Observations of the quadrupolar oscillations at GSI SIS-18*

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Abstract

Quadrupolar or beam envelope oscillations give valuable information about the injection matching and the incoherent space charge tune shift. An asymmetric capacitive pick-up was installed at GSI SIS-18 to measure these oscillations. We present the simulations performed to estimate and compare the sensitivity of the quadrupolar pick-up to the beam quadrupolar moment with respect to other pick-up types installed at SIS-18. Dedicated measurements with high intensity beams are performed at injection where the injection mismatch excites the envelope oscillations. The frequency spectra of the measured quadrupolar signal under various intensities give a direct measure of the space charge tune shift.

Quadrupolar moment and signal

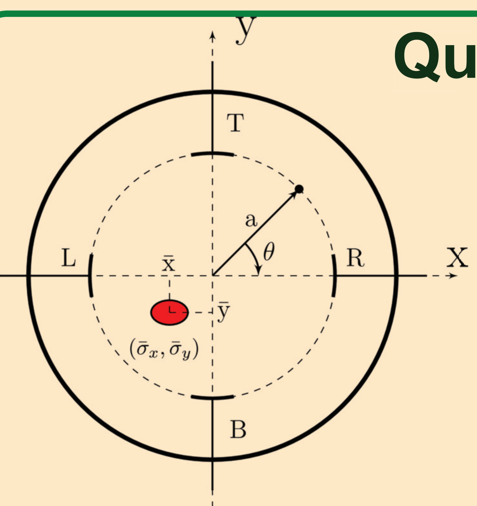


Fig. 1 Symmetric button pick-up for analytical expressions

The image current induced by the beam at the pickup (PU) electrodes are given by [1],

$$J_{image}(a,\theta) = \frac{I_{beam}}{2\pi a}\left\{ \begin{array}{c} 1 + 2\left[\frac{\bar{x}}{a}\cos\theta + \frac{\bar{y}}{a}\sin\theta\right] \\ +2\left[\left(\frac{\bar{\sigma}_x^2 - \bar{\sigma}_y^2 + \bar{x}^2 - \bar{y}^2}{a^2}\right)\cos 2\theta + higher\ order\ terms\right] \end{array}\right\}$$

The second order component which has beam width information is referred to as **quadrupole moment** $\kappa = \bar{\sigma}_x^2 - \bar{\sigma}_y^2 + \bar{x}^2 - \bar{y}^2 \qquad (Eq.1)$

It is obtained by connecting the electrodes, $\Xi = U_R + U_L - U_T - U_B$ and Ξ is referred as the **quadrupolar signal**.

Quadrupolar Pick-up

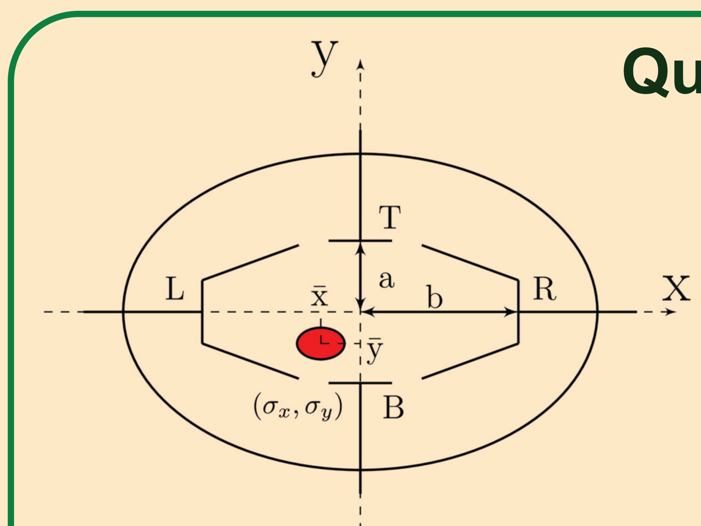


Fig. 2 Asymmetric pick-up used for the experiments.

