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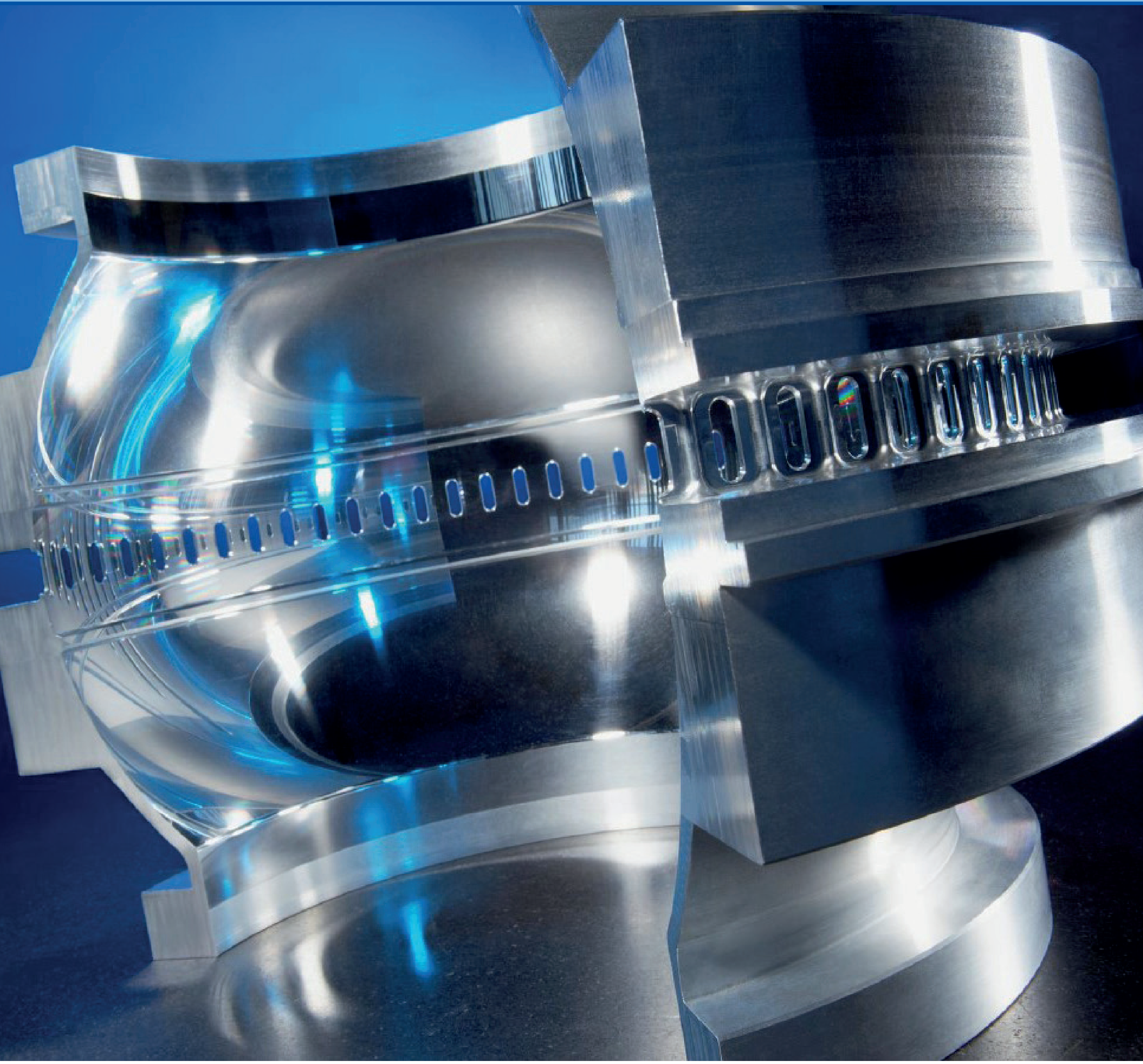

