

OPERATION OF THE DIGITAL MULTI-BUNCH FEEDBACK SYSTEMS AT ELETTRA

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Abstract

Bunch-by-bunch feedback systems have been installed at ELETTRA to counteract coupled-bunch instabilities. Following a novel approach both the transverse and the longitudinal systems rely on the same type of programmable digital processing electronics executing the proper software. After a description of the overall machine scenario in which the transverse systems are operated, the status of the longitudinal feedback commissioning is given.

OPERATION OF THE TRANSVERSE FEEDBACK SYSTEMS

Digital bunch-by-bunch Transverse and Longitudinal Multi-Bunch Feedback (TMBF and LMBF) systems have been developed in collaboration between ELETTRA and the Swiss Light Source (SLS). Their characteristics and diagnostic capabilities are described in [1, 2].

The first TMBF acting on the vertical plane has been routinely operating since November 2001 during the users shifts at 2.4 GeV (140 mA). At this energy a suitable setting of the cavity temperatures and higher order mode shifters can damp longitudinal instabilities. Horizontal instabilities are removed by increasing the strength of the harmonic sextupoles, which broaden the tune spread with amplitude of the electrons within the bunch. The resulting reduction in dynamic aperture affects the beam lifetime that nevertheless is still about 26 hours at 140 mA.

The 2 GeV (330 mA) scenario has significantly improved after the recent installation and cool down of the Superconducting 3rd Harmonic Cavity (S3HC) [3]. In addition to providing a better lifetime, the S3HC has a damping effect on the longitudinal instabilities, which can be completely eliminated by increasing the multi-bunch contiguous filling adopted during user shifts from 80 to 90%. The installation of a second TMBF system for the horizontal plane has further enhanced the 2 GeV scenario. The harmonic sextupoles setting could be restored to the nominal value with a considerable gain in lifetime. In this configuration a coupled-bunch instability free beam is delivered to the users also at 2 GeV and the lifetime at 300 mA is about twice the theoretical value. Further optimizations are in progress together with the full characterization of the S3HC.

Since their installation the operation of the TMBF systems has been effective and reliable. They are integrated in the ELETTRA control system with the *init*, *run* and *standby* procedures fully automated and easily activated from the control room panels running on the UNIX consoles.

LONGITUDINAL FEEDBACK SYSTEM COMMISSIONING

Back-End

Figure 1 shows the block diagram of the LMBF back-end. The 250 MHz bandwidth base-band signal generated by the DAC, which contains the longitudinal kick values for each of the 432 2 ns spaced bunches, is amplitude modulated (SSB modulation) using a coherent carrier at $3 \cdot f_{RF}$. The broadband signal is then amplified by a 250 W TWT (Travelling Wave Tube) power amplifier followed by a circulator that protects the amplifier against backward power coming from the kicker. The power signal is brought into the accelerator tunnel by a 7/8" coaxial cable and then split to drive the four wave-guide input ports of the kicker. The four output ports are terminated with 50 Ohm power loads installed nearby the kicker.

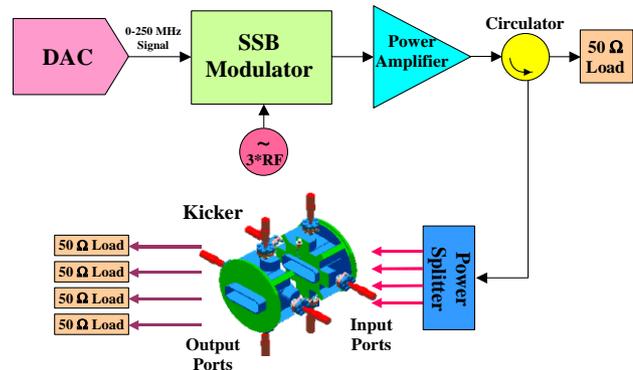


Figure 1: Block diagram of the longitudinal feedback back-end.

The installation of the longitudinal kicker (figure 2) was smooth and no additional coupled bunch modes have been observed in the beam, proving that it behaves as expected with respect to Higher Order Modes (HOMs) [4].

Particular care has been taken to optimize the operation of the back-end considering that the kicker behaves like a resonant cavity at $11/4 f_{RF}$ frequency. The bunch-by-bunch approach adopted by the digital multi-bunch feedback systems considers each bunch as an independent oscillator that can be damped by applying a dedicated feedback loop. This implies that the correcting kick for each bunch must not perturb the adjacent bunches, i.e. the voltage signal must have a maximum when the selected

bunch passes through the kicker and must be zero for the preceding and following bunches.

