MI-0244

" For the FMI Commissioning Team Main Injector Department Fermilab "

C.S. Mishra

July 22,1998

Main Injector Commissioning Plan

C. S. Mishra
For the FMI Commissioning Team
Main Injector Department
Fermilab

The Fermilab Main Injector is designed to deliver high intensity beams to the Tevatron, anti-proton production target and 120 GeV proton beams to the several beam lines. The Main Injector with the Recycler Ring will increase the luminosity of the Tevatron collider program to $2x10^{32}$ $cm^{-2}sec^{-1}$. This document describes the beam on commissioning plan of the Main Injector.

Introduction

The Fermilab Main Injector (FMI) is designed to accept protons from the Fermilab Booster at 8.9 GeV/c. The proton beam from the Booster is transferred to the FMI using the newly constructed MI8 beam transfer line. The MI8 line is made up of permanent magnets. Conventional electro-magnet sections accomplish the injection matching into the MI8 line from the Booster and out of the MI8 line into the FMI. The FMI will also accept antiprotons from the accumulator for transfer into the Recycler Ring. The injection momentum of the FMI is 8.9 GeV/c. The FMI is designed to support four different operation modes. Depending on the acceleration cycle it accelerates the protons or antiproton to 120 or 150 GeV/c.

Goals of FMI Commissioning

The DOE performance milestone goals of the FMI commissioning are to establish an efficient transfer of beams from the Booster to the Main Injector flattop energies. The following steps will achieve these goals.

- Establish beam in the full MI8 line.
- Understand and improve the performance of the full MI8 line.
- Establish efficient and matched transfer between the MI8 line and FMI.
- Establish beam in the FMI for all different operational modes.
  - Protons are transferred from the Booster into the Main Injector ring and accelerated to 120 and 150 GeV energy.
  - Protons are transferred from the Booster into the Main Injector ring and a total intensity of $1x10^{13}$ protons are accelerated to 150 GeV. This corresponds to $2x10^{13}$ proton per Tevatron cycle based on the planned use of two Main Injector cycles per Tevatron cycle. This will require multi-batch injection from Booster.

    - The proton injection and acceleration to 150 GeV efficiency of greater than 75% will be achieved. This efficiency is defined as the ratio of protons accelerated to 150 GeV to protons injected at 8GeV from MI8 line.
    - Protons are accelerated to 120 GeV in the Main Injector ring, at a 2.5 sec repetition rate.
    - A single Booster batch of $2x10^{12}$ protons will be injected into the FMI ring and accelerated to 120 GeV. They will be extracted in a single turn to the MI-40 beam abort. This demonstrates the ability to deliver $2x10^{12}$ protons at 120 GeV to the antiproton production target.
    - $2x10^{13}$ Protons are accelerated to 120 GeV in the Main Injector ring and resonantly extracted.
- Study the beam dynamics in FMI; determine the best operating point at injection and through out the ramp to improve performance.

We plan to achieve an overall proton transfer efficiency of 80% from Booster to FMI flattops by Dec 15 1998.

Operational Modes of FMI

- **Antiproton Production:** In the antiproton production cycle of the FMI, 1 Booster batch of $5x10^{12}$ protons will be accelerated to 120 GeV. The protons will be extracted in a single turn to the antiproton production target. The designed cycle time of FMI in this mode is 1.5 sec with a flattop of 40 msec.
- **FMI fixed target experiments:** The FMI is designed to support different fixed target experiments at 120 GeV. It will support two different types of HEP programs. One by sending 120 GeV beam using slow spill system with 1 sec flattop and other using the fast spill system with 1 msec extraction time. In these modes of operation 6 Booster batches of protons with a total intensity of $3x10^{13}$ will be accelerated to 120 GeV.
- **Tevatron fixed target experiments:** The FMI will also support the Tevatron fixed target program at 800 GeV. Five or six Booster batches each containing about 10^{12} protons will be injected into the FMI. The beam will be accelerated to 150 GeV and extracted into the Tevatron. The cycle time of this mode will be 2.4 sec with a flat top of 250 msec. In this mode of operation the FMI will inject a total of about 10^{13} protons into the Tevatron. Two Main Injector cycle each containing half the proton intensity will be required.
- **Tevatron Collider Injection:** The FMI will support a 36x36-bunch operation of the Tevatron during the first phase of Run II. In this mode of operation the FMI will accelerate both the proton from the Booster and antiprotons from the Recycler to 150 GeV. The proton bunches will be coalesced at 150 GeV before they are transferred to the Tevatron.

