Observations of the quadrupolar oscillations at GSI SIS-18*

R. Singh[1], P. Forck[1], P. Kowina[1], J. A. T. Tsonga[2], W. Mueller[2], T. Weiland[2], M. Gasior[3]
[1]Gesellschaft für SchwerIonenforschung (GSI), Darmstadt, Germany
[2] TEMF, Technical University of Darmstadt, Darmstadt, Germany
[3] CERN, Geneva, Switzerland

IBIC 2014

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

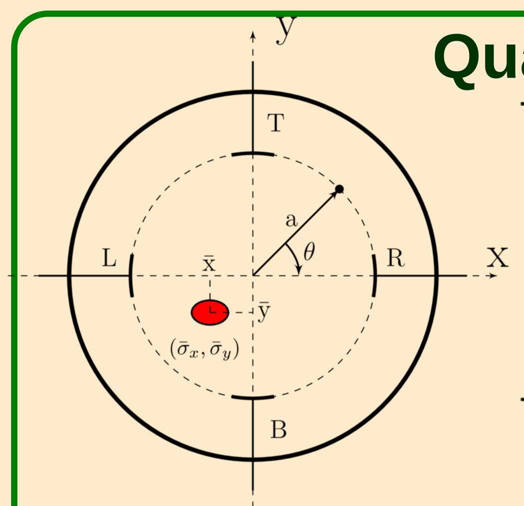


Fig. 1 Symmetric button pick-up for analytical expressions

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

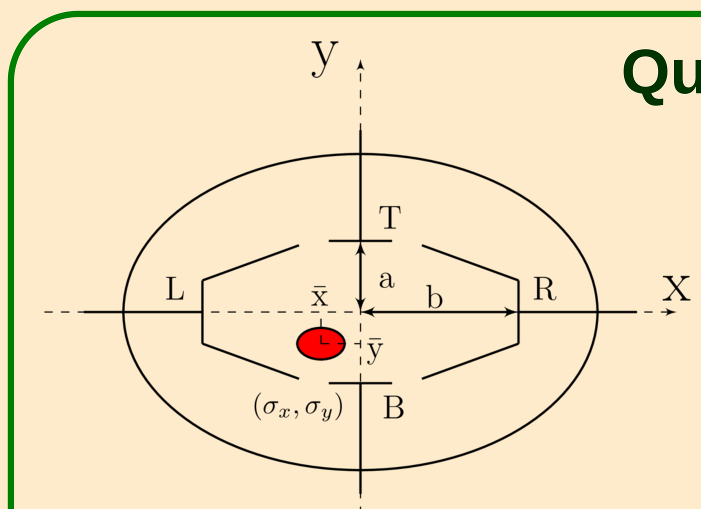


Fig. 2 Asymmetric pick-up used for the experiments.

