MIXED PBAR SOURCE OPERATION AT THE FERMILAB TEVATRON*

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Abstract

Recently we have adopted a scheme, called "Mixed pbar Source Operation" in the Fermilab Main Injector (MI). The purpose of this mode of operation is to transfer pbar bunches from the Recycler and the Accumulator to the Tevatron for collider shots. In this scheme, four 2.5 MHz pbar bunches are injected in to the MI, re-bunched in four groups of 53 MHz bunches at 8 GeV, accelerated to 150 GeV, and coalesced in to four 53 MHz bunches before transfer to the Tevatron. A special magnet ramp is needed in the MI to allow for pbar beam of slightly different 8 GeV energies from the Recycler and the Accumulator. Here we will present the status of this scheme.

INTRODUCTION

Run II [1] has commenced at Fermilab since 2002 and the ppbar peak and integrated luminosity has increased steadily and progressively. The Fermilab Tevatron facility continues to be the leading highest energy collider in the world till the LHC at CERN comes into operation late in the decade. Therefore, it is vital to utilize the existing facility as efficiently as possible during the next several years. In view of this, Fermilab Run II upgrade plans [2] are in place and have already helped immensely to improve the collider program. The primary goal of the Run II upgrades is to maximize the integrated luminosity delivered to the collider experiments.

As a part of Run II we have built the Main Injector [3], (8-150 GeV synchrotron) and the Recycler [4] (permanent magnet pbar storage ring) and, integrated them into the collider operation. So far, we are able to store ~200E10 pbars in the Recycler (~300E10 pbars in Accumulator and Recycler together) and use them for the collider operation.

The MI is a multi-purpose accelerator and plays one of the prime roles as the 150 GeV injector to the Tevatron. It accelerates protons from the Booster and the anti-proton beam from the Accumulator or from the Recycler. The MI is designed to use the 53 MHz (harmonic number h=588) rf system for beam acceleration. Intense proton and anti-proton bunches are produced at 150 GeV by coalescing [5] several 53 MHz bunches using the 2.5 MHz rf system [6]. Under present operating conditions, it is essential to keep the number of 53 MHz bunches ≤7 bunches/397 nsec for best coalescing.

During the early stages of Run II (and for entire Run I), the MI was receiving pbars only from the Accumulator. Four 2.5 MHz bunches of cooled pbars of desired longitudinal emittance (LE) were extracted from the Accumulator and were re-bunched using its 53 MHz rf system before injection in to the MI. This method found to have two problems: 1) the available rf voltage of the 2.5 MHz rf system in the Accumulator is very much limited and hence can not produce ≤7 bunches consistently (for example for 1.5 eVs bunches it produces about 11 bunches of 53 MHz type), 2) undesirable LE growth during 53 MHz rf capture. Therefore, it is highly advisable to transfer 2.5 MHz pbar bunches to MI 2.5 MHz buckets (which have larger dynamic range in terms of rf voltage, 0-75 kV) and adiabatically grow 53 MHz bunches in the MI. On the other hand, there is no choice for pbar bunches from the Recycler; it can inject only 2.5 MHz bunches in to MI. As a consequence of these limitations, a scheme is needed in the MI which accommodates 2.5 MHz pbar injection and 53 MHz beam acceleration.

In this paper we will report on the implementation of a scheme which satisfies the above requirements. The scheme involves accepting the 2.5 MHz pbars bunches from either of these two storage rings, compressing the bunch with in the MI 2.5 MHz bucket, bunching at 53 MHz, accelerating to 150 GeV using 53 MHz rf system, coalescing in the MI at 150 GeV, and finally transfer the beam to the Tevatron. A similar scheme was first proposed in ref. 7. Its feasibility was realized in the MI by experiments with proton [8].

2.5 MHZ BUNCH INJECTION AND COALESCING

At present the LEs of the pbar bunches from the Accumulator and from the Recycler are quite different. For example, from the Accumulator the LE (95%) per 2.5 MHz bunch is in the range of 0.5 -1.5 eVs and from the Recycler is kept at ~ 2 eVs. Therefore, it may not be useful to use same amount of 2.5 MHz bunch compression before 53 MHz capture. Also, it is important to note that after the 53 MHz capture the bunches will be having a distribution of LEs with the highest value for the central bunch. We must keep the LE of the 53 MHz bunches less than the momentum acceptance of the MI at its transition energy (±0.7%). Therefore, it is imperative to estimate the optimum amount of final 2.5 MHz rf voltage needed for adiabatic bunch compression before 53 MHz re-capture in the MI so that we end up with ≤7 bunches of acceptable LE distribution. In view of this a

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series of beam dynamics simulations were carried out using ESME [9].

