BASEBAND TUNE MEASUREMENTS AT GSI SIS-18 USING DIRECT DIGITIZED BPM SIGNALS*

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Abstract

A precise tune determination is crucial for stable operation of GSI SIS 18 synchrotron especially for intense beam conditions. In order to avoid nearby resonances in the tune diagram the fractional part of coherent betatron motion needs to be measured with a resolution of 10^{-3} also during ramping mode. This is achieved using a fast digital readout system for Beam Position Monitors (BPM) which delivers a bunch-by-bunch position. The tune is then determined in baseband directly by Fourier-transformation of the positions of a certain bunch typically over 2048 turns. This algorithm does not require any additional input parameter. Since particle losses due to emittance blow-up have to be avoided, excitation power has to be kept as low as possible. In order to find a working range where tune measurement can be implemented in normal machine operation without disturbing the beam several series of measurement have been performed using a digital random noise generator for beam excitation and an Ionization Profile Monitor for displaying alterations of beam profile.

SYSTEM OVERVIEW

The new data acquisition system for BPMs based on fast and direct signal digitization followed by digital signal processing offers a sensitive method for tune measurement [1, 2, 3]. By using the integrated bunch-by-bunch position information the coherent betatron motion can be extracted in baseband without external parameters. Such frequency spectrum is expressed in units of q and ranges from $0 < \mathrm{q} < 0.5$. The GSI heavy ion synchrotron has some particular machine parameters, namely the comparatively long bunches, the injection at non-relativistic velocity β = 15,5% and the acceleration frequency ramping from 0.8 to 5 MHz. The new method acts as a low pass filter with dynamically adapted filter bandwidth. Therefore it offers a high flexibility for the varying beam parameters at SIS 18, which cannot be realized by the sensitive analog baseband-q detection system BBQ [4].

As schematically shown in Fig. 1, the analog single plate BPM signals from all four plates of a shoebox type BPM [5] are fed to a high impedance amplifier and digitized. The digitization of the broadband BPM signal is performed using a sampling rate of 125 MSa/s which corresponds to a range of 18 to 140 Sa per bunch for SIS 18 typical beam parameters, depending on the revolution frequency. The signal is integrated bunch-by-bunch which minimizes thermal and digitization noise and the beam position is calculated.

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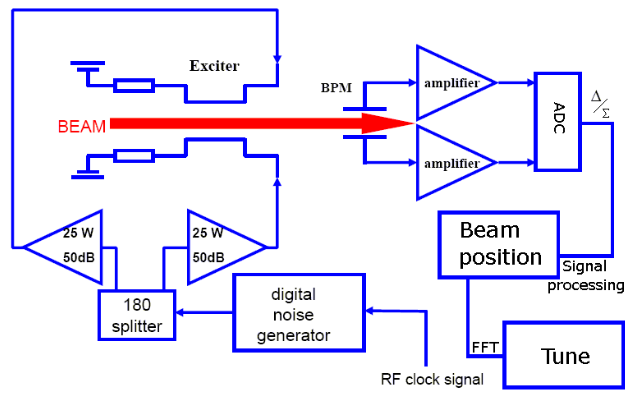

Figure 1: System schematics. The Beam Position Monitor is read out using a fast ADC. A white noise generator with limited bandwidth is connected to an exciter.

The position processing algorithm delivers a single value for vertical and horizontal position for each bunch and thus a certain bunch can be traced digitally. Signal shape and treatment as well as algorithm details for position evaluation have been described earlier [1, 2].

The coherent betatron motion cannot be observed for a stable and well adjusted beam, therefore the beam has to be slightly excited. This excitation is applied using a digital random noise generator connected to an exciter installed at SIS 18 (Fig. 1). It produces white noise with adjustable bandwidth on side bands of a carrier frequency f_c [6]. f_c is set by a frequency tracker connected to the SIS 18 rf signal. The noise bandwidth is set broad enough to cover the range of expected maximum tune deviation, which usually was chosen as $\Delta \mathrm{q} = 0.05$. The noise generator signal is split and each branch is amplified up to a maximal power of 25 W. Both signals are fed to a stripline exciter of 750 mm length and 200x70 mm horizontal/vertical aperture. Two independent exciters are installed at SIS 18 for horizontal and vertical plane respectively.

