TRANSVERSE FEEDBACK DEVELOPMENT AT SOLEIL

R. Nagaoka, L. Cassinari, J.C. Denard, J.M. Filhol, N. Hubert, M.P. Level, P. Marchand, C. Mariette, F. Ribeiro, R. Sreedharan, Synchrotron SOLEIL, St-Aubin, France
T. Nakamura, K. Kobayashi, SPring-8, Mikazuki-cho, Hyogo, Japan.

Abstract

The paper describes the bunch by bunch transverse feedback system developed and implemented at SOLEIL. In order to cope with diverse beam conditions involving multibunch and single bunch instabilities, a digital system has been developed. While a BPM, a RF frontend and a stripline developed in house are used in the feedback chain, the SPring-8 solution was chosen for the digital processor for its proven performance elsewhere. The commissioning of the system as well as attained feedback performance is presented.

INTRODUCTION

SOLEIL is the French third generation light source ring commissioned in 2006 and starting its user operation this year. Table 1 summarizes the machine parameters related to the transverse feedback. The combination of the envisaged high current modes of operation both in terms of total and local intensity, along with small vertical vacuum chamber aperture adopted all around the machine to match low insertion device gaps, results in severe transverse collective beam instabilities, as anticipated from simulation studies. In particular, it has been observed that shifting of chromaticity to large positive values, a known remedy against these instabilities, is not effective at SOLEIL, due to excitation of higher order head-tail modes at high current, as predicted. Moreover, the electron beam is driven strongly unstable by ions existing in the chamber. Foreseeing this situation, it had been decided to install a digital bunch by bunch transverse feedback system, with an objective to keep the beam stable at zero chromaticity without spoiling the small emittance (Table 1), as well as to make it operational since the beginning of the user operation.

Table 1: SOLEIL machine parameters

Energy [GeV]	2.75
Nominal current [mA]	500, 8×10
Revolution frequency [kHz]	846.2
RF frequency f_{RF} [MHz]	352.2
Harmonic number	416
Fractional betatron tunes $\Delta Q_H/\Delta Q_V$	0.2/0.3
Synchrotron frequency [kHz]*	2.4
Betatron phase advance between detector and kicker**	0.0
Beta values at detector β_H/β_V [m] **	10/10
Horizontal emittance [nm·rad]	3.7
Vertical emittance [pm·rad]***	5.0

*At RF voltage of 2.0 MV
**In the present configuration
***Measured at low beam current

DEVELOPED SCHEME

Due to the imposed time constraint and the initially limited expertise in the concerned domain of technology at SOLEIL, the strategy adopted was to make use of already existing schemes and devices developed in other labs. We have followed particularly the systems developed at ELETTRA, the ESRF and SPring-8.

Bunch Position Detector

We have started from investigating whether our SOLEIL BPM had enough sensitivity to meet our requirement. Evaluating the signal level induced on an electrode with 500 mA beam current having rms bunch length of 20 ps as a function of frequency, the peak is found around 1.4 GHz, which is roughly four times f_{RF}, the RF frequency (Fig. 1). Signal levels at the end of a 22 m long 50 Ω coaxial cable of several different types are also shown in the figure. Taking the best case (CNT 600) and including the effect of a hybrid operation that creates a sum signal at the end of the cable, the peak difference signal is found to have the sensitivity of Δ_{peak} of 47 μV/mA/μm. The obtained sensitivity is used to evaluate the noise level at the exit of the RF frontend.

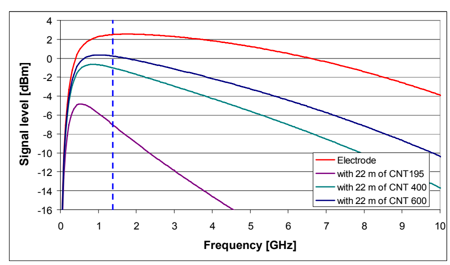


Figure 1: Sensitivity of a SOLEIL BPM against 500 mA beam (1.2 mA/bunch and bunch length of 20 ps).

