LOW ENERGY BEAM TRANSPORT FOR HEAVY IONS USING SPACE CHARGE LENSES *

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Abstract

Low energy beam transport (LEBT) of high perveance heavy ion beams suffers from high space charge forces and the high ion mass. Space charge compensation reduces the necessary focusing force of the lenses and the radius of the beam in the lenses. Therefrom the emittance growth due to aberrations and self fields is reduced as well. The use of electrostatic lenses is restricted due to decompensation by the electric fields the necessary high electrode potentials and the resulting technical problems. On the other side magnetic lenses for high mass ions, suffer from the necessary high magnetic fields.

A different approach for LEBT are Gabor lenses using a stable space charge cloud for focusing of an ion beam at drastically reduced magnetic and electrostatic fields strength. They could be a serious alternative to conventional LEBT systems. Double Gabor lenses (DGPL) combine strong cylinder symmetric focussing with partly space charge compensation and a high tolerance against source noise and current fluctuations at possibly reduced investment costs.

Experimental results using a high perveance Xe^+ beam using a double Gabor lens LEBT system will be presented together with numerical simulations. Detailed behaviour of the space charge cloud including the radial space charge density distribution and the temperature of the enclosed electrons and their relevance for the HIDIF project will be shown.

1 EXPERIMENTS

Two experiments have been performed. The schematic set up is shown in figure 1.

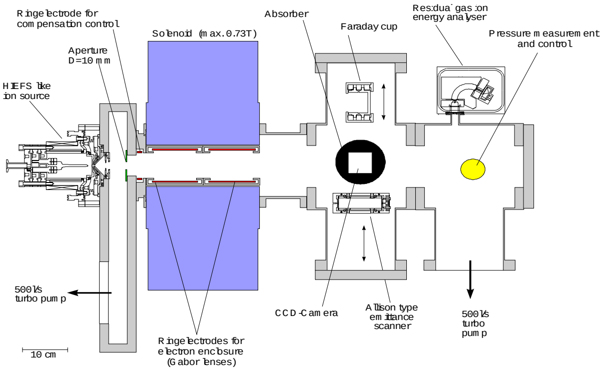


Figure 1: Experimental set up.

It consists of an volume type ion source, a first diagnostic chamber with a differential pumping system, a ring electrode to preserve compensation in the drift region and a second diagnostic section. In the second diagnostic chamber a Faraday cup for beam current measurements, an Allison type emittance measurement device and a slow scan CCD camera was installed as well as residual gas pressure measurement devices and control system. In a first step the emittance of the beam at the lens entrance was measured. The ion source delivered 0.52 mA (Xe^+, 12 keV, $K=2.93*10^{-3}$) and 2.28 mA (He^+, 12 keV, $K=2.25*10^{-3}$) reference beam. The two emittances at the lens entrance are shown in figure 2 (Xe: $\varepsilon_{n,rms,100\%} = 0.0076$ πmmmrad, He: $\varepsilon_{n,rms,100\%} = 0.0273$ πmmmrad).

