SLAC-PUB-12733
August2007

# CONTROL AND MEASUREMENTS OF LONGITUDINAL COUPLED-BUNCH INSTABILITIES IN THE ATF DAMPING RING*

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## *Abstract*

Damping ring at the Accelerator Test Facility (ATF) is a storage ring with 714 MHz RF frequency and harmonic number of 330. The ring is used in both single and multi-bunch regimes. In both cases, significant longitudinal dipole motion has been observed in the ring. A prototype longitudinal feedback channel using a Gproto baseband processing channel and a set of horizontal striplines has been constructed for the machine. The prototype allowed both suppression of the longitudinal motion and studies of the motion sources. In this paper, we present the results of these studies including measurements of steady-state oscillation amplitudes, eigenmodal patterns, and growth and damping rates. Using measured growth rates we estimate the driving impedances. We also present the effect of the longitudinal stabilization on the energy spread of the extracted beam as documented by a screen monitor.

## INTRODUCTION

Longitudinal instabilities have been historically observed in the ATF damping ring [1]. A series of feedback experiments described here has been performed with two goals: to characterize the instabilities and to demonstrate longitudinal stabilization.

## EXPERIMENTAL SETUP

Feedback system configuration used for this experiment is shown in Figure 1. Beam signal from a single beam position monitor (BPM) was passed through a 4-cycle comb generator at 2856 MHz, amplified, and mixed against a carrier signal, phase locked to the master oscillator. After low-pass filtering, the phase detector output was sampled by the Gproto bunch-by-bunch feedback system. Since in the ATF damping ring every other RF bucket can be populated, beam signal was sampled at RF/2 (357 MHz). Feedback output signal drove in-phase a set of horizontal striplines, which served as a low shunt impedance longitudinal kicker. Triggered diagnostic features of the Gproto were extensively used to tune the feedback loop and to study system performance. Since the ATF damping ring is a pulsed machine all data acquisition was triggered by the injection signal. Using a delay generator, the data recording snapshot window was positioned at different points during the storage cycle to study injection transients and steady-state performance.

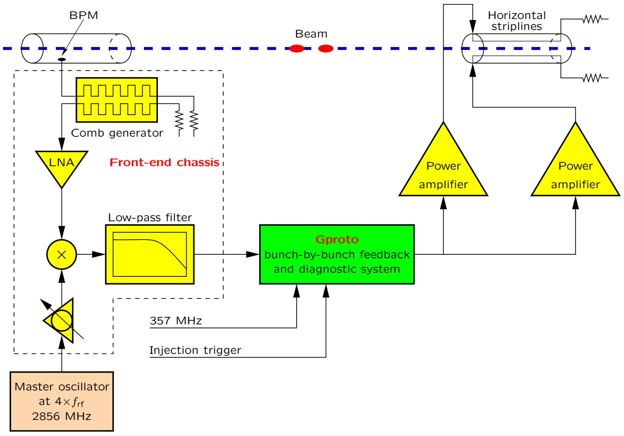

Figure 1: Block diagram of the experimental setup.

Feedback processing algorithm used a 16-tap finite impulse response (FIR) filter with a downsampling factor of 16. That is, the correction kick for a given bunch on turn $N$ used bunch position information sampled on turns $[N, N-16, N-32, \ldots]$. On turn $N+1$ the kick signal was computed from turns $[N+1, N-15, N-31, \ldots]$. In this approach the feedback correction signal uses information from 256 revolutions - 120 $\mu$s, comparable to the synchrotron period of 90 $\mu$s. This method of downsampling can be compared to the traditional approach, where the kick for a given bunch is computed and then repeated for $N_{\rm ds}$ turns. The new approach provides lower feedback channel group delay: $T_{\rm rev}/2$ versus $T_{\rm rev}N_{\rm ds}/2$. Technically, the processing was configured for a ”virtual” ring with harmonic number $N_{\rm ds}$ times the actual ring size, that is $16 \times 165 = 2640$.