RF Frontend

On the basis of the frequency dependence of the BPM sensitivity as found above, the ESRF scheme was followed to extract a band ($f_{RF}/2$) of beam signal at four times f_{RF} and down convert it to the baseband (Fig. 2). Fabrication of such RF frontend was made in house. The measurement precision was evaluated from the thermal noise generated in a 50 Ω cable transporting the 1.4 GHz band of signal, the noise amplification and the baseband conversion in the frontend. By comparing it with the above 47 μV/mA/μm, the resolution σ_δ at the entrance of the ADCs of the digital processor was deduced to be around 1 μm at 1 mA bunch current. On the other hand, Nakamura derived an equation that relates σ_δ to the rms

1-4244-0917-9/07/$25.00

beam size σ_z arising from the feedback, due to its limited resolution, given by $\sigma_z \sim \sqrt{T_0/\tau_{FB}} \cdot \sigma_\delta$, where T_0 is the revolution time and τ_{FB} is the feedback damping time [1]. Assuming τ_{FB} = 0.3 ms, a desired value, which was also confirmed achieved from the measurement (see below), we get σ_z = 0.06 µm at 1 mA. This means that the feedback induced beam size will not exceed one tenth of the vertical beam size (~10 µm) above the bunch current of 0.06 mA, or equivalently, the total current of 19 mA in the standard ¾ filling mode. We have thus concluded that the sensitivity of a SOLEIL BPM is sufficiently high.

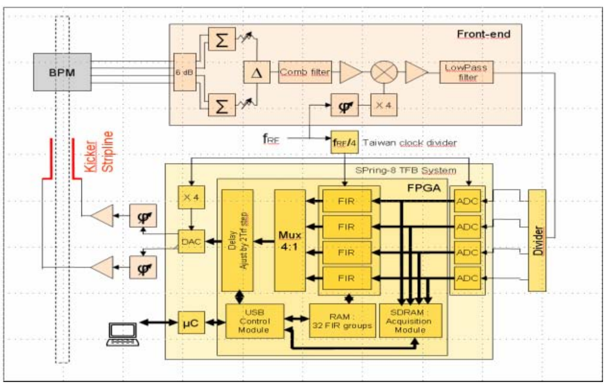


Figure 2: Layout of the SOLEIL feedback chain.

Digital Signal Processor

Among several solutions that were available, the digital signal processor developed at SPring-8 was chosen primarily for its proven performance in different machines. Details of its characteristics may be found elsewhere [2]. Here we merely note that it consists of 4 12-bit ADCs working at 88 MHz, 1/4th of f_{RF}, and having an analog bandwidth of 750 MHz. All FIR filters and multiplexers are integrated into one FPGA board, which allows achieving a latency of less than 1 turn (Fig. 2). The DAC has also 12-bit and works up to 1 GS/s. It must be mentioned that the willingness of TN and KK (the authors from SPring-8) to collaborate with the SOLEIL team, along with their expertise, was appreciable aid for the development of the present system.

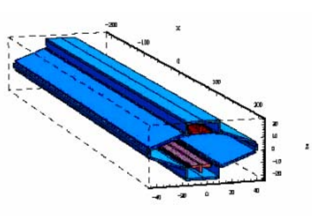


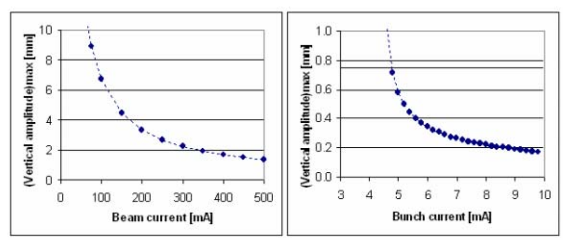
Figure 3: Vertical stripline with 2 electrodes.

