INVESTIGATION OF THE FOCUS SHIFT DUE TO COMPENSATION PROCESS FOR LOW ENERGY ION BEAM TRANSPORT*

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Abstract

In magnetic Low Energy Beam Transport (LEBT) sections space charge compensation helps to enhance the transportable beam current and to reduce emittance growth due to space charge forces. For pulsed beams the time neccesary to etablish space charge compensation is of great interest for beam transport. Particularly with regard to beam injection into the first accelerator section (e.g. RFQ) investigation of effects on shift of the beam focus due to space charge compensation are very important. The achieved results helps to obviate a mismatch into the first RFQ.

To investigate the space charge compensation due to residual gas ionization, time resolved measurements using pulsed ion beams were performed at the LEBT system at the IAP and at the CEA-Saclay injektion line. A residual gas ion energy analyser (RGIA) equiped with a channeltron was used to measure the potential distribution as a function of time to estimate the rise time of compensation. For time resolved measurements (Δt_{min}=50ns) of the radial density profile of the ion beam a CCD-camera was applied. The measured data were used in a numerical simulation of selfconsistant eqilibrium states of the beam plasma [1] to determine plasma parameters such as the density, the temperature, the kinetic and potential energy of the compensation electrons as a function of time.

Measurements were done using focused proton beams (10keV, 2mA at IAP and 92keV, 62mA at CEA-Saclay) to get a better understanding of the influence of the compensation process. An interpretation of the acquired data and the achieved results will be presented.

1 INTRODUCTION

To reduce the emittance growth in a magnetic LEBT section and to increase the transmission, space charge compensation can be used in absence of external electrical fields. In case of positive ions the electrons necessary for the compensation will be produced by the ionisation residual gas. At the IAP diagnostic methods were developed, which allow to analyse the compensation process of ion beams using undisturbing diagnostic tools. For time resolved measurements a residual gas ion energy analyser (to determine the beam potential $\phi(r)$) and a CCD-camera (to get the distribution of the beam ions $\rho_{BI}(r)$) were used [2]. In the case of positive beam ions the steady state of the compensated ion beam is given by the balance of electron production and losses. Under the assumption, that electron losses are negligible during the built up process and that the compensation electrons are only produced by ionisation of the residual gas, the minimal rise time of (100%) compensation can be estimated by the equality of the values of beam ion line charge density and electron line charge density [3].

2 EXPERIMENTAL SETUP

Within the scope of the cooperation between IAP and CEA-Saclay time resolved measurements of the rise time of compensation of a 92kV, 62mA proton beam at the SILHI test stand has been done [3,4]. A wide range of experiences on time resolved measurements had been gained at the IAP by the investigations of 10keV He^+, Ar^+ and H^+-beams at a current of 1-2mA [5].

At the diagnostic chamber the CCD-camera for time resolved measurements of the beam profile and a residual gas ion analyser for beam potential measurements were installed perpendicular to each other. Secondary electron suppression electrodes framed the diagnostic region to ensure, that the investigated compensation process is supported exclusively by electrons produced in the diagnostic region.

The ion source was operated in pulsed mode using a repetition rate of 1kHz and a duty cycle of 90%. The trigger signal starts the synchronised RGIA and CCD-camera measurements approximately 3µs after the first signal of the beam current appears, due to the fact that the trigger signal is given by the first beam monitor right after the extraction system, when the extracted current exceeds a fixed threshold [3].

The compensated ion beam has the focus infront of the diagnostics (CCD-camera, RGIA). Right after the diagnostic section the measured current was approximatly 62mA. The transmission was ~85%.

3 MEASUREMENTS

Figure 1 shows false colour representations of time resolved CCD-camera measurements of pulsed ion beams

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for a residual gas pressure of 57*10^{-6}hPa. The time resolution was 1µs. A selection of images are composed to show the temporal development of the transverse beam ion distribution during the compensation process.

At the beginning the beam is lightly divergent, the focus is in the center of the image. Like measurements at parallel beam had shown [3], the beam diameter should increase, due to the rise of the beam current. In the present case this can not observe. Contrary to the rise of the beam current the beam diameter decreases up to 4 due to an accumulation of electrons. Between 4µs and 10µ the divergence angle apparently changes from divergance to convergance. This is caused by the shift of the focus to the right out of the image. At 10µs the beam is convergent, the focus is right beside the image. In the following the beam diameter decreases continuously. Reduction of the self field of the ion beam yields to the shrinking of the beam radius and to a shift of the focus back in the right half of the image. Over the hole compensation process a shift of 40mm was observed.