## SINGLE-BUNCH MEASUREMENTS

Initial feedback studies focused on quantifying and suppressing single-bunch motion in the ring. In Fig. 2(a) single-bunch motion after injection without feedback is shown. Beam is longitudinally stable in this case and the motion decays exponentially with 19.6 $\rm ms^{-1}$ damping rate. This rate is very close to nominal 19.5 $\rm ms^{-1}$ longitudinal radiation damping rate. Once the feedback loop is closed, as shown in Figure 2(b), the injection transient damps much faster with the damping rate of 1.5 $\rm ms^{-1}$. Initial damping

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* Work supported by U.S. Department of Energy contract DE-AC02-76SF00515 and by the US-Japan collaboration in High Energy Physics

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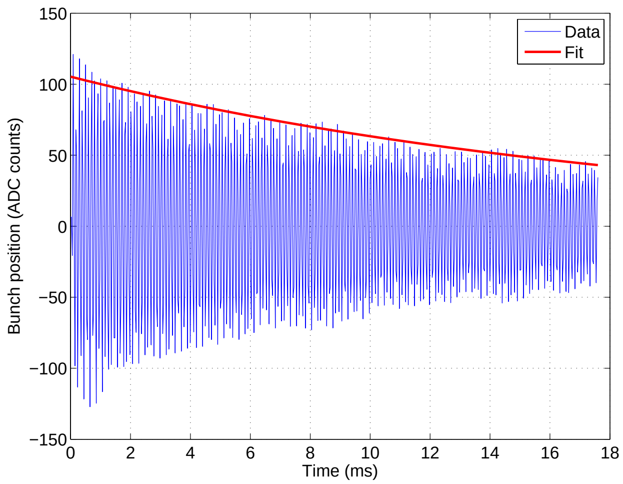
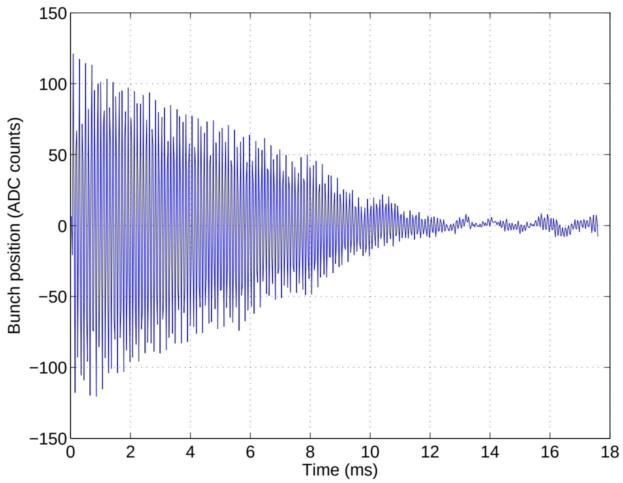
Contributed to Particle Accelerator Conference (PAC 07), 06/25/2007--6/29/2007, Albuquerque, New Mexico



(a) Open-loop



(b) Closed-loop

Figure 2: Single-bunch longitudinal motion immediately after injection

from 0 to 8 ms is linear due to feedback saturation.

Measurements with longer trigger delay showed that after injection transient damping there is significant residual motion, most likely driven by the RF system. The residual motion is strongly suppressed when the feedback loop is closed.

## MULTI-BUNCH MEASUREMENTS

After optimizing the feedback setup in the single-bunch regime we continued the studies with multiple bunches in a 45 bunch fill pattern. In the multi-bunch regime, we observed the traditional coupled-bunch instability with a band of even-fill eigenmodes (EFEMs) excited. The excited band is centered around mode 120 and is likely an artifact of the uneven filling pattern. In Fig. 3 a grow/damp measurement at 20 mA is illustrated. Note the bursting excitation of low-frequency modes driven by the RF system. Fitting complex exponentials to the growing and damping parts of the transient for EFEM 120 we extract the growth rate of $0.219 \pm 0.003\ \mathrm{ms}^{-1}$ and the damping rate of $0.441 \pm 0.008\ \mathrm{ms}^{-1}$.

