Diagnostics and equipments for single bunch operation at ESRF

J.L. Revol, E. Plouviez on behalf of the ESRF Project Team
European Synchrotron Radiation Facility
BP220, F-38043 Grenoble Cedex France

Abstract

Operation at ESRF with a limited number of high intensity bunches has been set during the last two years in order to provide users with a beam allowing time resolved experiments or within the frame of more general machine studies. To allow this mode of operation, we have tested and implemented several dedicated diagnostics and functionalities on the machine: bunch clock for the injection synchronization, main to parasitic bunches ratio measurements system based on photon counting, parasitic bunches cleaning system based on the resonant excitation of transverse oscillations, feedback for the stabilization of transverse instabilities, bunch length measurements [1]. This paper describes these systems, resumes the performances achieved and the problems encountered with their implementation.

1. INTRODUCTION

For time resolved experiments, the European Synchrotron Radiation Facility (ESRF) storage ring can be operated with a single bunch filling. For this mode of operation the requests of the light source users are then: high charge per bunch, long spacing between bunches, long lifetime, absence of parasitic bunches adjacent to the main bunches. The extra constraints of this mode of operation are: possible instabilities due to the large intensity per bunch, higher RF losses in the vacuum chamber, the need to detect and eliminate the parasitic bunches adjacent to the main bunch, a shorter lifetime due to the Touschek effect and the need to measure the bunch length.

For single bunch, the operation parameters are 5 mA average current per bunch and a time spacing of 2.8 µs [2]. In order to meet at the same time the requirement of all the users, the storage ring can run in the "few bunch mode", which offers both high average current and the possibility to make time resolved experiments. In the 16 bunch mode, the time between bunches is reduced to 176 ns and the average current is increased to 70 mA (to be compared to 100 mA in multibunch). The filling of the machine in a mixted mode (300*0.3 mA bunches plus one high intensity bunch) is planned for the next machine physics studies.

2. BUNCH CLOCK SYSTEM

The ESRF timing system for the synchronization of the three accelerators (Linac, Booster and Storage Ring) and the distribution of the reference triggers is based on a versatile Bunch Clock which allows a flexible filling of the SR. This system provides a set of reference clocks from the RF frequency (352.2 MHz), to track the bunch positions in the SR ($f_{rf}/992$) and the Booster ($f_{rf}/352$). After receiving the triggers from the slow timing, it provides the precise trigger for the Linac Gun and for the fast extraction magnets from the Booster to the Storage Ring. One or several SR bucket numbers can be remotely selected and the selection can be modified at any time so that any filling pattern is possible. Connected to this system, digital fast delay units triggered by the SR clock and clocked by f_{rf} are used for the SR beam diagnostics (2.8 ns steps, jitter < 10ps). This allows the triggering on one specific bunch of the SR. This is used in particular for bunch purity detection and for a streak camera (which is installed to measure the actual bunch length). All these electronics based on an ECL technology, are able to work up to 500 MHz.

3. SINGLE BUNCH PURITY

The purity in the single bunch mode of operation is essential for the time resolved experiments. Contrasts in population between the unwanted parasitic bunches and the main bunch are required in the range of 10^{-6} to 10^{-7} (e.g. for Mössbauer Spectroscopy) [1]. The measurement of the bunch population is performed using a photon counting method.

The photon flux is attenuated down to the level of a single photon per few tens of revolutions with filters, slits and a collimator. This single photon is detected with a micro channel-plate type photo multiplier (MCP-PM, Hamamatsu R3809U) which has an excellent time resolution and a small transit time spread (TTS = 50 ps). The time interval between the PM pulse and a reference trigger synchronized to the bucket is analyzed with a multi-channel analyzer. Three ranges of analysis are used (5 µs, 500 ns, 50 ns), giving a time resolution of 6.1 ps per channel in the lower range. This set-up is installed on one of the visible light channels in the optical laboratory of the Storage Ring.

A dynamic range of 10^6 (between the main bunches and the noise) and a 100 ps time resolution (FWHM) is achieved. The bunch population is obtained from the amplitude statistic after a one million count (ten minutes). The set-up is used to measure the ratio between the main bunch and the unwanted adjacent bunches in single bunch (single bunch purity).

Natural ratios in the few to several 10^{-3} only are obtained in the Storage Ring, after correct setting of the Linac pulse length, RF capture voltage and RF phases. Therefore a cleaning process has to be applied. For this we use the observation that the tune frequency of a high intensity bunch is shifted due to its interaction with the vacuum chamber impedance; the shift is -1.4 kHz per mA (for a low current tune of 141 kHz).

The small bandwidth of the resonance (≈ 200 Hz) allows to selectively excite oscillations of the parasitic bunches without perturbing the main bunch, as already produced at the Photon Factory [3]. This effect is used to eliminate the parasitic bunches, by excitation of their oscillation with a wide band low power dipole. The signal frequency is slowly swept around the low current vertical betatron frequency and the parasitic bunches can then be intercepted by a scraper. We operate with a jaw opening to 7 mm and a dipole signal amplitude of 0.15 G.m. The shaker is matched to 50 Ω up to 2.5 MHz and fed by a 50 W amplifier.

