Pbar Acceleration in the MI using 2.5 MHz Coalescing RF system

Tune-up Study Scheme with proton beam and Operational Implementation

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Luminosity requirements during the Run II is highly demanding. In order to meet the goals of Run II it is desirable to have high intensity low emittance proton and antiproton bunches in the Tevatron during collision. The past experience has shown that the conventional method of coalescing carried out at 150 GeV to get high intensity bunches has serious limitations in preserving low emittance. An alternative scheme has been suggested in the Recycler Ring Technical Design Report. In this method the coalescing process is completely eliminated to preserve the longitudinal emittance. Four intense bunches of particles will be accelerated in the MI using 2.5 MHz rf system for part of the acceleration cycle and 53 MHz rf system for the rest of the cycle. The simulations on this new scheme has shown no (or very small) emittance dilution and is ideal for reaching Run II luminosity goals. This method of pbar acceleration initiated many studies in MI which include development of slow MI ramps, studies on HLRF systems, LLRF systems and BPM instrumentation. Before making this method operational it is required to develop complete tuning scheme using protons from Booster (just like any other operational schemes were tested at Fermilab in the past)

In this report we summarize the present status of proposed pbar acceleration tune-up scheme in the MI using protons from Booster and future accelerator study plans.

MI Acceleration Scheme :

The pbar acceleration scheme in the MI discussed here has the following steps:

(a) Transfer four bunches of pbars from AR/RR to MI in 2.5 MHz rf buckets,
(b) Shrink the bunches adiabatically in 2.5 MHz buckets (only for RR beam)
(c) Accelerate to 25 GeV using 2.5 MHz rf system (“coalescing rf system”),
(d) Rotate the bunches at 25 GeV,
(e) Transfer to 53 MHz rf buckets at 25 GeV and
(f) Accelerate pbar bunches further using 53 MHz rf system
(g) Finally, transfer the batch of 4 bunches to the Tevatron

The longitudinal emittance specifications for pbar bunches are 1) Longitudinal emittance <1.5 eV-sec at 8 GeV in the MI and 2) ≈2 eV-sec at 150 GeV.

MI Pbar Acceleration Ramp :

A typical slow MI ramp is shown in Fig.1. The total cycle time is about 12 sec. The transition energy for the MI lattice is at about 20.49 GeV. The ramp has three frontporches; 8 GeV, 25 GeV and 150 GeV. The dp/dt (p is momentum) is held <4 GeV/sec below 25 GeV to accommodate maximum bucket area for 2.5 MHz rf bunches. A 0.5 sec long front-porch is set at 25 GeV for rf manipulation. At the end of the 25 GeV front porch the bunches are transferred to 53 MHz rf buckets and accelerated to 150 GeV.

