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

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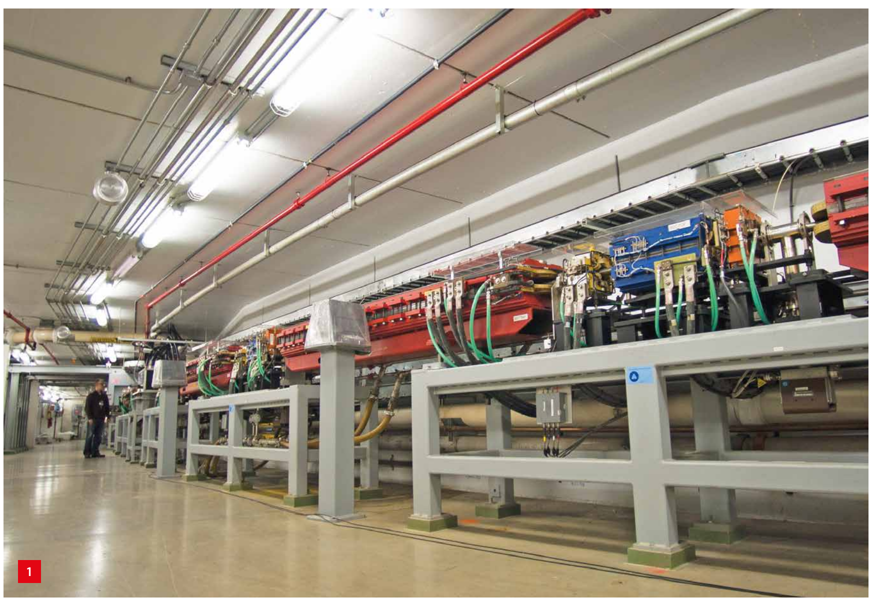
The instrument Preissner is designing is an x-ray microscope called the PtychoProbe. "This will be a unique, world-class instrument, and it will focus the x-rays down to five nanometers, which doesn't exist right now. So, it will be a world's first. The x-rays will be focused on the sample and are diffracted 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."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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.

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

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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

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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)

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 communicate that. After the course, I could go to a vendor and ask them to, for example, show us their error budget. Or I could talk to them about the controller dynamics overlaid with the mechanics dynamics."

Short timeframe

The course taught them this in a short timeframe. This is important for an engineer like Preissner, who is working on a time-sensitive project for a government-funded organisation. "We're under a high amount of pressure, so we were eager to learn, and did so quite fast. We looked hard for a course that could quickly package this knowledge for us. APS is also a government institution, so we're using tax dollars. We need to be mindful of how we spend them. We're always looking at ways to achieve goals in an effective manner, and this course taught us what we needed to know very efficiently."

All of this is a work in progress according to Preissner. "The synchrotron engineering community has been operating in a certain way for a long time. But now people realise that we need to do things differently. This course enabled us to take that different approach."

Model in a holistic way?

So far, the new mechatronics knowledge has mainly been used in contacts with vendors. But Preissner notes that going forward, they want to also use it to design new instruments from the ground up. "It's on the drawing board", he says. "We're wondering if we can take this new approach, and apply it in a more systematic way. Can we model the instrument, the control system model and the influences in a holistic way? What knobs do we need to turn? What control approach would make sense?"

For now, however, Preissner and his colleagues want to expand their knowledge of mechatronics. They're already looking forward to taking more courses. "If you don't use it, you lose it. So, we're feeling some pressure to apply what we learned as regularly as possible. The first part of the training was good, and now we're thinking about taking additional courses. When you learn new engineering techniques it takes a bit of time. You have to work with it. It has already changed our vendor interactions. The next step will be changing our own designs from the ground up."

Mechatronics system design – part 1

The course focuses on the essential basics in any multidisciplinary development of a mechatronic (motion) system, and is intended for architects, designers, engineers and project leaders with varying technical background. It is ECP²-certified (see page 28).

Contents:
- General introduction & introduction course project
- Basic modelling of motion systems
- Basic control
- Design principles (degrees of freedom, kinematic constraints, flexures)
- Electromechanics / motor selection
- Humanware (leadership development, feedback)
- Sensors & metrology
- 4th-order system
- Fundamentals of (digital) motion control
- Course project

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