Operation and Performance of a Longitudinal Damping System Using Parallel Digital Signal Processing

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Abstract

A programmable longitudinal feedback system based on four AT&T 1610 digital signal processors has been developed as a component of the PEP-II R&D program. This Longitudinal Quick Prototype is a proof of concept for the PEP-II system and implements full speed bunch-by-bunch signal processing for storage rings with bunch spacings of 4 ns. The design implements, via software, a general purpose feedback controller which allows the system to be operated at several accelerator facilities.

The system configuration used for tests at the LBL Advanced Light Source is described. Open and closed loop results showing the detection and calculation of feedback signals from bunch motion are presented, and the system is shown to damp coupled-bunch instabilities in the ALS. Use of the system for accelerator diagnostics is illustrated via measurement of injection transients and analysis of open loop bunch motion.

INTRODUCTION

The prototype longitudinal damping system installed at the Advanced Light Source uses a phase detection technique to process beam signals summed from four button-type pickups. The detection frequency is at the sixth harmonic of the ring rf (6 × 500 MHz or 3 GHz), and a periodic microwave coupler circuit is utilized to generate a coherent tone burst from the pickup signals. The design processing bandwidth of the detector is 400 MHz which allows measurement of each bunch's synchrotron motion in an independent manner for bunch spacings of 4 ns. The detected oscillation signal is digitized at the bunch crossing rate. A digital signal processing block computes bunch-by-bunch correction signals and applies them to the beam using a fast D/A, output modulator, power amplifier, and beam kicker [1,2,3,4].

The heart of the signal processing is a computational block composed of four AT&T 1610 digital signal processors. These 16 bit single chip processors are general purpose programmable elements, each with 16 K of dual port memory and a 25 ns instruction cycle time for cached instructions [5]. The feedback signal computation is implemented in these processors and specified by a programmable filter algorithm [6]. The four processors

allow closed loop control of 40–90 bunches in the ALS depending on filter complexity and downsampling factor [7].

The output stages of the system comprise a fast eight bit D/A stage running at the 250 MHz beam crossing rate and an output modulator which transfers the baseband D/A signal into a modulation on a kicker carrier signal. The kicker signal originates as a carrier at 2.25 times the rf frequency (1125 MHz) and is QPSK (quad phase shift key) modulated at the 500 MHz bucket crossing rate, which results in a strong 1 GHz component as well as higher sidebands. The QPSK signal is then amplitude modulated by the output D/A, resulting in a kicker signal which can span the 1–1.25 GHz range of the longitudinal kicker. The power amplifier stage is a 500 watt commercial unit. Each of the four longitudinal kickers is a wideband drift tube structure comprising two drift tubes and associated delay lines. [8].

OPERATION OF THE SYSTEM AT ALS

The quick prototype system was installed at the ALS in September 1993. Initial tests of the system concentrated on open loop studies of bunch motion and injection diagnostics as the kicker power amplifier and kicker vacuum structures were not installed until April 1994.

A series of closed loop measurements was performed using the transverse kicker as a weak longitudinal kicker (the high gain longitudinal kicker will be available for commissioning in July 1994). By driving the transverse kicker in a common mode configuration a wideband longitudinal kick can be generated, albeit at a small amplitude (roughly 90 volts vs. the 1200 volts of the true longitudinal kicker). Figure 1 presents a closed loop transfer function of the feedback system acting on a single bunch. The figure shows the open loop synchrotron resonance, plus responses for the DSP filter acting with both positive and negative feedback on the beam. The loop gain in these experiments was roughly 15 dB—the data show the damping of the resonance due to negative feedback as well as the anti-damping (higher Q) of the system operated with positive feedback.

The weak kicker can be used to control multi-bunch instabilities though the total ring current that can be controlled is modest. For the 90 V kick, a ring current of up to 36 mA could be controlled and kept free of synchrotron oscillations as long as the feedback system was on during
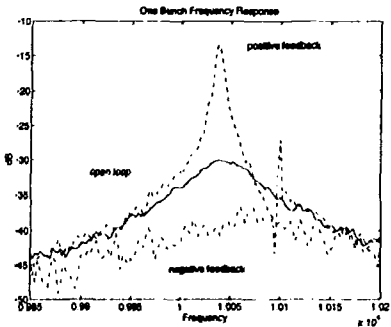
Figure 1. Measured frequency responses of a single bunch in the ALS. The open loop synchrotron resonance can be damped (via negative feedback) or anti-damped (via positive feedback).
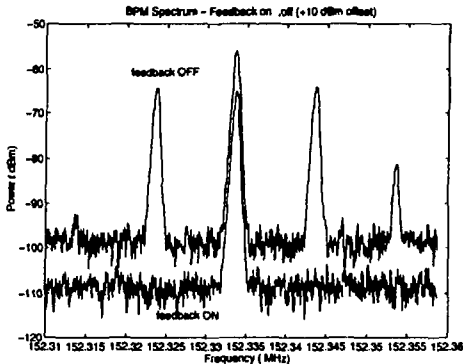

Figure 2. Spectrum of a BPM signal. The data are taken at 20 mA current for a pattern of 5 bunches with 4 ns spacing.

