INFLUENCE OF SPACE CHARGE FLUCTUATIONS ON THE LOW ENERGY BEAM TRANSPORT OF HIGH CURRENT ION BEAMS[*]

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Abstract

For future high current ion accelerators like SNS, ESS or IFMIF [1] the beam behaviour in low energy beam transport sections is dominated by space charge forces. Therefore space charge fluctuations (e. g. source noise, typically. 1-5 % below 10 MHz) can drastically influence the beam transport. Beam losses and emittance growth are the most severe problems. For electrostatic systems (uncompensated transport) either a LEBT design insensitive to noise has to be found, or the origin of the fluctuations has to be eliminated. For space charge compensated transport as proposed for ESS and IFMIF the situation is different: No major influence on beam transport is expected from fluctuations below a cut-off frequency given by the production rate of the compensation particles. Above this frequency the fluctuations can not be compensated totally, but particle production and redistribution of the compensation particles reduces the influence of the fluctuations. Above a second cut-off frequency given by the density and temperature of the compensation particles, their redistribution is slower than the space charge fluctuations. Transport simulations for the IFMIF injector including space charge fluctuations (±2 % at frequencies from 20 kHz up to 0.5 GHz) will be presented together with a determination of the cut-off frequencies. The results will be compared with measurements of the rise time for space charge compensation.

1 ION EXTRACTION

Simulations on the influence of varying beam current on beam extraction have been performed using the IGUN [2] code. It was assumed that a varying plasma density in the ion source is the main source for the current fluctuation. The geometry and the field distribution of the triode extraction system including the beam trajectories for the nominal current of 140 mA D^+ are shown in figure 1. The design philosophy for the extraction system was conservative ($j \approx 2.8$ mA/mm^2 and $E_z < 6$ kV/mm). Figure 2 shows the emittance at the beginning of the electrostatic LEBT for 3 different ion currents (137.2, 140 and 142.8 mA) and the time integrated case (gained by superposition of the three individual patterns).

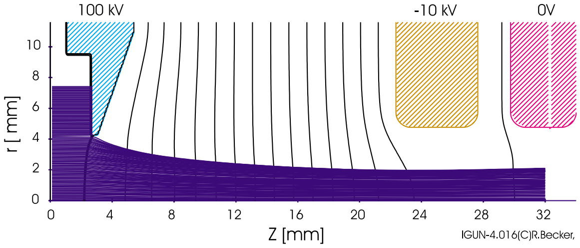

Fig. 1 : Geometry used for simulation of the ion extraction. The potential distribution and beam trajectories (nominal current 140 mA) are shown.

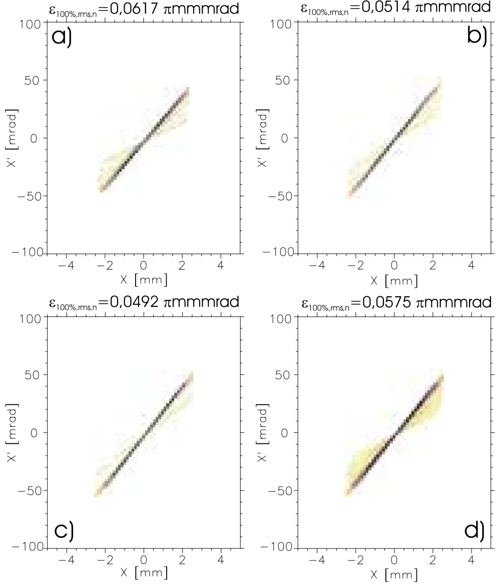

Fig. 2 : Emittances at the entrance of the LEBT system for varied extracted beam currents (a.) 137.2 mA, b.) 140 mA, c.) 142.8 mA, d.) time integrated (a+b+c)).

Due to the space charge forces the beam radius and angle increase slightly with the current. The decrease of the RMS-emittance with increasing beam current indicates, that the chosen extraction system is optimised for an slightly higher current than the nominal 140 mA.

2 ELECTROSTATIC TRANSPORT

In figure 3 the layout of the electrostatic LEBT system used for the calculations of the beam transport is shown. The LEBT was kept as short as possible ($E_z < 7.7$ kV/mm) to reduce the influence of the space charge forces.

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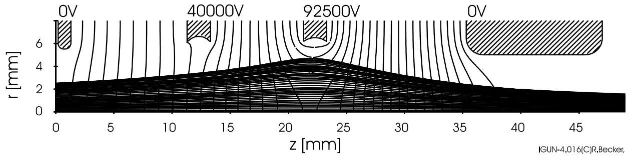

Fig. 3: Geometry of the electrostatic LEBT system used for the simulations. Additionally the distribution of the potential and the beam trajectories (140 mA) are shown.

