CLEANING OF PARASITIC BUNCHES FOR TIME STRUCTURED FILLING OF THE ESRF STORAGE RING DURING TOP UP OPERATION

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Abstract

In order to generate time structured synchrotron radiation the 6GeV ESRF storage ring can be operated with 16 buckets filled with 15 nC separated by 16 gaps of 61 nearly perfectly empty buckets. The contrast required by some users between the population of the main and empty buckets is 10^{11}. In order to obtain these empty buckets some RF knock out (cleaning) of the parasitic bunches is needed. Until now this cleaning was performed on the beam stored in the storage ring). Recently we have started to deliver this 16 bunches filling in a so-called top up mode, drastically increasing the rate of the storage ring refills. In this top up mode the time it takes to perform the cleaning in the storage ring is very penalizing so we are now performing it in the booster synchrotron which accelerates the 200 MeV beam coming from the linac up to 6 GeV. We describe the set up used to perform the cleaning in the booster and all the measurement and experiments performed in order to correctly understand the origin of the unwanted electrons populating the gaps separating the 16 main bunches.

INTRODUCTION

The storage ring (SR) 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 others buckets remain as empty as possible. Buckets which should normally be empty are populated by parasitic bunches in different parts of the 200 MeV linac and synchrotron booster (SY) during the production, acceleration and extraction of the electrons. The SY magnets are driven by a White circuit resonant power supply working at 10Hz and the acceleration takes 50 ms.

Linac Gun

The nominal length of the gun pulse is 1ns; however it takes several ns before the gun current drops below 10^{-4} below the nominal gun current, resulting in the pollution of several buckets after the main bunch bucket.

Linac Buncher Dark Current

In the first cell of the linac buncher the 3 GHz electric field is strong enough to extract electrons from the wall of the buncher accelerating structure. The charge due to this dark current is about 10^{-8} lower than the charge of the main buckets which is several order of magnitude higher than the level of impurity acceptable by our users.

Extraction Bump

At the end of the 50 ms SY acceleration cycle the bunches are extracted from the SY booster into the transfer line going to the SR using the Fig. 1 scheme:

A bump is created by B1, B2 and B3 during the last millisecond of the acceleration which bring the booster beam close to the Se1 septum magnet (Fig.1 thick dotted line).

During the duration of the right booster revolution period of 1µs of the acceleration ramp, the kicker ke is fired (100ns rise time and fall time), and all the buckets are extracted by the septum Se1 from the booster to the SY to SR transfer line (Fig. 1 thin dotted line); at the end of this transfer line the bunches are injected in the SR when they arrive at the output of the transfer line during the duration of a bump created by four kickers which brings the SR stored beam close enough to a septum magnet at the output of the transfer line. The rise and fall time of the SR kickers is 0.9µs and the flat top is 1µs allowing the extraction of every bunch of the booster with no perturbation of the beam stored in the SR (the SR revolution period is 2.8 µs).

However during the turn before the kicker firing, if the horizontal beam size is large enough, a few electrons can be extracted by the septum Se1 and eventually injected in the SR (with a bad efficiency) during the last part of the rise time of the SR injection kickers. This problem was discovered very lately, when we found that a few buckets corresponding specifically to an extraction one turn before the normal extraction turn were slightly polluted while the cleaning was perfect for the rest of the SR buckets.

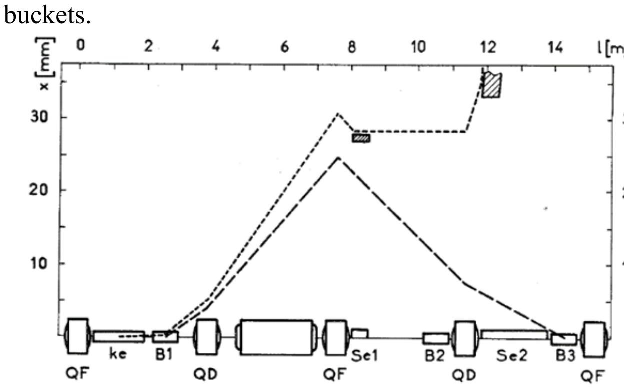

Figure 1: layout of the SY booster extraction scheme

CLEANING SET UP

We are using a stripline kicker 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 [2]: in this scheme the cleaning signal is cancelled during the application of a fast phase inversions to the betatron frequency excitation signal, as shown on Fig. 2 and Fig. 4. The transition time between the two phases 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.

