Influence of Space Charge Waves on Position Measurements with Pickups

E. Urazov, E. Bekhtenev, M. Bryzgunov, V. Parkhomchuk, V. Reva

Budker Institute of Nuclear Physics

Abstract

Experiments show that the propagation of space charge waves affects both the sum signal from pickup electrodes and the beam position measurements. Axially symmetric waves, in agreement with theoretical predictions, can significantly lower the sum signal compromising the accuracy of the measurements. Asymmetry in space charge modulation leads to transversal propagation of charge density modulation by the same order of magnitude as the size of the electron beam, which results in drastic errors in beam position monitoring.

Introduction

Background

- Efficiency of electron cooling requires matching the positions of an ion beam and an electron beam.
- Pickups monitor the precision of the matching.
- Pickups only measure the positions of longitudinally non-uniform beams.

Therefore, electron beam density modulation is necessary. We achieve it by applying small alternating voltage to the control electrode of an electron gun.

Experiments at NICA booster revealed that the sum signal from pickup electrodes depends on the position of a pickup along the setup.

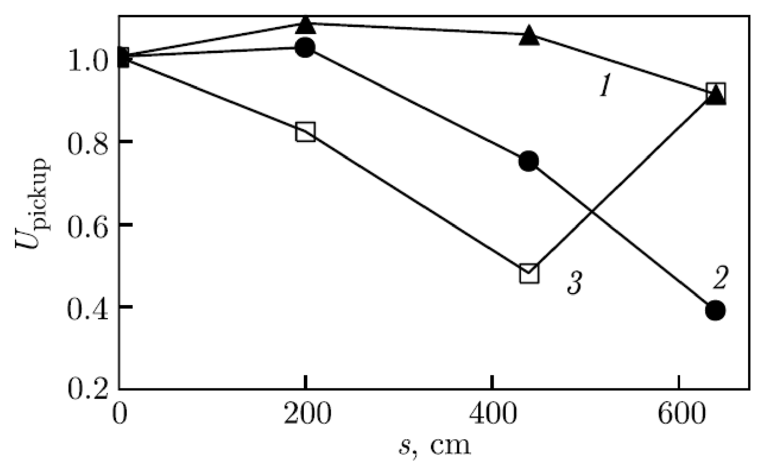

Figure: Position dependence of the sum signal on NICA booster. $E = 1.74$ keV, $I_1 = 42$ mA, $I_2 = 167$ mA, $I_3 = 440$ mA.

We surmised that electron beam density modulation creates perturbations in an otherwise longitudinally uniform beam that excite space charge waves.

Wave excitation

Coulomb repulsion causes the density perturbations to split and propagate along the beam.

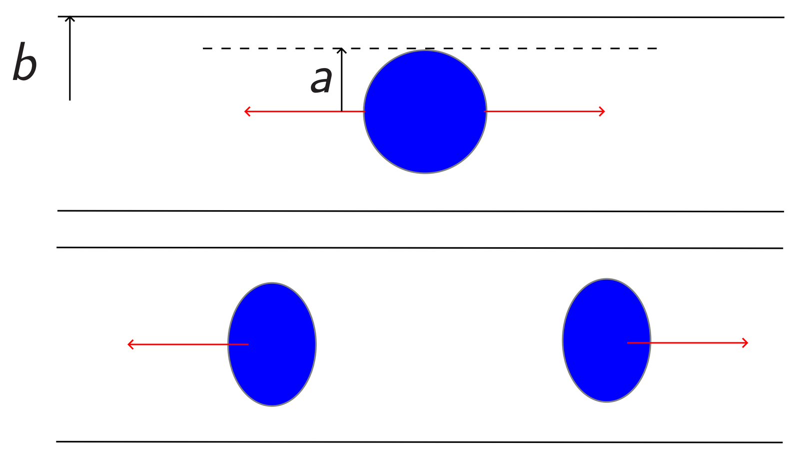

Figure: Wave excitation mechanism

The two propagating perturbations correspond to two kinds of waves. The resulting wave is a partial standing wave:

$$A\cos(\omega t - k_+ z) + B\cos(\omega t - k_- z)$$

For long axially symmetric waves in a beam moving with velocity u_0 in strong magnetic field:

$v_p = \frac{a\omega_p}{2}\sqrt{2\ln\frac{b}{a}}$ – phase velocity.

$k_\pm = \frac{\omega}{u_0 \pm v_p}$ – wave vector.

The formulae above contain frequency dependence, so changing the frequency and measuring the sum signal and the position allows us to gather a lot of experimental data even with a single pickup.

Apparatus

The electron gun at the bottom of the test bench generates an electron beam to be absorbed by the collector at the top. The diagnostics chamber contains the pickup.

