THE STATUS OF THE FERMILAB MAIN INJECTOR PROJECT

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The Fermilab Main Injector is a new 150 GeV synchrotron now in the fifth year of a scheduled seven year funding profile. An R&D program has been completed, and both civil construction and the production of technical components are well underway. The Main Injector Project is part of a larger upgrade program at the Fermi National Accelerator Laboratory called Fermilab III, which is designed to ensure a Collider luminosity in excess of $5x10^{31}$ $cm^{-2}sec^{-1}$ while simultaneously providing a 2 micro amp resonantly extracted 120 GeV beam. The 120 GeV beam will provide unique capabilities in the realm of rare neutral K decays and long baseline neutrino oscillation experiments. The use of permanent magnets for the 8 GeV transfer line into the Main Injector has been approved, and research in support of a proposal to build a permanent magnet Recycler Ring in the Main Injector enclosure has been initiated.

1. OVERVIEW

Fermilab III, a program to produce at least a factor of 30 increase in the Tevatron Collider luminosity as compared with a 1988-89 baseline of $1.6x10^{30}$ $cm^{-2}sec^{-1}$, has included several projects at Fermilab of which the Main Injector is designed to produce the final factor of five increase in luminosity. Projects already completed have produced initial luminosities in excess of $2x10^{31}$ cm^{-2}-sec^{-1}, leading to the hope of achieving a luminosity above $1x10^{32}$ $cm^{-2}sec^{-1}$ with the Main Injector. The Fermilab accelerator complex is a cascade of four accelerators (400 MeV Linac, 8 GeV Booster, 150 GeV Main Ring, Tevatron). The Main Ring and Tevatron share a single tunnel enclosure. The Main Injector will functionally replace the Main Ring in a separate tunnel enclosure. The Main Injector is an accelerator with the two-fold symmetry of a sheared oval, the exact shape being dictated by siting considerations. The circumference is 3319 meters, seven times the Booster or 28/53 of that of the present Main Ring. The lattice is based upon a 90^{o} FODO cell, with zero dispersion straight sections created with short dipoles. The normalized transverse admittance is 40π mm.mrad and the longitudinal admittance is 0.5 eV-sec. β_{max} is 58 meters representing stronger focusing than the Main Ring. In addition there are five beam lines to provide for: injection from the Booster at 8 GeV; two lines for proton and antiproton transfers from the Main Injector to the Tevatron at 150 GeV; and two lines at 120 GeV for extraction of protons for antiproton production and to the existing fixed target switchyard.

New technical components consist of 344 dipoles and 12 dipole power supplies, 80 long quadrupoles, 108 sextupoles, 208 dipole correctors, and 18 rf power amplifiers. As reported previously "recycled" technical components to be relocated from the existing Main Ring included 18 rf cavities, 128 quadrupoles and 6 power supplies, 102 correction magnets, 589 beam line magnets, and assorted power supplies, controls, and instrumentation. [1] During the last year a proposal to build the arc-segments of the 8 GeV transfer line from the Booster to the Main Injector with permanent magnets has reduced the recycled beam line magnets by 94 (to 495) and added 123 newly designed permanent magnets.

The 40π mm.mrad normalized admittance at 8 GeV has been achieved by the design of large aperture magnets and with great care to place injection and extraction devices at advantageous places in the lattice. These considerations, coupled with the requirement for a 1.5 second cycle time to 120 GeV for antiproton production, or a 1.8 second cycle time for neutrino production, have implied the necessity of designing new conventional copper and iron magnets with a good field quality over a large aperture with a cost effective high ramp rate. Power supplies and rf capabilities matching these requirements have also been developed.

2. DESIGN; R&D; FUNDING

Design reports were prepared before the project began. An R&D program for the guide field dipoles, the dipole power supplies, and a new solid state rf power amplifier has been completed. [1] The R&D program was expanded to include research to demonstrate the properties of permanent magnets for use in the 8 GeV transfer line, and to develop practical methods of construction. This portion of the R&D program is now nearing completion having constructed several short models of pure dipoles, gradient dipoles, and quadrupoles, as well as three full length gradient dipoles and two full length pure dipoles. A production readiness review for the pure dipoles has been completed, and the gradient dipoles are now undergoing magnetic testing.

