in the famous Evoluon – the former Philips technology showcase – organised by Mybusinessmedia. The central theme is: New norms under the Machinery Directive – from risk assessment to manipulation of safety functions.

www.engineersonline.nl/safetyevent

19 May 2011, Eindhoven (NL) Mechatronics Meet & Greet at Philips Innovation Services

Event on the High Tech Campus, from 16.00 till 19.00 hours, for anyone interested in a mechatronics career, to meet some of the key people, learn more about their projects, competences and customer base, and receive information about career openings.

www.innovationservices.philips.com/mechatronics-meet-and-greet

19-20 May 2011, Delft (NL) Second International Symposium on Compliant Mechanisms

Scientific event focused on fundamental issues and future research directions in compliant mechanisms research and design.

compliantmechanisms.3me.tudelft.nl

23-26 May 2011, Como (Italy) Euspen 11th International Conference

Conference and exhibition on precision engineering and nanotechnology, addressing the latest advances and market developments in precision processes and manufacturing, as well as fabrication, metrology, sensing applications and cutting-edge materials.

This year's conference topics will include:

- Ultra Precision Replication Techniques
- Nano & Micro Metrology
- Ultra Precision Machines & Control
- High Precision Mechatronics
- Ultra Precision Manufacturing & Assembly Processes
- Important/Novel Advances in Precision Engineering & Nano Technologies

www.como2011.euspen.eu

23-26 May 2011, Munich (Germany) LASER World of PHOTONICS 2011

Marketplace and "think tank" for the global laser and photonics industry, featuring more than 1,000 exhibitors from over 30 countries. The focus is on future prospects of the photon in the manufacturing, life-science, energy and environmental sectors.

world-of-photonics.net

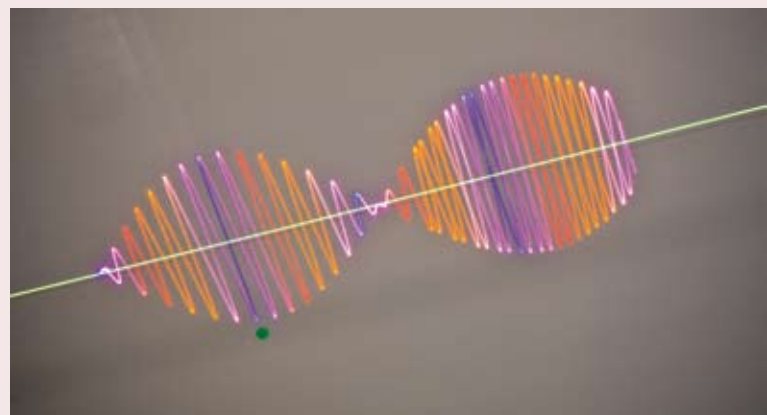


Image by LASER World of PHOTONICS 2009 exhibitor Coherent. (Courtesy Messe München)

25 May 2011, Nijmegen (NL)
VCCN Cleanroom Symposium

Symposium, combined with Contamination Control trade fair, organised by the Dutch Contamination Control Association, VCCN. Four parallel sessions feature disinfection using VHP (Vaporised Hydrogen Peroxide), the architect's role in a cleanroom project, logistics in cleanrooms, and commissioning.

www.vccn.nl

25-26 May 2011, Eindhoven (NL)
Materials Engineering

This trade exhibition offers a synoptic and transparent business-to-business platform for material, product, and design technology. This year's theme is "Smart and functional materials". In this context, for example, attention will be paid to piezo technology, in a special pavilion. Another special topic is devoted to aluminium.

www.materialsengineering.nl

25-26 May 2011, Veldhoven (NL)
Vision & Robotics

Knowledge and business network event, organised by Mikrocentrum, on robotics and automation solutions in the Benelux. The focus is on innovations and solutions for vision systems, robotics, motion control, sensors and machine automation. See also page 21.

www.vision-robotics.nl

26-27 May 2011, Aachen (Germany)
Aachen Machine Tool Colloquium

International meeting place for specialists and managers from industrial production companies. Over 1,000 experts from industry and research institutions are expected for an exchange on production technology.

www.awk-aachen.de

27 June - 1 July 2011, Eindhoven (NL)
International Summer school
Opto-Mechatronics 2011

Organised by DSPE, and hosted by TU/e, TNO Science and Industry, TUD, ESO and ASML. See also page 64.

