CLEANING OF PARASITIC BUNCHES IN THE ESRF BOOSTER SYNCHROTRON FOR TIME STRUCTURE MODES OF OPERATION

E. Plouviez, N. Michel, ESRF, Grenoble, France

Abstract

The ESRF injector booster synchrotron accelerates electron bunches from 200 MeV to 6 GeV and injects them into the storage ring.[1] It can accelerate a small number (1 to 5) of high charge bunches for the so called "time structure" filling mode operation of the SR storage ring. In this case we must avoid storing parasitic low charge bunches in the unused RF buckets of the SR. Until now this was achieved by a resonant knockout of these parasitic bunches on the beam stored in the SR. We have developed and implemented a system allowing the removal of these parasitic electrons during the acceleration in the booster, so that no extra cleaning is needed on the beam stored in the SR. This paper describes our setup and its key components, the tuning of the operating parameters of the system and presents the results .

INTRODUCTION

The ESRF storage ring provides users with synchrotron radiation produced by a 6 GeV stored beam. Some experiments require the beam to be stored in a limited number of RF buckets, while the other buckets remains as empty as possible. Until now, for these so called time structure modes of operation, we eliminated the parasitic satellite bunches using a resonant RF transverse knock out system implemented in the storage ring and based on a frequency selection of the low charge parasitic bunches: due to their higher charge the main bunches have a shifted betatron frequency with respect to the zero current betatron frequency. [2]. As an alternative to this system, we have developed and implemented a system allowing the elimination of these parasitic bunches before their injection in the storage ring, using an RF knock out system implemented in the booster and operating at low energy, around 300 MeV, at the beginning of the acceleration cycle. We will use this new system if we decide to operate the SR in topping up mode. Another motivation for this development is to have a back up system if the SR frequency selective system operation is hindered due to changes in the SR impedance, for instance.

SY CLEANING OPERATING CONDITION

The current injected in the SR when no cleaning is applied is shown in figure 1. The population of the RF buckets results from the linac gun response and the capture by the booster RF. The relative current stored in the buckets adjacent to the main bunch bucket is less than 10^{-6} for the buckets located before the main bunch, less than 10^{-5} for the first bucket following the main bucket and 5 10^{-4} for the next one. We aim at delivering a beam with a relative population of any satellite bucket of less than 10^{-8} with respect to the main bucket population.

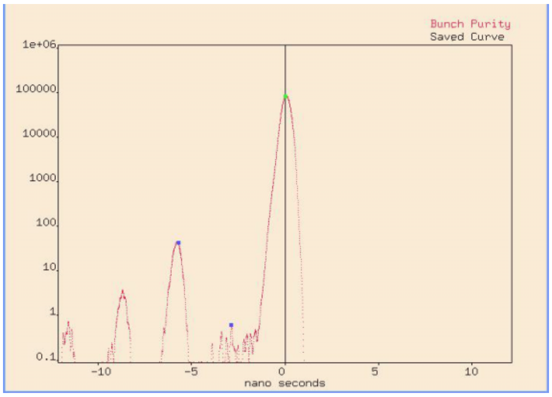

Figure 1:bunch purity in the SR without cleaning (measured by photon counting)

The revolution period of the booster synchrotron is 1µs or 352 RF periods T_{RF} (T_{RF} =2.8ns); the acceleration duration is 50 ms. The revolution period in the SR is 2.8µs or 992 RF periods, so there is generally no symmetry in the booster filling pattern when it is used to inject several high charge bunches in the SR. The figure 2 plot shows the variation of the tunes and chromaticity for the 50 ms acceleration cycle. For the time structure mode of operation for which the cleaning is required, we can inject 1, 2, 4 or 5 high current bunches per acceleration cycle, depending on the required SR filling pattern.

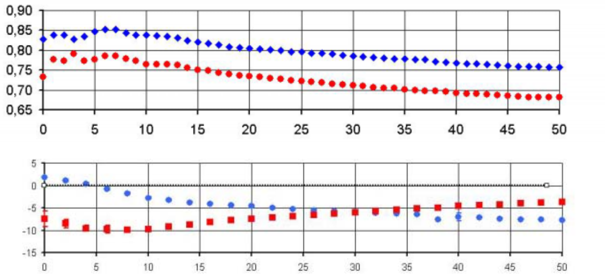

Figure 2: SY booster horizontal (blue) and vertical (red) tune (upper) and chromaticity (lower) during the 50 ms acceleration cycle.

