Frank DiMeo

SRF Cavities

A HIGHLY PRIZED TECHNOLOGY FOR ACCELERATORS

An Energetic Kick

A key component of any modern particle accelerator is the electromagnetic cavity resonator. Inside the hollow resonator cavity, large-amplitude, high frequency electromagnetic waves repeatedly "kick" charged particles to increase their velocity and energy. Most particle accelerators use microwave energy to propel particles. LEPP has developed cavities spanning a wide range of resonant frequencies between 200 and 3000 megahertz (one million cycles per second). For nearly three decades LEPP has been a world leader in developing and applying microwave cavity technology for uses in a range of areas, including elementary-particle physics, nuclear physics, basic materials science, and biology.

As physicists have demanded higher accelerating fields, cavities with continuous wave operation (pulsed operation at high-duty cycles) made out of traditional copper materials are increasingly uneconomical, because electrical resistance in the walls squanders energy. As an alternative, resonant cavities can be built with superconducting materials that have near-zero resistance. The microwave surface resistance of a superconductor is nearly a million times less than that of copper. Pure niobium metal is the superconductor of choice for most applications, because it has the lowest losses at the highest accelerating voltages. A niobium cavity becomes a superconductor when cooled in a bath of liquid helium, operating anywhere between 2 and 4.5 degrees above absolute zero (-273ºC). Although many thousands of watts of power are delivered to the cavity, almost all of it goes into accelerating particles, and fewer than 100 watts of power are absorbed by the walls and dissipated into liquid helium.

Superconducting RF cavities (SRF) are nearly perfect resonators, achieving a quality factor, "Q," of one to ten billion. This means that if the microwave power source were turned off, the electromagnetic waves inside the SRF cavity would oscillate ten billion times before dying away. To appreciate how amazing this is, if one of the bells in Cornell's McGraw Tower had a similar Q, it would ring continuously when struck for more than three years!

Having a Worldwide Impact

Under Maury Tigner's leadership, LEPP demonstrated the first applications of SRF technology in high energy physics

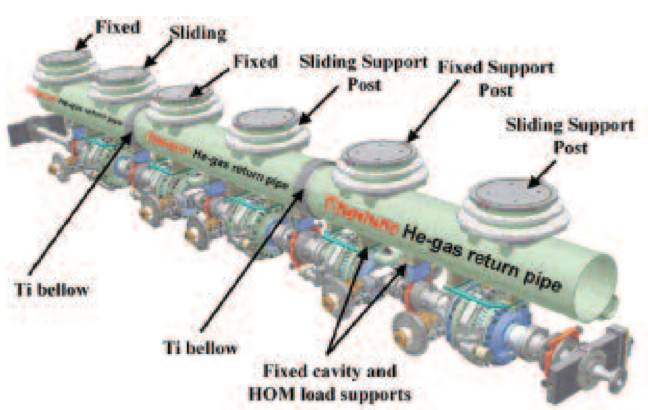
SUPERCONDUCTING RF CAVITIES (SRF) ARE NEARLY PERFECT RESONATORS, ACHIEVING A QUALITY FACTOR, "Q," OF ONE TO TEN BILLION. … TO APPRECIATE HOW AMAZING THIS IS, IF ONE OF THE BELLS IN CORNELL'S MCGRAW TOWER HAD A SIMILAR Q, IT WOULD RING CONTINUOUSLY WHEN STRUCK FOR MORE THAN THREE YEARS!

synchrotrons (1975) and storage rings (1985). These structures were about one meter long and provided a five million electron volt kick to the beams. In 1987, the CEBAF accelerator at Jefferson Lab (Newport News, Virginia) adopted the Cornell superconducting cavity design and technology to build 300 meters of cavities, providing one billion electron volts. At the frontier of nuclear science, CEBAF became the largest SRF installation in the United States.