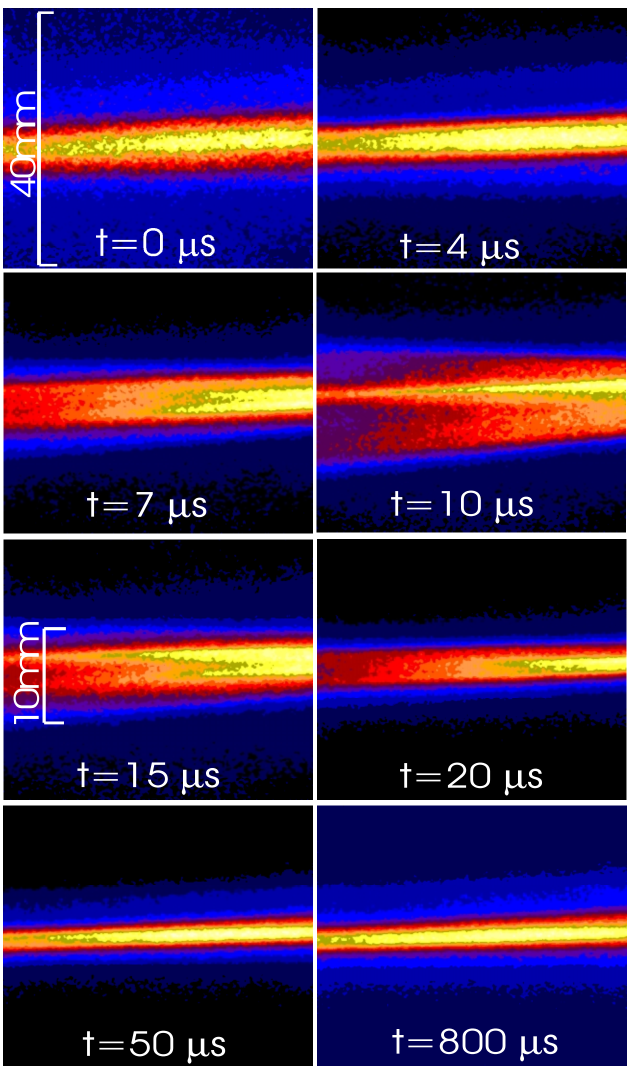

Fig. 1: False colour representations of time resolved CCD-measurements for different times: A significant shift of the ion beam focus can beam edge observed.

Due to the increasing compensation degree the focussing properties of the LEBT converge to the primary settings of the focussing system, which were adjust for the compensated state of the ion beam. Finally the beam shows a minimum diameter. After 50µs no further shift can be observe and the focus is again in the center of the image.

Figure 2 shows the time development of the beam potential, ascertained from RGIA measurements of a time resolution of 125ns. As well as the presented CCD-camera images the RGIA measurements were done for a residual gas pressure of 57*10^{-6} hPa.

The measurements show signals in two different energy regions (A&B). This were observed only for measurements on ion beams with a focus in the diagnostic section. It could not observe for parallele beams. This is an effect due to the focus shift, as a result of the rise of space charge compensation.

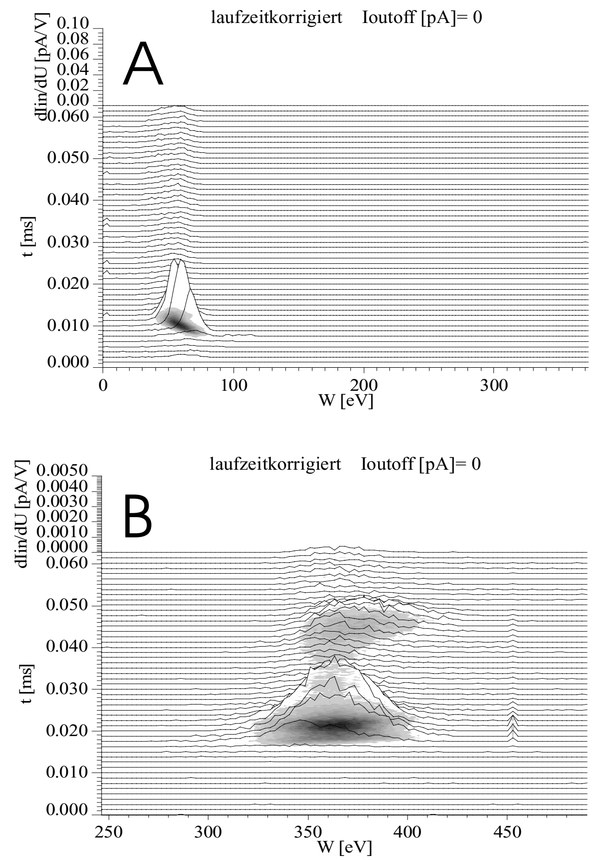

Fig. 2: RGIA measuremets of the temporal development of the beam potential for focused 92keV, 62mA proton beams.

