STATUS OF THE LINAC-COMMISSIONING FOR THE HEAVY ION CANCER THERAPY FACILITY HIT

M. Maier, R. Bär, W. Barth, L. Dahl, C. Dorn, T. Fleck, L. Groening, C. Kleffner, C. Müller, A. Peters, B. Schlitt, M. Schwickert, K.Tinschert, H. Vormann, GSI, Darmstadt, Germany
U. Ratzinger, A. Schempp, IAP, Frankfurt am Main, Germany
R.Cee, B. Naas, S. Scheloske, T. Winkelmann, HIT GmbH, Heidelberg, Germany

Abstract

The accelerator part of the clinical facility for cancer therapy using energetic proton and ion beams (C, He and O) has been designed by GSI, is presently installed, and under comissioning at the Radiologische Universitätsklinik in Heidelberg, Germany. In this contribution the current status of the linear accelerator is reported. After first tests of the RFQ at GSI with a proton beam, the commissioning of the injector linac in Heidelberg has started recently. The commissioning is performed in three steps for the LEBT, the RFQ and the IH-DTL successively. For this purpose, a versatile beam diagnostics test bench has been designed. This paper will provide for a status report of the linac commissioning.

INTRODUCTION

The heavy ion therapy (HIT) facility at the Radiologische Universitätsklinik in Heidelberg, Germany [1] consists of two ECR ion sources, a 7 MeV/u linac injector and a 6.5 Tm synchrotron to accelerate the ions to final energies of 50-430 MeV/u. The injector linac [2][3] shown in Figure 1 comprises the low energy beam transfer line (LEBT), a 400 keV/u Radio Frequency Quadrupole (RFQ) [4], and a 7 MeV/u IH-type Drift Tube Linac cavity (IH-DTL) operating at 216.8 MHz [5]. The commissioning of the linac injector is performed in three consecutive steps for the LEBT, the RFQ, and the IH-DTL.

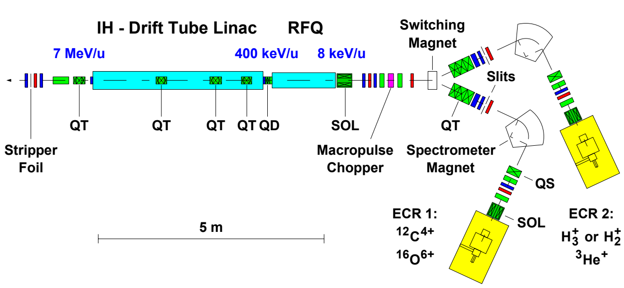

Figure 1: Layout of the Injector Linac [2]. QS = Quadrupole singulet, QT = Quadrupole triplet, SOL = solenoid, magnetic focusing and steering magnets (green), profile grids and the tantalum screen (red), and the beam current monitors (blue).

In October 2005 the building was finished preliminarily, thus the accelerator assembly could be started. Until February 2006, the LEBT and the ion sources have been assembled in the LINAC hall including the complete technical infrastructure required as shown in Figure 2. After commissioning of the LEBT without beam in March the first ion beam has been produced at the beginning of April 2006. After commissioning of the ion sources, systematic measurements of beam parameters at the RFQ injection are in progress since May 2006.

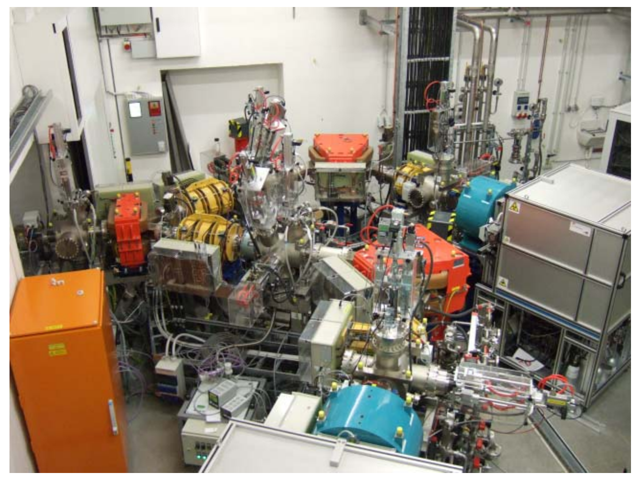

Figure 2: The assembled LEBT on site.

