HIGH INTENSITY EFFECTS ON BETATRON TUNE AT GSI SIS-18 *

R. Singh, GSI, Darmstadt, Germany and TEMF, Technische Universität Darmstadt, Germany O. Chorniy, P. Forck, R. Haseitl, W. Kaufmann, P. Kowina, K. Lang, GSI, Darmstadt, Germany T. Weiland, TEMF, Technische Universität Darmstadt, Germany

Abstract

There are two tune measurement systems called TOPOS and BBQ under parallel operation at GSI synchrotron SIS-18. Several tune measurement campaigns were performed with U^{73+} and Ar^{18+} ion beams at various intensity levels. The primary goal of these investigations is to observe and understand the high intensity effects on the tune spectra. Additionally, beam was excited with several excitation types with varying power to find the reliable regime for continuous tune monitoring. This contribution reports the present status of the tune measurement systems, modified tune spectra at high intensities, and the corresponding space charge effects.

INTRODUCTION

Betatron tune measurements are an integral part of the beam diagnosis for all circular accelerators and storage rings. The primary methods for tune measurement fall under either of the two categories, i.e., excitation based tune measurements or transverse schottky noise analysis [1]. Suitability of a particular method is determined by various factors, like specifications on storage time, measurement speed and "destructiveness" of the method. This contribution focuses only on the excitation based methods for tune measurement at GSI heavy ion synchrotron SIS-18, while the Schottky based measurements have been explained in ref.[2]. Several excitation types were tested in the procedure of commisioning the tune measurement system for normal operations. There are currently two distinct parallel tune measurement systems installed at GSI, namely the Tune, Orbit and Position measurement system (TOPOS) and Baseband Q measurement system (BBQ). The TOPOS system is primarily a digital position measurement system and also calculates tune from the calculated position if sufficient coherent beam excitation is provided. Whereas, the BBQ system performs tune measurement based on the concept of diode based bunch envelope detection concieved at CERN [3]. The first part of this paper compares the characteristics of two installations as well as the various excitation methods. The second part presents the selected tune measurements done at various beam conditions and beam excitation types. The subject of beam environment interaction, e.g., Laslett tune shifts [4] and head tail oscillations [5] at high intensities based on experimental observations is also highlighted.

METHODS

This section presents the types of beam excitation used in the measurements. The beam excitation method is common to both TOPOS and BBQ systems. A brief description of both the tune measurement systems and the experimental conditions is given.

Beam Excitation Methods

The electronics used for beam excitation consist of a signal generator connected to two 25 W amplifiers which feed power to 50Ω terminated stripline exciters as shown in Fig.1. Excitation types such as band limited noise and frequency sweep are utilized at various power levels to induce coherent oscillations.

Band limited noise: Band limited noise also called RF Knock-out is a traditionally used system for slow extraction at GSI SIS-18. The generation of this signal is done in the following way; RF is mixed with DDS generated fractional tune frequency, resulting in RF harmonics and their respective tune sidebands. This signal is further modulated by a pseudo random sequence resulting in a band limited noise source around the tune frequency. The main advantages of this system is an easily tunable noise source available during the whole acceleration ramp and the band limited nature of the resulting noise which results in efficient excitation of the beam. The main disadvantage is the difficulty in correlation of the resultant tune spectrum with the excitation signal.

Frequency sweep: Frequency sweep using a network analyzer for BTF measurements is commonplace. However, tune measurements during acceleration are not trivial using this method, and thus it is not suitable for tune measurements during the whole ramp cycle. This method offers advantages compared to the previous method for careful interpretation of tune spectrum in storage mode,e.g., injection plateau or extraction flat top. Frequency sweep is used during measurements at injection plateau to compare and to understand the output of noise excitation type.

TOPOS

Following the beam excitation, the signals from each of the 12 shoe-box type BPMs at SIS-18 pass through a high dynamic range (90 dB) and broadband (100 MHz) amplifier chain from the tunnel to the electronics room, where the signals are digitized using fast 14 bit ADCs at 125 MSa/s. Bunch-by-bunch position is calculated from these signals

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using FPGAs in real time, and displayed in the control room. Tune is measured by calculating FFT of the position data. Bunch-by-bunch position resolution is ≈ 1 mm. Hence, TOPOS is a versatile system which provides accurate bunch-by-bunch position, tune, longitudinal beam profile as well as beam intensity information. Further details can be found in ref.[6].



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

BBO

The BBQ front end system is divided into two distinct parts; a diode based envelope detectors and an analog signal processing chain consisting of input differential amplifier, and a variable gain signal chain of 1 MHz bandwidth. The simple schematic of BBQ system configuration at SIS-18 is shown in Fig. 2 and the detailed principle of operation can be found in ref. [3].