Illustration A (fig. 2) shows a signal chain between 50eV and 100eV. This signals have the same charakteristic like the tempral development of the potentials, achieved from RGIA measurements of parallel ion beams [3]: At first the potential rise, owing to the increasing beam current. After the potential maximum is reached the compensation yields to a continuous reduction of the beam potential until a

sutturation value of ~60eV is reached. With reaching saturation the compensation is complet.
Beside signals A after ~20µs a secondary signal chain B appears at substantially higher energy between 320eV and 420eV, which shows a barbell shaped structur.
Figure 3 & 4 show shematicaly drawings of possible trajectories of ions, which are limited by the acceptance angle (acceptance cones) of the RGIA, to illustrate effects of the observed focus shift on the energy distribution of the detected residual gas ions.

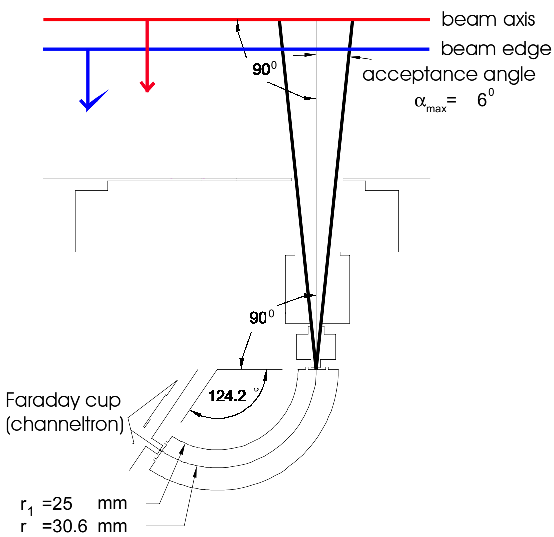

Fig. 3: Trajetories of detected residual gas ions of RGIA measuremets of the temporal development of the beam potential on a parallel ion beam.

In case of parallel beams (figure 3) it can be assumed, that the detected residual gas ions are accelerated lineally with mainly radial movement component and pass the entry slit in rectangular direction to the entry port of the RGIA. Therefore the detected ions obtain their kinetic energy mainly by the radial acceleration in the electrical field to the lining of the beam transport system. Hence the potential biased at the deflection electrodes of the RGIA corresponds to the beam potential at the point of production of the residual gas ions.
In case of focused ion beams (figure 4) it has to be considered, that additionaly gesidual gas ions with longitudinal components are abel to reach the RGIA detector. Subject to their start velocity this ions are detected at significant higher energies. In such case a correlation of the potential at the deflection electrodes of the RGIA and the beam potential is cruicial.
The measurements (figure 2) show, that first after 20µs signals appear at higher energies (B). The divergence angle of the beam have to exceed a limiting angle in the visual field of the RGIA to give conditions, under which residual gas ions with longitudinal momentum component are refocused in the deflection field of the RGIA and detected by the channeltron. To reach such conditions the focus have to shift in the pursuant area, which needs in the obove case 20µs.

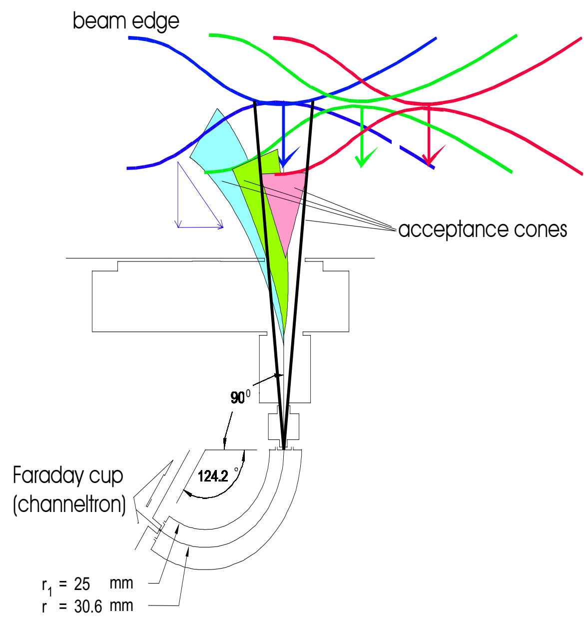

Fig. 4: Trajetories of detected residual gas ions of RGIA measuremets of the temporal development of the beam potential on a focused ion beam.

4 SUMMERY AND OUTLOOK

Time resolved measurements at focused ion beams show a significant shift (40mm) of the focus due to the rise of the space charge compensation. By optimizing and adjustiong an injection system this focus shift has to be takeen into account to obviate a mismatch into the first acceleration section (RFQ).
To investigate effects on the potential destribution and emittance growth due to changes of the cylinder symmetry of the ion beam during the compensation, it is planed to install two synchronized RGIA's in orthogonal orientation.

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