PRELIMINARY INVESTIGATIONS FOR A DIGITAL MULTI-BUNCH FEEDBACK SYSTEM FOR THE LNLS

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Abstract

The main facility of the Brazilian Synchrotron Light Laboratory is a 1.37 GeV storage ring. The accelerator ring can be filled with up to 148 electron bunches and the initial current of 250 mA with an average 22h lifetime. During refills, the beam energy is ramped down to 500 MeV, the current is topped up and the energy is ramped up again to 1.37 GeV for a new shift. Coupled-bunch instabilities (CBI) excited by different sources can negatively impact the light source performance either lowering the brilliance of the beam or causing beam losses in the energy ramps. The upcoming new insertion devices and beamlines are pushing up the beam stability requirements even more. We present the current status of a multi-bunch digital feedback system that is being designed for controlling transversal and longitudinal beam instabilities.

INTRODUCTION

The Brazilian Synchrotron Light Source operates with high reliability since its initial operation, usually above 97%. However several other issues have led to the decision of implementing a transversal and longitudinal multi-bunch feedback. The main reasons are described bellow.

Energy Ramps Repeatability

Currently the energy ramps are performed twice a day at LNLS. It is highly desirable that the accelerator remains in low energy configuration during the shortest possible time in order not to disturb the tunnel thermal stability and improve even more the reliability statistics. Therefore, both beam looses during the energy ramps and fluctuations in the injection efficiency should be avoided. Eventually the energy ramps no longer work properly and beam losses occur at specific energies – losses from few to several tens of mA can happen in these situations. “Harmless” transverse CBIs usually show-up in the energy ramps (observed in the spectrum analyzer used as tune monitor) and eventually, these instabilities become harmful causing beam losses. The feedback system should increase the reliability and robustness of the machine operation. Figure 1 shows both an example of harmless horizontal CBI occurred in the beginning of the energy ramp (from 0.5 to 1.37 GeV) and a strong instability that occurred in both plans and was responsible for a 70 mA beam loss in the ramp from 0.5 to 1.37 GeV.

Single-bunch Operation

The LNLS storage ring operates in single-bunch mode once a year during two weeks. All buckets except one are excited before during the energy ramp of the booster synchrotron accelerator in order to produce the single-bunch. Typically the ratio between the main bunch charge and the neighboring bunches is about 1000. The chromaticities are relatively high in the single-bunch injections ($\xi_x = \xi_y = 2$) while the standard value in multi-bunch injection is about 0.5 in both plans. Currently the single-bunch current is limited to about 8 mA due to saturation. Small changes in tunes and in the RF acceleration voltage can raise this limit up to 10 mA. The figure 2 shows an injection where the chromaticities were adjusted to zero. The beam instability threshold is less than 1 mA. The transverse feedback system (TFS) should increase this threshold even with lower chromaticity and allow higher injection efficiencies.

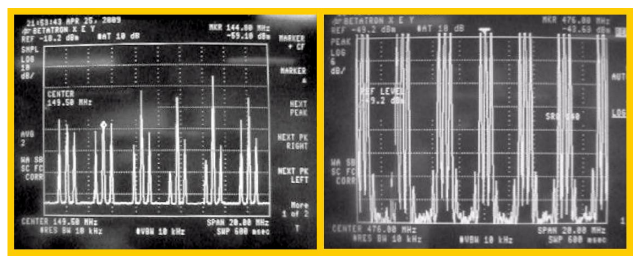

Figure 1: Typical harmless horizontal instability present at the end of the beam accumulation (right). Strong instability in both plans responsible for a 70 mA beam loss in the low energy ramp.

Another application for a transverse feedback system at LNLS would be betatron excitation in the storage ring in order to produce the single-bunch. In an optimum case, the system would operate as a bunch cleaner for all bunches, except one, for witch the system would damp the coupled mode oscillation.

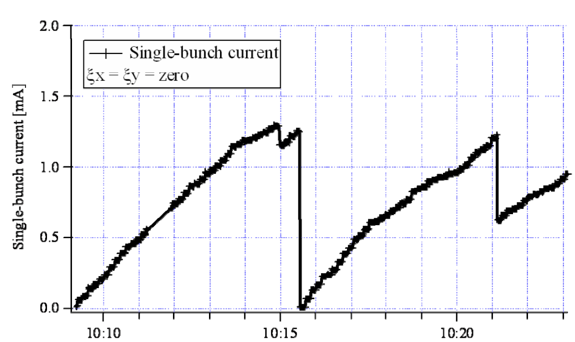

Figure 2: Single-bunch injection with zero chromaticities followed by sudden falls.