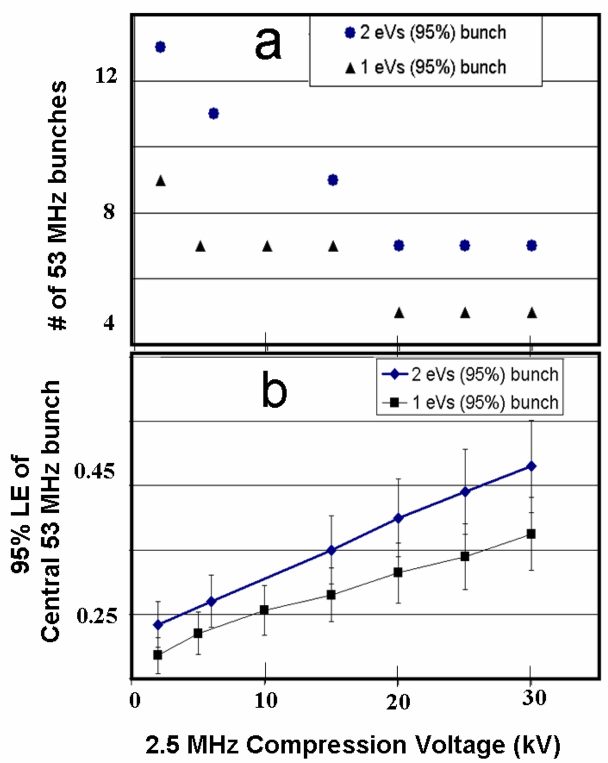

Fig.1. ESME simulations for 8 GeV bunch compression of 2.5 MHz pbar bunches in the MI. a) Number of 53 MHz bunches vs compression voltage and b) 53 MHz LE vs compression voltage.

The Fig.1 shows the results of simulations for two cases of initial LEs, 1 eVs and 2 eVs (95%). We find that for the 1 eVs bunches 5 -15 kV are sufficient to produce seven 53 MHz bunches and that for the 2 eVs, 20-30 kV of 2.5 MHz rf voltage is needed in the MI. In both the cases, one can keep LE of the central 53 MHz bunch <0.45 eVs. During acceleration we see up to about 20% emittance growth which mainly arises at transition crossing. We predict that the coalescing efficiency will be close to 100%.

This scheme was made operational after about one year of the commencement of Run II, using only the Accumulator pbars in the MI. During the injection of 2.5 MHz bunches, the MI 53 MHz rf system were turn off [10] and kept the 53 MHz beam loading compensation on. As a result of this the effect of 53 MHz rf system on the injected 2.5 MHz bunches were minimized. Fig. 2 shows the measured coalescing efficiency [11] for a number of pbar shots to the Tevatron as a function of the initial LE before and after the implementation of this scheme. It is obvious that for LE (95%) at 8 GeV>1 eVs, the coalescing efficiency is about 10% higher with the new scheme than with the scheme used during Run I. The ppbar luminosity at the Tevatron scales linearly with the increase in the pbar bunch intensity. Implementation of this scheme has lead to 7-10% increase in peak luminosity at the Tevatron.

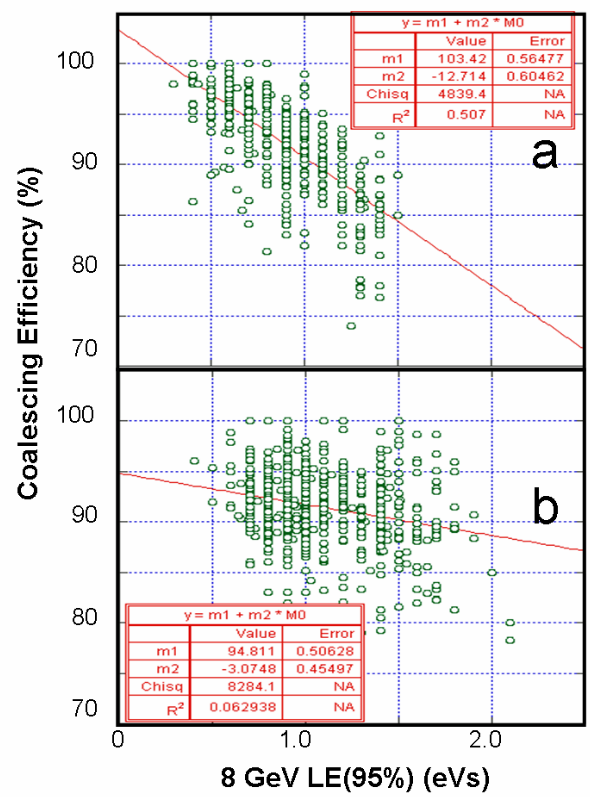

Figure 2: Measured pbar coalescing efficiency at 150 GeV in the MI as a function of 8 GeV LE. a) Before and b) after implementation of the new scheme. This data is from Accumulator transfers.

