ALTERNATIVE COMPACT LEBT DESIGN FOR THE FAIR INJECTOR UPGRADE*

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Abstract

In order to provide high intensity and brightness of the uranium beam for the planned FAIR project, the existing High Current Injector (HSI) at GSI has to be upgraded [1]. A part of the upgrade program is the design and construction of a compact straight injection line into the 36 MHz Radio Frequency Quadrupole of the HSI. As an alternative to a conventional LEBT design consisting of magnetic systems such as solenoids or quadrupoles, the application of Gabor lenses has been investigated.

The focusing force of the Gabor lens is created by the space charge of an electron cloud, confined by crossed magnetic and electric fields inside the lens volume. Therefore, the Gabor lens combines strong, electrostatic focusing with simultaneous space-charge compensation. In previously performed beam transport experiments at GSI a prototype Gabor lens has been tested successfully. Furthermore, the operation and performance of such a device in a real accelerator environment has been studied.

In this contribution an alternative LEBT design will be discussed and an improved Gabor lens design will be presented.

INTRODUCTION

The application of Gabor lenses as an ion optics system has been studied for a long period by different research groups. Due to its strong electrostatic focusing force in combination with the space-charge compensation of high-intensity ion beams the Gabor lens could find effective and relatively low cost application in the low energy beam transport section (LEBT) of heavy linear accelerators [2].

However, the experiments at the Institute for Applied Physics (IAP) in Frankfurt were limited to low intensities and low masses of the provided ion beam. For the first time a prototype Gabor lens was successfully tested with a space-charge dominated 2.2 keV/u Ar^+-beam at GSI in mid-2012 [3].

As a consequence of the previously performed beam transport experiments, the suitability of Gabor lenses as a compact LEBT for the transport of an uranium beam using the example of the existing GSI HSI-Frontend was numerically investigated. Furthermore, a technically improved Gabor lens, which would meet the requirements was designed and a control system to automatically adjust the focusing strength is under development.

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ION BEAM FOCUSING USING GABOR LENSES

There are several effects that lead to an emittance growth, which shall be discussed for Gabor lens focusing in general.

Chromatic aberrations have a strong influence on the imaging quality since the focal length of the lens is energy dependent and therefore sensitive to variations in beam energy [3]. However, the energy spread of the beam right after the ion source is negligible and usually doesn't contribute to an emittance growth.

Spherical aberrations in case of the Gabor lens differ from conventional, magnetostatic ion optics in the radial trend of the focusing force i.e. the space-charge field of the nonneutral plasma decreases towards its edge. As the beam passes this nonlinear part of the electric field that results from the Debye drop-off of the plasma cloud, aberrations in form of a negative s-shape in the phase space occur (see Fig. 1). This

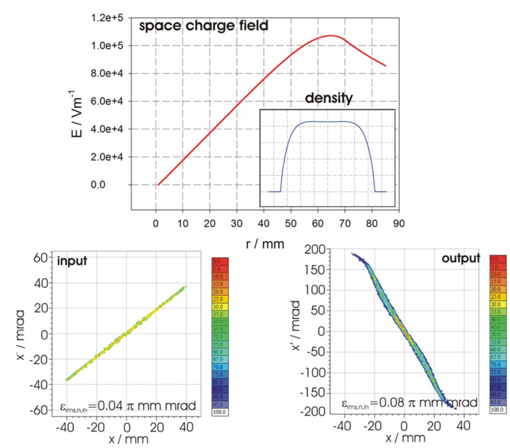

Figure 1: Example of spherical aberrations as a result of beam ions passing the nonlinear part of the electric space-charge field.

effect has a major contribution to an emittance growth.

Besides these well-known effects, an emittance growth is also observed when plasma instabilities arise if the Gabor lens is operated in a regime far from its working point for the electron confinement

$$\Phi_A = \frac{e \cdot R_p^2 \cdot \left(1 + 2 \cdot ln\left(\frac{R_A}{R_p}\right)\right) \cdot B_z^2}{8 \cdot m_e} \quad (1)$$

where Φ_A is the anode potential, R_p the ground radius, R_A the anode radius and B_z the confining magnetic field.

Accordingly, this effect does not contribute if the lens is operated appropriately.

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ALTERNATIVE LEBT DESIGN

Since the HSI-Frontend at GSI provides unique conditions concerning the intensity and brilliance of the provided ion beam, the phase space distribution of the extracted beam from the ion source [4] as well as the HSI-RFQ zero-current acceptance was used for beam transport investigations.

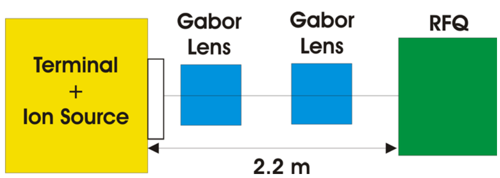

Figure 2: Layout of the alternative LEBT consisting of two Gabor lenses.

