

OPERATIONAL STATUS OF THE TRANSVERSE BUNCH BY BUNCH FEEDBACK SYSTEM AT SOLEIL

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Abstract

Recent progress made in the digital transverse bunch by bunch feedback system at SOLEIL is introduced and discussed, which is routinely in service since the first user operation in both the high average current and high bunch current modes. The above includes installation of a third chain with a dedicated 4-electrode stripline intended to operate in the horizontal plane, an attempt to sample the BPM signal directly at the RF frequency without down-converting to the baseband following the success at SPring-8, a series of FPGA applications enabling useful bunch excitation and damping, as well as post-mortem data analysis. The achieved performance and results are described. Encountered beam instability and the feedback efficiency in reaching our final current of 500 mA are also discussed.

INTRODUCTION

SOLEIL, the 2.75 GeV French third generation light source ring commissioned in 2006, is serving routinely for users in high multibunch and single bunch current. Transverse bunch by bunch feedback has successfully been operating since the beginning of user operation, which turned out to be essential in storing a stable high current electron beam. In particular, it allows operating the machine with reduced chromaticity and therefore with increased beam lifetime, which is vital for light source rings. The present paper reviews the latest development and achievements of the feedback system, along with our recent experience in reaching the final target beam current of 500 mA.

CONSTRUCTION OF A HORIZONTAL FEEDBACK CHAIN

Horizontal Stripline Development

Following the large success of the 2-electrode vertical stripline developed at SOLEIL [1], a 4-electrode stripline was designed and constructed under the same philosophy. Namely, the electrodes are smoothly embedded into the vacuum chamber wall without any taper transitions and their characteristic impedances are matched to 50 Ω (Figs. 1 left). In this way, high shunt impedance is achieved by keeping the coupling impedance small at the same time, as no change in the chamber cross section is introduced. A 4-electrode solution was searched and employed, since it could serve as a horizontal stripline and simultaneously as a backup to the vertical feedback, or as both by using the diagonal electrodes. The implementation is opportune especially because of the

large instability threshold reduction encountered horizontally when closing the in-vacuum undulator gaps, as they are located in high horizontal beta sections enhancing the coupling of the wake field into the corresponding plane.

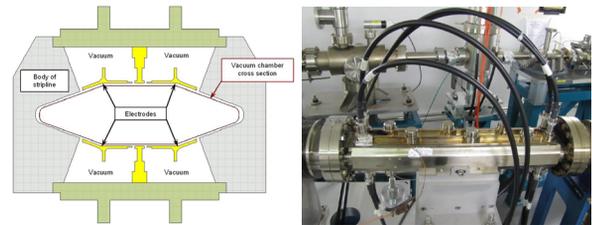


Figure 1: Geometry of the developed 4-electrode stripline (left) and its installation in the ring (right).

The shunt impedance $[Z(\omega)]_{sh}$, which is the figure of merit and defined by $V_{\perp}^2 / 2P$ (V_{\perp}^2 : Transverse voltage, P : Incident power) was evaluated in two ways, i.e. semi-analytically and numerically using *GdfidL*. The formula used in the former is given by

$$[Z(\omega)]_{sh} = 2Z_c \cdot (g / kh)^2 \cdot \sin^2(kL) \quad (1)$$

where Z_c is the characteristic impedance (50 Ω), g the geometric form factor, $k=\omega/c$, h , the effective chamber radius and L the electrode length of the stripline.

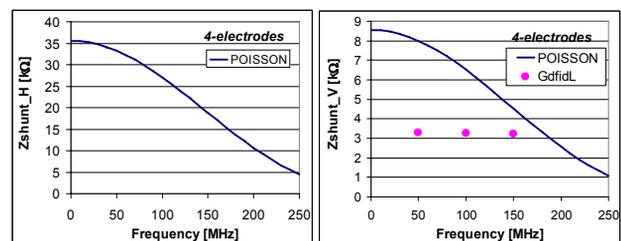


Figure 2: Horizontal (left) and vertical (right) shunt impedance estimated with an analytical formula (Eq. 1) and numerically with *GdfidL*.

The form factor g was evaluated numerically with the electrostatic code *Poisson*, while the coupling impedance was evaluated with *GdfidL*. The analytical method indicates that the shunt impedance is around 35 k Ω horizontally, which is nearly 4 times larger than the vertical of ~ 8 k Ω (Figs. 2). The vertical results with *GdfidL* tend to be significantly smaller, the reason of which is yet to be clarified. A similar relation was found for the 2-electrode stripline [1]. In addition, there was a problem of convergence in the horizontal shunt

impedance calculations with *GdfidL*, which also needs be understood. Reflecting the fact that the electrodes are displaced horizontally with respect to the beam axis, the coupling impedance is found to be smaller than the vertical stripline and is comparable to that of the shorted 4-electrode stripline used in the first chain. The vertical impedance is compared in Fig. 3.