- THEME: HIGH-TECH SYSTEMS
- REDUCING VIBRATIONS IN ROBOTIC SYSTEMS
- CONTAMINATION CONTROL MINI-SYMPOSIUM REPORT
- HOW A COURSE PUSHED THE SYNCHROTRON COMMUNITY FORWARD

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Publisher
DSPE
Julie van Stiphout
High Tech Campus 1, 5656 AE Eindhoven
PO Box 80036, 5600 JW Eindhoven
info@dspe.nl, www.dspe.nl

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Editor
Hans van Eerden, hans.vaneerden@dspe.nl

Advertising canvasser
Gerrit Kulsdom, Sales & Services
+31 (0)229 – 211 211, gerrit@salesandservices.nl

Design and realisation
Drukkerij Snep, Eindhoven
+31 (0)40 – 251 99 29, info@snep.nl

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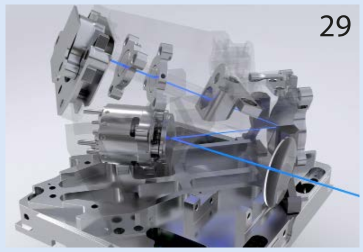
THEME: HIGH-TECH SYSTEMS



FEATURES

HOW TO STAY RELEVANT IN A FAST-CHANGING WORLD?

Recently, I returned to the Brainport region, back into the field of high-tech systems after spending seven years working in the Amsterdam region. I must admit, it feels really good to be back. Not that it has anything to do with a specific area, but I did come back with a different perspective on how we do things in this region.
I would not want to have missed the learnings I gained over those years in a different field of expertise (innovation & sustainability) and in a different type of companies (consultancy & software).

It's a common understanding that staying in one place, one ecosystem, or one company for too long can lead to tunnel vision. But stepping out of your comfort zone is scary and most people like predictability and stability, whether that's in their professional or their personal life.

If you do choose staying on your comfort zone path in life, there's one big pitfall: you forget to challenge yourself on how to stay relevant. Decades ago, this was not a major problem, because the world did not change that fast. Companies were able to uphold their business model for years and they grew by simply investing more budget in development and marketing. Thus, jobs and functions within these companies did not change that much and people got the chance to climb through the ranks or work in different departments.

However, the working landscape has evolved throughout my career. I've seen large companies go down, because they forgot to figure out how to stay relevant. Think of companies such as Nokia or car manufacturers in the US. But also Philips, which grew their business in for instance optical storage, until they couldn't anymore. Blown away by changing market needs.

How does this relate to the domain of high-tech systems and precision mechanics, you might ask. Well, let me give you an example. Vanderlande is transitioning from a company that designs, delivers and maintains 'moving steel parts' to a company that offers flexible solutions to move objects from one place to another in complex environments. Flexible, smart systems that incorporate more and more software. Their business model of selling 'tons of highly engineered steel' might need to change as well. Same applies to Philips, which only focuses on healthcare these days and makes more money on software (services) than it does on selling the complex hardware.

Don't get me wrong, the mechanical engineering will always fulfil a critical 'job to be done' in the world of tangible products and complex systems. Certain design principles remain steadfast and can provide solutions in diverse areas of engineering, beyond their initial applications. Examples are all over the place, such as small linear motors in optical drives and how that knowledge helped develop bigger and more precise linear actuators. The mechanisation of factories led to better high-tech systems, because the principles and ideas were scalable in terms of size. Thinking in parallel processes instead of serial production steps, offered huge advances in throughput. And keep in mind that engineering machines for 'low volume, high precision' offers different challenges compared to 'high volume, low price'.

My point: staying relevant as an engineer and understanding how your current knowledge is valuable in other application fields, is key if you want to have a career that still energises you after many years. Gain knowledge, share knowledge, venture out into other domains and applications, follow courses and always stay curious. That has been my mission in life so far and is also at the core of what Mikrocentrum aims to facilitate. Because we also need to understand how to stay relevant and continue to play a role in sharing, connecting and finding the right knowledge. We are at the heart of High Tech… and we will stay relevant.