LEBT

The main goal of this comissioning step is to achieve matched beam settings to the RFQ acceptance for all required ion species as listed in Table 1. As an example Figure 3 shows the calculated envelopes along the LEBT for a $^{12}C^{4+}$ beam matched to the RFQ injection. Additionally to the standard beam diagnostics elements [6] the test bench at the RFQ matching-in is shown, it consists of an AC beam transformer, a profile grid, a slit-grid emittance measurement device, and a Faraday cup.

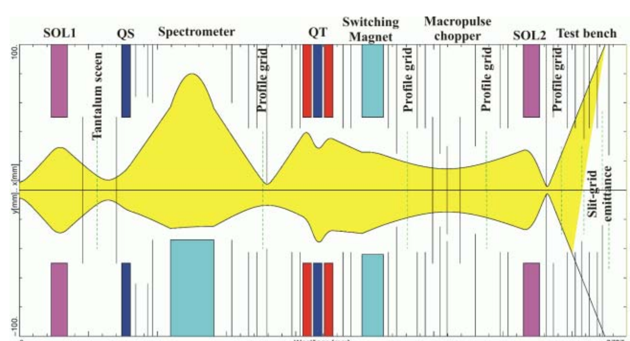

Figure 3: Beam envelopes along the LEBT and the beam diagnostics test bench as calculated with MIRKO [7]. The final solenoid magnet is adjusted to the RFQ.

Table 1: Specified ion species and intensities behind the 90° analysing magnet.

Ion	I / µA	U_{source} / kV
$3H^{+}$	700	24
$^{3}He^{1+}$	500	24
$^{12}C^{4+}$	200	24
$^{16}O^{6+}$	150	21.3

Behind SOL1 following each ECR ion source a tantalum screen is used to monitor the beam (Figure 4).

Figure 4: An image of a $^{4}He^{2+}$ beam measured with the tantalum screen behind SOL1.

Behind SOL1 a quadrupol singulet is used to match to the following dipole; in the horizontal plane for optimized resolution. A typical spectrum of the ECR ion beam for carbon operation is shown in Figure 5.

After selecting the desired ion species with the slits behind of the analysing magnet and adjusting the beam centre along the whole LEBT system with the steerers a transmission of 90% is achieved. Figure 6 shows top to bottom the measured beam profiles along the LEBT, the beam is matched to the RFQ-requirements as shown in Figure 3.

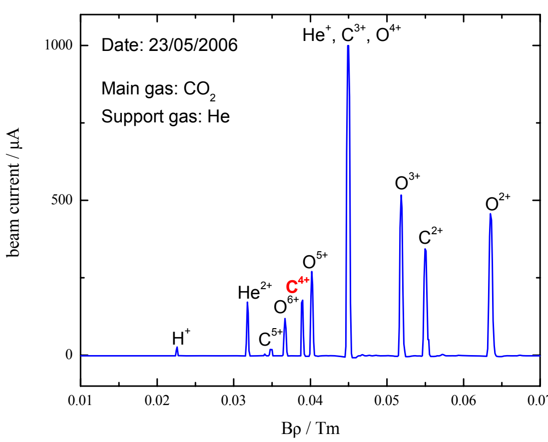

Figure 5: Spectrum of one of the ECR sources. The peak at Bρ = 0.0386 Tm corresponds to the desired $^{12}C^{4+}$.

As the beam behind the macropuls chopper is pulsed all beam diagnostics behind the chopper has to be triggered. In Figure 6 this applies to the last profile grid (bottom). Figure 7 shows the cup current at the end of the LEBT. The data aquisition time is chosen a bit longer than the actual beam puls (300 µs) to see the switching of the chopper.

