PROGRESS REPORT ON THE ENERGY DOUBLER

The Energy Doubler Group

Introduction

Since September 1973, the time of the last progress report on the Energy Doubler in these pages, substantial progress has been made on this important development for Fermilab's future. The purpose of this article is to report on that progress.

The possibility of building a ring of superconducting magnets was discussed in 1967 when the basic design decisions for Fermilab were being hammered out in the Laboratory's first temporary quarters in Oak Brook. It was concluded that the technology of superconducting magnets was not advanced enough to commit Fermilab's future to them and the Main Ring was designed with conventional steel and copper magnets. Space was left in the main-ring tunnel for another future ring of magnets, either below the main-ring magnets or suspended from the ceiling.

Almost no work was done here on a superconducting accelerator until 1972, after a 200-GeV beam was achieved and operation begun. A group then began exploring the design, fabrication, and use of superconducting magnets and accelerator systems, setting up shop in the former main-ring lab and houses in the Village. Superconducting magnets are fabricated and tested in the Industrial Buildings near the Main Ring.

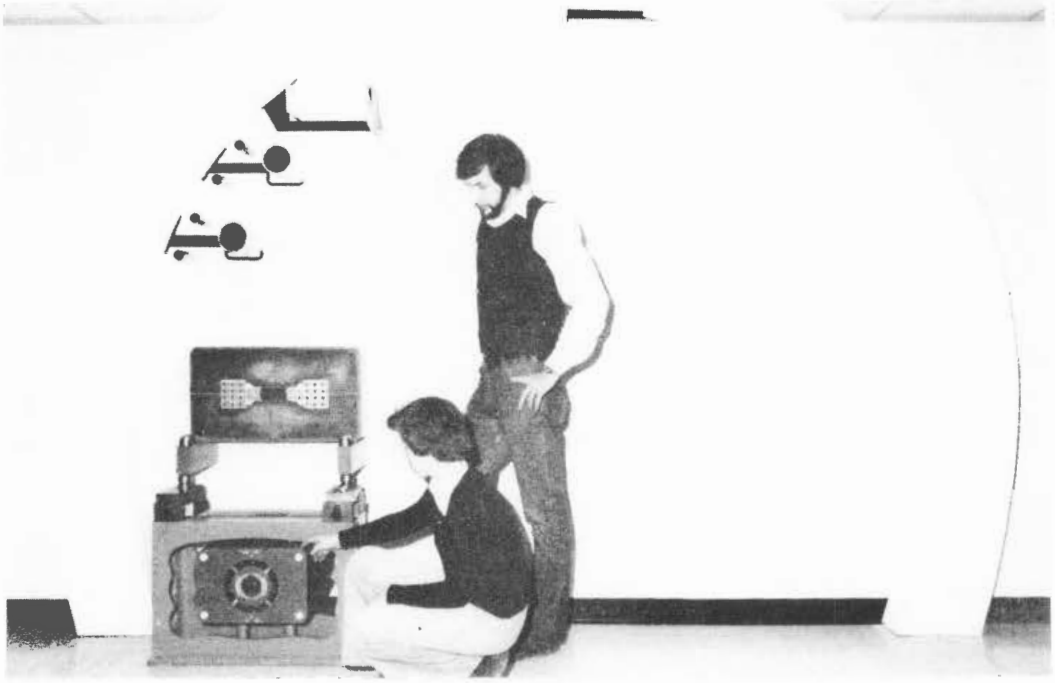
The basic goal of the Energy Doubler is to provide a means of accelerating protons to 1000 GeV, twice the peak energy of the Main Ring and to achieve this goal with systems that can be installed in the present main-ring

tunnel. Injection is to be from the Main Ring, at an energy of approximately 100 GeV. The present experimental areas can be upgraded for use at 1000 GeV.

