DIGITAL BEAM POSITION MEASUREMENT AT GSI-SIS AND CERN-PS

A. Galatis, A. Peters, GSI, Darmstadt, Germany
J. Belleman, Uli Raich, CERN, Geneva, Schwitzerland
A. Zoubir, Darmstadt University of Technology, Germany.

Abstract

New, digital BPM techniques needed in hadron machines, accelerating beams with fast varying frequencies, are to be presented. The role of analog electronics is reduced to signal amplification and attenuation as well as bandwidth limitation. This paper explores approaches for the position evaluation of acquired signals, suggesting systems for "free running" estimation as well as machine timing dependent methods. For accurate determining of the transversal bunch position, a good integration window estimation is needed. Two filtering methods will be introduced for this purpose, median and FFT filtering, both methods detecting peaks at bunch signal starting and ending points. Parallel to those a digital PLL approach is discussed in [1].*

PROBLEM DEFINITION

Beam position measurement and monitoring has a significant role in beam diagnostics. It can allow better controlling and regulation of the beam and can be used for estimating global feedback mechanisms. Both need a fast and accurate estimation for obtaining better results. Different approaches have been summarized in [2]. The problem is classified into two different tasks, hard- and software.

Hardware demands:

In order to have sufficient sample data points, while taking into account even short bunches of 30ns FWHM length, a sampling speed of 125MSa/s will be used. ADC resolution has to be large enough to be able to realize observations of transversal position movement in the order of 0.1mm. This fact and considering calculated signal dynamics of the SIS100, a resolution of 14 bit will be needed. The first processing will be done inside an FPGA, which will produce bunch integral data. Due to the high sampling rate and the resulting very short processing time while running the FPGA at sampling speed, complex calculations have to be made off-line and proposed software solutions for first data processing have to be as time efficient as possible to allow bunch-by-bunch resolution. After pre-processing, data rates will decrease to $h*f_{REV}$ (h being the machine harmonic). In order to also be able to use the hardware setup as a fast digitizer to record full acceleration cycles, sufficient RAM has to be provided.

Software demands:

Fast, online calculation of bunch signal integrals and centre of charge position should be achieved. Since the information primarily needed is the integration over a single bunch and not over all recorded data points, the algorithms determining the limits of a bunch structure will have to be running at full ADC sampling speed. This paper addresses only the software part of the described problem.

PROBLEM SOLUTIONS

As mentioned, integration windows have to be estimated in order to have fixed boundaries on bunch signals. For obtaining those windows, efficient algorithms for online calculation have to be developed. Two methods for determination will be discussed below.

Method 1: Median Filtering

Median filtering introduces a method using a window of N samples length. Data is filtered according to

$$y(n) = \frac{x(n)}{|\, median \;\; (x(n) + \ldots + x(n+N))\, |}$$

The filter smoothes the signal form, filtering out peaks and noise, allowing better estimation of the starting and ending points of a bunch. The variable length of the window indicated by N can be modified to get better results. Since this method is strongly dependent on the used filter window length, different lengths have been tested, with a good estimation level achieved for a length of 16 samples, even for poor SNR. In order to get less falsely detected bunch signals a version will be tested, which adapts the filter window length according to the revolution frequency.

Method 2: FFT calculation and interpretation

The FFT method implements a function that detects variations in the high frequency parts of signal spectra, which correspond to bunch signals emerging from baseline. A short-time FFT (DFT) is taken at consecutive parts of the signal. We again define windows at which we calculate the FFT. We expect to see a rise towards the higher frequency band in a transition from the baseline level to a bunch signal. From the general FFT we can get:

$$x(k) = \frac{1}{N}\sum_{n=1}^{N} X(n)\, e^{2\pi i(n-1)(k-1)/N}$$

$$= \frac{1}{N}\left(X(1)e^{0} + X(2)e^{2\pi i(n-1)/16} + \ldots + 0\right)$$

All X(n) for n>2, when using only two data points, are equal zero. It is obvious that for certain X(n) (X(n) being

---

* This project is part of the EU-RP6 SIS100 design study, collaborating members of this subtask being CERN-AB, GSI-SD, I-Tech, TUD and FZ-Jülich.

the discrete time data values) combinations the maximum will shift towards higher values of k.

We will see that an approach using only a few data points and zero padding up to a length of 16 points is suitable to obtain good results. Nevertheless, other lengths have been tested.

Since both methods can induce false integration window detections, the RF signal is used in parallel to filter those out. False detections in this context mean that a peak was detected even though there is physically no bunch existent. This can happen in cases were the data has a very low SNR.

