THE ELETTRA DIGITAL MULTI-BUNCH FEEDBACK SYSTEMS

D. Bulfone, V. Forchi', M. Lonza, L. Zambon, Sincrotrone Trieste, Trieste, Italy
M. Dehler, PSI, Villigen, Switzerland

Abstract

Multi-bunch instabilities degrade the performance of modern synchrotron light sources by leading to increased beam emittance, energy spread or even to beam loss. In order to damp any potentially excited transverse/longitudinal coupled-bunch mode of the 432 2-ns spaced bunches, a bunch-by-bunch feedback approach has been chosen for ELETTRA. The additional requirements for flexibility and availability of diagnostic tools have led to the development of a digitally based scheme which, running the appropriate software, is being used for both the transverse and longitudinal multi-bunch feedback systems. The transverse feedback has been installed and the latest operational results are reported. The design and current status of the longitudinal system are given.

1 INTRODUCTION

At ELETTRA, a consistent bunch-by-bunch scheme has been adopted for the Transverse and Longitudinal Multi-Bunch Feedback (TMBF and LMBF) systems. Both systems are based on a single-monitor-single-kicker architecture, where the processing is executed by an array of software programmable Digital Signal Processors (DSP), each of them being in charge of a given subset of bunches. Each bunch is considered as an independent oscillator at the betatron (synchrotron) frequency. To add a damping term to such oscillations the correcting kick signal must be shifted by π/2 betatron (synchrotron) phase with respect to the position (phase) error signal of the same bunch when it passes through the kicker. Starting from the position (phase) error signal detected by the monitor, the basic task of the digital filters executed by the DSPs is to calculate the kick values, including the suppression of the "stable beam" component that is not used by the feedback. More complex filters, however, can implement additional features. A subset of DSPs is concurrently dedicated to data acquisition and beam diagnostics. About 200 ms of continuous data acquired from all the stored bunches allows high-accuracy measurements, which can also be used to detect possible variations in the beam parameters and accordingly change the feedback digital filter coefficients on the fly.

2 TRANSVERSE FEEDBACK

A detailed description of the TMBF system and its diagnostic features is given in [1, 2, 3]. Having completed the commissioning phase [4], the TMBF has been installed and routinely operates in the vertical plane since last November during the users shifts at 2.4 GeV. In these conditions longitudinal instabilities are damped by appropriate settings of the cavity temperatures and higher order mode shifters, horizontal and vertical instabilities are damped by a slightly changed optics and the TMBF respectively so that a coupled-bunch instability free beam is delivered to the users. The improvement in beam quality is verified by the spectra of the insertion devices. Figure 1 shows the results for a plane and an elliptical undulator.

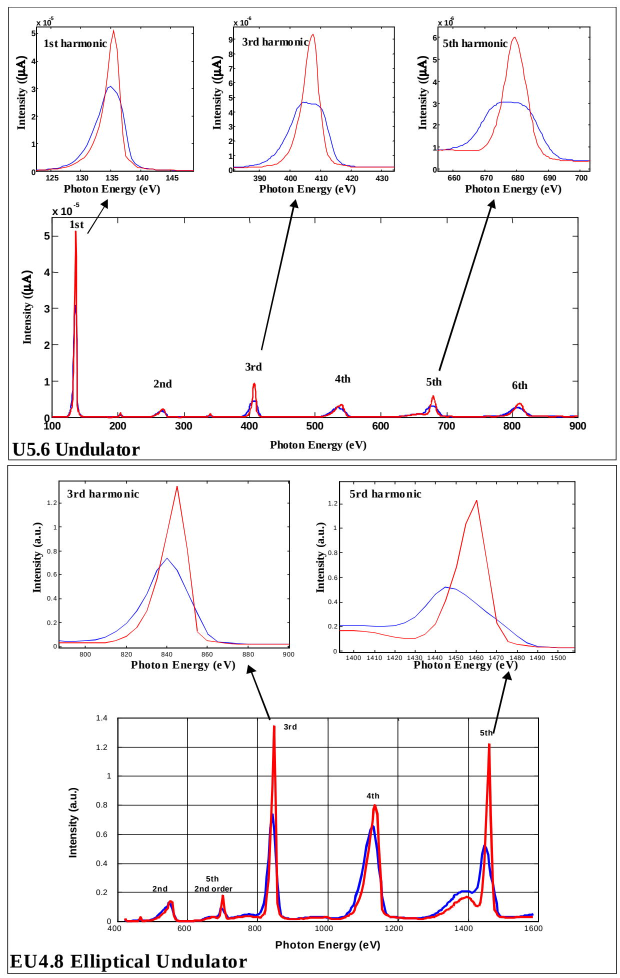

Figure 1: U5.6 undulator and EU4.8 elliptical undulator spectra (gap 20 mm) in the previous user mode (blue line) and with damped longitudinal/transverse instabilities (red line) (135 mA@2.4 GeV).

