MI-0206

List of Abstracts

Submitted to PAC 97

"Stability Tests of Permanent Magnets Built With Strontium Ferrite," H.D. Glass, D.F. Anderson, B.C. Brown, G.W. Foster, W.B. Fowler, R. Gustafson, G.P. Jackson, J.T. Volt

"Permanent Dipole Magnets for the 8 GeV Transfer Line at FNAL," H.D. Glass, B.C. Brown, G.W. Foster, W.B. Fowler, J.E. Haggard, D. J. Harding, G.P. Jackson, M.P. May, T.H. Nicol, J.F. Ostiguy, P. Schlabach, G.A. Smith, J.T. Volk

"Permanent Gradient Magnets for the 8 GeV Transfer Line at FNAL," H.D. Glass, B.C. Brown, G.W. Foster, W.B. Fowler, J.E. Haggard, D. J. Harding, G.P. Jackson, M.P. May, T.H. Nicol, J.F. Ostiguy, P. Schlabach, G.A. Smith, J.T. Volk

"Experience With The Procurement of Ferrite and Temperature Compensator for Permanent Magnets for Accelerators," William B. Fowler, Bruce Brown, James T. Volk

"Hybrid Permanent Quadrupoles for the 8 GeV Transfer Line at Fermilab," S.M. Pruss, B.C. Brown, G.W. Foster, H.D. Glass, D.J. Harding, G.P. Jackson, M.P. May, J.F. Ostiguy, J.T. Volk

FNAL Main Injector °t Transition Jump Beamtube Design," J. Leibfritz

"The Design of a °t-Jump System for the FNAL Main Injector" W. Chou, B.C. Brown, S. Fang, J. Leibfritz, K.-Y. NG, H. Pfeffer, I. Terechkine

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"Variations in the Steel Properties and the Excitation Characteristics of FMI Dipoles," P.S. Martin, D.J. Harding, J.F. Ostiguy, E.G. Pewitt, A.D. Russell

"Modifications to the Excitation Characteristics of FMI Dipoles by Machining," P.S. Martin, R. Baiod, D.J. Harding, J.F. Ostiguy, A.D. Russell

"Intensity Limitations in the FNAL Main Injector," W. Chou

"Design and Magnetic Measurements for the Main Injector Lambertson," D.E. Johnson, J.E. Dimarco, D.J. Harding, P.S. Martin, J.F. Ostiguy, D.G.C. Walbridge, R. Baiod

"Selecting Magnet Laminations Recipes Using the Method of Simulated Annealing," A.D. Russell, R. Baiod, B.C. Brown, D.J. Harding, P.S. Martin

"The Making of the Fermilab Main Injector Dipoles," D.J. Harding, E.G. Pewitt, J.I. Schultz, F.W. Ullrich, J. Chimbidis

"Air-Cooled Trim Dipoles for the Fermilab Main Injector," I. Terechkine, J.A. Carson, N.S. Chester, J.D. Garvey, G.E. Krafczyk, A. Makarov, D.J. Harding, V.A. Yarba

"Magnetic Field Strength and Shape Measurements of the Fermilab Main Injector Dipoles," D.J. Harding, R. Baiod, B.C. Brown, H.D. Glass, T.K. Kroc, P.S. Martin, C.S. Mishra, D.G.C. Walbridge, E.G. Pewitt

"Design for Fermilab Main Injector Magnet Ramps Which Account for Hysteresis," B.C. Brown, C.M. Bhat, D.J. Harding, P.S. Martin, G. Wu

"Magnet Field Strength and Shape Measurements of the Fermilab Main Injector Quadrupoles," D.J. Harding, B.C. Brown, J. Dimarco, H.D. Glass, T.K. Kroc, P.S. Martin, C.S. Mishra, D.G.C. Walbridge, E.G. Pewitt

"Magnet Field Measurements of the Main Injector Sextupole Magnets," C.M. Bhat, D.J. Harding, P.S. Martin, B.C. Brown, H.D. Glass, D.G.C. Walbridge

"Radiation Levels Around the Fermilab Main Injector Extraction Septa," C.M. Bhat, N.V. Mokhov

