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Low Energy Beam Transport for HIDIF

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Abstract

Low energy beam transport (LEBT) for a future heavy ion driven inertial fusion (HIDIF [1]) facility is a crucial point using a Bi^+ beam of 40 mA at 156 keV. High space charge forces (generalised perveance $K=3.6*10^{-3}$) restrict the use of electrostatic focussing systems. On the other hand magnetic lenses using space charge compensation suffer from the low particle velocity. Additionally the emittance requirements are very high in order to avoid particle losses in the linac and at ring injection [2]. Furthermore source noise and rise time of space charge compensation [3] might enhance particle losses and emittance. Gabor lenses [4] using a continuous space charge cloud for focussing could be a serious alternative to conventional LEBT systems. They combine strong cylinder symmetric focussing with partly space charge compensation and low emittance growth due to lower non linear fields. A high tolerance against source noise and current fluctuations and reduced investment costs are other possible advantages. The proof of principle has already been shown [5, 6]. To broaden the experiences an experimental program was started. Therefrom the first experimental results using a double Gabor lens (DGPL, see fig. 1) LEBT system for transporting an high perveance Xe^+ beam will be presented and the results of numerical simulations will be shown.

1. Theory and simulations

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 [7]. Gabor showed that by absence of external electric fields the transversal enclosure condition (first criteria) 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 (second criteria) is given by zero potential on the lens axis. This longitudinal enclosure condition is drastically influenced by thermalization of the enclosed particles and therefrom by losses of fast particles in the Maxwellian tail. Both of these criteria solely overestimate the space charge density significantly.

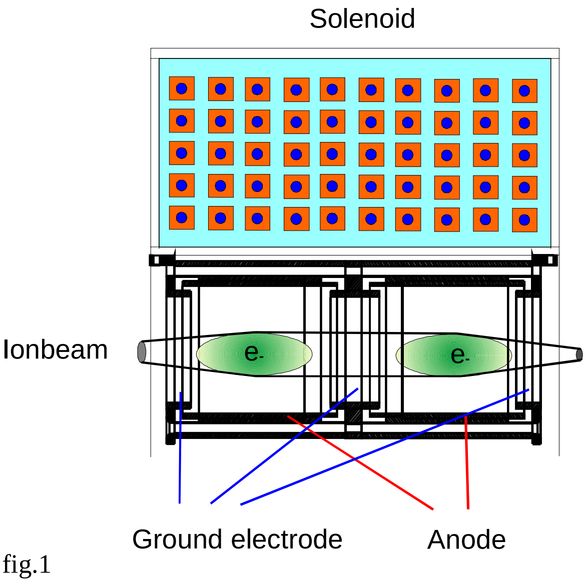


fig.1

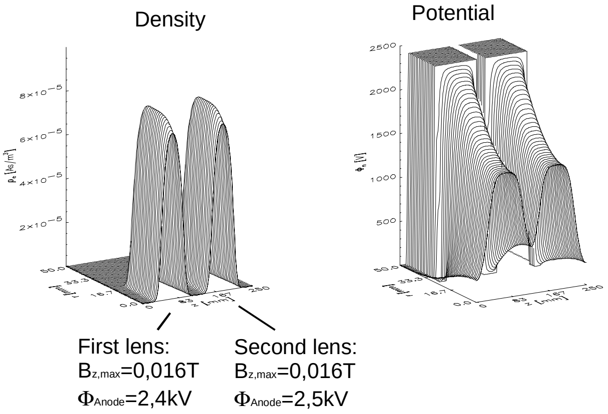


fig.2

Therefore a numerical simulation used to calculate the local density distribution for given external magnetic and electric fields[8]. Fig 2 shows the result of an simulation using the program code GABOR. The geometry and external fields (U_A=2.4 kV, B_z = 0.016 T) are equivalent to the DGPL of the presented experiment. On the right curve the resulting potential distribution including external fields and space charge (the potential depression by the space charge is ΔU= 500 V) is shown as a function of the radius and the longitudinal coordinate z. The radial electron density ($\rho_{e,max}$ = 8.3*10^{-5}As/m^3, electron temperature T_e app. 100 eV) distribution (left curve) is almost homogeneous (excluding the axis) and therefrom the focusing fields are nearly linear (reduction of aberrations). For comparison fig. 3 shows the result of an calculation for the HIDIF scenario using a similar geometry.