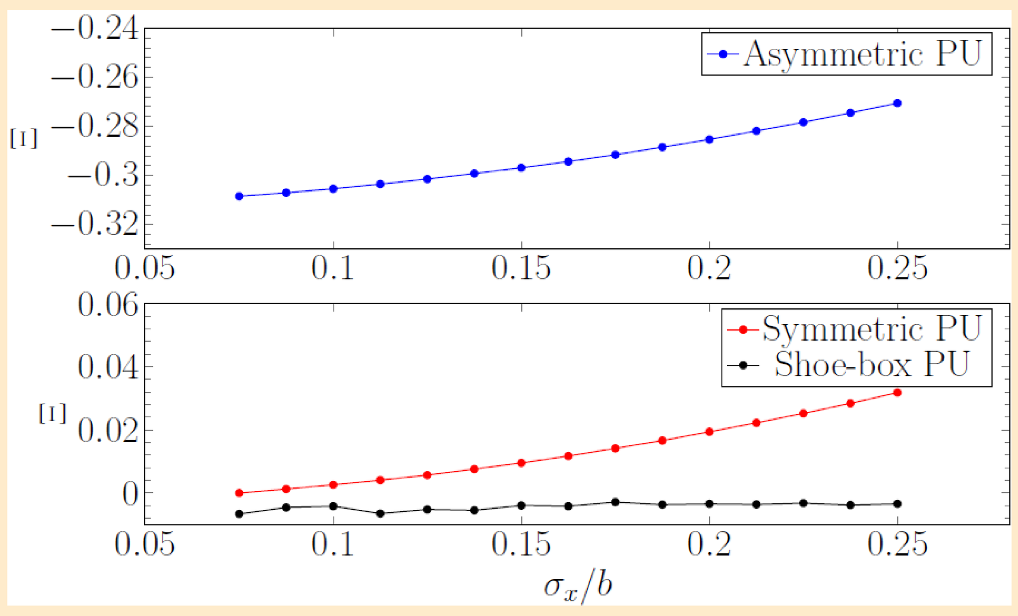


Fig. 4 Comparison of the quadrupolar sensitivity of the pick-ups installed in SIS-18.

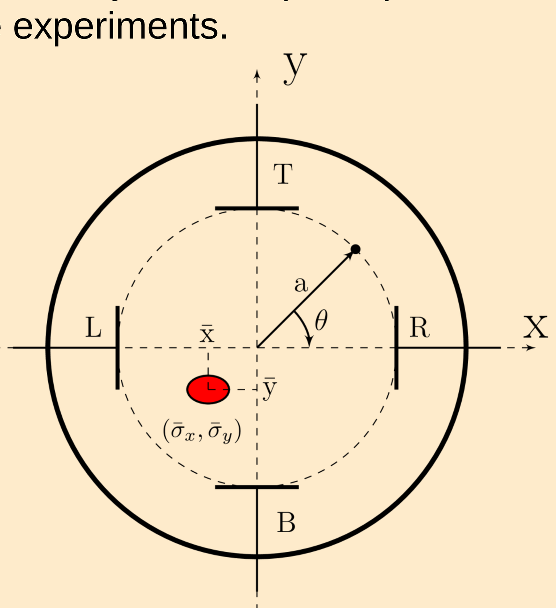


Fig. 3 Symmetric pick-up installed in SIS-18.

- 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

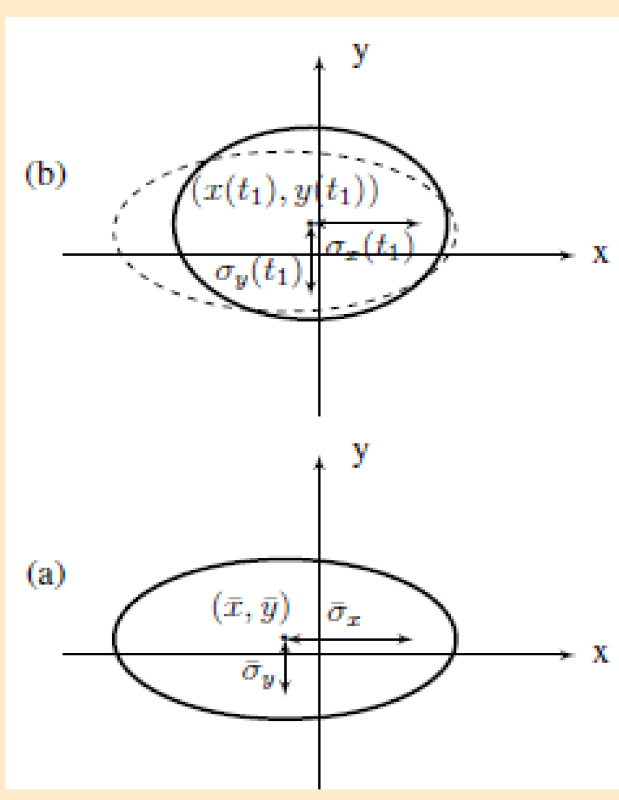


Fig. 6 The lower schematic shows a stationary beam with position $(\bar{x},\bar{y})$ and rms dimensions $(\bar{\sigma}_x, \bar{\sigma}_y)$.

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.

