Recycler Commissioning Plan

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November 11, 1998

Introduction

Because of the late financing of the Recycler, many subsystems will not be ready at the start of commissioning. In addition, because of the novel nature of the permanent magnet lattice and the lack of systematic dipole correctors, considerable study time is anticipated for establishing the closed orbit in the machine. For these reasons Recycler commissioning will take a staged approach.

The basic schedule assumed in this document calls for partial turn injection from MI-30 to MI-52 in December 1998. After installation of the rest of the Recycler magnets and vacuum system, first turn operations are anticipated to start in March 1999. From that point on commissioning progress is determined by the availability of hardware (such as kickers) and accelerator complex capabilities (such as antiproton injections), application programs (such a tune monitors and tune control), and the availability of people to run shifts.

In this document each stage of commissioning is discussed. After detailing what prerequisites are required to initiate a given stage, the goals for the stage and methods employed to attain these goals are reviewed. As a summary, table 1 contains the list of commissioning stages and the list of prerequisite capabilities and hardware components. Commissioning stages are discussed in the order that they are anticipated to occur.

Partial Turn Injection

In December 1998 enough Recycler magnets and vacuum sectors will have been installed to run beam in the Recycler of RR327 to RR519. The proton injection line from the Main Injector to the Recycler is just upstream of RR327, starting at MI321.

Of course, the first priority will be to have enough magnets installed in the transfer lines and Recycler. Similarly, the vacuum system from MI-30 to MI-52 must also be intact. There is no plan to perform an in-situ 150°C bake and fire the titanium sublimation pumps (TSPs) until very late in commissioning, so the vacuum will be maintained by the ion pumps. The Main Injector and Recycler vacuum systems will be isolated by a thin titanium window at the downstream end of the transfer line.

The most important components required for this stage of commissioning is beam diagnostics. The systems required are the beam position monitors (BPMs), toroids for measuring beam current, and the beam loss monitors (BLMs). The BLMs are actually part of the Main Injector, and are needed for Main Injector commissioning. Therefore, they do not need to be discussed further here.

The toroids are needed to understand the efficiency of the transfers between the Main Injector and Recycler. The locations of the toroids are MI-30 in the Main Injector, MI-32 in the transfer line, and MI-32 in the Recycler.

Table 1: Prerequisite capabilities/hardware components and commissioning stages. The • symbol signifies that a particular capability or hardware component is necessary for that particular operation.

	BPMs, Toroids, BLMs	RR-40 Kicker	Tune Monitors & DCCT	Profile Monitors	HLRF & RWM	LLRF	Bake & Fire TSPs	RR-20 Kicker	Inject Antiprotons	Stochastic Cooling	MI-30 Kicker	Steady Accumulator
Partial Turn Injection	•											
First Turn Injection	•											
5000 Turn Operations	•	•										
1 Second Operations	•	•	•									
Coasting Beam Storage	•	•	•	•								
Bunched Beam Storage	•	•	•	•	•							
Barrier Bucket Studies	•	•	•	•	•	•						
Long Term Lifetime Studies	•	•	•	•	•	•	•					
Intrabeam Scattering Studies	•	•	•	•	•	•	•					
Extraction RF Manipulations	•	•	•	•	•	•	•	•				
Ion Trapping & Clearing	•	•	•	•	•	•	•	•	•			
Beam Cooling Studies	•	•	•	•	•	•	•	•	•	•		
Emittances after Transfers	•	•	•	•	•	•	•	•	•	•	•	
Stacking Studies	•	•	•	•	•	•	•	•	•	•	•	•

The BPMs are crucial to the success of the Recycler. Because of the choice of permanent magnets and the lack of systematic dipole correctors, the closed orbit is determined by the movement of magnets. These magnet moves cannot be calculated unless the position of the beam in the BPMs is reliably determined. During this commissioning stage it is anticipated that first turn flash measurements will be the only measurements. This is enough information to calculated magnet translations and rolls needed to center the closed orbit.

For the BPM system to be used, a timing system must be established in order to fire the sample-and-holds in the "RF modules" at the correct time with respect to the beam pulse. Since kickers will not be available yet and dipole correction magnets will be used in their place, this timing system could either be a portion of the final system or could be a pulser set up at MI-60 to mimic the timing system.

For partial turn injection between MI-30 and MI-52 a horizontal steering magnet with a maximum deflection of 1.35 mrad exists in the Main Injector between the quadrupoles at locations Q303 and Q304 to send the proton beam into the MI-32 transfer line extraction Lambertson. Once the protons have left the transfer line and entered the Recycler, another horizontal steering magnet is used just upstream of the magnets around location Q330 to bring the beam onto the closed orbit.

The first goal of this commissioning stage is to assure that the energy of the Reycler and the energy of the 8-GeV line are matched. The second goal of this commissioning stage is to learn early how to adjust magnet positions in order to optimize the closed orbit. Since every variety of magnet is also in this section of beam line, it is also a test to make sure that all the magnets are being built with the correct multipole strengths. For this stage of commissioning we anticipate the need for at least two weeks of operations with time every day for entering the tunnel to make magnet moves.

