The European XFEL X-ray laser is installed in a facility with a total length of 3.4 km, located mainly in underground tunnels.

PC-based Motion Control in a superconducting electron linear accelerator

High-precision, ultra-dynamic drive control for European XFEL X-ray laser

An exciting new research facility is currently under construction in the Hamburg metropolitan region. Opening in 2017, the center will house the European XFEL X-ray laser, an apparatus generating ultra-short X-ray flashes – 27,000 times per second – with a brilliance that is a billion times higher than that of current conventional X-ray radiation sources. PC-based control and drive technology from Beckhoff is used to position a total of 91 special high-precision magnet assemblies (undulators) of the underlying electron accelerator.

Dr. Suren Karabekyan (left), research assistant at the European XFEL, explains the finer physical details of the undulator to Nils Burandt from the Beckhoff branch in Lübeck.

With its laser-like X-ray flashes, the European XFEL X-ray laser will open up completely new fields of research, enabling such features as three-dimensional nanoworld images, deciphering atomic details of viruses and cells, and examination of ultra-fast chemical reactions. The facility encompasses a total length of 3.4 km, located mainly in underground tunnels, and will be operated by the independent research organization European XFEL, Hamburg. It will be available for experiments to research teams from all over the world. Currently, it is built up by eleven countries: Denmark, Germany, France, Italy, Poland, Russia, Sweden, Switzerland, Slovakia, Spain and Hungary.

A special feature of European XFEL is the very high repetition rate of 27,000 X-ray flashes per second, facilitated by the superconducting accelerator technology. The flashes have a wavelength of 0.05 to 6 nm, which is so short that even atomic details become visible. Thanks to a time duration of less than 100 femtoseconds (1 fs = 10-15 s), it will even be possible to record the formation of molecules or the reversal of magnetizations. The laser light properties will enable 3D images at the atomic level.

X-ray flashes of accelerated electrons

The starting point for the formation of the X-ray flashes is a 1.7 km long, superconducting linear electron accelerator. Within, electron packets are accelerated to a high-energy state, nearly reaching the speed of light. The acceleration takes place in specially shaped voids, called "resonators". These provide superconduction and enable a very narrow and uniform electron beam, as required by an X-ray laser.

The accelerated electrons then speed through undulators – special magnet assemblies which force the particles through a tight slalom course. The electrons emit X-ray light, which is amplified further due to the interaction of the light with the electrons. Since light propagates faster than the electrons, the light "overtakes" the particles and affects them in this process. Some electrons are accelerated, others are decelerated, and as a result, the electrons form a multitude of thin discs. All electrons within a disc now radiate synchronously, resulting in ultra-short, intense X-ray flashes, which have properties similar to laser light.

To make this principle of self-amplified spontaneous emission (SASE) work, undulator systems consist of several devices, each located behind the accelerator in a fan-shaped array. The European XFEL will initially feature three undulator systems – SASE 1 and 2, each with 35 undulator cells, and SASE 3 with 21 cells. The total length of all undulator systems is 555.1 m.

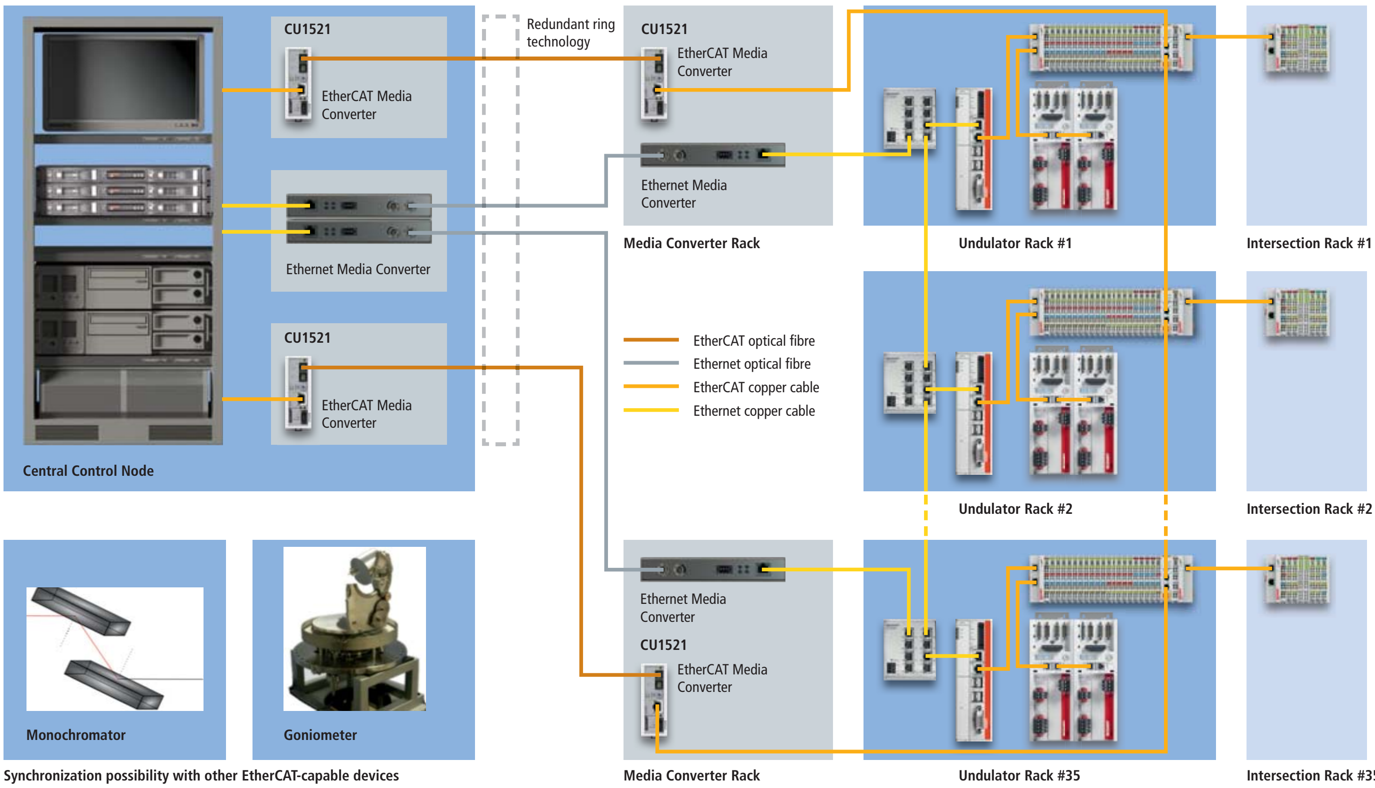
PC-based Motion Control provides precise undulator control