"Status of the Main Injector and Recycler," Stephen D. Holmes

"Impedance Scaling and Impedance Control," W. Chou, J. Griffin

"Accelerator Physics Issues of Really Large Hadron Collider," W. Chou

"Study of the Dynamic Aperture During Collisions in the LHC," D. Ritson, W. Chou

"Proposal for an Aluminum Beam Screen in the LHC," W. Chou, H. Ishimaru

"Design and Simulation of the Antiproton Recycler Lattice," N. Gelfand, S.D. Holmes, J.A. Holt, D.E. Johnson, L. Michelotti, C.S. Mishra

"Design and Operation of an Experimental Double-C "Transmission Line" Magnet for the Pipetron," G.W. Foster, P.O. Mazur, T.J. Peterson, C.D. Sylvester

"Beam Intensity Limits in the Main Injector through Transition with a Normal Phase Jump Scheme," C.M. Bhat, J. MacLachlan

Abstract Submitted
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Sorting Category: T.9

Stability Tests of Permanent Magnets Built With Strontium Ferrite H.D. GLASS, D.F. ANDERSON, B..C. BROWN, G.W. FOSTER, W.B. FOWLER, R. GUSTAFSON, G.P. JACKSON, J.T. VOLK, *Fermi National Accelerator Laboratory*[1] — Permanent magnets built using strontium ferrite bricks have been tested for stability against demagnetization. We built 12 test dipoles to monitor ferrite behavior under a variety of stressing conditions, including irradiation, mechanical shock, extreme thermal excursions, and longevity. These test magnets were geometrically similar to, but much shorter than, the magnets built for the 8 GeV transfer line at FNAL. No loss of magnetization was observed for bricks exposed to a proton beam, and a magnet exposed to several Gigarads of Co^{60} gamma radiation suffered no measurable demagnetization. The magnet strength was observed to decrease logarithmically with time. Irreversible demagnetization of $\sim 0.1\%$ was seen in cooling magnets to 0 °C, and the loss was $\sim 0.2\%$ for magnets cooled to -20 °C. Also, one of the long dipoles built for the 8 GeV line was periodically tested over the course of 3 months, and showed no measurable demagnetization.

[1]Work suported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Abstract Submitted
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Sorting Category: T.9

Permanent Dipole Magnets for the 8 GeV Transfer Line at FNAL H.D. GLASS, B.C. BROWN, G.W. FOSTER, W.B. FOWLER, J.E. HAGGARD, D.J. HARDING, G.P. JACKSON, M.P. MAY, T.H. NICOL, J.F. OSTIGUY, P. SCHLABACH, G.A. SMITH, J.T. VOLK, *Fermi National Accelerator Laboratory*[1] — The transfer line that will serve to transport 8 GeV protons from the Booster to the new Fermilab Main Injector has been built using permanent magnets. A total of 46 horizontal bend dipoles and 5 vertical bend dipoles were built for this beamline; 67 gradient magnets[2] were also built. The magnets were built using magnetized strontium ferrite bricks. Thermal compensation of these bricks was effected by use of a nickel-iron alloy. The dipole magnets were built with a mean integrated strength of 0.56954 T-m, and an rms spread of 0.06%. The magnets were thermally cycled from 20 °C to 0 °C to condition the ferrite against irreversible thermal losses, and the compensation was measured with a flipcoil. The magnet strength was adjusted by varying the number of bricks installed at the magnet ends. Details of the assembly process and a summary of magnetic measurements are presented here.

[1]Work suported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.
[2]"Permanent gradient magnets for the 8 GeV transfer line at FNAL," H.D. Glass et al., this conference.

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Permanent Gradient Magnets for the 8 GeV Transfer Line at FNAL H.D. GLASS, B.C. BROWN, G.W. FOSTER, W.B. FOWLER, J.E. HAGGARD, D.J. HARDING, G.P. JACKSON, M.P. MAY, T.H. NICOL, J.F. OSTIGUY, P. SCHLABACH, G.A. SMITH, J.T. VOLK, *Fermi National Accelerator Laboratory*[1] — The 8 GeV transfer line feeding protons into the new Fermilab Main Injector has been built using strontium ferrite permanent magnets. This article addresses the design and manufacture of the 67 combined function magnets; permanent horizontal and vertical bend dipoles[2] and quadrupoles were also built. The combined function magnets were built with a mean integrated strength at midaperture of 0.56953 T-m (central field nominally 0.15 T), and a gradient of 8.20% per inch relative to the dipole strength (nominal gradient = 0.48 T/m). Thermal compensation of these bricks was effected by use of a nickel-iron alloy. The magnets were thermally cycled from 20 °C to 0 °C to condition the ferrite against irreversible thermal losses; the compensation was measured with a flipcoil and verified with a rotating harmonics coil. We present details of the magnet assembly process and also summarize the magnetic measurements.