Under Hasan Padamsee, who has been leader of the SRF group since 1987, LEPP developed a superconducting system to push ever-higher beam currents in storage rings. By 1998, a system of four SRF cavities replaced the 20 copper cavities in CESR, increasing the beam current by more than a factor of two. For both CLEO and the x-ray users at CHESS, higher beam currents mean more data collected more rapidly.

The SRF Cavity Technology Transferred

The Cornell SRF group has graduated eight Ph.D. students who are now leading advanced SRF development at DESY, Fermilab, BESSY, and Michigan State University. LEPP transferred high current superconducting cavity technology to the ACCEL Company in Germany. The company is now providing turnkey systems for major storage ring light sources around the world, such as the upgraded Taiwan Light Source and the newly constructed Canadian Light Source. Upcoming x-ray facilities, the DIAMOND light source in England and the Shanghai Light Source in China, will also install CESR SRF systems. The KEK-B factory in Japan adopted many features of Cornell's high current technology. KEK-B is now the highest current storage ring in the world.



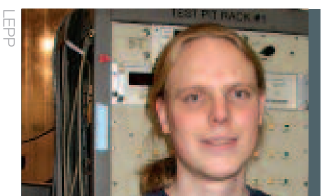
ERL Injector Cavity Assembly

Energy Recovery and Ultrahigh Stability

LEPP

Attendees of the 12th International SRF Workshop on tour of LEPP SRF facilities with the 200 MHz niobium coated copper cavity in the foreground

Most synchrotron radiation sources are currently based on storage rings. Next-generation energy recovery linacs (ERLs) based on SRF technology are destined to provide superior performance. The novelty of the ERL is that the SRF cavities in the linear accelerator (linac) both accelerate and decelerate the same particle beam. The particles first accelerate, create x-rays, and then decelerate. During deceleration, the enormous beam energy (many hundreds of megawatt power) is recovered by redirecting the beam back through the same linac at an out-of-phase condition. The energy from the particle beam is given back to the cavity and stored in the electromagnetic field of the resonator. This field then accelerates subsequent bunches. LEPP is now developing the SRF linac for the ERL.



