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S. Seletskiy

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Collider Accelerator Department

Brookhaven National Laboratory

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Some considerations about switching BPM channels

R. Hulsart, R. Michnoff, P. Thieberger, S. Seletskiy*

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Abstract

Switching the signals from two BPM buttons between the two channels was suggested for the LEReC BPMs. In this note we discuss how such a switching can help with determining the true position of the beam. We also describe the setup of the switching scheme for the BPMs in the LEReC cooling sections (CSs).

1 Introduction

The LEReC is the world's first bunched electron cooler. It is utilized for counteracting the intra-beam scattering in the colliding RHIC ion bunches and for the reduction in the transverse emittance of the ion bunches. Successful cooling requires that the ion and the electron trajectories in the LEReC CSs are well aligned. This requires high accuracy readings of both 704 MHz and 9 MHz LEReC BPMs. In this note we discuss the implementation of the BPM channels' switching [1], which allowed to improve the electron-ion alignment.

2 Theoretical considerations

Let us assume that the signals induced on the two opposing BPM buttons by the passing bunch of charged particles have amplitudes A and B. The true beam position in the BPM is given by:

$$x_{true} = \frac{A-B}{A+B} \tag{1}$$

*seletskiy@bnl.gov

For the sake of simplicity, and without the loss of generality, we assume here that the scaling coefficient is equal to 1 and that the mechanical displacement of the BPM is equal to 0.

If the two signals are transferred from the buttons to the digital module via two channels having different amplification (or attenuation) factors k_1 and k_2 then the measured position becomes:

$$x_{meas1} = \frac{k_1A - k_2B}{k_1A + k_2B} = x_{true} + x_{err1} \tag{2}$$

Here:

$$x_{err1} = \frac{2AB(k_1 - k_2)}{k_1A^2 + k_2B^2 + (k_1 + k_2)AB} \tag{3}$$

As Eq. 3 shows the resulting measurement error x_{err1} is dependent on the beam position with respect to the electric center of the BPM. It doesn't disappear when true position becomes 0, but rather approaches $\frac{k_1-k_2}{k_1+k_2}$. As a matter of fact, if the scaling factors are constant in time then this error is calibrated out in our beam based alignment procedure.

Now let us assume that we switch the signals across the channels and measure the beam position as:

$$x_{meas2} = \frac{1}{2}\left(\frac{k_1A - k_2B}{k_1A + k_2B} + \frac{k_2A - k_1B}{k_2A + k_1B}\right) = \frac{k_1k_2(A^2 - B^2)}{k_1k_2(A+B)^2 + AB(k_1 - k_2)^2} \tag{4}$$

Apparently, from Eqs. 1 and 4:

$$x_{meas2} = x_{true}\left(\frac{1}{1 + \frac{AB(k_1-k_2)^2}{k_1k_2(A+B)^2}}\right) \approx x_{true}\left(1 - \frac{AB(k_1 - k_2)^2}{k_1k_2(A+B)^2}\right) \tag{5}$$

We assumed here that $\Delta \equiv \frac{AB(k_1-k_2)^2}{k_1k_2(A+B)^2} \ll 1$. Taking into account that $\frac{AB}{(A+B)^2} \leq 0.25$, this assumption remains true even for a factor of 2 difference between k_1 and k_2.

As Eq. 5 shows the error in the measurement based on the averaging of the switching channels, $x_{err2} \equiv x_{true} \cdot \Delta$ is 0 when the beam is centered in the BPM. Also, for small $dk \equiv |k_1 - k_2|$, which probably is our case, $x_{err2} \propto (dk/k)^2$, unlike x_{err1}, which is proportional to dk/k. Hence, it is beneficial to base the measurements of our beam positions on the "channel switching" scheme.

3 Switching setup of LEReC BPMs

In this section we describe the actual realization of the switching scheme for the BPMs in the LEReC cooling section. The engeneering details of the switching system can be found in [2].

First, the channels for every CS BPM were switched manually. The BPMs showing large (> 500 μm) steps in position measurement, resulting from the switch, were identified (see Fig. 1). The scaling coefficients of the individual channels for these BPMs were readjusted to minimize the "position steps" resulting from the switching.

Figure 1: One of the CS BPMs showing a large change in position measurement when the channels are switched. The electron beam was in the CW mode during this test.

