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BEAM TRANSPORT EXPERIMENTS USING GABOR LENSES*

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Abstract

A prototype Gabor lens has successfully been tested at the GSI High Current Test Injector (HOSTI) [1].

The experiments comprised the investigation of an emittance dominated and a space-charge dominated beam transport. In particular, the high-current measurements represent a necessary step towards evaluating the focusing performance of the lens and to gain experience in a real accelerator environment.

Besides the evaluation of the technical feasibility, the behavior of the electron cloud was characterized by the parameter analysis of the confined non-neutral plasma during beam transport measurements as well as subsequently performed diagnostic experiments.

This contribution will present experimental results as well as numerical studies on an improved Gabor lens design for the possible application at the GSI High Current Injector (HSI) in the context of an upgrade program for FAIR [2].

BEAM TRANSPORT EXPERIMENTS AT GSI

In mid-2012 beam transport experiments at HOSTI using a prototype Gabor lens were performed (see Fig. 1).

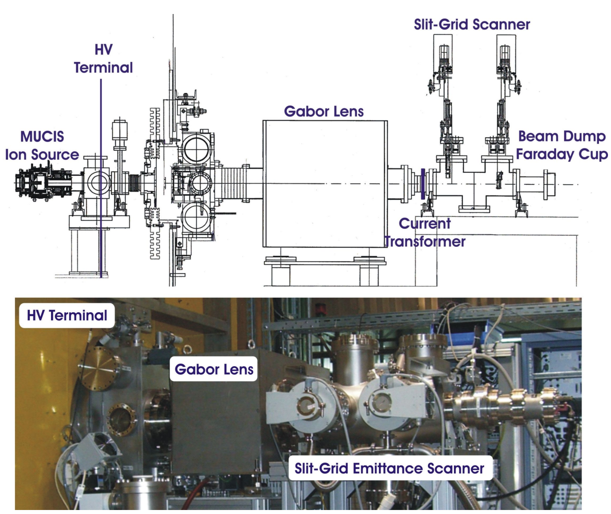

Figure 1: Scheme and photograph of the experimental setup for the beam transport measurements at GSI.

In both experiments– the emittance dominated as well as the space charge dominated beam transport – a good focusing performance close to the lens' operation point was demonstrated [3].

In particular, the transport of an 3.1 keV/u Ar^+ beam with a maximum intensity of I_B=35 mA looked very promising in order to use this kind of focusing device for intense uranium beams in the context of the HSI Frontend Upgrade for FAIR.

A parallel Ar^+-beam was achieved for a lens parameter setup of Φ_A=9.8 kV and B_z=10.8 mT at an increase in the normalized rms-emittance of only a factor of 1.38 (see Fig. 2).

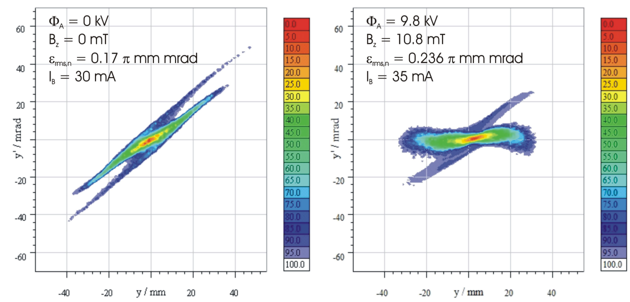

Figure 2: Measured phase-space distribution of the Ar^+-beam without focusing (left) and the beam focused by the Gabor lens (right). Both emittances were measured at the same position behind the lens.

Before the lens was put into operation, high-voltage conditioning was necessary to remove contamination such as dust and moisture, as well as other imperfections.

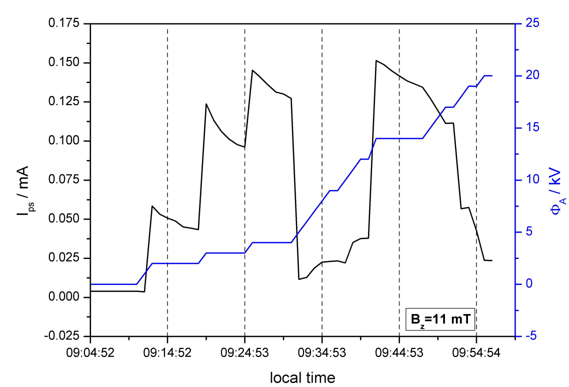

Figure 3: Example of high-voltage conditioning procedure for the prototype Gabor lens. I_{ps} denotes the power supply current.

During the applied conditioning procedure, loss electrons originating from the plasma cloud remove deposits from the electrode surface. Electron losses were experimentally investigated by detection of the emitted x-ray spectrum by a gamma-spectrometer [4].

