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CURRENT PER BUNCH DISTRIBUTION MEASUREMENT AT ESRF

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Abstract

During the last run of the ESRF machine, several instrumentation improvements have been carried out in order to be exported on the new EBS storage ring. In particular, the top-up operation mode has been implemented and it demanded for an accurate, fast, and reliable measurement of the current per bunch distribution. In this proceeding, we describe the characteristics and the performance of the setup chosen to perform this measurement, which consists in a stripline, connected with a high dynamic range oscilloscope and a dedicated data analysis. We also comment on the integration of the measurement in the top-up routine to selectively refill less populated bunches.

INTRODUCTION

The European Synchrotron Light Source (ESRF) is going through an upgrade phase, which will lead to the Extremely Brilliant Source (EBS). The new hybrid multi bend achromat lattice will reduce the horizontal emittance from 4 nm to 150 pm to provide the user with a more coherent photon beam [1]. The reduction in emittance, however, also cause a reduction of lifetime and for this reason EBS will operate in top-up mode.

This operation mode has been implemented and commissioned during last runs of ESRF. In order to guarantee a more uniform filling pattern and to enhance the beam stability, an injection routine to selectively refill the emptiest bunches has been developed and a diagnostics tool to measure the current per bunch distribution was needed.

The longitudinal structure of ESRF and EBS is composed by 992 buckets separated by 2.8 ns, defined by the 352 MHz RF-cavity system. The most typical operation mode of ESRF-EBS is the so called "7/8+1" filling mode, which consists in 190 mA of current distributed uniformly in a continuous train covering the 7/8 of the available bunches and delimited by two 1 mA "marker" bunches. A single bunch of 8 mA is located in the center of the gap to allow users to perform timing experiments. This particular filling mode foresees a ratio of 40 between the single bunch and the bunches of the train.

Due to this configuration, a new current per bunch monitor was developed to provide a good dynamic range to distinguish the main train from the noise, without saturating the single bunch. Moreover the acquisition and the data analysis had to be fast enough to provide a continuous, online monitoring. The device has been commissioned on ESRF and will be re-installed on EBS.

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EXPERIMENTAL SETUP

The experimental setup consists on a stripline coupled to a high dynamic range oscilloscope. Data are then directly acquired by the Tango control system, treated and are available to users through an application.

Stripline

An horizontal stripline has been chosen to perform this measurements because the sensitivity of such a pickup is high and allows to have a strong signal even at low current. This stripline was originally designed to kick the beam, i.e. it has both an input and output port on each blade. For current per bunch measurement, only the input port is connected to the scope. The output one is connected to a coaxial cable terminated with a 50 Ω load in order to avoid undesired reflections. The signal coming out from the stripline is quite strong and has to be attenuated before being fed to the scope. A 30 dB attenuator was installed in the tunnel, close to the stripline port, and a second 10 dB attenuator was inserted before the scope. These attenuators also ensure that the signal acquired will not be polluted by reflection coming from bad mismatch between cables and the stripline or the scope ports.

Oscilloscope

The requirements for the readout electronics were the following:

- High dynamic range, in order to be able to properly separate the signal from the noise, also when operating in 7/8+1;
- High sampling rate, in order to obtain enough samples of the single 2.8 ns bucket over the total ≃3 µs beam length;
- Few GHz bandwidth in order to avoid the attenuation of the main 352 MHz signal;
- Possibility of acquiring data online and to easily integrate the device in the Tango operative system.

To cope with this requirements the LeCroy WavePro 254 HD oscilloscope has been chosen [2].

The selected oscilloscope has a bandwidth of 2.5 GHz, which is enough to observe the 352 MHz beam structure. The sampling rate of 20 GSa/s provides 56 samples per bucket. The vertical dynamic range of 12 bit allows to measure bunches with very different population. The possibility of manipulating the signal by filtering, averaging, or performing other mathematical calculation is also offered. Finally the device can connected to the control system through an Ethernet port.

