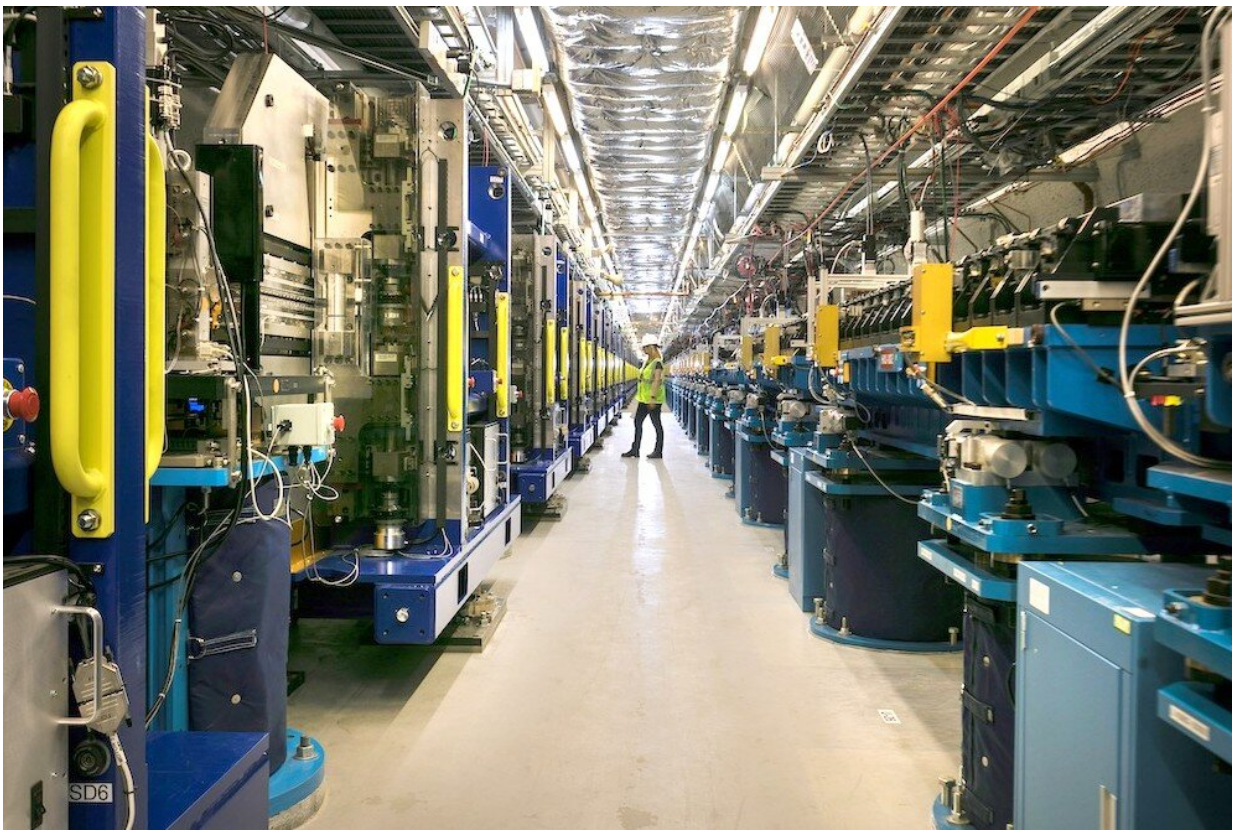
SLAC's upgraded X-ray laser facility produces first light

July 20 2020, by Glenn Roberts Jr.



A worker inspects the soft X-ray undulator at SLAC National Accelerator Laboratory. The hard X-ray undulator is visible at right. (Credit: SLAC National Accelerator Laboratory)

Just over a decade ago in April 2009, the world's first hard X-ray free-

electron laser (XFEL) produced its first light at the U.S. Department of Energy's SLAC National Accelerator Laboratory. The Linac Coherent Light Source (LCLS) generated X-ray pulses a billion times brighter than anything that had come before. Since then, its performance has enabled fundamental new insights in a number of scientific fields, from creating "molecular movies" of chemistry in action to studying the structure and motion of proteins for new generations of pharmaceuticals and replicating the processes that create "diamond rain" within giant planets in our solar system.