Edwin de Zeeuw
Managing director Mikrocentrum
e.zeeuw@mikrocentrum.nl, www.mikrocentrum.nl

TRAJECTORY GENERATION OR INPUT SHAPING?

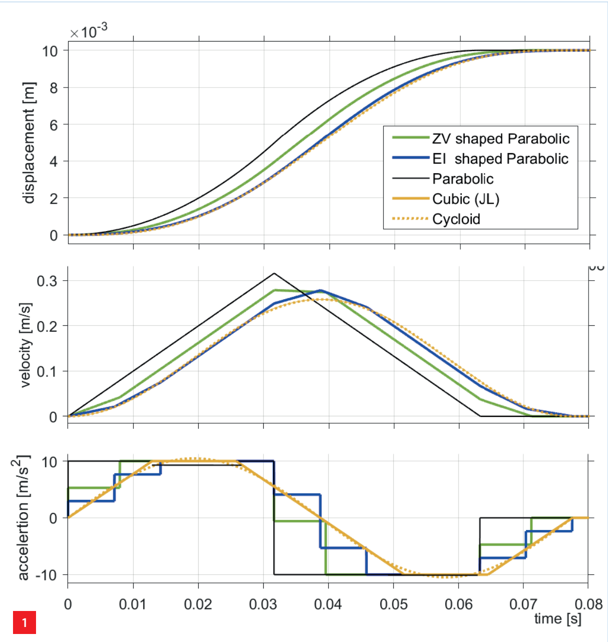
Input shaping can effectively reduce residual vibrations in flexible systems induced by the position trajectory. But misunderstanding of the implementation aspects and its use has led to limited applications in mechatronic systems, where the shaped reference trajectory could result in a reduced overall movement time. The main contribution of this article is a design method based on the relationship of the relative overshoot with the ratio of vibration time and move time. This allows the determination of the highest acceleration value that keeps accuracy within the desired range.

ROBBERT VAN DER KRUK AND AREND-JAN VAN NOORDEN

Introduction

Unwanted residual vibrations often limit the productivity of product handling by vacuum grippers or other suspended means. The pick & place actions in robotic systems often contribute the most to the vibration of the products to be handled. Input shaping provides a way to suppress the residual vibration frequency from the reference by shaping the spectral content of the motion profile by means of time-delay filters. Singer and Seering [1] created the framework of input shapers in the nineties.

For the control of cranes, the usefulness of input shaping is well known and implemented. However, a big knowledge gap is noted for applying input shaping to robotic systems. When robots have to operate in unknown environments, it is not sufficient to plan beforehand. They need to react to their sensors. In that case, a trajectory needs to be generated to execute the task within constraints such as maximum speed and acceleration, interpolating between waypoints to provide the reference position trajectory in real time. Trajectories for moving in a single direction, with constrained acceleration, are shown in Figure 1. We ignore the constant-velocity part of the trajectory, as it has limited effect on the dynamics and is not even reached for fast pick & place moves.



Acceleration-constrained comparison of parabolic, cubic, cycloid and ZV- and EI-input-shaped parabolic trajectories. ZV and EI stand for Zero Vibration and Extra Insensitive, respectively; see the text for explanation.

The topic of trajectory generation is related to the study of cam-shaft profiles [2], where cycloid profiles are widely used. Wim van der Hoek [3] introduced the $u_0(\tau)$ diagrams to clarify the relation between the relative overshoot u_0 and the relative vibration time τ. The objective was the design of lightweight and very stiff mechanisms in order to achieve high positional accuracy at high speeds.