[1]Work suported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.
[2]"Permanent Dipole Magnets for the 8 GeV Transfer Line at FNAL," H.D. Glass et al., this conference.

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Experience With The Procurement of Ferrite and Temperature Compensator for Permanent Magnets for Accelerators WILLIAM B. FOWLER, BRUCE BROWN, JAMES T. VOLK, Fermi National Accelerator Laboratory[1] — An 8 GeV proton beam line from the Fermilab Booster to the new Fermilab Main Injector has been implemented with permanent magnets. Similar magnet for a new 8 GeV storage ring to be installed in the Main Injector tunnel are about to start being produced. Strontium oxide ferrite was selected for the magnets due to its low cost and satisfactory magnetic properties for the 1.5 kilogauss fields required in the 2-inch gap magnets. Fermilab has received 96,000 pounds of ferrite. By working with the vendor (HATACHI, Edmore, MI), improved uniformity of Residual Induction (B_r) has reached 3905 gauss$\pm$0.65%. Field stability against temperature variations is achieved by compensation using a $\sim$30% nickel steel alloy. The ferrite B_r changes $\sim$-0.2% per degree C, which is compensated for by the 13% by volume of compensator alloy incorporated in the magnet. Fourteen thousand (14,000) pounds of this material has been received and in order to obtain sufficient uniformity we mixed equal amounts from each batch into each magnet. Results from these procedures will be given.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Sorting Category: T.9

Hybrid Permanent Quadrupoles for the 8 GeV Transfer Line at Fermilab S.M. PRUSS, B.C. BROWN, G.W. FOSTER, H.D. GLASS, D.J. HARDING, G.P. JACKSON, M.P. MAY, J.-F. OSTIGUY, J.T. VOLK, Fermilab[1] — Hybrid Permanent Magnet Quadrupoles for specialized portions of the 8 GeV transfer line from the Fermilab Booster to the new Main Injector have been built, tested and installed. These magnets use a 0.635 m long iron shell and provide an integrated gradient of 1.24 T-m/m with an iron pole tip radius of 0.0416 m. Bricks of 0.0254 m thick strontium ferrite supply the flux to the back of the pole to produce the desired 2.44 T/m gradient. For temperature compensation, Ni-Fe alloy strips are interspersed between ferrite bricks to subtract flux in a temperature dependent fashion. Adjustments of the permeance of each pole using iron between the pole and the return flux permits the matching of pole potentials. Magnetic potentials of the poles are measured with a Rogowski coil and adjusted to the desired value to achieve the prescribed strength and field uniformity. Similar quadrupoles are included in the design of the proposed Fermilab Recycler.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Sorting Category: T.14

FNAL Main Injector γ_t Transition Jump Beamtube Design, J. LEIBFRITZ, *FNAL*[1] — The design of the FNAL Main Injector γ_t-jump system calls for a special beamtube that is to be placed inside the pulsed magnets. The requirements are: an elliptical shaped tube that mates with the existing vacuum system, high electrical resistivity for reducing the eddy current effects, high strength for withstanding the vacuum load, simple fabrication and installation processes and low cost. Inconel 718 was selected to meet these criteria. Results obtained from analytical calculations, 2-D and 3-D finite element modeling, and testing of actual prototypes were in general agreement.

[1]Operated by Universities Research Association Inc. under contract with the United States Department of Energy.