www.summer-school.nl



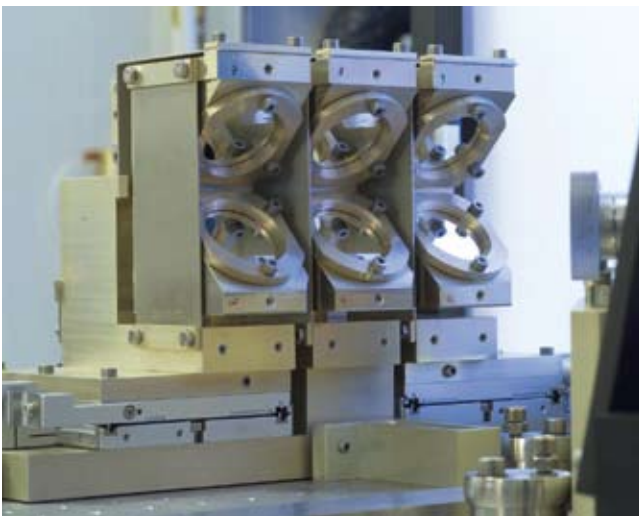
Summer school

Following the success of the 2008 to 2010 editions, DSPE and TNO organise the Summer school Opto-Mechatronics 2011, from 27 June to 1 July 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.

Summer school Opto-Mechatronics

Precision
Technology

The Summer school Opto-Mechatronics 2011 comprises five days of intensive course, taught by excellent Dutch professors and scientists in the field of precision engineering, combined with hands-on training by TNO specialists. 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.



Case work is done on the design of an optical delay line, such as the one developed by Dutch Space and TNO, for the ESO Very Large Telescope (VLT) on Cerro Paranal in Chile.

Programme

Monday 27 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 28 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 29 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 nanometre positioning accuracy.

Thursday 30 June: Opto-Mechanical Design

The trade-off made for a linear guiding of 66 metres, with sub-millimetre 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

Opto-Mechatronics 2011

the other key technologies needed (optics, control and electronics) and on the mechanical design itself.

Friday 1 July: 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



The 2010 Summer school attracted participants from the Netherlands, Germany, Spain and Taiwan.

Introducing DSPE board members: Edwin Bos



My name is Edwin Bos (34) and I am the chairman of the Young Precision Network of DSPE. Professionally, I am co-founder of Xpress Precision Engineering in Eindhoven, the Netherlands. Xpress provides advanced

design and engineering services related to metrology and high-precision positioning. We deliver a total solution in product development: from specification and initial concepts, to design, engineering, realization and testing of the design. Furthermore, Xpress is manufacturer of ultra-precision 3D measurement solutions, used for measuring μm -sized features with nm-repeatability. Applications include the 3D measurement of (fuel) injection nozzles, medical implants, calibration artifacts, etc. Customers range from global companies to start-ups and small businesses.

I studied mechanical engineering at Eindhoven University of Technology (TU/e). My Master project was the calibration of line scales using a laser interferometer. In

2003, I started Ph.D. research on high-accuracy probing systems for MEMS, guided by TU/e-professors Schellekens (Precision Engineering) and Dietzel (Micro- and NanoScale Engineering). In 2007, while finishing my Ph.D., I co-founded Xpress and was lucky enough to receive multiple awards and grants for my work. Currently, I am in charge of all research & development activities for Xpress.

Young Precision Network (YPN)

YPN organises activities for the young (at heart) part of DSPE. These activities include company visits and courses with a strong focus on technology and development of high-precision mechatronic systems. Recent visits included ASML, Mapper, Assembléon, Philips Applied Technologies, Philips Research, FEI, ESA and NTS.

Participants come from the Netherlands, mainly Eindhoven (40%), Delft (20%) and Enschede (20%). A typical group size is 25 participants, consisting (roughly) of final-year Master students (35%), Ph.D. students (30%) and young professionals (35%). Participation is free of charge.

www.dspe.nl/ypn
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Innovative solutions – Ceratec Technical Ceramics

Ceratec Technical Ceramics has specialised in industrial technical ceramic components since 1983. Ceratec's strength lies in the complete formula of problem analysis, development, prototyping and production. Ceratec Technical Ceramics has played a key role in applying technical ceramics in many ways. Customer-oriented solutions result in longer periods of operation, lower maintenance costs and fewer interruptions of production – in short, they lead to a cost-efficient production process.

Next to full-ceramic products, Ceratec develops composite products, such as ceramic-metal or ceramic-plastic products. The goal is to put the combination of the – often extreme – properties of technical ceramics and those of metals/plastics to its best use.



Production

Alongside various processing techniques, special joining techniques are applied for the production of composite products made of technical ceramics and metal. The requisite metal-working processes and assembly activities are carried out in-house. Ceratec produces both small and larger series. Throughout the production process, quality control is carried out in the advanced test room.

