

December 18, 2000

Fermilab Accelerator Advisory Committee

Third Meeting: December 4-5, 2000

Committee Report

The third meeting of the Fermilab Accelerator Advisory Committee took place on December 4 and 5, 2000. The Committee members in attendance were J.-P. Delahaye, G. Dugan (Chair), M. Harrison, J. Seeman, F. Willeke, and J. Wuertele. The charge to the Committee for this meeting, and the agenda for the meeting, are included as appendices to this report.

At this meeting, the focus of the presentations comprised an update on the progress of commissioning the Recycler; a report on the recently completed engineering run and preparations for Run II; and a comprehensive review of Fermilab's superconducting magnet R&D program. The committee was also presented with discussions of plans for Run IIb, and reports on future accelerator R&D (linear collider, VLHC, and muon collider/neutrino source).

The following sections present the committee's responses to each item in the charge, followed by some comments on items not expressed addressed in the charge.

Charge Item #1: Recycler Commissioning.

The committee is asked to review and comment on progress since the spring meeting with particular attention to the timetable for achievement of performance goals required to integrate the Recycler into Run II operations starting in spring 2001 .

The committee heard presentations on the overall status of the Recycler commissioning, the cooling systems, instrumentation upgrades, and impedance measurements. The committee considers that significant progress has been made in many areas since the last meeting. Hardware improvements in many areas have been made including the magnet alignment, magnetic shielding, vacuum, and beam position monitors. Using a 10π emittance proton beam, 90% transmission has been observed through the injection process and onto a circulating orbit. Lifetimes of up to 1 hour have been demonstrated. Using difference orbits, for which the BPM data are quite accurate, lattice measurements have revealed that beta waves of $\sim 70\%$ on the nominal lattice are present. The commissioners believe that this observation is consistent with the high beta insertion's permanent magnet quadrupoles having lost 1% of their strength since installation. Since transverse electron cooling is no longer required, the high beta region is no longer deemed necessary; the committee concurs with the decision to remove this feature from the lattice during the present shutdown. An additional benefit of this change will be to de-sensitize the beam to the Main Injector fringe fields.

The available aperture in the machine is still considerably less than the design of 40π mm-mrad. Magnet surveying has resulted in re-alignment of many elements and is continuing during the present shutdown. Precise aperture measurements are difficult to

perform due to the lack of dipole correction magnets in many places but the problem appears to be localized rather than systematic. The committee agrees with the decision to retrofit more correction magnets into the Recycler to expand local orbit control. We expect that the improved alignment, better orbit control, and lattice modifications will result in significantly more admittance and hence improve the beam lifetime. Whether this will result in the necessary 10 hour (or more) lifetime is difficult to judge at this time. On this general topic the committee notes that the injection Lambertson magnet produced a very significant single turn coupling on the injection orbit before local skew quad corrections were installed. The committee suggests that the possible effect of other field harmonics besides skew quad be considered.

The stochastic cooling of a proton beam has been demonstrated with a ~30 minute cooling time. The basic system concept and technologies has thus been proven and the committee congratulates the team on this achievement. Some problems remain such as orbit motion saturating the power amplifiers and thermal stability of the light links, but the committee agrees with the removal of the test proton cooling hardware to allow the antiproton system to be installed. The beam lifetime increased from 1 -> 2 hours with the cooling turned on. The committee notes that the subsequent emittance growth in this measurement when the cooling systems were turn off was quite rapid. Taken at face value, this is very disturbing. We suggest that this result should be aggressively investigated.

Broadband impedance measurements of the ring made by measuring the microwave instability on a debunched beam result in a Z/n estimate of ~10 ohms. While this seems marginally acceptable for antiproton stacking, the committee suggests that an analysis of the effect of a 10 ohm impedance on the unstacking dynamics would be prudent. The committee also feels that this impedance value is somewhat high given the basic machine parameters, and advises an investigation to determine its origin and see whether it is feasible to reduce it.

