EXPLOITATION OF THE INTEGRATED DIGITAL PROCESSING AND ANALYSIS OF THE ELETTRA/SLS TRANSVERSE MULTI-BUNCH FEEDBACK SYSTEM

R. Bressanutti, D. Bulfone, M. Lonza, V. Smaluk, L. Tosi, L. Zambon, Sincrotrone Trieste, Italy
M. Dehler, R. Ursic, Paul Scherrer Institut, Switzerland

Abstract

The ELETTRA/SLS Transverse Multi-Bunch Feedback is a bunch-by-bunch system using state-of-the-art DSPs (Digital Signal Processors) for the processing of the position data coming from all of the 432/480 2ns-spaced bunches. While a number of DSPs execute the feedback algorithms, the rest of them are dedicated to the real-time analysis of all the sampled bunch positions stored in up to 96 Mbytes of memory allowing time and frequency domain analysis with unprecedented depth and resolution. In addition to the advantages of feedback digital filtering, such as flexibility and reproducibility, this novel integrated mixing of functionalities opens the way to the implementation of a number of features that enhance system operability and the quality of the beam.

1 INTRODUCTION

The ELETTRA/SLS Transverse Multi-Bunch Feedback (TMBF) is a wide-band bunch-by-bunch system where the position of the 2ns-spaced 432/480 bunches are independently sampled and corrected. At ELETTRA, the wide-band signals from the buttons of a single standard Beam Position Monitor (BPM) are combined and demodulated into X and Y 0-250 MHz baseband signals. Each of the latter is sampled by an eight-bit 500 Msample/s Analog-to-Digital Converter (ADC) and digitally processed. The calculated corrective kick values are transmitted to a complimentary 500 Msample/s Digital-to-Analog Converter (DAC) and amplified by a RF amplifier that powers a single downstream port of a two-stripline kicker. A more detailed description of the system can be found in [1] and [2].

Software programmable Digital Signal Processors (DSP) are used for the processing of the data. The 500 Mbyte/s input data flux, carrying the position samples of all the 432 bunches, is first de-multiplexed towards six VME based processing boards. The data on each board is then distributed by means of a programmable switch among four available DSPs.

The flexibility of such a scheme allows for the organization of different processing arrangements. In the present configuration (figure 1) the 72 bunch samples arriving at each VME board are passed to the first DSP for on-line acquisition and diagnostics and concurrently split over the three other DSPs that execute the feedback algorithm on the 24 respective bunches.

Finite Impulse Response (FIR) digital filters have been implemented so far as the actual feedback algorithm.

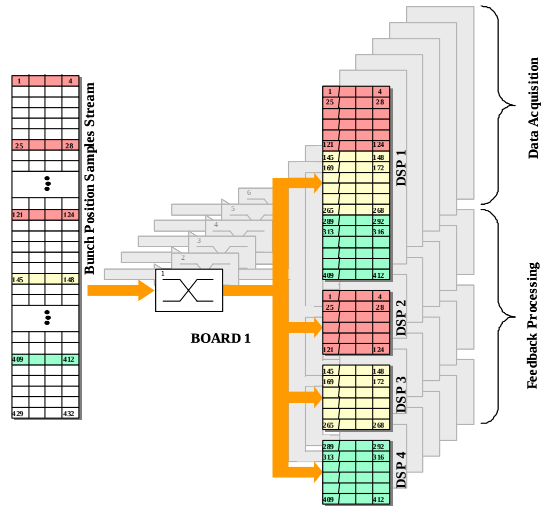

Figure 1: Bunch samples distribution.

They basically provide the right phase and gain at the betatron frequency, permitting any relative betatron phase between the BPM and the kicker that can therefore be installed anywhere in the machine, plus rejection of the closed orbit DC signal. Figure 2 shows the transfer function of a 5-tap FIR filter used. With its double zero at DC, it features a smooth behaviour at the lower frequencies so that spurious longitudinal components at the synchrotron frequency are also well rejected.

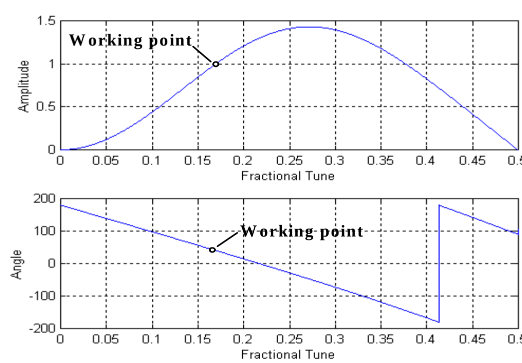

Figure 2: Transfer function of a 5-tap FIR filter used. The current working fractional tune value for the ELETTRA vertical plane is around 0.17.