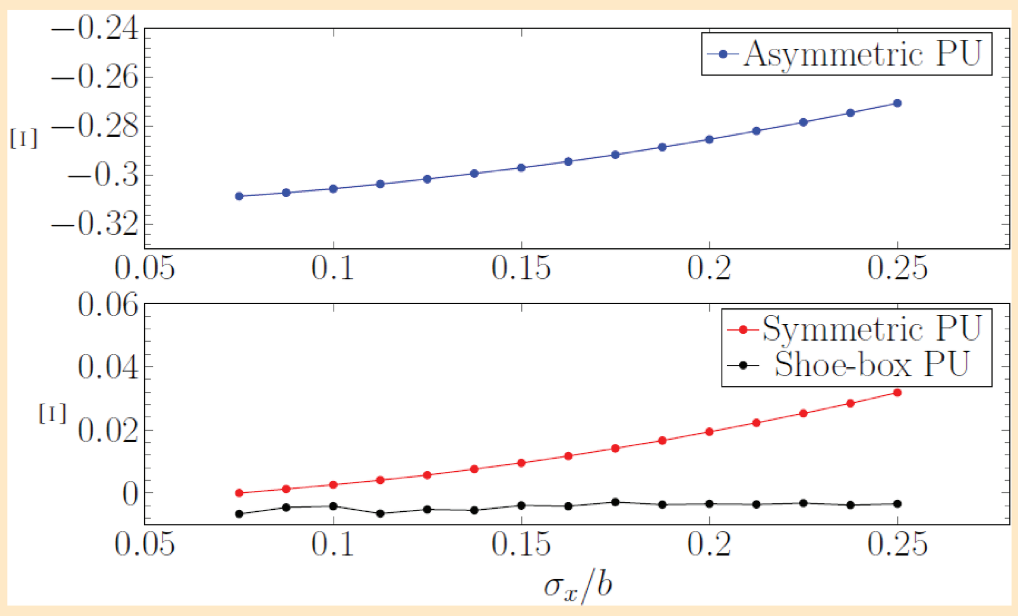


Fig. 4 Comparison of the quadrupolar sensitivity of the pick-ups installed in SIS-18.

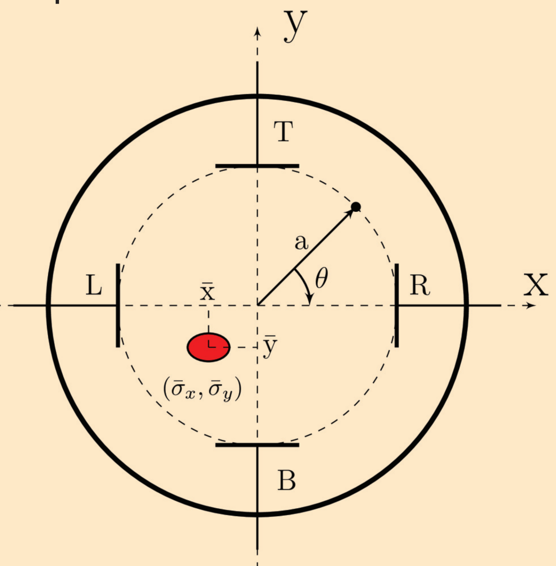


Fig. 3 Symmetric pick-up installed in SIS-18.

- Three pick-ups installed in SIS-18 are simulated for their sensitivity to quadrupolar signals. The aysmmetric pick-up (Fig. 2), symmetric pick-up (Fig. 3) and shoe-box pick-up [not shown]
- The simulation is performed electrostatically assuming long bunches compared to pick-ups as is the case at SIS-18.
- The best pick-up in terms of sensitivity and transfer impedance is the asymmetric pick-up (Fig. 2).

