TESTBENCH OF THE HIT RFQ AT GSI

C.-M. Kleffner, R. Bär, W. Barth, M. Galonska, F. Heymach, R. Hollinger, G. Hutter, W. Kaufmann, M. Maier, A. Reiter, B. Schlitt, M. Schwickert, P. Spaedtke, W. Vinzenz, GSI Darmstadt, Germany
A. Bechtold, A. Schempp, IAP, Frankfurt-am-Main, Germany
R. Cee, E. Feldmeier, S. Vollmer, HIT Heidelberg, Germany

Abstract

In April 2006 the commissioning of the ion linac for the Heidelberg Ion beam Therapy Centrum (HIT) facility in Heidelberg, Germany was started. In preparation of the commissioning of the RFQ cavity beam tests with protons were carried out at GSI. The RFQ for the HIT facility was delivered to GSI in March 2005. A testbench for the RFQ cavity was constructed at GSI to allow for exact measurements of the output energy with the time of flight (ToF) method in addition to previous beam tests at IAP Frankfurt using an analyzing magnet. Due to the fact that a double gap rebuncher is integrated into the RFQ-structure, beam studies with different mechanical settings of the rebuncher had to be conducted. For each setting the effective voltage of the rebuncher could be estimated. The final mechanical setting was chosen with respect to required longitudinal matching to the IH structure behind of the RFQ.

INTRODUCTION

The heavy-ion cancer treatment facility HIT [1] is presently under construction at the university clinics in Heidelberg. The accelerator part includes a Linac consisting of a low energy beam transfer line with two ECR ion sources as well as a 400 keV/u 4-rod RFQ and a 7 MeV/u drift tube linac (IH DTL) operating at 216,816 MHz [2]. A synchrotron with a maximal magnetic rigidity of $B\rho$ = 6.5 Tm will accelerate heavy ions up to 430 MeV/u. First ion beams were produced in April 2006 and various commissioning activities of the ion sources and the LEBT with ion beam have been performed until mid of July 2006 [3].

One crucially component of the linac is an exceedingly shortened matching section between the RFQ and the IH DTL. A compact matching section with a quadrupole doublet and steerer magnet for transversal matching is foreseen between the RFQ and the IH tanks. The longitudinal matching to the IH DTL is performed by two gaps integrated into the RFQ tank [4]. The rebuncher is thus a share of the resonant structure of the RFQ.

This design allows to dispense with a dedicated RF-amplifier for saving infrastructure and operating expense. The preliminary adjustment of the RF phase and amplitude of the rebuncher related to the 4-rod structure is a part of the low-level tuning process of the RFQ [4]. As shown in Fig. 1 the support for the 2. drift tube can be displaced along the slit in the last stem of the rfq-structure facilitating the modification of the RF amplitude in the rebuncher gaps.

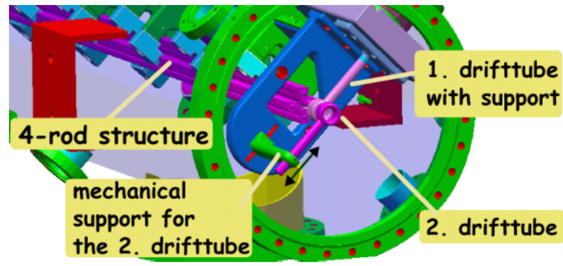

Figure 1: 3D-sketch of the integrated double gap rebuncher inside the RFQ tank.

The main objectives for the measurements at GSI in preparation to the commissioning at the HIT facility are the following:

- RF conditioning of the RFQ cavity up to 200 kW
- final low level tuning of the RFQ structure.
- verification of the output energy of 400 keV/u within a suitable RF power.
- longitudinal matching to the IH DTL.
- hardware tests of beam diagnostic hardware for the HIT facility.

In May 2005 the operation with an RF power up to 200 kW and a pulse width of 500 µsec could be accomplished successfully after a short time of RF conditioning to assure the operation with an RF power suitable for acceleration of $^{12}C^{4+}$.

LOW LEVEL MEASUREMENTS

A re-iteration of the adjustment of the electrode field flatness was necessary due to the completion of the set of tuning plates as well as the installation of smaller drift tubes delivered by IAP Frankfurt.

