The Fermilab Main Injector Project

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Abstract

The Fermilab Main Injector (FMI) is an 8-150 GeV synchrotron designed to replace the Main Ring. The FMI, soon to commence construction with completion scheduled for late 1996 (according to the funding profile guidance received from the Department of Energy), will increase the luminosity of the Tevatron collider to 5×10^{31}, double the intensity for Tevatron fixed target physics, and provide high intensity 120 GeV slow spill for test beams or dedicated experiments. The design of the accelerator and beamlines is described, and the construction schedule is presented, along with results from measurements of prototype magnets.

1 INTRODUCTION

The existing Fermilab Main Ring represents, with the changes required to accomodate the demands of the Tevatron era, a serious limitation in the beam intensities that can be provided by the Fermilab Booster. The proposed Main Injector will overcome these limitations and:

1. Provide > 5×10^{12} protons per batch at approximately a 1.5 second repetition rate for antiproton production.
2. Provide year-round 120 GeV high intensity (3×10^{13}) slow-spill beams for test beams and dedicated experiments.
3. Provide high intensity (6×10^{13}) beams for Tevatron fixed-target operation.
4. Provide high intensity (3×10^{11}) proton bunches for the Tevatron collider.
5. Provide nearly 100% transfer efficiency for antiprotons from stacks as large as 2×10^{12}.

These capabilities will allow the Tevatron Collider to achieve initial luminosities of 5×10^{31}. In addition, placing the Main Injector in a separate enclosure from the Tevatron will remove the backgrounds that the present Main Ring produces for the Collider detectors, CDF and D0. The Main Injector will allow doubling the intensity of fixed target beams from the Tevatron, and will provide high intensity 120 GeV beams directly, a capability not present in the existing Main Ring. The new FMI will be situated in the southwest corner of the Fermilab site, tangent to the Tevatron at the F0 straight section. The proximity to the site boundary dictates an oval-shaped ring. A two-fold symmetry is provided, with eight straight sections to accomodate the requirements of rf, injection and extraction devices. The ring will lie in a horizontal plane with the beam elevation at 715.72 feet above sea level, 2.332 m lower than the Tevatron beam elevation.

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2 DESIGN

2.1 Lattice

The Main Injector parameter list is shown in Table 1. The accelerator will be constructed of 344 new conventional dipole magnets, but using quadrupoles, accelerating rf cavities and instrumentation from the Main Ring.

Table 1. Main Injector Parameter List

Circumference	3319.419	m
Injection Momentum	8.9	GeV/c
Peak Momentum	150	GeV/c
Minimum Cycle Time @ 120 GeV	1.467	s
Number of Protons	3×10^{13}	
Harmonic Number	588	
Horizontal Tune	26.4	
Vertical Tune	25.4	
Natural Chromaticity (H)	-33.6	
Natural Chromaticity (V)	-32.9	
Number of Bunches	498	
Protons/Bunch	6×10^{10}	
Transverse Emittance (Normalized, 95%)	20π	mm-mrad
Longitudinal Emittance	0.4	eV-sec
Transverse Acceptance at 8.9 GeV/c	40π	mm-mrad
Longitudinal Acceptance	0.5	eV/sec
β_{max}	57	m
Maximum Horizontal Dispersion	1.9	m

The lattice features two types of cells: normal (34.6 m) cells in the arcs and straight sections, and dispersion-suppressor (25.9 m) cells adjacent to the straight sections to reduce the dispersion to zero in the straight. The tighter focussing and smaller dispersion result in physically smaller beams than in the Main Ring, and an acceptance over three times larger. The standard cell consists of a FODO lattice containing two dipoles in each half-cell; the dipole length is 6 m. The straight section cells are the same length as the normal cells. The dispersion suppressor cells require special length quadrupoles and dipoles; again, the lattice is a simple FODO array with two 4-m dipoles between quadrupoles. A portion of the lattice, including two straight section cells, two dispersion-suppressor cells, and two normal cells, is shown in Figure 1.

2.2 Dipoles

The dipole magnet has been designed and two prototypes have been constructed and measured. A cross-section of the magnet is shown in Figure 2. The dipole coils have approximately twice the amount of copper as Main Ring dipoles. There are four turns per pole of conductor with