The Energy Doubler also has other uses. The cost of electric power has more than doubled since the first estimates of operating budgets were made. The superconducting magnets of the Energy Doubler operate with virtually no power loss, so we could save almost all the power now used by the Main Ring (most of our power use) by using the Energy Doubler even at our present operating energy of 400 GeV. With this use in mind, we sometimes use the name "Energy Doubler/Saver."

The Energy Doubler can also be used as a beam stretcher, to increase the length of time over which beam is spilled out to experiments, thus increasing the efficiency of experiments now limited by counting rates. Lengthening the present "flat top" for the conventional magnets in the Main Ring is almost prohibitive because of the cost of electricity.

The course of physics in the last few years has stimulated great interest in colliding beams at Fermilab and many plans have been proposed to achieve such collisions. The Main Ring and Doubler together can produce p-p collisions if beam is accelerated in the reverse direction in the Main Ring. Recent experimental results on achieving smaller, brighter beams by "electron cooling" give interest in accelerating and storing antiprotons for $\bar{p}$-p collisions, which can also make use of the Doubler. To make these collisions as easy as possible to achieve, the Energy Doubler is to be located just under the present main-ring magnets. This location is shown in the figure on the next page.

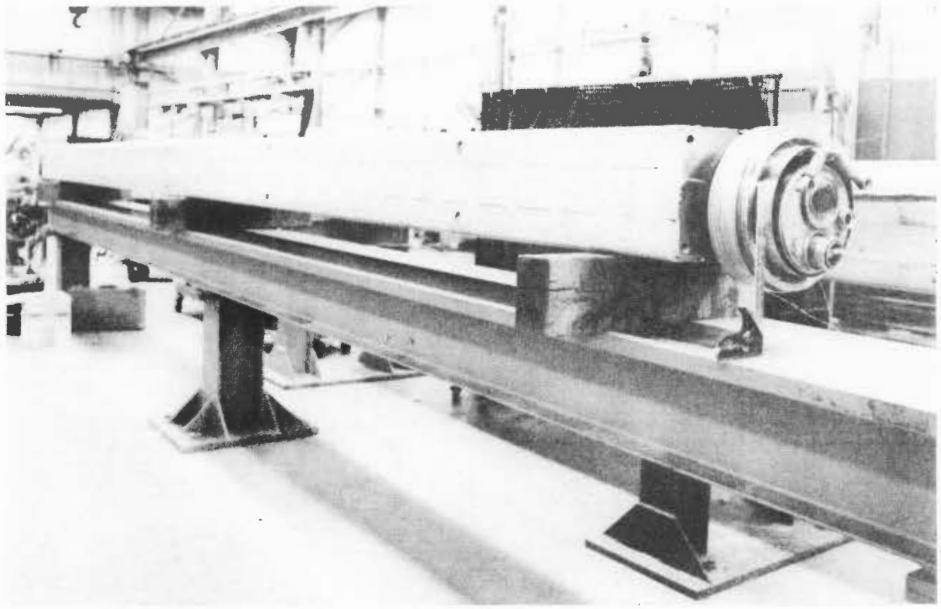


Louise Krafczyk points out the location of the Energy Doubler in the main-ring tunnel model to Wally Habrylewicz.

Most of the effort has been in developing good superconducting magnets and associated cooling systems, but other parts of the design of a complete accelerator have not been totally neglected. We shall review major elements of the design in the paragraphs below.

Magnet

It is entirely natural, since the Doubler must fit into the main-ring tunnel, to duplicate the separated-function main-ring lattice in the Doubler. It is also easier to build separated-function superconducting dipole and quadrupole magnets. A prototype dipole magnet is shown in the closeup on the cover and in toto in the photograph on the next page.



Magnet E22-7, the first full-length magnet constructed with keystone cable and elliptical bore tube.

