STUDY OF COMPENSATION PROCESS OF ION BEAMS **

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Abstract

For investigation of space charge compensation process due to residual gas ionization and the experimentally study of the rise of compensation, a Low Energy Beam Transport (LEBT) system consisting of an ion source, two solenoids, a decompensation electrode to generate a pulsed decompensated ion beam and a diagnostic section was set up. The potentials at the beam axis and the beam edge were ascertained from time resolved measurements by a residual gas ion energy analyzer. A numerical simulation of self-consistent equilibrium states of the beam plasma has been developed to determine plasma parameters which are difficult to measure directly. The temporal development of the kinetic and potential energy of the compensation electrons has been analyzed by using the numerically gained results of the simulation. To investigate the compensation process the distribution and the losses of the compensation electrons were studied as a function of time. The acquired data show that the theoretical estimated rise time of space charge compensation neglecting electron losses is shorter than the build up time determined experimentally. To describe the process of space charge compensation an interpretation of the achieved results is given.

1 INTRODUCTION

Space charge forces within ion beams lead to a notable divergence of the beam ions and to a disadvantageously emittance growth. To enhance the maximum transportable current and reduce the increasing emittance during the transport of the ion beams in a Low Energy Beam Transport (LEBT) line, it is essential to reduce the space charge forces. Therefore space charge compensation of positive beam ions by electrons [1], which are produced by residual gas ionization, enhance the maximum transportable ion current.

Measurements by use of a residual gas ion energy analyser based on the detection of residual gas ions produced by the interaction between beam ions and residual gas atoms. The produced residual gas ions are radial expelled by the beam potential. Therefore the kinetic energy of the residual gas ions corresponds to the beam potential at the point of production under the assumption of negligible start energy. Hence the residual gas ions energy distribution contains all necessary information about the radial distribution of the beam potential and thus about the degree of compensation [2]. For investigation of the space charge compensation process a time resolved residual gas energy analyser with a channeltron was used [3].

Calculated beam potential by self-consistent numerical simulations [4] were compared with the potentials yielded from the measured spectra. The combination of simulation and measurement allows the determination of all relevant beam plasma parameters [5].

2 MEASUREMENT AND CALCULATION

Time resolved measurements of ions repelled radially by the beam potential passing an energy analyser [6] with an inserted channeltron were done to investigate the rise time of compensation of a periodically decompensated 10kV, 3mA DC He^+ ion beam [7].

The simulation of the self-consistent equilibrium states of the beam requires the temperature and the relative density of the compensation electrons at the beam axis as varying free parameters and radial distribution of the beam ions as input data. A CCD-camera was used to investigate the radial distribution of the beam ions by observing the light emitted by the intersection of the beam ions with the residual gas atoms (photon emission). In fig. 1 a CCD-camera profile measurement I(x) of an 3.9 mA He^+ ion beam is shown, the corresponding density profile $\rho(r)$ can be calculated via Abel inversion.

Significant advantages of this profile measurements in comparison to measurements by a flying wire beam profile monitor [5] are the high time resolution and that the CCD-camera is an undisturbing diagnostic instrument. Therefore there is no disturbance of the equilibrium state of the compensated ion beam due to the production of secondary electrons. In addition to the residual gas ion energy analyser the CCD-camera was used to estimate the rise time of compensation in the present experimental set up.

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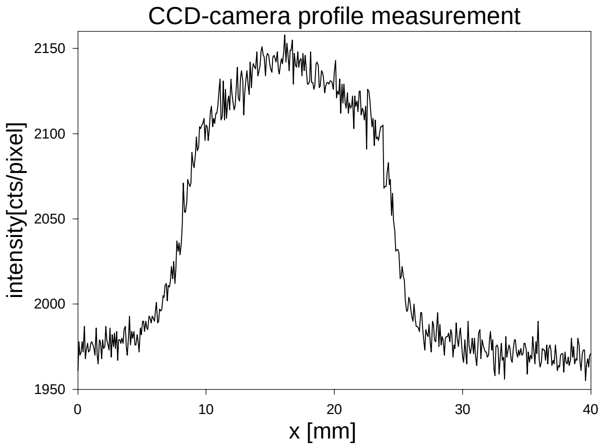

Fig. 1: Beam profile measurements by a CCD-camera. The exposure time was 2.5 s.

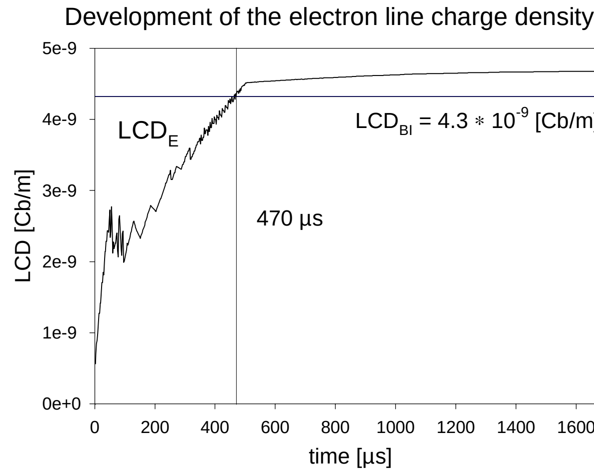

Fig. 2: Line charge density of compensation electrons and beam ions.

The minimum rise time of compensation τ can be estimated by a simple expression [5, 8], which is valid for idealized conditions (cylinder symmetry, electron losses neglected). Although the rise time of compensation determined by CCD-camera measurements are in good agreement with the calculated minimum rise time of compensation the evaluation of the residual gas ion energy analyser measurements shows that the compensation process is not finished at the minimum rise time mentioned above.