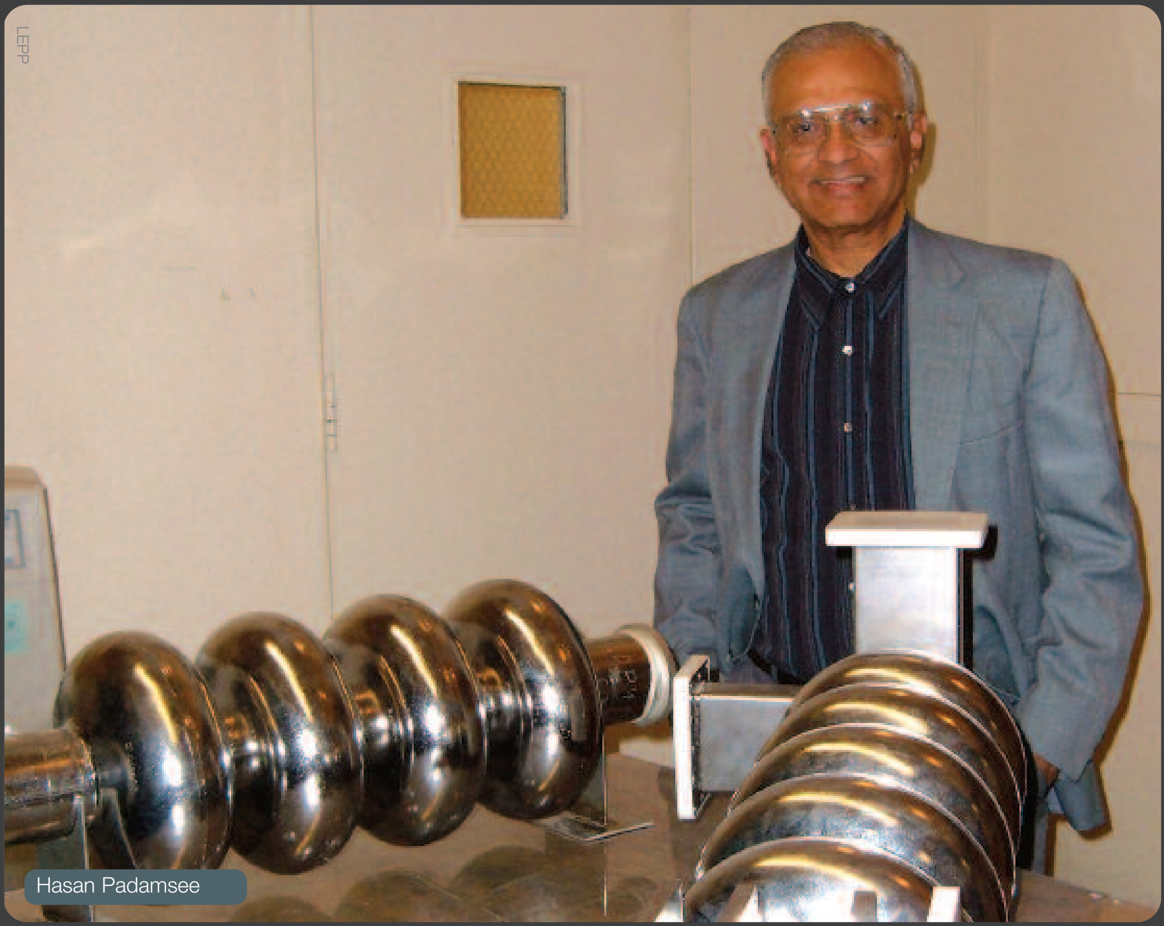
LEPP

Matthias Liepe

Because the ERL has stringent requirements for energy recovery, operating cavities with the highest possible Q and minimizing losses to the cavity walls can substantially lower capital and operating costs. Operating at such high Qs (typically several billion) is extremely challenging. At these levels, the cavities become supersensitive to minor perturbations. Simple microphonic noise from nearby sources, such as mechanical pumps or passing trains in the distance, can cause SRF cavity instabilities and wasted power. Building on techniques developed at DESY, Matthias Liepe, Physics, has led Cornell in developing a new digital RF control system that stabilizes Q values greater than 100 million. Recent testing of this system at the Jefferson Lab free-electron laser showed energy recovery with excellent stability.