Figure 2: BBQ: Baseband Q measurement system. Diode detectors (top) and signal chain (bottom).

TOPOS vs. BBQ

Assuming same pick-up, pre-amplifier noise and digitizers, the main difference in the BBQ and TOPOS system is the noise filtering. In BBQ, after bunch envelope detection, the signal chain has a high-order low-pass filter response

with cut-off at 1 MHz. In TOPOS, the whole bunch signal traverses the wideband amplifier chain and each bunch is integrated to determine position. Integration serves as a first order low pass filter whose response is defined by the number of samples integrated per bunch (in the range of 10-80). This difference results in higher sensitivity of BBQ \approx 10-15 dB compared to TOPOS in the present configuration. The second major difference comes from the digitizers. TOPOS uses fast 14 bit ADCs and only few bits out of its full range record differential tune signal. Whereas the BBO measures only slowly varying differential signal which allows usage of full range of (slow) higher resolution ADCs. Tune measurement with unbunched beams has also been performed with BBQ at injection.

Experimental Conditions

Experiments were done using U^{73+} and Ar^{18+} beam at 11.4 MeV on injection flat top for 600 ms since space charge effects are most dominant at low energies. The bunches from the injected particles were formed using slow RF amplitude ramps (adiabatic bunching). The experiment was repeated at various beam intensity levels. At each intensity level, several measurements were done with different types and levels of beam excitation in both planes. Tune measurement was done simulataneously using TOPOS and BBQ systems. The beam current and transverse beam profile is measured using beam current transformer and ionization profile monitor respectively [7].



Figure 3: Output of the BBQ system in horizontal plane for frequency sweep (left) vs. band limited noise excitation (right) at $5 \cdot 10^8 \text{ U}^{73+}$ ions. Tune is set to 65.6 KHz (0.315).

RESULTS AND DISCUSSION

This section presents some of the important results from the various experiments involving tune measurements.

Frequency Sweep vs. Band Limited Noise

Figure 3 shows the baseband BBQ tune spectra for frequency sweep and band limited noise for exactly the same intensity and accelerator settings. The measured tune value is found to be independent of the type of excitation. Small "residual" betatron oscillations are visible without any excitation as shown in the left figure.

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Laslett Tune Shifts

At high currents, there is a coherent tune shift due to beam environment interaction.

$$\delta Q_{coh} = \frac{\pi^2 r_0 IR < \beta_y >}{8ec\beta^3 \gamma h^2} \tag{1}$$

Eq. (1) gives an estimate coherent tune shift for theoretical KV beams. Tune shift is proportional to beam intensity (I) and inversely proportional to square of radii of vacuum chamber walls (h). The tune spectra for two beam intensities are depicted in Fig. 4. These tune shifts if uncompensated could lead to crossing of resonances resulting in beam blow-up.



Figure 4: Vertical tune spectrum using 1024 position points of an individual bunch for Ar^{18+} ions at injection plateau excited by band limited noise. The set tune, coherent tune shift and spacing between the "tune" peaks are indicated.

Head Tail Oscillations

Head tail transverse instabilities are well known in literature [5]. There are two separate mechanisms causing these oscillations classified as strong head tail instability (TMCI) and chromaticity driven head tail instability. The former is a resonance type phenomenon driven by transverse impedance and leads to fast particle losses above a certain threshold. Later is a non-resonance phenomenon and can occur at much lower intensities at unfavourable chromaticity values. Even though these are mostly studied for avoiding instabilities; below a certain threshold and under stable machine conditions, it is possible to excite these oscillations and learn about the machine parameters like transverse impedances, chromaticity and instability thresholds which are difficult to estimate otherwise. These type of oscillations have been observed several times during our tune measurements especially at high intensities. Figure 4 shows two such spectra with Ar^{18+} ions excited by 1 mW/Hz band limited noise excitation at different instensity levels. Figure 5 shows clean head tail oscillations by plotting difference bunch profiles overlapped on each other over few turns.

SUMMARY AND OUTLOOK

The present status of both the tune measurement systems at GSI SIS-18 is presented. Despite using different measurement principles, the tune measurents from both sys-



Figure 5: Difference of BPM data for the same bunch plotted over 13 consecutive turns (top) and 100 turns later (bottom). Colours are randomly chosen to enhance clarity.

tems agree for both excitation types. This proves the reliability of both the systems. When applying the frequency sweep, the measured tune spectra has a well-defined and relatively broad form. As a subject of future work, this form can potentially be correlated with some beam and machine parameters. As a second direction, the technique of excitation of head tail oscillations can be improved and its possible usage at SIS-18 has to be investigated.

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