INVESTIGATION OF THE RISE OF COMPENSATION OF HIGH PERVEANCE ION BEAMS USING A TIME- RESOLVING ION ENERGY SPECTROMETER**

A. Jakob*, H. Klein, A. Lakatos, J. Pozimski, L. Wicke

Institut für Angewandte Physik, University of Frankfurt, 60054 Frankfurt, Germany

Abstract

The knowledge of the build up time of space charge compensation (SCC) and the investigation of the compensation process is of main interest for low energy beam transport of pulsed high perveance ion beams under space charge compensated conditions. To investigate experimentally the rise of compensation an LEBT system consisting of a pulsed ion source, two solenoids and a drift tube as diagnostic section has been set up. The beam potential has been measured time resolved by a residual gas ion energy analyser (RGA). A numerical simulation for the calculation of self-consistent equilibrium states of the beam plasma has been developed to determine plasma parameters which are difficult measure directly. The results of the simulation has been compared with the measured data to investigate the behavior of the compensation electrons as a function of time. The acquired data shows that the theoretical rise time of space charge compensation is by a factor of two shorter than the build up time determined experimentally. In view of description the process of SCC an interpretation of the gained results is given.

1 INTRODUCTION

SCC by electrons [1] which are produced by residual gas ionization enhances the maximum transportable current in low energy beam transport lines. Due to the compensation process the beam pulses reach the final degree of compensation after a certain time.

The residual gas ions, produced by the interaction between beam ions and residual gas, are radial expelled by the beam potential. Under the assumption of negligible start energy, the kinetic energy of the residual gas ions corresponds to the beam potential at the point of production. Therefore the residual gas ions energy distribution contains information about the radial distribution of the beam potential and thus about the degree of compensation [2]. For investigation of the compensation process a time resolved RGA with a channeltron was used [3].

Self consistent numerical simulations [4] have been performed to calculate the beam potential for an equilibrium state of the beam plasma. The calculated beam potentials were compared with the potentials yielded from the measured spectra. The combination of simulation and measurements allows the determination of all relevant beam plasma parameters, like the temperature Te of the compensation electrons (CE), the relative density of the CE on the beam axis (RD), the line charge density of the CE, the kinetic and potential energy of the CE.

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2 MEASUREMENT AND CALCULATION

The rise time of compensation of a periodically decompensated 10kV, 3mA DC He+ ion beam has been investigated [5]. With the falling edge of a pulsed voltage the compensation of an uncompensated beam starts by trapping the continuously produced CE into the beam potential. Simultaneously the time resolved measurement of the residual gas ions flux passing the energy analyser [6,7] starts.

The simulation of the self-consistent equilibrium states of the beam requires the temperature and the RD as varying free parameters and the Abel inversion of the radial distribution of the beam ions as input data. The radial distribution was measured by a flying wire beam profile monitor. Significant disadvantages of this profile measurements are the disturbance of the equilibrium state of the compensated ion beam (due to the production of secondary electrons) and the lack of time resolved measurements.

In the meantime a CCD-camera is available to investigate the beam profile by observing the light emitted by the intersection of the beam ions with the residual gas atoms (photon emission). The CCD-camera is a non-intersecting diagnostic instrument, which is a big advantage due to secondary electron production and the possibility of time resolved measurements. In addition to the RGA, the CCD-camera was used to estimate the rise time of compensation in the present experimental set up.

In fig. 1 time-resolved measurements of the beam profile (straight line) with a CCD-camera [9] are shown for different times after the compensation starts. For every measurement an own baseline and the profile of the corresponding compensated beam (dotted line) is given, which was measured after a sufficient long time. To estimate the rise time of compensation the time has to appoint at which the time resolved profile and the profile of the compensated state are matched. The estimated value is given by 320 µs.

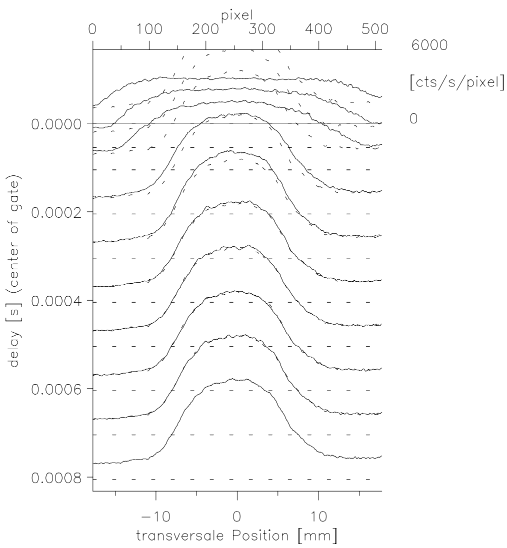

Fig. 1: Time developed CCD-camera beam profile measurements. The residual gas pressure was 3.45 * 10^{-5} hPa.

Under idealized conditions (cylinder symmetric, no electron losses) the electrons are produced continuously along the beam radius and all produced electrons are trapped in the beam potential, the minimum rise time or compensation t can be calculated by a simple formula with the cross-section of the electron production, σ_{CE}, the residual gas density n_{RG} and the velocity of the beam ions v_{SI}.

$$t = (\sigma_{CE} * n_{RG} * v_{SI})^{-1}$$

Figure 1 shows measurements for a residual gas pressure of 3.45 * 10^{-5} hPa. Accordingly the calculated min. rise time of compensation is 314 µs. The determination of the rise time of compensation by CCD-camera measurements are in good agreement with the calculated minimum rise time of compensation. But one have to consider that the represented appraisal is insensitive to small changes of the observed outside margin of the ion beam due to redistribution. Possible compensation processes which has only small effect on the outside margins can not be observed.