Prerequisite of Commissioning

The FMI department along with the FMI Level 3 managers is working to certify that all the subsystems are ready and safe to operate before beam can be injected into the Main Injector. The Level 3 manager has the responsibility to certify that their sub-system is ready for beam on operation (Appendix-1). But, the FMI operation will require safe operation of several sub-systems operating simultaneously. This may or may not be verified by individual Level 3 managers. The Beams Division head has appointed a Main Injector Safety Review Committee (MISRC) to review the readiness and safe operation of FMI subsystems from the FMI Commissioning point of view (Appendix –2).

The FMI Commissioning team in collaborations with the Beams Division Operation department is making several checks of the accelerator components, their connections and operation from the control room. A sample of checks being carried out is listed below.

- Complete bus inspection. Clear shorts and interference between power bus and accelerator elements and/or ground. Applying low voltage to the bus will test both the dipole and quadrupole bus.
- All bend bus manifold bolts at dipoles and quadrupole bypass locations will be checked for proper torque.
- Confirm all modes damping resistor connections.
- Visual check of corrector magnet connection. We are also performing a field check of the corrector magnet polarity.
- Visual check and confirmation of all LCW valves including valves in the abort system. We are also checking the operation of the valves using the LCW application program.
- Visual inspection of vacuum valves position read-back and operation using application software from the control room.
- Check the position and operation of multi-wires, BLMs. We are also working on checking the continuity and calibrations of the BPM.
- A smooth commissioning of FMI will require that the commissioning team have an easy access to all the relevant information. We have set up a group of people who are working on gathering, certifying and making these information available on the Main Injector Web page. (http://www-FMI.fnal.gov). The magnet data, detailed FMI lattice and Lattice functions will be available at several points in the acceleration cycle. The BPM and other calibration data will also be available.
- Several application programs are being written for the FMI operations. The author, overseers and members of the Main Injector Department (Appendix-3) will review each application program. All application programs, which will be used to measure, adjust and calculate lattice parameters will be tested using the Online Model. The Online model redirects the call from an application program to hardware to a software-simulated accelerator.

FMI Commissioning

Several modes of FMI operation will be commissioned during the commissioning phase. We have planned the FMI commissioning to take place in several phases. Each phase will be used to commission and understand one aspect of the FMI operation. There is no beam absorber in the MI8 of FMI till MI40 abort. The MI8 line and MI10 to MI40 sector of FMI will be setup to accept 8 GeV beams from the Booster. During the initial commissioning phase we will be using the minimum amount of Proton beam from Booster.

- Phase 1: Establish beam in the MI8 Line: In this phase of commissioning one batch and one turn of Booster proton beam will be injected into the MI8 Line. This beam will be used to match the injection from the Booster into the MI8 line. We have already done considerable amount of MI8 tuning during the earlier phase of partial MI8 line commissioning. The injection matching between Booster and the MI8 is well understood. We will be mostly working on tuning downstream of 833 location in MI8 line. Dipole correctors will be adjusted to establish loss less beam in the MI8 line. We will set the BPM timing for the downstream MI8 line.

  Initially a dipole kick will be used to inject the beam from MI8 line into the FMI at MI10 location. An initial rough lattice matching between the end of the MI8 line and MI10 injection point will be done to reduce the injection loss into FMI.

  The beam and lattice parameters will be measured and verified against the beamline model.

- Phase 2: Establish Single turn beam to MI40 Abort: In this phase of commissioning we will improve on the lattice matching between MI8 line and MI10 injection point. Using the dipole correctors the beam orbit will be adjusted to establish a loss less beam from MI10 to MI40.