Injection Mismatch

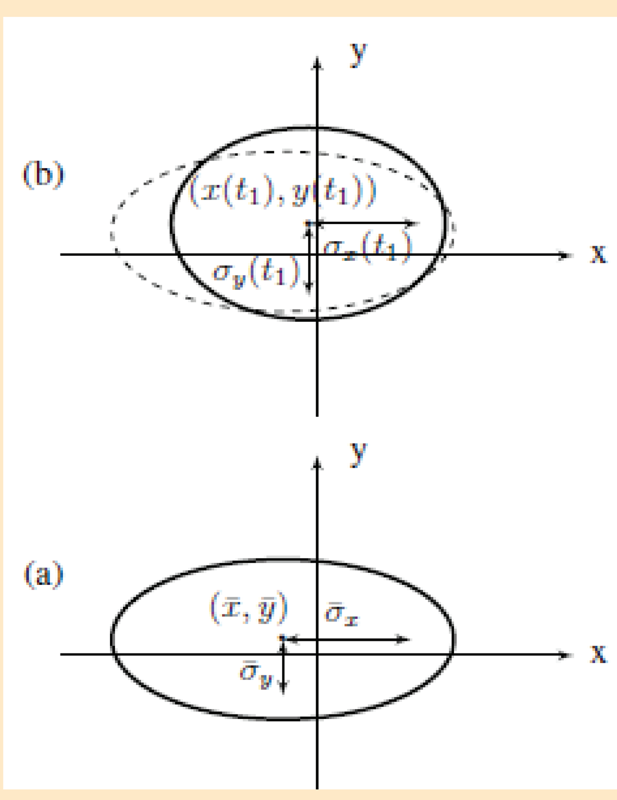


Fig. 6 The lower schematic shows a stationary beam with position $(\bar{x}, \bar{y})$ and rms dimensions $(\bar{\sigma}_x, \bar{\sigma}_y)$.

The upper schematic shows the beam position and size oscillations after the position and beta mismatch[3]. The beam position oscillations are given by betatron tunes (Q_x, Q_y) and envelope oscillations are $Q_{coh,1}$ for horizontal plane and $Q_{coh,2}$ for vertical plane.

