LEBT DYNAMICS AND RFQ INJECTION

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

Abstract

The Low Energy Beam Transport (LEBT) section at the accelerator-driven neutron source FRANZ [1] consists of four solenoids, two of which match the primary proton beam into the chopper. The remaining two solenoids are intended to prepare the beam for injection into the RFQ. In the first commissioning phase, the LEBT successfully transported a 14 keV He^+ beam at low intensities [2]. In the current commissioning phase, the beam energy is increased to the RFQ injection energy of 120 keV. In the upcoming step, the intensity will be increased from 2 mA to 50 mA.

Beam dynamics calculations include effects of different source emittances, position and angle offsets and the effects of space charge compensation levels. In addition, the behavior of the undesired hydrogen fractions, H_2^+ and H_3^+, and their influence on the performance within the RFQ is simulated.

INTRODUCTION

A LEBT can satisfy several tasks within an accelerator. While the most important task is the transport of the beam at low energy from the ion source into the downstream RFQ, which expects well defined beam properties at the injection point, another important aspect is the matching of the beam properties, the "RFQ injection parameters", which are usally given by the twiss parameters α_{Twiss}, β_{Twiss}, γ_{Twiss} and the emittance ε.

A possible additional task within a LEBT is to apply a time structure to the beam. A time structure is necessary to reduce the duty cycle of the RFQ or to provide the time structure required for the experimental needs.

Furthermore, beam diagnostics are an important task to ensure the required specifications and quality of the beam.

If the desired beam ion cannot be delivered in one fraction from the ion source, as, for example, for hydrogen beams, the LEBT should separate the unwanted fractions. Otherwise, these would be lost in an uncontrolled way within the RFQ or the later beamline, where high loss rates are intolerable.

This work will focus on the fraction separation within the FRANZ LEBT and gives an outlook on planned projects at the MYRRHA LEBT. Additionally the sucessful separation of an hydrogen beam at a solenoidal separation channel will be described.

FRACTION SEPARATION

Proton sources usually provide three fractions of charged hydrogen: H^+, H_2^+ and H_3^+. However, an RFQ is able to accelerate only one mass-to-charge ratio. Therefore, the two unwanted fractions have to be filtered by the LEBT in order to reduce their impact on the further accelerator. To perform this task, there are several possible solutions.

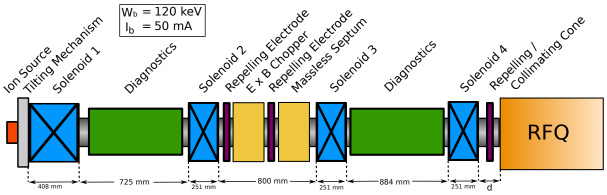

Figure 1: Schematic view of the FRANZ LEBT.

Dipole Separation

It is possible to separate the fractions with a dipole magnet, as is done for example at the SARAF LEBT [3].

⊕ separation efficiency up to 100 %
⊕ controlled dumping of separated beam possible

⊖ does not preserve beam symmetry
⊖ does not preserve space-charge compensation
⊖ small angle mismatches can lead to large offsets

Collimation System

Another possibility to separate the species is to exploit the momentum-dependent focusing of a solenoid in order to move every fraction to a different radius. A subsequent collimator system can scrape the fractions at high radii.

⊕ preserves beam symmetry
⊕ preserves space-charge compensation

⊖ separation efficiency always < 100 %
⊖ produces secondary particles
⊖ losses cause "hot spots"

Wien Filter

A third possibility is a Wien filter [4] composed of a magnetic dipole and an electric deflector. Particles that satisfy the Wien-ratio can pass, all others will be deflected.

⊕ preserves beam symmetry
⊕ controlled dumping of separated beam possible
⊕ separation efficiency up to 100 %

⊖ space-charge compensation is not preserved
⊖ complex to design and construct

FRANZ LEBT

The FRANZ LEBT (Fig. 1) consists of two sections. The first section ranges from the source to the chopper system, the second section from behind the chopper system to the entrance of the RFQ.

The first section has to transport the beam from the ion source into the chopper system. Between solenoid 1 and

