A NEW DESIGN OF THE RFQ CHANNEL FOR GSI HITRAP FACILITY

S. Yaramyshev#, W. Barth, G. Clemente, L. Dahl, V. Gettmann, F. Herfurth, M. Kaiser, M. Maier, D. Neidherr, A. Orzhekhovskaya, H. Vormann, G. Vorobjev, GSI, Darmstadt, Germany
R. Repnow, MPI-K, Heidelberg, Germany

Abstract

The HITRAP linac at GSI is designed to decelerate ions with mass to charge ratio of A/Z<3 from 4 MeV/u to 6 keV/u for experiments with ion traps. The particles are decelerated to 500 keV/u with an IH-DTL structure and finally to 6 keV/u with a 4-rod RFQ. During commissioning stage the deceleration to approx. 500 keV/u was successfully demonstrated, while no particles behind the RFQ with an energy of 6 keV/u were observed. Dedicated simulations with DYNAMION code, based on 3D-fotometrie of the fabricated RFQ electrodes were successfully performed comprehending the commissioning results. In a second step the simulations have been experimentally confirmed at a test-stand (MPI-K, Heidelberg). An input energy, accepted by the RFQ is significantly higher than design value. For this reason the longitudinal beam emittance after deceleration with IH structure does not fit to the longitudinal RFQ acceptance. To solve this problem a new design of the RFQ channel with a correct input energy has been started. New RFQ parameters and the results of the beam dynamics simulations are presented in this paper.

INTRODUCTION

The **H**eavy **I**on **Trap** (HITRAP) facility of the GSI Helmholtzcenter for Heavy Ion Research at Darmstadt has been built to decelerate highly charged heavy ions to an energy of 6 keV/u. Then ions can be captured in a Penning trap, cooled further to cryogenic temperatures, extracted and transported to the experiments for atomic, nuclear and solid state physics [1-2].

The HITRAP linac (Fig. 1) is foreseen to decelerate heavy ions with an energy of 4 MeV/u down to 500 keV/u by IH-DTL section and to 6 keV/u by a 108 MHz RFQ [3], designed by Prof. A. Schempp (IAP Frankfurt, Germany) and fabricated by NTG Company (Gelnhausen, Germany). A deceleration of the beam to 500 keV/u at HITRAP facility was successfully demonstrated, while until now all efforts providing for complete deceleration to 6 keV/u failed. Therefore a beam dynamics study for the RFQ by means of the advanced multiparticle code DYNAMION [4] has been carried out. As a basis for precise and reliable simulations the RFQ electrodes have been disassembled from the tank and measured by Sigma3D Company (Aachen, Germany). The photometric data has been used to build a 3D surface of the electrodes "as fabricated" (Fig. 2). Detailed distribution of the electrical potential inside an RFQ channel was calculated by means of a relaxation scheme. Obtained 3D electrical field mapping was used as an input data.

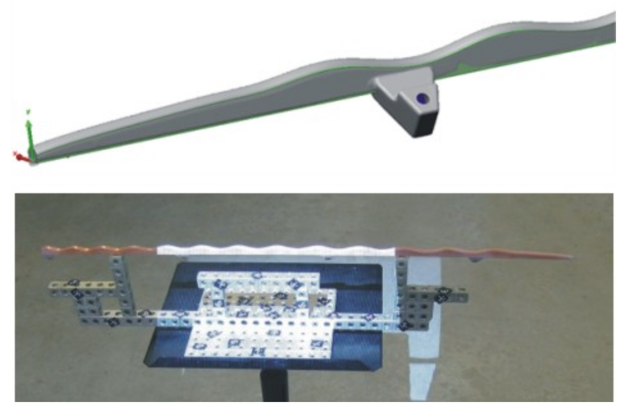

Figure 2: 3D surface of the rods (top) used for the simulations and created from the measurements (bottom)

The results of DYNAMION simulations for the HITRAP-RFQ demonstrated significantly higher (approx. 525 keV/u) beam energy than the design value of 500 keV/u. This fact can be the most probable explanation of the not reached deceleration of the beam to the design energy of 6 keV/u at HITRAP facility.

