New prototypes for superconducting undulators show promise for more powerful, versatile X-ray beams

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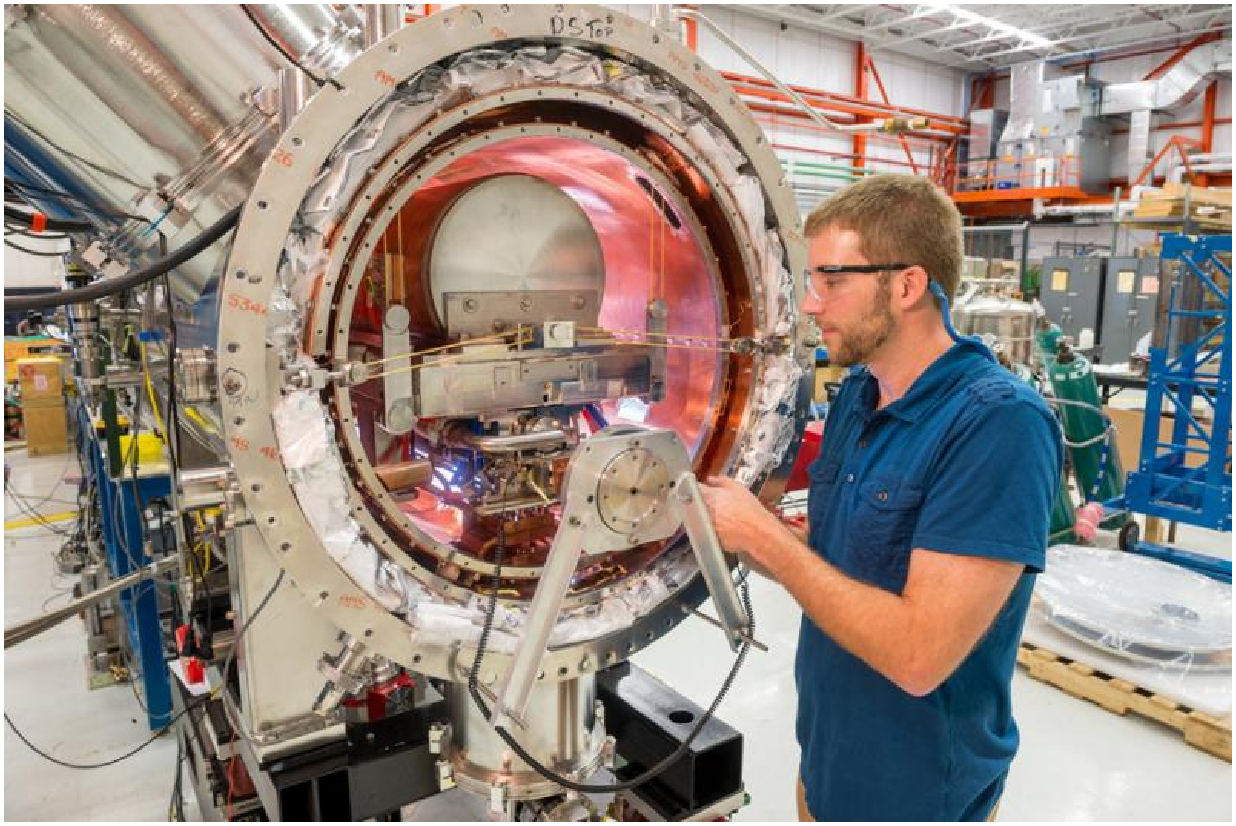

Argonne and Berkeley national laboratories have collaborated to design, build and test two superconducting undulator devices that could make X-ray lasers more powerful, versatile, compact and durable. Above: Argonne Accelerator Systems Division engineer Matt Kasa checks the instrumentation of the undulator. Credit: Argonne National Laboratory

Researchers at the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) and Argonne National Laboratory have collaborated to design, build and test two devices that utilize different superconducting materials and could make X-ray lasers more powerful, versatile, compact and durable.

These prototype devices, called superconducting undulators (SCUs), successfully produced stronger magnetic fields than conventional permanent magnetic undulators of the same size. These fields, in turn, can produce higher-energy laser light to open up a broader range of experiments.

Several large-scale X-ray lasers are in the works around the globe to allow scientists to probe the properties of matter at ever smaller and faster scales, and superconducting undulators are considered among the most enabling technologies for the next generation of these and other types of light sources.

Such light sources are powerful tools for studying the microscopic structure and other properties of samples, such as proteins that are key to drug design, exotic materials relevant to electronics and energy applications, and chemistry that is central to industrial processes like fuel production.

