A STUDY OF THE LONGITUDINAL COUPLED BUNCH INSTABILITY IN THE FERMILAB MAIN RING

K. Junck, J. Marriner, D. McGinnis, Fermi National Accelerator Laboratory, Batavia, IL 60510 USA

Longitudinal synchrotron oscillations of proton bunches in the Fermilab Main Ring have been observed during various portions of the acceleration cycle. These oscillations have an effect upon the ability to coalesce 11 proton bunches into one bucket for subsequent transfer into the Tevatron. The oscillations appear to be caused by a longitudinal coupled bunch instability. We report measurements made to characterize the instability as well as design of a narrow-band feedback system.

I. INTRODUCTION

The Main Ring coalesces one high intensity bunch from 11 bunches [1]. Once the 8.9 GeV injected beam is accelerated to 150 GeV, the 53 MHz RF cavities are counterphased to a low voltage and coalescing cavities at 2.5 MHz are turned on. After bunch rotation occurs, the 53 MHz cavities are rephased to recapture the single coalesced bunch. This procedure is sensitive to the longitudinal emittance of the beam and thus maintaining a small and constant longitudinal emittance is desirable.

Uncoalesced proton beam in the Main Ring has been observed to undergo a sudden growth in bunch length during the flattop portion of the 2B cycle (acceleration to 150 GeV for transfer to the Tevatron). The bunch size is determined by measuring the ratio of the 53 MHz (fundamental) and 159 MHz (third harmonic) components of the beam signal generated from a strip-line detector. Throughout the course of Collider Run IB, beam intensity has increased resulting in an earlier onset of this bunch length growth. The onset of bunch length growth is also dependent upon the number of bunches, with an earlier growth corresponding to a larger number of bunches.

It is thought that this phenomena is due to a coupled bunch instability. As a bunch passes through the RF cavity it sees not only the accelerating voltage applied to the cavity but fields excited by the previous bunches. A bunch is coupled to all of the previous bunches by these wakefields. Many higher order modes have been measured in the Main Ring RF cavities[2]. The 4 HOMs with the largest shunt impedance are at 67, 84, 127, and 227 MHz.

II. CHARACTERIZATION OF MODES

To characterize the oscillations of the beam, a 2 GHz Tektronix digitizer and LabView software with a Macintosh computer are used to capture and store the beam profile from a Resistive Wall Current Monitor. From this data (Figure 1) it can be seen that individual bunches are undergoing dipole synchrotron oscillations. By following the oscillations of one particular bunch (Figure 2) a growth in the oscillation amplitude can be seen.

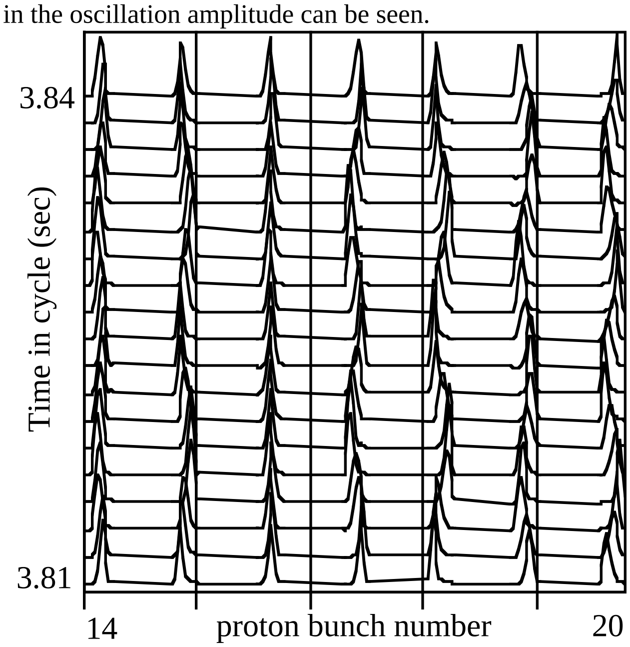

Figure 1. Mountain Range plot of proton bunches 14 through 20 showing synchrotron oscillations.