SY CLEANING IMPLEMENTATION

We are using stripline kickers fed by a pair of 100 W RF amplifiers to perform a transverse resonant RF knock out of the parasitic bunches at the betatron frequency. In order to preserve the main bunches and to remove their satellites, we must apply some fast modulation to the cleaning signal to suppress it during the passage of these main bunches. We choose to apply the very clever time modulation scheme invented at SPRING8 [3]: in this scheme the cleaning signal is cancelled during the application of fast phase inversions to the betatron frequency excitation signal, as shown on figure 4 and figure 5. The transition time between the two phase states must be less than $2*T_{RF}$. If the middle of the rising or falling edge of the stripline signal coincides with the bunch passage, this bunch will not be excited. Otherwise, it will be removed by the RF knock out. This modulation scheme is the most efficient in terms of required bandwidth for the high power amplifier and relatively easy to implement. The electrodes length is 830 mm (one RF wavelength) with a 38 mm gap. The length chosen for the stripline is the longest length allowing the time modulation of the cleaning signal to be correctly applied

A specificity of our cleaning system operating condition is that there is no constant energy part in our acceleration cycle; the energy variation over the 50 ms acceleration is determined by the shape of the cycle of the White circuit magnet power supplies; it has a 1-cosine shape with a small DC offset. So we needed to find inside the accelerating cycle the time interval when we have the best compromise between the tune stability, beam energy (the lower the better), and the lowest chromaticity. We found empirically that the horizontal plane was the best to perform the cleaning and that the best moment of the cycle was between 2 and 5 ms after the injection; the beam energy is then about 300 MeV. We apply the signal at a fixed frequency during 4ms and the cleaning takes really less than 1ms when the tune reaches the right value.

General Layout

The layout of our system is shown on figure 3.

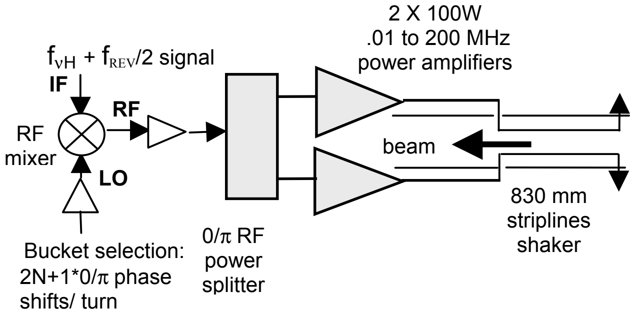

Figure 3:layout of the SY booster bunch cleaning system

The low level signal is generated using a double balanced RF mixer fed by a signal with a frequency equal to the sum of the betatron frequency $f_{\nu H}$ and half of the booster revolution frequency $f_{REV}/2$, as explained below, at the so called IF- intermediate frequency port; the fast rise time phase modulation signal is sent to the LO -local oscillator port. The mixer output RF port signal is equal to the IF input signal multiplied by the LO input signal. The phase inversion LO signal is generated using ECL logic signals from modules of the general timing system of ESRF accelerators followed by a 20 dB amplifier. ECL logic generates fast rise time signals perfectly suited for this application: the pulse to pulse delays are programmable and the level transitions synchronized on the RF reference with typically 10ps accuracy and jitter.

Generation of the bunch selection signal pattern

Since the LO input of the mixer cannot transmit DC signals, the phase inversion signal must not have any DC component. Since the filling pattern of the booster has no special symmetry over one revolution, this requirement can only be met over two revolution periods if we apply an odd number of phase inversions per period. In order to fulfill this requirement in the case of an even number of bunches, we must add an extra phase inversion to the timing pattern. This extra phase inversion is applied on a bucket to coincide with the rise of the injection kicker at the first turn of the acceleration cycle, in order to avoid the storage of a parasitic bunch accelerated in this bucket. Figures 5 shows the modulating signal in the case of the filling pattern used to inject four bunches spaced by 62 RF periods in the SR (for a final filling pattern of the SR of 16 equally spaced bunches). Due to these 2N+1 phase inversions per turn, the repetition frequency of the LO port signal is equal to $f_{REV}/2$. In order to excite large transverse horizontal oscillations of the beam, the stripline signal spectrum must be a combination of lines of frequency equal to N f_{REV} +/-$f_{\nu H}$.;so we must add $f_{REV}/2$ to the betatron revolution frequency to obtain the frequency of the IF input signal, in order to generate at the RF output of the RF frequency mixer a signal with spectral components which will be crossed by the transverse resonant frequency of the beam during the acceleration.

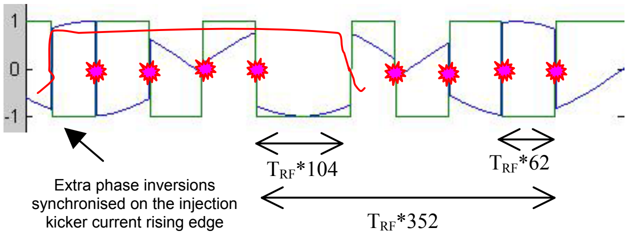

Figure 4: example of a cleaning signal (blue) with no DC component over 2 revolutions, for ν_H=.2 and four bunches accelerated (red: injection kick signal, pink: bunches)

Stripline power amplifiers

The RF power amplifier is a custom design made for ESRF by the company RFPA [4]. It is a key component of the system since it must transmit without distortion the rise and fall time of the signal at the phase inversions, in order to remove correctly the parasitic bunches adjacent to the main bunches. Figure 6 shows the plot of the output signal of the amplifiers during these transitions.