HITRAP-RFQ EXTERNAL TESTS

In 2011 the HITRAP-RFQ was transported to MPI-K (Heidelberg, Germany), installed at Pelletron accelerator and tested with H_2^+ beam (Fig. 3).

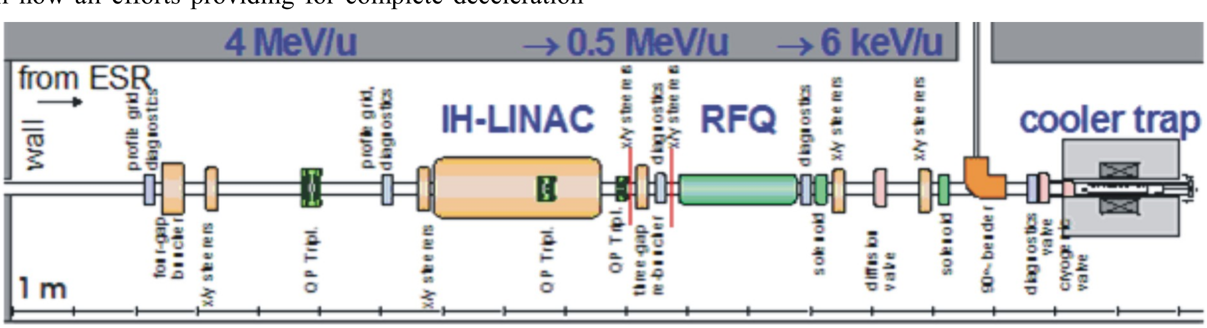

Figure 1.Schematic layout of the HITRAP facility

#S.Yaramyshev@gsi.de

ISBN 978-3-95450-122-9

Figure 3: Test stand at MPI-K.

The results of DYNAMION simulations were confirmed: the HITRAP-RFQ decelerates ions only with an energy of approximately 517±10 keV/u. Slight discrepancy between measurements and DYNAMION simulations could be explained by a significant misalignments of the rods, especially not fixed ends at the RFQ high energy entrance.

DESIGN OF THE NEW RFQ CHANNEL

On the base of the numerical study and experimental confirmation a decision to design new RFQ electrodes was done. The main goals were to provide for the correct input energy of 495 keV/u, as well as for an increased longitudinal acceptances. An additional complication for a design makes the requirement to the exact input- and output -energies, simultaneously with already fixed length of the electrodes (1981.0±0.5 mm).

New RFQ accelerating-focusing channel was designed with the interactive code DESRFQ [5], written at ITEP (Moscow, Russia). A typical screenshot, which illustrates a final stage of a design process, is shown on Fig. 4

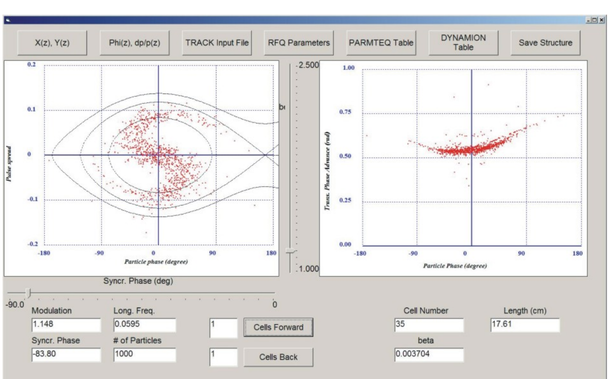

Figure 4: Typical screenshot from the code DESRFQ: beam portrait on longitudinal phase space (left) and stability diagram (right).

Main parameters for old and new design are presented in Tab. 1. New electrodes are designed with the constant average radius (average aperture). It allows for easier fabrication of the rods, as well as for machine tuning.