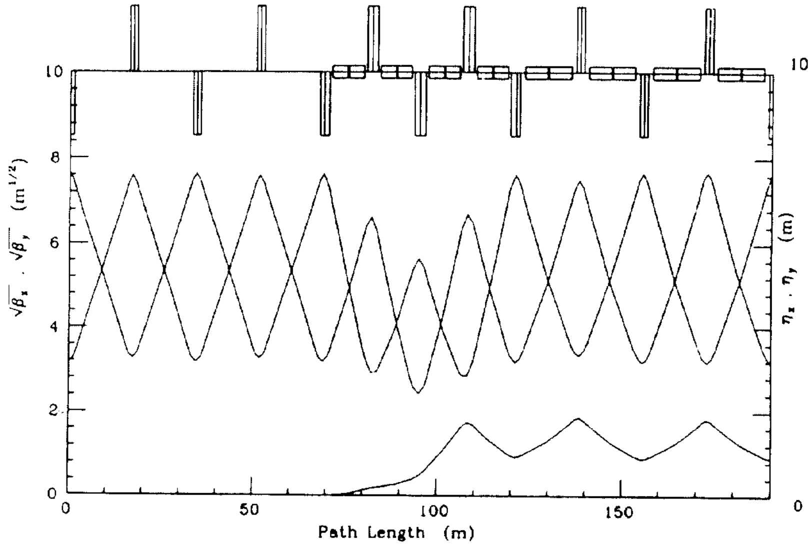

Figure 1. Lattice Functions for Two Straight-Section Cells, Two Dispersion-Suppressor Cells, and Two Normal Cells.

dimensions 2.54 cm x 10.16 cm, with a peak current of 9375 A, and a peak power of 75 kW. The poletip gap is 5 cm, and the good-field region ($\Delta B/B < 1 \times 10^{-4}$) exceeds ±4.4 cm at injection. At the peak field (1.72 T) there is significant saturation producing a sextupole field which determines the strength of the chromaticity-controlling sextupole magnets. Some measurement data[1] of the magnetic field at 8 GeV (injection), 120 GeV (slow extraction) and 150 GeV (Tevatron injection) are shown in Figure 3.

2.3 Beamlines

Four new beamlines are required to connect the FMI to the Fermilab accelerator complex: a 760-m 8 GeV line to connect to the Booster, two 260-m beamlines to connect to the Tevatron (one for protons and one for antiprotons), and a beamline to allow transport of 120 GeV protons to the antiproton production target or to the experimental areas. This latter beamline utilizes the Main Ring remnant that will remain in F-sector of the Tevatron enclosure. Designs exist for all of these beamlines.

The 8 GeV line has been designed with a lattice strongly resembling the Main Injector lattice, except for the matching section at the Booster end of the line. The beamline utilizes existing Main Ring dipoles for most of the bending elements. The quadrupoles will be of the Debuncher Ring style.

The two 150 GeV lines are almost mirror images of one another. They transfer beams to the Tevatron at a point 13 m downstream (in the proton direction) of the center of the F0 straight section with common Lambertson magnets to place the beam on the Tevatron horizontal closed orbit. These beamlines utilize Main Ring magnets for all of the dipoles and quadrupoles.

Beam transfers to the Main Ring remnant utilize the same beamline as for proton transfers to the Tevatron. The Lambertson magnets at the Tevatron are turned off, allowing the beam to continue upwards to the Main Ring elevation.

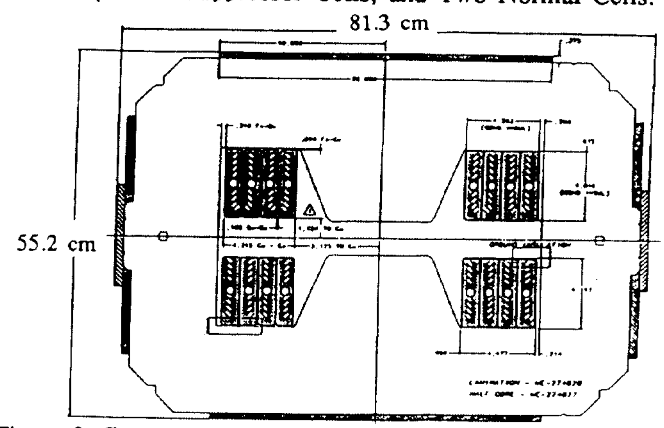

Figure 2. Cross-section of the Main Injector Dipole Magnet.

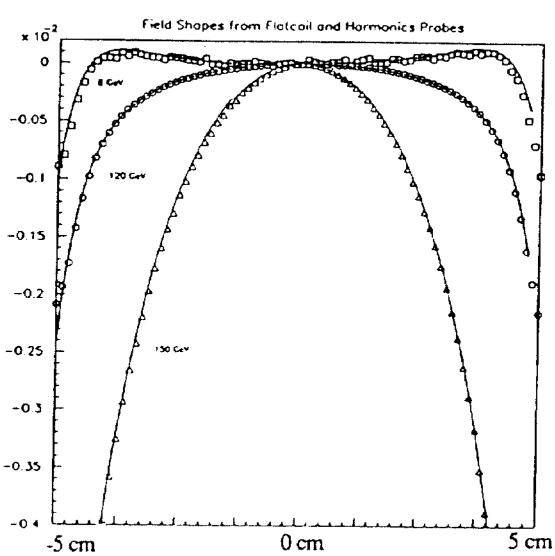

Figure 3. Magnet Measurement Data from the Prototype Dipole Magnet at 8 GeV, 120 GeV and 150 GeV.

