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

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Abstract

The maximum transportable current of space charge dominated ion beams in **l**ow **e**nergy **b**eam **t**ransport lines (LEBT) is mainly limited by space charge forces. Therefore, space charge compensation enhances the current limit. The **c**ompensation **e**lectrons (CE) are usually being produced by **r**esidual **g**as (RG) ionization. In this case beam pulses reach the degree of compensation necessary to achieve the maximum transportable beam current after a certain time. We developed a time-resolving **r**esidual **g**as **i**on (RGI) energy spectrometer and investigated the compensation process of a periodically decompensated beam. The results of these measurements will be compared to corresponding measurements at the stationary partially decompensated DC beam.

1 INTRODUCTION

The transport of an ion beam in a LEBT is often critical in respect to particle losses and the growth of emittance due to high space charge forces at low beam energies. Beams with **s**pace **c**harge **c**ompensation (SCC) can achieve higher beam currents under similar conditions and therefore the forces to focus the beam can be reduced. SCC can be derived from RG ionization and requires no further equipment. For this case the rise time lasts some 100 µs depending on the RG pressure and can be disturbing the transport of non DC ion beams. This problem was examined with our experiments.

First studies with a highly time resolving RGI energy spectrometer were presented at the EPAC 1994 [1]. This article describes supplementary the final results.

2 THEORY

Electrons and RGI are produced by ionizing and charge exchanging collisions of positive beam ions and RG atoms. The electrons are trapped in the beam potential and compensate the space charge of the beam. The RGI are expelled radially outwards. The kinetic energy of the RGI is given by the potential at the origin point, the start energy is negligible in most cases.

2.1 SCC rise time

The degree of compensation of an ion beam is usually defined by

$$K = \frac{Q'_c}{Q'_{uc}} \tag{1}$$

with the line charge Q'_c of the compensated beam and Q'_{dc} the line charge of the decompensated beam. Equation (1) is not very suitable for a practical use, because line charges are difficult to measure, but an estimate minimum rise time of the SCC by RG ionization can be deduced from it as

$$\tau = \frac{1}{N\sigma_e v_b}. \tag{2}$$

Here is N the RG density, σ_e the total cross section of the production of electrons ($5.5*10^{-17}$ cm^2 at 10 keV He^+ -> He) [2] and v_b the velocity of the beam ions. The simple equ. (2) takes no electron losses or sources of secondary electrons in consideration.

2.2 Self-consistent states

For a given density distribution of the beam ions and given temperature and axial density of the CE a self-consistent set of radial distributions of CE and RGI densities and beam potentials can be calculated [3] with a one dimensional model of the equilibrium compensation process. CE density and temperature are free parameters to be set randomly and specify a state in the multiplicity of all possible self-consistent states.

3 EXPERIMENTAL SETUP

3.1 LEBT

The LEBT consisted of an ion source, two solenoids for beam forming and the test box with a Faraday cup, a beam position monitor, the RGI analyzer and some cylindrical electrodes. Two of these electrodes were delimiting the drift region and were biased to a negative voltage of 600 V resp. 1.2 kV at the outlet to suppress CE losses and secondary electrons. The other electrode inside the delimited region was biased to a positive voltage (350 V, rectangle, 500 Hz) to decompensate the beam.

3.2 RGI energy analyzer

The RGI energy was examined with a 127° electrostatic spectrometer of the Hughes Rojanskij type. A fast single particle detector (Channeltron) allowed a time resolution of 2 µs (limited by the counter, not by the channeltron).

The time resolving measurements and the self compensation of the beam started with the falling edge of the pulsing voltage. A detailed description of the setup can be found in [1].

4 EXPERIMENTAL RESULTS

First, dynamic RGI energy spectra were taken of a periodically decompensated DC beam. To compare these results with a decompensated beam in an equilibrium state, in a second step the static RGI energy spectra were taken of a partially decompensated beam under similar conditions. Finally calculations of self-consistent states of the beam adapted in respect to the results of the energy spectra of the measurements were performed to get the CE distribution and temperature.

4.1 Dynamic self compensation

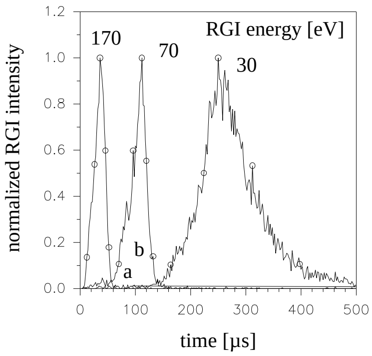

Figure 1: Some typical dynamic RGI intensities at certain RGI energies of an ion beam (He^+, 10 keV, 4.8 mA) as function of time after the start of the compensation ($4*10^{-5}$ hPa He RG pressure).

Fig. 1 shows the normalized raw data as recorded with the apparatus. Independently of the time the highest RGI energies are connected to the beam center and the lowest to the beam edge. Therefore, two limits (a,b) mark the time the beam edge (a) resp. center (b) having a certain potential.

Fig. 2 shows the beam potentials as deduced from many measurements as shown in fig. 1. The potential at the beam center decreases in the first 30 µs non linear (line marked difference). It is assumed that the CE fill the potential of the beam with a Maxwellian distribution determined by temperature.

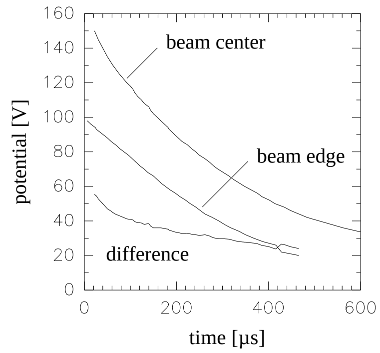

Figure 2: The potential of the beam center and the beam edge of an ion beam (He^+, 10 keV, 3 mA) as function of time ($5*10^{-5}$ hPa He RG pressure).