The Recycler BPM system is designed to handle pbar intensities, so a single turn of Booster beam is sufficient. Given that very little "tuning" is possible due to the lack of correctors, commissioning will be performed with the "single shot then think alot" philosophy. Therefore, no more than 4 transfers per hour are anticipated for most tasks. The one exception will be the Lambertson aperture scan at MI-32 to find the hole into the transfer line and set the MI trajectory around the Lambertson septum.

First Turn Injection

Of course the first requirement for this commissioning stage is for the magnets and vacuum system to be completely installed. All of the diagnostics required for the previous stage are sufficient for this stage.

During first turn injection kickers are not needed. Since the horizontal steering magnet in the Main Injector at MI-30 is used to also simulate the kicker for the MI-22 transfer line, the beam trajectory each transfer from the Booster will be as follows. First, the protons traverse a partial turn in the Main Injector from MI-10 to MI-30. At MI-30 the protons are directed into the MI-32 transfer line. At MI-40 a steering magnet sets the beam onto the closed orbit. The protons then traverse the Recycler ring until they hit the RR-40 steering magnet a second time. This second deflection sends the protons into the Recycler proton extraction line and into the Main Injector abort.

The first purpose of this commissioning stage is to align the magnets in the Recycler in order to optimize the closed orbit. The second purpose is to verify that the magnet strengths are correct. Again, sparse injections of single Booster turn batches of protons will be needed. It is anticipated that this stage of commissioning requires approximately 3 weeks, with time every day for entering the tunnel to make magnet moves.
[total = 3]

5000 Turn Operations

In order to get at least one full turn of beam in the Recycler, the kicker in the Recycler at MI-40, called the RR-40 kicker, is required. The minimum time between kicks is approximately 50 msec. Because this kicker needs to fire to put the beam on the closed orbit and then again to remove the beam, the minimum number of turns is approximately 5000.

There are three reasons for wanting to keep the beam in the ring for as short a time as possible. First, the instrumentation and controls needed for measuring and adjusting the tune of the machine may to be completely ready. Second, the vacuum pressure in the ring may still be relatively high. Third, since no RF system may yet be installed one wants to remove the beam before it spreads to a length longer than the flattop time of the kicker.

Some goals of this commissioning stage is to establish that the machine has a stable closed orbit, that all Lambertsons can be negotiated, and that there are no obstructions in the vacuum chamber. In addition, magnet moves in the region between the MI-22 and MI-32 transfer lines can finally be determined. Also, at this point the integer part of the tune can be determined by cusping and measuring the closed orbit. Finally, by observing turn-by-turn orbit data tune and chromaticity of the Recycler can be estimated with reasonable precision. To achieve these and all future goals, sparse injections of low intensity protons is sufficient. We will need approximately 1 week of operations, with time every day for entering the tunnel to make magnet moves.
[total = 4 weeks]

1 Second Operations

In order to start measuring the tunes in the machine and measure the beam intensity lifetime, the transverse tune monitors and DCCT must be installed. In addition, the ability to adjust the phase trombone at MI-60 is required.

The purpose of this commissioning stage is to precisely measure and set the transverse tunes of the Recycler in order to optimize the beam intensity lifetime. Because there is still no RF system installed, it is imperative to keep the beam in the machine the minimum amount of time necessary to measure the tunes. It is anticipated that this stage requires approximately 1 week of Recycler operations.
[total = 5 weeks]

Coasting Beam Storage

If transverse profile monitors are available but the high level RF is not yet installed, it makes sense at this point to inject protons periodically into the Recycler and store it until the beam intensity evaporates of its own accord. Because the lifetime is expected to be at least tens of minutes at this point, the ALARA concerns to this point which have required extraction of all beam pulses into the MI-40 abort dump is no longer very important.

One goal of this stage is to start learning about the dynamic aperture of the Ring. Using the correction sextupoles (where each of the 24 magnets are individually powered) and the correction quadrupoles (9 magnets at the MI-60 phase trombone which are also individually powered) one can generated 3rd order and half integer resonances. On the flip side, one can do beta-function measurements and 3rd order resonance width measurements in order to determine a harmonic correction. Another goal of this time is to learn how to perfect beta-function measurements using dipole bumps and the beam position monitor system. It is anticipated that the minimum time required to perform these tasks to some acceptable preliminary level could take 2 weeks.
[total = 7 weeks]

Bunched Beam Storage

Once the high level RF (HLRF) is installed it makes sense to require the installation of a resistive wall monitor (RWM). Once complete, one can now look at lifetime and emittance growth issues which are introduced by bunching the beam.

There is a lot of work to do at this stage. If the low level RF (LLRF) system is not yet installed, the HLRF will be operated via pulsers or a rudimentary form of the final LLRF. One of the capabilities we will want is to change the radial position of the beam. One big goal is to start doing precision dispersion measurements in order to find lattice problems and measure the momentum aperture of the Recycler. Any time the LLRF system is fully functional, we anticipate switching into the next commissioning stage.