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Sorting Category: A.4

The Design of a γ_t-Jump System for the FNAL Main Injector, W. CHOU, B.C. BROWN, S. FANG, J. LEIBFRITZ, K.-Y. NG, H. PFEFFER, I. TERECHKINE, *FNAL*[1] — In order to control the beam emittance and reduce the particle losses during the transition crossing at high intensity, a conceptual design of a γ_t-jump system for the FNAL Main Injector is presented. It is a first-order system employing local dispersion inserts at existing dispersion free straight sections. The goal is to provide a jump of $\Delta\gamma_t$ from +1 to −1 within 0.5 ms. The system consists of 8 sets of pulsed quadrupole triplets. These quads have pole tips of the hyperbolic shape and thin laminations. The power supply uses a GTO as the fast switch and a resonant circuit with a 1 kHz resonant frequency. The elliptical beamtube is made of Inconel 718, which has high electrical resistivity and high strength. Details of the lattice layout, subsystems design and components test results will be discussed.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Sorting Category: D.7

Analysis and Measurements of the Eddy Current Effects of a Beamtube in a Pulsed Magnet, S. FANG, W. CHOU, *FNAL*[1] — The power supply design of the γ_t-jump system in the FNAL Main Injector uses a resonant circuit.[2] A critical design parameter is the ac losses of the beamtube in a pulsed quadrupole. This paper gives an analysis to this problem. An equivalent circuit model based on the impedance measurement was established. The measured and calculated losses are in agreement. Another effect of the eddy currents is the distortion of the magnetic field inside the beamtube. A flat coil and a Morgan coil were used for field measurements up to 20 kHz. The results will be presented.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.
[2]W. Chou *et al.*, *The Design of a γ_t-Jump System for the FNAL Main Injector,* this conference.

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Sorting Category: T.12

A Coated Ceramic Beamtube in a Fast Kicker Magnet, W. CHOU, B. FELLENZ, C. JENSEN, B. PELLICO, *FNAL*[1] — To place a ceramic beamtube in a fast kicker magnet will generate significant coupling impedance between the beam and its environment. The impedance comes from the tube itself as well as from the tube connections. A solution to this problem is to coat on the inner surface of the tube with thin (a few μm thick) metallic strips. This can reduce the tube impedance and make it possible for the image currents to have a smooth transition from the strips to the stainless steel beamtube. This paper will discuss the requirements of the coating and present the measured data of the impedance and magnetic field degradation obtained from several coated tubes.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Sorting Category: T.12

A High Intensity Beam Absorber Core Box for the Fermilab Main Injector Abort System MARK REICHANADTER, C. M. BHAT, C. CRAWFORD, P. S. MARTIN, Fermilab[1] — The Fermilab Main Injector abort system will be capable of absorbing a uniform 150 GeV proton beam of 10 microsecond duration with $\sim 1 \times 10^{14}$ protons per spill, and a rep rate of 1 pulse/1.9 sec. Beam $\sigma_x = \sigma_y = 0.1$ cm. This paper describes the design of a graphite core box with respect to efficient energy transfer in the form of heat to the cooling system, and dissipation of mechanical stress waves resulting from the sudden deposition of beam energy. The results of these studies are presented and implications are discussed.

[1]Operated by Universities Research Association, Inc. under contract No. DE-AC02-76CH03000 with the U. S. Department of Energy

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Sorting Category: A.1

Excitation Characteristics of FMI Dipoles and Magnet Assignment to Reduce Closed Orbit Errors P.S. MARTIN, , C.S. MISHRA, Fermi National Accelerator Laboratory[1] — The Fermilab Main Injector project is building 344 dipoles, produced from steel with varying magnetic properties. The strategies for assigning dipoles, based upon their strength characteristics, are discussed. The closed orbit errors due to the strength variations are expected to be small in comparison to alignment errors.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Variations in the Steel Properties and the Excitation Characteristics of FMI Dipoles P.S. MARTIN, , D.J. HARDING, J.F. OSTIGUY, E.G. PEWITT, A.D. RUSSELL, Fermi National Accelerator Laboratory[1] — The Fermilab Main Injector project is building 344 dipoles, for which over 7000 tons of steel are required. Budgetary and logistic constraints prevented purchasing all of the steel required prior to production. Run to run variations in the magnetic properties of the steel have produced variations in the excitation curves of the dipoles. The variations in the B(H) curves for the steel as a function of run number, and the excitation characterisitics of the dipoles, are discussed.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Modifications to the Excitation Characteristics of FMI Dipoles by Machining P.S. MARTIN, R. BAIOD, D.J. HARDING, J.F. OSTIGUY, A.D. RUSSELL, Fermi National Accelerator Laboratory[1] — Twelve dipole magnets were built under the R&D phase of the Fermilab Main Injector project using steel from a different vendor than the production vendor. These dipoles exhibited an excitation-dependent difference in strength relative to the production magnets, with a maximum difference of about one percent observed at 1.3 T. This difference was too large to allow them to be used in the project. From calculations based on the differences in the B(H) curves of the two types of steel, the high-field strength of the twelve R&D dipoles was reduced by machining the back-legs of the cores. The machining technique will be described, and excitation curves before and after machining will be compared.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Sorting Category: A.4