Filter tap values can be verified/changed on the fly by reading/writing the DSP internal memory through the VME bus, without interfering with the currently executing code. A software driver has been developed that allows setting all of the 432 filters coefficients within

150 μs. Coefficients can also be changed in time according to a specified sequence of intervals to create controlled growth/damp transients.

A set of data acquisition tools has been developed taking advantage of the six DSPs that are not directly involved in the closed-loop operation. They can run in parallel to the feedback and allow one to acquire an array of bunch-by-bunch position samples of all the bunches during up to 192 ms, corresponding to 96 Mbytes of data.

All of the DSP software features above can be accessed through Matlab commands from the control room workstations, providing an integrated environment for TMBF system control, data analysis and graphical visualisation.

2 FEEDBACK OPERATION AT ELETTRA

As a compromise between lifetime and quality, a beam with controlled longitudinal coupled-bunch instabilities is delivered during standard users' shifts by acting on the cavity temperatures. Changing the current temperature values, longitudinal instabilities can be damped or minimized and consequently strong transverse instabilities appear, which require the use of the TMBF. The TMBF has been first installed and commissioned in the vertical plane [3], where stronger instabilities have been observed and user requirements are more demanding. Figure 3 shows the third harmonic of the U5.6 undulator radiation spectrum in the standard users' mode and in the case of combined damped longitudinal instabilities plus TMBF on. A 120mA@2GeV beam was used during the measurement.

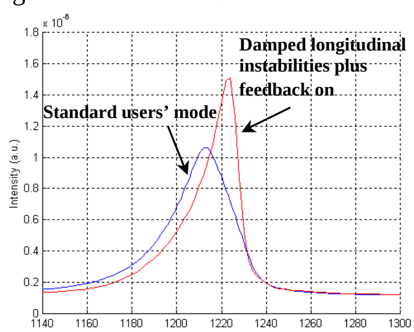

Figure 3: Third harmonic of the U5.6 undulator spectrum (40mm gap) in the standard users' mode and in the case of damped longitudinal instabilities plus TMBF on.

The TMBF loop has been successfully closed on beams of 320mA@2GeV and 130ma@2.4GeV, which are the nominal target values during operation with users.

3 TIME AND FREQUENCY DOMAIN ANALYSIS

3.1 Growth/Damp Transients

Switching the feedback off/on through the proper setting of the digital filter coefficients generates growth/damp transients. The position data of all the bunches during the transient can be acquired by the diagnostic DSPs, uploaded in the Matlab workspace and analysed. Figure 4 shows the spontaneous growth mechanism of the bunch oscillation amplitudes for a vertically unstable beam when the feedback is switched off and the following damping effect with the feedback switched back on. The bunch train gap can be clearly distinguished. The same transient can be analyzed in the frequency domain by plotting the evolution in time of the unstable vertical modes sidebands (figure 5).

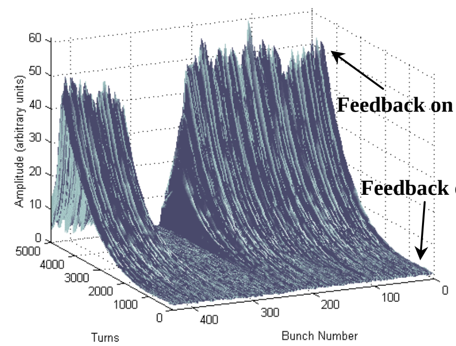

Figure 4: Growth/damp transient of the bunches of a vertically unstable beam created by switching the feedback off/on.

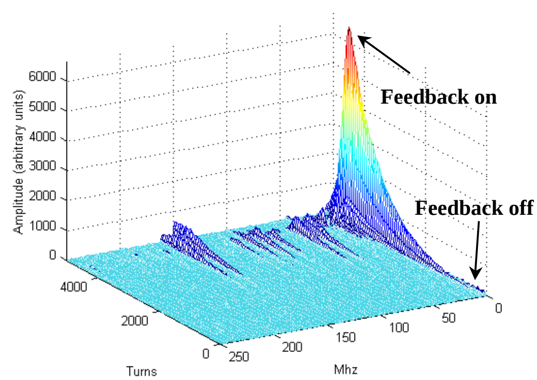

Figure 5: Growth/damp transient of vertical modes sidebands created by switching the feedback off/on.

By appropriately fitting the acquired data, rise times and damping rates of coupled-bunch modes throughout the whole operating frequency range can be measured.

Similar transients can also be started with an anti-damping period of positive feedback, which is obtained by inverting the sign of the filter coefficients. The anti-damping drive can excite coupled-bunch modes that are normally stable.