Given the considerable betatron tune variations that can be observed when opening/closing some insertion devices and during the energy ramping from 0.9 to 2 or 2.4 GeV, a family of 5-tap FIR (Finite Impulse Response) digital filters featuring compensation of the tune variations was designed and is currently implemented. These filters provide the right amplitude and phase in a given frequency interval around the nominal tune. Figure 2 shows the transfer function of a filter where fractional tune changes exceeding ±20% are possible while keeping the same damping performance of the TMBF system.

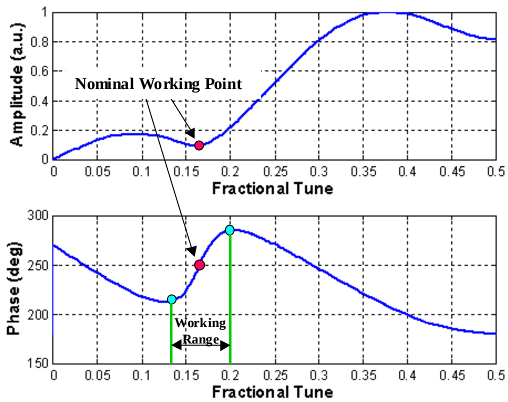

Figure 2: Transfer function of a 5-tap FIR filter featuring compensation of the tune variations.

A novel diagnostic tool has been recently developed that allows measuring the betatron tune without affecting user experimental activities. It consists of exciting with the TMBF only one (few) selected bunch(es) using an arbitrary downloaded waveform, while the remaining bunches are kept damped by the system itself that is concurrently running. A frequency domain analysis of the turn-by-turn position data of the excited bunch(es) clearly identifies the fractional betatron tune. In the case of figure 3, pink noise with power spectrum centered around the vertical tune frequency was used to excite two of the 432 bunches stored in ELETTRA. The upper part shows the amplitude of the vertical betatron oscillation component for the different bunches, the lower reveals the fractional tune as measured from one of the two excited bunches.

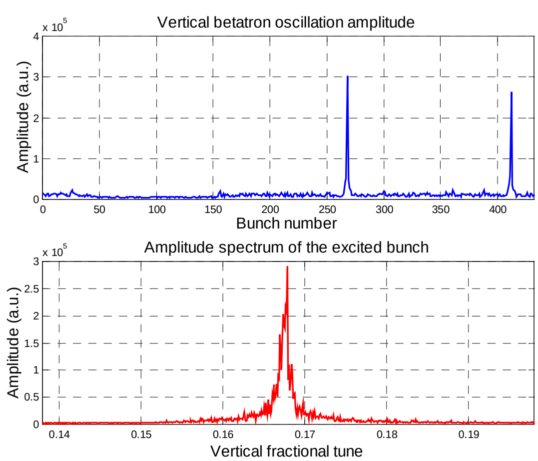

Figure 3: Excitation of two bunches with pink noise. Amplitude of the vertical betatron oscillation component for the 432 bunches (upper) and fractional vertical tune measured from one of the two excited bunches (lower).

3 LONGITUDINAL FEEDBACK

The block diagram of the LMBF is shown in figure 4. The overall architecture is quite similar to that of the TMBF. The system will re-use the same digital processing electronics running the appropriate software. Key differences exist in the front-end and back-end parts.

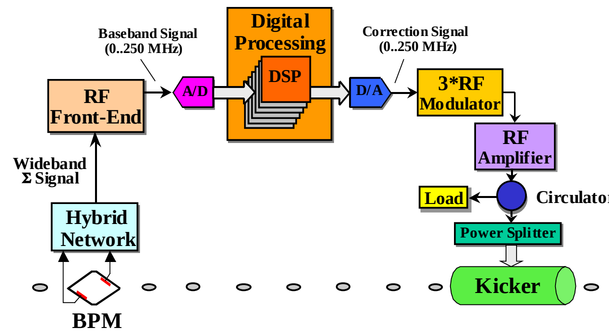

Figure 4: Block diagram of the Longitudinal Multi-Bunch Feedback system.

The wide-band signals from two opposite buttons of a standard Beam Position Monitor (BPM) are summed together in the hybrid network to produce a signal proportional to the bunch current that is insensitive to transverse beam motion. The RF front-end module, which is of the same type used for the TMBF system, works at a 3*RF (1.5 GHz) carrier frequency and is operated in phase-detection mode to provide a baseband bunch-by-bunch signal whose amplitude is proportional to the bunch phase error. The lowest operating frequency corresponding to the first synchrotron sideband at 2.4 GeV is 10 kHz.

On the side of the back-end, a heavily coupled cavity-type kicker equipped with four waveguide ports for driver and four for the loads and operating in the 1.25-1.5 GHz frequency band has been designed for both ELETTRA and SLS [5]. A maximum shunt impedance of 1500 Ohm is obtained by adopting the SLS vacuum chamber cross section (28 mm height, 88 mm width) inside the kicker, so that two tapering elements are needed for ELETTRA.