An undulator consists of two magnet structures and the distance between which – at constant energy of the accelerated electrons – ultimately determines the wavelength of the laser light. This makes the drive control very demanding, as Dr. Suren Karabekyan, a research associate with European XFEL, explains: "Two servomotors are used to move each of the two magnet structures. The control process has to be highly synchronized, in order to avoid a phase shift between the electron and photon bundles. This is a critical requirement for the spectrum raster experiments that we will conduct, and the sequence error must be less than 1 µm. In addition, repeatability of ±1 µm must be ensured with respect to the distance of the magnet structures, as this guarantees a high reproducibility of the magnetic field strength and therefore the photon wavelength. The intention was to meet these highly demanding requirements using a standard industrial automation system. After an evaluation phase lasting several months, the PC-based control and drive technology from Beckhoff emerged as the ideal candidate."

The high-performance TwinCAT software with integrated Motion Control functions offers a wealth of benefits, as Dr. Suren Karabekyan explains: "TwinCAT enables the implementation of a high-precision, very dynamic drive control

Each of the 91 undulator cells is controlled via PC-based control. The system features a C6925 control cabinet PC (right), numerous EtherCAT Terminals (center), and two AX5206 Servo Drives (left).

A total of four AM3052 servomotors per undulator cell – controlled via TwinCAT NC PTP – ensure that the magnet structures are precisely positioned. (The image shows the two motors of the upper magnet structure)



Configuration of the control technology for an undulator section

system, with the possibility to exactly synchronize several axes. The high synchronicity requirements can even be met for our long undulator systems with up to 35 cells. The demands for undulator control within an SASE section are also very stringent. This is because experiments for measuring the photon energy 'on the fly' require maximum synchronization of the magnet structure distance for all undulators within a section. A prime example for this is the 'Kinetic Rain' project at Changi airport in Singapore, in which more than 1200 servo axes are synchronized and controlled via TwinCAT. We are currently working on this, with dedicated support from the Beckhoff experts."

Large number of undulator cells necessitates complex automation system

The SASE undulator sections are each controlled using a C5210 19-inch slide-in Industrial PC. They are networked via an EtherCAT ring topology with cable redundancy. Fiber optic cables are used due to the tunnel being several kilometers in length. In addition, the undulator cells in each SASE section are linked with each other via Ethernet in the form of a daisy-chain system. In each undulator cell, a C6925 control cabinet PC is used, controlling the two AX5206 Servo Drives for the four AM3052 servomotors via TwinCAT NC PTP. The IPC also controls three stepper motors – two for a quadrupole mover and one for a phase shifter. The phase shifter motor runs synchronous to the Servo Drives and corrects the phase of the electron and photons packets between the individual undulator cells. The required I/O data is provided with 35 EtherCAT Terminals per undulator cell, digital and analog I/O's, as well as pulse train, encoder, and bridge terminals. Overall, the PC-based control solution therefore comprises three C5210 19-inch slide-in Industrial PCs, 91 C6925 control cabinet PCs, 182 AX5206 Servo Drives, 364 AM3052 servomotors, and approximately 3200 EtherCAT Terminals.

According to Dr. Suren Karabekyan, the result is a compact and powerful control system for the 91 undulator cells: "The fanless C6925 control cabinet PC is very compact. It was the smallest unit we could find with adequate computing power for dealing with all the control tasks within an undulator cell. These operations include high-precision synchronization between the master and slave axes for controlling the magnet structures, and exact synchronization of the phase shifter with respect to the changes in magnet distances. Further benefits result from the system-integrated safety technology offered by the AX5801 TwinSAFE option card of the AX5206 Servo Drives, used to implement the STO and SS1 safety functions. This high-performance control and drive technology is capable of positioning heavy components such as the undulator magnet structures in conjunction with the high magnetic forces (approx. 100,000 N = 10 t), or the quadrupole movers weighing around 60 kg ensuring µm precision."

Dr. Suren Karabekyan summarizes: "EtherCAT communication is a key component of our facility. It enables us to configure a very robust and reliable control system with redundant ring topology, even in a large installation such as ours. Overall, it is a very cost-effective solution, which is particularly important in the context of research projects funded via public institutions. Furthermore, we got always optimal support from the Beckhoff experts at any time."

Further information:
www.xfel.eu
www.beckhoff.com/motion