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 ΔQ_{sc} which can be expressed for a symmetric beam profile of homogeneous density as

$$\Delta Q_{sc} = \frac{qI_pR}{4\pi\epsilon_0 cE_0{\gamma_0}^2\beta_0^3\varepsilon_x} \quad (1)$$

. Here I_p is the peak bunch current, q the particle charge and $E_0 = \gamma_0 mc^2$ the total energy. The relativistic parameters are γ_0 and β_0, the ring radius is R and the emittance of the rms equivalent K-V distribution is ε_x. The image currents and image charges induced in the beam pipe, assumed here to be perfectly conducting, cause a real coherent tune shift

$$\Delta Q_c = -i\frac{qI_pR^2Z_x}{2Q_{x0}\beta_0E_0} \quad (2)$$

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 ΔQ_{sc}, or pipe effects, given by ΔQ_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 snychrotron 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 $2\cdot10^9$ and $1.5\cdot10^{10}$ 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 ΔQ_k with respect to beam intensity when fitted in the analytical predictions of Eq. 3 gives a direct measurement of incoherent tune shifts ΔQ_{sc}. The coherent tune shift ΔQ_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. $Z_x \approx -i(0.23 \pm 0.04)$ MΩ/m^2 and $Z_y \approx -i(1.78 \pm 0.04)$ MΩ/m^2. These values corresponds to the average beam pipe radii of the SIS-18 of 104 ± 6.5 mm and 37 ± 0.9 mm which closely match with expected values.

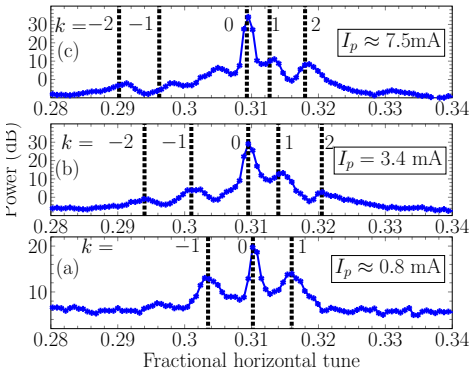

Figure 1: Horizontal tune spectra for U^{73+} ions (see text). The dashed lines indicate the head-tail tune shifts from Eq. 3.

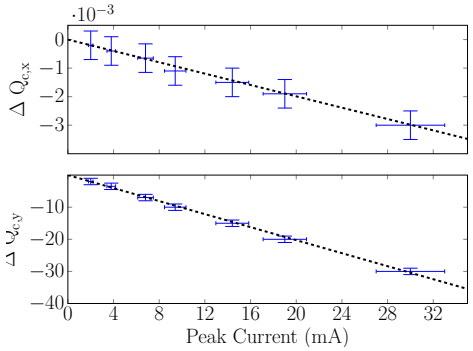

Figure 2: Coherent tune shift obtained from the measurement for the horizontal and for the vertical planes as a function of the peak beam current.

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)

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