The next major step in this field was set in motion in 2013, launching the LCLS-II upgrade project to increase the X-ray laser's power by thousands of times, producing a million pulses per second compared to 120 per second today. This upgrade is due to be completed within the next two years, and the DOE's Lawrence Berkeley National Laboratory (Berkeley Lab) is among a group of collaborators that have made major contributions.

Today, the first phase of the upgrade came into operation, producing an X-ray beam for the first time using one critical element of the newly installed equipment.

"The LCLS-II project represents the combined effort of five national laboratories from across the U.S., along with many colleagues from the university community and DOE," said Chi-Chang Kao, director of SLAC. "Today's success reflects the tremendous value of ongoing partnerships and collaboration that enable us to build unique world-leading tools and capabilities."

XFELs work in a two-step process. First, they accelerate a powerful electron beam to nearly the speed of light. They then pass this beam through an exquisitely tuned series of magnets within a device known as an undulator, which converts the electron energy into intense bursts of X-

rays. The bursts are just millionths of a billionth of a second long—so short that they can capture the birth of a chemical bond and produce images with atomic resolution.

The LCLS-II project will transform both elements of the facility—by installing an entirely new accelerator that uses cryogenic superconducting technology to achieve the unprecedented repetition rate in a free-electron laser, along with undulators that can provide exquisite control of the X-ray beam.

In addition to overseeing the construction and delivery of all of the "hard," or higher-energy X-ray undulator segments that enabled the latest milestone, Berkeley Lab is also making several other contributions to the LCLS-II project.

Berkeley Lab has designed and overseen the construction and delivery of the undulators for the lower-energy "soft" X-ray beamline; designed, built, and delivered the high-brightness injector source that provides the electron beam; and is collaboratively leading the development of hardware and software for the low-level radiofrequency (LLRF) control system that helps to control the superconducting accelerator that is a part of the soft X-ray line. And Berkeley Lab anticipates a role in the LCLS-II High Energy upgrade project, which will double the electron energy of the hard X-ray accelerator.

Powerful and precise

Over the past 18 months, the original LCLS undulator was removed and replaced with two new systems that offer dramatic new capabilities. Each of these undulator lines contains thousands of permanent magnets and stretches over 100 meters; together they create magnetic fields that are tens of thousands of times stronger than the Earth's. This generates forces equivalent to a few tons of weight while maintaining the rigidity

of the structure that holds the magnets within a hundredth of the width of a human hair.

The new hard X-ray undulators were prototyped by DOE's Argonne National Laboratory, designed by Argonne and Berkeley labs, built by Berkeley Lab, and have been installed at SLAC over the past year. Soft and hard X-rays can probe different sample types and properties. The LCLS-II soft X-ray undulator, driven by the superconducting accelerator, hasn't yet been tested.

Today, the hard X-ray system demonstrated its performance in readiness for the experimental campaigns ahead. Scientists in the SLAC Accelerator Control Room directed the electron beam from the existing LCLS accelerator through the array of magnets in the undulator.

Over the course of just a few hours, they produced the first sign of X-rays, and then precisely tuned the configuration to achieve full X-ray laser performance with the available undulator segments. Most of the hard X-ray undulator segments have been installed, and the remaining segments are scheduled for delivery and installation in the coming month.

"Reaching the first light is a milestone we all have been looking forward to," said Henrik von der Lippe, Engineering Division director at Berkeley Lab. "This milestone shows how all the hard work and collaboration has resulted in a scientific facility that will enable new science."

He added, "Berkeley Lab's contribution of the hard X-ray undulator design and fabrication used our experience from providing undulators to science facilities and our longstanding strength in mechanical design. It is rewarding to see the fruits from years of dedicated Engineering Division teams delivering devices that meet all expectations."

Thomas Schenkel, interim director of Berkeley Lab's Accelerator Technology and Applied Physics Division, said, "This is a great example of how our scientific foundation and engineering expertise come together." He added, "The Lab has decades of experience designing and building some of the most advanced undulators of their times, and we look forward to continuing to contribute to the DOE research complex in this way."