The scheme of the LEBT consisting of two Gabor lenses with an overall length of 2.2 m is presented in Fig. 2. Simulations with the 2D code *tralitrala* [5] were performed using an rms-equivalent KV distribution.

The distance between terminal and the first lens is 200 mm, the distance between first and second lens is 800 mm and the distance between second lens and RFQ entrance is 340 mm while the length of each Gabor lens is 436 mm. A space-charge compensation degree of 100% for the 2.2 keV/u $^{238}U^{4+}$-beam was assumed and the confinement parameters were Φ_A=9.8 kV, B_z=8 mT for the first and Φ_A=29 kV, B_z=13.7 mT for the second lens.

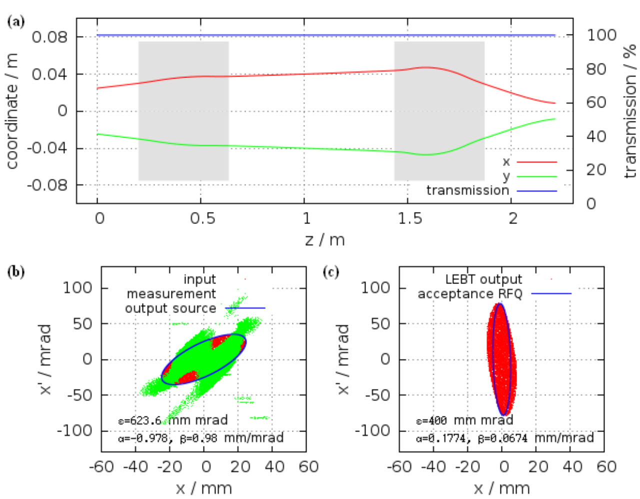

Figure 3: (a) Beam envelopes of the uranium beam, (b) KV input distribution in comparison with the measured beam emittance and (c) output distribution in comparison with the RFQ zero-current acceptance.

As shown in Fig. 3, although the transmission through the LEBT is 100%, obviously the full beam cannot be matched into the zero-current acceptance of the RFQ due to the higher emittance. Slight aberrations in the phase space distribution occur as the beam passes the nonlinear part of the electric space-charge field in the second lens.

In order to investigate which input distribution that is comparable to the measured data can be transported through the LEBT and matched into the RFQ without beam losses, backwards calculations were performed (see Fig. 4).

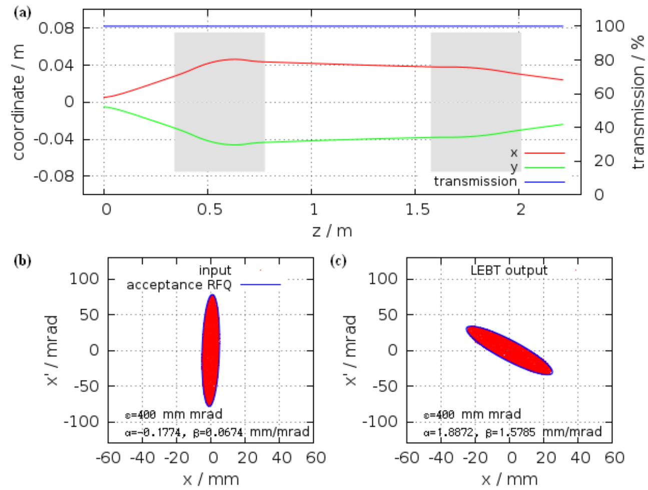

Figure 4: (a) Beam envelopes of the uranium beam, (b) KV input distribution equivalent to the RFQ zero-current acceptance and (c) output distribution of the LEBT.

The RFQ zero-current acceptance was used as input and the focusing strengths of the Gabor lenses were adjusted to match the beam according to the ellipse parameters of the rms equivalent KV distribution of the ion source output (see Fig. 3 (b)). Doing so, one can define an "ideal input" or "acceptance" of ϵ = 400 mm mrad, α=-1.8875, β=1.5785 mm/mrad for the presented LEBT layout.

Subsequently, particle distributions generated from measured data of the uranium beam assuming the partitions of the 3+ and 4+ charge states to 35% resp. 65% [6] were tracked through the beam line (see Fig. 5).