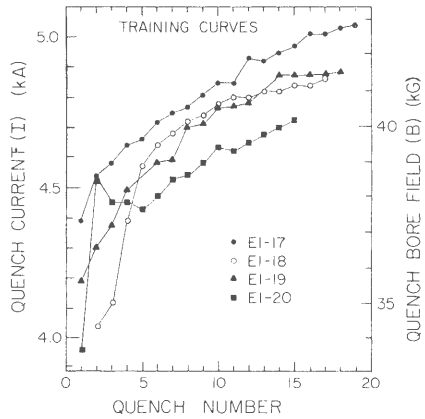
In both the dipole and quadrupole, the field shape is determined by the distribution of current around the bore of the magnet. The steel surrounding the magnet does not increase the magnetic field or affect its shape very much. Instead, it acts to contain the field, to correct a few selected multipoles and to provide mechanical support. The entire coil assembly, cooling channels, and vacuum tube are held in place inside by very light roller suspensions to reduce heat transfer from the room-temperature surroundings to the liquid-helium temperature coils. A current of 4343 amperes at 1000 GeV produces a field of 4.23 T in the dipoles and a gradient of 0.945 T/cm in the quadrupoles.

These fields represent a large amount of stored energy, approximately 0.5 MJ per dipole. A means must be provided to dump this energy outside

coil-clamp system. Electrical insulation is provided by wrapped plastic and glass tapes and epoxy between inner coil and ground and between inner and outer coils.

Test Program. Magnets that meet the requirements of the accelerator have evolved through a strenuous test program designed to understand and control the magnetic and force characteristics of the coils during excitation. The program has included studies of aperture size, mechanical design, wire construction, insulation, cooling methods, and quenching.

Superconducting magnets exhibit "training." That is, they can be excited to successively higher current and field values before they quench. Examples of training behavior are shown in the graph at the right. The evidence indicates that magnets train because the wire moves slightly, largely at the magnet ends, and we now construct magnets that are fully trained after 10 to 15 quenches, a minor part of the test routine for magnets.



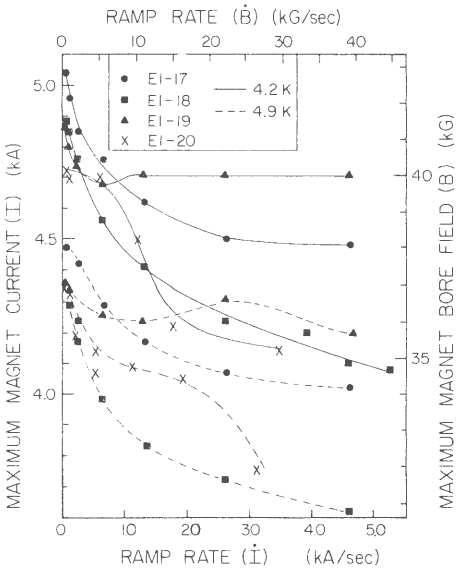
Training of four identically constructed magnets.

We have also studied the effects of ac losses in ramped magnets and have learned how to reduce the sensitivity of peak field to ramp rate. Some results are shown in the graph on the following page. It is clear that rf power and refrigeration, not the superconducting magnets, will be the limiting factor on Doubler ramp rate.

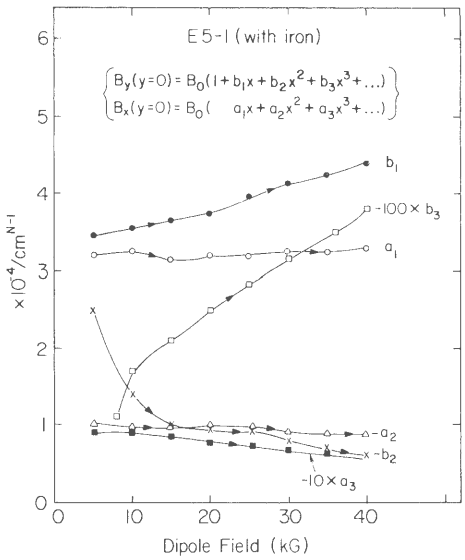
the magnets in the event of a quench, when, for example, the temperature rises above the critical temperature and the magnet "goes normal," that is, ceases to be superconducting. If this stored energy were to be dissipated inside the magnet, it could damage the coils. Electronic quench detectors provide signals to shunt the current through an external resistor by means of a thyristor.