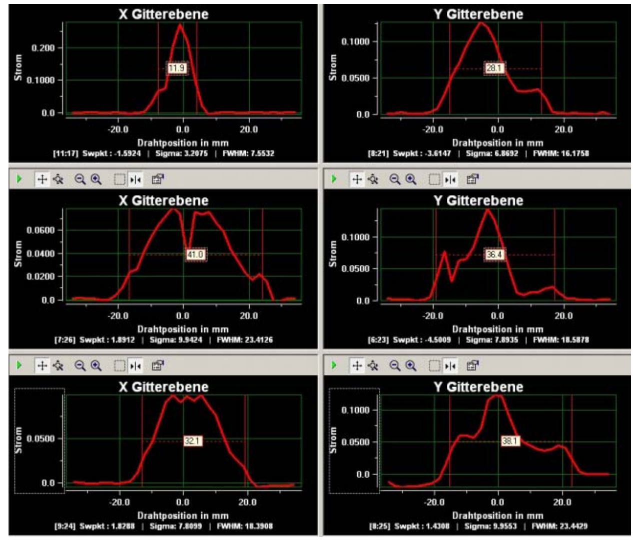

Figure 6: Measured profiles of a $^{4}He^{2+}$ beam along the LEBT. The achieved transmission in this case is 90%.

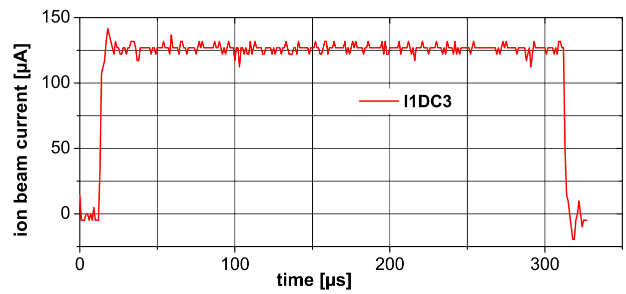

Figure 7: A triggered Faraday cup signal behind the macropuls chopper.

For these LEBT settings the emittance of the $^{4}He^{2+}$ beam is measured for varying solenoid field strength, an example (vertical plane) is displayed in Figure 8.

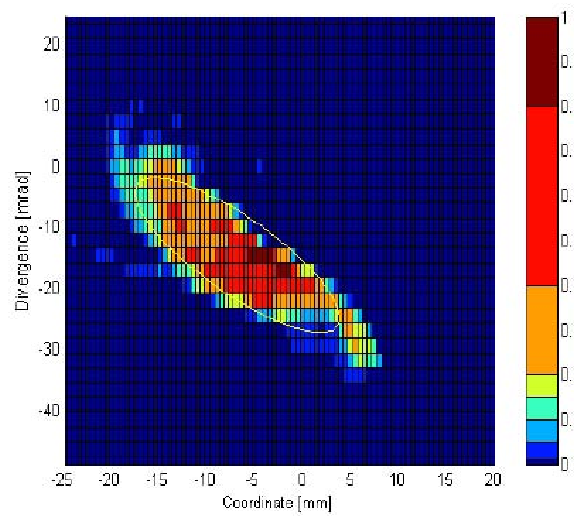

Figure 8: Example of a vertical emittance of a 200 µA $^{4}He^{2+}$ beam measured 0.7 m behind the RFQ matching point. The ellipse surface corresponds to a 4×rms emittance of 80 π mm mrad.

RFQ

The RFQ cavity for the HIT facility was delivered to GSI in the first quarter of 2005. Rf tests with an rf power up to 200 kW and a pulse width of up to 500 µs could be carried out successfully at GSI after a short time of rf-conditioning. In advance to the commissioning of the RFQ in Heidelberg an RFQ test bench shown in Figure 9 has been set up at GSI [8] in order to investigate and to adjust the operating parameters of the rebuncher drift tube setup integrated into the RFQ tank. Precise measurements of the output energy with the time of flight (ToF) method have been performed for various rebuncher geometries and voltages.

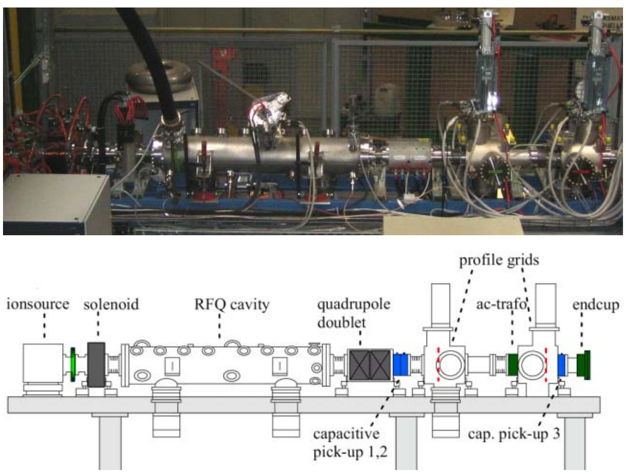

Figure 9: RFQ beam test bench at GSI.