4.2 RGI energy spectra

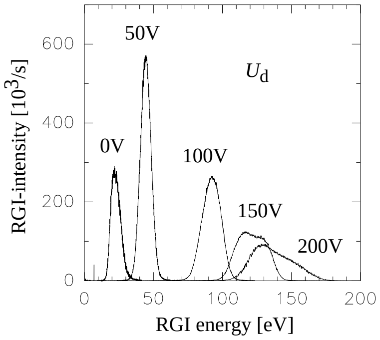

Figure 3: Some static RGI energy spectra of a partially compensated (electrode biased to U_d to decompensate the beam) ion beam (He^+, 10 keV, 3 mA).

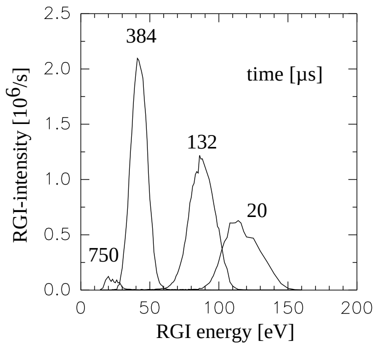

Figure 4: Some dynamic RGI energy spectra of an ion beam (He^+, 10 keV, 3 mA) at certain times ($5*10^{-5}$ hPa He RG pressure).

The energy spectra of partially decompensated beams were taken for different decompensation voltages (see fig. 3) to compare states of static decompensated beams with the dynamic states of the rise of the SCC.

Energy spectra are shown in fig. 4 at certain times after the start of the compensation process. The spectra were obtained from the data set shown in fig. 1 by rearrangement due to the exchange of the free (time) and the dependent (potential) variable. The shown dynamic spectra were selected in respect to the fact to have the same 10% base points as the static spectra.

4.3 Numerical calculations

Numerical calculations have been performed for differing CE temperature and density to get the same 10% base points as from the static and dynamic spectra. The following graphs show the results.

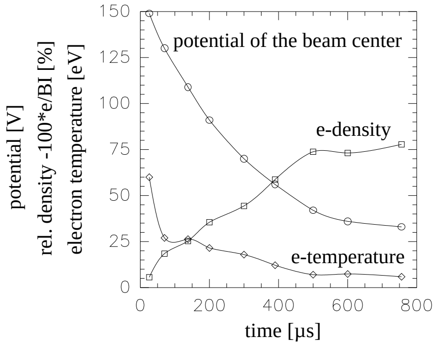

Figure 5: Relative electron density and temperature and the potential of the beam in the dynamic case as a function of the rise time obtained by self-consistent calculations (He^+, 10 keV, 3 mA, $5*10^{-5}$ hPa He RG pressure).

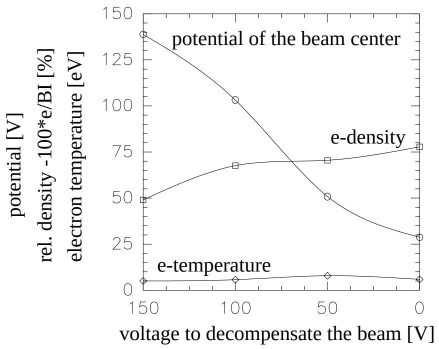

Figure 6: Relative electron density and temperature and the potential of the beam in the static case as a function of the decompensation voltage obtained by self-consistent calculations (He^+, 10 keV, 3 mA, $5*10^{-5}$ hPa He RG pressure).

In fig. 5 the potential of the beam drops monotonously in the dynamic process of SCC. This is in contrary to the very fast cooling of the electrons due to losses of hot electrons in the first 50 µs. The electron density at the center of the beam is linearly rising in the first 500 µs and then stable. In contrary the electron temperature seems to be stable in the static deompensation process (see fig. 6) and the compensation is only varied by the electron density.

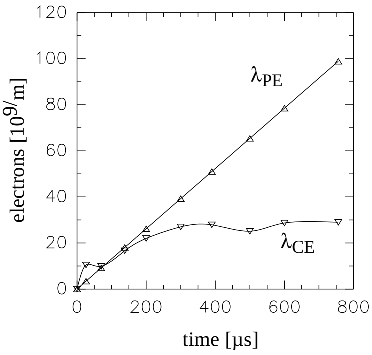

Figure 7: Electron line density of the produced (λ_{PE}) and the captured (λ_{CE}) electrons as a function of the time after the start of the SCC (He^+, 10 keV, 3 mA, $5*10^{-5}$ hPa He RG pressure).

In fig. 7 is shown that there are, during the first 70 µs, more CE trapped in the beam potential than produced by RG ionization, which might be due to the external secondary electrons in the static deompensation process. On the other hand the graph of the trapped electrons shows that with in the first 200 µs mostly all produced electrons are trapped and afterwards the loss of hot electrons becomes dominant. These app. 200 µs are in good agreement with the predicted rise time of the equ. 2 (217 µs).

5 CONCLUSIONS

A considerable expense of equipment and numerical calculations was invested to bring about the shown results, but the presented method is so far the only way to afford an insight into the process of compensation. The cooling of the electrons by losses of hot electrons at the beginning of the compensation and the increasing electron losses after the minimum rise time could not be investigated in detail as shown before.

Within the scope of a detailed examination the residual gas ion energy spectroscopy may lead to a fundamental understanding of the compensation process and an optimized build up of the SCC too. Therefore, possibly more detailed measurements and calculations are needed.

6 REFERENCES

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