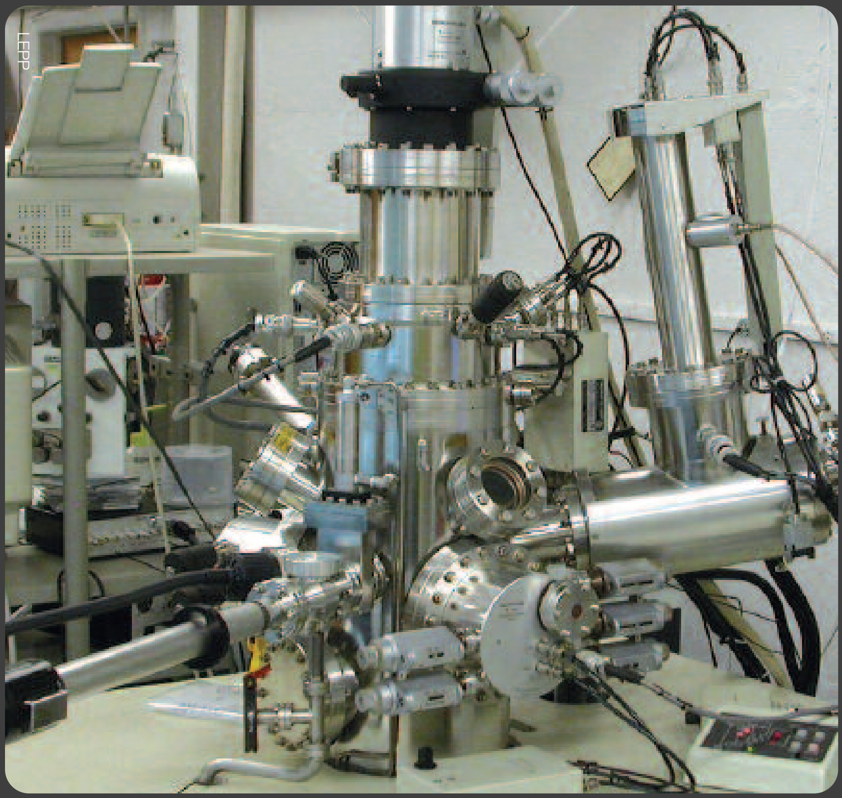
Shooting for a Trillion Electron Volts

Replacing today's circular ring particle accelerators most likely will be two linear accelerators aimed at each other, producing head-on collisions. In August 2004, the International Technology Recommendation Panel selected high-performance SRF technology for its future International Linear Collider (ILC) project. The ILC plan calls for two linear colliders, each accelerating particles to 500 billion electron volts. This fantastically large machine will need 16,000 superconducting cavities, each about one meter long, operating at two degrees above absolute zero, and providing more than a 30 million electron volt kick.



Hasan Padamsee

UNDER HASAN PADAMSEE, WHO HAS BEEN LEADER OF THE SRF GROUP SINCE 1987, LEPP DEVELOPED A SUPERCONDUCTING SYSTEM TO PUSH EVER-HIGHER BEAM CURRENTS IN STORAGE RINGS.



Inside Newman Lab

The cavities used to power CESR and the high energy physics programs for CLEO; the x-ray light source programs for CHESS, MacCHESS, and G-line; and prototype cavities for CEBAF and future linear colliders have all been built at Newman Lab across campus from Wilson Lab. Newman Lab houses extensive research and development facilities for RF superconductivity and for production, preparation, and cavity testing.

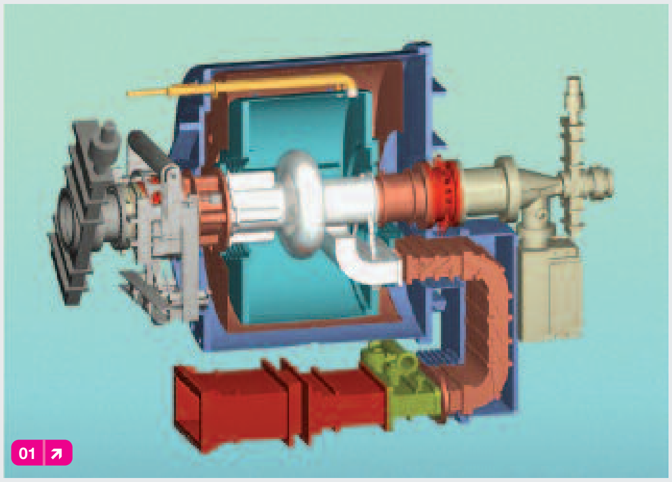
The lab's fabrication facilities include a 100-ton press for deep drawing, digital-control milling machines for precise die machining, an electron beam welder, and a UHV furnace to purify cavities at 1,300ºC. Cleaning facilities include open and closed cavity-etching systems, high purity water rinsing systems, and high pressure (100 atmospheres) water rinsing.

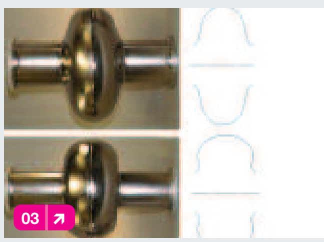
Newman Lab has a new 1,100-square-feet Class 100 clean room and a smaller Class 100 area for clean cavity assembly. Test setups include three radiation-shielded pits that accommodate a large range of cavity sizes. Radio frequency (RF) power is available from 200 watts continuous wave power sources and a 1.5 megawatt-pulsed klystron.