To date, all Recycler commissioning has been performed using protons. While the machine performance has improved greatly during the past several months it is still not operating at the required level to be ready for integration into the accelerator complex for antiproton operation. Even after the current round of improvements, the Recycler will need one more round to be fully useful. This next round will require the continued application of sufficient staff and resources, careful planning, and a supply of antiprotons. Since Run II will have started by this time, the Recycler will be in direct competition with the experimental program for antiprotons. The committee thinks it is appropriate at this point to start planning this step so that machine commissioning is integrated in the optimum way to minimize the impact on Run II operations. In this regard it might be productive to decelerate and recycle antiprotons from the Tevatron somewhat sooner than anticipated, as this could provide a source of "free" antiprotons for commissioning.

Charge Item #2: Superconducting Magnet R&D.

The committee is asked to review and comment on the Fermilab program in both high and low field superconducting magnet R&D. In particular, we would appreciate the committee's advice on the appropriateness of established goals and the effectiveness of the approach to these goals.

The committee heard a series of presentations from the Technical Division on superconducting magnet R&D. These presentations focused on low field (superferric) transmission line magnets, for a low-field VLHC, and on high field ($>10\text{T}$) dipole magnets (for VLHC or muon collider applications). The high field dipole magnets included an 11-12 T $\cos\theta$ design, and a 10-11 T single-layer common coil design, using Nb_3Sn superconductor in all cases. Fermilab is involved (with LBNL, BNL, and industrial producers of Nb_3Sn superconductor) in a national R&D effort to improve the quality and reduce the cost of Nb_3Sn superconductor for high energy physics applications. The committee heard a presentation on the materials R&D work being done at Fermilab, and its connection to the national effort.

The low field magnet work was described by Bill Foster. The presentation discussed several topics. The committee heard about the development and testing of the 100 kA transmission line, design of the magnet's iron poles, and cryogenic and quench protection systems issues. On the tour, the committee saw the site (MW8) for the implementation of a planned system string test, and saw prototype components for the 100 kA power supply and leads. The string test is planned to be functional by this summer.

Alexander Zlobin described the high field magnet R&D. The overall goal is a low cost, 10-12 T Nb_3Sn superconducting dipole magnet, with an aperture > 40 mm, with the 1986 SSC field quality specifications. The conceptual design study stage is basically complete. For the $\cos\theta$ magnet, there are single and dual bore designs, with both cold and warm yokes; no collars are used. The coils will be wound and then reacted. For the common coil design, a single layer design will be used, with a simple racetrack coil geometry having a 90 mm minimum bend radius. The coils will be reacted, and then wound. Large stresses which appear in the common coil magnet are handled by segmentation of the coil blocks ("stress management"). Persistent current effects are naturally suppressed in the common coil design, and can be compensated in the $\cos\theta$ design.

Currently, short model R&D, together with infrastructure development, is underway. The short model program relies on the LHC HGQ project tooling to speed it up. The first $\cos\theta$ model magnet has been wound, reacted, and impregnated; it will not be useful for power tests as shorts developed during the reaction process. The next set of $\cos\theta$ coils are planned to be completed in February 2001, and tested March-April 2001. A second model test is planned for May-June 2001. Practice common coils will be wound and tested for I_c degradation in February 2001; short model fabrication is planned for April 2001, and a magnet test is planned in FY02.

For the longer term, the program envisions building several single-bore $\cos\theta$ model magnets, followed by dual bore $\cos\theta$ models, with either cold or warm yokes. A similar number of common coil models would be built. Eventually, one would downselect to either common coil or $\cos\theta$, and then build full-length magnets.