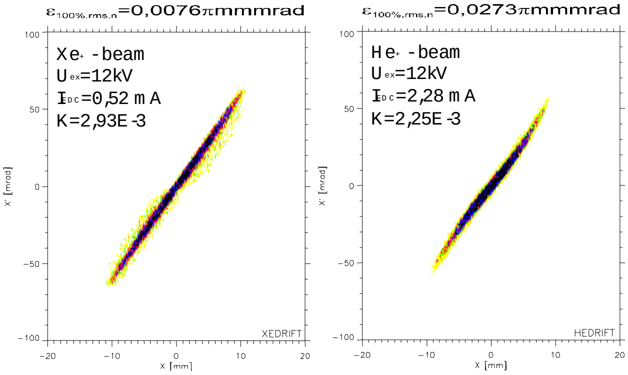


Figure 2: Emittance of the Xe^+ beam and reference He^+ beam at lens entrtance

Beam transport calculations using LINTRA [7] delivers a compensation degree of app. 95 % in the drift section. The Xe/He beam radius at lens entrance is 10,7/9.1 mm, therefrom the degree of lens filling is 100 %. To prevent a further increase of the beam diameter due to the heating of compensation electrons by lens electrons, the ring electrode (biased at –600 V) is used to separate the drift region and the lens electrically. After the measurements of the initial emittance the DGPL (see fig. 3) was inserted between the drift section and the second diagnostic chamber. Fig. 4 shows the phase space distribution of the Xe^+ beam and the reference He^+ beam behind the focus for given lens parameters. The measured emittance ($\varepsilon_{n,rms,100\%}$ = 0.0765 πmmmrad) (fig.4 left) shows, that a beam focusing can be reached using the lens parameters $B_{z,max}$ = 0,02 T and an anode voltages of 5,0 kV. One possible explanation for aberrations near beam axis are extraction of residual gas ions out of DGPL on high residual gas pressure. For given geometry the lowest external fields for establishing the space charge cloud into the DGPL [8] high charge density and expanse of the space charge cloud are in opposite to maximum extraction slight beam energy of only 12 keV. Minor changes at DGPL parameters yields to a virulence of beam behaviour therefore the investigation of the beam development is difficult.

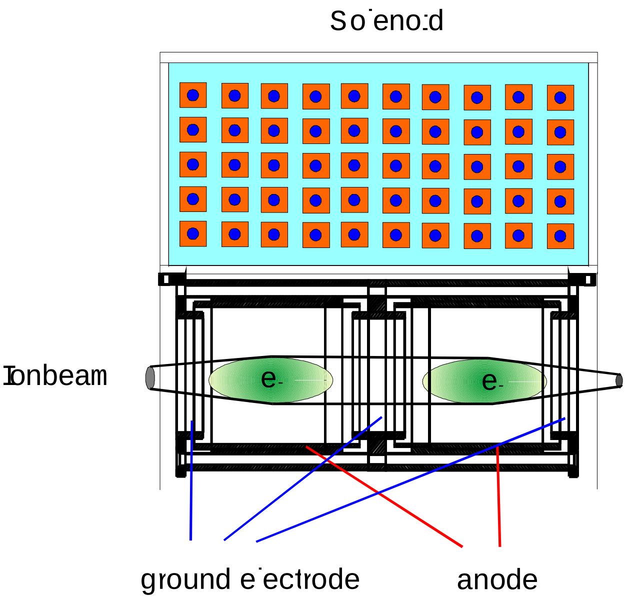


Figure 3: Double Gabor lens system.

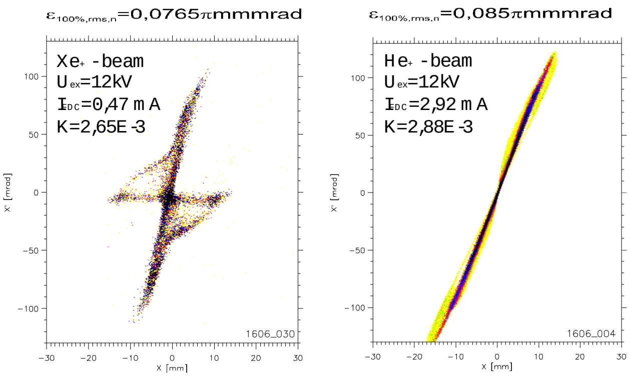


Figure 4: Measured beam emittance after the double Gabor lens system for given external fields.

2 THEORY

The charge density and the expanse of the space charge cloud determine the focusing strength of a Gabor lens. The space charge cloud can only be established if transversal and longitudinal enclosure conditions are simultaneously fulfilled [8]. Gabor showed that by absence of external electric fields the transversal enclosure condition is given by the Hull-Brillouin flow and therefrom the maximum electron density can be calculated by:

$$\rho_{e,\max,rad} = \frac{e\varepsilon_0 B_z^2}{2m_e}$$

The upper limit for the longitudinal enclosure condition is given by zero potential on the lens axis. Both of these criteria solely overestimate the space charge density significantly. Additionally the longitudinal enclosure condition is drastically influenced by thermalization of the enclosed particles and therefrom due to losses of fast particles in the Maxwellian tail. an numerical simulation calculating the local density distribution for given external magnetic and electric fields [9] yields good results in comparison to experiments. Fig 5 shows the result of an similar calculation for the presented experiment using the program code GABOR. On the right curve the external potential distribution is shown as a function of the radius and the longitudinal coordinate z. The radial electron density distribution is almost homogeneous (excluding the axis) and therefrom the focusing fields are linear (reduction of aberrations).