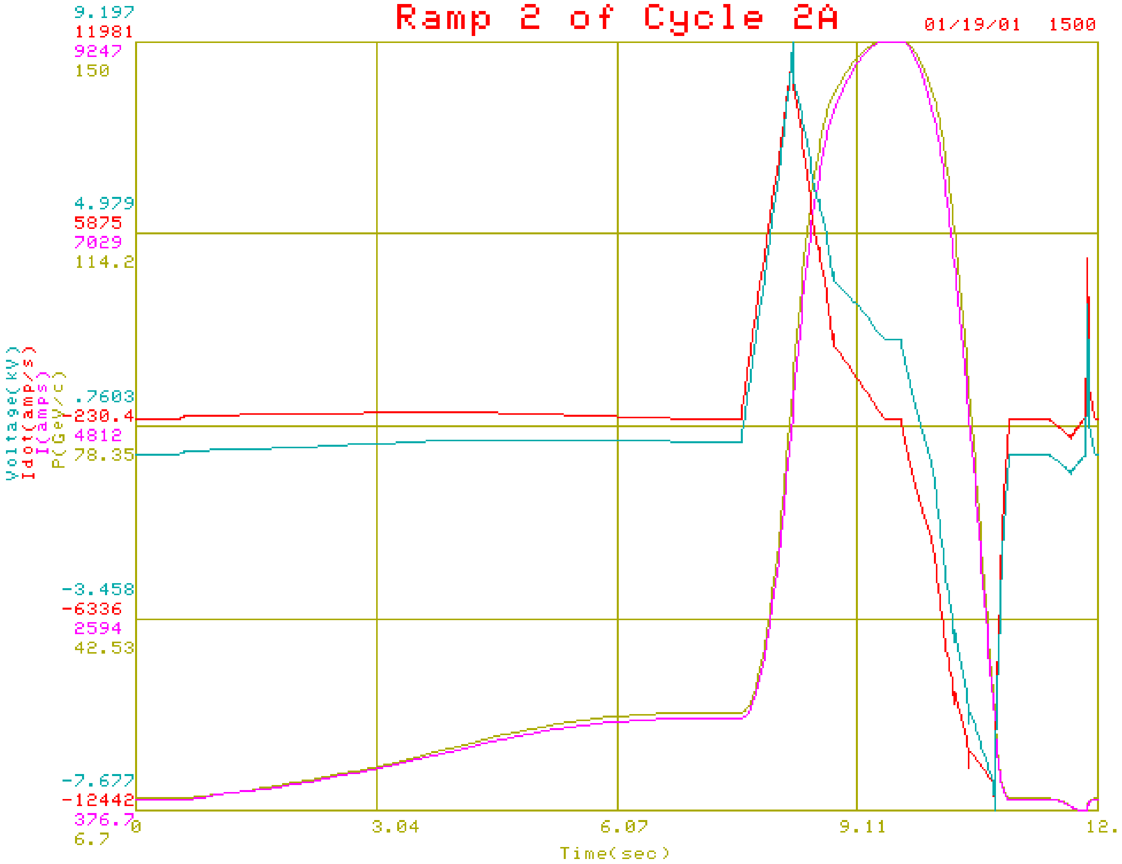

Figure 1. Pbar acceleration ramp. Below 25 GeV only 2.5 MHz (h=28) rf system will be used. Above 25 GeV we plan to use 53 MHz (h=588) rf system. This ramp has been tested in the MI with protons.

The ramp shown in Fig.1 has been tested in the MI. The MICAR learning time was typically about 8-9 cycles (which is common for any new type of cycles in MI) . We have also accelerated the beam from 8 GeV to 150 GeV using this cycle with 53 MHz rf system. The acceleration efficiency was about 80%. The beam loss was seen only at transition which is associated to the slow acceleration with 53 MHz rf system. (Notice that in a typical MI ramp we use dp/dt ≈ 220 GeV/c/sec near transition for acceleration with 53 MHz rf system.)

HLRF System :

Below 25 GeV we plan to use 2.5 MHz rf system for beam acceleration and above 25 GeV the 53 MHz rf systems will be used. The rf specifications (see Appendix-A) on 2.5 MHz rf system demand that

1. Vrf (2.5 MHz) to be 2kV to 50kV (±0.5kV)
2. Phase change 0 to 180deg (±1 deg)
3. RF phase jump at transition energy.

The 2.5 MHz rf cavity is originally built for p and pbar coalescing at 150 GeV. The coalescing process takes place only about 40msec for snap coalescing (Vrf ≈ 60kV) or a few sec for adiabatic coalescing (2kV<Vrf <60kV). But, the present case of beam acceleration scheme requires about 50 kV/five cavities for about 7 sec per acceleration cycle. This demanded the study of the cavity responses for heating. Recently, we (Joe Day and I) have studied the effect of heating on the cavities using a wave form which excites/heats the cavity for 15 sec and shuts off the cavity for 45 sec (see Appendix-B for the results of study conducted under different conditions of the cavity). The Fig. 2 shows results of such a study with a peak voltage of 10.4kV/cavity. The studies were conducted with voltage feed back system developed by Joe Dey (private communication). During the “on” time, the Vrf was held at constant voltage for 12 sec and at ≈ 1 kV/cavity for 3 sec. The cavity drive frequency was chosen to be 2.514 MHz, which corresponds to that of 8 GeV in MI. The study was done for a duration up to 4 hours.