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Figures 1 and 2 show the measurement of the 7/8+1 filling pattern and a zoom of the single bunch obtained with the LeCroy WavePro 254 HD compared with the one of an elder LeCroy WavePro with a sampling rate of 8 GSa/s and 8 bit dynamic range. The two traces have not been acquired simultaneously, however the effect of the highest dynamic range is evident when comparing the amplitude of the bunches in the train with respect to the noise in the gap. Also the higher sampling rate allows a finer definition of the stripline signal. This characteristics will be used for the data analysis.

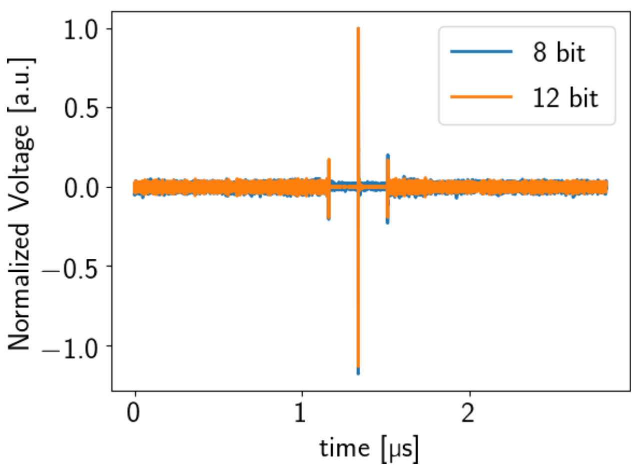

Figure 1: Filling pattern measured with the new LeCroy WavePro 254 HD (orange, 12 bit) and the elder LeCroy WavePro (blue, 8 bit).

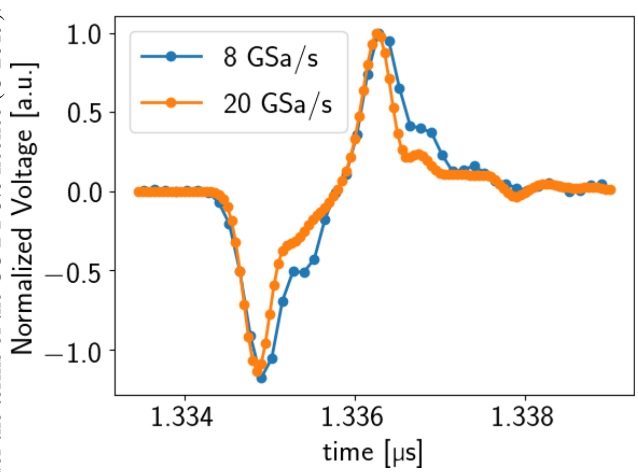

Figure 2: Single bunch measured with the new LeCroy WavePro 254 HD (orange, 20 GSa/s) and the elder LeCroy WavePro (blue,8 GSa/s).

Setup

The data is obtained by the stripline, attenuated and read by the oscilloscope. The oscilloscope is triggered by the SR clock (360 kHz) which provides a signal synchronous with the beam revolution period. In order to reduce the background without compromising the real-time response, the charge distribution is averaged over 50 turns, directly by the oscilloscope. The treated data is finally acquired by the control system and undergoes to further analysis.

A screen-shot of the oscilloscope during data acquisition in 7/8+1 operation mode is presented in Fig. 3: in pink the signal from the stripline, while in blue the trigger. The oscilloscope is set to visualize more than one turn: the time base was set to 500 ns per division to show a total time of 5 µs on the screen, while the beam revolution period is 2.8 µs and, for this reason, the single bunch is shown two times. Moreover, thanks to the high dynamic range, the difference between the bunches in the train and the noise in the gap is clear.