Table 1: Main RFQ parameters

	Old	New
Input energy (keV/u)	525	495
Voltage (kV)	77.5	89.5
Average radius (cm)	1.0-0.58-0.68	0.65
Rods rounding and width	variable	constant
Max. field strength (kV/cm) *Kilpatrick crit. 125 kV/cm*	~ 220	~ 175
Max. modulation	3.0	2.35
Min. aperture (cm)	0.34	0.39
Transverse normalized acceptance (cm mrad)	0.145	0.223
Long. acceptance (arb.u.)	~35	~70
Length (cm)	198.1	198.1

New laws for modulation and synchronous phase (Fig. 5) provides for the almost constant electrical field strength on the electrode surface, significantly lower than existing one, even in spite of higher voltage between adjacent electrodes.

An increased RFQ voltage allows to the lower modulation, what enlarges an aperture and subsequently a transverse acceptance of the RFQ.

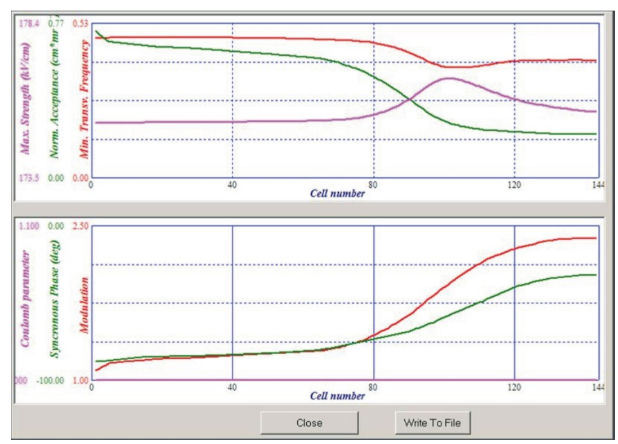

Figure 5: Main parameters of the new RFQ design along the structure: max. field strength, transverse acceptance, min. phase advance (top); modulation and synchronous phase (bottom).

The IH-**DTL structure** decelerate ions from 4 Mev/u to 500 keV/u. Beam dynamics simulations, as well as experiments demonstrate wide energy spread with a significant part of the high energy particles behind the DTL. It strongly hampers measurements of the beam parameters at the RFQ entrance. Therefore the beam parameters at the RFQ entrance were estimated from the results of beam dynamics simulation for the IH-DTL.

To keep the installation as flexible, as possible the design of the new RFQ channel was directed to provide for significantly higher longitudinal acceptance.

Calculations of the channel acceptance were performed with the input particle distribution, widely distributed in 6D phase space. For a comparison of both design the only particles with an energy below 7 keV/u behind RFQ are treated as accepted. These particles, filling the acceptance at the RFQ entrance, are shown on Fig. 6. The longitudinal acceptance for the new channel is increased on about factor of two. The transverse acceptances are some percent lower due to the strong coupling between transverse and longitudinal properties of the RFQ. Nevertheless the total 6D acceptance for the new design is significantly higher.

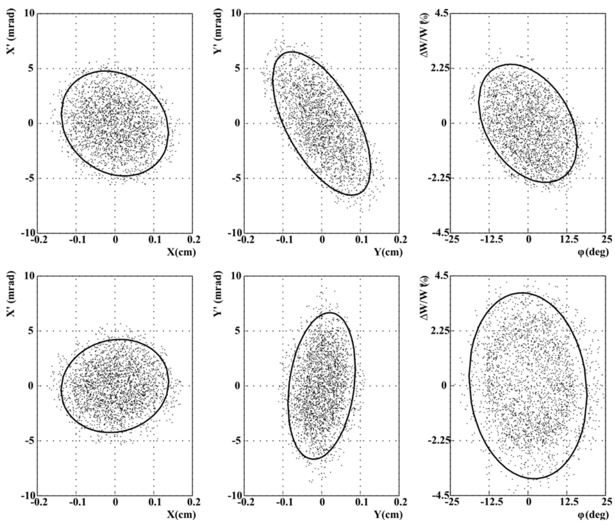

Figure 6: Particle distribution representing the transverse and longitudinal acceptances for old (top) and new (bottom) designs. The ellipses describe 90% of the particles.

The total transverse output beam emittances for the new design are significantly higher than for the old one due to the increased 6D RFQ acceptance. However the difference between output transverse rms beam emittances and brilliance is much smaller (Fig. 7).