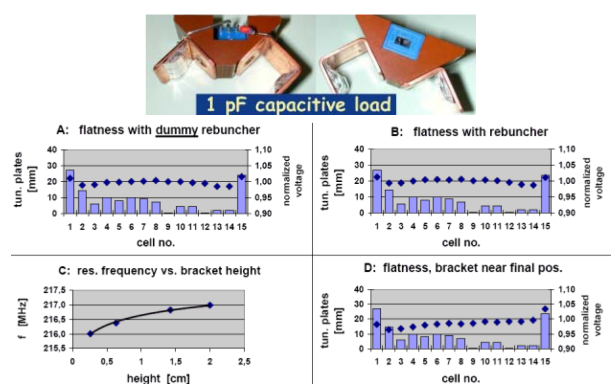

Figure 2: Photo of the utilized capacitive probe device. Height of tuning plates along the structure with estimated electrode field flatness without (A), with (B) rebuncher in its initial position. Adjustable range for the support holding (C). Flatness near final setting of the support (D).

The final setting for the tuning plates (Fig. 2) allows for an adequate tuning range for of the drift tube support with an acceptable (< 5%) field flatness. Within that range a re-tuning of the rfq-structure is not necessary.

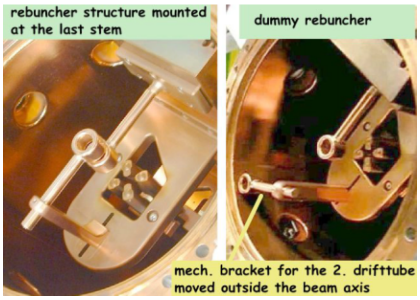

Figure 3: View on the installed rebuncher as well as on the drift tube tilted away from the beam axis but capacitivly coupled to the tank wall (dummy rebuncher).

Fig. 3 shows the rebuncher in its initial position as well as mounted for the dummy rebuncher measurements. In this case the drift tube had to be carefully adjusted to the tank wall to retain the RF frequency of the whole RFQ-structure.

TESTBENCH SETUP

The test bench for the RFQ was assembled at GSI. A MUCIS ion source delivered a hydrogen beam at 8 keV with a total beam current of > 5 mA with 50% protons and 50% H_3^+ . As shown in Fig. 4 a solenoid magnet matches the protons to the RFQ transversally. A magnetic doublet focuses the accelerated beam. The capacitive phase probes I and II are followed by a profil grid inside a diagnostics box for the transverse position measurements and by an AC transformer for the beam current measurement [5]. The phase probe III in the ToF line permits the exact and unambiguously energy determination. The original beam diagnostic hardware for the HIT facility as well as a preliminary controlsystem could be tested at the testbench.

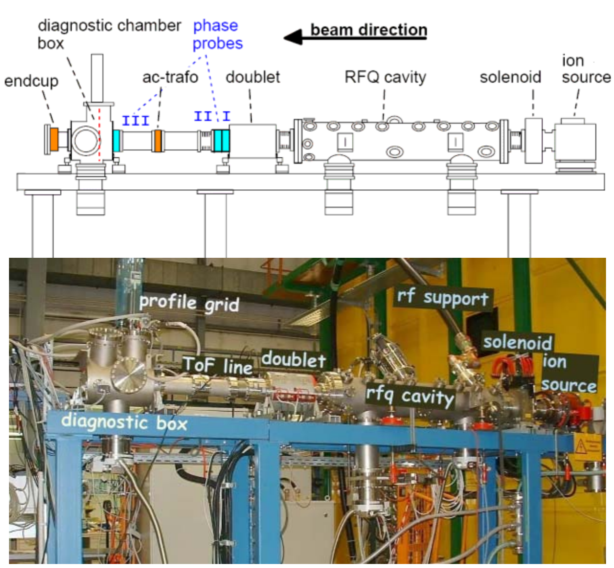

Figure 4: Layout and view of the testbench.