Using Van der Hoek's notation, we define:

$$u_0 = \frac{\max|r - x(t)|}{r}, \quad t > T_m \tag{1}$$

$$\tau = \frac{T_d}{T_m} \tag{2}$$

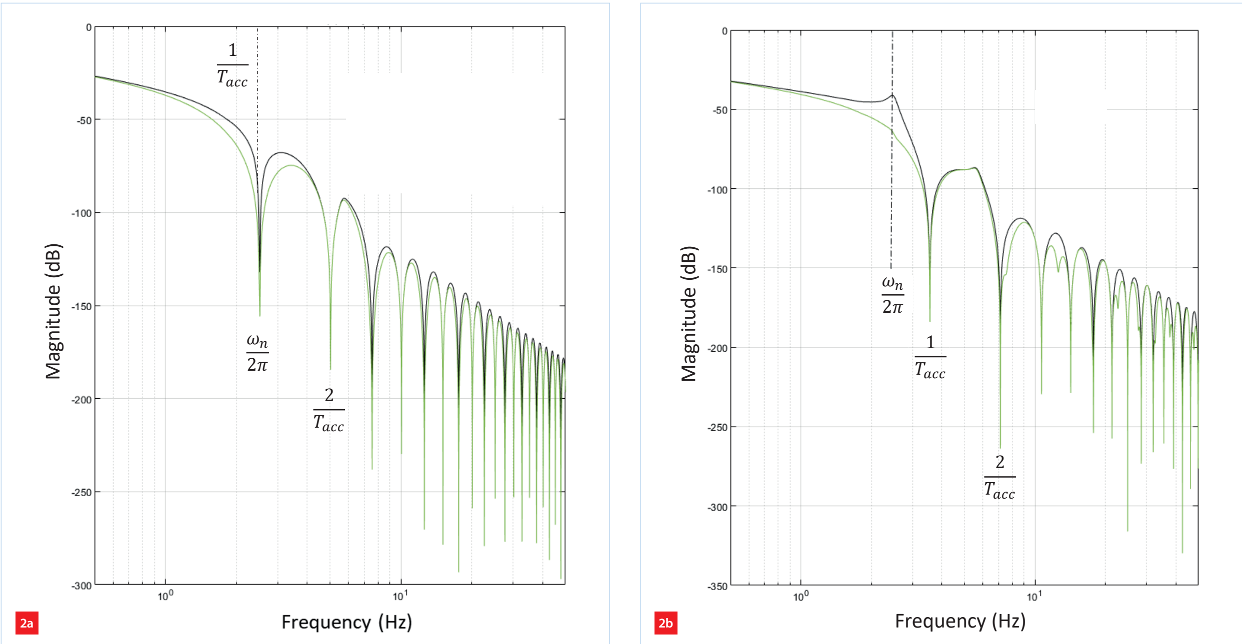
Here, $x(t)$ is the position of the object, r is the reference end position, T_d is the damped vibration time and T_m is the shaped reference move time.

In this paper, we use the $u_0(\tau)$ diagrams to relate overshoot to relative move time for selecting input-shaper methods and maximum acceleration. Trajectory profiles are commonly expressed in polynomials of second or higher order. It is usually concluded that their limited third derivative, or jerk, results in an attractive response as it approaches the cycloid; see Figure 1. However, the parabolic profile features the shortest move time. The parabolic

AUTHORS' NOTE

During the research described in this article, Robbert van der Kruk was a senior academic researcher in the Control Systems Technology group at Eindhoven University of Technology (TU/e) in Eindhoven (NL). He is a former R&D manager at Philips, ASML and Agilent Technologies. Arend-Jan van Noorden is a mechatronics engineer at ASML in Veldhoven (NL).

r.j.v.d.kruk@tue.nl
www.tue.nl/cst



Frequency responses of a robotically suctioned object excited by a parabolic (black) and ZV-input-shaped parabolic (green) trajectory, respectively.
(a) $\tau = 0.5$.
(b) $\tau = 0.7$.

and cubic, or jerk-limited (JL), trajectory profiles are available in most industrial digital motion controllers. The frequency response of the output x of the system excited by a (ZV-input-shaped) parabolic trajectory consists of sync pulses; see Figure 2 for an example.

The framework of input shapers was created in the time domain. For educational purposes, we will review input shapers and trajectory generation in both the time and the frequency domain (a detailed analysis is given in [4]). Typically, the main system excitation is not external but is generated by the trajectory itself. Some residual vibrations may exceed the error bounds and, therefore, affect the overshoot and settling performance. Figure 2 depicts the frequency spectrum of a flexible system excited by an unshaped and a shaped parabolic trajectory.

