# DIAGNOSTIC OF THE COMPENSATION PROCESS OF ION BEAMS WITH A TIME-RESOLVING ION ENERGY SPECTROMETER

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*Abstract*

Space-charge compensated high-perveance ion beams are of main interest for the injection into RFQ systems. Space-charge compensation enhances the maximum transportable current in low energy beam transport lines which is mainly limited by space-charge forces. The compensation electrons are usually produced by residual gas ionisation. In this case beam pulses reach the final degree of compensation after a certain time. To investigate the compensation processes of a periodically decompensated beam, a time-resolving residual gas ion energy spectrometer was developed. Results of measurements and corresponding numerical simulations will be presented.

## 1 INTRODUCTION

The **r**esidual **g**as **i**ons (RGI) produced by the interaction of beam ions and residual gas are expelled radially in the beam potential. Under the assumption of neglectable start energy of the RGI, the kinetic energy of the RGI corresponds to the beam potential at the point of production. The RGI energy distribution contains information on the radial beam potential distribution and thereby on the degree of compensation. For the investigation of the build-up time of space-charge compensation a time-resolving RGI energy spectrometer with a single particle detector (channeltron) [1] was used. The time resolution was limited to 2 µs, due to the data acquisition. Self-consistent numerical simulations of the compensated beam [2] have been performed for different electron temperatures and axial densities to match the 10 % base points of the measured spectra. The combination of simulation and measurements allows the determination of beam plasma parameters (electron temperature, electron line charge density and relative charge density of the compensation electrons compared to the beam ions on the beam axis) which are difficult to measure directly.

## 2 MEASUREMENTS

The rise time of the space-charge compensation of a periodically decompensated DC $He^+$ (10 keV, 3 mA) ion beam has been investigated. A pulsed voltage (350 V, 500 Hz, 50% duty cycle, rectangular) was provided to an electrode in order to periodically decompensate the ion beam. With the falling edge of the pulse the compensation of the uncompensated beam starts by trapping the produced compensation electrons in the beam potential. Simultaneously the time resolved measurement of the RGI flux passing the energy analyser (at a fixed analyser voltage) [3] begins. This was done for a variety of fixed analyser voltages. Rearrangement of the data gives the energy spectra at different times. The 10% base points of this dynamic energy spectra yield the time dependent potentials of the beam center and the beam edge (Fig. 1).

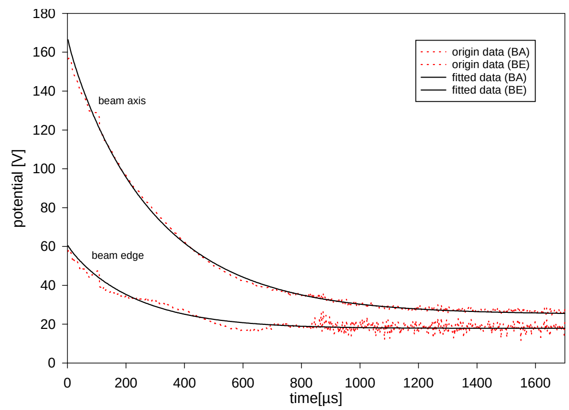


Figure: 1 Temporal development of potentials of beam axis and beam edge and analytical fit.

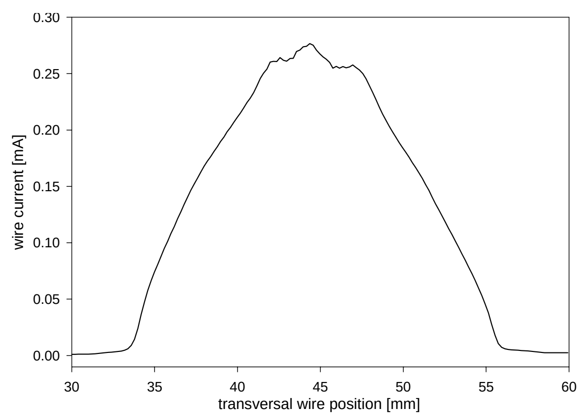


Figure: 2 Projection of beam profile measured with wire scanner.

The projection of the beam ion current density distribution was measured with a wire scanner at a DC beam for different voltages applied at a decompensation electrode. The settings of the focusing magnets were choosen in a way that the corresponding change of beam profile was neglectable. Fig. 2 shows a measurement for a decompensation voltage of 250 V. To receive the needed radial density profile from this measurement it was Abelinverted (Fig. 3). It was assumed that the profile of the dynamically compensating beam stayed unchanged as well.

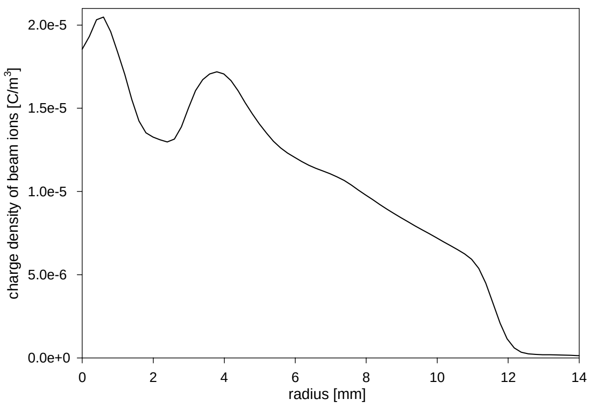


Figure: 3  Radial beam profile gained from Abel-inversion.