TOF MEASUREMENTS

The measurements of the energy of the accelerated protons have been estimated by the means of time of flight measurements (ToF). Waveform data from a high resolution digital oscilloscope (Fig. 5) with 4 channels have been stored as datafiles. With the calculation of the crosscorrelation function of two signals the ToF values could be estimated very accurately.

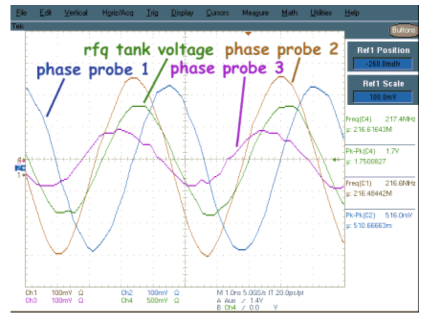

Figure 5: Phase probe signals.

ToF measurements with the de-activated integrated rebuncher (dummy rebuncher) have been carried out at different RF power levels. The estimated output energies have been compared with results of particle tracking simulations with RFQmed code [4] based on Parmteq. The characteristic steep incline for the output energy below 95% of the design voltage was used for calibration of the so called voltfactor. This value scales with the square-root of the RF power and is defined to be 1.0 for the design voltage.

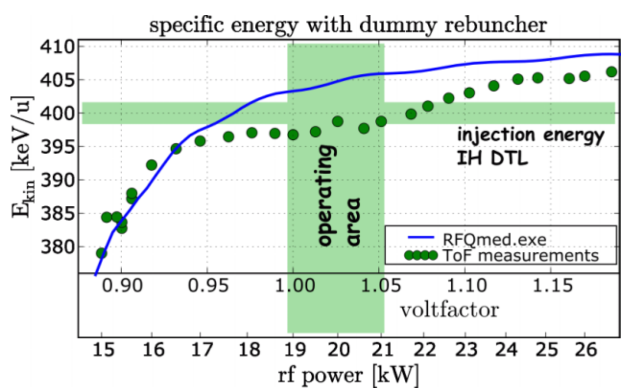

Figure 6: Comparison of simulated vs. measured beam energies at different RF power levels.

For acceleration of protons with a rod-voltage of 23.3 kV the estimated RF power consumption is about 19.0 kW as shown in Fig. 6. For acceleration of $^{12}C^{4+}$ ions with the maximum designed mass to charge ratio of 3:1 the expected power consumption for the RFQ could be appraised to be 170 kW respectively 190 kW for a voltage factor of 1.05. The "operating area" (Fig. 6) is the voltage factor range of about 1.00 to 1.05 which can be exploited for acceleration of ions in operation at the HIT Facility.

As shown in Fig. 7 the output energy measured with different rebuncher settings shows the expected dependency from the voltage factor due to its influence of the phase of the outgoing ions [7]. With increasing support height and from there increased rebuncher voltage the energy shift depending of the voltage factor is enlarged caused by the output phase dependency.

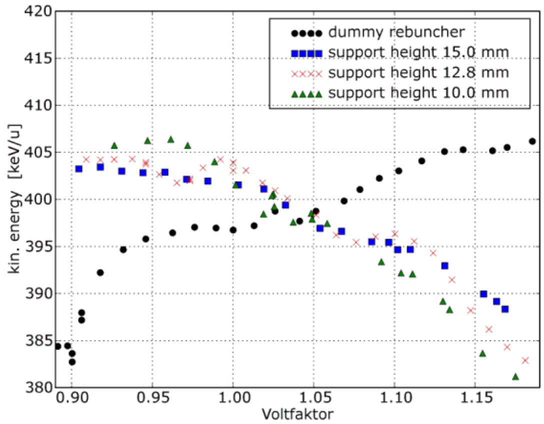

Figure 7: Specific energy in dependency of the voltage-factor for different mechanical rebuncher settings compared to the energy measurements with dummy rebuncher.

In addition to adjusting the height of the support for the 2. drift tube a correction of the distance between electrodes and the drift tubes by 1 mm towards the rods was needed for correction of synchronous phase of -90° to a voltage factor of about 1.04. The final setting allows changing the output energy from 398 to 405 keV/u within the operating area (Fig. 8).