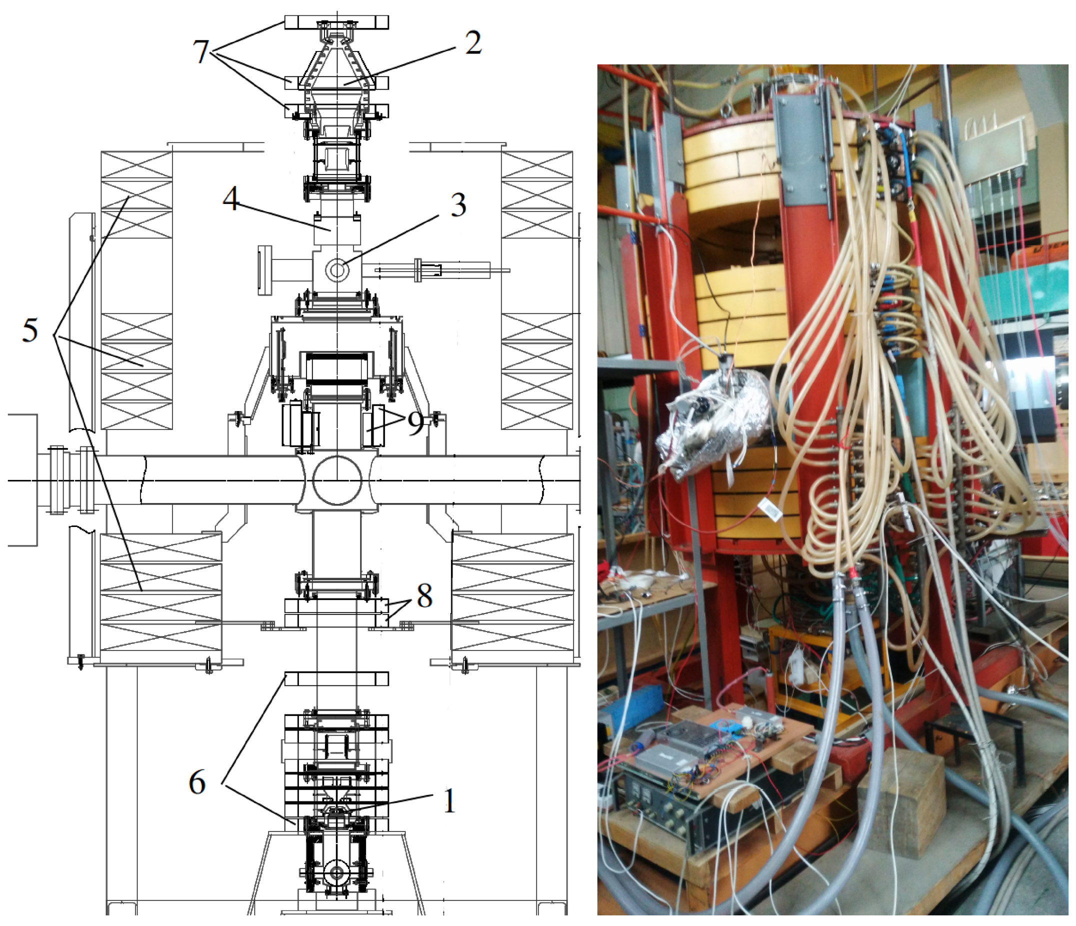

Figure: "Gun-collector" test bench: 1 – electron gun; 2 – electron collector; 3 – diagnostics chamber; 4 – pickup; 5-9 – magnetic field coils.

The control electrode of the electron gun is divided into four sectors allowing axially asymmetric modulation.

Measurement process

- Generate an electron beam
- Set the modulation frequency range and mode
- Measure the frequency response of the sum signal and the position

Longitudinal dynamics

We measured the frequency dependence of the sum signal for different energies and currents of electron beams with axially symmetric density modulation.

