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BEAM DYNAMICS IN THE LEBT FOR FRANZ

P. P. Schneider*, H. Dinter, M. Droba, O. Meusel, D. Noll, T. Nowottnick, O. Payir, H. Podlech, A. Schempp and C. Wiesner, IAP, Goethe-University, Frankfurt am Main, Germany

Abstract

The accelerator-driven neutron source FRANZ (Frankfurter Neutronenquelle am Stern-Gerlach-Zentrum) [1, 2] has two successive Low-Energy Beam Transport (LEBT) sections, which are separated by a chopper system [3]. Each LEBT section consists of two solenoids. The first section, which starts after the ion source, will match the beam into the chopper system. Downstream from the chopper system the second section will match the beam into the following Radio-Frequency Quadrupole (RFQ).

Particle simulations with varying parameter sets have been performed to determine the regions of best transmission and beam quality. Special focus has been set on the fact, that the high intense ion beam might deposit high amounts of energy. Beam losses have to be avoided if possible because they can cause heavy damage on structures.

INTRODUCTION

Systematic numerical investigations on the beam dynamics in both LEBT sections of FRANZ have been performed in order to achieve the best settings for the system. The beam current for the simulations shown is $I_\mathrm{b} = 50\,\mathrm{mA}$, while the beam energy is $W_\mathrm{b} = 120\,\mathrm{keV}$.

The goal for the first LEBT section is to adapt the beam, provided by the volume type ion source [4] with an initial emittance of $\epsilon_{\mathrm{norm,\,rms}} = 0.03\,\mathrm{mm\,mrad}$, for injecting it into the chopper system with minimum losses and lowest possible emittance growth.

The second LEBT section will catch the beam from the chopper system and adapt it for injection into the following RFQ. The matching has been performed by evaluating the emittance compared to the acceptance and the distribution in respect to the given injection parameters of position and transverse momentum.

A mismatch of the injection has been systematically investigated by adding a simulated offset to a generated, perfectly matched distribution. These sets have been tracked through the RFQ and the resulting offsets at the RFQ exit were evaluated.

Simulation Codes

The matching of the beam into the chopper system and the RFQ has been performed using the LINTRA code, developed at IAP, which allows to simulate cylindrical symmetric beams through solenoids including space charge forces of the transported beam.

The shown envelopes have been calculated using the *tralitrala* code, which was recently developed at IAP. This code involves a huge performance boost by using GPU computing. It will be used for future simulations.

The PARMTEC code has been used for tracking trough the RFQ.

* iap@fips-schneider.de

CHOPPER MATCHING

The matching for the first LEBT section was done by simulating all possible settings on a grid for the solenoids and plotting the resulting outcomes to interpret and select the best cases. One run requires 1360 simulations.

Simulations showed that the mounting of a collimator with an inner radius of 20 mm upstream the second solenoid can shield the chopper system from losses of the H_2^+ and H_3^+ ion fractions of the beam and will additionally improve the beam quality.

Space-charge compensation was assumed to be 95 % until the end of solenoid 2 and 0 % in the subsequent chopper system, because the chopper system starts with a repeller electrode, avoiding the electrons to travel further in the beam line. The chopper system will produce beam pulses with a length of less than 300 ns with a repetition rate of 257 kHz [3]. It is expected to have no significant space-charge compensation from residual gas ionisation for such short beam pulses, therefore the compensation is expected to be 0 % also in the second LEBT section.

Figure 1 shows the resulting beam current downstream from the chopper system. Two islands of maximum transmission are visible. The lower island covers the cases of a parallel beam from solenoid 1 to solenoid 2, the upper is-