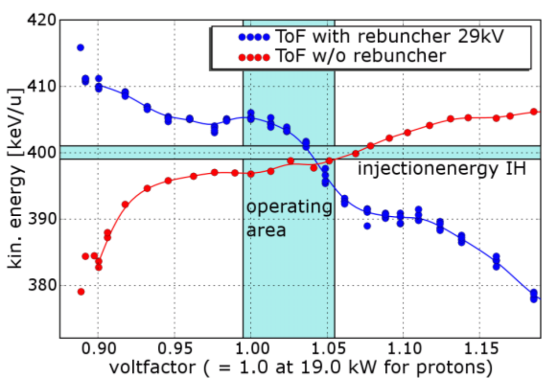

Figure 8: Estimated output energy of protons for the final mechanical rebuncher setting.

Additionally transversal profiles have been measured with the profile grid behind the ToF line as shown in Fig. 9. The estimated steering angles are below 10 mrad.

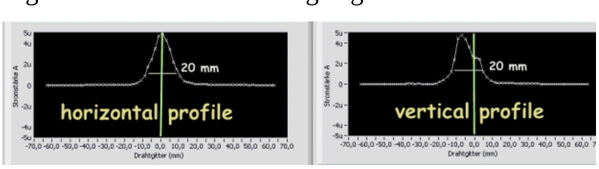

Figure 9: Horizontal and vertical beam profiles measured at the GSI testbench.

CONCLUSION

The rebuncher geometry was attuned with the help of ToF measurements. We expect that the output energy and the phase width of the bunches can be adjusted to the needs of the IH DTL within the operating area without any significant problems. Meanwhile the RFQ tank has been installed at the HIT facility in Heidelberg (Fig. 10). The commissioning of the RFQ with beam in HD is scheduled for September 2006. For this purpose a modified beam diagnostics test bench [3] will be additionally equipped with capacitive pick-ups providing for ToF energy measurements as well as an emittance measurement device. Furthermore ToF measurements at the GSI testbench are scheduled in September for the CNAO RFQ [8].

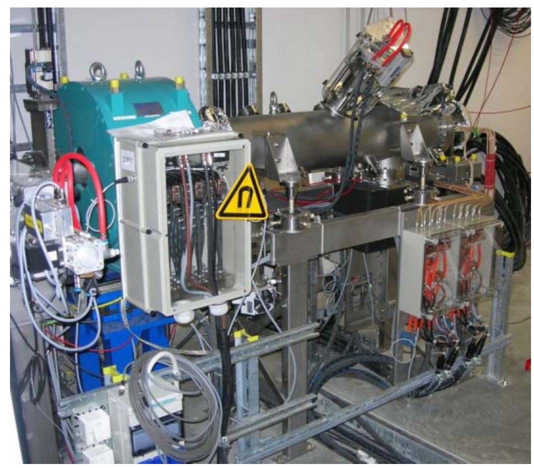

Figure 10: View on RFQ assembled in the linac hall of the HIT facility.

REFERENCES

[1] H. Eickhoff et al., HICAT - The German Hospital-Based Light Ion Cancer Therapy Project; EPAC 2004, p. 290

[2] B. Schlitt et al, Status of the 7 MeV/u, 217 MHz Injector Linac for the Heidelberg Cancer Therapy Facility , Proc. Linac 2004, p. 51

[3] B. Schlitt et al, this conference.

[4] A. Bechtold et al, "Eine integrierte RFQ-Driftröhren-kombination für ein Medizin-Synchrotron", PhD thesis, IAP Frankfurt, 2003.

[5] M. Schwickert and A. Peters, Proc. EPAC 2004, p. 2548

[6] A. Bechtold et al, Beam Test Stand of the RFQ-driftube-combination for the Therapy Center in Heidelberg. Proceedings of EPAC 2004, Lucerne, CH, p. 2568

[7] A. Bechtold et al, Beam Dynamics of an Integrated RFQ-Drifttube-Combination, EPAC 2006.

[8] U. Amaldi, CNAO – The Italian Centre for Light-Ion Therapy, Radiotherapy and Oncology, Vol. 73, Suppl. 2, Dec. 2004.