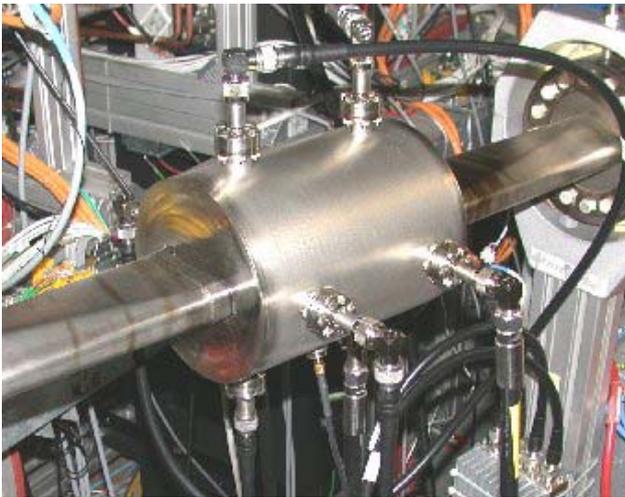


Figure 2: The longitudinal kicker installed at ELETTRA.

Starting from the SSB modulation scheme as described in [2], a number of modifications have been carried out to improve the time domain response of the back-end. The resulting response to a 2 ns long square pulse (i.e. the correction value for a given bunch generated by the DAC) measured on the kicker HOM coupler output is shown in figure 3. The signal features zero crossings at 2 ns from the maximum, while before/after 4 ns the voltage is negligible.

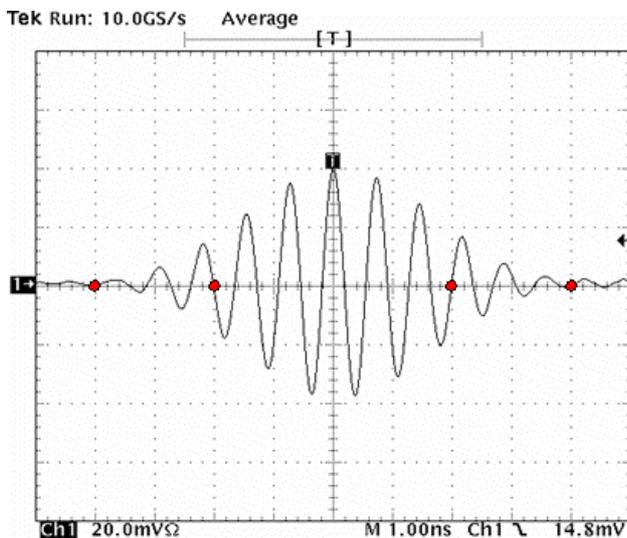


Figure 3: Back-end response to a 2 ns long square pulse generated by the DAC measured on the kicker HOM coupler output.

Longitudinal Feedback DSP Software

The same type of digital processing electronics used for the TMBF systems can be employed also for the LMBF by simply running different DSP (Digital Signal Processor) software. In the transverse planes the betatron fractional tunes are relatively high (at ELETTRA they are

about 0.2 in the vertical and 0.3 in the horizontal plane) and the position samples acquired at each machine revolution must be processed in order to calculate the correction signal used to damp the oscillation of a given bunch. In the longitudinal plane the lower synchrotron tune (0.0092 at 2 GeV) allows to down sample the digital phase error signal from each bunch and to use only one over n of the incoming samples to feed the digital filter; the correction signal is accordingly updated once every n revolution periods. The down sampling technique increases the time the DSPs have to calculate the correction values and more sophisticated digital filters can be implemented.

Thanks to the programmability of the system, the down sampling is carried out via software. The samples at full data rate (500 MSample/s) are acquired by the array of DSPs, which can concurrently record all of them for diagnostic purposes, but only one out of n is used by the feedback algorithm, the rest of them being discarded. After the processing, the DSPs' output buffer is filled with the same calculated value for n times.

At ELETTRA a down sampling factor $n = 10$ has been chosen resulting in a down sampled synchrotron tune of 0.092, which allows the digital filter to reject the DC component of the signal and to have at the same time a pretty high gain at the synchrotron tune. A 4th order digital IIR (Infinite Impulse Response) filter is currently implemented.

Commissioning Techniques

The commissioning of the LMBF is taking full advantage of the diagnostics capabilities provided by the digital processing system.

