FAST BEAM DYNAMICS INVESTIGATION BASED ON AN ADC FILLING PATTERN MEASUREMENT

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Abstract

A diagnostic tool to determine the longitudinal particle filling pattern has been installed at the $1.5\,GeV$ electron storage ring Delta. The instrument is PC-based using an ADC-conversion at a sampling rate of $2\,GS/s$ and a nominal bandwidth of $1\,GHz$ which is applied to the sum signal of a single storage ring beam position monitor (BPM). By sampling over successive turns the resolution is enhanced by one order of magnitude allowing an easy access to the longitudinal particle distribution inside the ring. The data obtained turn-by-turn over hundreds of revolutions can be further analysed by FFT-techniques allowing a fast detection ($\approx 1\,s$) of longitudinal coupled bunch mode (CBM) instabilities from the phase modulated spectrum. The application of the FFT to the amplitude modulated particle distribution moreover allows a ”post mortem”-investigation of CBM induced beam loss. The paper will present the layout of the diagnostic system and will report on filling pattern measurements as well as on investigations of longitudinal CBM-instabilities.

INTRODUCTION

A precise control of the filling pattern in Delta [1] is essential for beam stability and lifetime. This is achieved by measuring the filling pattern and by control of the injection timing. The developed instrument provides full knowledge of the time domain structure of the beam, bunch-by-bunch, with a sub-nanosecond time resolution. The application of the diagnostic instrument for the filling pattern measurement has shown that an investigation of CBM instabilities is possible, too. The stored data are analysed with respect to (a) the bunch charge (filling pattern) and (b) coherent longitudinal bunch oscillations. Advantages of the instrument are a frequency resolution of less than $4\,kHz$ and a measurement period, depending on the CPU power, of 2 seconds or less.

SETUP AND METHODS

The sum signal $S(t)$ of the standard BPM is proportional to the time derivative of the Gaussian shaped bunch charge distribution:

$$S(t) \propto \frac{d}{dt}q(t) \tag{1}$$

This four button sum signal, generated by a $500-5000\,MHz$ power combiner, is fed into an oscilloscope PCI card (ADC) [2]. The ADC samples the BPM-signal at a rate of $2\,GS/s$ with an analog bandwidth of $1\,GHz$ and 8-Bit resolution. The ADC is triggered with the revolution frequency of Delta ($f_R = 2.603\,MHz$). A low noise frequency divider generates the trigger signal by dividing the accelerator radio frequency (RF) by the harmonic number ($h = 192$). The ADC card is part of a Linux PC which performs the data analysis. The results are sent to the control system by an EPICS client.

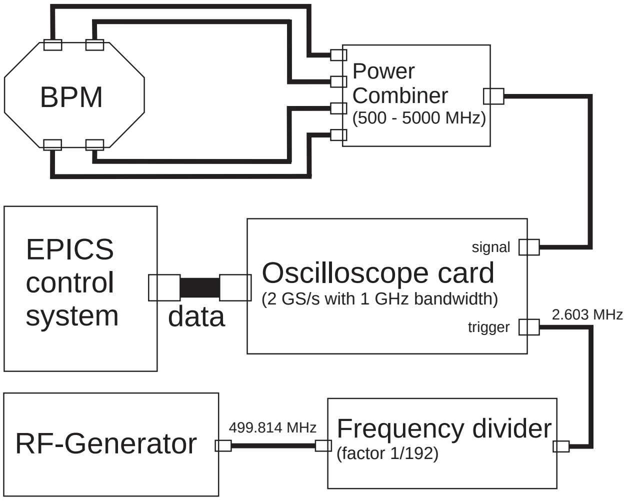

Figure 1: Layout of the diagnostic instrument for filling pattern measurement and CBM investigation.

Filling Pattern

Limited by the ADC sampling period of $0.5\,ns$ it is not possible to determine the bunch shape from single-shot measurements (see Figure 2, left diagram). The time resolution is increased by a sampling technique, i. e. the beam is recorded for several turns. The samples are shifted through the bucket, due to the frequency difference between the sampling frequency ($2\,GS/s$) and the accelerator RF ($499.814\,MHz$). An effective sampling rate of $14\,GS/s$ is obtained by overlaying seven successive revolutions (see Figure 2, right diagram). Slight variations of the accelerator RF do not spoil the overall performance. Unfortunately, this method generates high frequency artefacts that will deteriorate the obtained bunch shape by transforming lower frequencies to Nyquist bands above the ADC bandwidth of $1\,GHz$. Thus the generated data must be digitally filtered. A combination of a Chebychev low pass filter (4th order, $1\,GHz$, $0.5\,\%$ ringing) and a Butterworth high pass filter (4th order, $14\,MHz$) was implemented [3]. The high pass cutoff frequency was chosen

