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IMPROVEMENT OF BEAM TRANSPORT IN HIGH ENERGY TRANSFER LINES USING GABOR-LENSES

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Abstract

Transfer lines provide the beam transport from accelerators to experimental areas. In the study presented in this paper, commonly used beam optics are supplemented by Gabor-lenses (GL) to investigate their effect on the luminosity for fixed-target experiments. With GLs it is possible to confine a pure electron plasma with densities up to 10^{15} m^{-3}. The self-field of the homogeneous electron density provides a focal strength, whereas the space charge forces of the beam are fully compensated. The performance of GLs was numerically investigated in the GeV range (p, π^+, K^+) in the past. The weak but continuous radial focusing improved the acceptance of the whole transfer line. The preparation of the experiments is planned in two steps. First, a GL (GL2000) which provides a 2 m long electron column was commissioned successfully at the Van-de-Graaf beam line at Institute of Nuclear Physics of Goethe-University. Beam transport measurements to investigate the stability of the confined electron column were performed using He^+, H^+ and Xe^+ beams in an energy range of 0.5-2 MeV. In a second step the implementation of several GLs in an existing transfer line at GSI Darmstadt was investigated numerically. The beam transport simulations using TraceWin shall take into account, that existing focusing devices and beam instrumentation should not be affected by the implementation. This enables the possibility to provide and compare the beam transport with and without electron atmosphere.

INTRODUCTION

High-energy beam transport sections are mostly transfer lines, which connect the last stage of an accelerator chain with an experimental area. For large accelerator infrastructure transfer lines also connect the different accelerators of the chain. Examples are the planned transfer lines between SIS18 and SIS100 or between SIS18 and the HADES experiment at GSI/FAIR.

Nowadays, the beam line acceptance has to be improved to meet the request on higher luminosity to increase the event rate of the experiment. A better statistic of raw reactions as well as a more economical and ecological performance of the accelerator infrastructure are the motivation of the change request. The HADES beamline was chosen to be the system of interest, because of the difficulties arising during a system upgrade without affecting the operation of the experiment. The quasi-periodic lattice of the focusing channel defines the acceptance, which have to be modified. On the other hand the status quo of the position of the ion optic and steerer doesn't have to be changed to prevent beam failures or an undesired shutdown. To provide an upgrade under these circumstances it was studied to replace the ordinary beam pipe sections between the magnetic quadrupoles by Gabor-lenses. This lens type uses the self-field of a confined electron column for a weak and radial symmetric focusing. Hence, the particle beam propagates through a pure electron plasma, which in turn compensates the beam space charge force. By adjusting the confinement it is possible to vary the focal strength of the Gabor-lens as well as the radial density distribution of the confined electron ensemble.

In a first phase of the study, the status quo of the HADES beamline was evaluated numerically. Then the integration of the Gabor-lenses was tested and the optimal position for proof of principal experiments was determined. In parallel a prototype of a Gabor-lens, providing the confinement of an electron column with a length of two meters was designed and constructed. Experiments were performed to estimate the properties of the electron plasma and to test its stability.

HADES BEAMLINE

The HADES beamline [1] is characterized by a doublet lattice and mostly straight geometry. It is 155 m long and has 21 main quadrupoles, two main bending magnets, tilted by ±21.6°, and several steering magnets. The reason for these tilts is that the beam axis of HADES is 70 cm higher than standard transport lines at GSI. As it can be seen in Fig. 1, a large part of this beamline is shared with other beamlines to different experiments. The HADES experiment is operated with a wide range of different particles and beam intensities and normally at maximum beam rigidity. It has a possibility to use either primary beam or secondary particles, produced in pion target. For the pion beam operation a high-intensity nitrogen primary beam is used. Good transmission is very critical in order to avoid beam losses and an activation of the area. On the other hand, the beam intensity for HADES operated with primary beam is low, which makes beam diagnostic for proton beams difficult. For planning experiments with Gabor-lenses in the HADES beamline, one has to keep in mind several challenges:

- Beam availability disturbance has to be avoided as beamline serves not only HADES but many other experiments;

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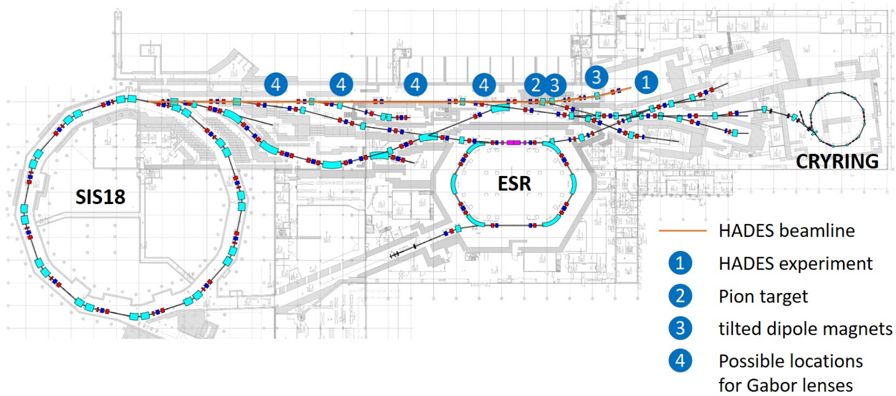

Figure 1: Position of the HADES beamline at GSI.