Wire Development. A niobium-titanium alloy is chosen for its critical properties and fabricating convenience. A strand of the superconducting wire contains 2100 superconducting filaments embedded in a copper matrix that provides stability against the spreading of local quenches. A cable contains 23 twisted strands in a flat (0.3 in. by 0.05 in.) array of keystone shape. Originally, it was planned to utilize a monolithic strip, but alternating-current losses when the magnets are ramped dictate the use of twisted cable. The Laboratory has purchased substantial quantities of strands for superconducting wire for the Doubler. Cable is routinely produced by several industrial suppliers.

Coil Collars. Earlier in the Energy Doubler development, the coils were held in place by inner rings and outer spiral-wrapped bands. These bands gave rise to significant twisting distortions and coil deformation during excitation. In a conventional magnet, the good-field region is masked from the exciting coils by the steel poles, but in a superconducting magnet the coils are inside the steel. Coil movement and the accuracy of coil placement therefore have major effects on the field shape. The banded structure was therefore abandoned and replaced by a laminated



Ramp-rate sensitivity of four identically constructed magnets.



Multipole components of E5-1 magnet.

The ramp-rate studies, the coil-collar design discussed in the preceding section, and many other aspects of coil placement and field accuracy have been made possible by development of a field-measurement system for rapid and precise determinations of field values. A nuclear-magnetic resonance and signal-averaging system is used with an on-line data-acquisition system. The graph on the right above shows measurements of multipole field components of a test magnet. The measurements indicate that most higher multipoles are acceptably small, but that the sextupole component is still larger than the design value. This problem is still being investigated.

Cooling System

The Fermilab design is unusual in that the liquid-helium refrigerant is transported around the accelerator through the magnets, not through a

separate transfer line. The helium is returned to the refrigerator in an outer counterflow channel that carries heat from the inner channel. A system of 24 satellite refrigerators will be located in main-ring service buildings, fed by a central liquifier. The compressor equipment for this central plant has been obtained as surplus from an Air Force liquid-oxygen plant in California. It will be installed in a building now being constructed for this purpose near the intersection of Roads D and B, near the Main Ring.

NOTES AND ANNOUNCEMENTS

MULTIPARTICLE SPECTROMETER WORKSHOP POSTPONED. . .

Information from different segments of our Users' community has led us to conclude that our plans for a workshop on December 9-10 to determine a second generation program for the Multiparticle Spectrometer were premature. Accordingly, we have now decided to postpone this workshop until a later as yet unspecified date. Interested readers should watch for announcements pertaining to the rescheduling of this workshop in future issues of NALREP.

MEETINGS TO COME. . .

A general schedule for PAC-related meetings to be held at Fermilab during the period January-June 1977 is currently in preparation and will appear in next month's issue of NALREP. In the meantime we call to the attention of our readers that Friday, January 28, 1977, is the deadline for receipt of new proposals in the Director's Office which are intended for PAC consideration at the spring meeting (March 10-11, 1977).

APPOINTMENTS. . .

Richard A. Carrigan, who has served as Director of Personnel Services, will now move into the Directorate to serve a stint as Assistant Director. In addition to his new duties in support of the Directorate, he will retain his previous responsibilities for scientific and engineering personnel. He will also continue his responsibilities for scientific and technical information.

Charles F. Marofske will serve as Acting Director of Personnel Services. He will continue to carry out his responsibilities as Personnel Manager.

Dennis Theriot has succeeded Richard Lundy as head of the Neutrino Department, and Richard Lundy has become associate head of the Neutrino Department.

Drasko Jovanovic has been appointed associate head of the Research Division, having served as assistant head since 1975.

A. Lincoln Read is now head of Research Services.