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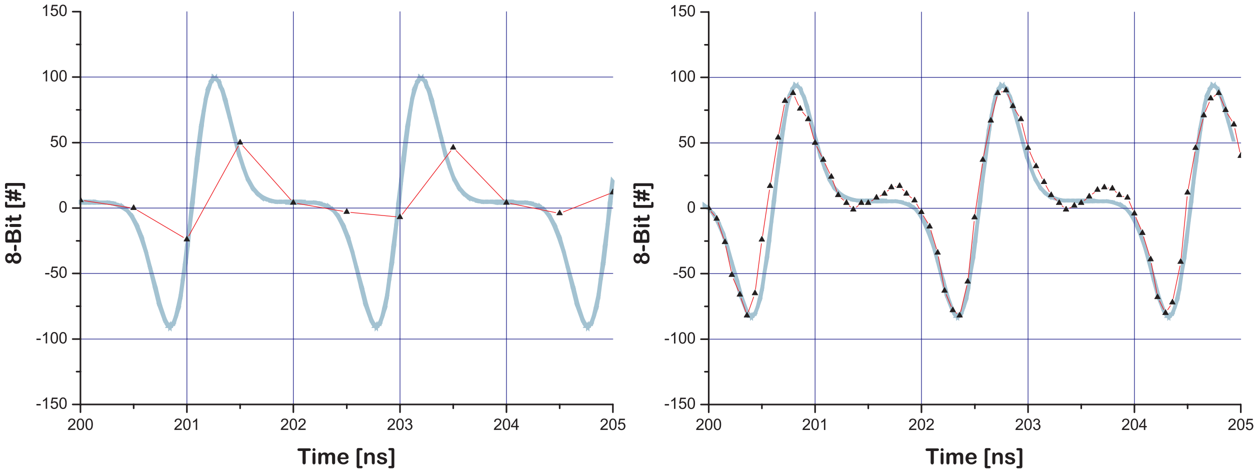
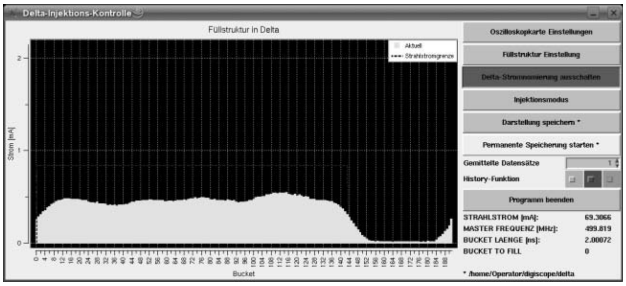


Figure 2: The left diagram shows the raw data of a single turn measurement compared to the computation of the derived Gauss-function. The right diagram shows the same measurement, but now with seven turns overlayed. There is a phase shift of $0.5\,ns$ between left and right diagram caused by the digital filter.

well below the accelerator RF and well above typical transverse beam oscillation frequencies. The bunch charge is derived from the difference between minimum and maximum of the obtained signal, assuming a constant bunch length. This assumption holds, since the measured bunch length is dominated by far by the bandwidth of the electronical setup. The values of the bunch charge are stored in an EPICS waveform record and displayed in a Tcl/Tk [4] program (Figure 3). As an option the bunch charge can be normalized to the cw beam current measurement of Delta (MPCT). The independence of the measured filling pattern on the beam position has been verified within the linear range of the BPM ($\pm 5\,mm$). Single- and multibunch fillings have been used to compare MPCT measurements and filling patterns to identify a bunch detection limit. A minimum bunch charge of approx. $40\,pC$ (i. e. $0.1\,mA$ single bunch current) is necessary to get a sufficient signal to noise ratio.



Gemittelte Datensätze 1
History-Funktion
STRAHLSTROM [mA]: 69.3066
MASTER FREQUENZ [MHz]: 499.819
BUCKET LAENGE [ns]: 2.00072
BUCKET TO FILL 0
* /home/Operator/digiscope/delta

Figure 3: A Tcl/Tk-program displays a standard 3/4 filling at a beam current of $70\,mA$.

Fast CBM Analysis

Induced by longitudinal wakefields, bunches in the ring may perform collective longitudinal oscillations. In the model of a linear chain of bunches, the number of orthogonal modes is determined by the number of oscillators, in our case a maximum of 192. An excited Coupled Bunch Mode (CBM) appears in the beam's power spectrum as a synchrotron sideband to a certain revolution harmonic. Because of the circulating beam, any frequency interval of $[h/2 \cdot f_R = 250\,MHz]$ contains full information of the beam‘s behaviour (Figure 4). Depending on the properties of our setup we chose the interval to be $500 - 750\,MHz$. A frequency resolution of at least $5\,kHz$ is required for a proper detection of the Delta synchrotron frequency sidebands ($f_S \approx 16 - 20\,kHz$).