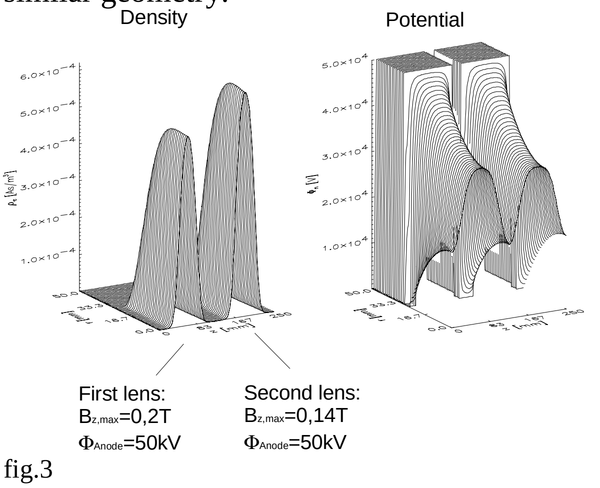
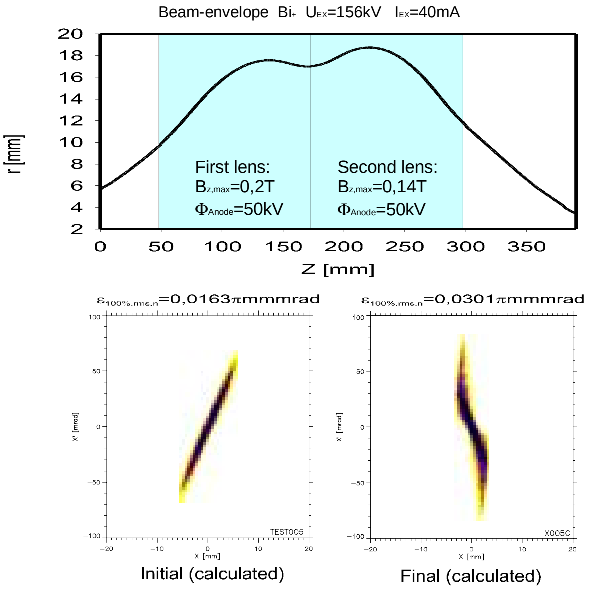


fig.3

Due to the higher external fields (U_A=50 kV, B_z = 0.2 T) the maximum electron density increases ($\rho_{e,max}$ = 6*10^{-4}As/m^3) as well as the potential depression inside the lens and the electron temperature (ΔU= 10 kV, T_e app. 1600 eV) and therefrom the focussing strength.

2. Beam transport simulations

The results of the compensated beam transport calculations for the proposed HIDIF injector using LINTRA [9] and GABOR are displayed in fig 4. The development of the beam envelope shows, that it is possible to focus a Bi^+ beam of 156keV and 40mA by using reasonable external electrostatic and magnetic fields. The emittance growths is $\Delta\varepsilon_{n,rms,100}$ = 0.014 πmmmrad,($\varepsilon_{initial,n,rms,100}$ = 0.016 πmmmrad, $\varepsilon_{final,\ n,rms,100}$ = 0.03 πmmmrad) at app. 90 % of lens filling. For the calculated transport the emittance is within the acceptance of the following RFQ.



