From turkeys to turn-keys

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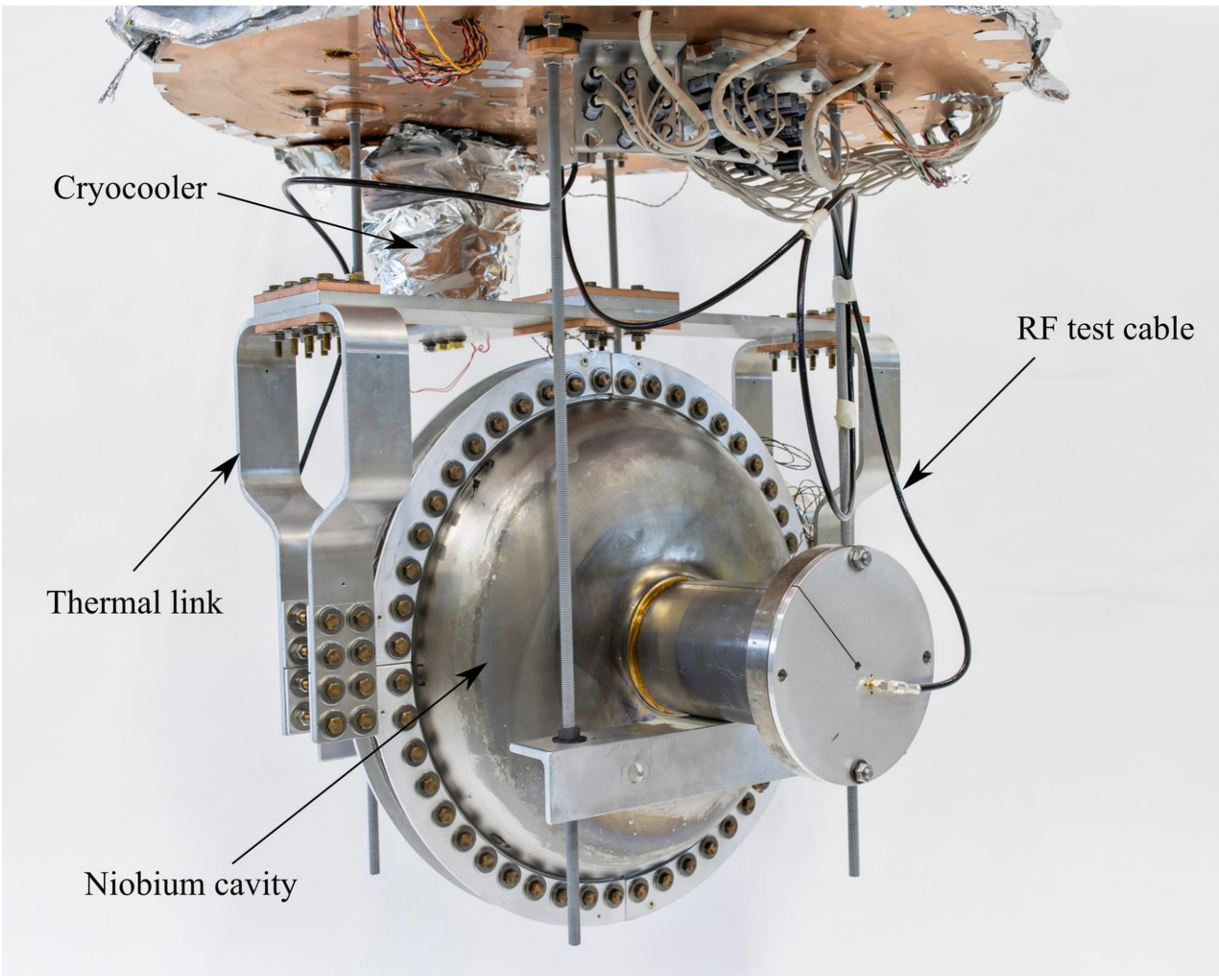

A superconducting radio-frequency accelerator cavity is mounted and connected to a cryocooler, cooling the cavity without the use of liquid helium. This new device could make it easier to produce high-average-power electron beams for industrial applications. Credit: Marty Murphy

Last week, millions of Americans unwrapped a shrink-wrapped turkey for Thanksgiving. If so, they owe thanks to electron beams, which made the shrink-wrapping possible. But the electron beam can do a lot more: It can sterilize medical equipment, treat wastewater and print metal parts. Industrial accelerators that generate these electron beams are rapidly expanding. The Illinois Accelerator Research Center (IARC) is on a mission to build a high-power, compact, superconducting electron beam accelerator that will serve all of these purposes.

High-power linear electron accelerators are typically made of structures called cavities, which impart energy to the particle beam, thrusting it forward. One such cavity is the superconducting radio-frequency, or SRF, cavity, which requires extremely cold temperatures to operate. These machines use liquid helium to maintain the temperature necessary for sustaining superconductivity. Liquid-helium operation demands complex infrastructure: a liquefaction plant, distribution lines, gas recovery, purification systems, and cavity cryomodules that can withstand high pressure. Although such an infrastructure is appropriate for large-scale research accelerators, it can be too complex and costly for industrial applications. The barrier is the need for ultracold liquid helium.

With Fermilab's never-say-impossible spirit, our team at IARC has broken this barrier. We have for the first-time cooled an active radio-frequency cavity to cryogenic temperatures without the use of liquid helium. We achieved this by connecting a cavity to a commercially available cryocooler, using a Fermilab-patented technology.

As with any exciting experiment, connecting the cavity to the cryocooler was a significant task that required investigating various materials and designing custom components. Our team produced niobium conduction rings and connected them to the cavity shell using electron-beam welding. They also developed niobium-aluminum joints that allowed heat to flow easily from the cavity to the cryocooler. To generate heat into the cavity, the team used a simple plug-and-play radio-frequency driver, as in laboratory accelerators.

Electromagnetic gradients are generated within SRF cavities; stronger gradients impart more energy to the beam. This first-ever cryogen-free operation produced a gradient of 0.5 megavolts per meter on a single-cell, 650-MHz niobium cavity. We plan on achieving gradients up to 10 megavolts per meter by using higher-capacity cryocoolers and capitalizing on other recent advances in cavity technology. The team is exploring the application of conduction cooling technology to higher frequencies, multicell cavities, and other radio-frequency structures.

Replacing liquid helium with plug-and-play cryocoolers makes SRF accelerators accessible to industry by making accelerators into simple, turn-key systems.

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