Excessive excitation of the beam must be avoided to prevent emittance blow-up. The search for a standard working range for tune measurement is subject of the studies presented in this contribution.

TUNE AND BEAM POSITION RESULTS

Detailed measurements have been performed with this system for various beam parameters. In the following we discuss the properties for a typical beam with the following parameters: $6.5 \cdot 10^9 Ar^{18+}$ ions accelerated from 11.4 to 300 MeV/u within 400ms, which corresponds to 220.000 turns. The vertical plane is discussed if not otherwise mentioned. The achieved results serve as a representation for a typical beam response.

Fig. 2 shows an example for the development of tune along the acceleration ramp. Every 2048 turns one value for tune and for beam position are obtained, which gives a repetition rate of more than 100 FFTs per second at SIS 18. Moreover, Fig. 2 shows the system dependency on beam excitation: the excitation level applied to the beam, from which data for the middle graph has been used, is too low in order to safely observe the tune along the whole ramp. As can be seen, the detection interrupts at about 180.000 turns due to a low signal intensity. When the excitation level increases the frequency is detected more precisely due to a better signal to noise ratio over the whole cycle. The preset machine tune for this measurement was 3.23, a mean fractional tune of 0.221 with fluctuations ± 0.005 has been measured. Other comparable results can be found in [7].

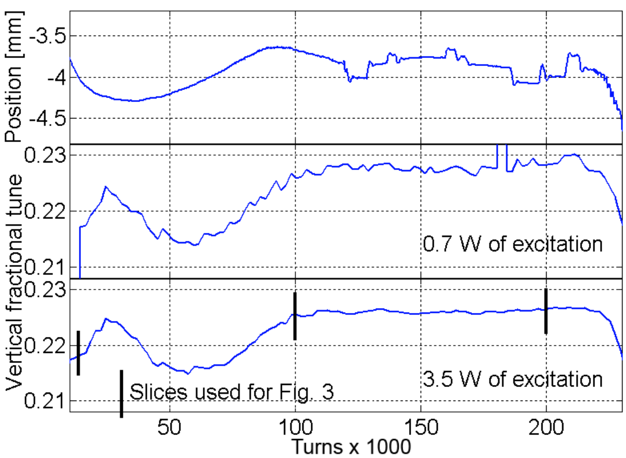

Figure 2: Vertical beam position and fractional tune, see text for beam parameters. Excitation at $q_{ex} = 0.23 \pm 0.05$ with amplitudes of $P_{ex} = 0.7$ W for middle graph and $P_{ex} = 3.5$ W for lower graph.

EXCITER WORKING RANGE

In order to investigate the correct working range for the excitation level, where the tune can be displayed properly without unnecessary emittance blow-up, a series of measurements has been performed. The exciter power was increased from zero to the maximum possible excitation power setting of 50W, which corresponds to a power spectral density (PSD) of 0.72 $\frac{mW}{Hz}$. Other beam conditions were untouched (Fig. 3). Out of the digitally stored position data for these different excitation levels spectra taken over 2048 turns are used.

As expected, an increase in excitation level leads to a linear increase in the tune signal amplitude. Up to a certain threshold for the excitation amplitude the frequency is not tracked safely. On the other hand, above about 10 W of exciter power, a PSD of 0.14 $\frac{mW}{Hz}$, the beam transmission suffers from particle losses.