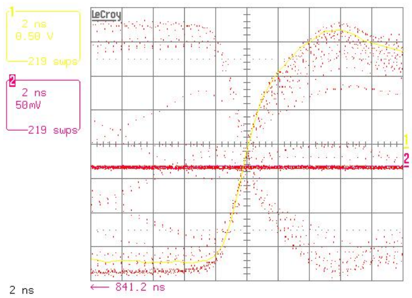

Figure 2: Kicker stripline signal rise and fall time during the phase inversions (2ns/div).

This modulation scheme is the most efficient in term of required bandwidth for the kicker power amplifiers and relatively easy to implement.

The excitation is applied in the horizontal plane. The stripline electrodes length is 830 mm (one RF wavelength). The length chosen for the stripline is the longest length compatible with the bandwidth required to apply the fast phase reversal of the cleaning signal without crosstalk between the cleaned buckets and the protected bucket.

We are using a stripline using the shape shown on Fig. 3 optimized in order to have both a good shunt impedance and a large enough physical aperture

Figure 3: The SY cleaning stripline kicker

The cleaning signal is applied during 3ms at the beginning of the acceleration cycle when the beam energy is about 400 MeV, 5 ms after the injection. For this beam energy the stripline kickers produces a kick of 32 µrad per turn when 100 V is applied on each stripline input (each stripline is terminated with 50 Ohms). The beta value is 10m both at the kicker and scrapper location. The parasitic electrons are lost on a +/- 15 mm aperture scraper.

Cleaning Signal Generation and OpticsTtuning

In order to work correctly, the number of phase reversal per revolution must be odd in order not to produce any kick at the zero crossing of the phase inversion signal modulating the betatron excitation signal; if the number of bunches in the booster is even, an extra phase inversion can be added just before the 100 ns rise of the extraction kick as shown on Fig. 4. The odd number of phase reversal per turn will shift the excitation frequency by $2N+1* f_{REV}/2$, so the excitation frequency before the application of the phase reversal modulation must be equal to $f_{\nu H} + f_{REV}/2$ as shown on Fig. 5.

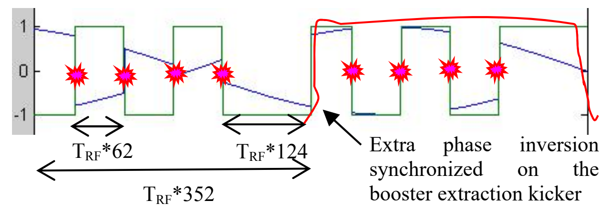

Figure 4: Example of a cleaning signal (blue) with no DC component over 2 revolutions, for ν_H=0.25 and four bunches (red: extraction kicker signal, pink: bunches, green: phase inversion modulation).

The set up used to generate the cleaning kicks is shown on Fig. 5.

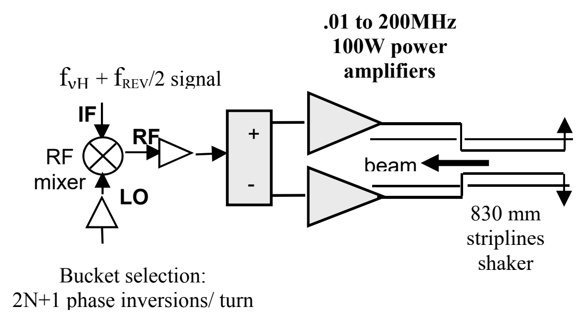

Figure 5: layout of the SY booster bunch cleaning system

In order to always build up a transverse oscillation of the parasitic bunches with a large enough amplitude we also implemented some extra for the generation of the excitation signal and respected some rules in the tuning of the SY booster optics:

- The frequency $f_{\nu H}$ of the cleaning signal is set at each injection, using the result of the calculation of the horizontal tune made using a measurement of the dipole and quadrupoles currents performed during one millisecond at the beginning of each injection, just before the application of the cleaning signal. The currents are measured using 20 bits ADCs and the tunes derived in an FPGA DSP and the cleaning signal generated by a DAC controlled by this DSP. This takes care of the variation of the tune due to the limited stability of the dipoles and quadrupoles currents produced by their power supplies.