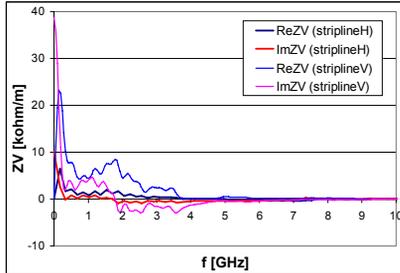


Figure 3: Comparison of vertical impedance between the 4- and 2-electrode striplines.

The overall results comparing the three striplines are summarised in Table 1.

Table 1: Comparison of the 3 striplines installed in the ring. Numbers in the brackets are the horizontal and vertical shunt impedance. The loss factor and the effective impedance are evaluated for a 20 ps long bunch.

	4-electrode horizontal	2-electrode vertical	Shorted 4-electrode
Length L [m]	0.426 ($\lambda/2$)	0.426 ($\lambda/2$)	0.213 ($\lambda/4$)
$[Z_{sh}(0)]_{Poisson}$ [k Ω]	(35.6, 8.6)	84.1	(8.5, 1.9)
Loss factor [V/pC]	0.009	0.075	0.007
$ Z/n _{eff}$ [m Ω]	0.45	1.62	0.27
$(ZV)_{eff}$ [k Ω /m]	0.04	0.88	0.03
Implemented in	Chain 3	Chain 2	Chain 1

Attained Feedback Performance

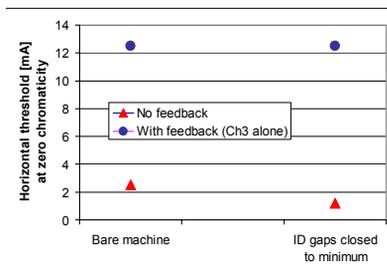


Figure 4: Achieved performance of the horizontal stripline in single bunch with zero chromaticity.

The 4-electrode stripline was installed in the ring in October 2009, completing the third feedback chain. Ever since, it has been utilised in all 3 modes (horizontal, vertical and diagonal), producing satisfactory results in both multibunch and single bunch. As what best characterises its performance, the gain in threshold with and without the in-vacuum undulator gaps closed was measured at zero chromaticity (Fig. 4). In both cases, a

large gain, of more than a factor of 6, was obtained on the instability threshold. The obtained factor of gain is much larger than roughly 3 obtained vertically with the 2-electrode stripline. However, it must be noted that a comparable gain was attained with the shorted stripline as well, and so the difference may rather be attributed to the nature of the horizontal instability.

FRONTEND WITHOUT DOWN-CONVERSION

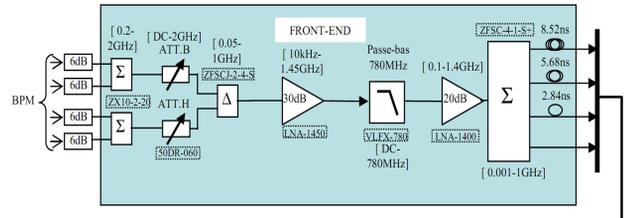


Figure 5: Scheme without down-conversion.

On the basis of the fact that the digital signal system that we use, developed at SPring-8, employs ADCs having an analog bandwidth of 750 MHz (Analog Devices AD9433) [3], the beam signal can be directly sampled at the RF frequency with 4 ADCs ($f_{rf} = 352.2$ MHz and $f_{adc\ sample} = f_{rf}/4$), instead of in the baseband ($0 - 176.1$ MHz) used up so far, to which the beam signal in the band of $4 * f_{rf} - (4 + 1/2) * f_{rf}$ is down-converted with a mixer. This option was already successfully tested at SPring-8 [2]. In view of the great amount of time regularly spent in tuning the feedback system at SOLEIL including that of the frontend, a simplified scheme without down-conversion appeared clearly interesting. Such a frontend was developed and implemented in the 2nd chain (Fig. 5).