The particular shape of the electrodes was used to flatten the field distribution and therefrom reduce aberrations. Figure 4 shows the emittances at the exit of the electrostatic LEBT. Due to the space charge forces the beam radius decreases slightly (1.6, 1.5 and 1.3 mm) and the envelope angle increases stronger (50, 60 and 80 mrad) with the beam current. This behaviour is caused by the increasing space charge leading to an higher degree of lens filling in the region of the last electrode causing a stronger deflection. The increase of the RMS-emittance shows the effect of higher lens aberrations due to the increased degree of lens filling. Due to the current fluctuations the RMS-emittance at source exit is slightly (12 %) higher than for the nominal current. At the LEBT exit the time integrated RMS-emittance has already increased from 33 % (compared with the nominal current) to 77 % and exceeds the requirements for IFMIF. The additional 44 % is mainly caused by the 142.8 mA case.

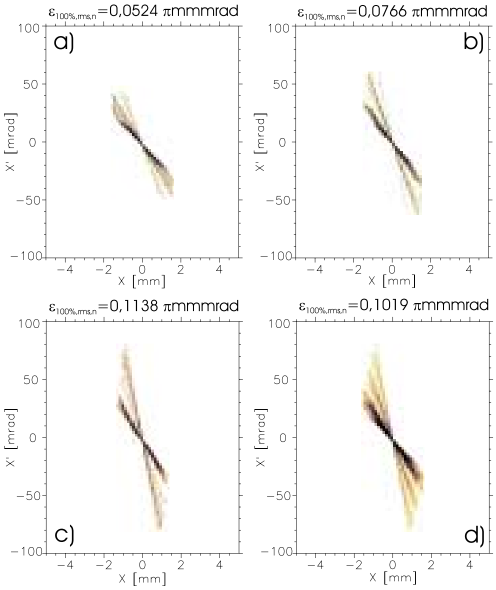

Fig. 4: Output emittances of the electrostatic LEBT gained by transport simulations using 3 different ion currents (a-c) and superposing them for time integration (d).

3 MAGNETIC TRANSPORT

For the simulation of the influence of varying beam current on space charge compensated beam transport the knowledge of the time scale of the disturbance (fluctuation frequency) in comparison with the reply time of the compensated beam plasma is necessary. Therefrom two frequencies can be defined. The maximum frequency is given roughly by the plasma frequency (for IFMIF $f_{max} \approx 0.5$ GHz) and the minimum frequency (f_{min}) is given by the production mechanisms of the compensation particles (rise time of compensation). Below f_{min} the compensation is adiabatic and can be neglected for beam transport properties, above f_{max} the compensation can not follow the disturbance.

3.1Rise time of compensation

For IFMIF f_{min} has been determined from rise time measurements at the H^+ injector in Saclay [3]. Figure 5 shows the development of the beam current (for a pulsed ion source) as a function of time. The rise time of the ion current is approximately 7 µs.

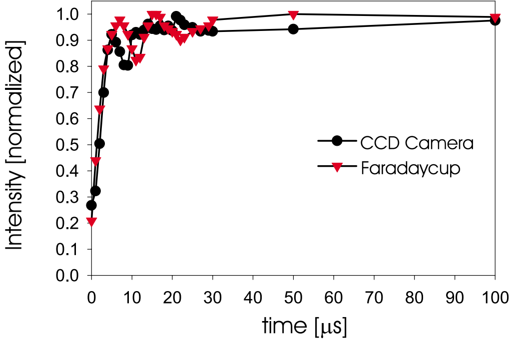

Fig. 5 : Normalised ion current as a function of time gained by faraday cup and CCD camera measurements on a pulsed ion beam (H^+, 67 mA, 92 keV).

Fig. 6 shows the development of the beam potential on beam axis as a function of time for different residual gas pressures and therefore for different theoretical rise times of compensation (2.3-10 µs). The rising potential for the first 2-3 µs is due to the rise time of the source, the falling potentials after 3 µs is already the effect of the establishing space charge compensation. For IFMIF the lower boundary frequency (f_{min}) for preservation of space charge compensation will be 200 kHz > f_{min} > 20 kHz (depending on the residual gas pressure).

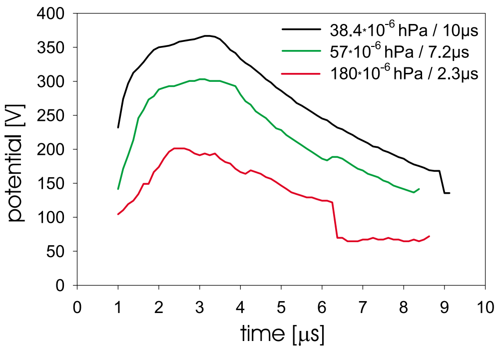

Fig. 6 : Development of the beam potential as a function of time for different residual gas pressures measured by time resolved residual gas ion energy spectrometry.