  This phase of commissioning will be used to commission FMI instrumentation, corrector elements and several application softwares. The injection and abort kicker will be timed-in. Using the dipole correctors we will perform a limited aperture scan to verify unobstructed aperture.

  The FMI sector from MI10 to MI40 can be treated as a beamline. Using the beam line analysis program, similar to the one used for MI8 line, we will make preliminary measurements of the lattice function.

- Phase 3: Establish Coasting Beam in FMI at 8 GeV: During the phase 2 of commissioning beam injected at MI10 was aborted at MI40 dump. In the phase 3 of FMI commissioning the beam will be allowed to go around the ring at 8 GeV for >0.4 sec after that it would be aborted into the MI40 dump. This will be used to study the beam lifetime in FMI at 8 GeV.

  All activities performed in the Phase 2 of the commissioning will be repeated in this phase. We will measure the tune and chromaticity of the FMI using the turn by turn hardware. The operating point of FMI in tune and chromaticity space will be adjusted to improve the lifetime of beam at 8 GeV. We will measure lattice function and compare them with design values.

- Phase 4: Establish Accelerated Beam and RF Capture: In this phase of commissioning the proton beam from Booster will be accelerated to 120 and 150 GeV. The results of the power supply commissioning will help us determine the ramp time and shape [redacted] to accelerate protons from 8 GeV to 150 GeV. It is possible that we will be required to perform small modification to the ramp rate with respect to the design values and RF settings to improve the performance of the FMI.

Several break points are setup between 8 and 150 GeV. The orbit-smoothing program will be used to smooth the closed orbit up the ramp. We will measure the tune and chromaticity of FMI at these break points and adjust them around the design value to improve the acceleration efficiency. All the measurements described in phase 2 and 3 will be repeated up the ramp.

At 150 GeV we will work on RF Bunch manipulations and coalescing of bunches.

- Phase 5: Intensity increase: At this point in the commissioning we have established nominal working points for FMI from injection to 150 GeV using one turn beam from the Booster. In this phase of the commissioning we will work on increasing the intensity of the beam injected from the Booster and repeat all the measurements performed in Phase 4. We will investigate the intensity limitations of FMI and adjust operating points to improve acceleration efficiency. The goal of this phase will be to reach the maximum design intensity in each mode of the FMI operations.

- Phase 6: Beam Transfer: In this phase of commissioning we will commission the proton beam transfer lines to pbar and Tevatron. The lattice parameters of the transfer lines will be matched to the FMI Lattice. The beam line analysis program will be used to study and improve the performance of the transfer line and attempts will be made to minimize the emittance dilution due to transfer.

- Phase 7: Optimization and Accelerator Physics Studies: In this final phase of FMI Commissioning we plan to spend considerable amount of time understanding the beam dynamics. Detailed measurements of FMI lattice will be made. We will utilize the FMI correction systems to improve the performance of the FMI. All of these improvements will be studied with detailed model. The FMI and Beam Physics departments have spent considerable amount of time developing a very detailed model of the FMI. This model includes all the magnetic measurement information. These studies and simulations will be performed at several points up the ramp.

Schedule of Commissioning

The FMI beam commissioning startup is tied with all the subsystems being completely ready and certified. The Booster shielding, LCW repair and power supply tests are the main tasks that will take time to finish. The current schedule for the beam commissioning to start is Sept 12 1998. We expect to be in the final phase of commissioning by the middle of Dec 98, except for resonant extraction system which will be commissioned early 1999.

Fermilab
Main Injector Department

July 14, 1998

To: Level 3 Managers

From: Phil Martin

Subject: Main Injector "Deliverables"

The enclosed draft document entitled "System Requirements For Beam Commissioning" outlines the documentation I would like to see from each Level 3 Manager prior to beginning beam commissioning of the FMI. Please review the requests and provide me feedback as to whether the requests are clear and are reasonable. Please also provide me with feedback as to when you will be able to satisfy this request.