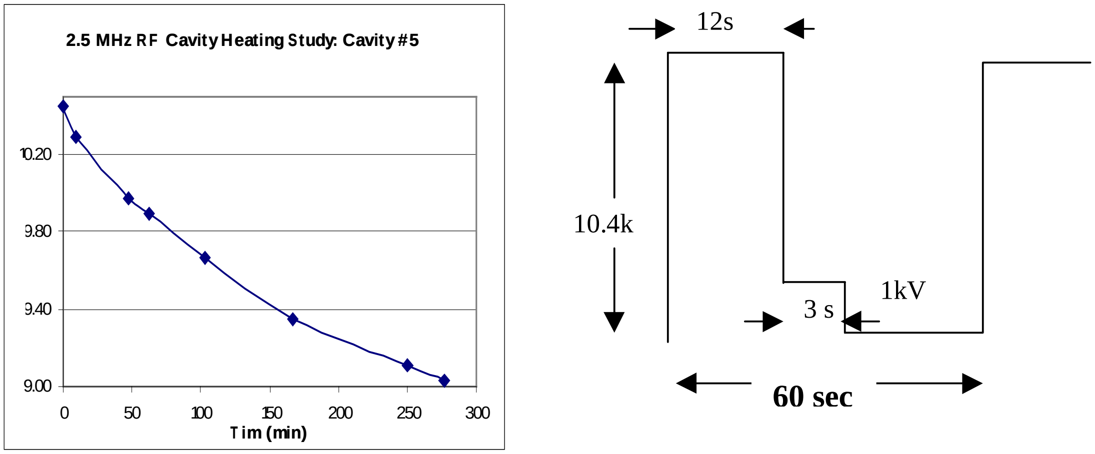

Fig. 2. 2.5 MHz rf cavity heating studies on cavity #5. The points show Vgap at its maximum operating voltage of 10 kV. The cavity was cooled using a water flow rate of 0.85 gl/min. The wave form used for exciting the cavity is shown on the left.

The study shows that the peak gap rf voltage will be reduced by about 15% and frequency change by about -20kHz in two hours of continuous heating with a wave form shown above. The Table 1 outlines some of the operating conditions for the 2.5 MHz rf system for beam acceleration as well as coalescing at 150 GeV.

Table 1

Revolution frequency in MI for particles with velocity c = 90377.26 Hz

P (GeV/c)	β	f=f0*β Hz	f(rf) for 53 MHz system	f(rf) for 2.5 MHz system	Δf (kHz) for 53MHz system	Δf (kHz) for 2.5MHz system
8.889	0.99448	89878	52.8483	2.5166	292.236	**13.916**
25	0.9993	90314	53.1046	2.5288		
150	0.99998	90375	53.1405	2.5305		

The Q of the 2.5 MHz rf cavity = 100 = f/Δf

Therefore Bandwidth = **25.305** kHz

The total bandwidth for the 2.5 MHz rf cavity is about 25 kHz. The frequency change in 2.5 MHz rf system during the acceleration from 8.9 GeV to 150 GeV (about 14kHz) and the change in frequency due to heating are within the bandwidth of the cavity. Hence, both frequency change as well as voltage reduction are acceptable from the stand point of tune-up studies with protons if we limit the cavity operation with the mode of operation discussed in this section for less than about two hours. (Notice that the ramp shown in Fig.1 suggests 2.5 MHz rf cavity to be at its maximum voltage only for about 7 sec out of 12 sec. This give further safety margin)

A constraint on 53 MHz rf system below 25 GeV front-porch is that Vrf(53 MHz) ≤ 1 kV. With the feed back system on the 53 MHz rf system developed and implemented recently by Joe Dey and Jim Steimel, we have achieved minimum for Vrf (53 MHz) ≈2kV during para-phasing. Above 25 GeV, we use only 53 MHz rf system.