Giorgio Ambrosio described the Fermilab effort in materials R&D. The program includes both strand and cable R&D, and is well-coordinated with the national Conductor Development Program. In this program, Fermilab, BNL and LBNL collaborate with industry to develop high-performance Nb_3Sn conductor, with $J_c=3000$ A/mm² at 12T, 4.2°K, and a cost under \$1.5/kA-m. The strand R&D studies heat treatments, characterizes the electrical, mechanical, and magnetic properties of the wires, and uses

scanning electron microscopy (Fermilab is purchasing an SEM) and chemical analysis to understand fundamental features of the strands. The cable R&D involves design optimization and studies of bending degradation to understand the details of how degradation in strand and cable relate, and how they translate into coil performance. Fermilab is in the process of getting a cabling machine. These studies of strand and cable characteristics are fed back to the wire manufacturers engaged in the Conductor Development program; these manufacturers do not do these tests themselves.

As the final presentation, Peter Limon discussed the overall scope and goals of the program. Currently available resources will allow the construction of 2-3 short model magnets per year. Peter argued that, in order to be able to make progress at a sustainable rate, and in particular to be able to survive the occasional development setback, a rate more like 6 magnets/year would be appropriate. To reach this rate, the committee was told that perhaps 20% more engineering and technical support would be required for the high field program (perhaps more for the low field).

The committee strongly supports superconducting magnet R&D work at Fermilab aimed at future accelerators. Fermilab is one of the world's leaders in building accelerator-style superconducting magnets, and it is essential to preserve and nourish this capability.

The low field magnet work continues, as in the past, to take an admirably innovative approach. Nevertheless, the committee felt that there were a number of very fundamental issues related to the low field magnet concept which remain open, and are perhaps more crucial than the system issues which are the current focus of the group's activities. These fundamental questions include the operating field, the field quality, the details of the vacuum system, the required magnet aperture, and the optimum magnet length. In addition, some members of the committee felt that the future direction of the program, beyond the immediate goal of a string test, was not clearly defined. The VLHC machine study that is just beginning should address the basic issues mentioned above, and it is hoped that this will provide additional focus and longer-term future direction for the program.

The high field magnet work is attempting to extend the technology of superconducting accelerator dipole magnets to fields beyond those attainable with NbTi. Such high field dipoles are the key enabling technology for the next generation of large hadron colliders, and may also be important in the longer term for muon colliders. This work is consequently of considerable significance. The approach being taken in the Technical Division to this problem is innovative and quite broad. A number of different designs are under consideration, with a variety of technologies; in addition, fundamental investigations of issues related to superconducting material properties are underway.

The committee felt that the high field magnet work could benefit from more clearly defined long term program objectives and outlines. Such outlines would put the work that was described, and the need for resources, into a better context. For example, it was difficult for the committee to assess the need for a rate beyond 2-3 magnets/year without such a long-term context. Some members of the committee felt that a slower and more analytical approach ought to also be considered, with a focus on specific problems: looking at fewer options, but in greater depth. It is possible that the VLHC study over the

next six months will help in the development and solidification of long-term goals, for high field magnet development as well as for the low field work.

Charge Item #3: Status of Preparations for Run II.

The committee is asked to review and comment on the recently completed collider engineering run, and the extrapolation from the recent experience to a goal of achieving a luminosity of at least $5 \times 10^{31} \text{cm}^{-2} \text{sec}^{-1}$ by the end of 2001. In particular, are there areas of concern beyond those identified by the Beams Division and/or areas for which the approach does not provide confidence that the desired performance will be achieved.

The committee is pleased to learn that colliding beam operation with 36 on 36 bunches could be achieved in the Tevatron, after four years of interruption due to Main Injector construction and commissioning, and fixed-target operation. The committee notes that the magnets of the Tevatron have been excited corresponding to beam energies of up to 1010 GeV and beam has been stored at 980 GeV. This is an important success.

The luminosity achievements of the engineering run in the summer of 2000, however, fell short of the expectations and plans. Despite this, several stores resulted in a few million events recorded by the CDF detector, allowing progress to be made in detector commissioning.