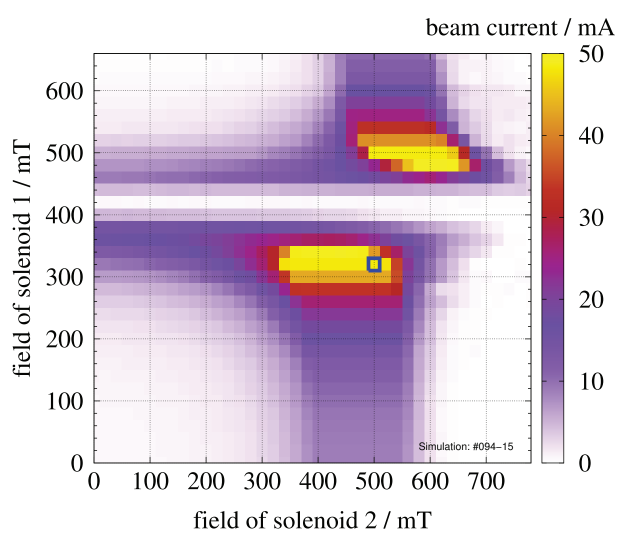

Figure 1: Transmission through the first LEBT section and the chopper system, evaluated at the exit of the chopper system. The best setting is highlighted with a blue square.

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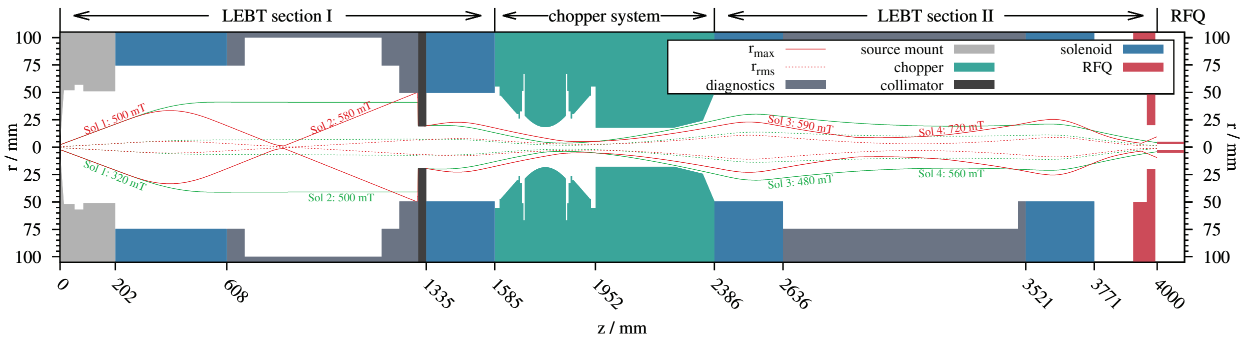

Figure 2: Beam envelopes in both LEBT sections and the chopper system. The green envelope shows the setting with parallel beam between the two solenoids of each LEBT section, the red one represents the setting with a focus in-between.

land represents these with a focus in-between the solenoids. The region of almost no transmission between the two regions is caused by beam loss within the beam separation device of the chopper system. As the beam is focused at the entrance of solenoid 2, this loss can not be prevented by this element, regardless of focusing field.

The emittance growth, shown in Fig. 3, is colored in blue for reduced emittance, caused by beam losses. The green part of the color axis represents emittance growth up to the acceptance of the RFQ, which is $\epsilon_{\text{norm, rms}} = 0.3$ mm mrad. Above this, the scale turns to red. Comparing both transmission islands (as given in Fig. 1) the emittance growth is significantly lower in the case of a parallel beam between the solenoids. The optimum setting is highlighted with a blue square. With $\epsilon_{\text{norm, rms}} = 0.05$ mm mrad the emittance growth is 66.7 % for a beam current of $I_b = 48.1$ mA.