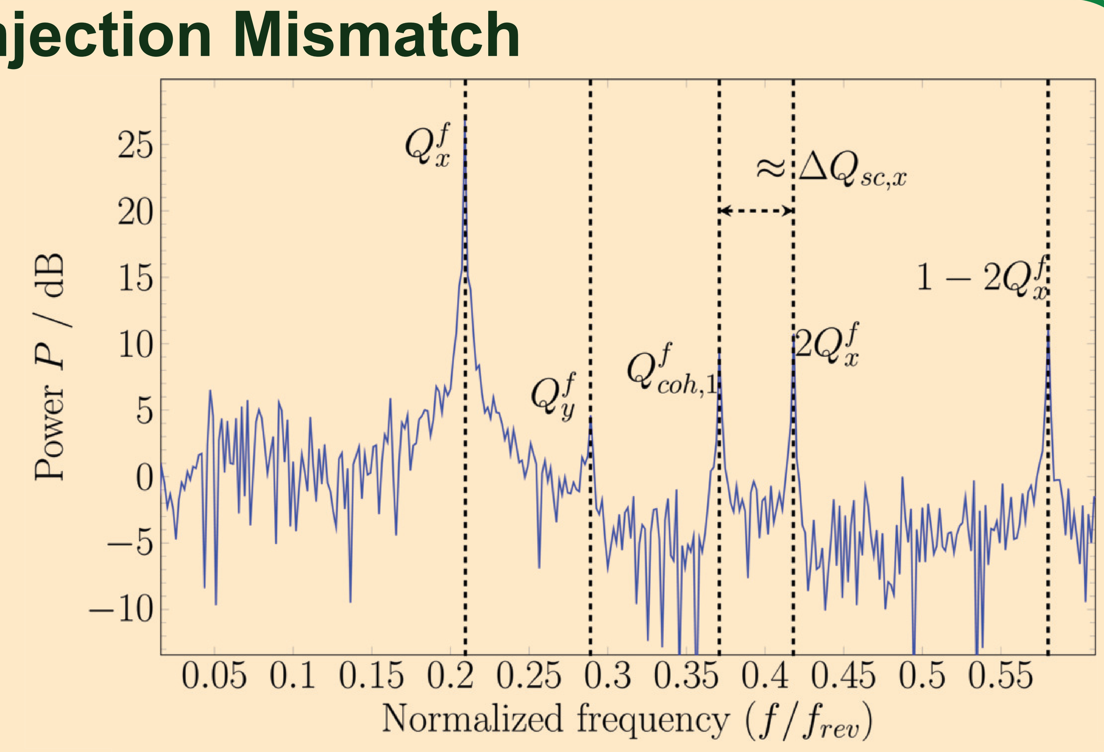


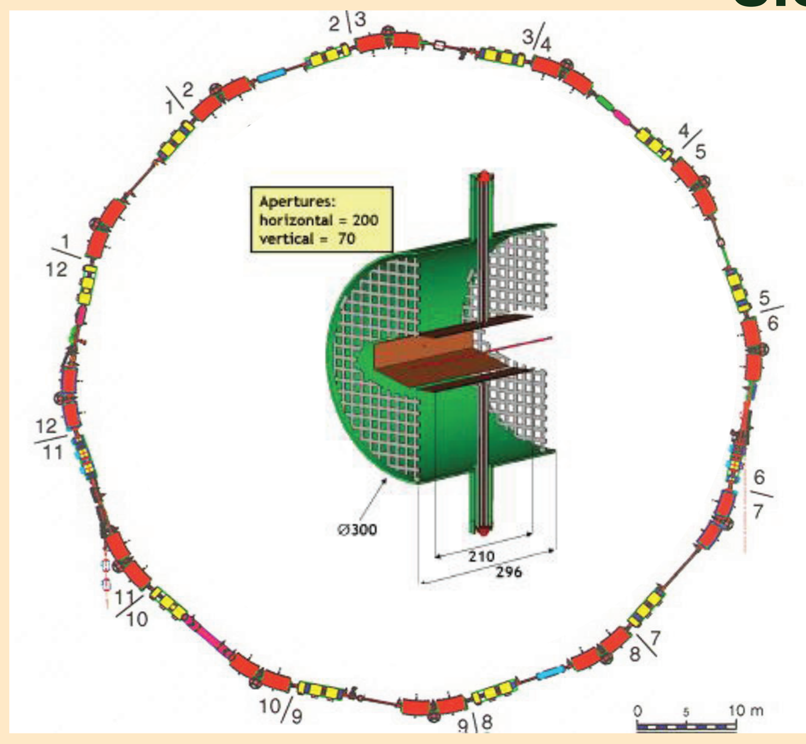
Fig. 7 The quadrupolar signal spectra for a high intensity beam, i.e. 6 mA for 11.4 MeV/u N^{7+} beam.

The fractional horizontal and vertical tune peaks (Q_x^f, Q_y^f) due to position oscillations are visible. Also, the peaks at twice the betatron tune $(2Q_x^f, 2Q_y^f)$ due to the second order beam position terms x^2, y^2 in κ are seen.

The component due to beam envelope oscillations in horizontal plane is also clearly visible. The frequency of coherent envelope oscillation is dependent on space charge[4,5],

$$Q_{coh,1} = 2Q_{x0} - \left(1.5 - 0.5\left(\frac{\sigma_x}{\sigma_x + \sigma_y}\right)\right)\Delta Q_{sc,x} \qquad (Eq.2)$$

SIS-18



Important parameters of SIS-18:

- Circumference	216 m
- Inj. type	Multiturn
- Energy range	11 MeV → 2 GeV
- Acc. RF	0.8 → 5 MHz
- Acc. harmonic	4 (no. of bunches)
- Bunching factor	0.6 → 0.2
- Ramp duration	0.2 → 1.5 s
- Typical tune h/v	4.16 3.31
- Ion range (Z)	1 → 92 (p to U)
- Design beams	2 x 10[11] U 28+ 1 x 10[13] p