As shown on the figure 1, three bunches were filled with an initial purity better than 10%. After cleaning bunch -1 and -2, we obtained one single bunch with at least a ratio of 10^6 between the main bunch and the adjacent unwanted bunches. Information from the Mössbauer Experiment at ESRF indicates a purity of a few 10^{-7} [1].

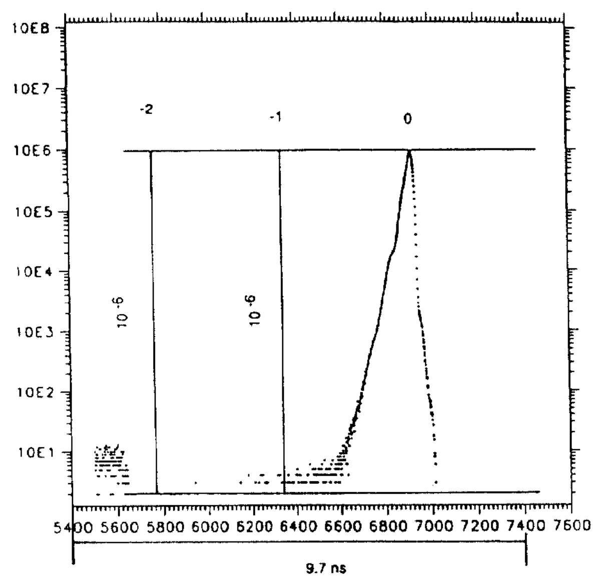

Figure 1: Bunch population after cleaning (I= 4.13 mA)

The cleaning process is now fully remotely controlled and is operational during user service. The same method is also applied to the cleaning of the 16 bunches in the few bunch mode of operation.

4. TRANSVERSE INSTABILITIES FEEDBACK

In single bunch operation, the maximum intensity is limited by transverse mode coupling instabilities [4]. To stabilize it, we apply the standard overcompensation of the chromaticity.

zero chromaticity ---> Imax = 2.5 mA

slightly positive chromaticity ---> Imax = 5 mA

increased chromaticity ---> Imax = 10 mA

High chromaticity has the disadvantage of limiting the dynamic aperture which leads to a lower injection efficiency and to a reduction of the lifetime.

In order to damp the beam instabilities with a standard chromaticity, we have developed a transverse feedback. The vertical motion of the beam is fed back to a shaker with an opposite phase. The phase and gain setting are obtained using a digital signal processor (Fig. 2). This precise setting also allows reactive feedback (shifting of the betatron frequency).

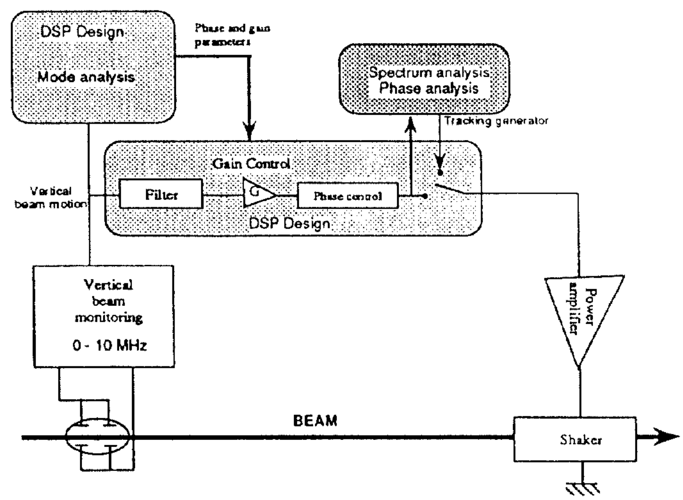

Figure 2: Single Bunch feedback layout

4.1 Beam position measurement

The beam position is measured using a block of four capacitive electrodes. The 352.2 MHz components of each pick-up are filtered, recombined with RF junctions and detected in a RF mixer by synchronous detection as shown on the figure 3. The bunch moves are detected with less than 50 nm/√Hz of noise for a 5 mA bunch. The bandwidth at the Z output is 2.5 MHz which allows the measurement of up to 16 bunch moves.