the injection process. In Fig. 2 we see a bunch spectrum obtained via a BPM for a five bunch, 20 mA fill (4 ns buckct spacing). The figure shows a revolution harmonic and presents data for feedback ON and OFF states. The data show the action of the feedback system in suppressing the synchrotron motion (evidenced in the 10 kHz sidebands) by more than 35 dB to below the noise floor of the spectrum analyzer

OPEN LOOP MEASUREMENTS AND ACCELERATOR DIAGNOSTICS

As the DSP processors are general purpose function blocks, each with 16 K of memory, it is possible to study longitudinal multi-bunch motion by using the DSP memories to record long time records of bunch motion [9]. Figure 3 shows such a time record for four bunches in the ALS. The system is self-excited, and the bunches each
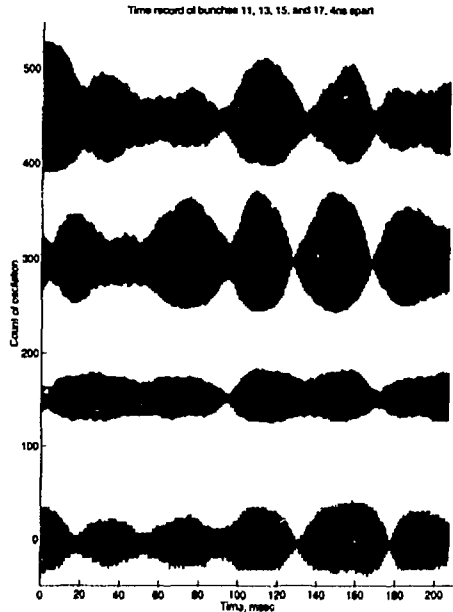

Figure 3. Time record of four consecutive open loop bunches in the ALS, showing multi-bunch synchrotron oscillations. The time record spans over 300,000 turns.

execute complicated modulated synchrotron oscillations of roughly 10 degrees at the rf frequency. The DSP data can be analyzed off-line—in Fig. 4 we see the power spectra of each bunch. The synchrotron resonance is seen to be composed of the four normal modes of the four bunch system. Two modes are particularly strongly excited (the lines at 11.2 and 11.225 kHz). The frequency difference of the lines is a function of the coupling strengths between the bunches. This modal analysis is general and does not require even bunch filling patterns

Another use of the DSP memories is to record injection transients. The phase and energy mismatches of the injector produce a damped injection transient. By recording many transients, histograms of the injection error can be generated. Figure 5 shows histograms of the transient amplitudes for three different injector phases. Since the magnitude of the injection transient is a factor which effects the required kicker power, such an injection jitter study is particularly useful.

SUMMARY

This longitudinal coupled bunch feedback system is installed at the Advanced Light Source (ALS) at Lawrence Berkeley Laboratory and is used to develop techniques to control multi-bunch instabilities. The system demonstrates
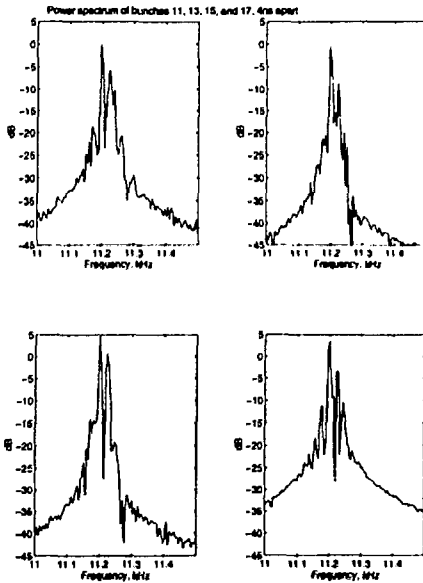
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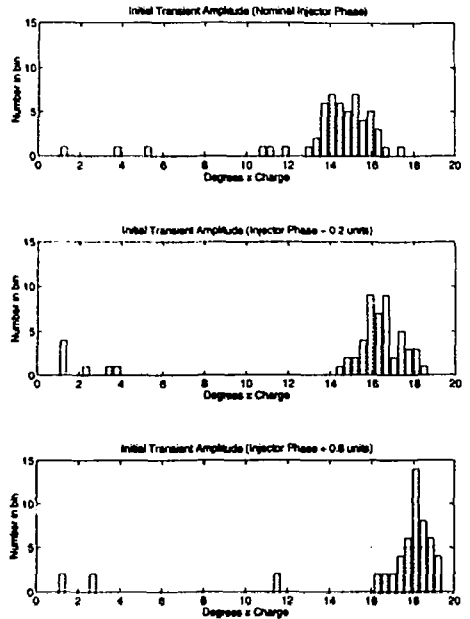Figure 4. Power spectra of the oscillation data.

Figure 5. The system can be used to record injection transients as an accelerator diagnostic. Histograms of the longitudinal transient amplitudes for three adjustments of injector phase.

all of the components and functions required for the PEP-II accelerator. The system damps unstable longitudinal motion in the ALS, and because of the general-purpose nature of the signal processing, can be used for a variety of accelerator measurements. Closed loop operation has been achieved using a low gain wide band kicker, and operation with a high gain kicker is scheduled for July 1994. With this kicker we anticipate being able to control longitudinal instabilities at the 400 mA design current[10]

ACKNOWLEDGMENTS

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