---

* schneider@iap.uni-frankfurt.de

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-THPF024

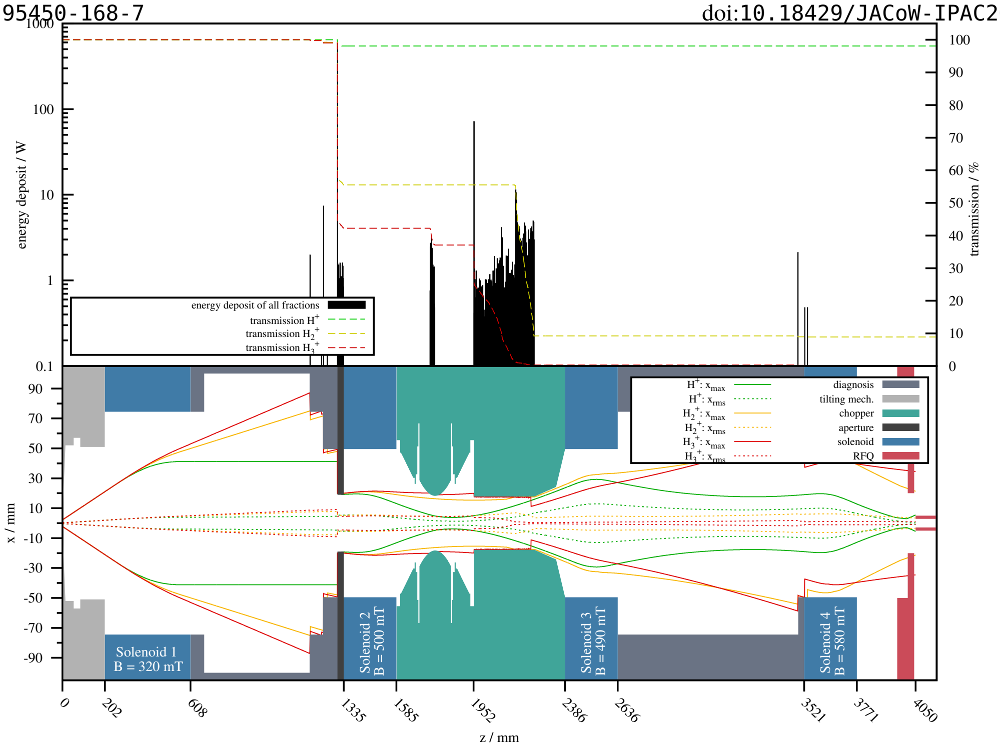

Figure 2: FRANZ LEBT with a collimation system. The upper panel shows the transmission for each fraction, H^+ in green, H_2^+ in yellow and H_3^+ in red. In addition, the energy deposition of the beam losses of all fractions accumulated is given in black. The lower panel shows the envelopes for the three fractions using the same color-scheme as in the upper panel.

solenoid 2, a faraday cup is mounted for diagnostics. In section I, the separation of fractions is done by collimating the beam either in the transport channel itself or at a collimation system which is mounted before solenoid 2. This section also matches the beam into the downstream chopper system.

The chopper system [2] is based on the principle of a Wien filter [4]. By default, the beam is deflected by a magnetic dipole field into a beam dump. For every pulse the magnetic field is superimposed by an electric field, which cancels out the magnetic deflection and the beam can pass straight through the system. This superposition fulfills the Wien-ratio and can therefore work only for one particular particle speed. A massless septum system [5] increases the deflection of the unwanted beam into a following beam dump while the straight beam is unaffected.

The second section transports the beam from the chopper system into the RFQ. Diagnostics are realized by a current transformer and an optical beam tomography unit [6]. Section II will adapt the beam to the RFQ injection parameters and match it into the RFQ.

Separation by Collimation System

To study the behavior of the three hydrogen fractions in the FRANZ LEBT, simulations have been carried out to estimate the filter capabilities of the LEBT with and without a collimator system in front of solenoid 2.

Fraction separation without the collimator system works well, the H_2^+ fraction is reduced to 27 % of its inital value and the H_3^+ fraction is reduced to less than 0.2 %. The mounting of a collimator reduces the H_2^+ fraction to 9 %. Another advantage of a collimator is the reduction of losses on the deflector plates. This helps to avoid sparks between the plates. The calculation results with the collimator system are shown in Fig. 2. The transmission, the power deposited by beam losses and the envelopes are depicted.

Separation by Wien Filter

The Wien-ratio has to be adjusted to one mass-to-charge ratio for a given particle energy. As long as the mass-to-charge ratio is different for each fraction, the E × B chopper will also separate the fractions. It is possible to operate the chopper system with static fields. Then, a DC-beam can be transported and the E × B chopper will separate the fractions.

Numerical and experimental studies of the separation efficiency are planned at the FRANZ LEBT.

During the commissioning phase, the E × B chopper will be used to measure the fraction ratio of the used source at different energies. Furthermore, comparisons between the separation by the solenoidal channel and the separation by the E × B chopper are planned.

Additional it is possible to study the effect of unwanted fractions on the RFQ injection and transport.

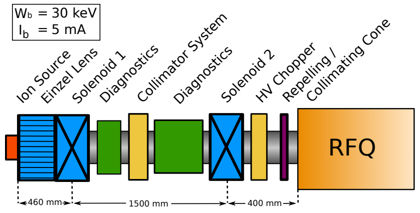

Figure 3: Schematic view of the MYRRHA LEBT.

