MEASUREMENT OF LONGITUDINAL MODE MIXING IN THE FERMILAB LARGE HADRON ACCELERATORS†

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Abstract

Fermilab High Energy Physics research program for RUN-II requires rapid generation of antiprotons and high intensity protons. We had previously observed longitudinal mode mixing in the Main Ring and Tevatron at intensities desirable for the RUN-II. We incorporated high-speed digitizer (RTD-720) and (LeCroy 9384CM) to measure the time domain, and further spectral analyses were performed to measure the mode couplings. We have refined our measurement analysis in conjunction with higher digitization to pursue higher mode couplings. Data during the commissioning of the newly constructed Main Injector will be compared to previously obtained data.

1. INTRODUCTION

The Main Injector Sampled Bunch Display pickup (wide-bandwidth resistive wall monitor) is used to measure the longitudinal time evolution of the beam. Three different data acquisition systems are used for this paper; 1) fast 4 Gs/s LeCroy 9384 Oscilloscope and a LabVIEW analysis program, 2) Two Gs/sec RTD-720 digitizer with 1024 segment-able memory in conjunction with the Fermilab control system, 3) Five Gs/sec dual-channel TVS-645 digitizer with a proprietary Tektronix snapshot capture PC-based data acquisition software.

Longitudinal bunched beam modes and their interaction with the beam were first described by Sacherer in 1973. For M equidistant bunches, there are M coupled bunch modes characterized by n waves $0 \leq n \leq M-1$ around the storage ring. The theory of longitudinal bunched beam contain radial and within-bunch modes. Due to lack of high resolution pickups, DSP's and possibility of Landau damping of the higher order modes, only the lowest radial and azimuthal modes are observed. The interaction among charged particles and their surrounding environment, such as RF cavities, kickers and bellows can drive the beam unstable resulting in unwanted longitudinal coherent beam oscillations. These oscillations will cause the eventual growth in longitudinal emittance. The beam acceleration throughout the cycle is a result of two fields: one is externally controlled by the RF cavities and the other comes from the wake fields generated by the frontal bunches. This wake field is clearly intensity dependent. As the bunch intensity increases, the wake potential produced by the frontal bunches need to be considered in the particle equation of motion. The RF cavities installed in the newly constructed Fermilab Main Injector, were a part of the decommissioned Main Ring. This paper addresses the search, observation and measurements of the coupled bunch modes in the Main Injector at 8 GeV. Modeling and the cure of the longitudinal mode coupling is left out.

2. EXPERIMENTAL RESULTS

The purpose of the rapidly cycled Main Injector is to provide high intensity beams to different experimental areas within a supercycle (a repetitive cycle that could include beam transmission for antiproton production, 120 GeV fixed target, collider run injection and so on). The complex supercycles could require holding beam in the Main Injector for power supply reconfiguration. We have

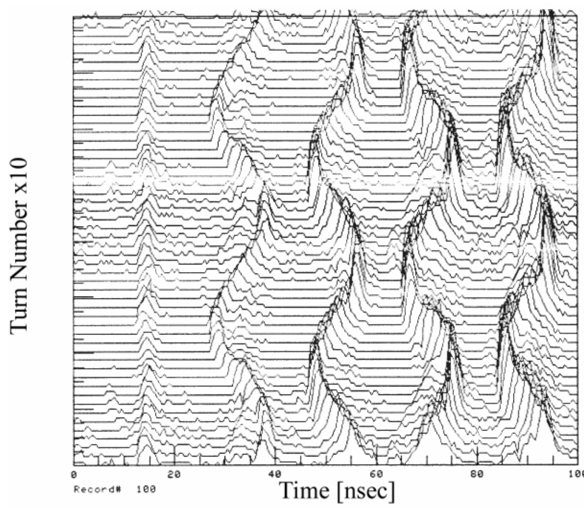

Fig.1) Each trace shows 5 consecutive bunches starting from bunch one (leading bunch). Every 10 turn is shown.

observed (Fig. 1) coupled bunch modes in Tevatron few seconds after injection.

Each trace in the above figure is triggered externally based on a count down of the RF and recorded by the segment-able memory RTD720 for 10240 consecutive turns. Every 10 turns is registered to enhance the synchrotron oscillation observation. We have injected 11 bunches into 11 consecutive buckets and leaving the remainder of the ring empty. we observe that leading

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bunch does not go under any oscillation and the wake field generated by the bunches decays prior to the return of the first bunch. We also observe that the wake field is additive as expected by the theory. We also observe the longitudinal bunch length of the 5th bunch has drastically increased.