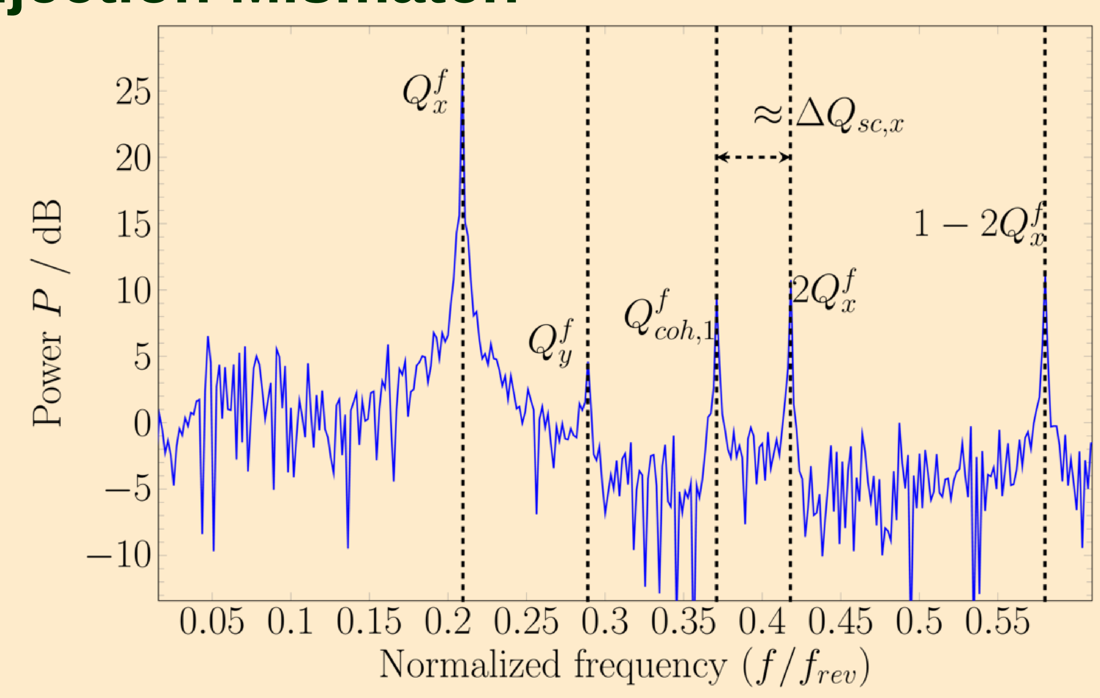


Fig. 7 The quadrupolar signal spectra for a high intensity beam, i.e. 6 mA for 11.4 MeV/u N^{7+} beam.

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.

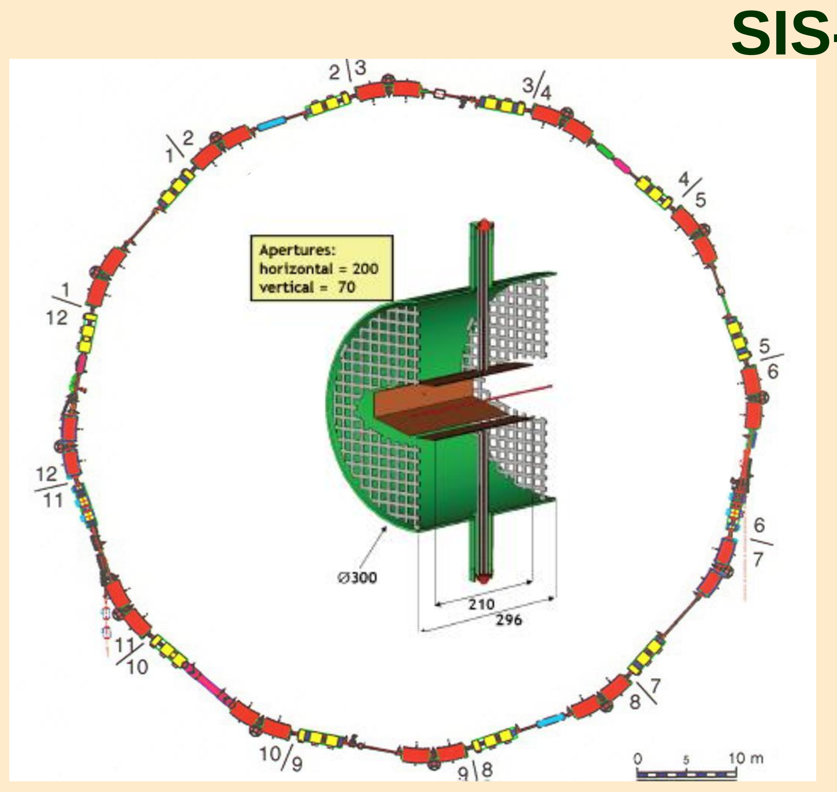
The component due to beam envelope oscillations in horizontal plane is also clearly visible. The frequency of coherent envelope oscillation is dependent on space charge[4,5],