An example of the high-voltage conditioning procedure is depicted in Fig. 3. The increasing current of the voltage power supply can be explained by a growth of the production

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rate in the plasma: in case of the prototype lens CO is leaking from the Vinidur insulator and additionally, the electrodes contribute as a result of the electron bombardment.

However, during the measurement campaign, an increased incidence of high-voltage sparks caused by the damage of the insulator between ground electrode and anode was observed. Figure 4 shows a picture of the lens' inside that was taken during a technical assessment, indicating metallic spots on the insulator and also a metallic splint, which lowered the distance between anode and ground electrode.

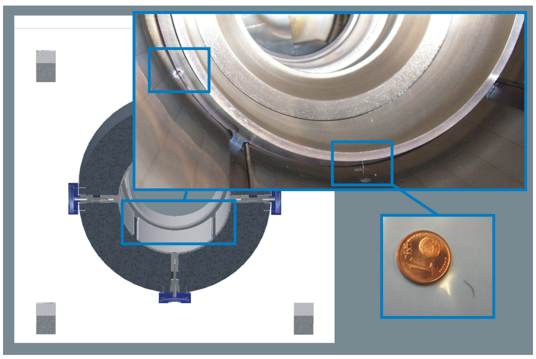

Figure 4: Technical assessment of the prototype Gabor lens during the measurement campaign.

In order to protect the insulator from further damage from the beam and to prevent sparking, the measurements of the space-charge dominated beam transport were performed using an iris of d=50 mm mounted at the entrance of the lens.

With respect to a possible future application at the HSI, the design of the Gabor lens has to be improved technically concerning the high-voltage strength of the electrode system.

IMPROVED GABOR LENS DESIGN

As previously mentioned, one major technical concern is the protection of the insulator. For this reason, the influence of shielding electrode rings installed at the inner anode surface on the electron confinement has been investigated.

In Fig. 5 the electron density distribution longitudinally (top) and the radial electric space-charge field (bottom) for a cylindrical anode of r_A=85 mm with and without the shielding electrode ring is presented.

Due to the shape of the electric field, the electron column in case of an anode with shielding electrode has a wider spread in z while the extension in its radial dimension becomes smaller.

Beside necessary technical improvements that ensure the reliable operation, another important design issue is the dimension of the Gabor lens and the system length in particular. Therefore, simulations have been performed to investigate the electron confinement and the related focusing strength as a function of the anode length. The results are presented in Fig. 6.

The simulation results show a linear correlation between anode length and longitudinal extension of the plasma column, i.e., with increasing anode length also the confined electron column becomes larger in its longitudinal dimension. Therefore, the effective action of the generated space-charge field on the beam and – assuming the validity of the

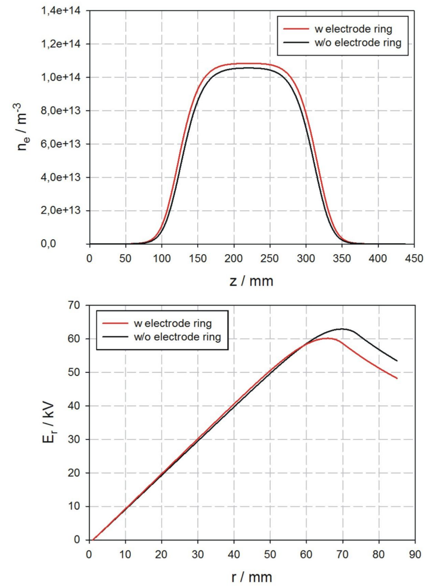

Figure 5: Influence of different anode geometries on the longitudinal electron density distribution (top) and the radial electric space-charge field (bottom). The Gabor lens parameters are Φ_A=9.8 kV and B_z=8 mT.

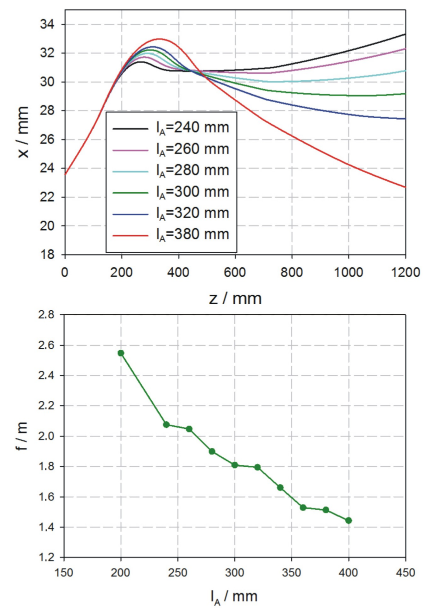

Figure 6: Envelopes x_{max} and y_{max} of an 2.2 keV/u $^{238}U^{4+}$ beam for a KV input distribution with ϵ_{rms}=0.167 mm mrad transported by lens assuming an space-charge compensation degree of 95% (top) and the focal length (bottom) as a function of the anode length. The Gabor lens parameters are Φ_A=9.8 kV and B_z=8 mT and the electron densities are calculated for each case.