Kicker

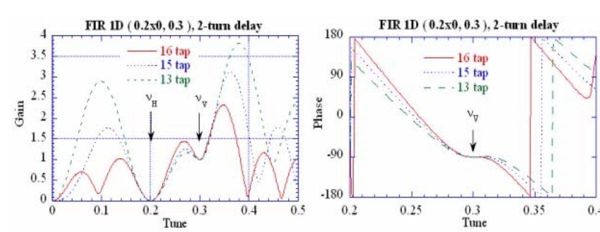
An extension of the already installed stripline, used for the tune measurement, was made to develop one that has higher shunt impedance, in view of generating a large beam deflection with a reasonable amount of power. In view of the strong vertical single bunch instability, a two-electrode structure (Fig. 3) was adopted for a vertical stripline for its much higher attainable shunt impedance as compared to a four-electrode structure, although the latter works in both transverse planes. The developed stripline achieves the shunt impedance of ~66 kΩ at 50 MHz and is planned to be installed during the forthcoming summer shutdown. Details are described in Ref. 3. The existing short-circuited stripline, the shunt impedance of which is estimated to be ~0.6 kΩ, is used for the feedback as a temporary solution.

RF Amplifiers

The necessary RF power was evaluated from the instability growth rate calculated with the impedance budget of the machine and the expected shunt impedance of 66 kΩ at 50 MHz attained for the developed vertical stripline. Estimating the maximum betatron amplitude damped by the system upon the condition $\tau_{FB} < \tau_G(I)$, where $\tau_G(I)$ denotes the current dependent instability growth time, we obtain the results as shown in Figs. 4, for the multibunch (left) and single bunch instabilities (right), respectively. A total RF power of 150 W (75 W per electrode) is well suited for the current-dependent resolution in position detection discussed above. Three units of 75 W (10 kHz-250 MHz) amplifiers were purchased.



Figures 4: Estimated maximum current-dependent betatron amplitude damped by the feedback system.



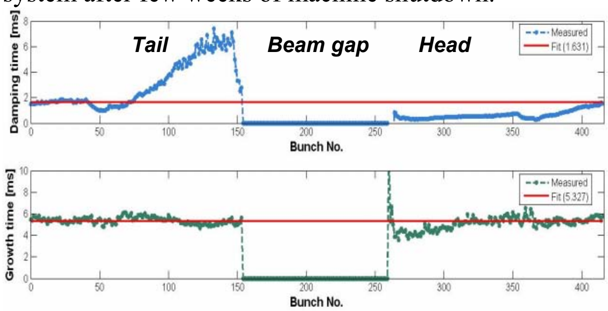
Figures 5: Phase and gain of the FIR filters.

COMMISSIONING OF THE SYSTEM

The entire feedback chain was commissioned with beam during two machine shifts in December 2006, in collaboration with TN and KK from SPring-8. As noted earlier, a shorted type 4-electrode stripline, dedicated to the tune measurement, was used as a provisional kicker, and a BPM in its vicinity as a detector (Table 1). The RF frontend was placed in a nearby rack. For easier operation, the digital processor and its dedicated pc were placed in the control room. The digital filtering was performed using a 16-tap FIR, according to the leastsquare fit of the betatron oscillation scheme developed by Nakamura [2]. The optimized gain and phase of the filter are shown in Figs. 5 for the vertical case. Taking into account 1.12 μs of delay created due to the distance between the control room and the stripline, the FIR was shifted by 2 turns. Due to the number of RF amplifiers available, only two electrodes were used diagonally to deflect the beam. This, on the other hand, left us the possibility to try the feedback in the horizontal plane as well as in both transverse planes, by tuning the FIR filter. It turned out that the system managed to keep the beam stable up to the maximum allowed current of 300 mA at zero chromaticity in all three cases.