As shown in Figure 9 a solenoid magnet matches the protons to the RFQ entrance. A magnetic doublet focuses the accelerated beam transversely into a drift section. Two capacitive pick-ups are followed by two profile grids inside the diagnostic boxes for the transverse position measurements and an AC transformer for the beam current measurement [6]. A third capacitive pick-up permits the exact and unambiguous energy determination.

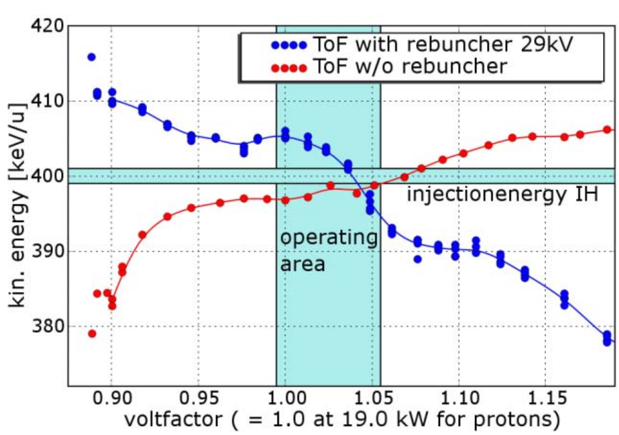

Figure 10: Beam energies behind the RFQ measured at the RFQ test bench at GSI vs. the RFQ voltage factor.

With the final mechanical settings the rebuncher can be operated with a synchronous phase of -90 deg and an effective voltage of about 29 kV for protons. The output energy of the protons with the integrated rebuncher with respect to the electrode voltage factor shows the expected energy shift. The estimated rf power consumption for the design RFQ electrode voltage of 23.3 kV is 19.0 kW for protons as shown in fig. 10. At carbon level the expected power consumption within the operation area will be between 170 and 190 kW.

IH-DTL

At the 20 MV IH-DTL shown in Figure 11 several RF measurements and RF tuning steps have been performed successfully already at the factory PINK GmbH Vakuumtechnik in Wertheim, Germany. The IH tank has been delivered to GSI in June 2005 and was copper plated at GSI afterwards. After several vacuum tests and some mechanical refinishing operation, the assembly of the drift tubes within the final tank was performed (Figure 11). Rf tuning is in progress.

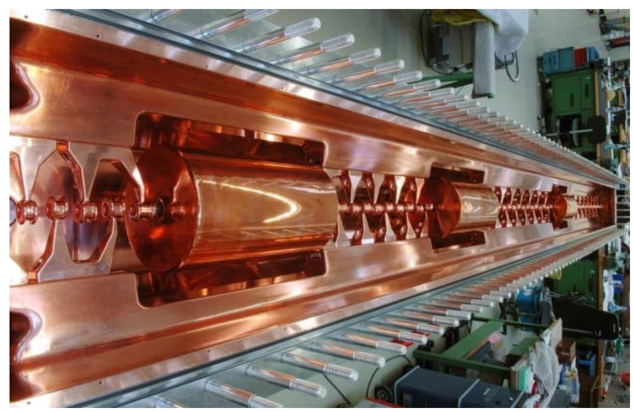

Figure 11: Open IH cavity after copper plating and installation of the drift tubes.

OUTLOOK

After the commissioning of the LEBT the RFQ will be installed in July 2006. For this purpose the beam diagnostics test bench will be additionally equipped with capacitive pick-ups providing for ToF energy measurements. The commisioning of the IH-DTL is accordingly planed for the fourth quater of 2006.

REFERENCES

[1] H. Eickhoff et al., Proc. EPAC 2004, p. 290.
[2] B. Schlitt et al., Proc. Linac 2004, p. 51.
[3] R. Cee et al., this conference.
[4] A. Bechtold et al., Proc. PAC 2001, p. 2485.
[5] Y. Lu et al., Proc. Linac 2004, p. 57.
[6] M. Schwickert and A. Peters, Proc. EPAC 2004, p. 2548.
[7] www-linux.gsi.de/~redelbac/MIRKO/index.html
[8] C. Kleffner et al., Testbench of the HIT RFQ, GSI annual report 2005.