TUNE MEASUREMENTS WITH HIGH INTENSITY BEAMS AT SIS-18*

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Abstract

To achieve a high current operation close to the space charge limit, a precise tune measurement and correction during a full accelerating cycle is required. A tune measurement system has been commissioned at the GSI synchrotron SIS-18, which allows evaluation of tune using digital position data throughout the acceleration cycle. Tune measurements were conducted using this system at injection plateau and accelerating ramp using a high intensity $^{40}_{18}\mathrm{Ar}^{18+}$ ion beam with stored number of particles ranging from $2 \cdot 10^9$ to $2.5 \cdot 10^{10}$.

INTRODUCTION

High current operation at injection energies in hadron accelerators lead to large tune shifts which can result in emittance blow up or loss of particles due to resonance crossings. Emittance blow up is undesirable for precise measurements in storage rings or accelerators, thus it is required to station the tune (Working Point) at an appropriate location in resonance diagram.

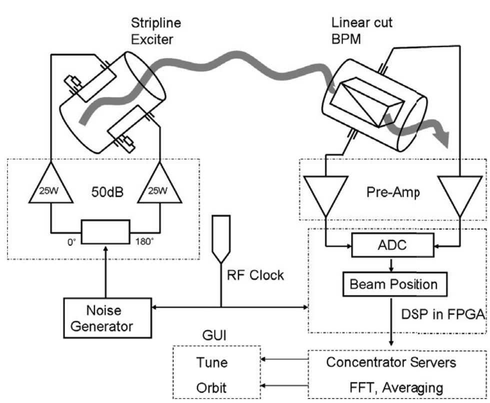

Figure 1: TOPOS: Tune, Position and Orbit measurement system.

A new system has been commisioned at GSI for position, orbit and tune measurements. It consists of three distinct parts; An exciter which provides power to excite coherent betatron oscillations in the bunched beam; Fast ADCs digitize the BPM signals at 125MSa/s; The post processing electronics integrate the data bunchwise to acquire one position value per bunch. Subsequently the baseband tune is determined by Fourier transformation of the position data. One tune value can be calculated typically from 256 turns to 4096 turns depending on the investigation needs. The objective of this work is to observe the tune spectra at injection plateau and on acceleration ramp operations at high beam intensity.

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METHODS

This section highlights the working of the tune measurement system as a whole, and explains the types of beam excitation used and the experimental conditions.

TOPOS: Tune Orbit Position Measurement System

TOPOS is the tune, orbit and position measurement system established in SIS-18 at GSI [1]. Figure 1 gives an overview of the fragment of TOPOS used for tune measurement.

Particles revolve in an accelerator with unrelated phases due to finite momentum spread commonly referred to as Landau ”damping”, and thus the barycentre of a bunch of particles does not provide any information on the transverse movement of the particle bunches i.e tune. Thus the beam needs to be excited to make the motion of particles coherent, and capture the their transverse movements for tune measurement. Excitation can be provided in many ways; either using a single kick, chirp noise, white noise or band limited noise. We employed single kick and band limited noise for the excitation during these experiments. The beam excitation signal is fed to the exciter through a fixed gain 50dB amplifier. Following which the beam signals are measured by a shoe-box type pick-up [2] in both horizontal and vertical planes. These signals are digitized for both planes and processed in an FPGA in real time to get one position data per bunch per plane using an algorithm described in [3]. The position data is transferred to concentrator servers where FFT is performed resulting in a tune spectra to be displayed in the main control room. The measurement system should be reasonably fast giving a tune value every 500-1000 turns to cater the need for a future feed-back tune control system. More details on the system can be found in [4].

Beam Excitation

If the tune measurement system has to be used during normal machine operation, the ideal beam excitation should satisfy the following conditions. First, it should not disturb the beam parameters like emittance and lifetime above given thresholds while giving atleast 6dB Signal to noise ratio (SNR) in tune spectra under all operating conditions. Second, it should allow continual monitoring of the tune during the whole acceleration cycle. Single kicker or Q-Kicker has been historically used at GSI SIS-18 for tune measurements. It can be fired only once in an acceleration cycle and thus cannot be used for the tune measurement during the whole cycle since the beam is Landau detuned after certain number of turns. So it does not satisfy the conditions for ideal beam excitation. More recent excitation method is white noise or band limited noise excitation, in which low continous power is transferred to the beam [5]. The excitation power required in this method for getting 6dB SNR varies depending on the beam rigidity, beam intensity, machine settings etc. and there is no single minimum value for all operating conditions. However, it causes minimal disturbance to the beam and can be used throughout the ramp for continous monitoring of the tune [6, 4]. As shown in Fig. 2, the noise excitation (1mW/Hz) results in small increase in beam position envelope while the single kick (20KV, 1.5μs pulse) deflection of the particles in much larger, which could trigger particle losses.