Figure 2 shows that during the high intensity

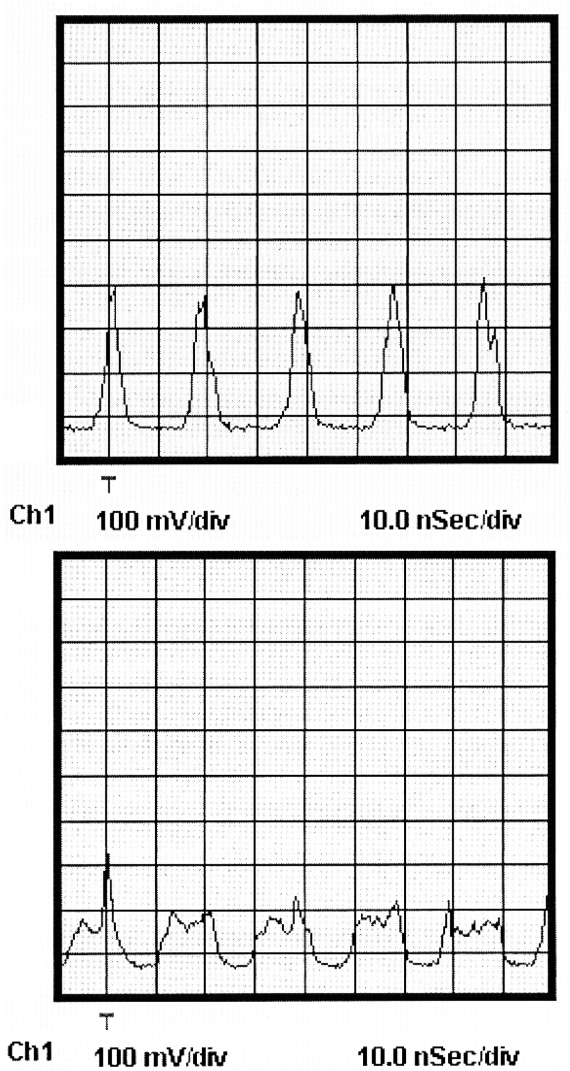

Figure 2) The above trace shows 5 bunches of a 40 bunch injected immediately after injection and the lower figure shows the same bunches after 3 second.

commissioning of the Main Injector an increase in the bunch length as we kept the beam for periods up to 10 second at 8 GeV.

In the Main Injector, the wake field for the higher order cavity modes can reach several kV for a beam with 3E12 particles per bunch while the peak fundamental RF voltage at 8 GeV is 1.1MV per turn. The above observation lead us to seek the reason for the above behavior. Figure 3 and 4 show that as the intensity increases by filling the MI with beam, some bunches undergo oscillation and their bunch length increases. We can cures the instability by changing the injection synchronous phase. We note that bunch intensity can

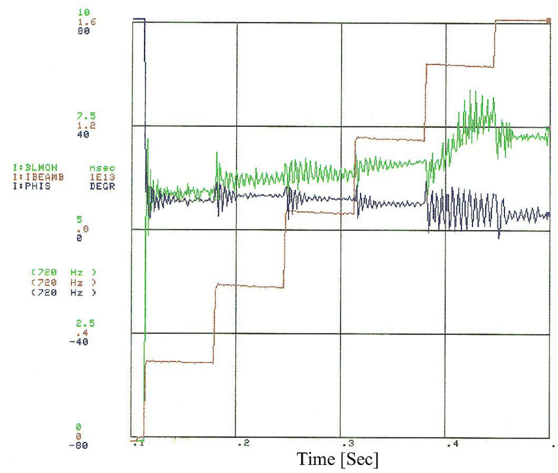

Figure 3) The above figure shows that 5th and 6th batch exhibit oscillations much larger than the 1st to 4th and their bunch length increases.

vary during the operation of the MI and continues synchronous phase manipulations is not favorable. A successful longitudinal feedback system is installed by McGinnis et. al.

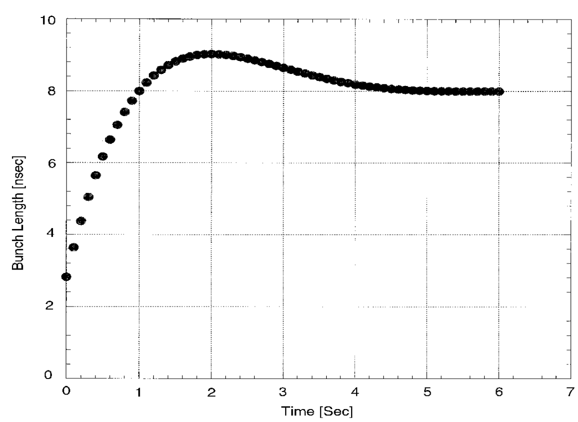

Figure 4) Bunch length grows at 8 GeV from 2.8 nsec at injection to greater than 8 nsec after 2 seconds.

Time evolution of one bunches at 8 GeV is measured

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and shown below. We observe that the decrease in the bunch length after 2 seconds is correlated with beam loss rather than cooling.