The scientific impact of the new undulators will be significant. One major advance is that the separation between the magnets can be changed on demand, allowing the wavelength of the emitted X-rays to be tuned to match the needs of experiments. Researchers can use this to pinpoint the behavior of selected atoms in a molecule, which among other things will enhance our ability to track the flow and storage of energy for advanced solar power applications.

The undulator demonstrated today will be able to double the LCLS' peak X-ray energy. This will provide much higher-precision insights into how materials respond to extreme stress at the atomic level and into the emergence of novel quantum phenomena.

The "noodle": A unique, challenging undulator design

The completed hard X-ray undulator will have 32 segments. Each segment weighs 2.3 tons and is about 13 feet long. The design of the hard X-ray undulator segments is unique because it essentially rotates the traditional undulator design 90 degrees, which also posed unique engineering challenges.

To fit inside the undulator tunnel at SLAC, the undulator segments had to be much thinner than usual—Berkeley Lab engineers dubbed the design the "noodle." This design also made the steel support, or strongback, containing the many magnets in each unduluator segment

more subject to unwanted bending due to the roughly 4 tons of magnetic force they must withstand.

The unique, rotated design of the undulators required an array of about 150 springs per undulator segment that can be precisely adjusted to keep the hundreds of magnets in alignment.

But even small temperature changes, and simple machining such as bolting on new components, altered the strongback support structures beyond what was allowed—the devices had to remain straight to within 10 millionths of a meter.

So the early design of the segments had to be completely rethought, said Matthaeus Leitner, Berkeley Lab's lead engineer for the LCLS-II undulators.

"For a long time we didn't quite have a solution," Leitner said. "We basically had to change each individual component of the device. This was a team effort by highly skilled engineers and technicians."

John Corlett, who has served as Berkeley Lab's senior team lead on the LCLS-II project and is now Lab Project Management Officer, said, "This was a very challenging mechanical engineering problem. It was a collaborative effort between SLAC, Berkeley, and Argonne labs working together. We held a number of workshops, and we worked together to solve problems. It's fantastic that we succeeded in doing this in the very short time frame needed by the project."

Leitner added, "A big strongpoint at Berkeley Lab is the array of engineering resources. If a problem comes up, we can immediately put a lot of resources into solving a problem. We could solve this seemingly insurmountable issue within a couple of months. This was incredible. It was only possible because we have large-scale tooling, precision

measurement devices, and excellent engineering support equipment."

There was also a substantial effort by Berkeley Lab engineers to work with and train the three vendors that manufactured and assembled the undulators. Berkeley Lab utilized its magnetic design and measurement capabilities, and developed precise methods to assemble and to efficiently tune the undulators.

The uniquely rotated design of the hard X-ray undulators will ultimately improve the X-ray laser's performance by delivering more X-rays to samples in experiments, Leitner noted. "It gives you a significant boost in the available output power of the hard X-rays," he said.

Leitner and Corlett said that the design, known as vertical polarization, will likely be adopted by other X-ray free-electron lasers and light sources now that the design challenges for the capability have been worked out.

"This has never been done before," Corlett said.

Next steps

Beyond the undulators lies the Front End Enclosure, or FEE, which contains an array of optics, diagnostics, and tuning devices that prepare the X-rays for specific experiments. These include the world's flattest, smoothest mirrors that are a meter in length but vary in height by only an atom's width across their surface. Over the next few weeks, these optics will be tested in preparation for more than 80 experiments to be conducted by researchers from around the world over the next six months.

"Today marks the start of the LCLS-II era for X-ray science," said Mike Dunne, LCLS director. "Our immediate task will be to use this new

undulator to investigate the inner workings of the SARS-CoV-2 virus. Then the next couple of years will see an amazing transformation of our facility. Next up will be the soft X-ray undulator, optimized for studying how energy flows between atoms and molecules, and thus the inner workings of novel energy technologies. Beyond this will be the new superconducting accelerator that will increase our X-ray power by many thousands of times."

He added, "The future is bright, as we like to say in the X-ray laser world."

Provided by Lawrence Berkeley National Laboratory

Citation: SLAC's upgraded X-ray laser facility produces first light (2020, July 20) retrieved 22 September 2024 from https://phys.org/news/2020-07-slac-x-ray-laser-facility.html