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Upcoming Undulator Beamline

A high-resolution Plane Grating Monochromator (PGM) beamline based on an elliptically polarized undulator (EPU) insertion device is under construction. The beamline will produce high brightness photons in the 100 to 1 keV range. This beamline has strict requirements on the beam characteristics. Several actions are being conducted to increase the long term beam stability [1] and to reduce the vertical beam dimensions [2], but little can be done about the energy dispersion in the present accelerator configuration.

As one can see in Fig. 3, the beam horizontal dimension shows a significant dependence on the beam intensity and, surprisingly, it is not related either to the RF phase modulation adopted to minimize the interaction of the beam and a specific cavity high order mode [3], nor to transversal CBIs, as the transverse spectra are quite clean in the user shifts.

A more direct evidence of the energy spread is some bunch lengths measurements done in two different situations: at 6 mA the theoretical FWHM length of 100 ps is verified, but, at high currents (150 – 200 mA), FWHM bunch lengths of 280 ps are measured. A longitudinal feedback system (LFS) can significantly reduce this effect. Figure 4 shows the longitudinal length of several bunches averaged during thousands of synchrotron periods.

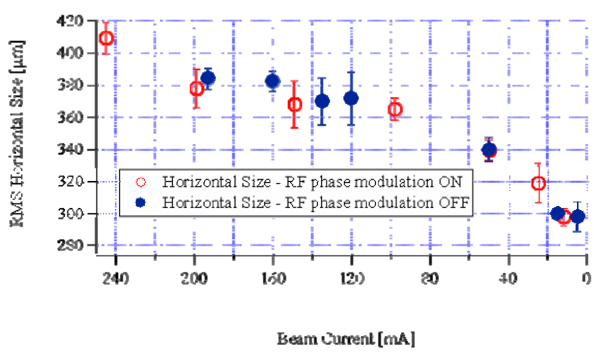

Figure 3: Beam horizontal dimension dependence on the beam current. The increased energy spread caused by the normal conducting RF cavities probably is causing it rather than the RF phase modulation.

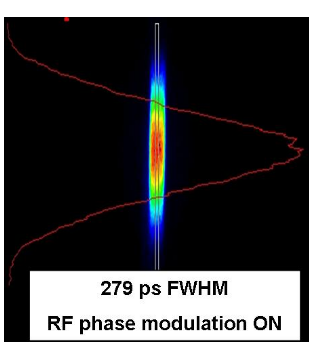

Figure 4: FHWM longitudinal beam size at high current.

PROCESSING ELECTRONICS

In order to stabilize the electron beam in a synchrotron light source, a system should sense the beam motion signals (in the three axes) within a certain bandwidth, apply a proper filter in the information around the longitudinal and transversal tunes, delay the signals and finally, apply it back to the beam with a suitable amplitude and/or modulation. If one needs to control the individual bunch motion, those correction signals occupy a bandwidth of $F_{RF}/2$, where F_{RF} is the accelerating resonant frequency. For the LNLS F_{RF} is 476.06865 MHz. In the same way, the correction signal occupies a similar bandwidth.

A number of light sources have implemented analog multi-bunch feedback systems in the past years [4-6]; these systems works pretty well but the frequent necessity of tuning cable phases and the filter parameters makes it a non optimized choice. The LNLS multi-bunch feedback system will be implemented using a commercial solution offered by I-Tech and already tested by several laboratories [7-9].

IMPLEMENTATION ISSUES

The commercial analog RF front-end and digital processors were acquired and will be commissioned still this year. It implements just part of the entire system, whose simplified block diagram is shown in the Fig. 5.

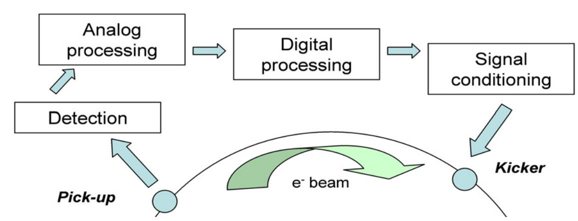

Figure 5: Multi bunch feedback system block diagram.

Detection & Analog Processing

In an ideal system the sensor (pick-up) is noise-free and its sensitivity is adequate to detect the smallest beam displacements, and the processing units have small noise figures and an infinite dynamic range. As a mater of fact, the sensitivity of the BPM is limited by geometrical factors and the smallest displacements are hidden by the thermal noise in the system. The electronics also have a finite dynamic range. Table 1 lists the available pick-ups and its characteristics regarding to the sensitivity and the betatron and dispersion functions at the locations where they are currently available in the LNLS storage ring.

