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PBAR ACCELERATION IN THE MI – TUNE-UP STUDIES USING PROTONS

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Abstract

We discuss both simulations as well as experimental studies of a potentially benificial acceleration scheme in the MI for pbars from the Accumulator Ring or Recycler Ring. The scheme involves accepting the pbar bunches with 2.5 MHz rf structure from either of these two synchrotrons. re-bunching using 53 MHz rf system iso-adiabatically and accelerating using 53 MHz rf system from 8 GeV to 150 GeV. Further we try to coalesce the beam using the 2.5 MHz rf system. Various stages of rf manipulation are discussed and some improvements are also suggested.

1 INTRODUCTION

The Fermilab collider Run-II has an initial goal to achieve ppbar instantaneous luminosity of $5\times10^{31}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ and an integrated luminosity of $2\mathrm{fb}^{-1}$ in the Tevatron[1]. Presently, the pbars from Accumulator Ring (AR) are accelerated in the Main Injector (MI) from 8 GeV to 150 GeV using 53 MHz rf system and 7-11 beam bunches are coalesced into one bunch before injecting to the Tevatron. The advent of the Recycler Ring (RR)[2], a new pbar storage ring, will facilitate in the accumulation of about two and half times more pbars than can be accumulated in the Accumulator Ring and boost the ability of the Tevatron to provide more luminosity to the collider detectors. The RR is designed to produce 2.5 MHz (or 7.5MHz) pbar bunches. The MI at present is not capable of accelerating pbars from RR without further rf manipulations. This paper describes an viable method to meet the short term goals of the Run II.

The scheme described here involves the transfer of the pbars from AR/RR to MI in 2.5 MHz rf buckets and bunch adiabatically in 53 MHz rf buckets in MI, accelerate them to 150 GeV and coalesce into one bunch before transfer to the Tevatron. The feasibility of this scheme is realized both by full scale theoretical simulations as well as experiments with beam. The simulations are carried out using the longitudinal dynamics code ESME[3] and experiment is carried out using proton beam. A full account of this work is given elsewhere[4].

2 BEAM DYNAMICS SIMULATIONS

A train of four pbar bunches in the 2.5 MHz rf buckets, each with a longitudinal emittance of 1.5 eVs[2] are transferred from RR to MI at 8 GeV. These bunches are expected to have parabolic distribution in shape. In our longitudinal beam dynamics simulations the bunches are populated using parabolic distribution in a rf bucket with a matching rf voltage of 2kV. The space charge force and a borad-band impedance are included. The MI parameters are taken from ref. 5. The 2.5 MHz bunches are re-bunched into 7-11 bunches iso-adiabatically by slowly developing 53 MHz rf wave before acceleration in the MI. This process typically takes about 1.3 sec. Adiabatic re-bunching is very important to maintain the emittance of the beam particle distribution. Within next 1 sec the 53 MHz rf bunches are accelerated to 150 GeV. Finally, the bunches are coalesced into one bunch at 150 GeV.

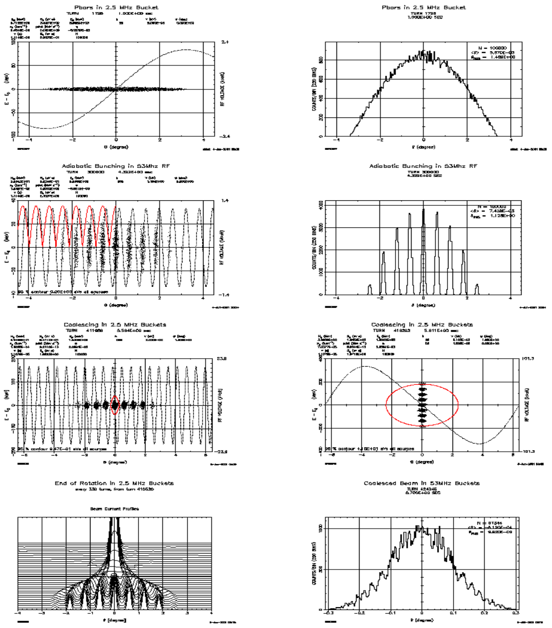

Figure 1: ESME results for 1.6 eV sec pbars in the MI.