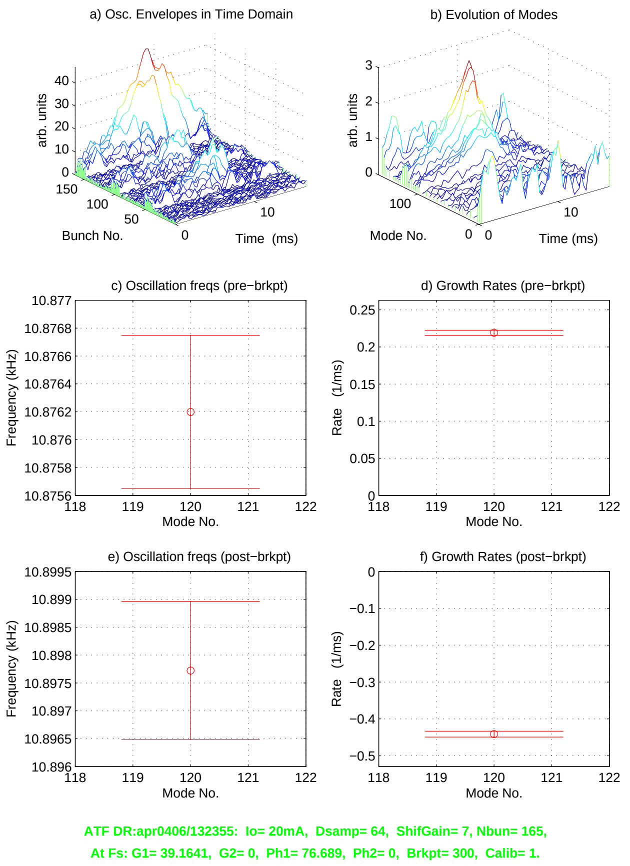


Figure 3: Grow/damp experiment: 45 bunches, 20 mA.

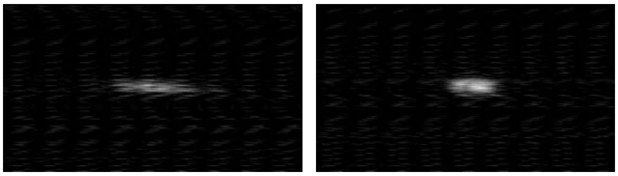
Due to aliasing of the HOM impedances by the beam, identifying the unstable mode restricts possible HOM frequencies to $259 + n \cdot 357$ MHz. A known cavity HOM around 2.36 GHz [2] is the likely source of the instability. By performing growth rate measurements at 20 mA and 40 mA and assuming the driving impedance at 2.4 GHz we can estimate the effective longitudinal impedance of the HOM as 33 kΩ.

## ENERGY SPREAD IN THE EXTRACTION LINE

As an independent measurement of feedback performance, we observed the transverse beam profile in a dispersive region of the extraction line using a screen monitor. In this case, the horizontal profile of the beam is a superposition of the following contributions:

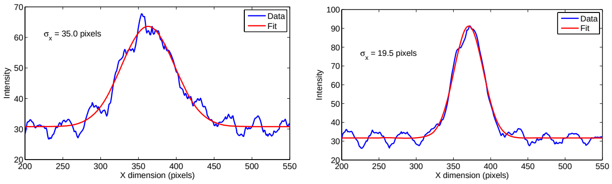
- Horizontal beam size;
- Intra-bunch energy spread;
- Inter-bunch energy spread (multi-bunch case).