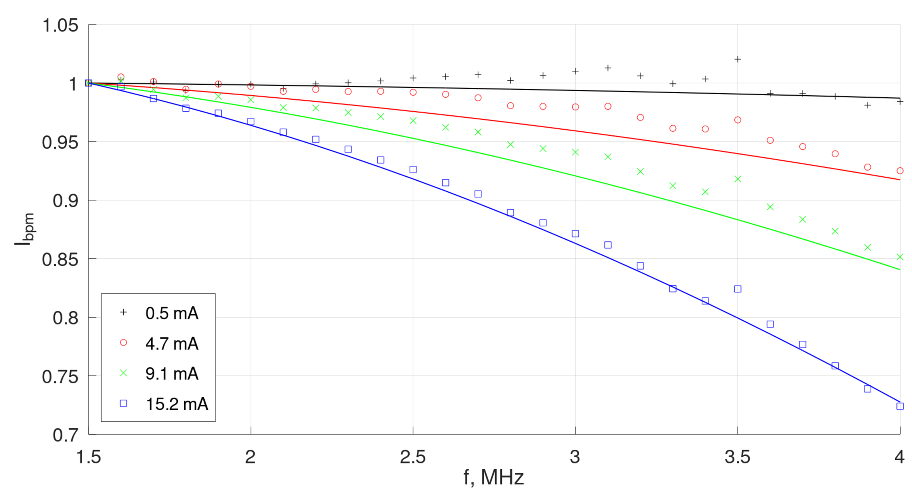

Figure: Sum signal frequency dependence for 0.5 kV cathode voltage

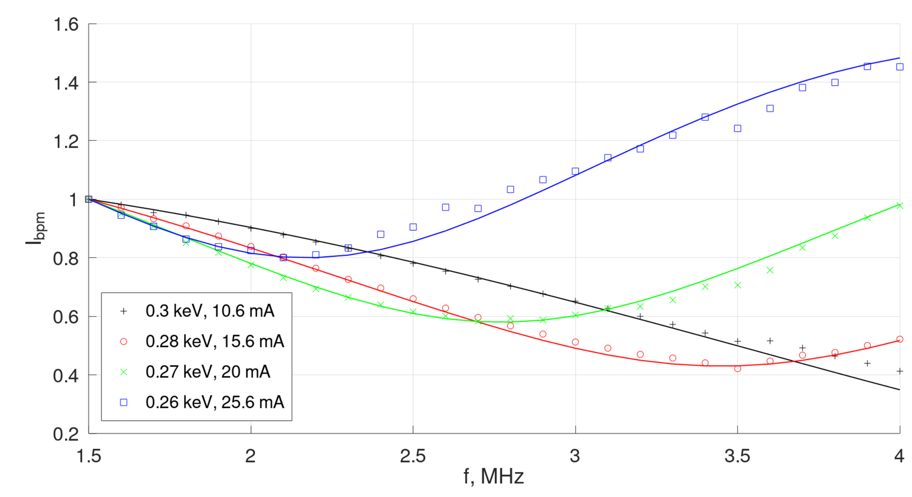

Figure: Sum signal frequency dependence for 0.3 kV cathode voltage

Increasing the modulation frequency lowers the sum signal from the pickup electrodes until it reaches the minimum. Further increase of the frequency results in the growth of the sum signal. The minimal observed ratio of the minimum to the maximum is 0.4.

Transversal dynamics

We conducted experiments with axially symmetric modulation to measure the position of the center of the beam, then repeated our measurements after introducing axial asymmetry to find the frequency dependence of the transversal position of the beam density perturbation.

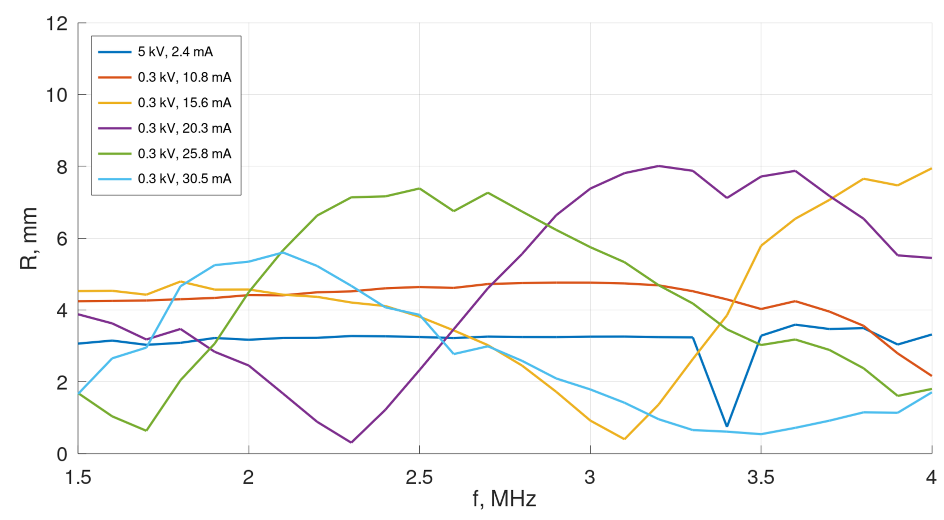

Figure: Frequency dependence of the average measured beam position relative to the center

For the relatively high energy of the electron beam $E = 5$ keV the measured position remains constant except the point $f = 3.4$ MHz, which corresponds to the local minimum of the pickup frequency response. For lower energies the measured position approaches the center of the beam and then starts moving outward.

Conclusion

- Theoretical models predict the behaviour of space charge waves with sufficient accuracy.
- The highest observed fall of the sum signal is 0.4. Lower values are theoretically possible, drastically compromising the accuracy of the measurements.
- Axially asymmetric modulation creates transversally propagating perturbations. Due to its propagation not only does it interfere with the positioning of the electron beam, but also the angling.

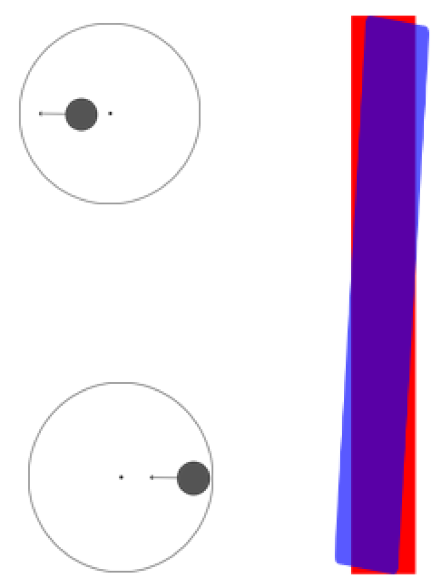

Figure: Transversal movement perturbations result in the misalignments of electron and ion beams