Figure 1 shows the phase space behavior of the beam particles in rf buckets. First figure on the top-left shows the particle distributions in $(\Delta E,\Delta\phi)$-space at injection from RR in 2.5 MHz rf bucket of MI (E is synchronous

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energy and ϕ is azimuthal angle around the MI). The closed contours represent rf buckets. The rf wave is also shown. The figure on top-right shows the bunch profile. The second row shows similar simulated distribution immediately after bunching with 53 MHz rf wave. The first and second figures on third row show expected particle distributions just before coalescing and after bunch rotation during coalescing at 150 GeV. Entire coalescing is shown in 7th figure and bunch profile before injection to the Tevatron is shown in 8th figure.

The longitudinal emittances predicted in our simulation at various stages of the rf manipulation are listed in Table 1. We find that the coalescing efficiency is a strong function of final emittance just before the coalescing. Under any case it is not possible to achieve the final emittance after coalescing to be exactly same as the sum emittance of bunches before the coalescing.

The simulations have shown that the best achievable longitudinal emittance after coalescing before injecting to the Tevatron is about 3.5eVs. This emittance is about 33% larger than Run II emittance budget[2].

Table 1: Longitudinal emittance in the MI from ESME simulations.

Energy	**Emittance (1.5eVs Bunch)**
@ 8GeV	1.0 /2.5 MHz bunch
@8 GeV	1.9 eVs (sum emittance in 53MHz buckets)
@150 GeV before coalescing	2.3eVs (sum emittance in 53MHz buckets)
@150GeV after coalescing	3.5 eVs (53MHz bucket) Coalescing efficiency ≈95%

3 EXPERIMENT WITH PROTON BEAM

We have carried out experiments in the MI to test the proof of the principle of rf manipulation of the beam bunches outlined earlier. Four groups of seven proton bunches which are separated by 21 rf buckets of 53 MHz from Booster are injected into the MI 53 MHz rf buckets with 2kV on 2.5 MHz rf system. Then they are debunched into four bunches by adiabatically bringing down the 53 MHz rf voltage from 890kV to ≈0kV, holding the 2.5MHz rf voltage. This gives rise to proton bunches of longitudinal emittance of about 1 eVs each. The final longitudinal emittance of a bunch can be varied by adjusting the adiabaticity constant for 53 MHz rf wave voltage change. The four proton bunches in 2.5 MHz rf buckets mimic the injected pbar bunches from the RR. These bunches are re-bunched using 53 MHz rf system and accelerated to 150 GeV. And are coalesced into four high intensity bunches as outlined earlier. The multi-bunch coalescing achieved here was first of its kind at Fermilab. Typical data taken in the MI during this process is shown in fig.2.

The beam signal in fig.2 clearly shows that almost 100% transmission efficiency during the entire rf manipulation.

Table 2: Measured longitudinal emittance in the MI for first group of Booster batch (see figure 3). In all cases the bunch length (BL) are for 95% area.

Energy	**95% BL (nsec)**	**95% Emittance (eVsec)**
@ 8GeV	5.1	0.1 /53 MHz bunch
@ 8GeV	140	1.0 /2.5MHz bunch
@8 GeV	6.3	0.1 /53 MHz bunch
@150 GeV	4	0.8 /53 MHz bunch
@150GeV after coalescing	12.5	4.8 /53 MHz bunch

We have used a resistive wall pickup monitor to look at the bunch length profile of the beam. A typical sample bunch display (SBD) of the proton beam for the entire cycle is shown in figure 3. The four traces shown is for the four Booster batches of beam. The 4th trace of the bunch profile from the top is for the beam fully debunched in 2.5 MHz rf bucket. From that point the beam is recaptured in 53 MHz and accelerated to 150 GeV and coalesced in to four bunches.

We have measured the longitudinal emittance of the beam in the MI as a function of cycle time using the data on rf voltage and bunch lengths. The phase of the beam bunch relative to the rf wave form is known to an accuracy of a fraction of a percentage only at 8 GeV and at 150 GeV. During acceleration the phase is known only to a few degrees. As a result of this we could not get accurate information on the longitudinal emittance of the beam during acceleration. The longitudinal emittance of the beam are listed in table 2. In the case of 53 MHz buckets the bunch length and emittance are for the central bunches only. For non-central bunches the measured emittances are smaller than central bunch. For example the last bunch had about 40% smaller emittance compared with central bunch. We saw significant emittance growt during acceleration in MI. About 15% emittance growth is seen in the course of coalescing. We are doing further investigation on the causes of emittance growth in the MI during acceleration. We believe that main causes of emittance growth is from mismatched rf voltage and power supply ripples.

