# PERFORMANCE OF BUNCH BY BUNCH TRANSVERSE FEEDBACK AND EVOLUTION OF COLLECTIVE EFFECTS AT SOLEIL

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*Abstract*

Latest development and achievement of the transverse bunch by bunch feedback system, as well as evolution of collective beam instability and impedance at SOLEIL are reported.

## INTRODUCTION

SOLEIL is the French third generation light source ring commissioned in 2006 and 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. Not only, but feedback allows operating the machine with reduced chromaticity, and therefore with increased beam lifetime, which is vitally important for light source rings. The present paper reviews the latest development and achievements of the feedback system, along with evolution of beam collective effects observed.

## LATEST FEEDBACK DEVELOPMENT AND ITS PERFORMANCE

### *Basic System Characteristics*

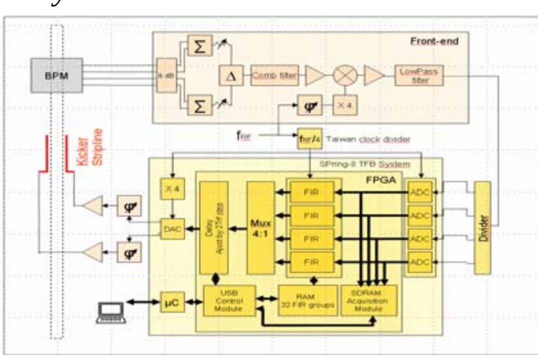


Figure 1: Layout of the SOLEIL feedback chain.

The first feedback chain constructed is composed of (Fig. 1): – A standard SOLEIL BPM. – A RF frontend that extracts a half of RF frequency band ($f_{RF}/2$) of beam signal at four times $f_{RF}$ and down converts it to the baseband. – A digital processor (SPring-8 development) that consists of four 12-bit ADCs working at 88 MHz (1/4$^{th}$ of $f_{RF}$), with an analog bandwidth of 750 MHz, a single FPGA board comprising all available FIR filters and multiplexers, five 12-bit DACs working up to 1 GS/s. – 75 W RF amplifiers (2 to 4). – A four electrode short circuited stripline [1]. Normally, feedback is running in the *diagonal* mode using only two diagonal electrodes of the BPM and the stripline. It suppresses the beam instability both horizontally and vertically with a 2-turn delayed 16 tap FIR, following the scheme developed by T. Nakamura at SPring-8 [2].

### *Construction of the 2$^{nd}$ Chain*

A two electrode vertical stripline (Figs. 2) developed under the concept of maximising the shunt impedance to combat the strong headtail instability in single bunch, simultaneously minimising the coupling impedance [3], was installed in the ring in spring 2008.

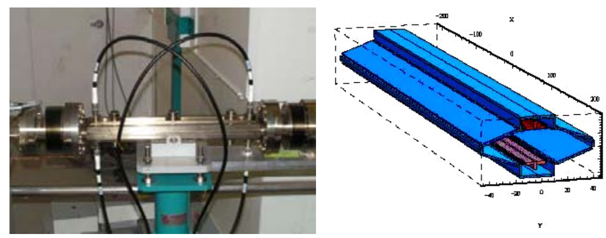

Figure 2: Picture of the vertical stripline installed in the ring (left) and a sketch of its structure (right).

With another set of constituents, the second feedback chain was constructed using the vertical stripline. Testing its performance in single bunch, the vertical TMCI threshold could be raised from ~2.5 mA to ~8 mA, namely by more than a factor of 3 (Fig. 3). Although the factor of gain on the threshold is reduced as the chromaticity is increased (Fig. 3), we expect that this is due to loss of feedback efficiency as the electron bunch exhibits more non-dipolar motions. With the first chain, the increase in the TMCI threshold was severely limited to below ~1 mA, indicating the lack of power with the shorted stripline. The obtained result agrees with the expectation that the vertical stripline has nearly 100 times larger shunt impedance than the shorted one.

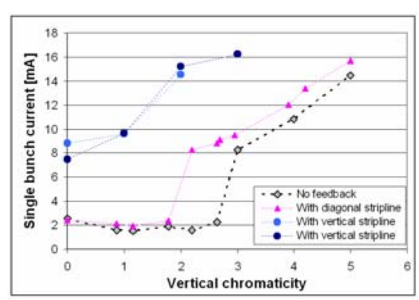


Figure 3: Attained performance of the vertical stripline in single bunch in comparison with previous results.

The performance of the vertical stripline is confirmed in multibunch modes as well with much reduced feedback gain to stabilise the beam. However, some unexplained instability occurs at high current above 400 mA, or in 8-bunch mode, which is currently under investigation.