Intensity Limitations in the FNAL Main Injector, W. CHOU, *FNAL*[1] — The design beam intensity of the FNAL Main Injector is 3×10^{13} ppp. This paper investigates possible limitations in the intensity upgrade. These include the space charge, the transition crossing, microwave instability, coupled bunch instability, resistive wall, beam loading (static and transient), rf power, aperture (physical and dynamic), coalescing, particle loss and radiation shielding, intrabeam scattering, and residual gas, *etc.* It seems that to increase the intensity by a factor of two from the design value is straightforward. Even a factor of five is possoble provided that the following measures are to be taken: an rf power upgrade, a γ_t-jump system, longitudinal and transverse feedback systems, rf feedback and feedforward, stopband corrections and local shieldings.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Design and Magnetic Measurements for the Main Injector Lambertson[1] D.E. JOHNSON, J.E. DIMARCO, D.J. HARDING, P.S. MARTIN, J.-F. OSTIGUY, D.G.C. WALBRIDGE, Fermilab, R. BAIOD, H&L Technique — A new 1.1 Tesla Lambertson for Main Injector injection/extraction and Tevatron injection has been designed and the magnetic properties of the first production magnet have been measured. The Main Injector Lambertsons will be used for injection of 8.9 GeV/c antiprotons from the Antiproton Source and 150 GeV/c antiprotons recycled from the Tevatron, and the extraction of 120 GeV/c protons for antiproton production, 120 GeV/c resonant extraction, and 150 GeV/c protons for Tevatron Injection, and the Main Injector abort. This magnet must accomodate Main Injector and Tevatron circulating beam in its field free region while the field region is at all excitation levels with minimal impact on the circulating beam. The design specifications and results of magnetic measurements in both the field region and field free region for the first production magnet are discussed.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Selecting Magnet Laminations Recipes Using the Method of Simulated Annealing A. D. RUSSELL, R. BAIOD, B. C. BROWN, D. J. HARDING, P. S. MARTIN, Fermi National Accelerator Laboratory[1] — The Fermilab Main Injector project is building 344 dipoles using more than 7000 tons of steel. Budget and logistical constraints required that steel production, lamination stamping and magnet fabrication proceed in parallel. There were significant run-to-run variations in the magnetic properties of the steel [2]. The large lamination size (> 0.5 m coil opening) resulted in variations of gap height due to differences in stress relief in the steel after stamping. To minimize magnet-to-magnet strength and field shape variations the laminations were shuffled based on the available magnetic and mechanical data and assigned to magnets using a computer program based on the method of simulated annealing. The lamination sets selected by the program have produced magnets which easily satisfy the design requirements. Variations of the average magnet gap are an order of magnitude smaller than the variations in lamination gaps. This paper discusses observed gap variations, the program structure and the strength uniformity results.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.
[2]Martin, P.S., et al., Variations in the Steel Properties and the Excitation Characteristics of FMI Dipoles, this conference

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The Making of the Fermilab Main Injector Dipoles[1]

D.J. HARDING, E.G. PEWITT, J.I. SHULTZ, F.W. ULLRICH, *Fermilab*, J. CHIMBIDIS — Fermilab has built over 90% of the dipoles for its Main Injector project. Major subassemblies are fabricated by industry and assembled at Fermilab. We have adhered to a tight quality assurance program internally and have required that our subcontractors do the same. In addition to intensive written documentation on the work process for each component, we have prepared a lengthy video documenting the processes. An abridged version of the video will be shown.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Sorting Category: T.9