4. SUMMARY

We have developed a potential method of pbar acceleration scheme for the beam coming from RR during Run II and a solution to achieve the initial luminosity

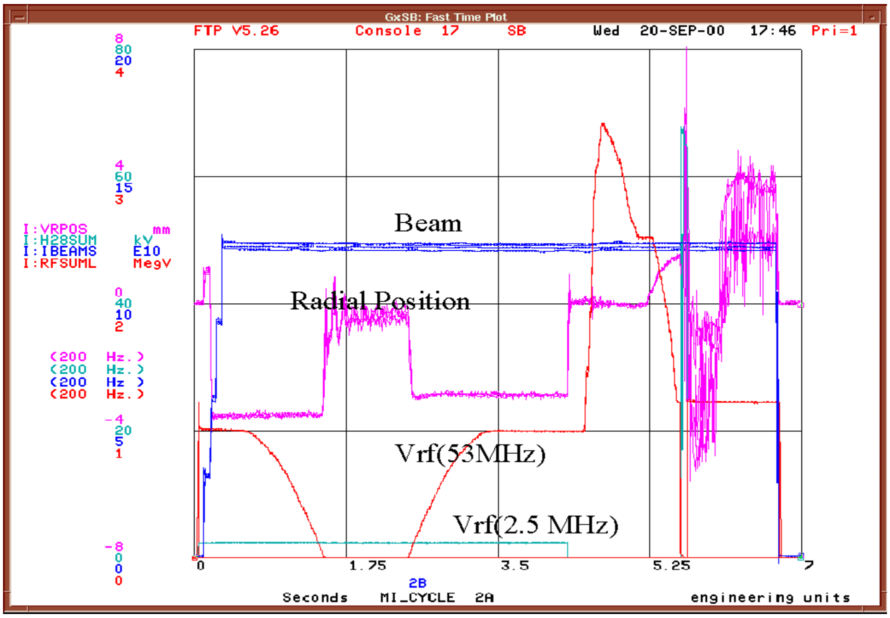
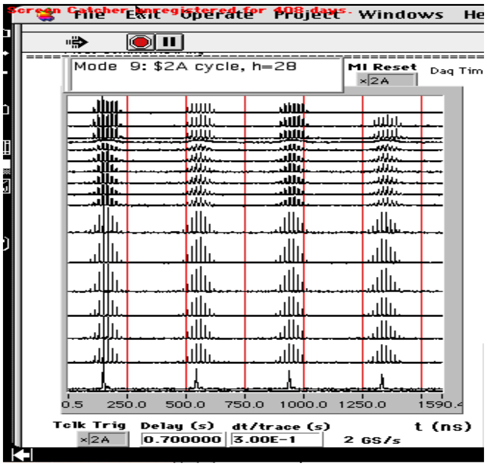


Figure 2: Typical MI beam, radial position, rf voltages (53 MHz as well as 2.5 MHz) for multi-batch proton injection as a function of acceleration time (total of 7sec cycle). Beam was at 8 GeV up to about 4.5 sec. Adiabatic reduction of the 53 MHz rf voltage (Vrf53MHz) to create bunches in 2.5 MHz (Vrf2.5MHz) is also shown. Since the radial position signal detector looks at the 53 MHz components of the beam, there were not information on beam position during Vrf(53MHz) off. Beam coalescing takes places at about 5.6 sec.



Mode 9: $2A cycle, h=28

Delay (s) 0.700000

dt/trace (s) 3.00E-1

Figure 3: Bunch length profile for four groups of protons from the Fermilab Booster . The bunch length evolution in time is shown. The cycle time runs from top to bottom. The first trace is at 0.7 sec and subsequent traces are separated by 0.3 sec. The last trace is taken immediately after the coalescing in MI.

goals . We have carried out detailed theoretical as well as experimental studies on this method. The method developed here is very robust and does not need any new hardware or software developments in the MI. However, in the long run, pursing to a method which does not need coalescing at any stage of the pbar acceleration[2,6] is very essential if we have to meet the pbar emittance budget for Run II.

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