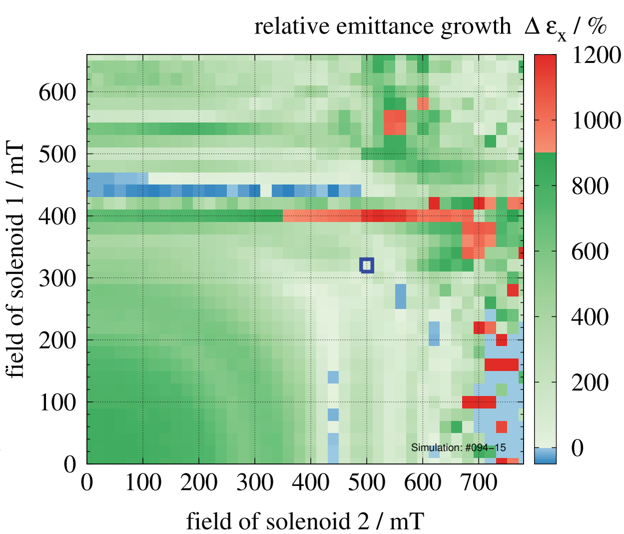

Figure 3: Emittance growth in the first LEBT section and the chopper sytem, evaluated at the exit of the chopper system. Green indicates an emittance growth up to the RFQ acceptance, red an emittance growth to above it.

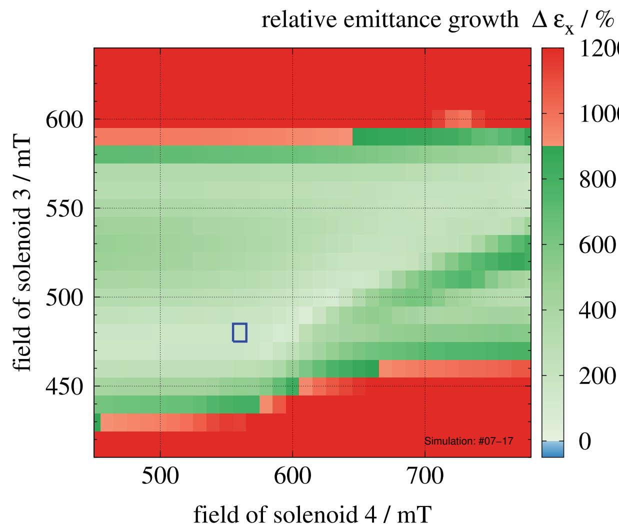

Figure 4: Emittance growth after the second section of the LEBT, evaluated at the beginning of the RFQ electrodes. Green indicates an emittance growth up to the RFQ acceptance, red an emittance growth to above it.

RFQ INJECTION

The distribution resulting from the optimum settings of the first LEBT section is transported through the second section. 2938 simulations have been carried out.

The given RFQ injection parameters are a maximum beam radius of $x_{\text{max}} = 2.8$ mm, a maximum transverse momentum $x'_{\text{max}} = 41.2$ mrad and an acceptance of $\epsilon_{\text{norm, rms}} = 0.3$ mm mrad.

To identify the best position of the RFQ in the setup, 17 particle monitors from 29 mm to 429 mm behind solenoid 4 have been evaluated. A position 229 mm downstream from the last solenoid of the LEBT provides the best result.

Figure 4 shows the emittance growth up to the beginning of the RFQ electrodes. Green indicates an acceptable growth below the RFQ acceptance, it suggests a wide range of possible settings to match into the RFQ, but the other injection parameters, x_{max} and x'_{max}, are unconsidered. Taking x_{max} and x'_{max} into account, it is possible to calculate the beam fraction which matchs all three injection parameters.

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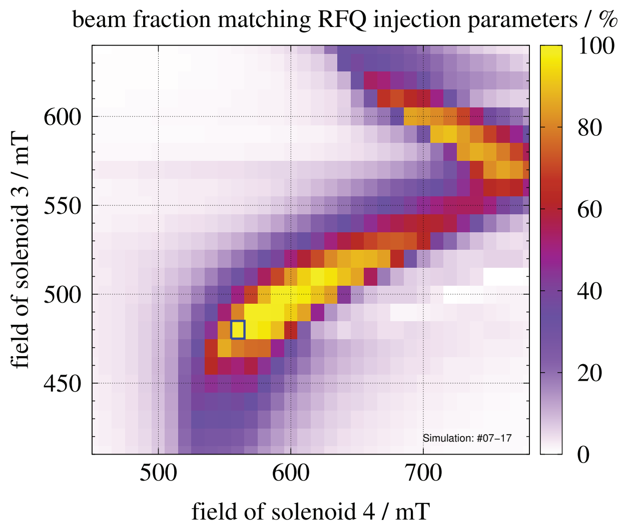

Figure 5: Beam fraction matching the RFQ injection parameters, evaluated at the beginning of the RFQ electrodes. The best setting is highlighted with a blue square.