Input-shaping methods use superposition of delayed parts of the original profile such that the steady-state position equals the original end position. The residual vibration is suppressed by generating an input that cancels its own vibration. The simplest input shaper, the ZV (Zero Vibration) shaper, provides zero vibration at the desired frequency and consists of two impulses. The first impulse starts the system vibrating, the second impulse is delayed by a half period of the damped vibration, thereby cancelling it. The two parameters of the ZV shaper are the damped vibration period Td and the damping ratio ζ.

The Extra Insensitive (EI) method [1] uses an additional branch (a third pulse trailing the existing two ZV pulses) with a full delay of T_d. Unlike the ZV shaper, it does not attempt to force the vibration to zero. A small level of vibration is allowed at the modelling frequency, while enhancing the insensitivity to frequency modelling errors. The ZV shaper and its derivative(s) are made using a constraint that there should be zero vibrations at the desired frequency. The constraints of the shaper could be relaxed such that its residual vibration percentage remains below a tolerable vibration level specified by the designer. The EI shaper utilises this idea. The main advantage of relaxing these constraints is that a higher robustness can be achieved with the same time elongation of the shaped trajectory as with the ZVD (Zero Vibration Derivative) shaper. The large insensitivity of high-order EI shapers is rarely needed. The three parameters of the EI shaper are T_d, ζ and tolerable vibration level.

The jerk-limiting input shaper (JL) can be created by a Finite Impulse Response (FIR) filter applied to the parabolic trajectory or by direct generation of a trajectory. The JL shaper has only one parameter, the desired damped vibration period. The difference equations of these input shapers are given in [4].
Input shaping of the parabolic reference results in pulsed acceleration profiles for ZV and EI as shown in Figure 1. Notice here the difference with the smooth acceleration profile of the cycloid and the cubic profile. Input shaping of the trajectory is realised by a simple digital filter and can be used to process the acceleration, velocity or position data such that the implementation is independent of trajectory generation and control algorithms.

The frequency responses (Bode diagrams) of the input shapers are plotted in Figure 3. The magnitude plot shows

HOW A COURSE PUSHED THE SYNCHROTRON COMMUNITY FORWARD

Working as a particle accelerator engineer at Argonne National Laboratory, Curt Preissner ran into the limits of their design philosophy. Which is why he and a colleague took the Mechatronics system design – part 1 course at High Tech Institute (HTI). This allowed them to introduce a new design approach into the synchrotron community, and better talk to vendors. "You need to be able to communicate what keeps you up at night."

TOM CASSAUWERS

Curt Preissner is a mechanical engineer at the Advanced Photon Source (APS) at Argonne National Laboratory (see the text box). He is designing a very specific component in this synchrotron (Figure 1). "In a particle accelerator you accelerate electrons with the use of radio-frequency energy. They then oscillate back and forth between the north and south poles of magnets, which produces what we call synchrotron radiation. In our machine, that radiation is in the form of x-rays. The energy of the x-rays we produce ranges from a few keV all the way up to 100 keV, so it's highly penetrating. We take those x-rays and use something called a monochromator to select a particular wavelength."

AUTHOR'S NOTE

Tom Cassauwers is a freelance journalist and content writer from Belgium. This article was contributed by High Tech Institute, located in Eindhoven (NL).

www.hightechinstitute.nl

The instrument Preissner is designing is an x-ray microscope called the PtychoProbe. "This will be a unique, world-class instrument, and it will focus the x-rays down to five nanometers, which doesn't exist right now. So, it will be a world's first. The x-rays will be focused on the sample and are diffracted by it. The diffracted x-rays will then be collected by a detector, from which we process the data to generate an image that shows the structure of the sample."

1

The APS booster synchrotron. (Photo: R. Fenner, Argonne National Laboratory)

New engineering philosophy

Preissner and his colleagues realised that this new design, which demands high degrees of precision, would require them to adopt a new engineering philosophy. "The specifications we work with can be very challenging", says Preissner. "Generally, our system is static. Yet on the side of the beamline, things are moving. We have to scan our samples in a different way because the new beams are much brighter. This brightness will allow us to see our samples in greater detail."