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

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.

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 10¹¹ U 28+
	1 x 10¹³ p

Data Acquisition and signal processing

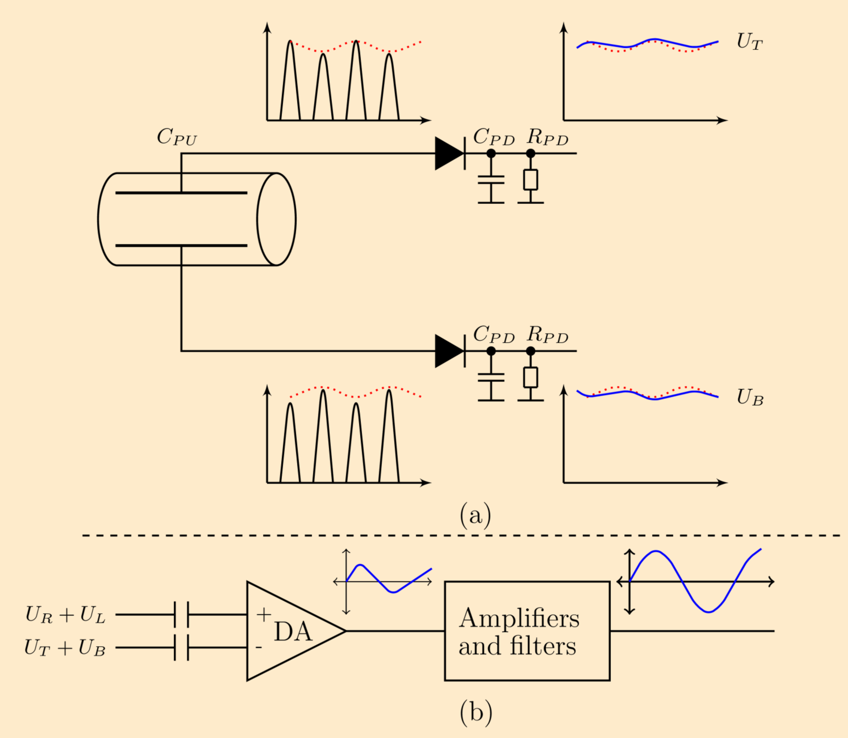


Fig. 5 BBQ based quadrupolar signal acquisition.

- 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.