In order to create an appropriate driving signal for the kicker, the baseband correction signal from the Digital-to-Analog Converter enters a Single Side Band (SSB) modulator that uses the lower side band of the third RF harmonic and covers the 1.25-1.5 GHz frequency band. The simplest way of doing a SSB modulation is to combine a standard amplitude modulator, which generates both upper and lower side bands, with an appropriate high or low pass filter in order to suppress the unwanted side band. The disadvantage of this method, however, is that it typically introduces phase rotations and delay variations in the signal, which does not satisfy the synchronization requirements of a bunch-by-bunch feedback system. The more complex set-up of figure 5 was therefore adopted. The modulating signal is split in two parts and the second is sent through a 6-tap FIR Hilbert filter that creates a

90 degrees phase shift for frequencies up to 280 MHz. The output together with the original signal is led into an I/Q type modulator and mixed with the 1.5 GHz carrier.

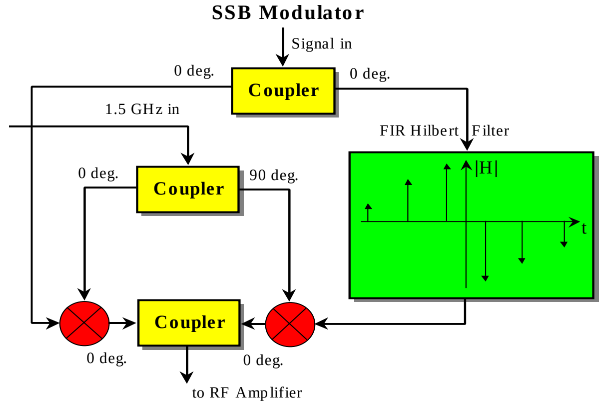

Figure 5: Functional block diagram of the SSB modulator.

The big advantage of this scheme compared to the simpler one described above is that inaccuracies in the filter implementation show up only as a lowered efficiency due to the increased power in the upper side band, which gets eventually rejected by the kicker. Phase and delay variations in the beam voltage cannot show up, since the filter output modulates the phase shifted 1.5 GHz carrier, which does not impact any voltage to the beam. The frequency domain behaviour of the modulator has been measured and is given in figure 6, where both the lower and upper side band response are plotted. For higher frequencies, one obtains an upper side band suppression of 15-20 dB. Near DC, the FIR Hilbert filter with its limited number of taps gives a near zero response, so the modulator actually behaves as an amplitude modulator resulting in the symmetry of the lower and upper side bands. For feedback operation, this is not a problem, since the kicker is still efficient in that frequency band.

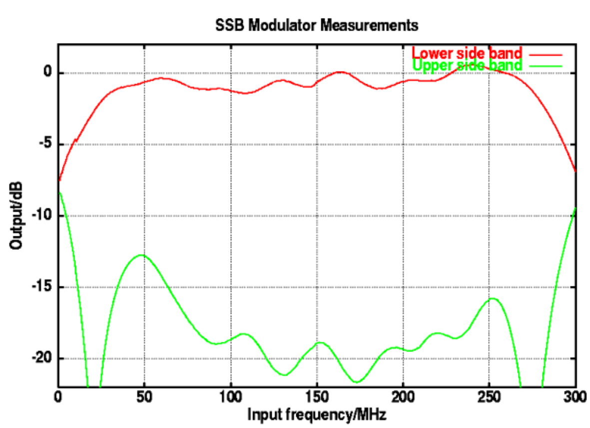

Figure 6: Measured lower and upper side band response of the SSB modulator.

A 250 W Travelling Wave Tube RF amplifier covering the 1.0-2.5 GHz frequency band followed by a circulator and a splitter will be used to feed the requested RF power inside the kicker.

4 CONCLUSIONS

The TMBF is routinely used during the user shifts at 2.4 GeV, where an improved beam featuring completely damped transverse and longitudinal coupled-bunch oscillations is delivered. The resulting brilliance of the higher undulator harmonics is enhanced by at least a factor of two.

With the goal of simplifying machine operating conditions, a complementary LMBF is under development. All the LMBF components have been ordered. The RF front-end electronics has been installed and characterized measuring the longitudinal oscillations of the bunches. The SSB modulator and the kicker, designed by the SLS, will be installed in the coming weeks of the June shutdown.

Both the ELETTRA and SLS LMBF systems will take advantage of the same digital processing electronics already developed for their TMBFs. The appropriate digital filter software to be executed by the DSPs is under development.

5 ACKNOWLEDGEMENTS

The contribution of R. Bressanutti to the development of the ELETTRA multi-bunch feedback systems is greatly acknowledged.

6 REFERENCES

[1] D. Bulfone et al., “Design Considerations for the ELETTRA Transverse Multi-Bunch Feedback”, PAC’99, New York, March 1999.

[2] M. Lonza et al., “Digital Processing Electronics for the ELETTRA Transverse Multi-Bunch Feedback System”, ICALEPCS’99, Trieste, October 1999.

[3] D. Bulfone et al., “Exploitation of the Integrated Digital Processing and Analysis of the ELETTRA/SLS Transverse Multi-Bunch Feedback System”, PAC’01, Chicago, June 2001.

[4] D. Bulfone et al., “First Commissioning Results of the ELETTRA Transverse Multi-Bunch Feedback”, DIPAC’01, Grenoble, May 2001.

[5] M. Dehler, “Kicker Design for the ELETTRA/SLS Longitudinal Multi-Bunch Feedback”, these Proceedings.