# A FAST BEAM POSITION MEASUREMENT SYSTEM FOR CELSIUS

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*Abstract*

A new beam position measurement system has been constructed for CELSIUS in order to significantly increase the measurement speed of the original system, which is based on narrowband analog techniques. The new system is an adaptation of a data acquisition system [1] to beam position measurements. It uses direct digitization of pick-up signals with 14-bit resolution and sampling speeds up to 10 Msamples/s. The position information is extracted on a digital signal processor both with FFT and time domain techniques. Results from successful tests are presented.

## 1 INTRODUCTION

The CELSIUS ring [2] is equipped with a beam position measurement system, which multiplexes pick-up signals into a narrowband analog position detector unit. This technipue is sensitive, but rather slow. In many cases we can sacrifice sensitivity for increased speed in order to improve the creation of energy ramps. In order to achieve this goal we have adapted a newly developed data acqusition system [1] to beam position meaurements. Two different position evaluation techniques are studied. One is based on Fourier methods while the other analyzes the data in the time domain.

The data acquisition system is based on two 10 Msamples/s 14-bit Analog-to-Digital Converters (ADC) from Analog Devices (AD-9240), a 32-bit SHARC (ADSP-21061) floating point Digital Signal Processor (DSP) running at 40 MHz, 8 Mbyte SRAM to store two million samples and a direct digital synthesizer used for triggering the ADCs. The DSP emulates a parallel interface in software which is used to communicate with the system from a Linux PC.

The raw data presented were taken in CELSIUS when storing about 0.7 mA protons in a first-harmonic bunch at the injection energy of 48 MeV at a revolution frequency of 1.13 MHz. The raw BPM sum and difference signals are passed to the ADCs through a 5 MHz low pass anti-alias filter.

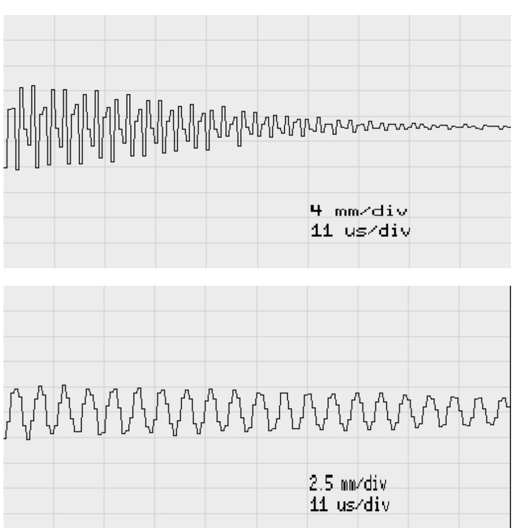


Figure 1: Horizontal and vertical positions as a function of time after a kick determined by the frequency domain method.

## 2 FREQUENCY DOMAIN PROCESSING

The position of the beam at a pick-up is found by use of the Fast Fourier Transform (FFT). The FFT of the sum and difference signals are calculated and the peak frequency $\hat{f}$ corresponding to the revolution frequency is found in the FFT of the sum signal. Then the ratio of the difference and the sum signal at the peak frequency is proportional to the position of the beam.

$$position \propto \frac{\mathcal{F}\Delta(\hat{f})}{\mathcal{F}\Sigma(\hat{f})} \tag{1}$$

where $\mathcal{F}\Delta$ denotes the (Fast) Fourier transform of the signal $\Delta$.

With this technique we can calculate the position of the beam, both over longer time periods (average position) with high sensitivity or shorter time periods (single passage bunch position) with lower sensitivity. In order to calculate the position in a single bunch passage when there are only a few samples per bunch available and hence the FFT size would be very small, extra samples are constructed by simply adding zeros to the input of the FFT. Figure 1 displays the positions for 128 turns after the beam is kicked. With only 5 samples per turn a 128 point FFT with 123 zeros and 5 measurements was used.

We have implemented a system in which the DSP controls the multiplexer and measures and displays averaged horizontal and vertical positions at all BPMs once every 20 ms.

## 3 TIME DOMAIN PROCESSING

In the alternate approach we process the raw data directly in the time domain [3]. Note that in Fig. 2 the difference signal has the largest excursion when the sum signal is positive and very small when it is negative. This indicates that the beam's position is indeed encoded in the difference signal and the amplitude of the difference signal at the sum's peak is proportional to the position of the beam.

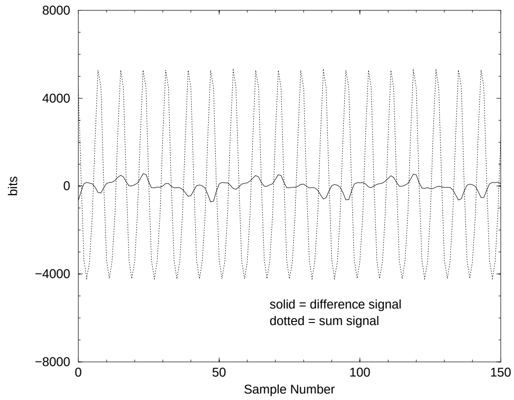


Figure 2: Filtered BPM sum and difference signals.