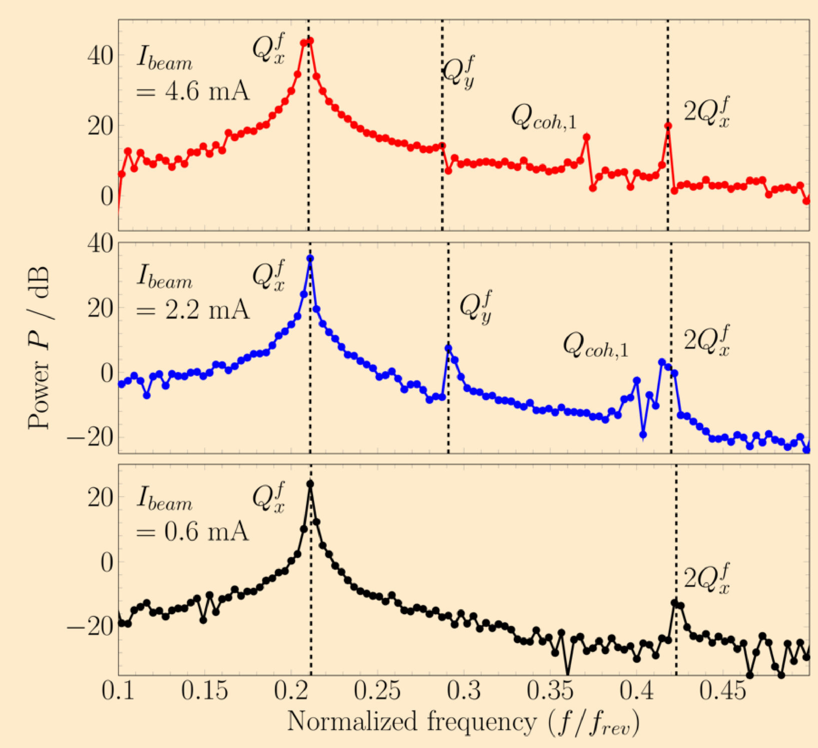


Fig. 8 The quadrupolar signal spectra with varying beam current

- .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.

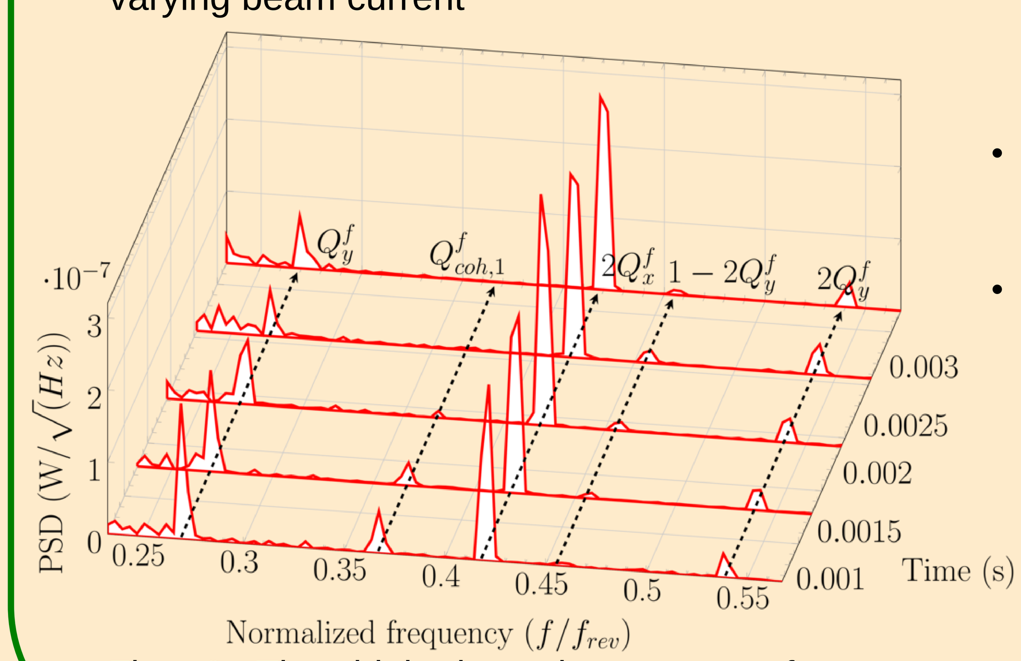


Fig. 9 The high intensity spectra from previous figure over time

- .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.

References

1) R. Miller et al., "Non invasive emittance monitor", PAC83, Washington, 1983.
2) M. Gasior et al., "The principle and first results of betatron tune measurement by direct diode detection", LHC-Project- Report-853 ; CERN-LHC-Project-Report-853. - 2005. - 31p.
3) M. Minty et al., "Injection envelope matching in storage rings", Proc. 1995 Part. Acc. Conf. and Intl. Conf. on High Energy Accel (Dallas, TX, 1995) 536
4) W. Hardt, "On the incoherent space charge limit for elliptic beams", CERN/ISR/Int. 300 GS/66.2.
5) I. Hofmann, "Stability of anisotropic beams with space charge" Physical Review E 57 (4), 4713.