This list is also being given to Frank Nezrick and the MI Safety Review Committee which is charged with reviewing our commissioning plans. I expect that many of you will be requested to supply supplemental information to the MISRC.

Fermilab
Main Injector Department

System Requirements For Beam Commissioning
(Draft)

Prior to beginning beam commissioning, the following systems are required to be operational. The operational readiness of each system is to be certified by the appropriate Level 3 Manager (L3M) in a memo transmitted to the Associate Project Manager For Accelerator Systems. This list pertains to the Main Injector Ring and the MI-8 beamline; additional instructions will be given for the Recycler Ring and its transfer lines, and for the transfer lines to the Tevatron and Main Ring remnant.

1. Magnets. The L3M shall provide assembly drawings (latest revision) of each magnet type used in the 8 GeV line and the MI ring. The Technical Design Handbook should be reviewed for accuracy of the basic magnet parameters listed in the various tables and any errors or omissions corrected.
2. Power Supplies. The L3M shall verify the readiness of the 12 dipole and 6 quadrupole power supplies. The L3M shall also verify the completion (continuity) of the dipole and quadrupole electrical circuits. MECAR and the MECAR application page, I2, shall be loaded with appropriate ramps and circuit parameters for each of the MI cycles. The L3M shall verify the readiness of the 2 sextupole power supplies together with interlocks and alarms, the control cards for the power supplies, and the application program for loading ramp waveforms. The L3M shall also verify the completion (continuity) of the sextupole electrical circuits. Null ramp waveforms shall be loaded into each power supply control. The L3M shall verify the readiness of all correction element, MI-8 line, injection and abort power supplies, together with interlocks and alarms, water-cooling (if appropriate), control cards for the power supplies, and the application program for loading ramp waveforms. All correctors should initially be set to zero. A description of the harmonic corrector configuration should be provided.

3. Vacuum. The L3M shall verify that the ring is under vacuum with an average pressure of less than 2 x 10^{-7} Torr, and a maximum pressure of less than 5 x 10^{-6} Torr, and that the status of all vacuum valves are read back properly via the controls system. Any closed valve should alarm in the Main Control Room. A "final" set of vacuum drawings should be provided, showing all vacuum elements in MI-8 and MI ring.
4. RF. The L3M shall verify that the rf cavities are installed and aligned, and that the high level rf system is operational with appropriate interlocks and alarms enabled and with control cards and application programs for reading and setting of the high level rf. The L3M shall also verify that all known requests for cable pulls and terminations have been completed for the low level rf and for the MI-60 region instrumentation.
5. Kickers. The L3M shall verify that all kickers systems are operational, and that the appropriate amplitude and timing control cards and diagnostics have been provided. A description of each kicker system, including ACNET device names, nominal and maximum operating levels, etc. should be provided.
6. Instrumentation. The L3M shall verify that all BPMs are checked out to the maximum extent possible, and that BLMs are installed and connected. Profile monitors and beam current monitors shall be installed and tested; a short description of the various devices, including ACNET names, device locations, calibration factors, etc. shall be written to aid the commissioning crews.
7. Controls. The L3M shall verify that the appropriate controls and networking are provided at all Main Injector service buildings, including TCLK and MIBS. If any are missing, a list of missing elements together with a schedule for completion should be provided.
8. Safety system. The L3M shall verify that both the radiation and electrical safety systems are fully operational, that the Operations Dept. has been trained in search and secure, and that initial entry procedures for the MI enclosure and the abort enclosure have been developed and approved.

