BUNCH CLEANING AT THE CANADIAN LIGHT SOURCE

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Abstract

A high-purity single-bunch operating mode, required for time-resolved experiments, has been introduced into the CLS storage ring. The newly deployed Transverse Feedback (TFB) system, which uses the Libera Bunch-by-Bunch system as the feedback processor, has added features that inherently enable bunch cleaning. The bunch purification mechanism is based on a frequency-modulated signal that drives the unwanted bunches into betatron oscillation to remove them from the storage ring. Bunch purities of 10^{-6} are achieved, limited only by the leakage rate from adjacent bunches.

INTRODUCTION

Time-resolved experiments usually require a high purity single-bunch in the storage ring. Ideally, injecting a single bunch to fill a single bucket in the storage ring is preferred. However, this is not possible with the existing LINAC gun of the CLS because the switching time of the video deflectors is too long. Since single bunch injection cannot be achieved, any unwanted bunches have to be kicked out after injection [1] [2] [3]. The newly deployed TFB system has added features that enable bunch purification in the time-domain. The bunch purification mechanism is based on a frequency-modulated signal that drives the unwanted bunches into betatron oscillation to remove them from the storage ring. When a bunch to be retained passes through the kicker, a 180 degree phase shift is introduced to the kick signal to create a zero-crossing near the bunch center. With this method, any unwanted bunches can be kicked out in a few seconds and bunch purities of 10^{-6} are achieved.

CLEANING MECHANISM

The CLS TFB system has been recently deployed to damp the betatron oscillation associated with coupled-bunch instabilities. Theoretically, running the TFB system in an anti-damping mode can remove unwanted bunches. However, if the targeted bunch has a small charge and betatron amplitude, it may not be detected by the Beam Position Monitor (BPM) and feedback will not be initiated. Therefore, the bunch cleaning mechanism is based on a free running oscillator tuned to the betatron frequency rather than feedback through the usual FIR filters. Because the bunch tune varies with the bunch charge and the amplitude of oscillation, it is also necessary to modulate the oscillator frequency to ensure all unwanted bunches are eventually driven out. Since the vertical aperture in the CLS storage ring is smaller than the horizontal aperture, bunch cleaning is done in the vertical plane.

The above cleaning mechanism requires a signal generator with signal frequencies in the vicinity of the betatron frequency [3], and a method to apply the cleaning signal only to certain bunches [3]. Both issues are resolved in the signal processing core implemented on the FPGA Xilinx chip in the Libera Bunch-by-Bunch digital processing unit.

Free-Running Oscillator

The free-running oscillator is a Numerically Controlled Oscillator (NCO) tailored for the needs of the bunch cleaning process. The finite state machine diagram describing the operation of the NCO is depicted in Figure 1.

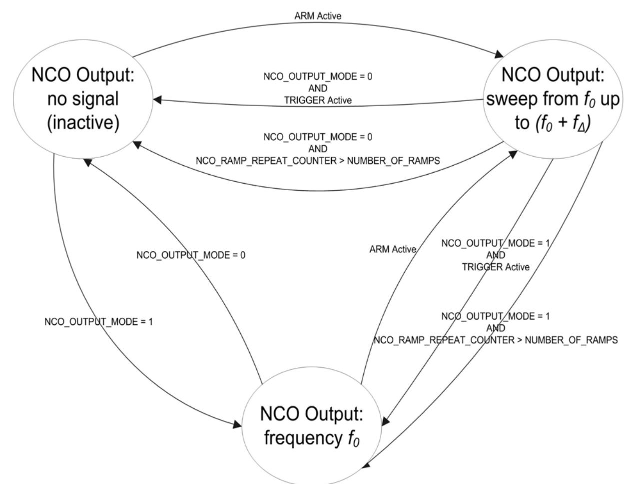

Figure 1: finite state machine diagram of the NCO.

The NCO has three main states; inactive, single output frequency and sweep mode [4]. Output modes can be initiated in different ways via arm/trigger signals that may have a software or hardware origin after a specified number of iterations (time), etc. The inactive mode as well as generation of single output frequency is self-explanatory. In sweeping mode, NCO starts with frequency f_0. At every FPGA clock cycle NCO adds a calculated value to the phase of the generated signal. For a single frequency, this value is constant. The phase advance in sweeping mode is different with every FPGA clock cycle resulting in generation of numerous sine components. The value of the phase advance is calculated based on the delta frequency f_Δ and period for one sweep sequence; the operating rate of FPGA is also included in the calculations.

To utilize the NCO for bunch cleaning purpose, the NCO should work in the sweeping mode. The centre frequency of the sweeping, $f_0 + {}^{f_\Delta}\!/_{2}$, is tuned to the betatron frequency.

Bunch-Selection Mask

In order to remove certain bunches and retain others, a bunch-selection mask is mixed with the frequency-modulated signal. The bunch-selection mask crosses zero when the retained bunches arrive and has a maximum when the unwanted bunches arrive. If an isolated bunch is to be retained, a 180 degree phase shift is introduced to create the zero-crossing. A 180 degree phase shift is necessary because of the limited bandwidth of the power amplifiers. If two or more adjacent bunches are to be retained, zeros are simply inserted into the bunch-selection mask. Figure 2 presents an example of the bunch-selection mask, where bunches 3, 7, 8 and 9 are to be retained.