The amplitude of the cleaning signal one RF period after the phase zero crossing at the middle of the phase inversion is 70% of the final amplitude; this results in a degradation of the cleaning efficiency on this bucket. However, this degradation is still compatible with the required final purity of the stored beam, given the initial level of charge present in this bucket (see figure 1 and the test results below).

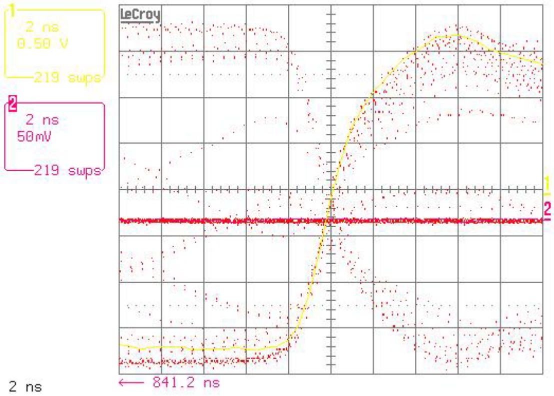

Figure 5: high power stripline signal rise and fall time during the phase inversions (2ns/div).

TEST RESULTS

The system is working as expected and its tuning is relatively straightforward. The bunch purity measured in the SR after cleaning in the booster is shown on figure 7. It shows a stored current level one period after the main bunch of less than 10^{-6} for a 200s counting time, which is the practical limit of the resolution of our photon counting system.

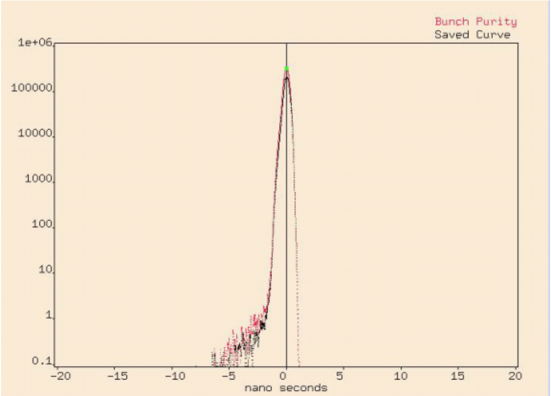

Figure 6: bunch purity measured on a beam stored in the SR after cleaning in the booster

In order to obtain a more accurate estimate of the cleaning efficiency, an indirect method was used to evaluate this purity after cleaning.

We first measured on a beam stored without cleaning the charge ratio P_{-1} and $P_{+1}$of the bunches stored in the buckets just before and just after the main bunch with reference to the main bunch charge (see figure 1).

We then measured the relative injection rate with reference to the injection rate in the main bucket selected by the cleaning system, in the RF bucket just before (R_{-1}) and just after (R_{-1}) this main bucket. To measure these very low injection rates, we used the photon counting of the bunch purity measurement system in the following way: we used as a reference the number of photons N_0 counted during 200s on the main bunch bucket after the injection of a beam at a constant injection rate during 70s (about 4mA); we then made the same counting after injecting during the same time in the buckets located one RF period before and one RF period after the bucket selected by the SY cleaning gating to get N_{-1} and N_{+1};.and we derived $R_{-1} = N_{-1} / N_0$ and $R_{+1} = N_{+1} / N_0$

We then derived from the parasitic bunches ratio Pc_{-1} and Pc_{+1}, after cleaning, in the bunches stored one RF period before and after the main bunch:

$Pc_{-1} = P_{-1} * R_{-1}$ and $Pc_{-1} = R_{+1} * P_{+1}$

The results of these different measurements are given below:

P_{-1} and P_{+1} linac purity:

$<3.10^{-6}$ one RF period before the main bunch

1.10^{-5} one RF period after the main bunch

R_{-1} and R_{+1} relative injection in the SR efficiency with SY cleaning ON:

2.10^{-5} one RF period before the main bunch

2.10^{-3} one RF period after the main bunch

Bunch purity in the SR after SY cleaning:

$<10^{-10}$ one RF period before the main bunch

2.10^{-8} one RF period after the main bunch

CONCLUSION

The SY cleaning concept tested at ESRF is working and is an alternative to the cleaning system implemented in the SR and presently used in operation.

AKNOWLEDGMENTS

The tuning and tests of this system could not have been carried out without the help of Y. Papaphilippou, .A. Panzarella and V. Serrière who spent a lot of time on the tuning of the synchrotron booster and the linac of the SR injector.

REFERENCE

[1]ESRF foundation Phase Report, Chapter 3, 1987, J.M. Filhol et al, EPAC 92, Berlin 1992

[2]J.L. Revol, E. Plouviez., Diagnostics and equipment for single bunch operation at ESRF, " EPAC 94, London 1992

[3]H. Suzuki et al, Formation of a single bunch beam in the booster synchrotron at Spring-8, Nucl. Instr. and Meth. A 444 (2000) 513-533

[4]RFPA: http://www.rfpa.com