Linear accelerator could improve X-rays, particle colliders

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One drizzly morning in September, a giant metal tube painted Cornell red was loaded on a truck at the Wilson Synchrotron Laboratory annex to make a slow, steady journey across campus.

The 32-foot metal canister, which arrived without incident at a Newman Hall basement workspace, is the vacuum chamber for a cutting-edge, Cornell-developed linear accelerator that could provide particle beams for a wide range of science: elementary particle physics, material and biological sciences, and semiconductor lithography. It could also one day offer the brightest X-ray beams the world has ever seen.

Scientists at the Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE), supported by the National Science Foundation, have been working for the last decade on research and development of an Energy Recovery Linac (ERL) as a new X-ray light source. The research program has led to the creation of the particle accelerator, which offers a wide range of applications beyond the ERL.

With all accelerating components now assembled, and united with their vacuum chamber, the researchers are busy outfitting the accelerator with controls, sensors and other machinery for experimentation.

Because of the accelerator's high efficiency, it can accelerate particles continuously and provide an uninterrupted beam of electrons. It is this characteristic that could lead to many applications, including use for an ERL.

The accelerator produces a very dense beam of electrons accelerated to near the speed of light and characterized by extreme brightness, which is a measure of how tightly the beam is packed together. The extreme density and continuity of the electron beam means it can give off light like a laser, as opposed to a light bulb. If used for X-ray science, the X-ray beams could provide atomic-resolution investigations, such as origination of cracks in hard materials, or the crystal structure of proteins. Or, extremely intense ultraviolet light from the X-rays could be used for lithography of small integrated circuits.

"You can take this tightly focused electron beam and produce a tightly focused X-ray beam," said Georg Hoffstaetter, professor of physics and ERL principal investigator. "And just like X-rays penetrate your body, this tightly focused beam can penetrate all types of matter."

An ERL would also be a "green" accelerator. First theorized by Maury Tigner, Cornell's Hans Bethe Professor of Physics Emeritus, an ERL improves efficiency through an innovative reclamation and re-use of the energy initially used to accelerate the electron beams.

"We've been working very hard to improve the energy efficiency of these devices," said Ritchie Patterson, director of CLASSE. "We've reached goals people around the world thought were hopeless."

The prototype module in Newman basement has taken two years to build. Inside the red canister are six beam-accelerating structures, called superconducting radiofrequency cavities (SRF cavities) to be cooled to 2 Kelvin (-456 degrees Fahrenheit) in a bath of liquid helium. Sitting horizontally, these seven-cell cavities embody some of the key technological breakthroughs by Cornell scientists over the course of the ERL project.

To be accelerated, the electron beam passes through the specially designed SRFs. The electric fields inside the cavities oscillate a billion times per second and allow current to flow almost unrestricted, reducing energy loss – wasted energy – by a factor of a million compared to conventional accelerators, according to Matthias Liepe, associate professor of physics. The ERL design is an extremely efficient way of accelerating a very high-quality electron beam.

"The cryomodule can support a factor of 10 higher average currents than anyone has done before in a linear accelerator," Liepe added.

In the last several years, accelerator physics has pushed toward using ERL technologies like Cornell's not only for X-ray light sources, but for anything from nuclear physics to particle colliders, said Ralf Eichhorn, crymodule project manager and a visiting professor of physics. In fact, an upgrade to SLAC National Accelerator Laboratory's free electron laser is using fundamental technology provided by the ERL team at Cornell.

"This is a technology you can apply to different accelerator complexes," Eichhorn said.

Provided by Cornell University

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