Data Acquisition and signal processing

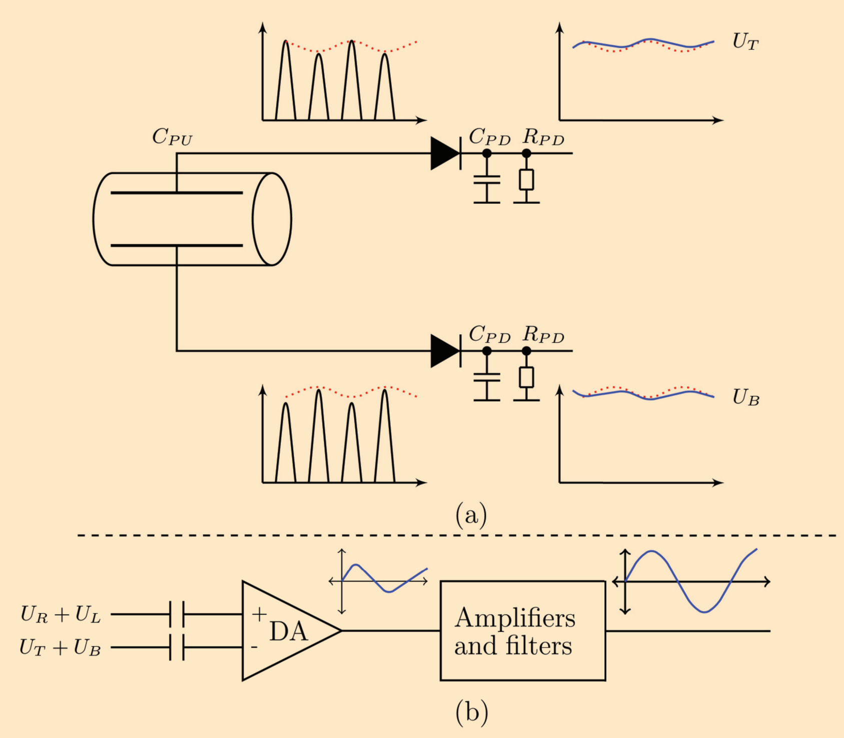


Fig. 5 BBQ based quadrupolar signal acquisition.

- Beam envelope is detected using diode based peak detectors [2]. There is a trade-off between time-constant and pick-up transfer impedance.
- Peak detector suppresses the common mode signal.
- The peak detector outputs are connected in quadrupolar configuration to suppress the dipolar signals.
- The quadrupolar signal in processed with a 12 bit ADC equipped real time spectrum analyzer.

Measurements and Results

Table.1 Beam parameters for the N^{7+} beam experiment

Parameters	Values
W_{kin} (MeV/u)	11:45
I_{beam} (mA)	0.6-6
$\epsilon_x, \epsilon_y(2\sigma)$ (mm-mrad)	32;51
Q_{x0}, Q_{y0}	4.21, 3.3

Beam experiments were performed at injection with an unbunched beam i with the parameters given in Table 1. Beam emittence in measured with Ionization profile monitor.