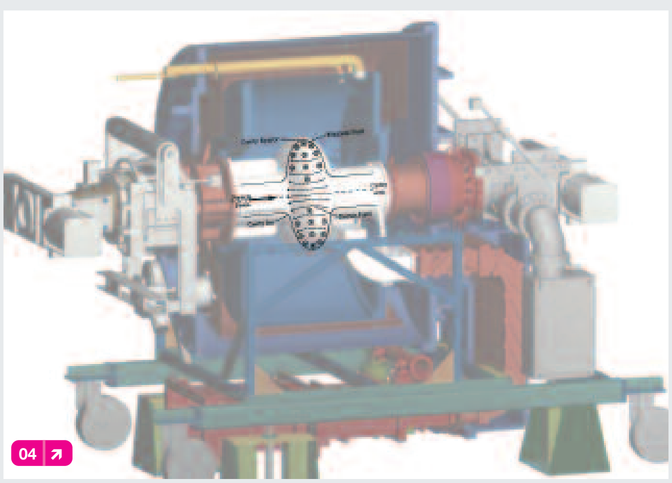
Newman's surface analysis capabilities include a dedicated scanning electron microscope (SEM) with energy dispersive analysis and an Auger System with SIMS Analysis, both installed in a Class 1000 clean room.

The Newman RF facility is an integral part of worldwide collaborations to develop the next generation of particle accelerators. Looking to the future, particle colliders might switch from accelerating electrons to muons. Muons—200 times more massive than electrons—live for a very short time and have a large beam size, which puts extra constraints on the RF cavity design. In 2003, LEPP and CERN started a collaboration to design, fabricate, and test a 200 megahertz copper cavity. It is the largest diameter RF cavity in the world. This cell achieved an accelerating field of 10 million electron volts per meter. To keep costs reasonable, CERN made the cavity out of copper (50 times less expensive than niobium) and sputter-coated the inside with a thin film of superconducting niobium.

Cavities







01. CESR cavity in a helium vessel
02. 500 MHz, niobium cavities developed for CESR
03. New cavity shape developed by LEPP to reach 50 million volts per meter, compared to the (Upper) standard shape cavity developed for the Linear Collider.
04. SRF cavity: Highlighted area shows electric fields produced in the superconducting niobium cell and the path the particle beam takes as it travels through the cavity.

LEPP

(l.) Rongli Geng (r.) Valery Shemelin

LEPP has been one of the main proponents for using SRF cavities to power linear colliders. In 1990 LEPP hosted the first international workshop covering this topic. LEPP has been a key player in the steady advances in SRF science and technology. The achievable electric field gradient of niobium cavities has more than quintupled over the last two decades, making projects such as the ILC plausible. In 1995 LEPP led a collaboration with Fermilab and DESY to break the world record in accelerating voltage for linear collider structures of 25 million volts per meter. For the future, SRF developments at LEPP will continue to push accelerating gradients even higher. LEPP researchers Valery Shemelin and Rongli Geng designed and built in 2005 a uniquely shaped cavity that established a new record of 47 million electron volts per meter. To promote international collaboration, LEPP sent a similar cavity to KEK in Japan, where they repeated and soon bettered the record to 50 million electron volts per meter.

Simple microphonic noise from nearby sources, such as mechanical pumps or passing trains in the distance, can cause SRF cavity instabilities and wasted power.

With the success of completed projects and demonstrated superior performance, niobium SRF cavities have become an enabling technology, offering upgrade paths for existing facilities and for frontier machines in development.

Hasan S. Padamsee
LEPP

For more information:

E-mail: hsp3@cornell.edu
Website: www.lepp.cornell.edu/public/CESR/SRF/