Significant hints that the compensation process is not finished after the rise time of compensation estimated by optical method respective the minimum rise time of compensation are given by the evaluation of the RGA measurements. The following figures illustrate measurements for a residual gas pressure of 5 * 10^{-5} hPa, hence the calculation of the minimum rise time of compensation yields 220µs.

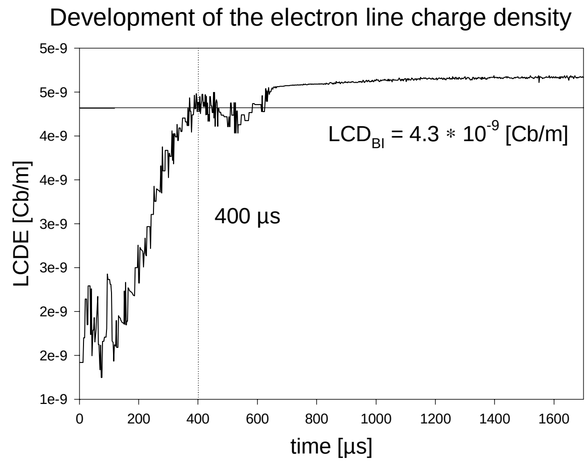

Fig. 2. Electron and beam ion line charge density.

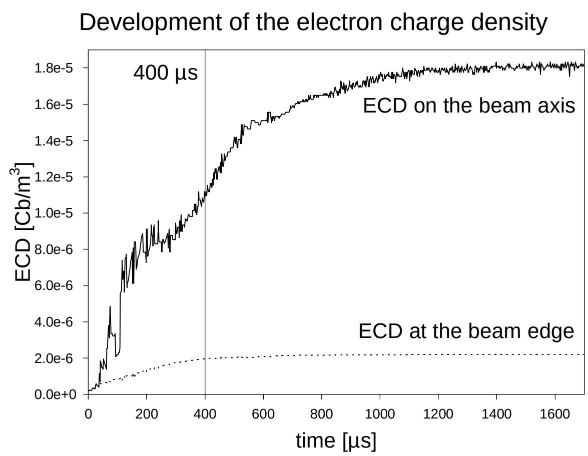

Fig. 3. Development of the electron charge density.

Fig.2 shows the development of the electron line charge density during the compensation. The rise time of compensation is determined by the intersection point of the increasing electron (LC_{DE}) and the beam ion line charge density (LCD_{BI}) and is given by 400 µs. Due to electron losses the rise of compensation needs longer then the min. rise time of compensation.

Figure 3 shows the evolution of the electron charge density during the compensation. The straight line indicates the electron charge density (ECD) on the beam axis; the dotted line is the electron charge density at the beam edge. As long as electron losses are negligible, the intersection point of the LCDE and the LCDBI indicates the time which is needed to produce enough electrons to compensate the space charge of the beam ions (figure 2). Figure 3. shows that the compensation process is continuous over the estimated rise time of compensation; the redistribution processes are not finished until 1000 µs.

For a better understanding of the compensation process the development of the kinetic and potential energy density of the produced electrons can behold.

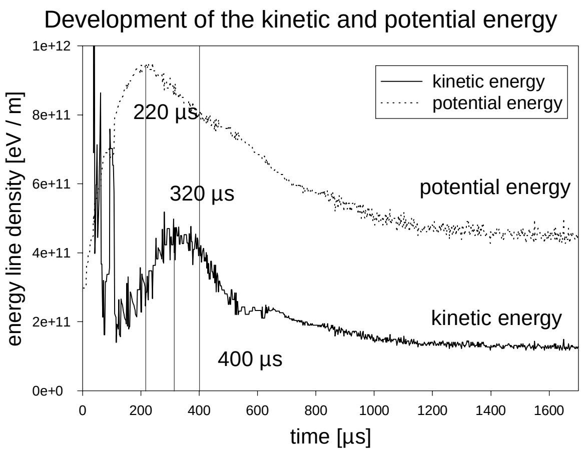

Fig. 4: Development of kinetic and potential energy

Figure 4 shows the development of the kinetic and potential energy line density of the CE. After the maximum at 320µs the kinetic energy decreases continuously, due to the dominant effect of decreasing temperature, due to cooling processes by losses of „hot" electrons. Up to the maximum at 220 µs the potential energy increases, due to accumulation of produced CE in the beam potential, then electron losses and the decrease of the beam potential causes the progression of the energy. Both curves saturate after 1000 µs, then all redistribution-, production- and loss-processes reach an equilibrium state. From 80 µs on the potential energy exceeds the kinetic energy, hence the compensation electrons are trapped in the beam potential.

The comparison of the LCDE with the electron charge density in regard to the decrease of the kinetic energy and the continuous increase of the relative density of the electrons on the beam axis (rE / rBI), shows a significant concentration of CE at the beam axis that takes longer than the actual rise time of compensation. The redistribution of CE (hot electrons are replaced by cold electrons, concentration on the beam axis) leads to a continuously decrease of the beam potential and the net space charge forces up to 1000 µs. This processes has no significant effect on the optical observable form of the ion beam. Therefore this redistribution process can not be observed by CCD-camera measurements.

3 SUMMARY

The compensation process and the rise time of compensation of a periodically decompensated 10 keV DC He+ ion beam has been investigated with a time resolved ion energy spectrometer. The acquisition of the ion energy spectra yields the potential of the beam edge and the beam axis. The experimental rise time of compensation differs from the minimum rise time, calculated for idealized conditions by a factor of 2. The experimentally determined rise time of compensation is 400µs.

In the future work the beam profile monitor will be replaced by a CCD camera. Further 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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