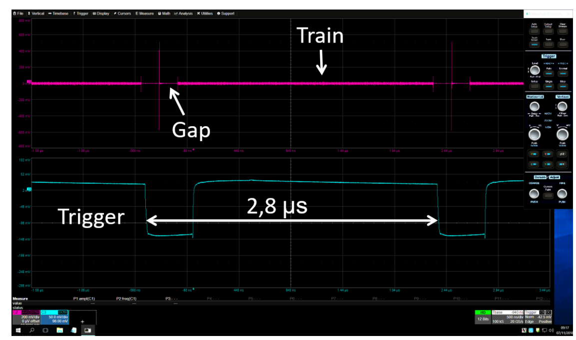

Figure 3: Screen-shot of the oscilloscope during acquisition. Top graph (pink) the signal from the stripline. Bottom graph (blue) trigger signal.

The amplitude of the signal, read by the stripline, is proportional to the current contained in each bunch. The total current is measured separately by using a Bergoz Parametric Current Transformer (PCT) [3]. The signal form the stripline is normalized and scaled according the measured current during the data treatment.

DATA ANALYSIS

In order to improve the dynamic range and to extract current per bunch information, a specific data analysis has been implemented, based on the cross-correlation principle. The response signal of the stripline to a single bunch has a specific shape defined by the pickup characteristics. This is the same for each filled bunch and its amplitude is proportional to the amount of current per bunch. The idea is to calculate the cross-correlation between the signal of a single bunch g and the filling pattern f:

$$(f \star g)(\tau) = \int_{-\infty}^{+\infty} \overline{f(t)} g(t+\tau) \mathrm{d}t. \quad (1)$$

The cross-correlation provides, intuitively, the product of the filling pattern and the single bunch signal when shifting it in time. The product will have a maximum when the two signals are similar and will average on a ground level if no correlation is present, for instance when comparing the single bunch and the noise.

An example of the result obtained is presented in Fig. 4: a zoom of the filling pattern comprehending the first marker

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and the part of the bunches in the trains are shown. The raw data presents the bipolar single bunch signal (Fig. 2) repeated for all the filled buckets. The result of the cross-correlation calculation shows an uni-polar signal and each peak is isolated with respect to the others. The amplitude of the bunches from the raw and the treated signal is maintained.

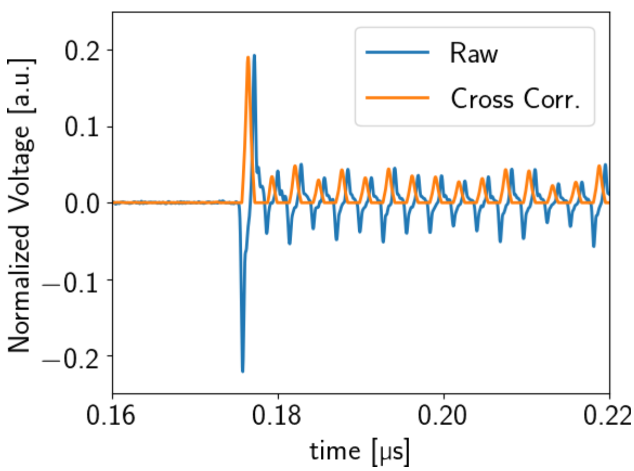

Figure 4: Zoom of the raw data from the filling patter (blue) and of the result obtained from the cross-correlation (orange).

The result of the cross-correlation has a specific structure with the peaks centered with respect to the bucket. To estimate the distribution of current per bunch, the signal is divided in 992 slots representing the storage ring buckets. For each slot, the value of the amplitude at the center is considered. If the signal is generated by a real bunch, its maximum will be around that position and will be proportional to the current in the bunch, while if the signal is dominated by the noise a random value will appear. This process improves the noise suppression and help in the result visualization.

Finally the distribution is normalized and multiplied by the value of the current read by the PCT. The output is an array with 992 slots. Each slots corresponds to a buckets and the assigned value is the current contained in each bunch. The bucket zero is identified as the single bunch and it is shifted at the good position, if needed. The result is shown in Fig. 5. Thanks to the good vertical dynamic range of the scope and the data analysis, the noise level in the gap is very small and the presence of a spurious bunch at bucket 30 can be spotted in this specific data set.