Initial (calculated) Final (calculated)

fig.4

3. Experiments

An schematic drawing of the experimental set up is shown in figure 5. It consists of an volume type ion source delivering an maximum current of 0.6 mA Xe^+ at 10 keV, a first diagnostic chamber with a differential pumping system, a drift section, 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 device and control system. In a first step the emittance of the beam at lens entrance was measured without the DGPL. The beam emittance is shown in figure 6 (Xe$^+$, 10 keV,0.32 mA, $K=3.36*10^{-3}$,. $\varepsilon_{n,rms,100\%}$ = 0.0051 πmmmrad). Beam transport calculations using LINTRA proof a compensation degree of app. 95 % in the drift section. The beam radius at lens entrance is 18 mm, therefrom the degree of lens filling is 80 %. 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 electrically the drift region from the lens.

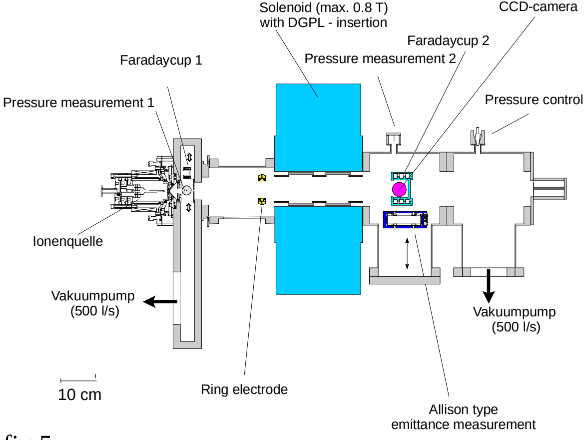


fig.5

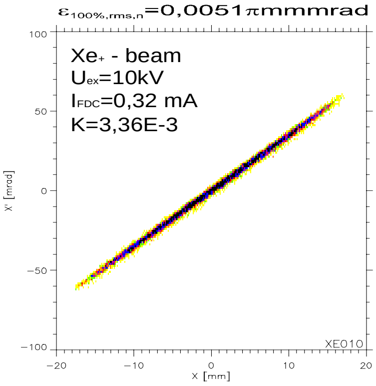


fig.6

After the measurements of the initial emittance the DGPL was inserted between the drift section and the second diagnostic chamber.The very first (preliminary results) show the development of the phase space distribution in dependence of two different settings of lens parameters. For low anode potential ($B_{z,max}$ = 0,016 T, U_A=1.6 kV see fig 7 left) the measured beam emittance shows anti S-shaped aberrations. This can be interpreted as the formation of a small space charge cloud near the axis of the DGPL. For higher anode potential ($B_{z,max}$ = 0,016 T, U_A=2.4 kV see fig 7, right) and therefrom improved electron enclosure the emittance measurements ($\varepsilon_{n,rms,100\%}$ = 0.0069 πmmmrad) shows an beam behind the focus.

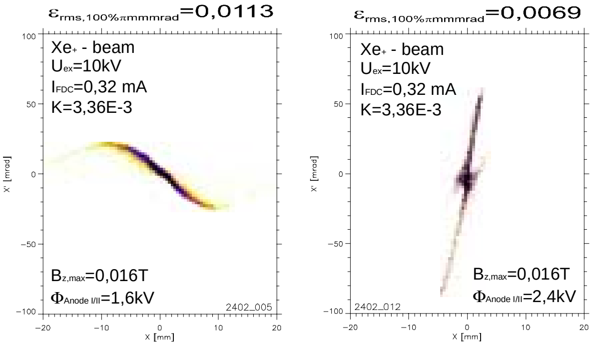


fig.7

Conclusions

The presented simulations show in principle the ability of a DGPL to fulfil the required injection parameters. Within the first experiments the input emittance of an Xe$^+$ beam at low beam energy was measured and a constant space charge cloud was established in both lenses simultaneously. Very first measurements on the influence of the space charge cloud in the lens on beam propagation have been performed with encouraging results. Further investigation on beam transport properties are planned.

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