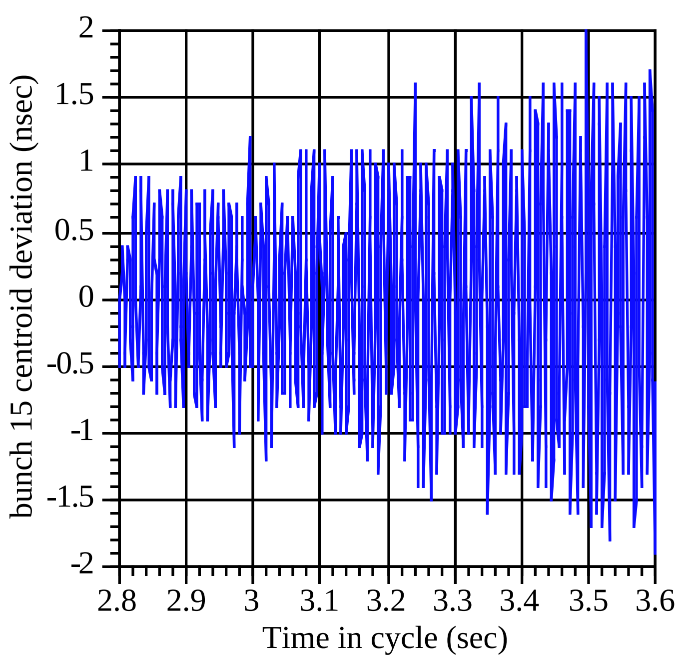

Figure 2. Growth in amplitude of synchrotron oscillation for an individual bunch. 1 nsec deviation is 19 degrees of RF phase.

At a given instant in time, the centroid of each bunch with respect to the RF bucket center will vary from bunch to bunch. Figure 3 shows data from an 84 bunch beam at a single moment. In a full ring with coupled bunch mode 1 present, this plot of deviation versus bunch number would have 1 full oscillation. A Fourier transform of this data and other snapshots in time, yields the power spectrum of the coupled bunch modes and is shown in Figure 4 [3]. The four major HOM of the RF cavities would be expected to produce modes 291, 465, 436, and 306. However Figure 4 shows that the dominant mode is 174. Although pulse to pulse variation is very common, under a wide variety of conditions (beam intensity, number of bunches, and applied RF cavity voltage) mode 174 is most prevalent. The exponential growth of this mode has been found to have a rise time on the order of 200 to 400 ms.

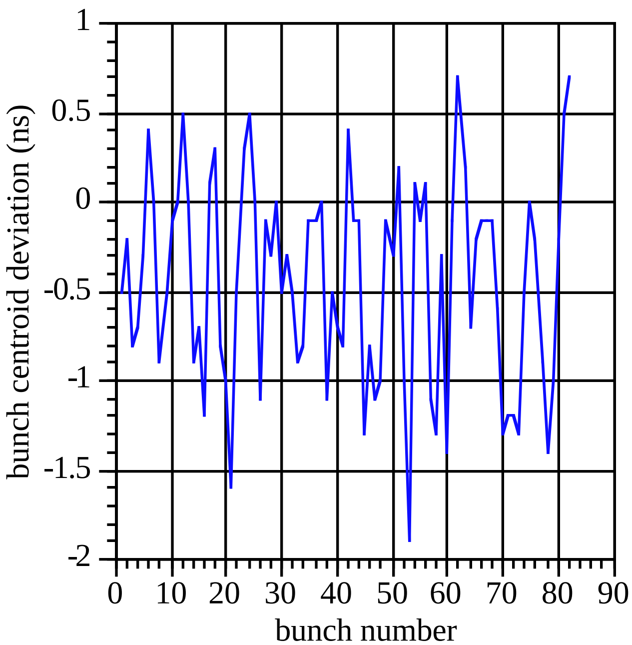

Figure 3. Bunch centroid deviation from center of RF bucket versus bunch number at a single point in time.

III. DAMPER CIRCUITRY

The signature of a coupled bunch mode N in frequency space is the presence of a sideband at the synchrotron frequency above or below the Nth revolution line above or below a multiple of the rf frequency [4]. In order to detect this signal and create a narrowband damping system for these coupled bunch modes, a two-path circuit has been constructed. A schematic of this circuit is shown in Figure 5. A programmable direct digital synthesizer (DDS) provides two outputs (sine and cosine) that are used to select the mode to be damped.

After mixing the beam signal with the DDS, the output mode signal should be at the synchrotron frequency and have an amplitude proportional to the mode intensity. An example of this signal is shown in Figures 6 and 7. Figure 6 shows that the mode initially is excited at transition and Figure 7 shows further growth later in the cycle after acceleration has been completed.