The data sets for which the results are going to be shown are from a ^{86}Kr^{34+} acceleration cycle acquired at GSI-SIS18. The first data set is taken shortly after injection where the bunches are only partly formed and the energy of the beam is low, the second data set while bunches are formed and the third data set after acceleration. Since the signal form coming from the CERN-PS is alike the signal form of the bunched beam at GSI-SIS, no results on the CERN data are exposed here, refer for that to [1].

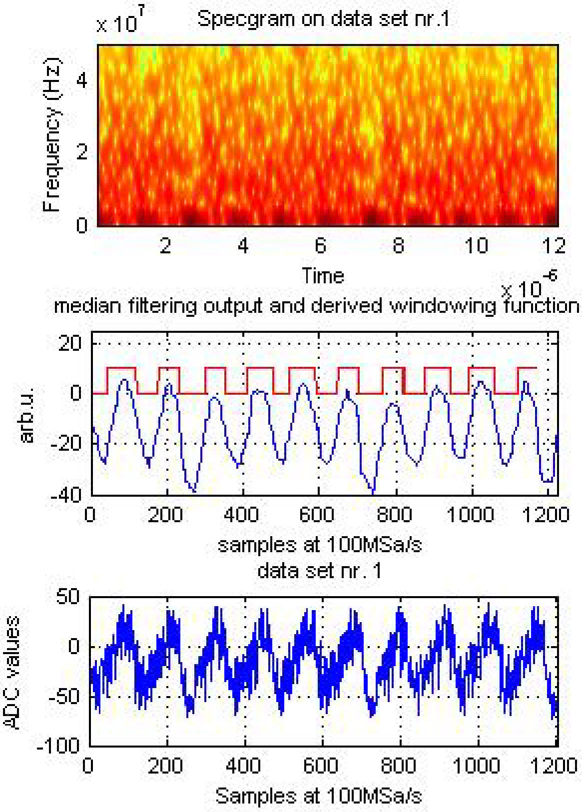

Figure 1: Spectrogram, median filtering of data set nr.1

Top graph of fig. 1 we see the spectrogram of the first data set with peaks at the points where bunches are located (dark red areas in low frequency regions). The time span in the spectrogram is the same as in the time plot of the original data, see bottom plot in Fig. 1.

RESULTS

In order to test both algorithms, the worst-case scenarios were used to prove the method's reliability. The parameters that were used in the FFT approach were a FFT window length of 16 and the number of real data was set to 2. For the case of median filtering the filter length was set to 16 for the data sets at the end of the acceleration, and 64 for the data sets at injection. A tradeoff for the filter length has to be taken into account for any filtering approach, because of the relatively wide span of window or bunch length during an acceleration cycle at GSI. This is starting at about 120 samples (all oncoming number of samples refers to a sampling speed of 100MSa/s) at injection and going down to about 15 samples before extraction.

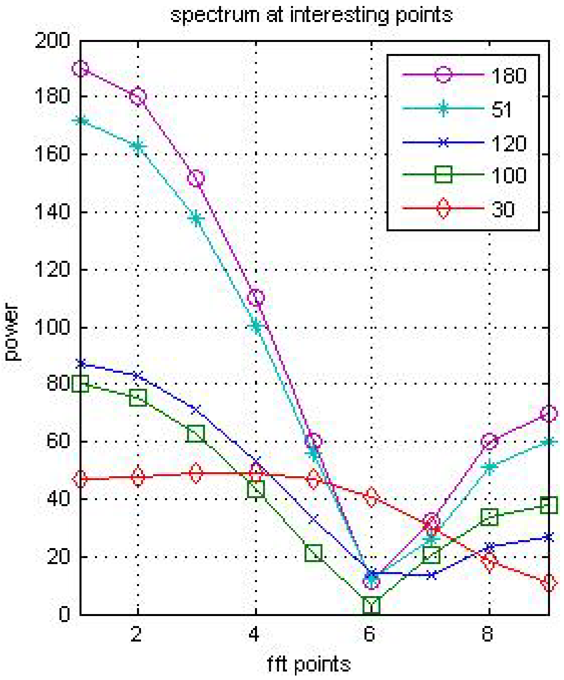

Figure 2: Results obtained by the FFT method, Indices are the time starting points of one bunch structure of fig. 1 bottom graph

In Fig. 2 we see the spectrum of the signal shown in bottom graph of fig. 1 at some points of interest. The indices 51 and 180 of the corresponding graphs are the starting points of the FFT taken from the corresponding time plot. They are the starting and the ending point of an up to that point not well formed bunch structure. The other three depicted graphs are plotted in order to see the differences that can be detected while using that method. The decision bound is, due to the very low signal intensity, very narrow (a factor of two maximum).