We do not need 5 MHz rf system during the acceleration. At 25 GeV, the 5 MHz rf system helps significantly for bunch rotation. But the bunch rotation time is typically 40 msec which has no/little effect on the cavity performance.

LLRF System :

MI operation and various rf manipulations are controlled using LLRF states. We need two MI states in this case to satisfy our needs.

MI state 1 (tune-up studies): The purpose of this is to tune the MI with proton beam. The first step of this operation is preparing proton bunches in 2.5 MHz rf buckets which is very similar to that adopted for RR tune-up cycles with protons [MI note 263]. Next, 2.5 MHz bunches will be accelerated in the MI using 2.5 MHz rf system. For this one needs,

i) voltage control
ii) phase control and
iii) phase jump at transition.

During this time Vrf(53 MHz) ≤ 1kV. At the end of the 25 GeV front porch the bunches have to be transferred to 53 MHz bucket and accelerate to 150 GeV. In the existing LLRF system, voltage control for 2.5 MHz rf system has already been implemented. The phase control for acceleration has yet to be implemented.

MI state-2 (state used during operation): Beam transfer from RR/AR.(If it is from AR we need to do frequency jump as it was done during the Run II commissioning). Beam acceleration is very similar to the one outlined for MI state-1. But, we use pbars which requires different RPOS signal processing. Finally, before injection into the Tevatron, we need to cog the bunches to align with the Tevatron buckets (this procedure is very similar to the existing case of pbar transfer).

Instrumentation :

We have four special purpose BPM detectors which can be used for 2.5 MHz RPOS and closure. They are at Q526, Q530, Q612 and Q616. All of them are at high dispersion locations (with Dx~1.5 meter). These detectors are yet to be commissioned for 2.5 MHz operation. Besides, we have two more split plate detectors in the MI ring near 602, one in each plane. These two detectors are currently being used as beam-line tuner-BLT (Wim Blockland) for pbar closure. One needs

1. 2.5 MHz bpms for closure (minimum 2 in each plane). For 2.5 MHz bunches we need BLT to be tuned.
2. RPOS detectors for p and pbars at h = 28 and h= 588
3. phase detectors for p and pbars at h = 28 and h= 588

We have the necessary instrumentation in the MI tunnel but they have to be commissioned for the present purpose.

Commissioning of pbar Acceleration with 2.5 HMz rf system:

As outlined earlier, MI LLRF state-1 will be used for tune-up studies. The cavity heating study showed that it takes > 2 hours for reaching steady state Vrf with a peak voltage (of 13kV) depleted by about 15 %. This effect becomes more relaxed if cavity is operated at a lower peak voltage like 10 kV and at this voltage we should be able to conduct the tune –up studies for up to about 4 hours with out any noticeable depletion in cavity behaviour.

With five 2.5 MHz rf cavity the beam sees about 50 kV, which is sufficient in the present case. Hence we propose the following tune up study scheme:

For a 60 sec super-cycle we can have 15 sec long tune-up cycle which will take-up about 25% of the total super-cycle time. In the cycle shown in Figure 1, the 2.5 MHz rf cavity will be at its peak voltage only for about 7 sec continuously which is about a factor of 1.6 times less than the “on” time used during cavity heating study. As a result of this, we have nearly a factor of two safety margin. Hence, the tune-up study can be carried out up to four hours continuously at a time without deteriorating the quality of acceleration or coalescing of protons if needed soon after the study. As a precaution it may be helpful to monitor integrated power input on the cavities at any given study time (private communication with John Reid).

We need about 5 shifts per week, each with about four hours. Tune-up studies may take about 6 weeks. The studies with pbar about 4 shifts.

References :

1. Appendix – A : “ rf specifications for 2.5 MHz acceleration” MI-Note 260
2. Appendix – B : “2.5 MHz rf cavity heating studies”