IV. DAMPER SYSTEM

A first attempt to damp these oscillations considered the use of the existing power amplifiers and accelerating RF cavities to kick the beam. However the high Q of the cavities (1000-4500) and the bandwidth of the power amplifiers (50 to 90 MHz) do not provide sufficient gain for the damper system. Construction of dedicated kicker cavities will be necessary for the next phase of the project.

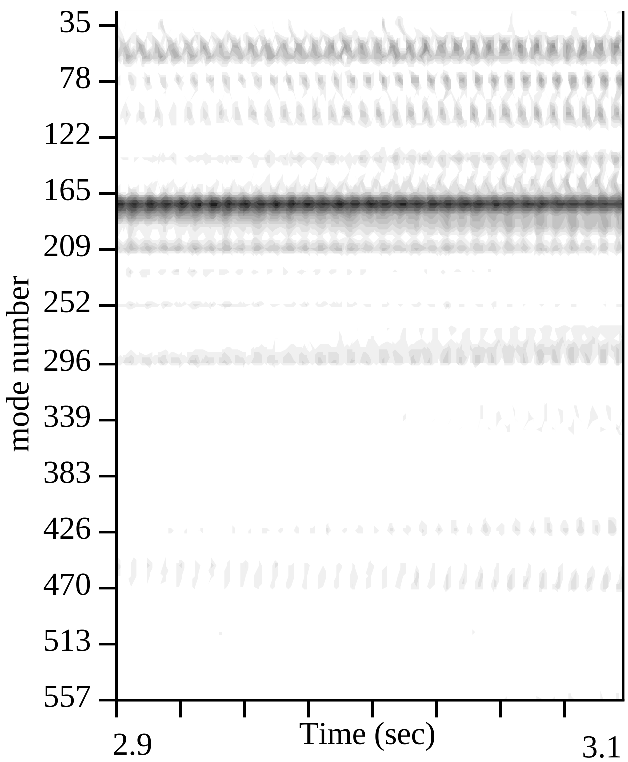

Figure 4. Power spectrum of coupled bunch modes with darkness indicating intensity.

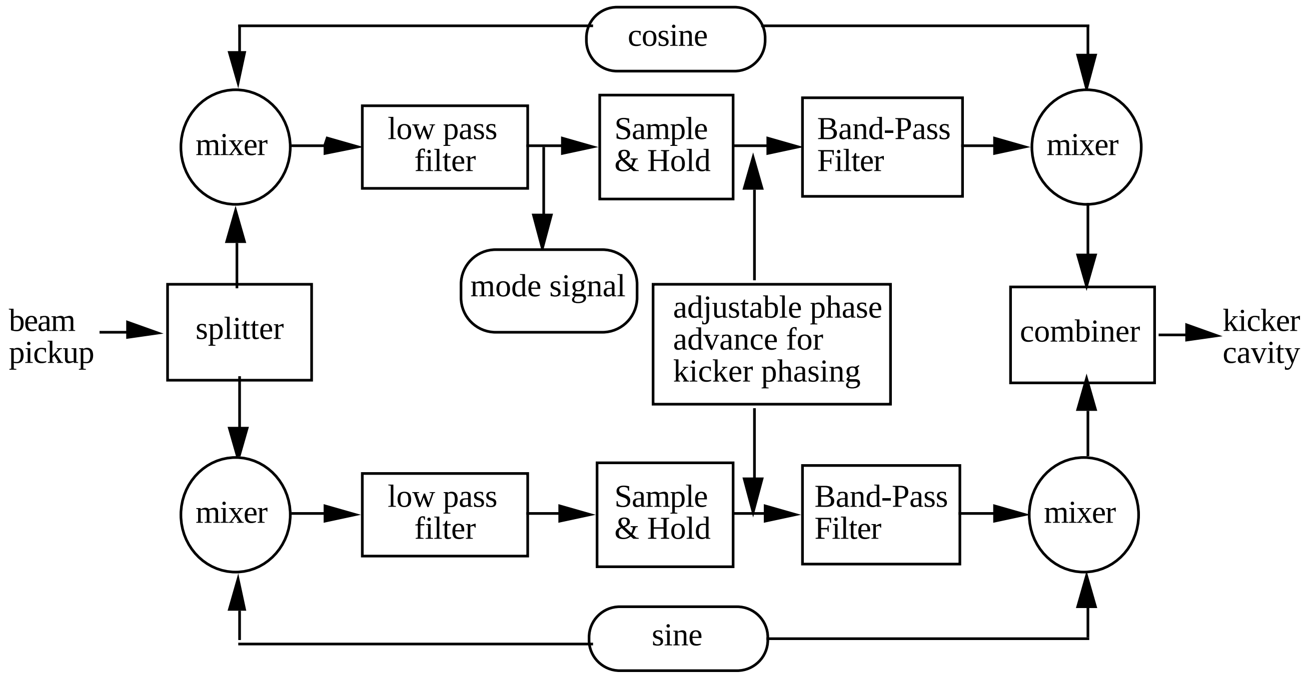

Figure 5. Schematic diagram of two-path damper circuitry.