The limited machine luminosity was due in part to hardware problems discovered during start-up. Initially, many vacuum leaks into the insulating vacuum were detected and fixed. This delayed the cool-down of the superconducting magnets by several weeks. There were in addition isolated technical problems, such as bad splices in the main superconducting bus, shorted voltage taps, and a roll error of 10 mrad at a low beta quadrupole, all of which contributed to the further delay of the of beam commissioning operation. The committee does not consider these problems as unusual, considering the fact that much new hardware has been installed, and operations have been interrupted for a long time. However, at the end of the engineering run, there was not enough time left for necessary optimization and tune up of the beam. As a consequence, the beam quality and quantity were insufficient: the life time at injection was poor, and the intensities as well as longitudinal and transverse emittances of protons and antiprotons were far from the design goals.

Antiproton production for the collider profited from the upgraded Main Injector. The Main Injector performed well, providing up to 4.4×10^{12} protons per cycle on target (design 5×10^{12}) at an energy of 120 GeV for antiproton production. Stacking rates of 4×10^{10} antiprotons per hour were demonstrated. This corresponds to 40% of the designed stacking rate for Run IIa (10^{11} antiprotons per hour) but a large part of the difference is due to the low repetition rate of the antiproton production process: every 3 sec instead of 1.5 sec as foreseen.

The proton beam intensity achieved in the collider was only 15% of the nominal value. However, the Main Injector is able to deliver protons of the required intensity, and the coalescing process seems to work at the required beam intensities. It has been demonstrated that these proton intensities can be transferred in principle to the Tevatron without large problems.

The antiproton production and acceleration chain is still very lossy. The overall transmission efficiency of the antiproton beam extracted from the accumulator to the low beta squeeze at high energy in the Tevatron is low (20%). The transverse emittances during collision of both the proton and antiproton beams are quite high (240% the design value). The main reasons for the low transfer efficiency and high emittance seem to be well understood: a large blow-up of the longitudinal emittance of the antiproton beam during unstacking in the Accumulator, and substantial antiproton beam loss and large transverse emittance blow-up during acceleration in the Tevatron. The inability of diagnostic systems to detect the very low density beams contributed to the problems. Additional difficulties were provided by the lack of repeatability of the antiproton transfer line, which has to be ramped from 8 GeV to 120 or 150 GeV.

The committee is particularly concerned by the possible interference between the Tevatron operation and the continuation of the Recycler commissioning, which will use a non negligible part of the antiproton beams and which will certainly require a number of accesses into the Main Injector tunnel. If problems and delays in Recycler commissioning prevent progress from being made in improving the beam lifetime, the lifetime might be too short to provide useful intermediate pbar storage. In this case the Accumulator will have to stack at a high rate into large stacks, and this could be a problem that potentially limits the luminosity below $5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$. Emphasis should be put on both achieving the Recycler design lifetime and cooling performance, and, in addition, on stacking performance with large stacks in the Accumulator.

The achieved luminosity of $4 \times 10^{29} \text{ cm}^{-2} \text{ s}^{-1}$ is still two orders of magnitude lower than the target figure of $5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ foreseen at the end of next year. Nevertheless, the committee did not see any fundamental problems uncovered during the 2000 engineering run, which would preclude achieving that goal. However, it is apparent that a significant amount of work remains to be done to reach the goal.

Comments on other items, not explicitly addressed in the charge.

Fermilab has many accelerator activities on its plate, including work for the present as well as future accelerators. One of the most important activities underway is planning for Run IIb. The committee has heard of this planning in previous meetings, and was presented with an update by Dave McGinnis at this meeting. Given the inevitable resource limitations at Fermilab, the committee feels that the Run IIb projects need to be prioritized, based on a cost-benefit analysis which includes both down time and commissioning time for each project, and which aims to maximize the integrated luminosity.

The Run IIb goal of 15 fb^{-1} is very challenging. Even with the prioritization suggested above, significant incremental resources beyond those currently assigned to the Beams Division will be required to meet this challenge.

