Space charge effects on quadrupolar oscillations in SIS-18

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Quadrupolar or beam envelope oscillations give valuable information about the injection matching and the incoherent space charge tune shift. The shift in quadrupolar mode oscillation frequency with respect to beam intensity gives a direct estimate of space charge tune shift. An asymmetric pick-up [1] is installed in SIS-18 to observe the quadrupolar moment oscillations.

Figure 1 shows the quadrupolar pick-up installed in SIS-18 along with an ion beam with horizontal and vertical displacement of $(\bar{x}, \bar{y})$ with respect to pick-up center and transverse dimensions of (σ_x, σ_y) . Let U_R, U_L, U_T and U_B be the voltages induced on right, left, top and bottom electrodes by the beam.

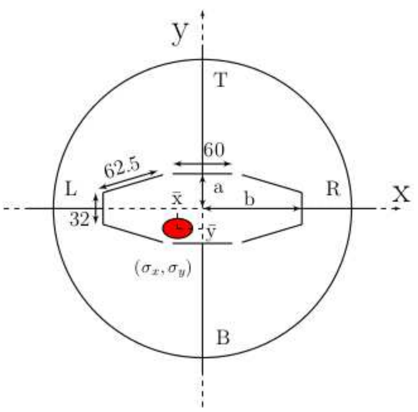

Figure 1: Front view of the pick-up design; a = 35.3 mm, b = 100.3 mm, length of the electrodes in longitudinal plane l = 216 mm. All the lengths are given in mm units.

The electrodes are connected in the "quadrupolar" configuration, i.e. $\Xi_q = (U_R + U_L) - (U_T + U_B)$ such that the quadrupolar moment of the beam $({\sigma_x}^2 - {\sigma_y}^2 + \bar{x}^2 - \bar{y}^2)$ is extracted as the first order signal component.

$$\Xi_q \propto Z \cdot I_{beam} \cdot m \cdot \left({\sigma_x}^2 - {\sigma_y}^2 + \bar{x}^2 - \bar{y}^2\right) \quad (1)$$

where Ξ_q is the quadrupolar signal, Z is the transfer impedance of the pick-up and m is the quadrupolar sensitivity of the pick-up. Z and m are determined by electromagnetic simulations [1].

The frequency of quadrupolar oscillations is directly affected by the incoherent space charge tune shift as discussed in references [2, 3]. For an elliptic beam with a uniform transverse distribution, the space charge dependence of quadrupolar mode frequency is given by,

$$Q_{coh,1,2} = 2Q_{x,y} - (1.5 - 0.5\frac{\bar{\sigma}_{x,y}}{\bar{\sigma}_x + \bar{\sigma}_y})\Delta Q_{sc,x,y} \quad (2)$$

where ΔQ_{sc} is the incoherent tune shift, Q_x, Q_y are the horizontal and vertical tunes and $Q_{coh,1,2}$ represent the normalized quadrupolar mode frequencies. At low intensities, $Q_{coh,1,2}$ is twice the tune frequency $2 * (Q_x, Q_y)$.

Due to the absence of any suitable quadrupolar exciter in SIS-18, quadrupolar oscillations were excited using the injection beta mismatch from UNILAC to SIS-18. The beam conditions were kept similar except the injected beam current was varied from the UNILAC to increase the incoherent tune shift ΔQ_{sc}, while the quadrupolar signal Ξ_q, the mean transverse beam profile over several turns $(\bar{\sigma}_x, \bar{\sigma}_y)$ and the beam current I_{beam} was recorded.

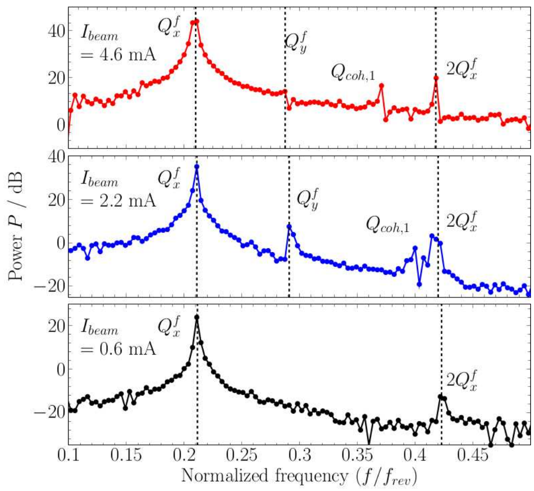

Figure 2: Shift of quadrupolar mode $Q_{coh,1}$ with respect to beam current. Q_x^f denotes the fractional part of Q_x.

Figure 2 shows the quadrupolar signal spectrum at three beam current levels. A strong mismatch was only induced in horizontal plane, and therefore only $Q_{coh,1}$ is visible in the spectrum. There was a clear dependence of $Q_{coh,1}$ on beam current in accordance to Eq. 2, as it moves away from $2Q_x^f$ as the beam current or ΔQ_{sc} is increased. Detailed report on these measurements can be found in [4].

References

[1] J. A. Tsemo Kamga et al., "Calculation of the quadrupole moment ${\sigma_x}^2 - {\sigma_y}^2$ for an asymmetrical Pick-up", GSI scientific report 2013.

[2] W. Hardt, "On the incoherent space charge limit for elliptic beams", CERN/ISR/Int. 300 GS/66.2.

[3] I. Hofmann, "Stability of anisotropic beams with space charge", Physical Review E 57 (4), 4713.

[4] R. Singh et al., "Observations of the quadrupolar oscillations at GSI SIS-18", Proc. of IBIC'14 (2014)

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