MYRRHA LEBT

The fraction separation at the MYRRHA LEBT (Fig. 3) is based on a two-step separation. The first separation is realized by a collimator system between the first and second solenoid. This is similar to the collimation in the first section of the FRANZ LEBT. The second separation is based on the mismatch of the RFQ injection parameters for the undesired fractions.

In a future study, investigations on the effectiveness of the fraction separation are planned as well as an optimization of the beam transport and matching. Additionally, the influence of wrong fractions on RFQ transport will be studied.

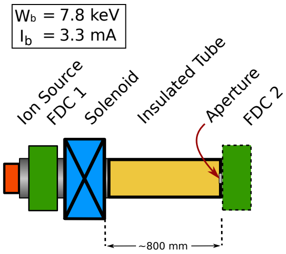

Figure 4: Schematic view of the test separation channel.

EXPERIMENTAL TESTS OF A SEPARATION CHANNEL

To prove the fraction separation at low energies with a solenoid, a collimation channel has been set up for injection tests at the Figure-8 experiment in Frankfurt [7]. In this experiment, the injection of an ion beam with a solenoidal separation channel into a toroidal transport channel is studied. For this purpose, a proof-of-principle experiment consisting of a hydrogen ion source, a solenoid and an insulated drift tube with a collimating aperture at the end was built. The setup is shown schematically in Fig. 4. For variable focusing strengths of the solenoid, the loss current on the drift tube and the current in a faraday cup downstream the collimation aperture were measured. In Fig. 5, the separation of the fractions depending on the strength of the magnetic field in the solenoid is visible.

CONCLUSION

A LEBT has to perform several important tasks. The beam transport, the matching into the RFQ and additional tasks like diagnostics, time structures or fraction separation might or must be done at low energies. In this contribution, a special focus was put on fraction separation in the LEBT.

Three main possibilities were described for fraction separation: a dipole, a collimation system and a Wien filter.

The fraction separation in the FRANZ LEBT was simulated and the positive effect of a collimation system was confirmed.

Finally, an experiment was shown, which proves the ability of a solenoidal transport channel to separate the beam fractions.

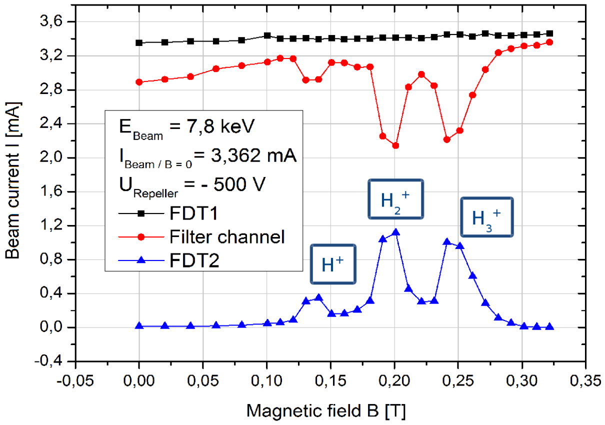

Figure 5: Resulting current direct from the source in FDC 1 (black) and the current in FDC 2 (blue) for several field strengths of the solenoid. Red shows the loss current on the insulated drift tube. The source was not optimized for proton production. Image by courtesy of Heiko Niebuhr [7].

ACKNOWLEDGMENTS

The authors would like to thank Jean-Luc Biarrotte and Frederic Bouly for their support with simulations regarding the MYRRHA LEBT.

REFERENCES

[1] Meusel, O., et al., “FRANZ–Accelerator Test Bench and Neutron Source” MO3A03, LINAC’12, Tel-Aviv, Israel, 2012.

[2] Wiesner, C., et al., “Chopping High-Intensity Ion Beams at FRANZ”, WEIOB01, LINAC’14, Geneva, Switzerland, 2014.

[3] K. Dunkel, F. Kremer, C. Piel, “Performance of the SARAF Ion Source”, TUPAN009, PAC’07, Albuquerque, New Mexico, USA, 2007.

[4] Wien, W., “Untersuchungen über die electrische Entladung in verdünnten Gasen” Annalen der Physik 301.6, pp. 440–452, 1898.

[5] Payir, O., et al., “Massless Beam Separation System for Intense Ion Beams”, THPF023, IPAC’15, Richmond, Virginia, 2015, these proceedings.

[6] Reichau, H. et al., “Optical Diagnostics for Frankfurt Neutron Source” TUPD60, DIPAC2011, Hamburg, Germany, 2011.

[7] Droba, M. et al., “Simulation Studies on Beam Injection into a Figure-8 Type Storage Ring” TUPRO045, IPAC 2014, Dresden, Germany, 2014.