COMMISSIONING OF THE BESSY-II LONGITUDINAL FEEDBACK SYSTEM*

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Abstract

A longitudinal bunch-by-bunch feedback system was installed at BESSY-II. Results from the successful commissioning of the system in fall 1999 are presented.

1 INTRODUCTION

BESSY-II, a high-brilliance synchrotron radiation source in Berlin-Adlershof, was commissioned in 1998 [1]. Already in 1997 the decision was made to build and install feedback systems to control longitudinal and transverse coupled-bunch instabilities.

The longitudinal feedback system (LFB) is a digital bunch-by-bunch system originally developed for use at the ALS (LBNL/Berkeley), PEP-II (SLAC/Stanford) and DAΦNE (INFN/Frascati). In its first version, the system has been operating reliably at the ALS over many years [2]. The BESSY-II feedback electronics was fabricated in parallel with almost identical hardware for the PLS/Pohang [3] and SPEAR/Stanford. The system was installed in summer 1999 and commissioned during several machine development periods. Commissioning and operational aspects of all six installations are described in [4], whereas this paper emphasizes the BESSY-II experience.

The transverse feedback system, also installed in 1999, is described in [5].

2 FEEDBACK SYSTEM LAYOUT

Figure 1 shows the LFB schematically. The bunch signal from a pickup passes a comb filter to produce a burst for phase detection at 3 GHz. The moment signal (phase·charge) is digitized at a rate of 500 MHz, downsampled and handed to an array of DPSs, where a 6-tap FIR filter produces a correction signal for every bunch. The D/A-converted output modulates a quadrature phase shift keyed (QPSK) carrier at 1374 MHz (11/4 times the rf frequency). More details of the electronics and software architecture can be found in [2] and references therein.

The correction signal is applied to a 220 W solid-state power amplifier that drives a cavity-type kicker. The kicker design, originally made for the longitudinal feedback of DAΦNE, was modified to meet the BESSY-II requirements [6].

* Funded by the Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie and by the Land Berlin.

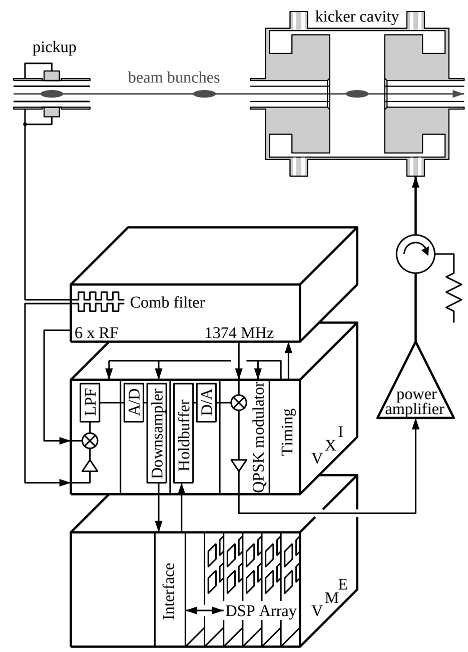

Figure 1: Longitudinal feedback system layout.

The fact that this system is now used at six facilities of rather different size and purpose (four synchrotron light sources and two e^+e^- colliders) proves the flexibility of its design. While the basic hardware is always the same, the size of the DSP array depends on number of bunches and the synchrotron frequency. The amplifier/kicker configuration is chosen according to the respective power requirements and space restrictions. All relevant parameters such as synchrotron frequency, sampling rate, feedback gain and the filter properties are under software control and can be easily modified.

3 COMMISSIONING EXPERIENCE

The modularity of the system allows commissioning of hardware and software at different stages. As shown in figure 1, the hardware consists of

- VXI-based modules for the basic functions
- VME-based DSP-boards
- a chassis with rf components
- pickup, kicker, power amplifier, circulators

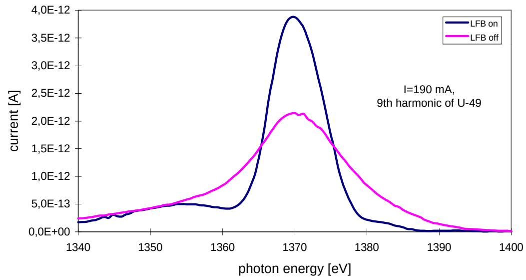

Figure 2: Undulator line shape with LFB on and off [12].