The performance of the 2nd chain with the new frontend turned out to be unaltered, while we gained the expected reduction in the amount of tuning work and time. Although there was initially a concern on a possible increase of the noise level associated with the rise of the bandwidth frequency due to time jitter in the sampling, no effect has so far been noticed on the beam size. It must also be noted that the frequency divider used (Analog Devices ANAAAD9515/PCB) that clocks the processor has time jitter of merely 215 fs rms at 352.2 MHz. A more precise and systematic comparison of the two frontend schemes is to be carried out in future.

FPGA APPLICATIONS AND POST-MORTEM

Keeping the betatron tunes constant is of great importance at SOLEIL against beam life fluctuations. However, measurement of tunes is usually hindered by transverse feedback suppressing the tune peaks. A new FPGA design was implemented to single out a selected bunch from being damping and to excite it with an external signal to measure its tunes [4]. Since then, a number of useful modes have been additionally

implemented, allowing for example, superimposition of a FIR filtered signal with an external signal on a selected bunch. One can in this way damp a CM (centre of mass) motion of a bunch, simultaneously blowing it up incoherently (for lifetime reasons), or to kill a selected bunch by exciting it externally followed by anti-damping. The latest FPGA design introduces a module that adds signals arriving from different ADC channels prior to being multiplexed (Fig. 6)

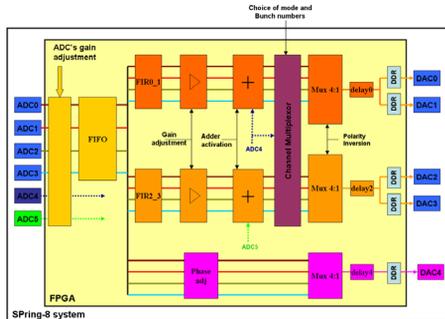


Figure 6: Extended use of the FPGA structure of the digital system.

The huge amount of ADC data available (128 Mega word of sampled data) allowed developing a post-mortem system that revealed to be quite helpful in identifying the origin of sudden beam losses at high current. Applications have been recently added to perform online display of the bunch CM motions (Fig. 7), the bunch and the beam spectra, as well as the betatron phase of each bunch.

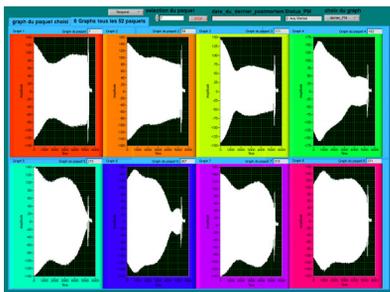


Figure 7: An example of several bunch CM motions reconstructed from post-mortem data.

OVERALL FEEDBACK PERFORMANCE

The three feedback chains constructed allow configuring them in several different modes including the one in which all work in the vertical plane. The machine has up so far been operated with chromaticity shifted to positive values, typically 2 to 3 (un-normalised) in both planes for lifetime reasons, but feedback works satisfactorily in all filling modes up to the authorised beam current with moderate feedback gains. Although the feedback efficiency generally improves as the chromaticity is reduced, in filling modes that involve high bunch current such as in single bunch and 8-bunch modes, the total beam current is limited by the feedback performance in the zero chromaticity limit. The above is

due to TMCI (Transverse Mode Coupling Instability) in single bunch, and presumably due to the combination of the former with the resistive-wall instability in the 8-bunch mode.

In reaching the targeted multibunch current of 500 mA, we suffered much from sudden beam losses occurring typically at around 10 minutes after beam fill. Up to that instance the beam could be kept stable with transverse feedback roughly at its nominal size. The phenomena were later understood to be due to FBII (Fast Beam Ion Instability) that appears following a localised pressure rise. The beam loss implies that the present system is not capable of damping FBII. More details are described in Ref. 5.

SUMMARY

The transverse bunch by bunch feedback system at SOLEIL has proven its performance, allowing to reach the target intensity in the multibunch mode (500 mA), as well as in the time structure mode (8×10 mA), under all insertion device configurations. Thanks to the dedicated striplines designed and installed in each plane, the TMCI threshold was raised by more than a factor of 3 in both planes. Simplified FE without down-conversion brought about a significant simplification in the system tuning. The impact of noise on the beam size has yet to be evaluated in more details. The feedback system is fully integrated into the machine control system with useful applications for machine operation such as tune measurement and post-mortem. A series of FPGA applications have been developed allowing to select a single bunch and excite it, while superposing positive or negative feedback. Characterisation and optimisation of the system shall be continued. Thanks to the developed FPGA applications, systematic instability measurement can be made to help pursue the fast ion instabilities.

ACKNOWLEDGEMENT

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