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There is a 40 MeV difference between Accumulator injection energy and that of the Recycler. Accumulator pbar injection energy is about 8.8855 GeV and that of the Recycler injection energy is 8.847 GeV. This leads to further complications in the way the MI acceleration ramp is set earlier.

Fig. 3 shows the schematic view of the special magnet ramp presently in use which allows for pbar beams from both of the storage Rings. This ramp has two parts: 1) a magnetic field reset ramp which starts at 8.8855 GeV and ends up at 8.847 GeV, and 2) 8-150 GeV ramp has two "front porches", one at 8.847 GeV (Recycler beam injection energy) and 8.8855 GeV (Accumulator injection energy). The rest of the acceleration part is similar to the ramp used for 150 GeV acceleration.

After the pbar beam injection from the Recycler the beam accelerates to the Accumulator energy through the "Mini-Ramp" with out any radial position control. The 53 MHz capture is carried out at the Accumulator energy. The rest of the beam acceleration process is the same as other ramps.

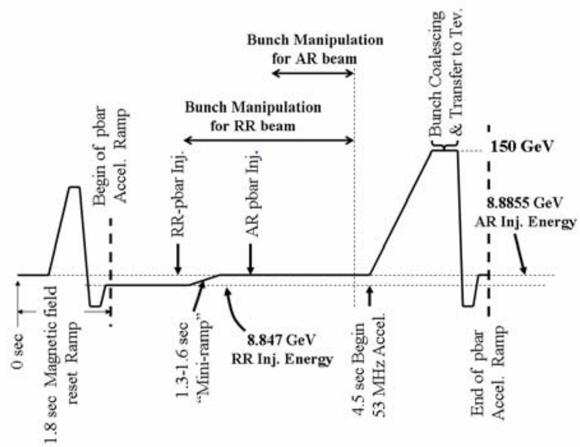

Figure 3: A schematic view of the MI pbar acceleration ramp presently in use. The regions of bunch manipulation at 8 GeV for Recycler and Accumulator pbar injection are also shown. The horizontal dashed indicates the two 8 GeV energies in the MI, one for Recycler and another for Accumulator pbar injection.

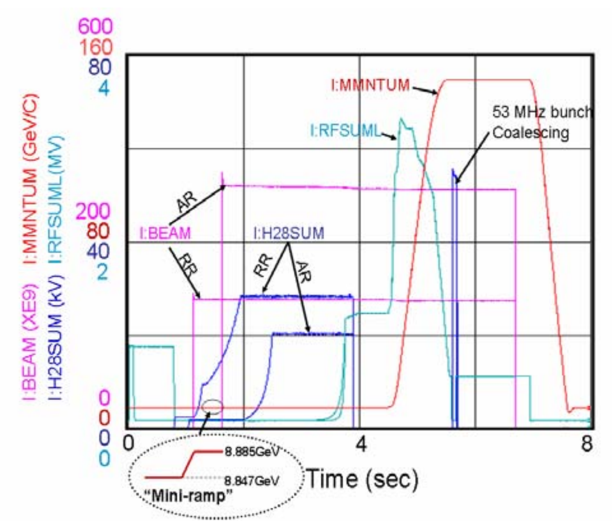

Figure 4: Experimental data on pbar injection, rf manipulations, acceleration and coalescing. I:BEAM, I:H28SUM, I:MMNTUM and I:RFSUML measure beam current, 2.5 MHz rf voltage, magnet ramp and 53 MHz rf voltage, respectively. The Mimi-Ramp is also shown.

Fig. 4 shows a typical case of experimental data on the pbar injections from the Recycler and Accumulator. Various stages of 2.5 MHz rf bunch manipulation and their acceleration and beam coalescing are also shown. At any one time, either the Recycler beam or Accumulator beam will be present in the MI. Presently this method of pbar acceleration is being used in the MI.

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