### *Integration into the Control System*

Another noteworthy progress lies in its integration into the SOLEIL Tango control system, which allows most of the standard control in remote from any terminal on the network (Figs. 4 and 5). Although Tango devices presently communicate with the original Linux version of the feedback processor driver, the latter shall be replaced by the Windows version provided by the SPring-8 group.

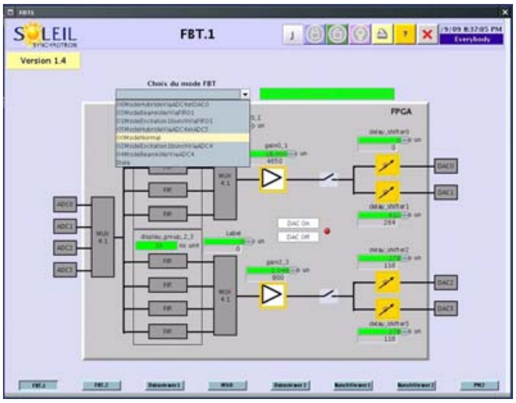


Figure 4: Main control panel of chain 1.

A large advantage of the integration into the control system that follows is the possibility of displaying the bunch by bunch information, such as the beam filling pattern or oscillation amplitude online (Fig. 5 left), as well as developing a post-mortem system. The former turned out to be particularly useful in diagnosing the feedback system itself, whether it stays in phase with the RF system, a crucial condition for the feedback performance, as the displayed filling pattern gets distorted once the phase relation drifts. The post-mortem turned out to be useful as well, providing rich information in analysing unidentified beam losses. At the same time, the FPGA program of the feedback processor has been modified to allow selecting a bunch or bunches, either to stay out of feedback and be excited instead by external signals sent to the stripline, or to be feedbacked with a different gain and/or a FIR filter from the rest of the bunches. These additional functions enable, for example measuring the tunes of the excited bunch and displaying its spectrum online (Fig. 5 right), which would otherwise be difficult as feedback damps tune signals.

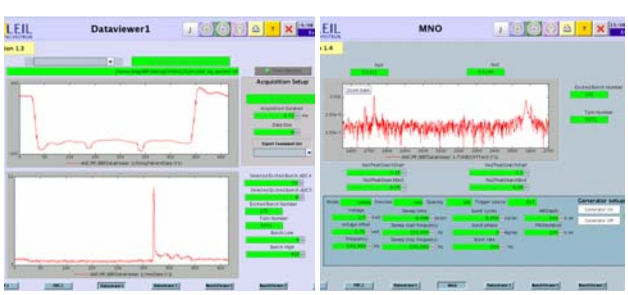


Figure 5: Left: Online acquisition showing the ¾ filling pattern (upper) and oscillation amplitude (lower). The peak seen represents the excited bunch for the tune measurement. Right: Tune spectrum of the excited bunch.

## EVOLUTION OF COLLECTIVE EFFECTS

### *Weakening of Ion Induced Beam Instability*

One of the marked changes observed on beam instability with respect to earlier commissioning times is the reduction of those induced by ions, which should be reasonable in view of the constant improvement of the vacuum level in the ring with accumulated beam dose. Ion-induced instability is usually distinguished from impedance originated ones by the spectral content of the beam motion [4]. More specifically, bunch by bunch data stored by the feedback processor could be used, by letting the beam grow spontaneously unstable with feedback turned off over a short period of time (typically ms order) [4]. Comparing the oscillation amplitude along a bunch train under the same condition, a notable reduction in the excitation level was found with respect to earlier observations (Fig. 6).

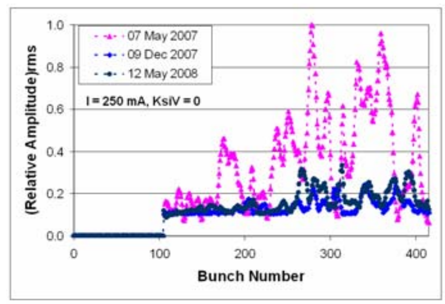


Figure 6: Oscillation amplitude along a bunch train at 250 mA in ¾ filling with zero chromaticity, measured with feedback switched off. Different colors correspond to measurement done at different times.

What seems to happen as a result of this change is that the beam behaves more *monochromatically*, namely, with less dispersion within itself. At early times, the beam could easily be blown up without being lost, or just the tail part of the bunch train getting lost leaving a fully distorted filling pattern.

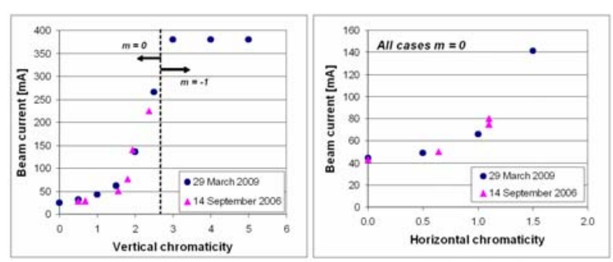


Figure 7: Vertical (left) and horizontal (right) threshold current measured in ¾ filling as a function of chromaticity. Different colors correspond to measurement done at different times.