2.4 Power Supplies

The dipole magnets (peak current 9375 A) are powered by twelve 1 kV power supplies located in six service buildings evenly spaced around the ring. The bus is a folded loop, folded at each end of the rf straight section. The power supply system will have a 24-pulse regulating power supply, and 12-pulse supplies for the remaining power supplies. The peak voltage to ground will be approximately 1 kV, and the peak voltage between the through-bus and the coil will be approximately 1.8 kV. These high values arise from the sequential turn-on order of the power supplies to reduce the rms feeder currents. The average power for slow-spill 120 GeV operation is 8 MW for the dipoles, and 4.4 MW for the quadrupoles. The power supplies must be capable of ramping the magnets at 240 GeV/s (2.75 T/s).

2.5 Tracking Studies

Extensive tracking studies are underway. To date, the most complete studies have been done at the injection energy of 8 GeV. These studies include the measured multipoles from the prototype Main Injector dipoles, and from the Main Ring quadrupoles. Random errors have been included, with distributions based on the more extensive data from Main Ring dipoles. Misalignment errors have been included, with rms position errors of .25 mm assumed in both x and y for dipoles and quadrupoles, and rms roll angles of .5 mrad for the dipoles. The tracking studies include chromaticity-correcting sextupole magnets which correct the chromaticites to -5 in both planes. The rf voltage is turned on at the nominal injection value, and synchrotron oscillations corresponding to the maximum expected momentum offset are included. The tracking studies reveal an uncorrected closed orbit error of 4 to 8 mm, varying with the seed of the random distribution, and survival for the full 35,000 turns (the nominal injection dwell time for injecting six Booster batches) for particles with initial amplitudes of less than 20 mm. This corresponds to an admittance of almost 60 π mm-mrad, a full factor of two larger than the largest (95%) beam emittances anticipated. It appears that the admittance at 8 GeV is limited by the amplitude-dependent tune shift from the octupole component on the Main Ring quads. The inclusion of octupole correction elements (which can be recycled from the Main Ring) may increase the admittance even further.

Limited tracking studies have been done at transition, 120 GeV and 150 GeV. While the work done so far has yielded no surprises, much more work remains, particularly with regards to the resonant extraction of the beam at 120 GeV.

3 PROJECT STATUS

The Fermilab Main Injector proposal was submitted to the US Department of Energy in 1990 with a three-year construction schedule. The project was included in the President's FY1992 budget with a four-year projected construction period. The project has been reviewed by DOE in 1991 and by technical review panels (one at CERN and one convened at Fermilab) in 1989. An Independent Cost Estimate was performed in conjunction with the 1991 DOE review; the ICE panel validated the Fermilab cost estimate. It was given top priority by the 1990 HEPAP Subpanel which was asked to review non-SSC physics initiatives. The recent (autumn of 1991) HEPAP meetings have also recognized the important role of the Main Injector in maximizing the physics capability of the Tevatron. The Fermilab Main Injector was included in the President's FY1993 budget with an appropriation of $30M and a five-year funding profile. The project was again reviewed by the Department of Energy in early March, 1992.

Some aspects of the civil construction have changed over the past year out of concern for environment, health and safety issues. The ring enclosure was lowered by 1.8 m in order to increase the shielding in the vicinity of a creek which crosses the ring, but resulting in more extensive earth-moving during construction. The service buildings were moved off the berm to afford unlimited occupancy and a water main encircling the ring was included to provide water in the event of a fire in any of the buildings or in the enclosure. Relatively detailed designs exist for service buildings and for all enclosures, with the exception of the changes necessitated by the new beamline designs.

Much work has been accomplished in technical design, in project management and in permit applications. Fermilab was awarded a grant from the State of Illinois, with which the architect/engineering firm Fluor-Daniel has been contracted to provide advance conceptual design work for the civil construction and site mitigation required for the project. The following documents have been prepared or are under revision:

1. Conceptual Design Report, Revision 3.1, detailing the technical design of the FMI.
2. Environmental Assessment, recommending a Finding of No Significant Impact (FONSI), for the project.
3. Preliminary Safety Analysis Report.
4. Configuration Management Plan.
5. Project Management Plan

Permit applications have been filed with the US Corps of Engineers, Illinois Department of Transportation, Illinois Environmental Protection Agency, US Environmental Protection Agency, Illinois State Historical Site Preservation Office, and the Department of Fish and Wildlife. Money contained in the FY92 Congressional authorization has been released and it is expected that the initial site preparation and wetland mitigation efforts will commence during the summer of 1992. Publication of a FONSI in the Federal Register and a review of comments received by the DOE regarding the FONSI will have to occur prior to any construction.

The schedule entails a seven-month shutdown of the Tevatron for construction of the beamline enclosures connecting the Main Injector and Tevatron; commissioning is scheduled to begin in early 1997.

References

1. D. J. Harding, et al., "Design Considerations and Prototype Performance of the Fermilab Main Injector Dipole", Conference Record of the 1991 IEEE Particle Accelerator Conference, pp. 2477-2479.