HIGH ENERGY PHYSICS *made painless*

Magnets, Part I

Text by Hank Glass, Technical Support Section
Edited by Donald Sena, Office of Public Affairs

The experiment is ready and waiting. The researchers have calibrated each calorimeter crystal and adjusted the high voltages on every wire in the tracking chambers. Every one of the hundred thousand readout channels of the detector is primed to record the swift passage of hadronic jets, electrons, muons, and other debris ejected from a violent subatomic collision. All that the experimenters are waiting for now is the arrival of high-energy protons and antiprotons, streaming in from opposite directions to collide head-on in the center of the detector.

But how do the protons know where to go? They don't have a road map. They can't hop on a bus. They can't stop a random pedestrian and ask, "Hey, mister, do you know the way to CDF?"

The protons need magnets to show them the way.

The two main jobs of a particle accelerator are to raise the energy of the particles and to steer them in the right direction. These jobs are performed by different devices: RF cavities use electric fields to accelerate the particles, while magnets use magnetic fields to steer the particles. This article will explore some of the different kinds and uses of magnets in accelerators.

Photo by Fred Ullrich

Steel laminations at one end of a dipole magnet for the Main Injector.

Magnetic Personality

How are the magnets used at Fermilab different from the magnets you use to stick your grocery list to the fridge? Obviously they're bigger—a Main Injector dipole is 20 feet long and weighs 42,000 pounds, making them impractical for kitchen use. But they're different in another important way: unlike your kitchen magnets, in which the fields go around the outside of the magnet, an accelerator magnet has its field on the inside. Accelerator magnets have a pipe going through the middle of them where the protons travel; in Fermilab's magnets, the field is directed into that pipe to steer the particles, and very little field escapes outside the magnet.

Magnetic fields act in ways unlike any other force in nature. In a familiar force, such as gravity, all objects are accelerated in the same direction. We don't see some things fall up, some down, and others sideways. Magnetism is more complicated. First, it only acts on electrically charged particles; when humans, who are all electrically neutral, stand next to a magnet, they don't feel much (unless of course they've got a steel wrench in their pocket). Not only must the particle be charged, it must also be moving: a proton sitting in the middle of a strong magnet will just sit there and spin the time away, but another proton zipping in at high speed will get kicked by the field. The force exerted by a magnetic field on a moving particle not only depends on how fast it's going, but in which direction: one particle, travelling at high speed in the direction of the field (that is, along a magnetic line of force) will experience no force at all, but another particle, moving at the same speed but at right angles to the field, will be deflected by it.

Magnet Types

A simple type of magnet is called a dipole, and consists of two poles. Magnetic lines of force emerge from one pole (North) and re-enter the magnet at the other pole (South). In the space between the poles, where the beam pipe resides, the field is nearly uniform. Magnet builders arrange these dipoles around the circumference of a circle, and have all their fields pointing straight up, which is just what is needed to get a beam of protons to circulate around the circle in a clockwise direction. Antiprotons, having negative charges, would circulate around these same magnets counterclockwise.

The dipoles are all Fermilab would need were it not for the fact that a beam of protons is a disorderly bunch. They're not all moving in exactly the same direction, but, instead, some want to drift sideways while others want to move up or down, away from the plane of the ring. To keep them in line, we need another type of magnet called a quadrupole, which means a four-pole magnet (two North and two South poles). The field in this type of magnet is zero at dead center, but grows linearly as you move further away from the center. This means that a well-behaved proton moving along the center, where it's supposed to go, will be left alone by the quadrupole. But an unruly proton, wandering off the beam axis, will be pushed back towards the center. The further away it is, the harder it gets pushed. This results in a focusing of the beam of protons, similar to what a glass lens does to a beam of light. ■

Next issue: Part II of Magnets, including magnet fabrication technology and superconducting vs. "normal" magnets.