Air-Cooled Trim Dipoles for the Fermilab Main Injector[1] I. TERECHKINE, J.A. CARSON, N.S. CHESTER, J.D. GARVEY, G.E. KRAFCZYK, A. MAKAROV, D.J. HARDING, V.A. YARBA, *Fermilab* — New trim dipole magnets, horizontal and vertical, have been designed for the Fermilab Main Injector and are being manufactured. Both types of magnet are 43 cm in length (30.5 cm steel length) and have similar cross-section dimensions. For the horizontal (vertical) magnet the gap is 50.8 mm (127 mm) and the target integrated strength is 0.072 T-m (0.029 T-m). The major design effort lay in making air cooling possible for these magnets. This report presents the magnets' thermal and magnetic properties and discusses the limitation on excitation current.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Magnetic Field Strength and Shape Measurements of the Fermilab Main Injector Dipoles[1] D.J. HARDING, R. BAIOD, B.C. BROWN, H.D. GLASS, T.K. KROC, P.S. MARTIN, C.S. MISHRA, D.G.C. WALBRIDGE, E.G. PEWITT, *Fermilab* — Over 90% of the dipoles for the Fermilab Main Injector have been built and measured. The magnets are 6 m and 4 m in length with a 51-mm gap. In operation, the magnets run from 0.101 T at 8.9 GeV/c to 1.378 T at 120 GeV/c and 1.720 T at 150 GeV/c. These points correspond to injection, Main Injector fixed target physics and antiproton production, and extraction for transfer to the Tevatron. Good field uniformity is required to ensure a stable beam over the whole acceleration cycle. The performance of these dipoles, in both integrated strength and field uniformity, is presented. All magnets produced meet the accelerator requirements.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Design for Fermilab Main Injector Magnet Ramps Which Account for Hysteresis B.C. BROWN, C.M. BHAT, D.J. HARDING, P.S. MARTIN, G. WU, Fermilab[1] — Although the dominant fields in accelerator electromagnets are proportional to the excitation current, precise control of accelerator parameters requires a detailed understanding of the fields in Main Injector magnets including contribution from eddy currents, magnet saturation, and hysteresis. Analysis of magnet measurements and design of control system software is presented. Field saturation and its effects on low field hysteresis are accounted for in specifying the field ramps for dipole, quadrupole and sextupole magnets. Some simplifying assumptions are made which are accepted as limitations on the required ramp sequences. Specifications are provided for relating desired field ramps to required current ramps for the momentum, tune, and chromaticity control.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Magnetic Field Strength and Shape Measurements of the Fermilab Main Injector Quadrupoles[1] D.J. HARDING, B.C. BROWN, J. DIMARCO, H.D. GLASS, T.K. KROC, P.S. MARTIN, C.S. MISHRA, D.G.C. WALBRIDGE, E.G. PEWITT, Fermilab — All of the new quadrupoles for the Fermilab Main Injector ring have been built and measured. The magnets are 2.95 m and 2.54 m in length with a 41.7 mm bore. In operation, the magnets run from 1.61 T/m at 8.9 GeV/c to 15.7 T/m at 120 GeV/c and 19.6 T/m at 150 GeV/c. These points correspond to injection, Main Injector fixed target physics and antiproton production, and extraction for transfer to the Tevatron. Good field uniformity is required to ensure a stable beam over the whole acceleration cycle. A significant octupole is included to assist in resonant extraction. The performance of these quadrupoles, in both integrated strength and field uniformity, is presented. All magnets produced meet the accelerator requirements.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Magnetic Field Measurements of the Main Injector Sextupole Magnets C. M. BHAT, D. J. HARDING, P. S. MARTIN, B. C. BROWN, H. D. GLASS, D. G. C. WALBRIDGE, Fermilab[1] — The Fermilab Main Injector is a high intensity proton synchrotron which will be used to accelerate (decelerate) protons and anti-protons from 8.9 GeV/c to 150 GeV/c (150 GeV/c to 8.9 GeV/c). To achieve stable beam in the accelerator throughout the acceleration or deceleration process, two families of chromaticity compensation sextupole magnets are required. The operating schemes for the chromaticity compensation systems will be different for acceleration and deceleration modes because of the hysteresis of these sextupole magnets and the changed sign of the sextupole field component from beam tube eddy currents in the dipoles. Hence we have carried out detailed magnetic field measurements on four sextupole magnets. Very low fields, including hysteresis effects on unipolar and bipolar ramps (for possible bipolar operation) have been studied. Here we present the results of the measurements and their implications on the acceleration and the deceleration cycles of the Main Injector.