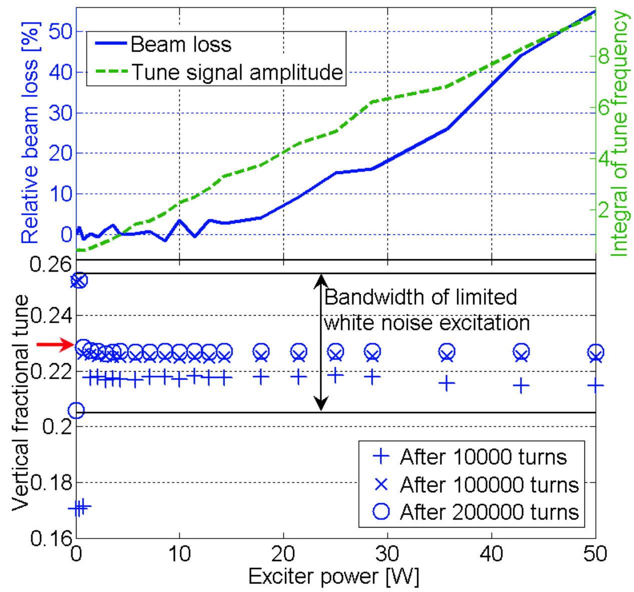

Figure 3: Beam response on noise excitation for dedicated times on ramp. Red arrow in lower part marks the machine preset tune value.

A possible way to mark the begin of the exciter working range is to analyze the variation of the obtained tune frequencies for a certain excitation amplitude. If the PSD is not large enough, noise dominates the spectrum and the result fluctuates statistically. Fig. 4 identifies the beginning of the working range. Each point represents the momentum value of 50 tune frequency spectra measured for each respective exciter amplitude setting. As the standard deviation of each value in the working range is typically close to its mean value, which is 0.0019 for this example, a small tolerance limit of $\Delta\sigma = 4 \cdot 10^{-4}$ can be found. This is the decisive parameter which defines the minimum excitation power to about 2 W, which equals to a PSD of 0.029 $\frac{mW}{Hz}$. The typical system resolution within the working range based on several measured machine tune spectra is better than $\Delta q = 2 \cdot 10^{-3}$, including machine fluctuations.

It is of interest whether beam excitation leads to an emittance blow-up, which has to be avoided. An Ionization Profile Monitor (IPM) installed at SIS 18 [8] has been used to observe the effect of beam profile broadening by monitoring one profile for both horizontal and vertical plane every 10 ms. By observing the profile alteration of several consecutive profiles of an excited beam, the difference between excited beam profiles and those taken from a non-excited beam can be compared. As shown in Fig. 5, the beam profiles show a broadening only for high excitation levels.

Again a series of measurements has been analyzed in order to find a range, where tune measurement is possible but no profile alteration can be measured. The broadening of the beam profile can be expressed by measuring its alteration of the standard deviation σ compared to a non-excited one. For this purpose profiles at the end of the ramp are taken and averaged over 20 cycles, leading to an error

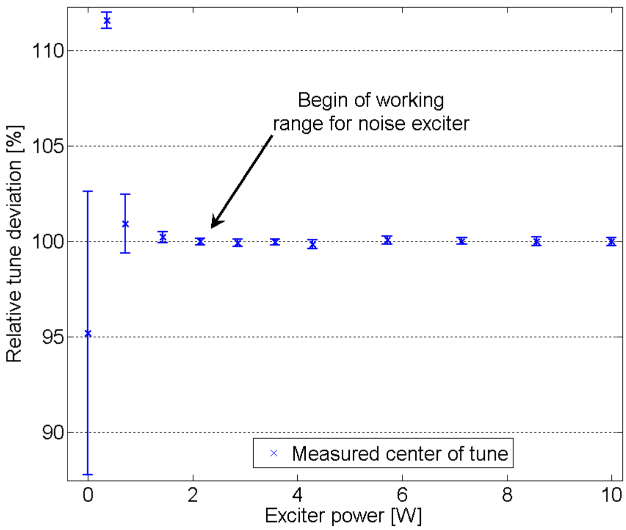

Figure 4: Points represent the mean value of 50 tune spectra with equal time offset to ramp start. Due to the fluctuations of obtained tune at low excitation the exciter power needed for the working range can be defined.