Figure 5 shows the fraction of the beam that matches the RFQ injection parameters for a range of possible settings. The best case, highlighted with a blue square, matches almost 95 % of the beam into the acceptance and the injection boundary conditions.

OFFSET AT RFQ INJECTION

To study the influence of a beam offset at the injection point on the beam at the exit of the RFQ, 20 simulations have been performed. Two sets with either a position offset between $\Delta x = -2.5$ mm and $\Delta x = 2.5$ mm or an angle offset between $\Delta x' = -40$ mrad and $\Delta x' = 40$ mrad were generated. The distributions were tracked through the whole 1.8 m long RFQ designed for the FRANZ project and the resulting beam properties at the RFQ exit were plotted in Fig. 6 and 7.

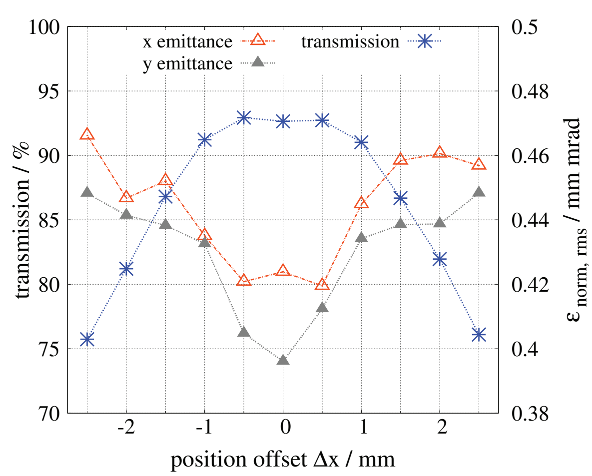

Figure 6: Transmission and emittance at the RFQ exit for different beam position offsets at the RFQ injection point.

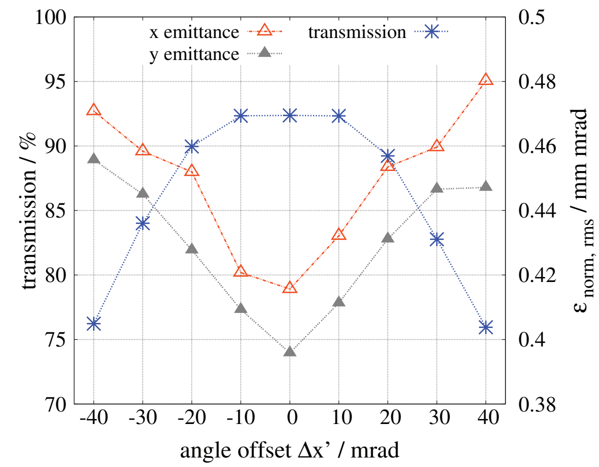

Figure 7: Transmission and emittance behind the RFQ for different transverse momentum offsets at the injection point.

As the design of the electrodes has been slightly revised between the two simulation sets, small deviations in the no-offset case are visible.

Figure 6 shows transmission and emittance for different position offsets. Between 92 % (for a maximum offset of $\Delta x = 0.5$ mm) and 75 % (for an offset of $\Delta x = 2.5$ mm) of the beam is transmitted. The emittance growth rises from 33 % for the perfectly matched beam to more than 50 % in case the beam has 1.5 mm or an even higher offset.

In case of the transverse momentum offset, shown in Fig. 7, again 92 % maximum transmission is found for a maximum offset of $\Delta x' = 10$ mrad. The worst case of $\Delta x' = 40$ mrad results in a transmission of 75 % and an emittance growth of 60 %.

CONCLUSION

Systematic analysis of the beam dynamics in both FRANZ LEBT sections have been performed and show promising results for the transmission as well as the beam quality. The best setup for the RFQ was found 229 mm behind solenoid 4.

Influences by offsets from the ion beam matching into the RFQ have been investigated and show good performance as we expect less offsets than assumed in the simulations.

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