Recently, on the contrary, the beam tends to get entirely lost once it becomes unstable. To follow the possible impact of this change on the instability threshold, the threshold curves versus chromaticity in the standard ¾ filling were recently updated. The obtained results however showed almost no change of threshold in both planes (Figs. 7). It must be noted, however, that strong ion-induced instabilities are still present after vacuum interventions, or at high multibunch current (400~500 mA), requiring dedicated studies for better understanding of the mechanism.

### *Closure of In-Vacuum Undulator Gaps*

In the SOLEIL ring, there are currently four in-vacuum undulators, whose vertical gaps can be closed to as narrow as 5.5 mm. Nevertheless, since they are located where the vertical beta function is low (~2 m), their impact on the instability threshold was found small vertically. The above was not true horizontally, due on the contrary to the high horizontal beta function of ~18 m. In particular, a significant reduction on the horizontal TMCI threshold was observed (Fig. 8).

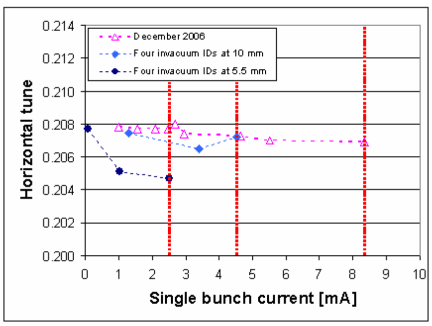


Figure 8: Measured horizontal single bunch detuning and TMCI threshold. No in-vacuum undulators (magenta). 4 in-vacuum undulator gaps closed to 10 mm (light blue) and 5.5 mm (dark blue).

The measured threshold current of 2.5 mA at the gap of 5.5 mm is as low as the vertical one. This worrying situation would be relieved by the installation of a horizontal stripline. It must be added that the tapers of these undulators, which are the main source of impedance, generate serious beam induced heating as well. A new taper with much reduced impedance was therefore designed and confirmed to alleviate the heating problem, which will replace the old ones.

### *Installation of 2nd SOLEIL Cavity*

Out of the calculated impedance budget, the cylindrical cavity taper whose radius varies from 5 cm to 13 cm over 32.5 cm represents the largest contributor longitudinally. The simulation also predicted that with 2 RF units installed, the microwave instability threshold would significantly be reduced. The longitudinal single bunch instability was therefore re-measured after the installation of the 2nd RF unit that occurred in summer 2008. The measured bunch lengthening showed nearly 20% of increase (Fig. 9). On the search of microwave threshold, single bunch current was ramped under three RF voltages of 1.2, 2.0 and 2.8 MV, following the energy spread via the transverse beam size measured by an X-ray pinhole. While at the two higher voltages no effective changes with respect to the previous data were observed, at 1.2 MV a strong longitudinal blow up occurred at around 18 mA, associating a longitudinal profile distortion measured by a streak camera (Figs. 10). It would be interesting to reproduce the observation with simulation using the obtained information.

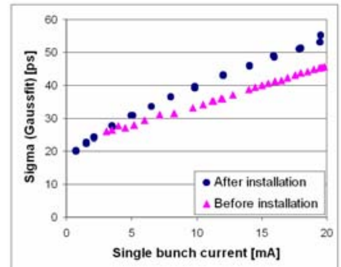


Figure 9: Bunch lengthening measured before (magenta) and after (dark blue) installation of the 2nd RF unit.

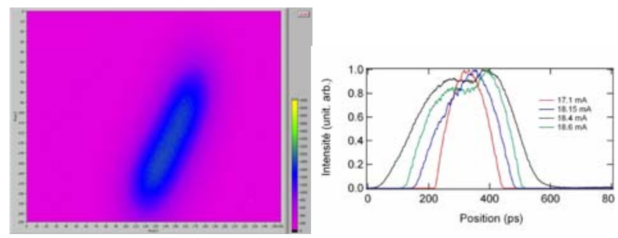


Figure. 10: Observed microwave instability after installation of the 2nd RF unit. Left: An X-ray pinhole image. Right: Longitudinal profile measured with a streak camera.

## SUMMARY

Good performance of the 2nd feedback chain was demonstrated, which, combined with the 1st chain happily provides us with much more flexibility in the feedback operation. With the foreseen installation of a horizontal stripline and noise reduction by bypassing the RF frontend that we currently use, further enhancement of feedback performance is expected. The described evolution of both beam instability and the machine impedance confirms the constant need of experimental and theoretical follow up of the former, in order to guarantee the overall storage ring performance.

## ACKNOWLEDGEMENT

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## REFERENCES

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