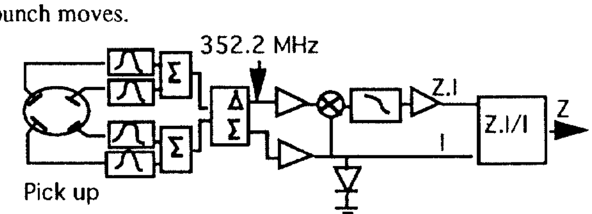

Figure 3: ΔZ Detection

4.2 Signal processing by DSP

The setting of the phase between the pick up and the shaker is obtained from a finite impulse response filter (FIR).

$$H(Z) = b_0 + b_1.Z^{-1} + b_2.Z^{-2}$$

The three coefficients are calculated in order to set the phase ø in function of the tune (Q) and to reject the DC and the revolution frequency.

$$b_0 = -(b_1 + b_2)$$

$$b_2 = -\frac{\sin(ø) + b_1 \sin(2\pi Q)}{\sin(4\pi Q)}$$

$$b_1 = \frac{\cos(ø)\sin(4\pi Q) - \sin(ø) + \sin(ø)\cos(4\pi Q)}{\sin(2\pi Q) - \sin(4\pi Q) - \sin(2\pi Q)\cos(4\pi Q) + \cos(2\pi Q)\sin(4\pi Q)}$$

The signal is sampled by a 12 bits Analog to Digital Converter (10 MHz bandwidth) and processed by a DSP (Digital Signal Processor) implemented on a VME board. The actual processing time of 840 ns will be decreased by a factor two with a new dedicated board based on the recent 2171 DSP from Analog Device (which is under development at the ESRF).

For single bunch, a sampling frequency of 355 kHz (revolution frequency) synchronized to the circulating bunch allows feedback of the unstable mode peaked at 140 kHz. An extension of this system is under development to feedback more than one bunch (16 bunches) by increasing the sampling frequency or the number of DSP. The actual system working on one bunch could be extended to the mixted mode.

The feedback simulation and analysis was made with a numerical computation software, Matlab [5]. An extension of this software was developed to compute real signals from the feedback, in order to perform the modelisation and the coefficient setting.

The correction is applied with the same shaker magnet as the one used for parasitic bunch cleaning.

5.5 Feedback analysis

Under the instability threshold, the growth rate of the instability is compensated by the natural damping time of the beam. The instability threshold could be increased with the chromaticity. The action of the feedback can be seen as an additionnal damping time (Fig. 4).

This behaviour modelled under Matlab shows that the feedback adds poles which have to be taken into account to analyse the stability, for a given loop gain, the stable phase range is limited. This behaviour was confirmed on the machine running with a reduced chromaticity.

This could be a limitation for a reactive feedback, which could be used to control the shift of the tune frequency.

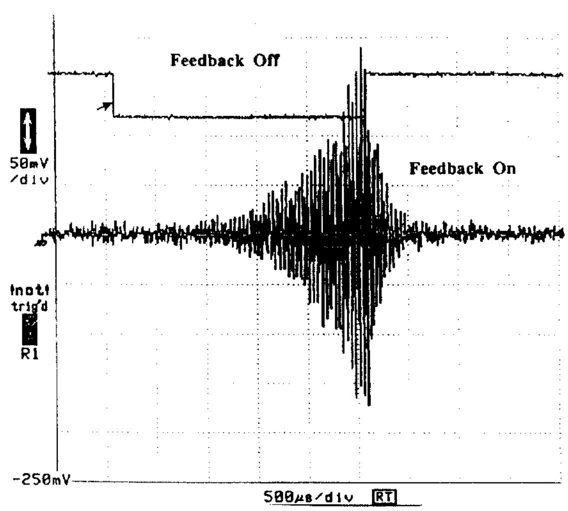

Figure 4: ΔZ Motion, Feedback On/Off

5.6 Results

Experiments have confirmed that with a machine unstable at 3 mA, the feedback allows the storage of 10 mA with a lifetime of 28 hours. It was also demonstrated that the feedback is compatible with the bunch cleaning procedure. With a higher chromaticity we have stored 17 mA, apparently limited only by outgassing problems. A complete program of characterization in term of lifetime and emittance of the beams stabilized by feedback is under way. An operational version of the feedback for single bunch will be installed on the machine.

6. CONCLUSION

Single and few bunch mode of operation is now routinely used. Specific diagnostics and tools are available.

The dynamic range of the purity measurement has still to be improved in order to achieve the requested 10^{-7} detection.

The increase of performance in term of maximum single bunch current is under progress, the transverse feedback will be routinely implemented. The application for few bunch mode is under consideration.

7. ACKNOWLEDGMENTS

The excellent work performed in single bunch is mainly due to the efficient coordination of A Ropert (machine physics study coordinator) and the involvement of JM Filhol (Operation Manager). The authors want to acknowledge the efficient support from all of the other ESRF groups, and in particular the RF group .

8. REFERENCES

[1] J.-L. Revol, E Plouviez; The ESRF timing system and single bunch operation; submitted to Synchrotron Radiation News.

[2] Foundation Phase Report, European Synchrotron Facility,1988.

[3] Photon Factory Activity Report, 1990.

[4] J. Jacob, C. David, J.-L. Revol; P.Barbier, D. Vial, J.M. Rigal, D. Boilot, N. Michel, M. Skoric, "RF System Developments for High Current Accumulation in the ESRF Storage Ring ", these Proceedings.

[5] Matlab is a Trademark of The MathWorks Inc.