Next, the automatic switching with 760 Hz frequency was introduced to the CS BPMs. This frequency corresponds to 1 switch per 100 RHIC turns (the RHIC revolution frequency at relativistic $\gamma = 4 - 5$ is 76 kHz). To test the operation of the auto-switching script we chose the BPM with the well balances channels, intentionally increased the calibration coefficient for one of the channels (and observed the respective change in measured position), manually switched the channels and observed the jump in the measured position and finally, turned the auto-switching on and observed that the measured position returns to its initial "true" value. With auto-switching on even a factor of 10 imbalance in the channels calibration factors had no effect on the measured beam position. Figure 2 illustrates the described experiment.

Figure 2: The test of auto-switching script. Initially the auto-switching is off. At 14:53:40 an artificial imbalance is introduced to the channels of 9 MHz BPM. At 14:53:47 the imbalance is introduced to the 704 MHz BPM. At 14:53:52 the channels are manually switched, at 14:54:02 the channels are manually switched back. At 14:54:09 the auto-switching is turned on. The electron beam was in the 76 kHz mode with 5 macro-bunches during this test.

In auto-switching the actual switch of the channels is controlled by the 9 MHz horizontal position measurement board. This board forces the respective synchronized sign switching in the 9MHz vertical position measurement board and in both the 704 MHz horizontal and the 704 MHz vertical position measurement boards.

An important parameter of auto-switching is the relation of its frequency to the averaging frequency of the BPM measurements. The LEReC BPMs average beam position over 2^{12} turn-by-turn samples. Hence, the switching frequency is about 41 times higher than the averaging frequency. Simple simulations show that for the channels imbalance high enough to create 0.5 mm of the switching step, the given choice of frequencies results in 10 μm noise in the BPM readings. We checked these simulations with the settings which result in easily observable beating in BPM readings. Figures 3 and 4 show the simulated and the experimentally obtained noise for channels imbalance resulting in 1.5 mm switching step and for switching happening once per 1000 and 4000 turn-by-turn samples. The simulations are in good agreement with the experiment. Since the switching step was minimized for all the CS BPMs, we expect that the additional noise introduced by switching is not higher than a few microns.

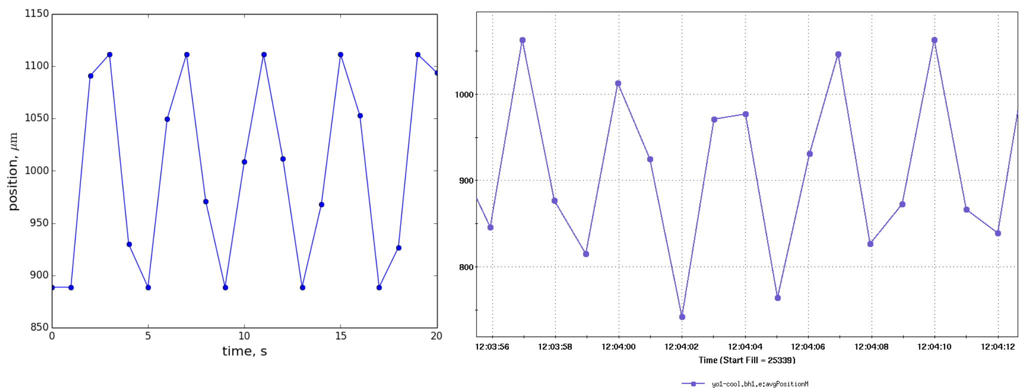

Figure 3: The simulated (left plot) and the experimentally observed (the right plot) beating of the BPM signal for 1.5 mm switching step and one switch per 1000 samples.

The only problem that we noticed with our switching scheme was the erroneous single-turn position readings, which occurred at the moment of the switch on 704 MHz electronics. These transients could be as large as 3 mm (see Fig. 5), but since their weight in averaging was 1/100 the resulting error in position measurement was just 30 μm maximum.

Nonetheless, the switching spikes were much larger than expected, due to the switching happening in the middle of one turn. Not only did the analog signal transient from the switch perturbed the A and B root sum square values, but the calculation treated the whole turn as $A - B$ or $B - A$, not able to switch in the middle.