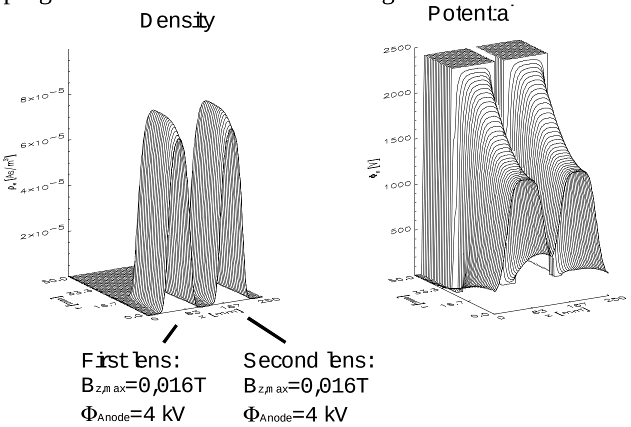


Figure 5: Calculated local density distribution for given external fields.

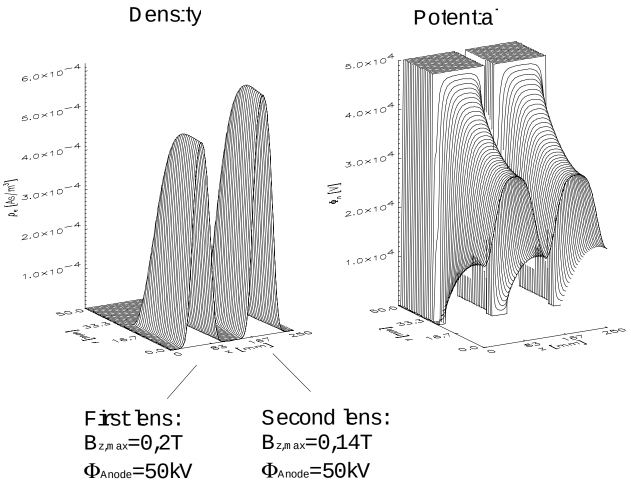
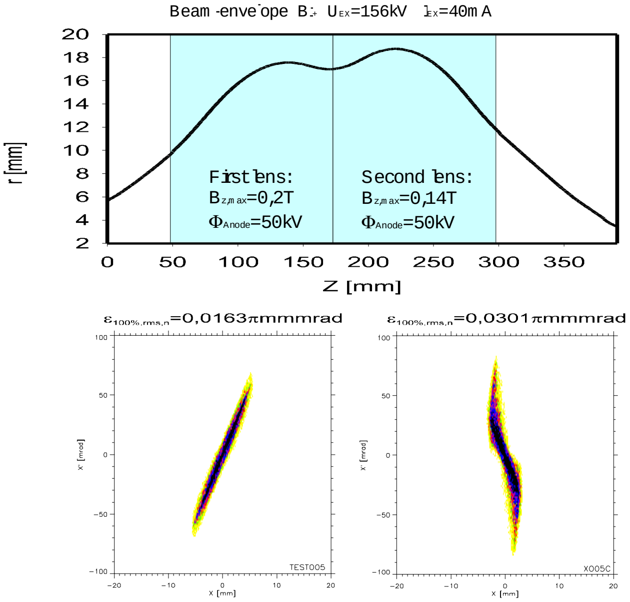


Figure 6: Calculated local density distribution for given external fields for HIDIF scenario.

For comparison fig. 6 shows the result of an calculation for the HIDIF scenario with higher and different radial electron density distribution and the external potential distribution.

3 BEAM TRANSPORT SIMULATIONS

The results of the compensated beam transport calculations using LINTRA and the results of GABOR are shown in fig 7 for the proposed HIDIF injector. The development of the beam envelope shows the possibility of a focusing of a BI^+, 156kV, 40mA ion beam by small external electrostatic and magnetic fields. The phase space distribution for the calculated transport reach the acceptability of the following RFQ.



Initial (calculated)

Final (calculated)

Figure 7: Calculated beam transport using LINTRA for proposed HIDIF injector.

4 CONCLUSIONS

The presented experiments and simulations show that by using of DGPLs the LEBT-requirements for an heavy ion injector are fulfil. Further investigation using Xe^+ ion beams with beam energy above 12 keV and pulsed beams are in preparation. Also the optimization of the geometry of the DGPL will upgrade the enclosure conditions and therefore the attributes of the lens.

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