Berkeley Lab Science Beat

World Record Magnet 300,000 Times Field Strength of Earth's Magnetic Field

Is there a more rewarding thrill than to break a record? Whereas most of us must content ourselves with breaking personal bests, earlier this month the scientists and engineers of Berkeley Lab's Superconducting Magnet Group experienced the rush of shattering a world record. The team's newest niobium-tin dipole electromagnet reached an unprecedented field-strength of 14.7 Tesla. This is more than 300,000 times the strength of Earth's magnetic field.

The RD-3 Magnet

BERKELEY LAB'S RD-3 MAGNET REACHED A WORLD-RECORD 14.7 TESLA FIELD STRENGTH IN THE FINAL QUENCHING TEST

"Our job is to push the technology envelope as far as we can in terms of high magnetic field strength and that is what we have done," says Steve Gourlay, a physicist with the Accelerator and Fusion Research Division (AFRD) who lead the team that designed and built the new champion.

Dubbed RD-3, the new world record-holding magnet is one meter long and weighs several tons. It consists of three magnetic coil modules (a double-pancake outer and single-layer inner) which were wound from more than eight miles worth of niobium-tin wire. The previous record field strength for a dipole electromagnet was 13.5 Tesla. It was set in 1997 also by a niobium-tin electromagnet designed and built here at Berkeley Lab.

Members of the new record-holding team in addition to Gourlay were Robert Benjegerdes, Paul Bish, Doyle Byford, Shlomo Caspi, Daniel Dietderich, Ray Hafalia, Charles Hannaford, Hugh Higley, Alan Jackson, Alan Lietzke, Nate Liggins, Alfred McInturff, Jim O'Neil, Evan Palmerston, GianLuca Sabbi, Ron Scanlan, and James Swanson.

Dipole magnets are used to bend and maintain the path of accelerating particle beams. The higher the field strengths of the magnets, the tighter the arc of the beam. With stronger dipole magnets, an accelerator can push particles to much higher relativistic energies around the same-sized circular beam path.

That conventional electromagnets cannot attain a dipole field strength much above 2 Tesla has meant the continuing development of new and better superconducting alloys. However, the use of high field-strength superconducting electromagnets presents its own formidible technical challenge in that superconductivity has a tendency to weaken and disappear in the presence of a strong magnetic field.

"We're charged with developing superconducting magnet technology that not only yields high field strength but is also cost effective for the next generation of accelerators," says Gourlay. "To achieve this, we have been working with a niobium-tin superconductor (Nb_3Sn) and emphasizing simplicity in our design."

Today's most powerful particle accelerators, including the Tevatron and the Large Hadron Collider, rely on dipoles fashioned out of a niobium-titanium alloy. This material while offering the distinct advantage of being ductile is limited to a field strength no greater than 10 Tesla. The niobium-tin superconductor was believed in theory to be capable of reaching field strengths in excess of 14 Tesla. However, until the 1997 record-setting performance of the Superconducting Magnet Group's D20 magnet, niobium-tin was considered too brittle and fragile to be able to withstand the forces that threaten to push the coil windings apart.

"These forces are enormous, about 3 million pounds or more than the combined thrust of more than a dozen 747 planes," says Gourlay. "To withstand this force, we needed a really good support structure design."

The design Gourlay and his colleagues employed is centered around a "common-coil racetrack" geometry, an idea that originated at Brookhaven National Laboratory, in which a pair of coils shaped like an oval racetrack are shared between two apertures to produce opposing magnetic fields.

"A racetrack coil design offers a flat geometry that can handle the forces and is well suited for use in a particle accelerator," says Gourlay. "It also offers a simplicity of construction that helps make it cost-effective."

To overcome the brittleness factor of niobium-tin, Gourlay and his team made their coil modules using a "wind and react" technique. The cable was made from separate strands of niobium and tin which were fabricated by Oxford Superconducting Technologies. It was then wound around an iron "pole piece" and impregnated with an epoxy filler to make each coil module. Not until after the cable was wound into the three coil modules were the strands "reacted" to make the superconducting alloy. This reaction was accomplished by heating the cable to about 950 Kelvin (680 degrees Celsius) and baking it at that temperature for two weeks.

To complete the magnet, the coils were encased in an iron yoke then wrapped in a 40-millimeter-thick aluminum shell. For the coils to become superconducting, they have to be cooled to a temperature of about 4.2 Kelvin (-270 degrees Celsius). This starts the process whereby a magnet is "trained" to attain its peak field strength. A magnet will be chilled to make its coils superconducting, then energized up in field strength until an inadvertent warming along some part of the coils causes the magnet to lose its superconductivity. This temporary loss of superconductivity is called "quenching." After quenching occurs, the magnet is re-cooled and training resumes. The process will be repeated until the magnet reaches the field-strength limit dictated by the properties of its superconductor.

"This magnet trained slowly," says Gourlay. "It took us 35 quenches to reach 14.7 Tesla at 4 Kelvin (the old record of 13.5 Tesla was achieved at 1.8 Kelvin)."

Records are made to be broken and already the Superconducting Magnet Group is planning the design of a magnet that should reach a field strength of 15 Tesla.

"We’re always looking forward," says Gourlay. "After we reach 15 Tesla, we’ll aim for 16 Tesla."

Gourlay does say that in the next magnet, he and his group will concentrate on improving the quality of their magnetic field as well as the quantity.