One of the most important tasks when setting up the feedback is the synchronization of the kicks with the bunches. The feedback system itself can be used for this purpose. By kicking only one bunch with an excitation signal and analyzing the spectrum of each bunch, the actually excited bunch is determined and the system delay is then adjusted until the chosen bunch is kicked. The excitation signal can be generated in Matlab, which runs on the control room workstations, and is downloaded through the control system directly into the DSPs' memory. In the transverse planes excitation with pink noise featuring a frequency band around the fractional betatron tune has been employed. In the longitudinal plane the lower efficiency in kicking the beam led us to excite the bunch with a sinusoid at the synchrotron tune. Using fine adjustments (10 ps resolution) the timing can be further optimized by maximizing the excitation amplitude of the selected bunch while minimizing the spurious excitation of the adjacent ones. Figure 4 shows an example of bunch excitation and demonstrates the selectivity of the system.

Another technique used to optimize the feedback settings (timing, gain, filters, etc.) and to evaluate the feedback performance in terms of damping capabilities is the generation of transients.

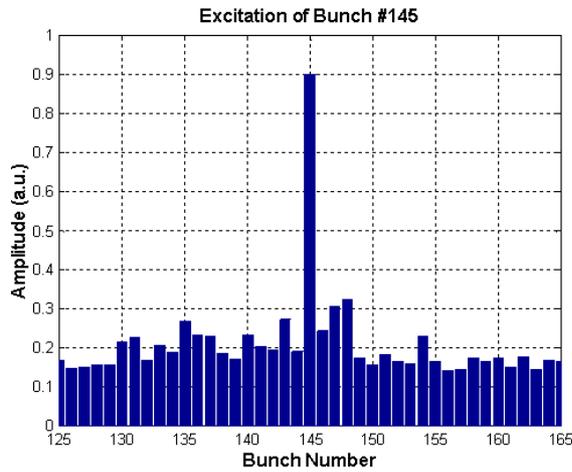


Figure 4: Amplitude of the synchrotron tune spectrum component of a number of bunches when selectively exciting only bunch #145.

Figure 5 shows examples of transients created by the LMBF system, which can record up to 192 ms of bunch-by-bunch samples during the transients. The data are immediately uploaded in Matlab and analyzed. In this experiment the beam is originally stable, being the potential longitudinal coupled-bunch modes due to cavity HOMs below their excitation threshold. By properly setting the feedback filter coefficients an anti-damping effect is produced and the coupled-bunch mode #91 gets steadily excited with 11.5 degrees oscillation amplitude.

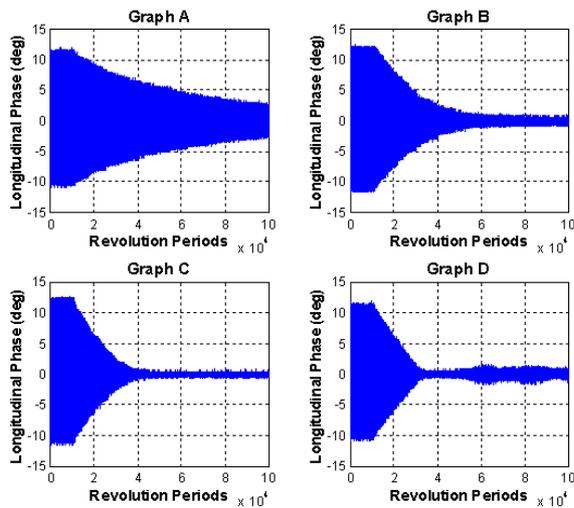


Figure 5: Longitudinal oscillation of one bunch during four different transients generated by the feedback system. A: natural plus Landau damping. B: damping with feedback at half gain. C: damping with feedback at full gain. D: damping with saturated feedback.

After 12000 revolution periods from the beginning of the data acquisition the filter coefficients are changed to create four damping transients of different type:

- A: filter coefficients set to zero. The decay is due to natural and Landau damping.
- B: filter coefficients set to damping values. The filter is linear producing an exponential damping.
- C: filter coefficients set to damping values and filter gain set to twice the value of case B. The filter is still linear producing a shorter exponential damping.
- D: filter coefficients set to damping values and filter gain set to its maximum. The filter is saturated and the decay is linear.

The combination of the linear equations obtained from the cases above allows to easily determine the LMBF performance.

Status and Plans

The LMBF equipment and electronics have been installed and the commissioning is in progress. Due to the cessation in the construction of the commercial 500 MSample/s ADC and DAC boards adopted by the system, the digital processing electronics of one of the two TMBF systems running the appropriate software is used for the commissioning of the LMBF. A new family of conversion boards developed in collaboration with SLS will be ready soon [5].

By activating the LMBF from the beginning of the injection process, up to 280 mA of a longitudinally stable beam at 0.9 GeV have been accumulated.

REFERENCES

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