- The position of the magnets cannot be changed and Gabor-lenses have to be installed in already existing free spaces;
- The operation of Gabor-lenses has to be as reliable as conventional magnets in order to be used for standard operation in the future.

GABOR-LENSES

Gabor-lenses [2, 3] consist of cylindrical electrodes immersed in a solenoid to produce an axial magnetic field. The electrode system, consisting of an anode surrounded by two ground electrodes, forms a potential well. Whereas the magnetic field provides the radial confinement, the potential well provides the longitudinal confinement of the pure electron plasma. By changing the magnetic field and the anode potential the electron density n can be adjusted and hence the focusing strength [4] of the Gabor-lens as shown in Eq. (1).

$$\frac{1}{f} = \frac{n_e e \Delta l}{2\varepsilon_0 \beta c} \frac{1}{B\rho}, \tag{1}$$

with $B\rho$ as the magnetic rigidity of the beam, Δl the length of the lens and n_e the electron density.

The high voltage used for the longitudinal confinement bears the risk of sparking. Therefore, the maximum electron density is limited. The comparison of the focusing strength of a magnetic quadrupole with those of a Gabor-lens shows the weak focusing strength of this lens type. As an example for n_e in the range of $10^{14}\,\mathrm{m}^{-3}$ and for β=1 it reaches 1% of the performance of the quadrupole. On the other hand, the beam passes an electron plasma providing a smooth radial symmetric focusing of the beam. At the same time the beams space charge force is fully compensated. A Gabor-lens was constructed to confine an electron column of two meter length. The aperture is comparable to this of the vacuum chambers of the HADES beamline. To evaluate the stability of the non-neutral plasma and its inability to provide beam induced instabilities experimental test at low beam energies were performed at Van-de-Graaf accelerator of University Frankfurt. No degradation of the stability of the confined electron column was observed by the use of H^+-, He^+- and Xe^+- beams. Unfortunately, the beam current was in a range of a few µA and therefore space charge forces are neglectable.

PARTICLE TRACKING SIMULATIONS

Particle tracking simulations with the tool TraceWin [5] were performed to investigate beam transport effects caused by a Gabor-lens array placed in the HADES beamline.

Therefore the whole beamline was implemented in TraceWin and cross checked with MAD-X program [6] used at GSI. Both programs were evaluated and agree well in calculation of standard optic settings as presented in Figs. 2 and 3.

The chosen beam parameters are shown in Table 1, number of tracking particles N=100000 was set and initial rms emittances were given $\varepsilon_{n,rmsx} = 1.696$ mm.mrad and $\varepsilon_{n,rmsy} = 1.5264$ mm.mrad. In the next step a Gabor-lens (GL) was implemented as an element with drift-kick-drift approximation in TraceWin, chosen drift-step $\Delta s = 0.1$ m. Under assumption of a trapped electron density of $n_e = 10^{15}\,\mathrm{m}^{-3}$, kicks of $1/f = 6.22 \cdot 10^{-4}$ were implemented.

Table 1: Beam Parameters for Proton Beam

W_{kin}	β	γ	P [GeV/c]	W_0
1 GeV	0.875	2.0658	1.696	938 MeV

Initial Gaussian 3σ distribution was transported without Gabor-lenses (GLs) and compared to the transport with an 8 m long column of GLs positioned at distance z=84.5 m in the HADES beamline. This position, in long free section just in front of the GTH2QD21 quadrupole, was chosen for the first numerical tests, to check suitability for possible beam experiments. Additionally, no beam space charge was assumed for the first investigations.

Quadrupoles focusing strengths have to be optimized to conserve beam optics properties after GLs downstream for x and y respectively. Halo particles of 10% intensity and 25 times greater emittance were generated around initial distribution to evaluate acceptance of the beam line. There is also

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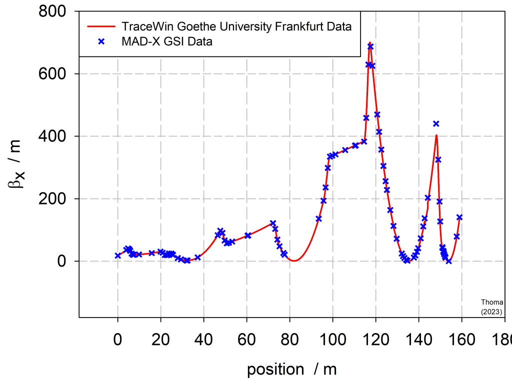


Figure 2: β_x-envelope MAD-X data implemented to TraceWin.