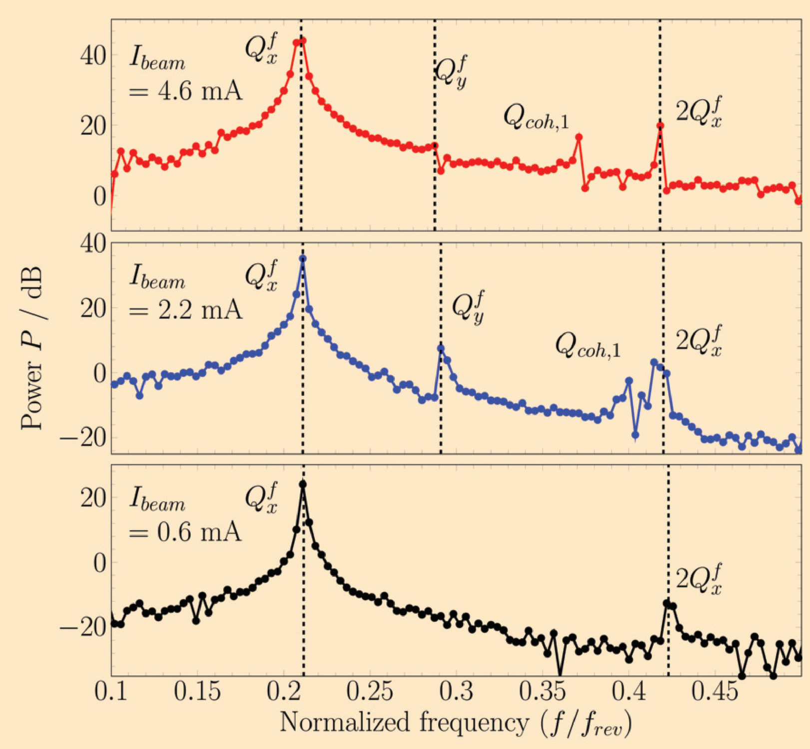


Fig. 8 The quadrupolar signal spectra with varying beam current

- .Three subsequent spectra for increasing currents are shown. The current was varied from the UNILAC, such that the injection parameters were unchanged.
- While the positon related oscillations are relatively independent of space charge effects, the envelope oscillation mode shifts proportional to space charge tune shift.
- This provides a method for direct measurement of space charge tune shift.
- Only horizontal beta mismatch occured for the set injection settings.

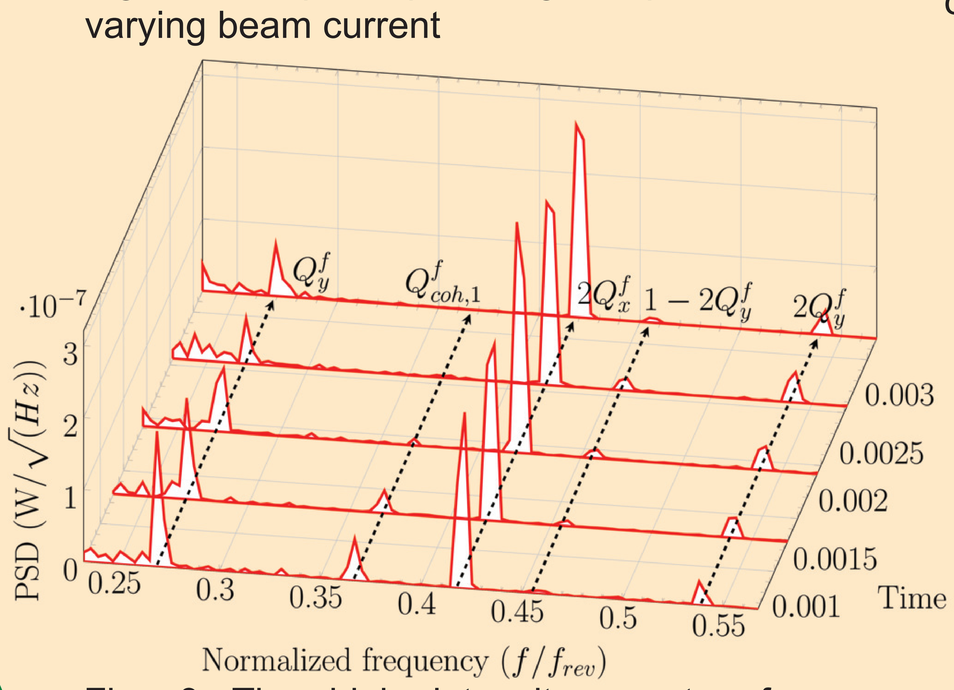


Fig. 9 The high intensity spectra from previous figure over time

- .The highest intensity spectra from Fig. 8 is shown for first 800 turns.
- Coherent beam envelope oscillations are damped in less than 200 turns, while position related oscillations are sustained for a longer time. Space charge tune shift play a direct role in fast damping.

Summary and Outlook

- Three pick-ups were simulated to compare for their sensitivity to the quadrupolar moment of the beam.
- Envelope oscillations induced by injection mismatch were measured under various beam intensities.
- The coherent quadrupolar oscillation mode in the horizontal plane was measured and a clear correlation of mode frequency shift with the space charge tune shift was found.
- Quadrupolar exciter installation and optimization of the pick-up is foreseen.

References

1) R. Miller et al., "Non invasive emittance monitor", PAC83, Washington, 1983.
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