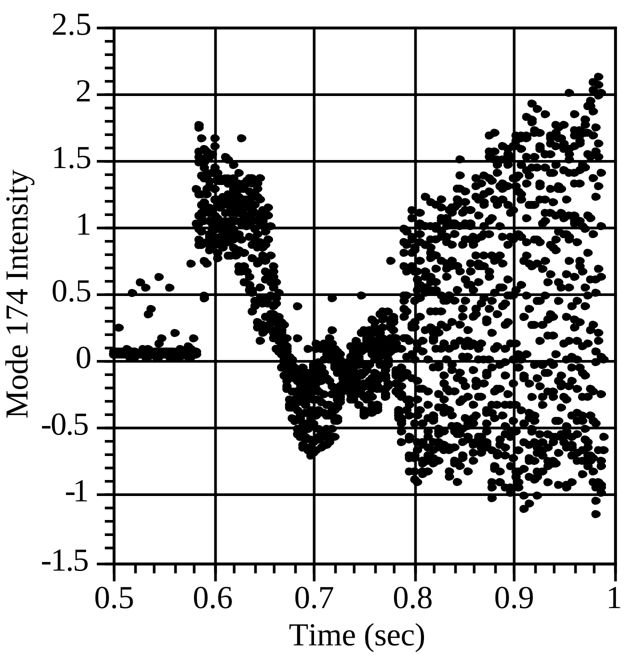

Figure 6. Intensity of Mode 174 signal during acceleration cycle. Signal increases dramatically at transition time (0.779 sec).

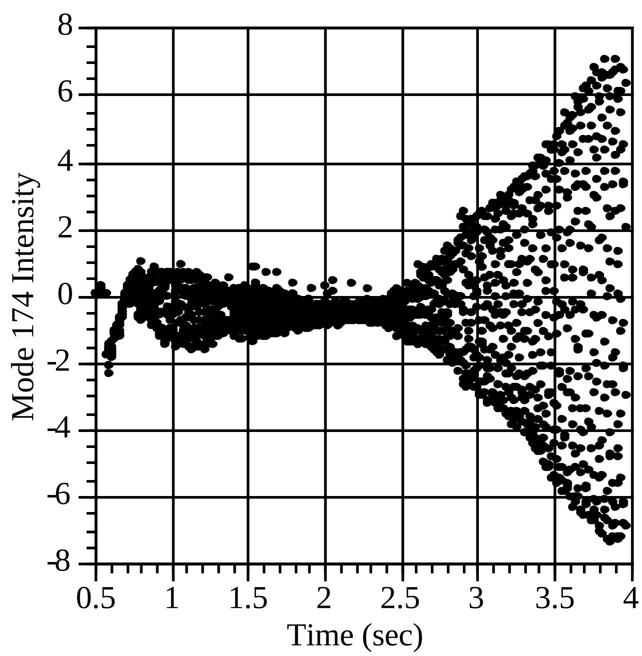

Figure 7. Growth of mode 174. Signal begins after transition and goes through exponential growth at the end of the acceleration portion of the cycle (2.4 sec).

IV. REFERENCES

[1] I. Kourbanis, "Improvements in Bunch Coalescing in the Fermilab Main Ring", Paper RAQ13, these proceedings.

[2] J.Dey, D. Wildman, "Higher Order Modes of the Main Ring Cavity at Fermilab", Paper WPP09 these proceedings.

[3] D.P. McGinnis, "Coupled Bunch Mode Instabilites Measurement and Control", 1991 Accelerator Instrumentatin Converence, AIP Conf. Proc. 252, W. Barry, editor, 1992, p. 65.

[4] J.N. Galayda, "Feedback Control of Multibunch Instabilities", 1989 & 1990 USPAS, AIP Conference Proc. 249, M. Month, ed., 1992, p. 664.