Engineering

Ceratec Engineering offers professional support in the area of material selection, economical design and backup for incorporation of ceramic components. Ceratec uses technical ceramics for products and components of which the material properties produce distinct added value. For instance, wear problems with metal or plastic components can be a reason for calling on the services of Ceratec engineering.

Custom-made products

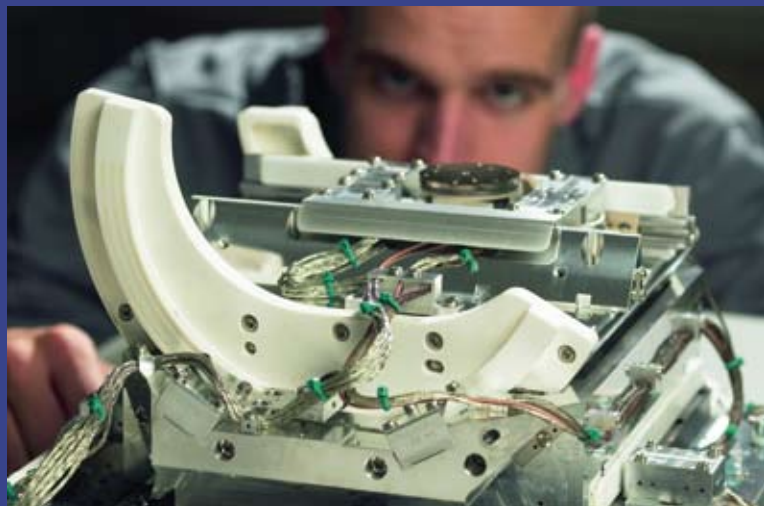
Ceratec develops and manufactures technical ceramic products for customer-specified applications. Examples are:

- precision components (electronics, mechatronics);
- wear parts (nozzles, linings);
- pump components (sliding and ball bearings);
- machine parts (positioning);
- cut and mould parts (knives, dies).



Standard products

Additionally, high-tech developments at Ceratec have led to a wide range of standard ceramic industrial products.



Information

www.ceratec.nl



ENGINEERING EVENT 10 Mei 2011 SAFETY

SISTEMA Manipulatie van veiligheid Risicobeoordeling Safety re-engineering Risicoanalyse PL en SIL EN 954 / EN 13849

Heeft u ook vragen rond deze thema's?

Kom voor praktische antwoorden naar het Engineering Event: Safety 2011.

Locatie: Evoluon Eindhoven. **Datum:** 10 mei 2011.

De dag bestaat uit een aantal plenaire, to the point presentaties, interactieve learnshops én ronde-tafel gesprekken met onze safety-doctors.

Aanmelden:

www.engineersonline.nl/safetyevent



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The DSPE website is the meeting place for all who work in precision engineering.

The Dutch Society for Precision Engineering (DSPE) is a professional community for precision engineers: from scientists to craftsmen, employed from laboratories to workshops, from multinationals to small companies and universities.

If you are interested in a button or banner on the website www.dspe.nl, please contact Sales & Services.

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page

■ Aerotech Ltd www.aerotech.com	35
■ Applied Laser Technology www.alt.nl	71
■ ASML www.asml.com	61
■ Heidenhain Nederland BV www.heidenhain.nl	72
■ IAI Industrial Systems www.iai.nl	42
■ Materials Engineering 2011 www.materialsengineering.nl	59
■ MI-Partners BV www.mi-partners.nl	60
■ Mikroniek Guide	68
■ Minimotor Benelux www.faulhaber.com	41, 46
■ NTS-Group www.nts-group.nl	12
■ Reliance Precision Mechatronics www.rpmechatronics.co.uk	47
■ Safety Engineering Event 2011 www.engineersonline.nl/safetysite	67
■ Schaeffler Nederland B.V. www.schaeffler.nl	20
■ TNO www.tno.nl	2

DSPE

Mikroniek

Mikroniek is the professional journal on precision engineering and the official organ of the DSPE, The Dutch Society for Precision Engineering.

Mikroniek provides current information about technical developments in the fields of mechanics, optics and electronics and appears six times a year.

Subscribers are designers, engineers, scientists, researchers, entrepreneurs and managers in the area of precision engineering, precision mechanics, mechatronics and high tech industry. Mikroniek is the only professional journal in Europe that specifically focuses on technicians of all levels who are working in the field of precision technology.

Publication dates 2011:

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3	20-05-2011	24-06-2011 - Optomechatronics
4	29-07-2011	02-09-2011
5	09-09-2011	14-10-2011
6	14-10-2011	25-11-2011 - Precision Fair

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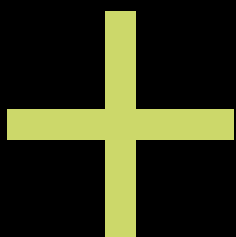


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