

## Determination of coherent and incoherent tune shifts at SIS-18\*

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### Introduction

Currently two systems for tune measurements are under operation in SIS-18 i.e. TOPOS and BBQ [1]. We present the measurement of coherent and incoherent tune shifts by evaluating relative spectral positions of various head tail modes in the tune spectra as a function of beam intensity.

### Experiments and Results

At high beam intensities, the transverse space charge force together with the coherent force caused by the beam pipe impedance affects the motion of the beam particles and modifies the tune spectrum. The space charge force induces an incoherent tune shift  $\Delta Q_{sc}$  which can be expressed for a symmetric beam profile of homogeneous density as

$$\Delta Q_{sc} = \frac{qI_p R}{4\pi\epsilon_0 c E_0 \gamma_0^2 \beta_0^3 \epsilon_x} \quad (1)$$

. Here  $I_p$  is the peak bunch current,  $q$  the particle charge and  $E_0 = \gamma_0 m c^2$  the total energy. The relativistic parameters are  $\gamma_0$  and  $\beta_0$ , the ring radius is  $R$  and the emittance of the rms equivalent K-V distribution is  $\epsilon_x$ . The image currents and image charges induced in the beam pipe, assumed here to be perfectly conducting, cause a real coherent tune shift

$$\Delta Q_c = -i \frac{qI_p R^2 Z_x}{2Q_{x0} \beta_0 E_0} \quad (2)$$

where  $Z_x$  is the purely imaginary horizontal impedance. For the vertical plane the procedure is the same, with  $x$  replaced by  $y$  in Eq. 1 and Eq. 2. In the presence of incoherent space charge, given by  $\Delta Q_{sc}$ , or pipe effects, given by  $\Delta Q_c$ , the shift of the synchrotron satellites in bunches can be reproduced rather well by [2],

$$\Delta Q_k = -\frac{\Delta Q_{sc} + \Delta Q_c}{2} \pm \sqrt{(\Delta Q_{sc} - \Delta Q_c)^2/4 + (kQ_s)^2} \quad (3)$$

where  $Q_s$  is the synchrotron tune and  $k$  is the mode number.

Experiments were conducted to understand the effects of high beam intensity on tune spectra at injection plateau of 11.4 MeV/u with  $U^{73+}$  and  $N^{7+}$  bunched ion beams up to  $2 \cdot 10^9$  and  $1.5 \cdot 10^{10}$  particles, respectively. Fig. 1 shows the tune spectrum obtained in horizontal plane at three different intensities with the same machine settings. The shift of head tail modes  $\Delta Q_k$  with respect to beam intensity when fitted in the analytical predictions of Eq. 3 gives a

\* This work is supported by DITANET (novel Diagnostic Techniques for future particle Accelerators: A Marie Curie Initial Training Network), Project Number ITN-2008-215080

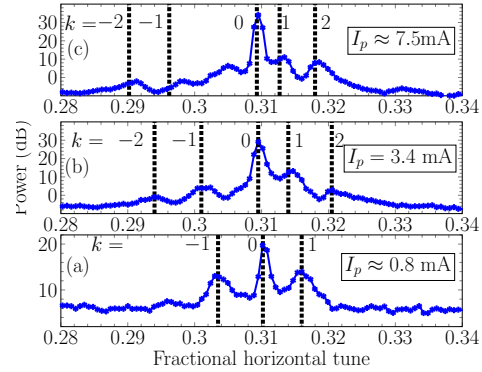


Figure 1: Horizontal tune spectra for  $U^{73+}$  ions (see text). The dashed lines indicate the head-tail tune shifts from Eq. 3.

direct measurement of incoherent tune shifts  $\Delta Q_{sc}$ . The coherent tune shift  $\Delta Q_c$  can be obtained by measuring shift of the  $k = 0$  line as a function of the peak bunch current as shown in Fig. 2. The transverse impedance is thus obtained by a linear regression fit of the measured shifts in both planes to Eq. 2, i.e.  $Z_x \approx -i(0.23 \pm 0.04) \text{ M}\Omega/\text{m}^2$  and  $Z_y \approx -i(1.78 \pm 0.04) \text{ M}\Omega/\text{m}^2$ . These values corresponds to the average beam pipe radii of the SIS-18 of  $104 \pm 6.5 \text{ mm}$  and  $37 \pm 0.9 \text{ mm}$  which closely match with expected values.

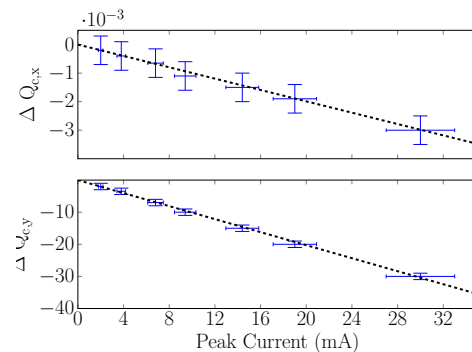


Figure 2: Coherent tune shift obtained from the measurement for the horizontal and for the vertical planes as a function of the peak beam current.

### References

- [1] R. Singh et al., "Interpretation of transverse tune spectra in a heavy-ion synchrotron at high intensities", Accepted for publication in Phys. Rev. ST Accel. Beams, Feb. 2012.
- [2] O. Boine-Frankenheim et al., Phys. Rev. ST Accel. Beams, **12**, 114201 (2009)