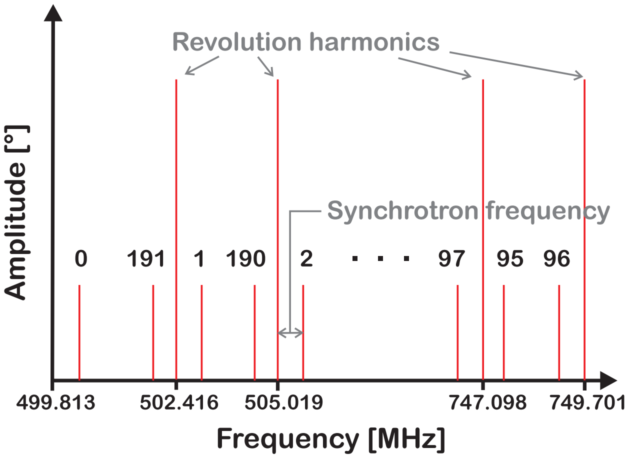


Figure 4: Sketch of CBM-identification in an evenly filled storage ring. In a span between 500 and $750\,MHz$ the revolution harmonics will be detected and the excited CBMs analysed.

The ADC records 700 revolutions in Delta to obtain a frequency resolution Δf:

$$\Delta f = \frac{f_R}{\#electron\ revolutions} = 3.72\,kHz \qquad (2)$$

After applying a fourier transformation the power spectrum of the beam is scanned for synchrotron sidebands of revolution harmonics [5]. Due to noise in the power spectrum close to $500\,MHz$, CBMs $0-5$ and $186-191$ can not be correctly detected up to now.

The amplitudes of the sidebands are displayed on a separate Tcl/Tk surface (see Figure 5).

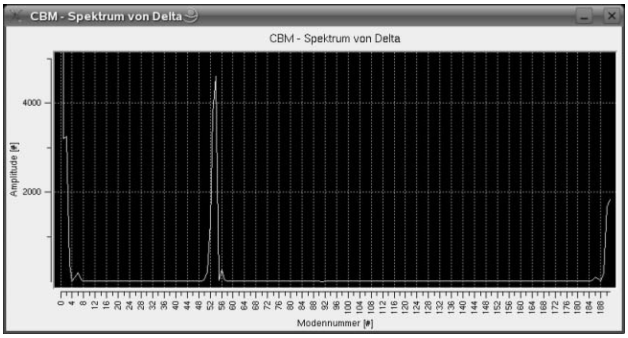


Figure 5: CBM spectrum at 3/4 filling of the storage ring with 120 mA beam current (see Figure 3). The hint of excited modes at the beginning and the end of the spectrum are generated by the noise dominating the first five harmonics. The excitation at mode 54 is a longitudinal excited CBM [7].

During operation we have observed periodically modulated filling patterns after a partial beam loss (see Figure 6). These loss can, in a post-mortem analysis for the filling pattern, be traced back via FFT techniques (amplitude modulation) to a coupled bunch mode instability. The power spectrum is comparable to results of a CBM spectrum measured with a different method [5] before the partial beam loss.

CONCLUSION

A low-cost filling pattern measurement for the Delta storage ring has been set up and commissioned. The filling pattern can now be safely detected with a threshold of approx. $40\,pC$ bunch charge on a bunch by bunch basis. Furthermore the setup allows a continuous monitoring of CBM beam instabilities. The setup has been benchmarked against [5]. Although sensitivity and the signal to noise ratio are lower, the advantages of this method is its short measurement period of approx. $2\,s$. Optimized FFT-techniques and a faster CPU are necessary to lower the measurement period below $1\,s$. Furthermore we plan to increase the resolution of the frequency spectrum to detect synchrotron sidebands around the accelerator RF and the first five harmonics. This setup will be used also as the standard CBM instability monitor at DELTA, allowing a fast detection of CBMs for better machine operation and control. A similar diagnostic instrument as for Delta was developed for the booster synchrotron BoDo and is being commissioned. The combination of both instruments will be used for an optimization of the injection into Delta.

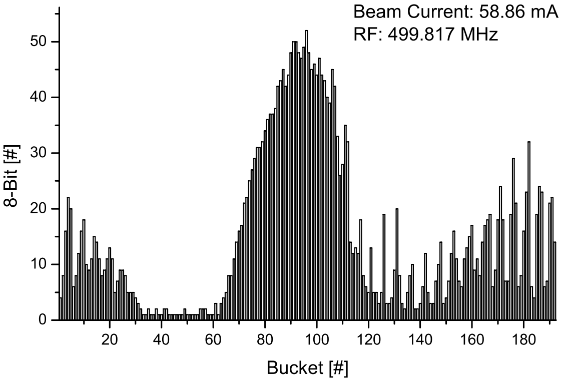


Figure 6: Filling pattern after partial beam loss of $15\,mA$. The period of the maxima is on the average 6 buckets.

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