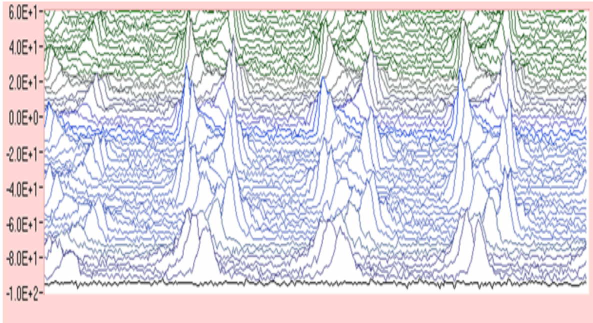

Figure 5) At 8 GeV, an equivalents to the synchronous phase to stabilize the oscillation in figure 3 is added to generate the phase error and measure the coupled bunch mode prior to dilution.

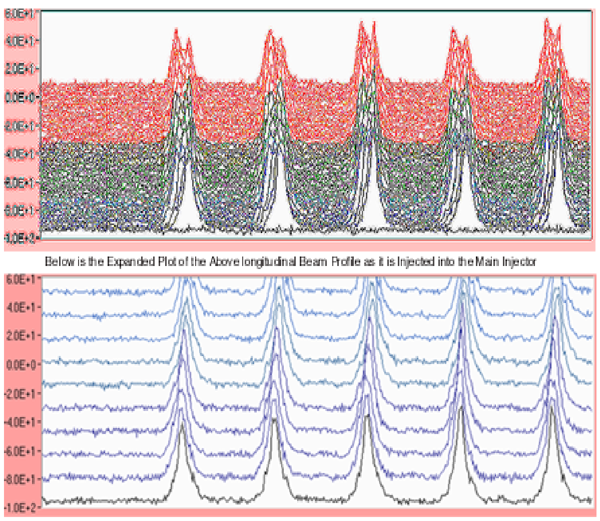

Figure 6) Time evolution of longitudinal motion. The first trace of the above figure is prior to the injection and followed by plots of every 13 turns.

The remainder of this paper tries to pursue the characteristics of the bunch lengthening and how one can reduce or eliminate that.

The resulting time series data gathered in figure 7) is broken up to 1000 realizations. Each realization contains data from every 15 turns of each bunch which are then Fourier transformed. The phase shift $\Delta\varphi$ of the perturbing bunch motion with respect to a reference bunch is $2\pi n/M$. We then infer the wake field mode structure by calculating the wavenumbers $k_n = \Delta\varphi_n / \Delta x$.

3. CONCLUSION

Although we have just recently started to commission the Main Injector, we have achieved intensities to the highest

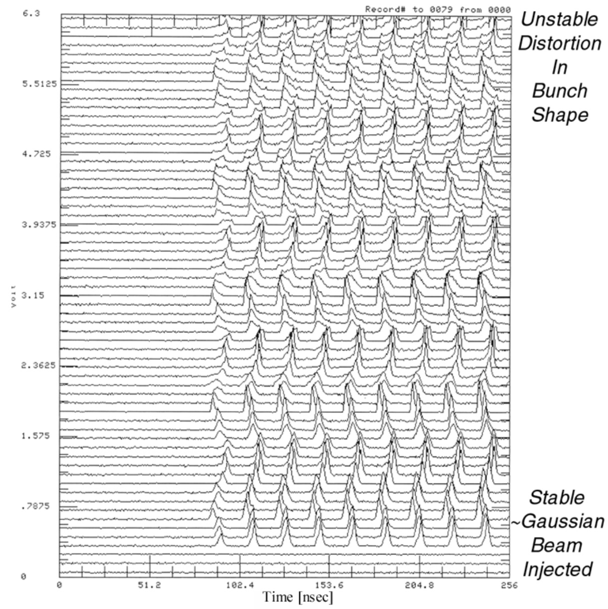

Figure 7) Waterfall plot of Main Injector beam vs turn number. We observe that all bunches oscillate and the bunch shape distorts as time progresses.

intensities of the Main Ring but we have only observed the lowest longitudinal mode. Unlike the Tevatron or the Main Ring, the Main Injector does not exhibit higher longitudinal coupled bunch modes although the same particle flux density is present.

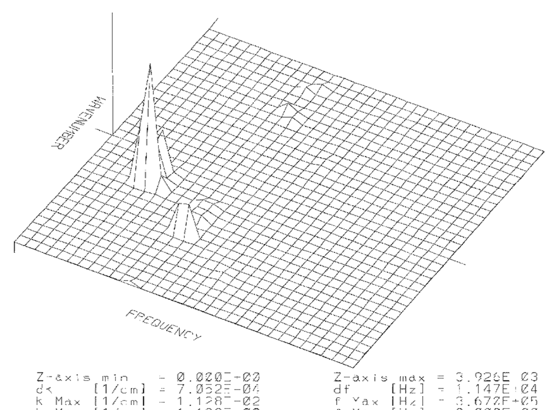

Figure 8) Measured Peak is associated with dipole oscillation between adjacent bunches

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