The following figures illustrate results gained from measurements for a residual gas pressure of $5*10^{-5}$ hPa, accordingly the calculated minimum rise time of compensation is 220 µs.

The determination of the plasma parameters, like the temperature of the compensation electrons (CE), the line charge density of the CE, the kinetic and potential energy of the CE by comparison of the simulation with the measured data reacts sensitive to fluctuation of the measured record. Therefore the measured data are fitted mathematically to smooth fluctuations of the measured data. The smoothed curves in the following figures show the appraisal of mathematically fitted measured data.

Fig.2 shows the development of the electron line charge density during the compensation process. The rise time of compensation is determined by the intersection point of the increasing electron (LCD_E) and the beam ion line charge density (LCD_{BI}) and is given by 470 µs.

The rise time of compensation estimated by the residual gas ion energy measurements exceeds the minimum rise time compensation τ by a factor of two due to electron losses, which is not taken into account in the above mentioned theoretical estimation.

Fig. 3 shows the evolution of the **e**lectron **c**harge **d**ensity (CD_E) during the compensation. The straight line indicates the CD_E on the beam axis, the dashed line is the CD_E at the beam edge. Fig. 3 clarify that the compensation process continues over the estimated minimum rise time of compensation τ of 220 µs. The minimum rise time indicates the time, which is needed to produce enough electrons (without consideration of electron losses) to compensate the space charge of the beam ions. With decreasing space charge forces during the compensation the electron losses increases continuously until an equilibrium state of electron losses and electron production is reached. The increasing electron losses yields to a prolongation of the compensation process up to 470 µs. Furthermore fig.3 and fig. 4 illustrate that redistribution processes are finished not until 1000 µs.

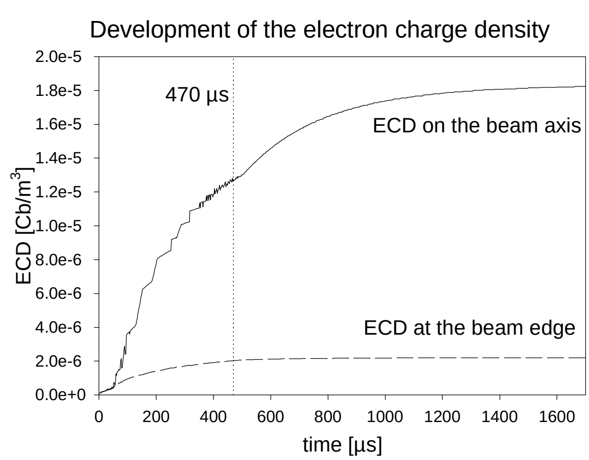

Fig. 3. Development of the electron charge density.

Fig. 4 shows the development of the kinetic (dotted line), potential (straight line) and total (dashed line) energy line density of the CE. The kinetic energy decreases continuously due to the dominant effect of decreasing temperature. The electron temperature decreases due to cooling processes by losses of „hot“ electrons. The maximum of the kinetic energy curve at 320 µs, represented in an antecedent presentation [5], which has not cleared till then, is an effect of the above mentioned fluctuations of the measured data. A new execution of the represented appraisal with smoothed measured records do not show this maximum.

From 80 µs on the potential energy exceeds the kinetic energy, hence the compensation electrons are trapped in the beam potential, this shows that the used theory and simulation is valid. Up to the maximum at 220 µs the potential energy increases, due to accumulation of produced compensation electrons in the beam potential, then electron losses and the decrease of the beam potential causes the progression of the energy. All three curves saturate after 1200 µs, then all redistribution-, production- and loss-processes reach an equilibrium state. The total curves shows clearly, that the energy still decreases, although the compensation process is complete. This effect is attributed to the above mentioned cooling process and redistribution within the ion beam, without a further accumulation of compensation electrons.

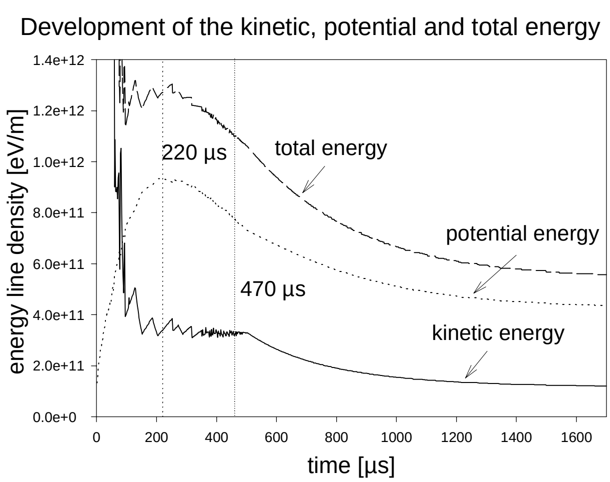

Fig. 4: Comparison of the development of kinetic, potential and total energy line density of the CE. The kinetic energy has a maximum at 220 µs. After 470 µs the compensation process is completed, after 1200 µs the development of the kinetic, potential and total energy line density saturates.

3 SUMMARY

The compensation processes of a periodically decompensated 10 keV DC He^+ ion beam has been investigated by usage of a time resolved ion energy spectrometer with installed channeltron. By application of an appraisal procedure of time resolved measurements using self-consistent calculations the rise time of compensation can be determined. A derivation by a factor of two was found between the experimentally detected rise time of compensation and the minimum rise time calculated for idealized conditions. The rise time of compensation was experimentally determined and has a value of 470 µs.

In the future work the time resolved residual gas ions measurements will perform on a pulsed ion beam, instead of a pulsed decompensated ion beam. For this investigation the gas discharge of the ion source will be pulsed directly.

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