## 3 SIMULATIONS

A self-consistent equilibrium state of the compensated beam can be calculated numerically with radial beam ion density distribution and residual gas density as input data and electron temperature and density at the beam axis as free parameters. A two dimensional multiplicity of appr. 10000 self-consistent states was calculated. From this variety suitable self-consistent states could be choosen for every measured couple of beam axis and beam edge potentials. (A computer code was developed to compare the measured potentials with the potentials calculated by the simulation. The minimum distance between the measured and calculated value in a two dimensional plot (potential of beam center versus potential of beam edge) is determined and the corresponding equilibrium state is choosen.)

The resulting time-dependent evolution of electron temperature, **r**elative electron **d**ensity on beam axis (RD) and **e**lectron **l**ine **c**harge **d**ensity (ELCD) are shown in Figs. 4, 5, 6 (dotted lines). The same procedure was applied to an analytical fit of the original data (full lines). By comparison can be seen that the electron temperature is (only at higher temperature values) critically dependent on fluctuations of the input parameters while RD and ELCD are only weakly affected. Further the temperatures resulting from the simulation are unplausible high at the beginning of the compensation process (first 30 µs) since electrons with kinetic energies exceeding the appr. 100 eV corresponding to the uncompensated beam potential are expected to be lost instantaneously. Both effects are due to the fact that a beam edge potential which is only a little higher than what is compatible with beam axis potential and total charge density profile requires electrons outsides but not insides the beam radius, to be made self-consistent again. In certain limits this can be provided by using higher electron temperatures in the simulation. But for nearly uncompensated beams already little errors of the input parameters can result in unrealistic temperatures.

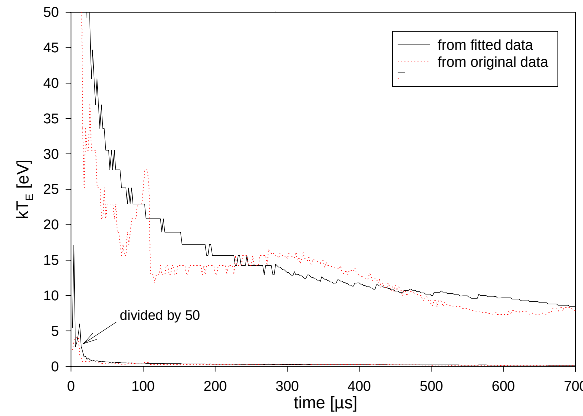


Figure: 4  Temporal development of electron temperature.

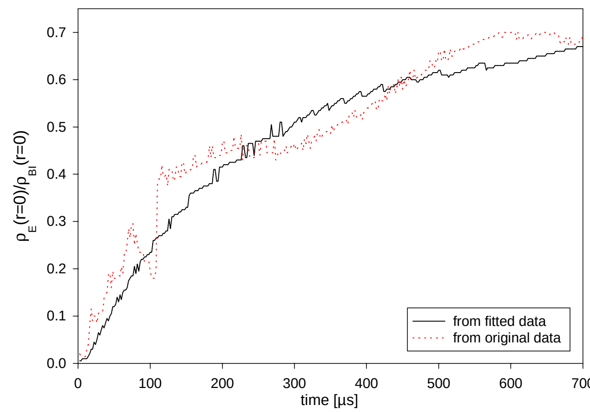


Figure: 5  Relative electron density on beam axis as a function of time.

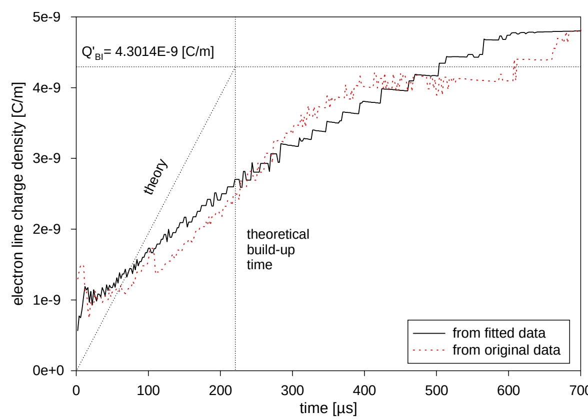


Figure: 6  Electron line charge density as a function of time.

From Figs. 1, 5, 6 can be seen that the build-up of space-charge compensation needs a time of at least 700 µs. The theoretical build-up time is shorter by a factor of 3. This is plausible because the simple calculation takes no electron losses into account. The build-up of RD and ELCD takes place approximately simultaneously during the first 700 µs, which are actually covered by simulations. This indicates a relatively constant shape of the spatial electron distribution and is consistent with the approximately constant relations of beam axis potential, beam edge potential and electron temperature. In the later stages of the process the quotient of beam edge potential to beam axis potential decreases (Fig. 1) indicating a stronger confinement of the electrons to the inside of the beam and a further cooling of the electrons.

## 4 FUTURE WORK

The simulations will be extended to the later phases of the build-up process. The beam profile monitor will be replaced by a CCD camera. The CCD camera is an undisturbing diagnostic instrument which might be a big advantage, because secondary electron production is avoided and it allows for a time-resolved measurement of the beam profile. In the following time resolved beam profile measurements will be compared to the RGI spectra. Furtheron the time-resolved RGI measurements will be performed on a pulsed ion beam, instead of a continuous beam with pulsed decompensation. For this investigations the ion source will be pulsed.

## REFERENCES


[1] K.Reidelbach et al., GSI-94-10 (1994) 36
[2] J.Pozimski et al., GSI-93-17 (1993) 38
[3] K.Reidelbach et al., GSI-95-5 (1995) 31