The recent development effort was motivated by SLAC National Accelerator Laboratory's upgrade of its Linac Coherent Light Source (LCLS), which is the nation's only X-ray free-electron laser (FEL). The new project, now underway, is known as LCLS-II.

X-ray FELs now use permanent magnetic undulators to produce X-ray light by wiggling high-energy bunches of electrons in alternating magnetic fields produced by a sequence of permanent magnets.

But for the first time, Argonne scientists have demonstrated that a superconducting undulator could be used as a free-electron laser amplifier for the contemporary X-ray FELs.

The team at the Department of Energy's Advanced Photon Source (APS) at Argonne successfully built and tested a 1.5-meter-long prototype SCU magnet designed to meet FEL undulator requirements. This SCU utilizes niobium-titanium superconducting wire for winding its magnetic coils.

This significant achievement could pave the way to expanding the X-ray energy range at existing light sources without increasing the electron beam energy. This is an important point because the construction cost of light facilities is mainly defined by the energy of the electron beam, said Efim Gluskin, an Argonne Distinguished Fellow and a physicist and interim group leader of the Magnetic Devices Group in the APS's Accelerator Systems Division.

Gluskin said the niobium-titanium-based SCU has been designed to meet all challenging technical requirements applied to the X-ray FEL undulator, including high-precision field quality and consistency all along the magnet. In fact, it has been experimentally proven that this device has met all of these requirements. The APS SCU team has used in-house-developed cryogenic systems and magnetic measurement techniques to validate the SCU performance.

"The main challenge is to maintain the consistent wiggle motion of electrons inside of an SCU," said Gluskin, adding that the range of accepted deviation from the straight line of the beam motion across the distance of several meters is just a few microns. For comparison, an average human hair is 100 microns wide.

"That leads to very stringent requirements on the quality of the magnetic field generated by SCU magnets," Gluskin said.

SLAC's Paul Emma, the accelerator physics lead for the LCLS-II upgrade project coordinated the superconducting undulator development effort.

"With superconducting undulators," Emma said, "you don't necessarily lower the cost but you get better performance for the same stretch of undulator."

A superconducting undulator equivalent in length to a permanent magnetic undulator could produce light that is at least two to three times and perhaps up to 10 times more powerful, and could also access a wider range in X-ray wavelengths, Emma said. This produces a more efficient FEL.

Superconducting undulators have no macroscopic moving parts, so they could conceivably be tuned more quickly with high precision. Superconductors also are far less prone to damage by high-intensity radiation than permanent-magnet materials, a significant issue in high-power accelerators such as those that will be installed for LCLS-II.

There appears to be a clear path forward to developing superconducting undulators for upgrades of existing and new X-ray free-electron lasers, Emma said, and for other types of light sources.

"Superconducting undulators will be the technology we go to eventually, whether it's in the next 10 or 20 years," he said. "They are powerful enough to produce the light we are going to need – I think it's going to happen. People know it's a big enough step, and we've got to get there."

In this case, the APS team developed the technology of SCU construction to deliver a ready-to-go device right off the assembly bench.

"The SCU team found unique solutions for making this undulator performance within strict specifications of the LCLS undulator system," said Yury Ivanyushenkov, a physicist with the Argonne Accelerator Systems Division. "Over the years, the SCU team has put together a robust set of technological steps and processes to design and build state-of-the-art superconducting undulators that successfully operate at the APS. The success of this project is the direct result of the systems and facilities in place at the APS."

Geoffrey Pile, Associate Division Director of the APS Engineering Support Division at Argonne and former director of the APS LCLS-I undulator project, said the APS has a long history and expertise with designing and constructing undulators for the APS and other national labs.

One of the Argonne projects was the design and construction of the LCLS-I undulator system – 440 feet of sophisticated technical components that incorporated 33 cutting-edge undulators. The LCLS-I facility at the SLAC National Accelerator Laboratory has now been operating successfully for more than seven years.

In addition, APS scientists and engineers recently designed and built a revolutionary new Horizontal-Gap Vertically Polarizing Undulator prototype for the LCLS-II project. It was adopted and incorporated into the LCLS-II final design, and 32 production units will be constructed for SLAC by Lawrence Berkeley National Laboratory and industrial partners.

"For the past couple of decades, the APS engineering team has been constructing undulators for use at Argonne and across the country, and the SCU may be the most challenging project so far," Pile said. "It has moved the technology forward in leaps and bounds and highlights the expertise throughout the APS. Importantly, many industrial partners, people at Argonne, and our collaborators at SLAC and Berkeley contributed to the success of this project and deserve credit."

Gluskin agreed: "The development of this prototype is a culmination of more than a decade of Argonne commitments to new and innovative SCU technology that will benefit all DOE light sources."

Provided by Argonne National Laboratory

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