However, the high photon flux can actually damage the sample. "So, we want to do this quickly. We don't need to work as fast as some semiconductor manufacturing equipment. We scan around seven millimeters per second, which aren't extremely high velocities. But for what we're used to, this is quite high. The sample and the x-ray lens, called the zone plate, also need to maintain registration on the order of 1.25 nm. That's pretty tight. We do that over length scales of about 10 mm. This is new territory for us. Which is why we're looking for new engineering approaches to achieve this."

Integrated approach

After some research, they realised that mechatronics could offer an answer. "We first started in the synchrotron community, which isn't that big", explains Preissner. "There are a countable number of synchrotron instrumentation engineers, probably around a few hundred, less than a few thousand for sure. The community is not that big. So, when we didn't find the answers we were looking for, we started

Advanced Photon Source

The Advanced Photon Source (APS, Figure 2) at the U.S. Department of Energy's Argonne National Laboratory in Lemont (Illinois) provides ultra-bright, high-energy storage-ring-generated x-ray beams for research in almost all scientific disciplines. These x-rays allow scientists to pursue new knowledge about the structure and function of materials in the centre of the Earth, in outer space, and all points in between; for example, to make images of the nanostructure of materials.

Currently, the APS is undergoing a comprehensive upgrade to replace its original electron storage ring with a new, state-of-the-art accelerator. This will increase the brightness of APS x-ray beams by up to 500 times, and new beamlines will be constructed to take advantage of these improved capabilities.

2

The Advanced Photon Source location at Argonne National Laboratory. (Photo: R. Fenner, Argonne National Laboratory)

WWW.APS.ANL.GOV

3

Curt Preissner is a mechanical engineer at the Advanced Photon Source: "The instrument I'm designing will need to be scientifically productive for at least the next ten years. A mechatronic approach is very interesting here. It's great to think about things like error budgetting and dynamic models from the get-go. It's a more integrated approach." (Photo: Mark Lopez, Argonne National Laboratory)

researching other fields with similar performance specifications. This is how we ended up with semiconductor manufacturing equipment, and in turn the mechatronics approach."

This approach, while common in some fields, is new to the synchrotron community. Mechatronics, however, might be what they need to keep pushing the technology forward. "In the last generation of instruments, ten to fifteen years ago it wasn't uncommon for a mechanical engineer to sit down with a beamline scientist and just design the mechanics, connect a motion controller, maybe some interferometry, and achieve results that got the scientific job done. The only consideration to dynamics in the design was vibrations, and there was certainly no system-level approach."

But now the advancements in the accelerator and x-ray optics technology are really forcing synchrotron instrumentation engineers at APS to push the limits of what they can do. "That old approach will not work. We need to look ahead; science does not allow us to stand still. The instrument I'm designing will need to be scientifically productive for at least the next ten years. A mechatronic approach is very interesting here. It's great to think about things like error budgetting and dynamic models from the get-go. It's a more integrated approach."

Ending up in the Netherlands

Which is how Preissner and a colleague ended up in the Netherlands taking the Mechatronics system design (metron) – part 1 course at High Tech Institute in Eindhoven. For them it was the ideal way of being quickly plunged into the field. "At the APS we don't always have the luxury to be able to do a huge amount of R&D. We're in a time crunch with this project. We need to gain knowledge fast, so we can work with vendors or do our own design. If you look at for example the wafer scanners of ASML, their performance is very impressive. But an important thing to remember is that there's roughly forty years of development behind them. When we're designing these instruments, we don't have that time. We need to learn as fast as possible."

Vendors

One important thing they learned in the course was a new type of language, which allowed them to better speak to their vendors. "We're not just going out and buying something", says Preissner. "We're proposing things, and deciding whether a vendor can make certain designs. So, knowing techniques like error budgetting is important, besides being able to look at designs with a mechatronics view. Getting some formal training accelerated our ability to talk to vendors. There are certain key issues in this design that keep me up at night, and we need to be able to