Software is required on different hardware levels:

- a set of digital filters running on the DSPs
- EPICS-based code on VXI/VME-CPUs (VxWorks)
- EPICS-based operator software (UNIX)
- MATLAB macros for offline data analysis.

In a first step, the VXI and VME components were tested to verify correct operation of the digital filter and peripheral tasks like temperature monitoring of all modules. Addition of the rf chassis that includes a “fake beam generator” allowed to simulate a beam signal and generate the QPSK-modulated correction signal. This way, much of the work was not restricted to dedicated machine shifts. The final steps that required beam (and beam-related hardware like pickup, amplifier and kicker) included adjusting the timing of phase detection (frontend) and kick signal (backend) and optimizing the FIR filter coefficients.

A serious difficulty arose from the fact that BESSY-II had no single-bunch injection capability at that time. The shortest producable bunch train still had a FWHM of ∼30 bunches, and the comfortable timing tools developed for the installations could not be used to overlap the kick signal with the correct bunch. The solutions that were found by different techniques were not always unique, since most coupled-bunch modes can still be significantly damped if the kick is applied to the wrong bunch.

Meanwhile, a single-bunch electron gun has been installed at BESSY-II [7] and arbitrary fill shapes can be produced by rf clearing of selected buckets [8].

One interesting discovery was that the QPSK sequence for the BESSY kicker operating at $11/4 \cdot f_{\rm rf}$ must be reversed compared to the other installations operating 1/4 *above* a multiple of $f_{\rm rf}$. Otherwise, only every other bunch is kicked correctly. Surprisingly, even before correcting the sequence, the system had adequate performance to damp beam instabilities.

The software was remotely commissioned by the SLAC system designers. Even though great care had been taken to create an easily portable distribution common to all users, the installation turned out to be a major task for the SLAC team and required BESSY to deviate from its control system standards regarding the UNIX system, the version of EPICS-related software and network security issues. Once debugged, the software worked reliably on all levels.

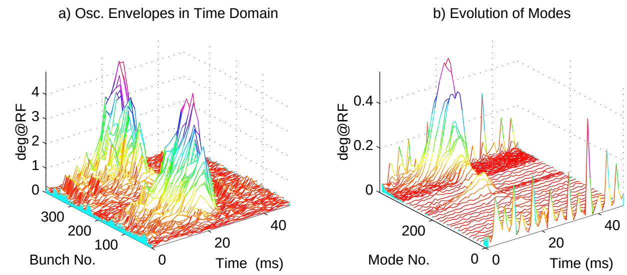

Figure 3: LFB data record with feedback switched on after 20 ms. Shown are oscillation amplitudes versus bunch number (left) and versus mode number (right).

4 RESULTS

Several indicators of longitudinal instabilities were used to verify successful damping by the LFB:

- synchrotron sidebands in the beam spectrum
- grow-damp data from the LFB (see below)
- pickup signals recorded with a digital oscilloscope [9]
- synchrotron light spot size with dispersion
- bunch oscillations seen in streak camera images [10]
- energy spread from Compton backscattering [11]
- line shape in the undulator spectrum [12]

The beam spectrum is the most obvious indicator for the operator, while the last item reflects the main objective of the LFB i.e. to increase the intensity of undulator radiation. Figure 2 shows the 9th harmonic of a U-49 undulator (49 mm period length) at a beam current of 190 mA. Closing the feedback loop doubles the intensity at the peak. With future operation at higher beam current, the improvement is expected to be even more significant.

One of the most useful features of the LFB is its ability to transfer a stream of digitized data without interrupting the feedback. This can be used to verify proper operation of the system as well as for accelerator physics studies. Since only downsampled data are stored, a large time span (typically 30-50 ms) can be analyzed. While recording data, the digital filter function may be changed. Figure 3 shows an example, starting with zero gain and damping the beam after 20 ms. Figure 3a shows oscillation amplitudes as a function of time and bunch number with the standard fill pattern of two bunch trains. The modal analysis (figure 3b) reveals an excitation around multibunch mode 360 growing at a rate of 0.3 ms^{-1}, most likely driven by a higher order mode (HOM) of the 3rd-harmonic cavities. The oscillation around mode zero, not influenced by the feedback, is driven by noise from the rf system. Since this noise is common to all bunches, it can be used to extract bunch charge and phase from the detected moment signal [13]. In the example of figure 4, the synchronous phase variation is a combination of a slope due to beam loading in the main cavities and a 5 MHz modulation from the 3rd-harmonic cavities tuned about 4 revolution harmonics away from $3 \cdot f_{\rm rf}$.