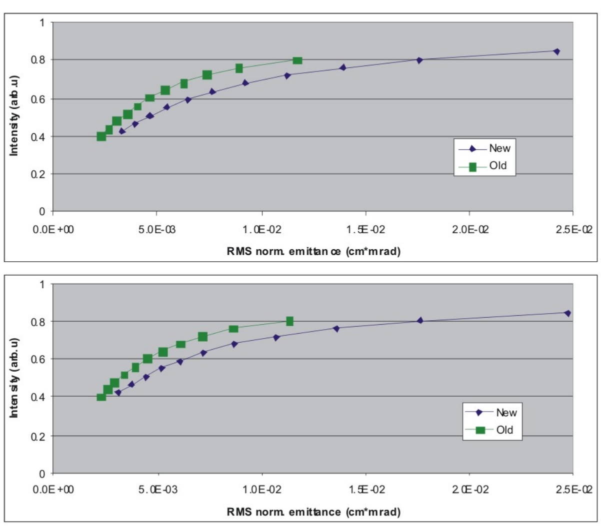

Figure 7: Beam intensity inside given horizontal (top) and vertical (bottom) normalized rms emittance behind RFQ.

The simulated energy distribution behind new and old RFQs is presented on Fig. 8. Longitudinal particle distribution on phase (space) is almost DC with some variation of the particle density.

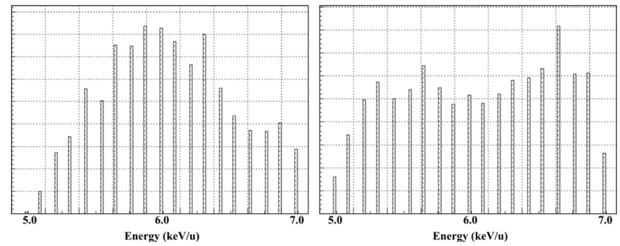

Figure 8: Low energy particle distribution behind RFQ for old (left) and new (right) design.

CONCLUSION AND OUTLOOK

An improved design of the HITRAP-RFQ channel was proposed. Main goals of the design are the correct input energy and twice increased longitudinal acceptance. This should provide for easier beam matching to the RFQ and successful deceleration of the ions to the design energy of 6 keV/u at GSI HITRAP facility.

The fabrication of the new rods and stems is ongoing. Commissioning and the test experiments with the upgraded RFQ are planned in November 2012 at MPI-K (Heidelberg). Afterwards the RFQ will be installed into the HITRAP beam line at GSI.

A completely new RFQ design, including new tank with improved rf properties, as well as mechanical and thermal stability is strongly recommended. In parallel a new design of the RFQ channel, based on the refined experimental and numerical information about beam parameters behind IH-DTL, should be elaborated.

Further improvement of the RFQ beam dynamics might be reached with a special law of synchronous phase along channel, as well as with use of the trapezoidal modulation [6] for the RFQ high energy part.

REFERENCES

[1] O. Kester et al., "DECELERATION OF HIGHLY CHARGED IONS FOR THE HITRAP PROJECT AT GSI", LINAC 2006, Knoxville, Tennessee USA, MOP063 (2006).
[2] F. Herfurth et al., "HITRAP Decelerator and According Beam Instrumentation", HIAT 2012, Chicago, Illinois USA, THB05 (2012).
[3] B. Hofmann et al., "A RFQ-DECELERATOR FOR HITRAP", PAC07, Albuquerque, New Mexico, USA, TUPAN020 (2007).
[4] S. Yaramyshev et al., "Development of the versatile multi-particle code DYNAMION" NIM A, Vol 558/1, pp 90-94, (2005).
[5] S. Yaramyshev et al., "Advanced beam dynamics simulations with the DYNAMION code for the upgrade and optimization of the GSI-UNILAC", HB2010, Morschach, Switzerland, THO1A04 (2010).
[6] O. Belyaev et al., "IHEP EXPERIENCE ON CREATION AND OPERATION OF RFQS", LINAC-2000, Monterey, California, USA, MOD21 (2000).

ISBN 978-3-95450-122-9