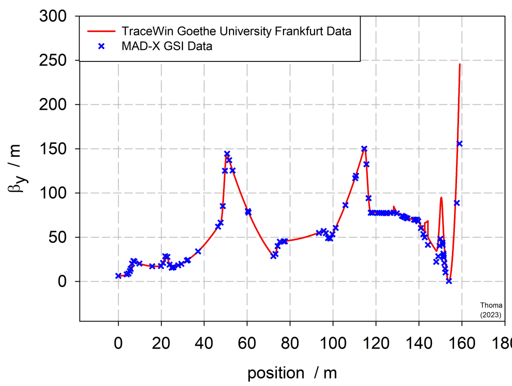
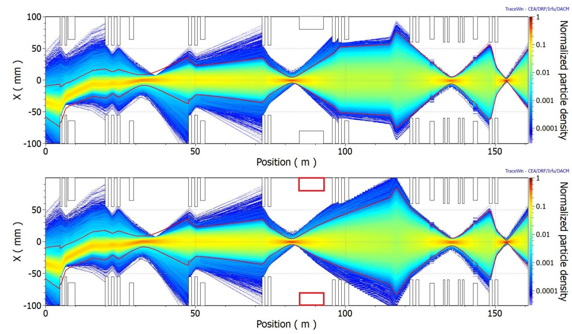


Figure 3: β_y-envelope MAD-X data implemented to TraceWin.

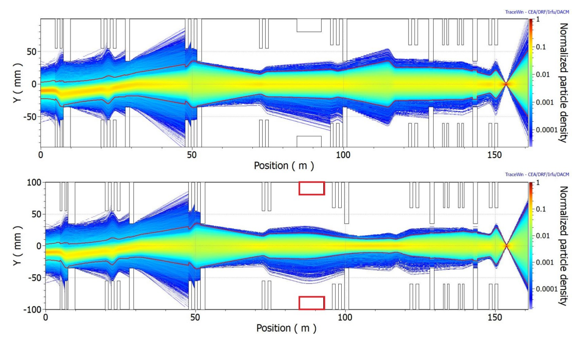
some offset in initial horizontal beam position and a drift in the beam position during the spill caused by different effects of the SIS18 extraction system [7, 8]. Resulting envelopes are shown in Fig. 4. Transmission is in this case 88% the same as for beam line without GLs. Phase space distribution projections at target position z=153.9 m fulfill the parameter conditions for the beamline and are shown in Fig. 5.

OUTLOOK

The replacement of the ordinary vacuum tanks of the HADES beamline by Gabor-lenses enables the possibility to transport the hadron beam through a pure electron plasma. The self-field of the electron column provides a smooth radial symmetric focusing and space charge compensation at the same time. The numerical study shows that the acceptance of the beamline was increased and the focusing strength of the magnetic quadrupoles has to be reduced. First simulation demonstrated agreement between standard optics and parameter set found for the beamline with 8 m long GL channel included. However, because of a new focusing device in the chain, there exist now possibilities to investigate also additional schemes numerically, with chance to improving quality and transport of the beam. Clearly, beam radius



(a) x-plane



(b) y-plane

Figure 4: Beam envelopes in transversal plane calculated by TraceWin particle tracking simulation without and with Gabor-lenses (red marked). Gabor-lenses are positioned at z=84.5 m.

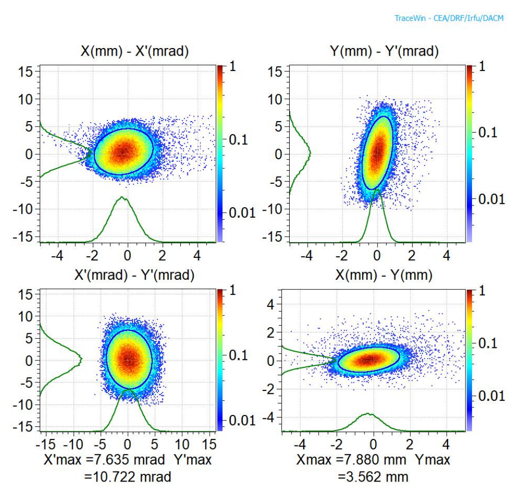


Figure 5: Beam phase space projections at target position. Beam 3σ rms-radius is less than 2.5 mm.

in the sections around GLs is reduced, which is improving acceptance of the system at least locally. Other proposed positions (Fig. 1) will be investigated numerically in the future. Another possibility is to positioning GLs lattice off-axis and using it as a steering device. Implemented radial focusing lattice of GLs brings new free parameters for optimization and can be used for damping of a beam oscillation around the axis.

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