The project is now authorized, excluding R&D, as a seven year project with a total, then year cost, estimated at $229.6M. Including R&D the total costs are $259.3M. Now in the fifth year of funding appropriations, the total appropriated to date (FY92 through FY96) is $146.65M plus all R&D. The actual appropriations have been FY92

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$11.65M, FY93 $15M, FY94 $25M, FY95 $43M, FY96 $52M and budgeted amounts for future years are FY97 $52M, and FY98 $30.60M, with commissioning extending into FY99. On May 1, 1996, the cost estimate included $101.9M for technical components, $90.8M for civil construction, $8.3M for project management, $1.4M for G&A, and the remainder ($27.2M) was unassigned contingency. Of the $146.65M appropriated to date $132.9M has been obligated and $104.8M has been costed for completed work. The costs are $0.9M ahead of the project baseline schedule and the project is on budget.

3. CIVIL CONSTRUCTION

The civil design for the Main Injector Project is now complete [1,2,3]. The design work was initiated by Fermilab staff and the detailed design performed by Fluor Daniel, a national A&E firm. The basic civil requirements of the Main Injector are: 1) a Ring Enclosure for the accelerator consisting of 1181 precast units in an inverted "U" shape and cast-in-place tunnel segments at 'non-standard' locations; 2) tunnel connections for transport of 8 GeV Protons from the Booster to the Main Injector (211 more precast units), and for transfer of 150 GeV Protons and Antiprotons from the Main Injector to the Tevatron; 3) connections to existing enclosures at the Booster and at MR/Tev F0; 4) service buildings at appropriate locations around the Main Injector, on the 8 GeV transfer Line, and as necessary for connection to the Tevatron; 5) site utilities - water, electrical, new 345 kVolt service, etc.; and 6) various other installations. The funding profile led project management to divide the civil work into approximately 24 packages for construction and/or procurement. A list of the bid packages (civil construction contracts) and civil procurement items is found in the following table. Projects for which the civil construction is completed are indicated "complete". Details about the scope and bidding of 'completed' projects have been previously reported. [1,2] Projects in progress are so indicated. Projects to be funded in this or future fiscal years are indicated by the notation of the fiscal year when the obligation is expected.

1) Wetlands Mitigation (complete)
2) Accelerator Enclosure at MI-60 (complete)
3) MI-60 Service Building (complete)
4) Site Preparation, roads, utilities (complete)
5) Substation Hardstand (complete)
6) Ring Enclosure Precast Units (complete)
7) 8 GeV Line Precast Units (complete)
8) Main Injector Ring Enclosure (95% done)
9) 8 GeV Line (3 phases-complete)
10) 8 Main Injector Service Buildings (40% done)
11) Cable Trays in Enclosures (in progress)
12) 13.8kV Distribution (FY96)
13) 345kV transmission Line (FY96)
14) Kautz Road Substation (in progress)
15) Commonwealth Edison 345kV link (in progress)
16) MR-F0 Service Building, new F17 (FY97)
17) Cooling Ponds and Cooling System (FY96)
18) Connect Main Injector to MR/TeV F0 (FY98)
19) Connection of 8 GeV line at Booster (50% done)
20) Landscaping, Road Paving, etc. (FY98)
21) Various Transformer Procurements (in progress)
22) Shielding Steel Procurements (complete)
23) Survey Monuments (complete)
24) Reconstruction of E4R facility (in progress)

Delivery of all 1392 of the enclosure inverted "U" precast units was completed in August 1995, and the last pieces set in the ring enclosure and the 8 GeV line by February 1996. The final ten pieces were set in the Booster connection in June 1996. The below grade ring enclosure was completed on April 18, 1996, and occupancy of the last section was achieved May 8, 1996. The remaining work included in the enclosure contract, valued at less than 5% of the enclosure contract, consists of setting some additional shielding steel, constructing shielding berm, some utilities installation, and preparation of the last service building site. The 8 GeV transfer line enclosure was completed in May 1996. When the decision was made to use permanent magnets in the 8 GeV transfer line arc segments, it became possible to commission the 8 GeV line in 1997 without waiting for the components to be relocated from the Main Ring in 1998. A contract was awarded in late 1995 to build the 8 GeV connection at the Booster during 1996. The work in proximity to the Booster was accomplished during a laboratory shutdown from February through June 1996, and all work will be completed by September 1996. A contract was awarded for the construction of the eight service buildings around the Main Injector ring and on the 8 GeV transfer line in September 1995. This work was 40% complete on May 1, 1996. Installation of cable trays in the tunnel enclosures was awarded in Spring 1996 and is beginning as parts are being delivered.

4. TECHNICAL COMPONENTS

The technical components for the Main Injector Project have been divided into ten "WBS Level 3" areas, each with a "Level 3 Manager" responsible for the cost estimate, scheduling, and overall design and production. These ten areas are: 1) Magnets; 2) Vacuum; 3) Power Supplies; 4) rf Systems; 5) Kickers and Slow Extraction; 6) Instrumentation; 7) Controls; 8) Safety Systems; 9) Utilities and Abort; and 10) Installation.