Considering the available installed pick-ups and the operation frequency of the front-end electronics (3 x F_{RF}), for the transversal planes the gain choosing the longest pick-up is reduced due to its location which was optimized to detect synchrotron oscillations. A maximum factor 1.3 is obtained comparing the effective sensitivity of both pick-ups in both transversal planes. The minimum detectable power of the I-Tech RF front-end is about -60 dBm (200 µV RMS). Using the best available pick-up and considering an overall 6 dB loss in cables and connectors, a 5 µm motion only can be detected with a relatively high stored current – 80 mA.

Table 1: Available pick-ups

Stripline Type	S [V/A/mm] @ 476 MHz / 1.43 GHz	$\sqrt{\beta_X}$ / $\sqrt{\beta_X}$ / $\eta\,[m]$
6-cm short-circuited	0.42 / 0.73	4,1 / 3 / 0,0
15-cm matched	1.41 / 1.42	2,1 / 1,3 / 1,0

The 15-cm stripline seems to be a good choice for measuring the longitudinal motion due to its higher sensitivity (factor 2). The phase noise introduced in the longitudinal error signal should be as low as possible in order to minimize residual energy oscillations during the system operation. Besides not detecting small beam oscillations, the overall noise floor of the system (either in amplitude or phase) can increase the beam effective emittance [10]. The use of ultra low-noise amplifiers and high performance cables (0.03 dB / meter @ 500 MHz) in the signal chain is being considered. Still about the RF front-end, filters to reject the revolution harmonics should be employed in order to keep the electronics far from the saturation limits.

Digital Processing

Once the beam oscillation signals are down-converted and amplified by the analog processing unit, the processing electronics (one per plane) digitizes the signal with F_{RF} sampling rate. The processing electronics, through FIR filters programmed by the user, selects a narrow band of frequencies for the three error signals. When the proper delay is applied to the filtered signals, the correction signals are generated and are ready to be applied to amplifiers and kickers. For the longitudinal plane the correction signal should be modulated to the RF frequency.

Currently both horizontal and vertical tunes change about 300 kHz during the energy ramps. The wider the filters bandwidth, the lower is the gain of the feedback system. High gains combined with high bandwidths tend to cause unstable operation.

Kickers

The chosen strategy for the installation of the multi-bunch feedback system was to focus on the transversal plan, for which we count on a set of four striplines assembled in the same body (non-rotated). The striplines are 157-mm long, 29º wide (half-aperture) and the beam stay-clear aperture is 60 mm. Figure 6 shows a 3D model of the available stripline, as well as its shunt impedance (calculated trough [10]). The same figure shows the effect of possible future improvements in the stripline length.

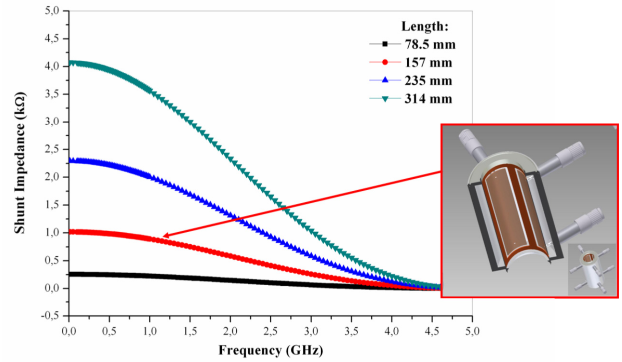

Figure 6: Multi Bunch feedback system block diagram.

In the same way, the stripline aperture angle could also be increased in a future design: for this geometry, each ten degrees adds about 750 Ω in the shunt impedance. The combined effect of a wider (60º half-aperture angle) and longer (half wavelength) stripline represents a considerable increase in the present shunt impedance: from 1 kΩ to 13 kΩ.

By employing high shunt impedance stripline kickers, besides the expensive power amplifiers, one avoids several other problems, like the unavailability of broadband high-power circulators and the risk of damaging the stripline trough the excitation of in-vacuum resonances.

With the current 1 kΩ transversal kicker will be possible to damp 1 mm amplitude instabilities (horizontal / vertical) within (0,5 / 0,2 ms) using 50 Watts power amplifiers. Increasing the shunt impedance would decrease proportionally the required power or make possible to reduce even more the achievable damping times.

FINAL REMARKS

The initial requirements for the multi-bunch feedback system for the LNLS were presented. Further studies on kickers as well as on the source of the beam energy spread are necessary. The detailed design of the longitudinal kicker will be completed in the near future.

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