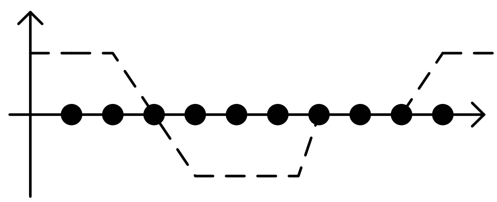

Figure 2: Bunch-selection mask.

Libera Bunch-by-Bunch uses one bit per bunch to select what type of signal is sent to the output DAC, either a transverse feedback processed signal or a NCO generated signal [4]. To enable the required functionality, zero crossing for bunches of interest and maximum for unwanted bunches, an additional 17-bit gain per every bunch is implemented in Libera. With proper setting of those two parameters, the bunch-selection mask as exemplified by Figure 2 can be properly shaped.

TRANSVERSE FEEDBACK SYSTEM

Since the vertical part of the TFB is utilized for bunch cleaning, we will only discuss the vertical part of the TFB system in this section. Figure 3 depicts the block diagram of the vertical part, showing only those components that are used in bunch cleaning mode. The system consists of a Libera Bunch-by-Bunch unit, a motorized phase shifter, a single-to-differential converter, power amplifiers, low-pass filters and vertical kicker. The system bandwidth spans roughly 10 Hz to 220 Hz.

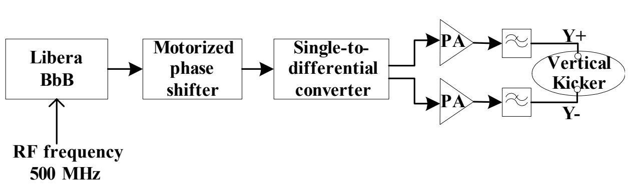

Figure 3: Vertical part of the CLS TFB system. The diagram only shows the components that are used in bunch cleaning mode.

Libera Bunch-by-Bunch

As we described earlier, the digital processing unit Libera Bunch-by-Bunch is used as a free-running oscillator for bunch cleaning. Since the transverse feedback is not operational, beam position information from the BPM is not processed. Thus, the only necessary input for the processing unit is the RF frequency, which is 500 MHz at the CLS.

As stated above, the NCO and the bunch-selection mask are the subset of Libera Bunch-by-Bunch features [4] [5] used in the bunch cleaning. All other embedded processing blocks become irrelevant in this mode of operation.

Motorized Phase Shifter

It is necessary that the zero-crossing occurs at the exact moment when the bunch to be retained passes through the kicker. To achieve this, accurate delay timing is required. However, Libera Bunch-by-Bunch can only adjust the output delay in steps of ${}^{1}\!/_{f_{RF}}$, which is 2 ns. With a motorized phase shifter connected, the output delay can be adjusted between 0 to 2 ns, with an accuracy of several ps.

Power Amplifier and Kicker

The amplifiers are AR model 150A220 with 150 W of rated output power and 10 Hz-220 Hz bandwidth. These amplifiers have a short RF rise time (3 ns), which is important for bunch cleaning. As shown in Figure 2, the RF signal undergoes a 180 degree phase shift at the bunch that is to be retained in the storage ring. At the same time the adjacent bunches, which are to be kicked out of the storage ring, need to be excited by the full amplitude of the RF signal. A short RF rise time is necessary to produce such a fast crossover of the RF signal. Both the horizontal and vertical kickers are based on the kicker design from Swiss Light Source [6], aside from minor changes to accommodate the profile of the CLS vacuum chamber.

TEST RESULTS

Bunch cleaning can be performed during injection or after injection. A fill pattern monitor [7] is used to measure bunch purities, which is based on single-photon counting of the synchrotron radiation from each bucket.

Bunch purities of 10^{-6} are readily achieved after cleaning. Figure 4 illustrates an example of bunch purity measurement after cleaning, where x-axis is the bunch number and y-axis is the number of counts, in logarithmic scale. Bunch 258 has approximately 10^{6} counts, bunch 259 shows 1 count, all other bunches have 0 counts.

If the cleaning is done after injection, any unwanted bunches can be kicked out in a few seconds. Various fill patterns can also be achieved by setting up the appropriate bunch-selection mask, such as a single bunch or three equally spaced bunches in the storage ring.

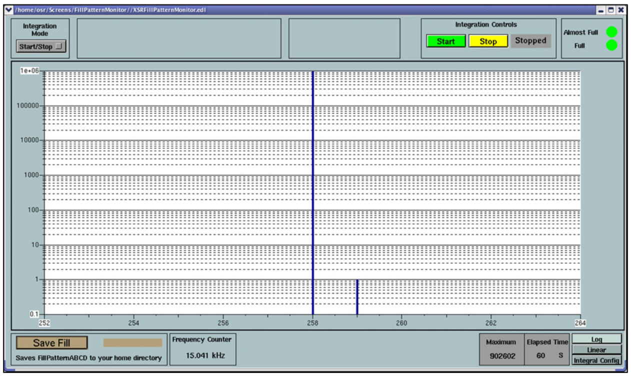

Figure 4: Bunch purities of 10^{-6} achieved.

CONCLUSIONS

A bunch cleaning system, based on the Libera Bunch-by-Bunch system, is now in routine operation at the Canadian Light Source. Bunch purities of the rejected bunches relative to the retained bunches are 10^{-6} or better, limited mainly by charge leakage from adjacent buckets. Targeted bunches are all cleaned simultaneously by utilizing a bunch-selection mask, so an arbitrary fill-pattern is established in a few seconds. The bunch cleaning system is a sub-component of the Transverse Feedback system presently being commissioned at the CLS.

REFERENCES

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