To resolve this issue a new code allowing a variable delay in the switch control signal was deployed. The signal was adjusted manually for varying cable lengths for individual BPM buttons. As a result we got the main switch transient in between the turns, so that only the tail of the switching transient

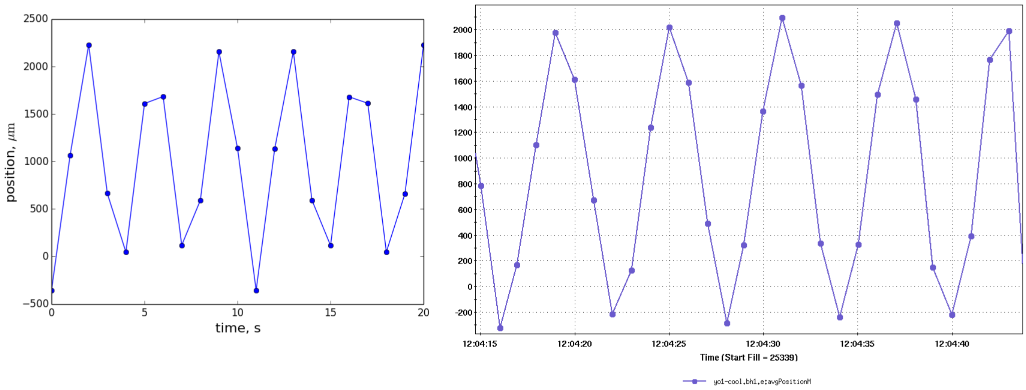

Figure 4: The simulated (left plot) and the experimentally observed (the right plot) beating of the BPM signal for 1.5 mm switching step and one switch per 4000 samples.

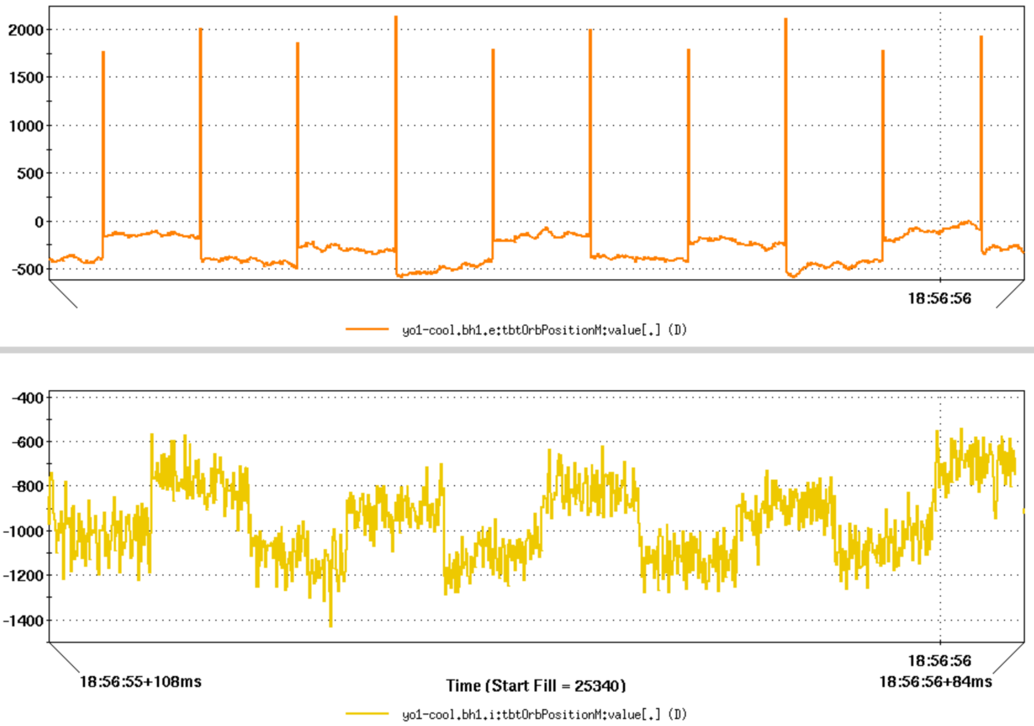

Figure 5: The switching transients were observed on turn-by-turn data from 704 MHz BPM board (upper plot). No transient effect was seen from 9 MHz board (lower plot).

is affecting one turn. Figure 6 shows that the switching spikes disappeared in our turn-by-turn data after the discussed change was implemented.

Figure 6: No transients are observed on turn-by-turn data for any BPM boards with the new switching software controls. Here we show the 704 MHz BPM signal.

4 Conclusion

Implementation of continuous switching allowed to improve the accuracy of the LEReC BPMs dramatically. This improvement allowed to achieve the required alignment of the electron and ion trajectories in the LEReC cooling sections. As a result, the functional transverse electron cooling was achieved and the RHIC luminosity was substantially increased.

References

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