DRAFT 2
June 30, 1998

To: Frank Nezrick, Chairman Main Injector Safety Review Committee

From: Steve Holmes, Beams Division Head

SUBJECT: REVIEW OF THE READINESS TO UNDERTAKE MAIN INJECTOR COMMISSIONING WITH BEAM

In approximately three months the Main Injector will be ready to accept 8 GeV protons from the Booster. The Main Injector Project will use these protons first to establish circulating beam and then to accelerate beam to the full design energy. An Accelerator Readiness Review (ARR) covering this activity has been conduction by the Fermilab ES&H Section and their report has been forwarded to the director. The ARR basically confirms the adequacy of the Safety Assessment Document (SAD) for commissioning and identifies a punchlist of items that need to be completed before the configuration of the Main Injector is consistent with the SAD and can be safely commissioned. Once I, as Beams Division Head, feel all systems are in a state to allow the introduction of beam into the Main Injector in a safe manner I will forward the beam permit for this to the Fermilab director, accompanied by documentation of satisfactory resolution of the ARR punchlist items. Following review of this documentation, and with the concurrence of DOE, the Fermilab director will authorize the introduction of beam into the Main Injector at intensities specified in the beam permit.

I would like the Main Injector Safety Review Committee to assist me in this process by providing an evaluation of the readiness of the Main Injector for commissioning. Specifically, I would like you to assess whether the major subsystems of the Main Injector can be operated safely for beam commissioning activities, and in conformance with established Beams Division ES&H policies and procedures. This request does not include commissioning of the Recycler—I will submit a subsequent request for review of those activities at the appropriate time.

Your review should follow the sequence of activities described in the Main Injector commissioning plan. This plan should be available from Phil Martin. To set the review in context, I am basically looking for advice on signing the beam permit—emphasizing aspects that may lie at the interface between systems and so may not be covered by the department heads' sign off.

I imagine a two step process for completion of your review. As a first step I am asking you to review the readiness of the major systems to operate safely as an integrated system. Any recommendations you would make should be forwarded to me as part of this step. I would like to receive your initial report containing your findings and recommendations by August 15. As a follow-on I would like you to verify that recommendations generated in step 1 have been dealt with satisfactorily. I would hope that this step can be completed by September 1. At that time I would also like you to issue recommendations on the operating intensity that should be allowed in the Main Injector during the commissioning period.

For input to your review I would like you to rely on Phil Martin and Shekhar Mishra for commissioning planning and sequences, and Linc Read as liaison to the Beams Division Shielding Committee and the ES&H Section Accelerator Readiness Review.

Thank you for your help.

cc
D. Bogert
G. Jackson
P. Martin
S. Mishra
L. Read

Fermilab
MAIN INJECTOR DEPARTMENT

C. Shekhar Mishra
Fermi National Accelerator Laboratory
M.S. 323, Main Injector Department
Batavia, IL 60510
(630) 840-4094
Fax: (630) 840-8461
Email: Mishra@fnal.gov

July 16, 1998

To: Distribution

From: Shekhar Mishra

The current Main Injector turn on schedule shows that we will be injecting beam into the FMI sometime in late Aug 98. Several people in the Beams Division have been working on writing application programs for the FMI operation. Starting 15 June 98, I will like to start reviewing these applications programs. The overseers of these application programs should review them and report to Brian Hendricks and me.

The application programs, which are developed to measure and control the accelerator lattice parameters can be tested using the online mode the Beam Physics Department has been developing. I will like to use the online model to the extent possible to debug these applications program before the FMI commissioning.

I will like Brian to co-ordinate this activity of the code review with the programmers, overseers and the Beam Physics Department Online Model Group when necessary. I will like the following people from the FMI department to interact with the programmers to insure that all the information needed is available and correct to the best of our knowledge.

Bruce Brown:	Magnet Data
Alan Hahn:	Instrumentation and Calibration
Ioanis Kourbanis:	RF
Saeed Assadi:	Lattice Parameters and Displays
Dave Johnson:	Injection and Extraction
Chandra Bhat:	Correctors

I have requested Jim Holt to help coordinate this activity from the Online Modeling Group. I am sure this will generate a lot of interaction between different groups.

Thanks for your co-operation.

Distribution:

Saeed Assadi
Chandra Bhat
Dixion Bogert
Bruce Brown
Alan Hahn
Brian Hendricks
Steve Holmes
Jim Holt
Gerry Jackson
Dave Johnson
Ioanis Kourbanis
Phil Martin