The middle blue graph of fig. 1 shows the output produced by the median filtering method. In red we see the derived integration window from the output signal. The filter length is set to 64, which is about half of the length of a bunch. The estimated window length is, the machine running on harmonic four, almost stable for consecutive turns, with a variation in length of about two samples, therefore an error resulting from noise of one sample as well as one sample jitter error.

In the top graph of fig. 3 we see the spectrogram of data set three. In contrast to Fig. 1 we see a better resolution in the high frequency regions and it is easier to identify the bunches. The better resolution between bunch signals and signal free areas is due to the better SNR. If we look into the low frequency areas, we see points with less energy than others, which we can use as transition points for building an integration window.

As explained earlier, while using the median filtering approach we need to shrink the filtering window length over the acceleration cycle in order to obtain better results. In the case of the middle graph of fig. 3 the length of the window is set to 16. The derived integration window is shown in the red curve. The window length, derived from the filtered signal, is stable for all bunches.

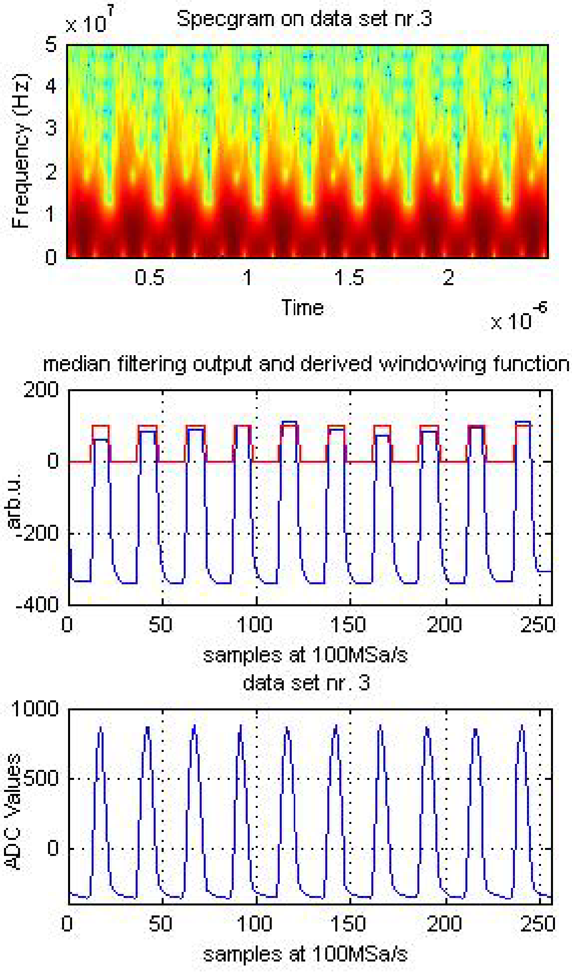

Figure 3: Spectrogram, median filtering on data set nr.3

CONCLUSIONS

Both methods, median and FFT filtering, tend to better results while the SNR, e.g. the bunch forming process completes. At injection levels, they both have their difficulties distinguishing bunches. There have also been made simulations to determine the robustness of the introduced methods. In order to test that the SNR was artificially decreased and the behaviour was observed. The limit was reached at an SNR decrease of about 15-20dB when bunches are completely formed. Both methods will be implemented using the actual RF as a function indicating the actual location of a bunch signal. This information will eliminate false window detections and provide the median filtering method with essential information for the window length variation.

The detection using median filtering works even if we keep the filter window length constant at 16 samples. The FFT method shows a dependency on the FFT length chosen and the amount of data points used. In both cases, a trade off between speed and accuracy has to be made.

The effect of the phase shift between the actual RF master signal and the pick-up signal of up to 25° on the calculated position should be investigated. The jitter should vary between some samples (~10) at injection and about one sample at the end of acceleration. Since both methods will use the RF information as a reference point this jitter should be of no influence.

It is intended to implement both methods in FPGA logic, which directly implies short time factors and very low computational load. Since the FPGA will be running at sampling speed, i.e. 125MHz a calculation time of less than 10ns has to be achieved. From this viewpoint, the median filtering method seems to be the least expensive. First implementations on real hardware should be ready in the next months and tests on efficiency and realisation feasibility will follow.

ACKNOWLEDGEMENTS

We acknowledge the support of the European Community-Research Infrastructure Action under the FP6 “Structuring the European Research Area” programme (DIRACsecondary-Beams, contract number 515873).

REFERENCES

[1] J. Belleman, A New Trajectory Measurement System for the CERN Proton Synchrotron, these proceedings.

[2] G. Vismara, The comparison of signal processing systems for beam position monitors, IT05, DIPAC1999, Chester.