CHARACTERISATION OF THE SYSTEM PERFORMANCE

We are currently at the stage of testing the system stability, reproducibility without retuning, as well as characterizing its performance, prior to fully introducing it during the user operation. It has been verified that the feedback efficiency is not sensitive to tiny orbit changes. We neither observed noted degradation restarting the system after few weeks of machine shutdown.



Figures 6: Observed bunch by bunch feedback damping and instability growth times at 50 mA in 3/4th filling.

Using the digital processor's capability to store bunch by bunch data over hundreds of milliseconds, damping and growth times have been pursued by triggering the data acquisition in switching off of the feedback over typically a few ms. The obtained data not only allow us to characterize the feedback performance, but also provide useful bunch by bunch information on the collective instability, particularly, on ion induced dynamics [4]. An example is shown in Figs. 6 where the feedback damping is found notably shorter at the head of the bunch train as compared to the tail, in the standard 3/4th filling. At the maximum allowed current of 250 mA, a growth time of $\tau_G(I)$ =0.93 ms and a damping time of $\tau(I)$ =0.49 ms were measured at zero chromaticity. The feedback damping time deduced from the former values is τ_{FB} = 0.32 ms.

Regarding the impact of the feedback on the vertical beam size, it has been observed that while the feedback manages to keep the beam size constant against beam current, the feedback generates a slight beam size increase at low current. A measurement performed with the lowest achievable emittance coupling of 0.125%, the vertical emittance increased by ~12%, namely the beam size by ~6% when switching on the feedback at low current. However, there was no further increase up to the maximum current of 200 mA followed [5]. A measurement comparing the beam size with and without feedback with a non-zero chromaticity is shown in Fig. 7.

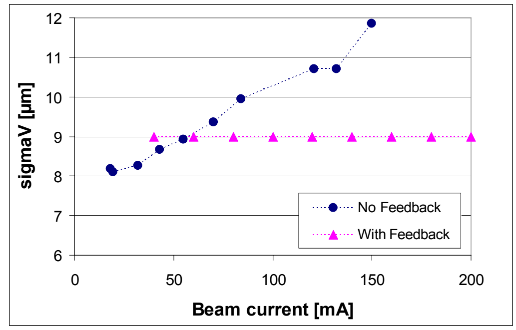


Figure 7: Vertical beam size versus current measured with a pinhole camera [5] at a non-zero chromaticity.

CONCLUSION

By applying the schemes already developed in other machines, a bunch by bunch digital transverse feedback system was implemented and made operational in effectively a year time after the project was started. The system installed has proven to suppress impedance and ion induced beam instability up to 300 mA at zero chromaticity, in one or the other or both transverse planes simultaneously, with a single digital processor, developed by the SPring-8 group. The increase of the small vertical beam size due to the feedback observed so far appears to be within 10% of the original size at zero chromaticity. In future, further optimization and extension are to be continued to reach the ultimate performance in both multibunch and single bunch modes of operation.

ACKNOWLEDGEMENT

Authors from SOLEIL thank E. Plouviez and G. Naylor at the ESRF, D. Bulfone and M. Lonza at ELETTRA for useful discussions and technical support, and K. Hsu at NSRRC (Taiwan) for kindly offering them a frequency divider for the digital processor. Thanks are also to the SOLEIL commissioning team and the operators for their active support in the control room.

REFERENCES

[1] T. Nakamura, "Residual Beam Motion Driven by the Noise at Transverse Feedback", Nanobeam2005, Kyoto University, Japan.

[2] T. Nakamura, K. Kobayashi, "FPGA Based Bunch-by-Bunch Feedback Signal Processor", ICALEPCA 2005, Geneva, Switzerland, and references therein.

[3] C. Mariette et al., "SOLEIL Vertical Stripline Development", DIPAC, Venice, May 2007.

[4] R. Nagaoka et al., "Beam Instability Observation and Analysis at SOLEIL", this conference.

[5] M.A. Tordeux et al., "Ultimate Resolution of SOLEIL X-ray Pinhole Camera ", DIPAC, Venice, May 2007.