Work on the linear collider and neutrino factory/muon collider continues to make good progress in contributing to the respective collaborations. The neutrino factory study, which took a hard and critical look at a system, provides a good model for the upcoming VLHC study. The committee acknowledges the critical need for future planning, but feels that the priority must remain on Tevatron performance in Run IIa and IIb.

Appendix 1: Charge (Draft #2)

The December 2000 meeting of the Fermilab Accelerator Advisory Committee (AAC) will cover a variety of areas, related both to the upcoming collider run and to R&D directed toward the longer term future. The meeting will share a joint focus on the status and plans for Recycler commissioning and a review of the superconducting magnet R&D program. In addition we will present for comment short status reports on activities related to preparations for Run II activities and R&D on future accelerator facilities.

The AAC is asked to review the status of preparations and plans, to comment on their appropriateness, and to recommend the next steps, if any, in the following areas:

- **Recycler Commissioning.** The committee is asked to review and comment on progress since the spring meeting with particular attention to the timetable for achievement of performance goals required to integrate the Recycler into Run II operations starting in spring 2001 .
- **Superconducting Magnet R&D.** The committee is asked to review and comment on the Fermilab program in both high and low field superconducting magnet R&D. In particular, we would appreciate the committee's advice on the appropriateness of established goals and the effectiveness of the approach to these goals.
- **Status of Preparations for Run II.** The committee is asked to review and comment on the recently completed collider engineering run, and the extrapolation from the recent experience to a goal of achieving a luminosity of at least $5 \times 10^{31} \text{cm}^{-2} \text{sec}^{-1}$ by the end of 2001. In particular, are there areas of concern beyond those identified by the Beams Division and/or areas for which the approach does not provide confidence that the desired performance will be achieved.

The AAC will also be presented with short status reports on planning for Run IIB and on R&D relating to our efforts on VLHC, Muons, and linear colliders. These presentations are intended to be primarily informative and as such no specific comments are solicited at this time. However, any comments the committee might wish to make are welcome.

It is requested that a concise report responsive to this charge be forwarded to the Fermilab Director by January 5, 2001.

Appendix 2: AAC Agenda

December 4-5, 2000

(DRAFT #2)

Monday December 4

8:30 Executive Session (Dugan)

8:50 Welcome. Presentation of charge (Holmes/5 minutes)

Recycler Commissioning

9:00 Status of the Recycler, commissioning and upgrades in progress (Mishra/45 minutes)

9:55 Status of the Recycler cooling (Pasquinelli/20 minutes)

10:20 Break

10:45 Status of the Recycler instrumentation and future plans, Jim Crisp/15 minutes)

11:05 Microwave instability in the Recycler (Jackson/Klamp/15 minutes)

11:25 Discussion of Recycler commissioning

11:45 Lunch

12:45 Tour (High Field and Low Field SC magnet facilities)

Run II

1:45 Report on engineering run and preparations for Run II (Church/30 minutes)

2:25 Report on planning for Run IIB (McGinnis/30 minutes)

3:05 Discussion

3:15 Break

Future Accelerator R&D

3:40 Report on Linear Collider activities (Dombeck/Holtkamp/30 minutes)

4:20 Report on VLHC Study activities (Strait/30 minutes)

5:00 Executive Session

7:00 Dinner

Tuesday, December 5

8:30 Report on Muon activities (Geer/30 minutes)

SC Magnet R&D

9:10 Introduction to the Superconducting Magnet R&D Program (Limon/5 minutes)

9:15 Low-field magnet R&D results and plans (Foster/30 minutes)

9:55 High-field magnet R&D results and plans (Zlobin/30 minutes)

10:35 Break

10:55 Materials R&D results and plans and the U.S. collaboration (Ambrosio/30 minutes)

11:35 Summary – resources and budgets (Limon/10 minutes)

11:45 Discussion

12:00 Working Lunch

3:00 Closeout (Closeout time is tentative)