Collecting screen images for both single-bunch and multi-bunch fill patterns allows us to separate the contributions from the intra and inter-bunch energy spreads. Figures 4(a) and 4(b) show the screen monitor snapshot for the open and closed-loop conditions respectively. There is a visible reduction in the horizontal spot size. To quantify the effect, we performed Gaussian fits to horizontal projections of the snapshots as illustrated in Fig. 5. The spot size RMS is reduced from 35 to 19.5 pixels in this case. Results of the fits to 28 images collected in different ring conditions is summarized in Fig. 6.



(a) Open-loop (b) Closed-loop

Figure 4: Screen monitor images in the multi-bunch regime



(a) Open-loop (b) Closed-loop

Figure 5: Gaussian fits to the horizontal projections of the screen monitor images

When the longitudinal feedback is operational, the horizontal spot size is held constant in both single and multi-bunch modes. Turning off the feedback produces a significant spot size increase in the multi-bunch case. This increase is mostly driven by the large bunch-to-bunch energy spread. With unstable beam there is a large variation of the spot size shot-to-shot due to the variability of the saturation mechanisms and the modal beating patterns. An interesting feature of this measurement is a consistent single-bunch energy spread increase without feedback. Since the data is from a single-shot single-bunch image, it suggests a mechanism of the intra-bunch energy spread increase due to RF-driven centroid oscillation.

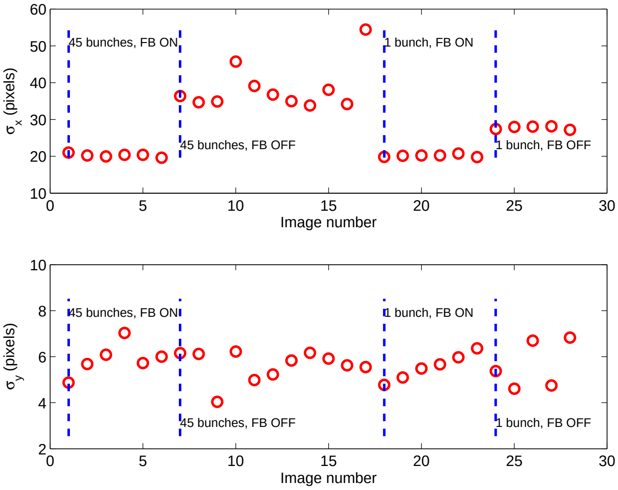


Figure 6: Horizontal and vertical spot sizes for multiple screen monitor images.

Horizontal spot size measurements presented in Fig. 6 are summarized in Table 1. Additional studies are needed for more precise quantification of the extracted beam energy spread and of the observed single-bunch energy spread change with feedback.

Table 1: Extraction line measurement summary

| Fill | Parameter | FB OFF | FB ON |
|---|---|---|---|
| Single | $\sigma_x$, pixels | $28.02 \pm 0.25$ | $20.26 \pm 0.13$ |
| bunch | $\sigma_x$, $\mu$m | $925 \pm 8$ | $668 \pm 4$ |
| Multi | $\sigma_x$, pixels | $38.8 \pm 1.8$ | $20.26 \pm 0.18$ |
| bunch | $\sigma_x$, $\mu$m | $1281 \pm 59$ | $669 \pm 6$ |

## SUMMARY

We have demonstrated control of longitudinal coupled-bunch instabilities in the ATF damping ring. Unstable beam motion has been analyzed to extract instability growth rates and the feedback damping rates. Observed spectral information has been used to link the unstable modes to known RF cavity HOMs. These measurements can be used to determine the necessary kicker voltage, if a permanent feedback system is desired. Observations of the beam spot size in the dispersive region of the extraction line show significant reduction in the extracted beam energy spread.

## REFERENCES

[1] M. Ross and R. Meller, “Detection and feedback of synchrotron oscillations in the ATF damping ring,” Tech. Rep. ATF-04-06, ATF, Tsukuba, Japan, 2005.

[2] S. Sakanaka *et al.*, “Low power measurement on a HOM damped cavity for the ATF damping ring,” Tech. Rep. KEK-PREPRINT-94-79, KEK, Tsukuba, Japan, 1994.