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thin-lens approximation – the focal strength of the Gabor lens also increases.

For the possible application at the new straight-line branch of the HSI a compact design of the Gabor lens is favored.

In order to transport a 35 mA $^{238}U^{4+}$ beam with an expected maximum radius of r_B=30 mm a lens aperture of 150 mm is proposed. Since the expected, necessary magnetic field strength is limited to B_z=50 mT the overall diameter of the device might not exceed d_{gl}=320 mm, while the overall length might reach l_{gl}=436 mm.

A ceramic insulator and an electrode system with an shielding electrode ring that creates a confining potential of maximum Φ_A=35 kV is also planned.

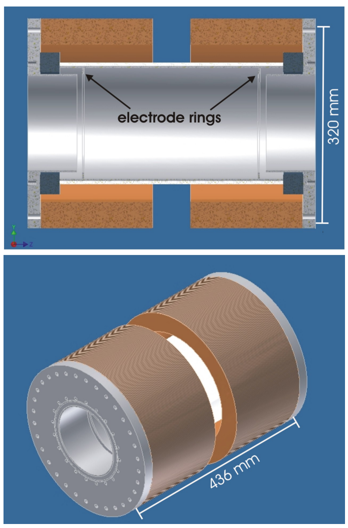

Figure 7: Possible Layout of the improved Gabor lens.

Figure 7 illustrates the design of the improved Gabor lens. Technical details will be specified in a next step.

ALTERNATIVE LAYOUT OF THE LOW ENERGY BEAM TRANSPORT SECTION

For the additional straight-line branch at the HSI a LEBT consisting of magnetic quadrupoles or solenoids is under design.

However, the application of two Gabor lenses to transport the extracted uranium beam was investigated.

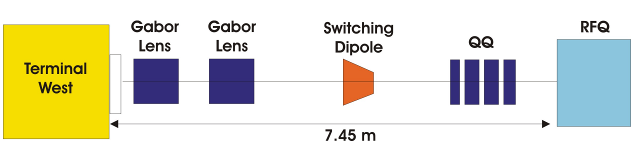

Figure 8: Alternative layout of the Compact LEBT at the GSI High Current Injector.

Figure 8 gives an overview of the alternative LEBT design. Beside the Gabor lenses the existing beam line components of the HSI, i.e., a switching dipole and a quadrupole quartet are used to inject the beam into the RFQ. The overall length of the LEBT is 7.45 m whereas the Gabor lenses have a length of 436 mm each.

As shown in Fig. 9 a first Gabor lens immediately after the extraction is needed and a second one in order to match the beam through the switching dipole into the quadrupol quartet.

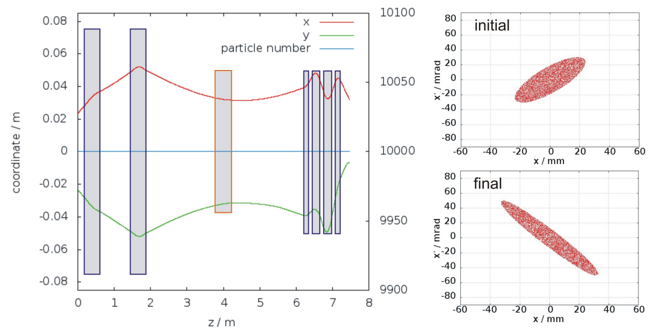

Figure 9: Envelopes x_{max} and y_{max} of a 2.2 keV/u $^{238}U^{4+}$ beam transported through the alternative LEBT (left) as well as the input and output phase-space distribution (right).

As all three injection lines meet at the switching dipole, the small transverse dimension of the Gabor lens might be an important feature.

In this first evaluation of the beam dynamics using the code *tralitrala* [5], a KV distribution of $\epsilon_{rms,n}$=0.246 π mm mrad derived from the emittance measurements behind the north-terminal of the HSI is transported through the alternative LEBT. The parameters in the presented case are Φ_A=4.8 kV, B_z=5.5 mT for the first and Φ_A=5.7 kV, B_z=6 mT for the second lens, while a space-charge compensation degree of 100% was assumed.

SUMMARY AND OUTLOOK

In this contribution a possible layout of an improved Gabor lens designed for the application at the HSI and a proposal for an alternative LEBT consisting of two of these lenses has been presented.

A non-interceptive, transverse diagnostic to determine the confined electron density during operation as well as a controlling system for a simplified operation of the lens is currently under preparation.

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