[1]Operated by Universities Research Association, Inc. under contract No. DE-AC02-76CH03000 with the U. S. Department of Energy

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Radiation Levels Around the Fermilab Main Injector Extraction Septa C. M. BHAT, N. V. MOKHOV, Fermilab[1] — The Fermilab Main Injector extraction system will be capable of delivering a uniform 120 GeV beam of $\sim 3 \times 10^{13}$ protons per spill to the fixed target experiments. Up to 2% of the beam is expected to be lost at the extraction septum wires and the Lambertson septum. As a result, one expects increased radiation levels around the septa compared to other parts of the Main Injector. Realistic Monte-Carlo simulations have been performed to estimate the instantaneous and residual radiation levels in the beam extraction region. The results of these studies are presented and implications are discussed.

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Abstract for an Invited Paper
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Status of the Main Injector and Recycler

STEPHEN D. HOLMES, *Fermi National Accelerator Laboratory*[1]

The Fermilab Main Injector is a new 150 GeV synchrotron under construction at the Fermi National Accelerator Laboratory. The FMI has been designed to support a factor of five increase in luminosity available from the Tevatron proton-antiproton collider while simultaneously providing a 2 mA resonantly extracted 120 GeV proton beam. Recently a new antiproton storage ring, the Recycler, has been incorporated within the scope of the project with an expected luminosity gain of a factor of two. Project status, schedule for completion, and expected performance characteristics of the Main Injector and Recycler will be presented.

[1]Operated by Universities Research Association under contract to the U.S. Department of Energy

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Sorting Category: D.2

Impedance Scaling and Impedance Control, W. CHOU, J. GRIFFIN, *FNAL*[1] — When a machine becomes really large, such as the Really Large Hadron Collider (RLHC),[2] of which the circumference could reach the order of megameters, beam instability could be an essential bottleneck. This paper studies the scaling of the instability threshold *vs.* machine size when the coupling impedance scales in a "normal" way. It is shown that the beam would be intrinsically unstable for the RLHC. As a possible solution to this problem, it is proposed to introduce local impedance inserts for controlling the machine impedance. In the longitudinal plane, this could be done by using a heavily detuned rf cavity (*e.g.,* a biconical structure), which could provide large imaginary impedance with the right sign (*i.e.,* inductive or capacitive) while keeping the real part small. In the transverse direction, a carefully designed variation of the cross section of a beam pipe could generate negative impedance that would partially compensate the transverse impedance in one plane.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.
[2]G. W. Foster and E. Malamud, Fermilab-TM-1976 (June, 1996).

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Sorting Category: A.1

Accelerator Physics Issues of a Really Large Hadron Collider, W. CHOU, *FNAL*[1] — A Really Large Hadron Collider (RLHC) was proposed for the post-LHC future.[2] This paper gives a quick survey of a number of accelerator physics issues based on the information obtained from the parameter spreadsheets SSP.[3] The main technical challenges to build such a machine appear to be: the large number of events per crossing (in hundreds), enormous beam stored energy (equivalent to tens tons of TNT), ground motion (which is particularly harmful when the synchrotron frequency is in the sub-Hertz range), small dynamic aperture (due to a long filling time), fast growth of the resistive wall instability (in a fraction of one turn), low threshold of the single bunch transverse instability (due to the big machine size), strong synchrotron radiation (at a level close to the LEP) and short radiation damage lifetime, *etc.* Possible solutions to some of these problems will also be discussed.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.
[2]G. W. Foster and E. Malamud, Fermilab-TM-1976 (June, 1996).
[3]R. Schwitters *et al.*, Proc. 1993 Particle Accelerator Conference, Washington, D.C., May 17-21, 1993, p. 3781.

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Sorting Category: A.1

Study of the Dynamic Apertue During Collisions in the LHC, D. RITSON, W. CHOU, *FNAL*[1] — The dynamic aperture (DA) during collisions in the LHC is mainly determined by the beam-beam effects and by the multipole errors of the high gradient quadrupoles (the triplets) in the interation regions. The computer code JJIP has been modified to accomodate the LHC lattice configuration and parameters and is employed in this study. Simulations over a range of machine parameters and tune modulations are carried out. Empirical scalings (DA *v.s.* the crossing angle, the triplet aperture, the beam emittance and β^*, *etc.*) will be presented.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Sorting Category: A.1

Proposal for an Aluminum Beam Screen in the LHC, W. CHOU, *FNAL*, H. ISHIMARU, *KEK* — This paper proposes a cold beam screen made of high strength, high electrical resistivity aluminum alloy (such as A7N01) as an alternative to the present LHC design that is based on a copper co-laminated high Mn content stainless steel.[1] The main advantages of an aluminum screen are: low cost, simple manufacturing processes and high quality assurance, elimination of millions of small slots and of TEM waves, no adhesion problem, no helium leak problem (vacuum tight), non-magnetic, and others. The available aperture is equivalent to the present design when a non-uniform wall thickness is adopted. A prototype was built to demonstrate the design and the end connections. Concerns about the multipactoring, surface resistance and cryopumping using anodized aluminum[2] will be addressed.