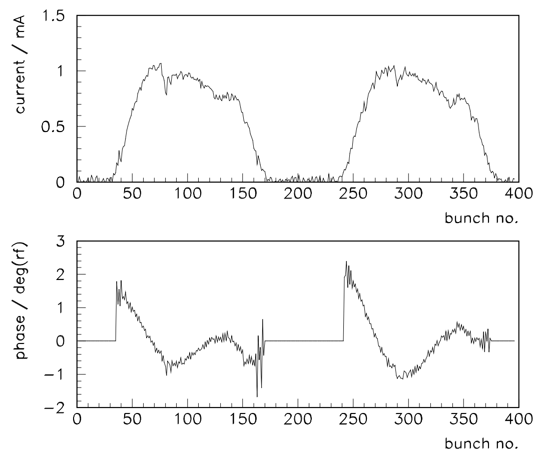

Figure 4: Bunch current and relative synchronous phase extracted from the detected moment signal.

5 FUTURE OPERATION

A major issue for the future performance of the LFB is the presence of four 3rd-harmonic cavities, installed in November 1999 in order to increase the Touschek lifetime by bunch lengthening. The issue has several aspects:

1) The harmonic cavities have several strong HOMs. Increasing amplifier power P or the number of kickers N is expensive and increases the kick voltage only $\sim \sqrt{N \cdot P}$. With careful tuning of the harmonic cavities, stable beam conditions were demonstrated up to ∼350 mA, while standard user operation requires presently ≤ 220 mA.

2) For a non-even fill pattern, passive harmonic cavities cause large variations of the synchronous phase. The moment signals may exceed the range of the 8-bit-A/D-converter. Phase detection at $6 \cdot f_{rf} = 3$ GHz fails for variations above ± 15 degrees at f_{rf}, and lowering the detection frequency at the cost of sensitivity may be required. Presently, the tuning of the harmonic cavities is a compromise between improved Touschek lifetime and moderate phase transients. Figure 5 shows the peak-to-peak phase variation as function of the length of one or two bunch gaps. Despite large uncertainties in the measurement (dots) and numerical evaluation (dashed line), some conclusions can be drawn:

- The bunch gap should be as small as possible.
- A second gap yields no significant improvement.
- The rise with current is faster than proportional.
- Modulating the transients with one of the harmonic cavities tuned several revolution harmonics away (as in figure 4) can be used to minimize the number of bunches with excessive phase offset.

3) Flattening the rf potential causes a synchrotron tune spread. If the bandwidth of the usual 6-tap FIR filter becomes insufficient, a newly developed IIR filter scheme will be applied [4].

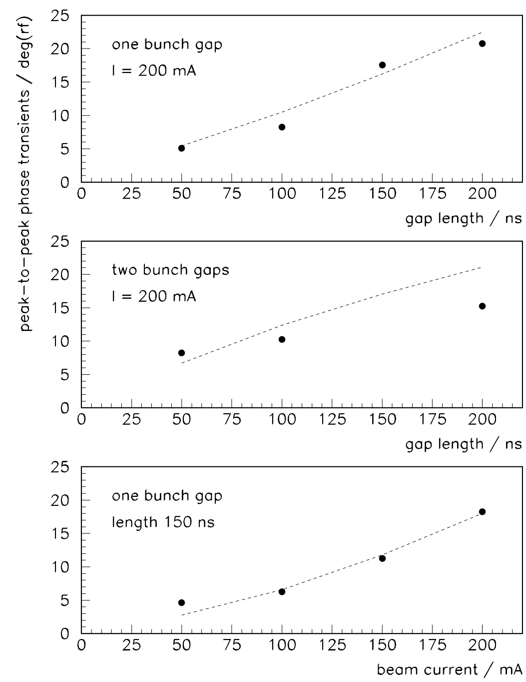

Figure 5: Peak-to-peak variation of synchronous phase as a function of gap length and beam current.

ACKNOWLEDGEMENTS

The support of several groups (hardware & software) at SLAC, ALS, INFN and BESSY involved in the installation and commissioning of the LFB is gratefully acknowledged.

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