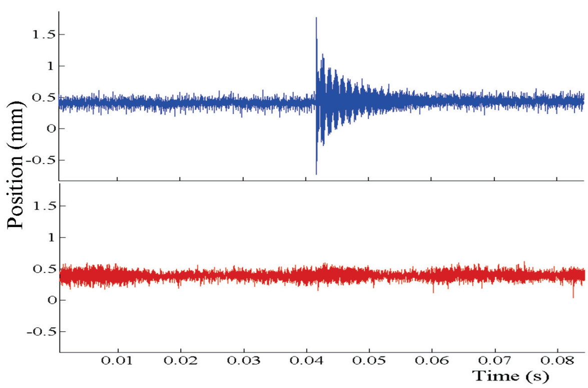

Figure 2: Vertical position after single kick vs white noise excitation.

Experimental Conditions

The experiment were done in two phases using Ar^{18+} beam. First phase was done at 11.4 MeV/u on injection plateau. The beam was injected, adiabatically bunched and kept for 600ms while continously monitoring the tune. The measurements were repeated at decreasing intensities of stored ions from $\mathbf{2.5 \cdot 10^{10}}$ - $\mathbf{2 \cdot 10^{9}}$ to observe the effect of beam intensity on the tune spectrum. Second phase was done on the accelerating ramp with energy increasing from 11.4 MeV to 600 MeV at two levels of stored particles $\mathbf{2 \cdot 10^{10}}$ and $\mathbf{1 \cdot 10^{10}}$. The movement of tune during the ramp was observed. During the whole experiment, several measurements were done with different levels of noise excitation power ranging from 0.01-3 mW/Hz in both planes.

RESULTS AND DISCUSSION

In this section the tune measurements at injection and acceleration ramps are presented. The FFT size should be chosen carefully while evaluating tune at injection plateau or at during ramp. During acceleration cycles tune frequency is rapidly changing along with revolution frequency, which calls for smaller FFT sizes. Tune spectra with longer FFT window size allow better frequency resolution, while shorter FFTs allow more averaging for same number of data values to reduce the noise floor.

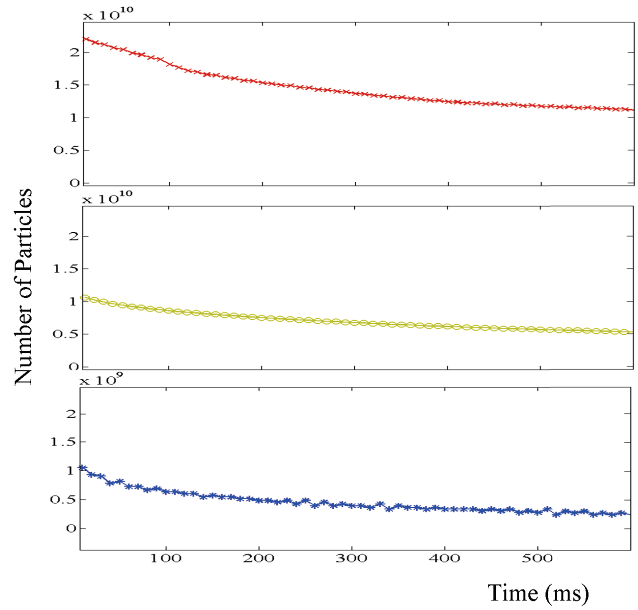

Figure 3: Various levels of stored particles for the tune measurements at injection plateau.

Tune Measurements on Injection

The tune evaluations are done immediately after the beginning of adiabatic bunching for a period of 600 ms . Figure 3 shows different current levels ranging from $\mathbf{2 \cdot 10^{9}}$ to $\mathbf{2.5 \cdot 10^{10}}$ at which measurements were done. The transverse beam size is approximately twice the vertical beam size for normal operation at GSI. In vertical plane we see a tune shift due to longitudinal focussing during bunch forming, and further we see the tune moving back to set value with the reducing beam current as shown in Fig. 4. In the horizontal plane, this effect is not visible since the transverse size of beam is large and hence the space charge effects are smaller. This can be seen in Fig. 5. These measurements are independent of excitation levels as long as beam excitation does not cause significant particle losses[7].

Tune Measurements on Accelerating Ramp

The tune measurements are started immediately after the beginning of ramp and continued throughout the ramp in

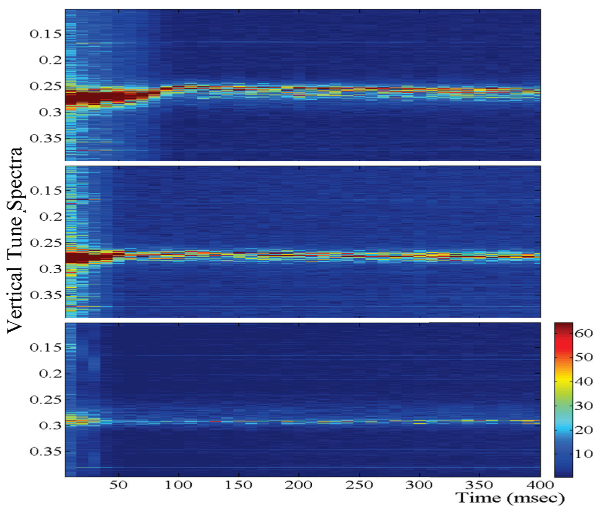

Figure 4: Vertical tune measurements at injection energy of 11.4 MeV/u. At number of injected particles $\mathbf{2.5 \cdot 10^{10}}$ (Top), $\mathbf{1 \cdot 10^{10}}$(Middle), $\mathbf{2 \cdot 10^{9}}$(Bottom).