Barrier Bucket Studies

Once the LLRF system is fully functional, everything short of storage lifetime, intrabeam scattering, stochastic cooling, and ion clearing studies can be performed. At this point all longitudinal manipulations can be exercised. The combined total study time required to commission and study all of these manipulations, and to perform all the work outlined in the previous commissioning stage, is estimated to be at least 6 weeks.
[total = 13 weeks]

Long Term Lifetime Studies

Once all of the mechanics of the ring are worked out and the installation of hardware into the vacuum system has stabilized, it is time to perform the first 150°C bake of the beam pipe. Since there are 208/8=26 vacuum sectors in the ring, and each vacuum sector will take a day to bake, it is anticipated that this process will require 2 weeks if 2 bake-out crews are working in parallel. During this time the titanium sublimation pumps (TSPs) should have their filaments degassed at 30 Amperes.

Some long term lifetime studies will be desirable at this point since the pressure one should be able to attain at this point is not yet near the expected operating vacuum pressure. Therefore valuable data on beam intensity lifetime can be made at this stage. A week of time to do these lifetime studies should be sufficient.

When the TSPs are fired, they are stepped from 30 Amps for 2 minutes to 40 Amps for 1 minute to 48 Amps for a few minutes. Because the outgassing at this point is so slow, each TSP can be fired separately. It should take approximately 2 sectors per day per crew, so 1 week of time should be enough.

After firing the TSPs the vacuum pressure in the machine should drop dramatically. At this point the accelerator should be well below an average pressure of 1 nTorr, and should continue a slow improvement toward and average vacuum pressure of 0.1 nTorr. Again beam intensity lifetime studies should be performed, again requiring approximately 1 week.
[total = 18 weeks]

Intrabeam Scattering Studies

Once the vacuum pressure in the Recycler is close to 0.1 nTorr, it will be possible to measure longitudinal and transverse emittance growth rates vs. proton intensity, peak current, and momentum spread. These studies should take a minimum of 2 weeks.
[total = 20 weeks]

Extraction RF Manipulations

Once the RR-20 kicker is installed and commissioned, it will be possible to transfer protons out of the Recycler into the Main Injector, and back into the Recycler again. Not only will this be a good test of the lattice matching between the machines (because you are using the same emittance diagnostic after each transfer cycle), but it will also verify the emittance penalty paid by using a titanium window to separate the Recycler and Main Injector vacuum systems. Finally, at this point we can perform precision tests of stacking and unstacking in the Recycler. It is anticipated that it will require a week to install the kicker (and recover the vacuum), followed by at least a week of dedicated studies.

[total = 22 weeks]

Ion Trapping & Clearing

The prerequisite capability for starting this commissioning stage is the ability to inject antiprotons previously stacked in the Accumulator. After verifying that proton transfers accurately predict antiproton transfer performance, the first studies to perform are related to beam lifetime and the effect of ion trapping. At this point the various ion clearing mechanisms, including using BPMs as clearing electrodes and bunching the beam in barrier buckets, should be tested. This means that the diagnostics, probably the wideband transverse pickups, must be installed and commissioned. Before beam cooling is commissioned, it is anticipated that the above tasks will take a minimum of 2 weeks.
[total = 24 weeks]

Beam Cooling Studies

If one talks to Ralph Pasquinelli it is clear that the stochastic cooling tanks will be the last piece of hardware to be installed in the Recycler. The time required to perform the installations, reestablish vacuum, wire the tanks, and commission the hardware in the tunnel is approximately 2 weeks.

The studies required at this point are to confirm the existence of Schottky signals in all 4 systems, close the loops and see signal suppression, and then study cooling time vs. delay and attenuator settings should take at least 4 weeks.

Once the stochastic cooling system is commissioned and beam cooling is demonstrated, the Recycler should no longer be part of the Main Injector project but instead should be declared a victory and complete.
[total = 30 weeks = 7 months]

Emittances after Transfers

When ready the MI-30 kicker needs to be installed in the Main Injector. Up to this point a horizontal steering magnet has been used to performed the transfers between the Main Injector and Recycler. Once this kicker is installed, the lattice matching issue between the machines can be much more fully explored. This is because up to now, if one wanted to extract beam from the Recycler and then reinject it, only a single turn in the Main Injector was possible. Because the Main Injector vacuum system is not baked, the total time to complete this commissioning stage is no more than 1 week.

Stacking Studies

At this point the Recycler is fully functional and Recycler operations can commence. In order to study the full stacking capabilities of the Recycler, steady stacking of antiprotons at a rate above 10 mA/hr in the Accumulator is required.

Final Comments

Note that the time from single turn injection (where the ring magnets and vacuum system are completely installed) to the end of commissioning of the stochastic cooling system is 7 months. The required end date for these activities is March 1, 1999. Counting back 7 months, these activities can start no later than September 1, 1998. Given that a 50% contingency on these time estimates is probably minimal, we actually need to establish single turn Recycler operations in June of 1998.