level below 5 %. As can be seen in Fig. 6 no effect on beam profiles at all could be detected for excitation levels below 8.5 W (PSD $= 0.12\frac{mW}{Hz}$). If the excitation level is increased, the profiles start to broaden and above 10 W of excitation power beam losses occur, as depicted in Fig. 3. Thus we have shown, that the working range for stable tune measurement without emittance blow-up is below 10 W, which gives a satisfying range. Fig. 6 shows in addition horizontal profile broadening. For higher excitation levels a slight width increase is visible, which serves as a sensitive method for measuring the horizontal-vertical tune coupling strength; further investigations are necessary.

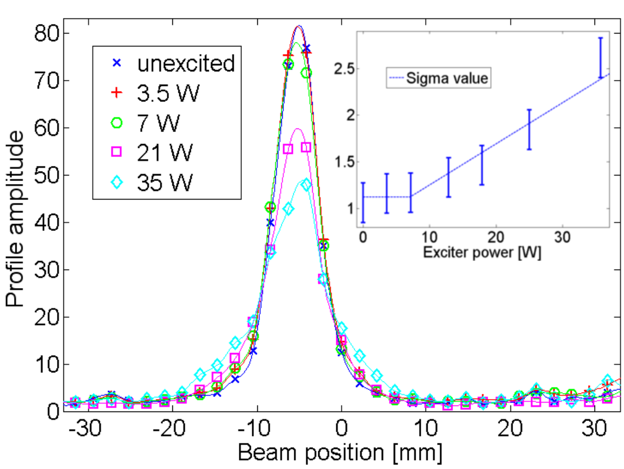

Figure 5: Vertical beam profiles of Ar^{18+}-beam measured by an IPM. Profile alteration by increasing exciter power is shown.

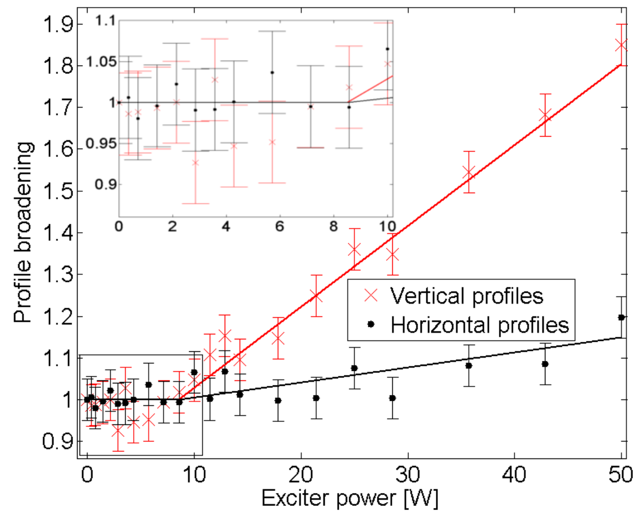

Figure 6: The increase of the standard deviation of beam profiles is shown as a function of exciter power. Points represent a mean value of 200 beam profiles of IPM, recorded at the end of the ramp.

CONCLUSIONS

The baseband digitization of BPM signals together with limited white noise excitation of the beam allows precise tune determination on the synchrotron ramp. The measurements yield reproducible results on a low excitation level using a PSD of below 0.1 $\frac{mW}{Hz}$, thus defining the right working range for tune measurements and preventing detrimental emittance blow-up. Displaying the measured machine tune with a resolution of $\Delta q < 2 \cdot 10^{-3}$ next to a precise beam position with a resolution below 30 μm [1, 3] gives a powerful tool for machine operation. Therefore, the presented system is a promising prototype for tune measurements at FAIR and is actually being implemented at SIS 18.

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