RESULTS

Using this experimental setup and the dedicated data analysis, the current per bunch distribution can be measured with a dynamic range of 10^3. The cross-correlation data showing the presence of the spurious bunch at bucket 30 is presented in Fig. 6. The peak corresponding to the real bunch signal is well defined and centered with respect to the bucket. The signal in the surrounded buckets is instead dominated by noise since no clear structure is shown. The

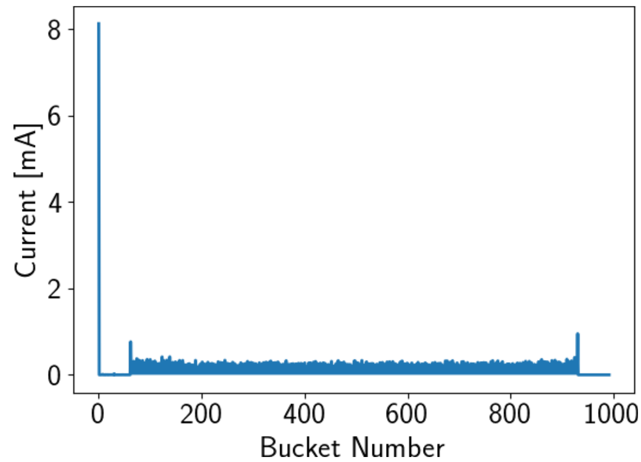

Figure 5: 7/8+1 filling pattern after the data analysis. A small peak, corresponding to a spurious bunch, can be seen around bucket 30.

value at the central position of the correspondent bucket is random and lower or equal to the maximum noise level.

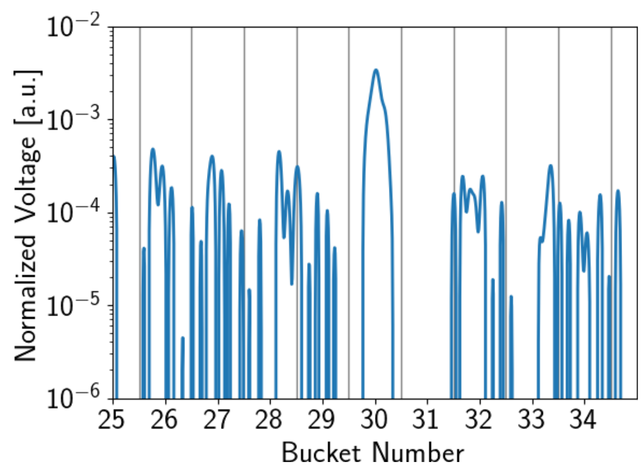

Figure 6: Spurious bunch detected in bucket 30 with a dynamic range of 10^3.

As a prof of the results, the same spurious bunch has been detected using the time correlated single photon counting setup [4], as shown in Fig. 7. This experimental setup achieves a much higher dynamic range (10^7) but it takes several minutes and the ADC can only measure a small portion of the beam. Moreover, in order to achieve such a dynamic range, x-rays are used and this strongly deteriorate the detector which cannot perform the measurements continuously. This technique is used once per day to check the purity of the beam and to decide if to perform the cleaning in the storage ring.

USERS APPLICATION

The new current per bunch measurement has been optimized to obtain a continuous, online monitoring of the filling pattern, with a sufficient dynamic range. Data are acuired and analyzed at 1 Hz repetition rate and the result

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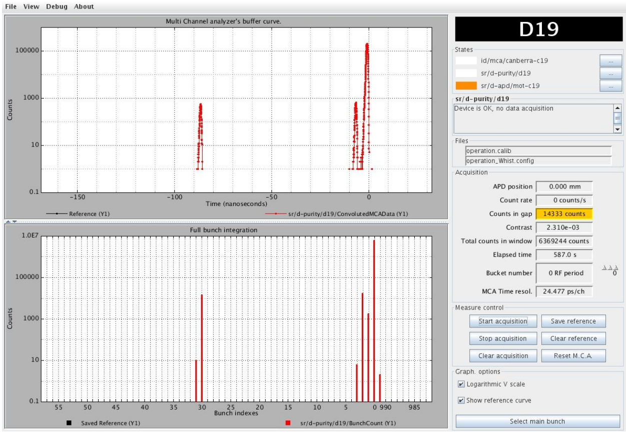