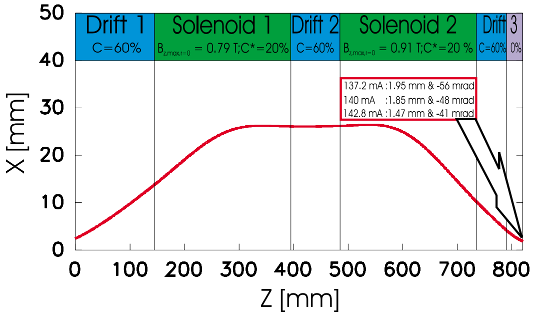

Figure 7: Schematic drawing of the magnetic LEBT for IFMIF including beam envelope for 140 mA.

3.2 Beam transport calculations.

Simulations have been performed for the LEBT system shown in fig. 7 using the LINTRA [4] code for 3 different scenarios (f_{noise}<20 kHz; f_{noise}≈100 kHz; f_{noise}>500 MHz). The degree of space charge compensation (C) has been varied along z according to [5]. Figure 8 shows the results of simulations for source noise below 20 kHz (no space charge fluctuation). The variation of the emittances at the exit of the LEBT is exclusively caused by the varying input emittances (see fig. 1).

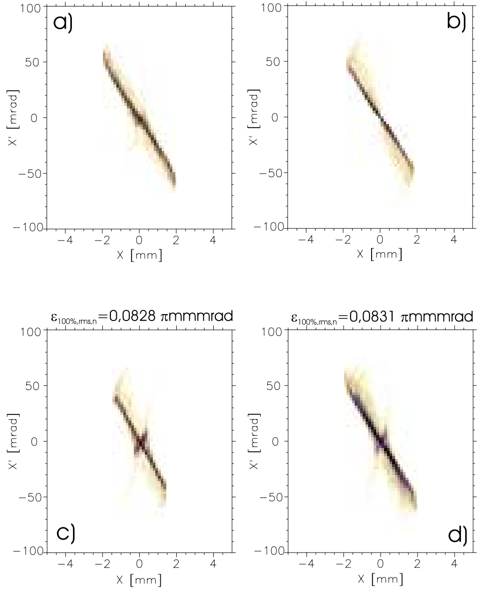

Figure 8: Simulation of beam transport for constant space charge (f_{noise}<20 kHz) using entrance emittances according to fig. 1.

Figure 9a) shows the result of a simulation under the assumption of source noise frequencies of ≈100 kHz (space charge fluctuations are partly compensated, the variation is ±1.2 %). The variation of the emittances at the exit of the magnetic LEBT section is still mainly influenced by the variation of the input emittance delivered by the ion source only. Figure 9b) shows the result of a simulation under assumption of source noise frequencies above 500 MHz (constant number of compensation particles). The variation of the emittances at the exit of the magnetic LEBT section is still mainly influenced by the variation of the input emittance.

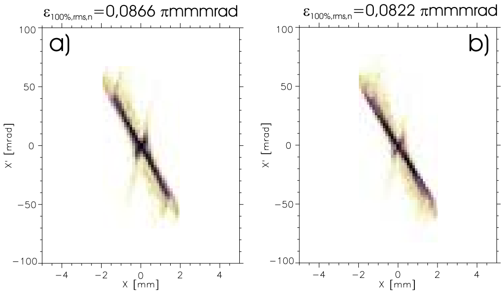

Figure 9 : Time integrated emittance gained from simulations of beam transport using entrance emittances according to fig.1(a) f_{noise}≈100 kHz, b) f_{noise}≈500 MHz).

4 CONCLUSIONS

The influence of current fluctuations of ±2 % on low energy beam transport has been determined numerically for 2 different transport systems. For electrostatic systems the largest growth of the time integrated emittance has been found (77 %, at app. 50 % degree of lens filling). This emittance growth is partly caused by the variation of the delivered source emittance and the varying space charge in the lens. Therefrom electrostatic focussing is not sufficient for IFMIF. Space charge compensated transport shows better results (44 % for solenoids below a frequency of 20 kHz at 50 % degree of lens filling). For compensated transport the main source of emittance growth is the variation of the source emittance. An overall growth of the time integrated emittance of 15 % from the nominal 0.075 πmmmrad) to 0.0866 πmmmrad (see fig. 9 a, worst case, overall emittance growth 50 %) is not significant and mostly caused by the variation of the input emittance delivered by the ion source. Therefrom a current variation of ±2 % is not dominant for compensated transport.

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