In order to use all available information in the determination of the position – namely, using all data points – we determine the first minimum of the sum signal and then fit the next eight data points of the sum signal $x_i$ to the eight data points of the difference signal $y_i$. In that case the fit amplitude $a$ is proportional to the beam's position. The fit equation thus reads

$$y_i = a x_i \quad \text{for } i \text{ in a single turn.} \tag{2}$$

We can easily determine $a$ in the least square sense and obtain

$$a = \frac{\sum_i x_i y_i}{\sum_i x_i x_i} \tag{3}$$

where the sum in $i$ extends over the points in one turn. This procedure is then repeated for each consecutive set of eight points and thus the position on consecutive turns is extracted. The position over the first 200 turns after the kick is displayed on the top of Fig. 3. From the positions we can easily calculate the betatron tune by Fourier transformation which is also shown in Fig. 3. The peak lies at 0.170 which is the alias of the vertical tune at 1.830. The small shallow peak towards the right at $0.379 = 2 - 1.621$ is a weak sign of the horizontal tune, which is visible on a vertical BPM due to imperfectly compensated coupling and the fact that the tune-kicker is mounted at a 45 degree angle in order to excite both planes simultaneously.

The algorithm for the position determination is so fast that our SHARC DSP should be capable of calculating it in real-time. The operations count for the above system is $2 \times 8$ multiply-accumulate operations and one division for the determination of one position per turn. Thus we have about 17 operations per $\mu$s. This compares favorably with the rate of a 40 MHz SHARC that can handle 40 instructions per $\mu$s. This area we will investigate further in the future.

If we were to observe the average position over a larger number of turns we could simply extend the range over which the fit is done, that is, extend $i$ in eq. 2 over more than the 8 samples of one turn. Thus we can determine the the positions more accurately but less frequently, i.e. averaged over more turns. Further inspection of eq. 3 reveals that the numerator is the cross-correlation or mixing product of

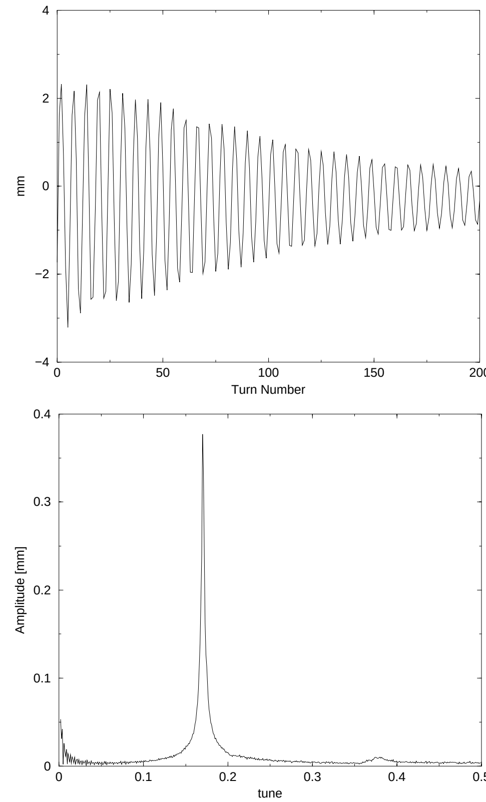


Figure 3: Reconstructed vertical beam positions and tune by using the time domain method.

sum and difference signals and that the denominator is the auto-correlation of the sum signals. Furthermore, note that the process of fitting the sum signal to the difference signal is equivalent to the ratio of the Fourier amplitudes of difference and sum signals at the revolution frequency i.e. the method used in section 2.

# 4 CONCLUSIONS

We have developed a system to measure turn-by-turn beam positions in CELSIUS in which two methods are used to extract the position information. One is based on Fourier methods while the other uses time domain data directly. Moreover, the calculated positions can be used to determine the betatron tunes.

# REFERENCES


[1] M. Bengtsson, T. Lofnes, V. Ziemann, "A DSP controlled data acquisition system for CELSIUS", Nucl. Instr. and Meth. **A 441,** 76, 2000.

[2] D. Reistad, "Performance and Perspectives on CELSIUS", Proc. XVI RCNP Osaka Int. Symp. on Multi-GeV High-Performance Accelerators and Related Technology, Osaka, Japan, March 12-14, 1997.

[3] V. Ziemann, "Turn-by-turn Beam Positions in CELSIUS using Time Domain Signal Processing," TSL-00-49, June 2000.