Fermilab acts as the general contractor for the dipole magnets and only performs the final assembly (about 6% value added). Production has reached a steady state of one dipole completed in less than two working days. There are two streams of material which meet just prior to final assembly for this to work correctly. The magnets each consist of two insulated copper coils and two steel half-cores fabricated from stacked steel laminations. One stream has to provide the insulated coils at the rate of a pair every two days, and the other stream has to provide a pair of stacked half-cores every two days.[1] As of the end of May 1996, approximately 190 production dipoles have been completed and measured. Continued attention to variations in steel properties and to the quality of the insulation process has been necessary, but the dipole magnets are now being selected for particular locations in the lattice based upon magnetic performance measurements, and more than 100 dipoles have been installed in the ring enclosure. The 12 R&D dipoles were built with steel from a different vendor. This steel exhibited higher strength at higher currents. A modification to reduce the strength of the 12 R&D dipoles by reducing the size of the return leg has been successfully demonstrated and all 12 will be used in the Main Injector.

The Main Injector will utilize recycled quadrupoles from the Main Ring for most of the quadrupole requirements. Eighty additional quadrupoles are required for the Main Injector Ring lattice. All 35 of the 254 cm (100") and all 52 of the 295 cm (116") quadrupoles have been fabricated at Fermilab (including seven spares). A total of 113 sextupole magnets are required and 61 have been built at Fermilab at the rate of two per month. All of the completed magnets have been powered and measured at the Magnet Test Facility.[4,5] The first production Lambertson magnet has been fabricated and magnetic measurements are underway. C-magnets and trim dipoles are under construction, and some additional quadrupoles (3Q120 and 3Q60) will begin fabrication in FY97. The permanent magnet R&D program for the 8 GeV arc segments is complete and production of dipoles has begun. Gradient dipole production will begin at the end of FY96.

Construction of dipole power supplies, kicker supplies, beam position monitors, and rf components is well underway. Utilities have been installed for the low conductivity water (LCW) system in the MI-60 service building, and have been completed in approximately one-half of the ring enclosure. More than 90% of the ring enclosure and 8 GeV line LCW piping is under contract, and the remainder is being bid.

5. SCHEDULE; POSSIBLE SCOPE ADDITIONS

It will be necessary to turn off the Fermilab physics program for a period of approximately nine months to connect the Main Injector to the existing complex at the Tevatron rf straight section (called MR/Tev F0). To minimize the down time of Fermilab all the rest of the civil and technical construction, and the installation of new components, must be completed prior to the final civil interconnections at MR/Tev F0. Technical staff cannot be double counted during the shutdown, so all possible prior work must be completed so staff is available to dismantle, remove, and recondition items, such as the Main Ring quadrupoles, being recycled into the Main Injector. According to the present funding profiles which require $52M in FY97, it will be just possible to complete the pre-shutdown work in time to permit the 9 month shutdown to begin in February 1998 so that commissioning can be completed in early 1999. It is absolutely necessary that the present funding profile be maintained if this schedule is to be met.

An addition to the scope of the Main Injector Project is under consideration. This proposed work would encompass the construction of an 8 GeV Recycler Ring using permanent magnets in a ring of essentially identical lattice design located immediately above the Main Injector. This ring would function both as a super-accumulator accepting antiprotons periodically from the present accumulator ring and as a repository of antiprotons recovered at the end of a collider store. It is anticipated that collider luminosities in excess of $1x10^{33}$ $cm^{-2}sec^{-1}$ might be ultimately achieved with the recycler ring and additional accelerator improvements. Design reports and cost estimates are being reviewed in house in preparation for proposing this additional scope of work to the U.S. Department of Energy.

6. REFERENCES

[1] D. Bogert, W. Fowler, S. Holmes, P. Martin, and T. Pawlak, "The Status of the Fermilab Main Injector," Proceedings of the 1995 Particle Accelerator Conference, Dallas, TX, Vol. 1, p. 391,[May 1-5,1995].

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[3] D. Bogert, W. Fowler, S. Holmes, P. Martin, and T. Pawlak, "The Status of the Fermilab Main Injector Project," Proceedings of the 1993 Particle Accelerator Conference, Washington, D.C., Vol. 5, p. 3793, (May 17-20, 1993).

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[5] D. J. Harding et. al., "Magnetic Field Measurements of the Initial Fermilab Main Injector Production Quadrupoles", Proceedings of the 1995 Particle Accelerator Conference, Dallas, TX, Vol. 2, p. 1337,[May 1-5,1995].