Study of Main Injector BLT

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Introduction:
The Struck Main Injector (MI) BLT system, currently used for closing 2.5MHz beam transfers, is designed to measure the transverse oscillations of the beam injected into the Main Injector. The introduction of a new system, the Echotek BPM-based BLT system, aroused suspicion of the accuracy of the data produced by the BLT systems, because the position data produced by the two systems did not agree (see Figures 1a and 1b). Therefore, we started a detailed analysis of the Struck BLT system.

Background Information:
The position of the beam is determined by measuring the signals induced by the beam on strip-line style pickups. The Struck system takes the signals from the strip-lines and passes these signals through a 24.5dB amplifier, a 5MHz low pass filter, and a 20dB amplifier. The signals are digitized with a 12-bit digitizer at the MI Injection RF, approximately 53MHz. 105 samples (2μs worth) are taken each turn for 600 turns to capture the signals from the four antiproton bunches.

The signals from one of the plates are called "A" and are called "B" on the other plate. The online data analysis takes the digitized data and down converts the information at approximately 2.5MHz by multiplying the data by $e^{-i2\pi N/21}$ where N is the sample index number minus 1. The down converted data are then convolved with a rectangular window, designed to cover the four antiproton bunches; the window is 105 samples in length composed of 11 zeros, 84 ones, and 10 zeros (see Figure 3). The maximum values of the magnitude of these convolutions are the A and B values for the horizontal and vertical beam positions. The position in millimeters is determined by using the following equation.

$$position(mm) = 45.68 * \frac{A - B}{A + B}$$

Note: The correct conversion factor is 35.09, but the online analysis currently uses 45.68.

The Echotek System uses the same signals from the strip-lines after they have passed through the 5MHz low pass filter. The signals are digitized with a 14-bit digitizer at 80MHz.

Analysis:
We started our analysis by collecting data with the Echotek system and the Struck system to make sure that they were looking at the same turns. An offline program was written in Matlab that calculated the position using the raw data given by the Struck BLT. The positions determined by the offline Matlab program and by the Echotek system were similar. The sidebands visible in the FFT plots in the online analysis of the raw data were now gone in the offline analysis as can be seen from the position plots in Figure 2a and the FFT plots in Figure 2b.

We continued our analysis by studying the online LabVIEW program that is currently used by the Struck system. The difference between the offline and the online analysis concerned the window used for the convolution. It was intended that a single rectangular window covering all four bunches would be used. The online code, however, was unintentionally programmed to use the complement of this window (see Figure 3).

By using the complement of the window instead of a window that covers the four bunches, the data processing uses two windows: one that is eleven samples wide and another that is ten. One can see how this affects the final positions calculated by analyzing the convolutions of the four-bunch window and the convolutions of the complement of the four-bunch window.

The convolution scans the window across the down converted data (shown in Figure 4) and takes the area of what lies within the bounds of the window. When taking the convolution with a window that covers the four bunches, the maximum of the magnitude of the convolution will result in the integral of the data from all four bunches (see Figure 5). The index of the maximum of the convolution always resides in the plateau of the peak of the convolution when this window is used (see Figure 7). However, taking the maximum of the convolution when the complement of the rectangular window is used will select one peak, i.e. one bunch (see Figure 6). Because the convolution is taken once per turn, it can select a different bunch every turn (see Figure 8). Not only can it select different bunches every turn, but it can select different bunches for the A and B values it uses to calculate the positions for a given turn (see Figure 9).

Because of the imperfection in the injector kicker magnet, the four bunches can each have different injection oscillations. The convolution obtained from using the four-bunch rectangular window will calculate the average transverse position of the bunches. When the complement of this rectangular window is used, the program will still work provided that the four bunches have the same phase and intensity. If the phase and the intensity differ significantly between the bunches, it is hard to predict what would happen. It should be remembered that the BLT does in fact work.

Future:
A question that arises is what technique to use for closing. If the bunches are in fact significantly different, should we take the average of the four bunches or concentrate on one particular bunch? The present online program was designed to use the average.

We have found that bunch-by-bunch analysis is possible by using a single-bunch Hanning window that is 21 samples wide with 84 zeros after it, 105 samples total (see Figure 10). We are currently looking into doing single bunch analysis (see Figures 11a and 11b).

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