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- In order to take care of the amplitude dependant tune variation during the oscillation build up and also to make sure that the excitation signal frequency will always match the beam resonant frequency we also apply a small 10 KHz frequency sweep to the cleaning signal during the 3 ms duration of the cleaning.
- We tune the sextupoles in order to have a horizontal chromaticity equal to zero during the cleaning period.
- We also found empirically that the cleaning reliability was very sensitive to the choice of the tune value, though we do not clearly understand yet why a fractional tune value of .71 is more favourable than a value of .75

PARASITIC EXTRACTION AT THE END OF THE ACCELERATION

The cleaning set up described above takes care of the parasitic electrons generated in the linac gun and in the linac buncher. It cannot take care of the parasitic bunches due to the parasitic extraction of electrons one turn before the extraction kick.

We found two means to reduce this effect:

- We reduce the amplitude of the extraction bump to the minimum value still resulting in an acceptable extraction efficiency rather than aiming at the best extraction efficiency.
- We minimize the horizontal beam emittance by coupling the horizontal and vertical tunes at the extraction time.

DIAGNOSTICS

Measuring the relative charge of the parasitic bunches present in the storage ring and understanding their origin required the implementation of several dedicated diagnostics.

Photon Counting

To measure the bunch purity in the SR, we use the photon counting method. If the signal from the photo diode is gated the contrast on the measurement of the population of the parasitic bunch relative to the main bunches population can be improved [4]; this technique is used on one of the ESRF beam line (ID18) and allows to measure the contrast of 10^{11} which is requested by some users. However this diagnostic is not available when the beam line is operated for the users. It was used to assess the quality of the cleaning ultimately achieved at the completion of the project but is not usually available in normal operation. Another photon counting set up which does not use the gating of the photo diode signal is also permanently available in the control room of the storage ring; however it only provides a purity measurement with a contrast of about 10^{-7}.

Photo Multiplier

When the problem of the parasitic extraction of electrons during the turns preceding or following the normal extraction turn appeared, we had to use a special diagnostic to assess the origin of the effect. In case of parasitic extraction most of the electrons will hit the Se1 or Se2 septum; to get a very sensitive detection of any current extracted in the transfer line, we use a photomultiplier followed by a Libera Spark [3] acquisition electronics to detect if electrons are hittingSe1 or Se2; the photo multiplier is sensitive enough to detect one single electron and has a good resolution in the time domain (20 MHz BW); if we trigger the extraction bump, but not the extraction kicker, no current should be detected in the transfer line. Depending on the amplitude of the extraction bump we found that a few electrons could be extracted during the flat top of the bump. The same diagnostic was used to test the effect of optimising the bump amplitude and coupling the horizontal and vertical tune to suppress this parasitic extraction.

Current Monitoring in the Booster

During user mode operation with 16 bunches stored in the SR and a top up every 20 minutes we need a quick diagnostics to check before each top up that the efficiency of the elimination of the parasitic bunches is still good enough. We get this figure by positioning the phase reversal of the cleaning signal + or - one (or several) buckets away from the main bunches buckets. In this situation the beam should be totally killed. We then measure the current in the booster after the end of the cleaning and compare it to a reference measure of the current done when the phase reversal is positioned normally on the main bunches bucket (.4mA usually with 5 bunches accelerated in the booster). The current measurement set up uses a stripline as a pickup. The stripline signal is processed using a Libera Spark electronics [3] slightly modified to improve its noise figure. The current is measured by summing the turn by turn sum signal measured by the Spark over 20ms (or 4 10^4 turns) giving a resolution of 1 nA. We assume that if the current measured with this set up over 100 test booster cycles is below the measurement threshold of this monitor, the tuning of the cleaning will be good enough to perform a top up without spoiling the SR bunch pattern purity.

PERFORMANCE OF THE SYSTEM

Our cleaning set up has already been used during 6 weeks of operation in top up mode. During this time one cleaning sequence was performed in the storage ring every 24 hours, while we relied on the SY cleaning for all the others top-ups performed every 20 minutes. During these 6 weeks we had no complaint from our users relative to parasitic bunches.

OUTLOOKS

During the year 2017, we are going to replace the present White circuit resonant power supply used to drive the SY booster magnets by a new H bridge switched power supply which we hope will be more stable.

We are also considering performing the cleaning in the vertical plane instead of the horizontal plane. These changes will require some extra tunings and tests.

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