Figure 7: Measurement of the spurious bunch using the time correlated single photon counting. Note: the time is inverted with respect to the current per bunch measurement using the stripline.

is shown in the control room by an application. Figure 8 shows a screen shot of the 7/8+1 filling pattern during user operation. In order to have a clearer visualization the 8 mA single bunch is shown in a separate window with respect to the train.

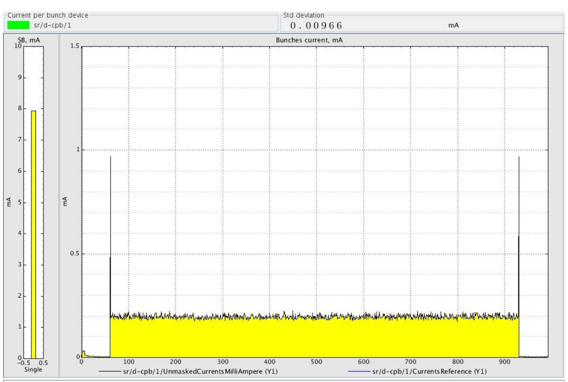

Figure 8: Application displaying the current per bunch distribution.

An "expert" application has been also developed to be able to control some parameters of the oscilloscope remotely, such as the trigger delay. However, the whole software has been conceived to automatically retrieve the best settings.

SELECTIVE TOP-UP

The main purpose of the current per bunch measurement is to generate an input for the selective top-up routine. This injection mode aims to selective refill the emptiest bunches through single bunch injections. The priority of the bunches to be refilled is decided according to the measured current per bunch distribution. The final goal is to reach a flat filling pattern to improve the machine stability.

A good indicator of the flatness of the filling pattern is the standard deviation of the current contained in the bunches of the train. Figure 9 shows the evolution of this value after several selective top-up injections.

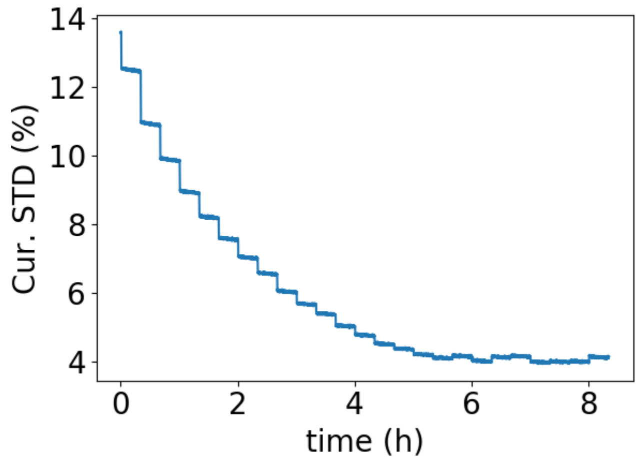

Figure 9: Standard deviation of the current contained in the train bunches when selective refilling each 20 minutes.

It is clear that the selective top-up injection mode improve the flatness of the filling pattern during the first 4 hours until reaching a plateaus defined by the current injected at each shot. The standard deviation could be improved further at the price of the injection time: less current per shot injected would allow a finer control of the filling pattern but would increase the refill time. A compromise was found to balance the situations.

CONCLUSION

A new experimental setup to measure the current per bunch has been developed at ESRF. The device provides a continuous, online monitor of the filling pattern with a dynamic range of 10^3 thanks to the 12 bit oscilloscope and the dedicated data analysis. An application has been developed for monitoring purpose and the measurement output has been used to perform selective top-up. The same setup will be used in EBS.

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