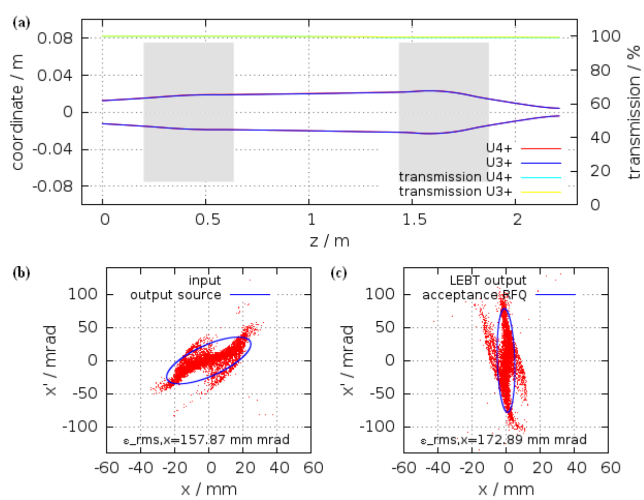

Figure 5: (a) Rms envelopes of the uranium beam, (b) particle distribution generated from the measured data of the uranium beam and (c) output distribution in comparison to the zero-current acceptance of the RFQ.

The overall transmission decreases to 99.3% i.e. 99.2% for the 4+ and 99.4% for the 3+ fraction. By reducing the space-charge compensation of the 50 mA uranium beam to 95%, first simulations show a decrease in the transmission to 98% but this remains to be studied in more detail.

The different uranium fractions are not separated in a LEBT consisting of Gabor lenses. A static Wien filter (see [7]) between the two lenses could be used to eliminated the unwanted beam fraction. Its suitability for the given beam parameters will further be investigated.

GABOR LENS DESIGN

During the measurement campaign at GSI, an increased incidence of high-voltage sparks caused by the damage to the insulator between ground electrode and anode of the prototype Gabor lens was observed. With respect to a possible future application at GSI, the design of the Gabor lens was improved technically concerning the high-voltage strength of the electrode system. Additionally, the impact of the electrode length on the confinement efficiency was investigated numerically [8].

Figure 6 illustrates the improved design of the Gabor lens.

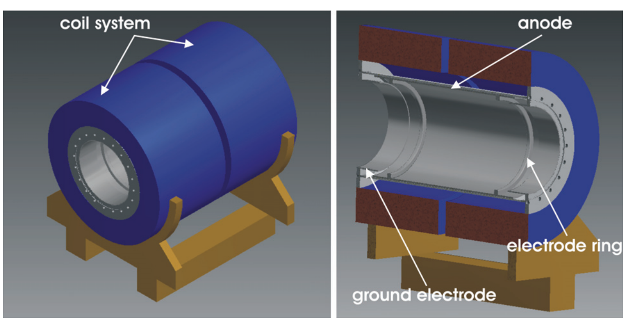

Figure 6: Technical drawing of the improved Gabor lens design.

In order to transport a $^{238}U^{4+}$ beam with an expected radius of at least r_B=30 mm, a lens aperture of 150 mm was chosen. Since the expected, necessary magnetic field strength will not exceed B_z=50 mT the overall diameter of the device will reach d_{gl}=340 mm, while the overall length will be given by l_{gl}=420 mm instead of l_{gl}=436 mm.

The potential created by the electrode system with a shielding electrode ring to protect the ceramic insulator will be limited to $\Phi_{A,max}$=35 kV.

Note that the potential created by the electrode system as shown in Fig. 6 was used for the numerical studies previously presented. However, the magnetic field of the coil system was assumed to be homogeneous since its design is still in progress.

CONTROL SYSTEM

A control system based on MDACS [9] is under preparation which allows the adjustment of the lens' focusing force. The focal length of the Gabor lens is dependent on the confined electron density and given by

$$\frac{1}{f_G} = \frac{e n_e l}{4\epsilon_0 U_a} \quad (2)$$

where l is the effective length of the space charge lens and U_a the beams' accelerating voltage provided by the terminal.

For given beam parameters to achieve the requested focal length, the external fields will be set with respect to the operation function (see Eq. 1) to confine the required electron density.

This presumes a reliable real-time measurement of the electron density as feedback for the control system (see Fig. 7). For this reason the applicability of a transverse diagnosis by installed antennas is currently under investigation.

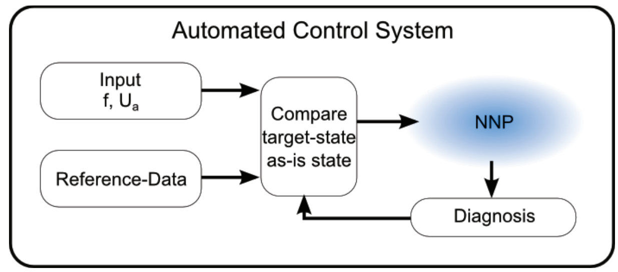

Figure 7: Flow diagram of the automated control system for the improved Gabor lens [10].

CONCLUSION AND OUTLOOK

A LEBT consisting of two Gabor lenses is a feasible alternative for the transport of high-intensity uranium beams, although the effect of the beams' space charge and the separation of the different uranium fractions needs to be investigated in more detail.

After finalizing the design, the new Gabor lens will be built and tested in a next step.

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