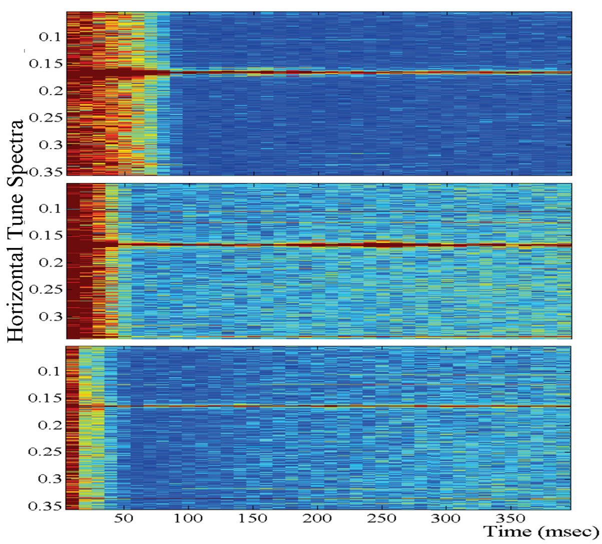

Figure 5: Horizontal tune measurements at injection energy of 11.4 MeV/u. At number of injected particles $\mathbf{2.5 \cdot 10^{10}}$(Top), $\mathbf{1 \cdot 10^{10}}$(Middle), $\mathbf{2 \cdot 10^{9}}$(Bottom).

both horizontal and vertical planes. We see S-shaped tune movements along the ramp in both the planes for both current levels as shown in Fig. 6 and Fig. 7. These movements have been observed earlier also[3] and are attributed to shift from doublet to triplet focussing during the ramp. The difference in the tune spectrum between low current and high current case is seen in the beginning of the ramp which can be understood as coherent tune shift[8].

SUMMARY AND OUTLOOK

Precise tune measurements with high intensity Ar^{18+} were done at the injection plateau and acceleration ramp. At higher currents and low energies, tune shift was expectedly observed at injection plateau and beginning of acceleration ramps. This experiment proves the usability of the new tune and orbit measurement system built at GSI for accelerator and beam physics experiments.

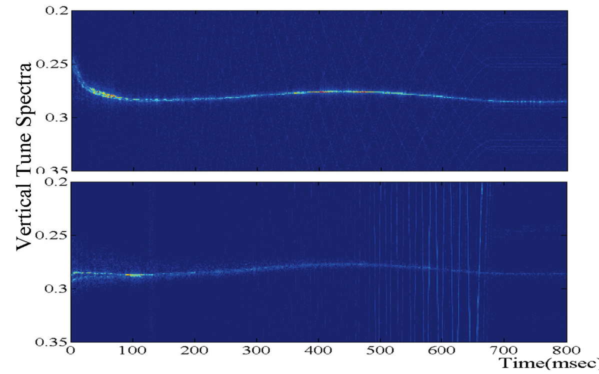

Figure 6: Vertical tune measurements at accelerating ramp from 11.4 - 600 MeV/u. At number of injected particles $\mathbf{2 \cdot 10^{10}}$ (Top), $\mathbf{1 \cdot 10^{10}}$(Bottom).

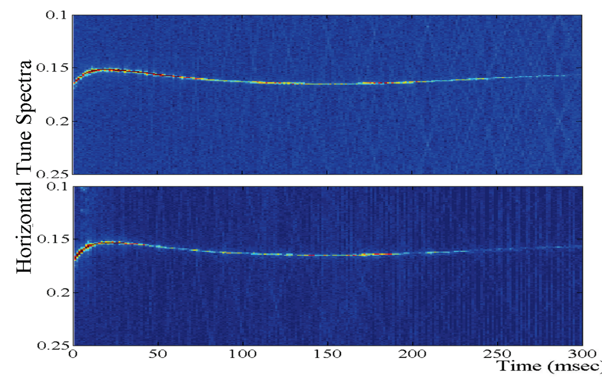

Figure 7: Horizontal tune measurements at accelerating ramp from 11.4 - 600 MeV/u. At number of injected particles $\mathbf{2 \cdot 10^{10}}$(Top), $\mathbf{1 \cdot 10^{10}}$ (Bottom).

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