3.2 Transients on Selected Bunches

Taking advantage of the bunch-by-bunch basic principle, where each bunch is individually controlled by the feedback, and of the developed system architecture the growth/damp transients can also be generated, for example, on a subset of 24 bunches managed by a single DSP. This is done by changing the filter coefficients of only the selected DSP. Figure 6 shows the time domain evolution of an anti-damping/damping transient of this type. As shown in figure 1, the 24 bunches are distributed in six smaller groups each having four bunches. The remaining bunches are not affected by the transient and are kept damped by the TMBF system that is concurrently running.

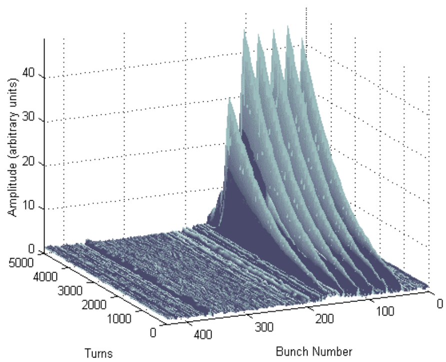

Figure 6: Anti-damping/damping transient obtained on a subset of 24 bunches.

3.3 Tune Measurements

The TMBF system set-up can be used for high-resolution betatron tune measurements. When the beam is already affected by transverse coupled-bunch instabilities, a simple frequency domain analysis of the turn-by-turn position data of a given bunch clearly reveals a line at the fractional betatron tune. Figure 7 is an example of a single bunch position signal spectrum showing also the presence of spurious longitudinal components.

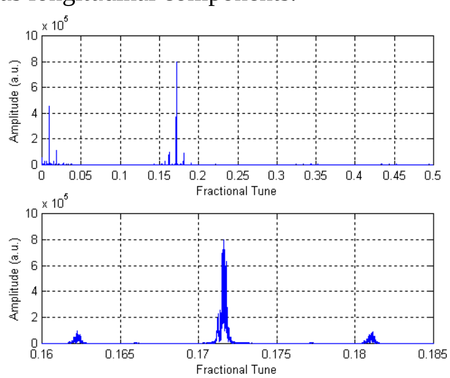

Figure 7: Different zoom spectra of the turn-by-turn position signal of a single bunch showing the fractional betatron tune and spurious longitudinal components.

The TMBF scheme allows to capture and process over 222k position samples, which provide a resolution in frequency of about 5 Hz. Spectra can be continuously monitored in the control room at a repetition rate of about 0.5 Hz.

During operation with users, however, the beam is kept transversally stable through the action of the TMBF. In this case short anti-damping/damping transients are induced on a subset of 24 bunches and the tune is measured by analyzing the resulting oscillation data. This technique allows for continuous tune measurements with no deterioration of the stored beam and no effect on the users' experimental activities.

4 TUNE TRACKING

As digital filters are designed to provide the right phase and gain at the nominal betatron frequency, changes of the tune affect the feedback performance by increasing the resulting damping time. At ELETTRA, tune variations can be observed during the opening/closure of some insertion device types and, in particular, during the energy ramping from 0.9 to 2-2.4 GeV, where deviations of up to 20% of the fractional tune value have been measured.

In order to keep the TMBF operation at its optimum working point even in presence of large betatron tune variations, a novel technique called tune tracking has been tested. It consists of periodically measuring the tune by using the method just described above, calculating the feedback digital filter coefficients according to the updated tune value and downloading these coefficients into the running DSPs. Positive tests have been performed using a Matlab script that has a repetition period of about one second. An improved version of the algorithm, to be run in the low-level host computer inside the VME crate where the DSP boards are also located, is under development.

5 CONCLUSIONS

A two-fold concurrent exploitation is being made of the ELETTRA/SLS DSP based processing architecture. On one hand, different digital filter types provide the best appropriate closed loop operation. On the other, bunch-by-bunch data acquisition and on-line analysis is performed in parallel to the loop execution. Such diagnostic features, which can be accessed from any control room Matlab session, are an invaluable tool for the understanding of both the TMBF system and beam physics. A newly developed adaptive technique, called tune tracking, takes full advantage of these integrated features and keeps feedback operation optimized irrespective of machine tune changes.

During the coming months the TMBF system will be installed at the SLS where 480 2ns-spaced bunches can be stored. A Longitudinal Multi-Bunch Feedback is also underway for both facilities and will employ the digital processing hardware already developed for the TMBF.

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., "First Commissioning Results of the ELETTRA Transverse Multi-Bunch Feedback", DIPAC'01, Grenoble, May 2001.