[1]W. Chou, *Feasibility Study of Using Aluminum Alloy for the LHC Beam Screen,* LHC Project Note 3 (SL/AP), October, 1995.
[2]M. G. Rao, P. Kneisel and J. Susta, *Cryogenics,* V. 34, p. 377, 1994.

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Design and Simulation of the Antiproton Recycler Lattice[1] N. GELFAND, S.D. HOLMES, J.A. HOLT, D.E. JOHNSON, L. MICHELOTTI, C.S. MISHRA, Fermilab — The Recycler in a new antiproton storage ring designed to improve antiproton production and allow recovery of antiprotons at the end of stores in the Fermilab Tevatron. The ring will be situated in the Main Injector enclosure, with a circumference of 3319 meters, and will operate at 8 GeV. The design of the Recycler utilizes permanent magnets. Lattice design considerations and performance modeling will be described.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Design and operation of an experimental double-C "transmission line" magnet for the Pipetron. G.W. FOSTER, P.O. MAZUR, T.J. PETERSON, C.D. SYLVESTER, Fermilab[1] — An experimental version of a warm iron, two-in-one superconducting magnet for a low cost multi-TeV hadron collider was built. The magnet consists of a 50-70 kA superconducting power transmission line encircled by an iron yoke with a gap on each side. Each of the two gaps contains one of the circulating proton beams for a p-p collider. Beam focusing is provided by a modest alternating gradient of approximately 10 T/m and therefore the structure need not be interrupted for quadrupoles. The five meter long experimental apparatus contains a one meter long solid iron yoke assembly excited by the shorted secondary of a superdconducting current transformer. Operating experience and plans for future development are discussed.

[1]Work supported by the U.S. Department of Energy under contract number DE-AC02-76CH03000.

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Beam Intensity Limits in the Main Injector through Transition with a Normal Phase Jump Scheme C. M. BHAT, J. MACLACHLAN, Fermilab[1] — The Fermilab Main Injector, a high intensity proton synchrotron to be completed by the March of 1999, will be capable of accelerating (decelerating) protons and antiprotons from 8.9 GeV/c to 150 GeV/c (150 GeV/c to 8.9 GeV/c). Presently, the plan is to accelerate or decelerate the beam through the transition energy of 20.49 GeV, using basic normal phase jump scheme. The details of the operation of the Main Injector for the acceleration and the deceleration cycles differ considerably because of the hysteresis of the Main Injector magnets and the initial beam conditions. The performance of the Main Injector in the deceleration mode is critical if antiprotons are to be recycled during the collider runs of the Tevatron as planned for the Recycler Ring Project. We have performed extensive longitudinal beam dynamics simulations for both modes of operation to determine the beam intensity limits and other properties. We discuss the results and implications of these calculations.

[1]Operated by Universities Research Association, Inc. under contract No. DE-AC02-76CH03000 with the U. S. Department of Energy

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Sorting Category: D.6

Complete Madness DAVID C. CAREY, Fermi National Accelerator Laboratory*, Batavia, Illinois 60510 — The use of MAD notation for the representation of charged particle optical systems has proved to be surprisingly popular. Originally, the MAD notation was intended to be used in other computer programs only for the representation of the beam line itself. Preliminary specifications, calculations to be done, and fitting procedures would all continue to be expressed in the notation peculiar to the various programs.

One such program is TRANSPORT. Retention of the original notation has been a source of much confusion. It is better to have everything in the data be in the MAD style format. We have now accomplished this change. Details will be provided.

*Operated by the Universities Research Association, Inc. under contract with the U.S. Department of Energy.

[1] TRANSPORT, D.C. Carey, K.L. Brown, F. Rothacker, SLAC Report No. R-95-462, May 1995.

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