LINAC FRONT-END UPGRADE AT THE CANCER THERAPY FACILITY HIT

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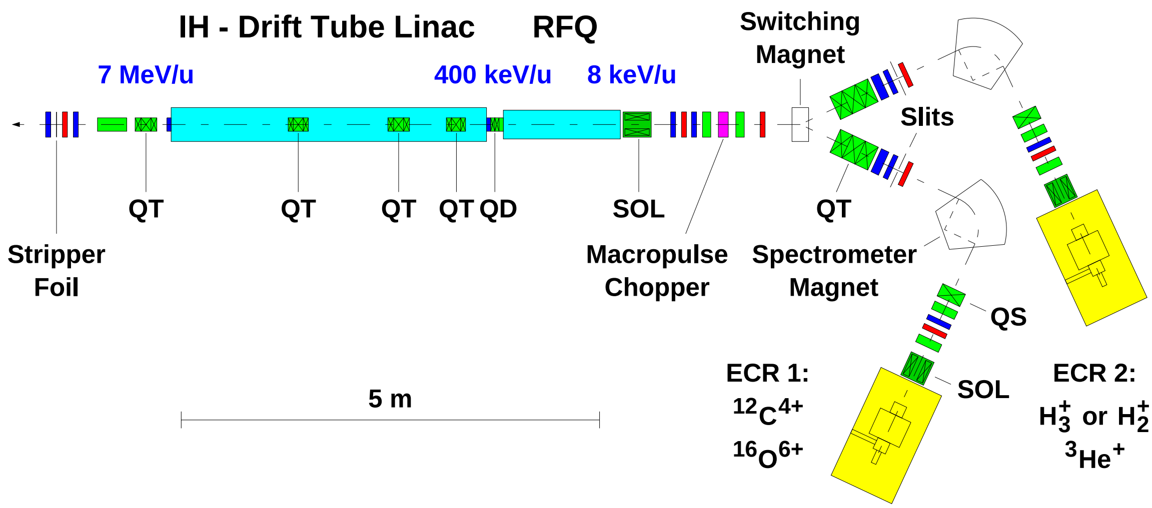

Figure 1: Layout of the Injector Linac [1]. QS = Quadrupole singulet, QT = Quadrupole triplet, SOL = solenoid, magnetic focusing and steering magnets (green), profile grids and the tantalum screen (red), and the beam current monitors (blue).

Abstract

A clinical facility for cancer therapy using energetic proton and ion beams (C, He and O) has been installed at the Radiologische Universitätsklinik in Heidelberg, Germany [1]. It consists of two ECR ion sources, a 7 MeV/u linac injector, and a 6.5 Tm synchrotron to accelerate the ions up to 430 MeV/u. The linac [2] comprises a 400 keV/u RFQ [3] and a 7 MeV/u IH-DTL [4] operating at 216.8 MHz and has been commissioned successfully in 2006 [5]. Yet the overall achieved transmission through the injector linac did not ecxeed 30 % due to a mismatch of the beam at the RFQ entrance. Thus a detailed upgrade programm has been started to exchange the RFQ with a new radial matcher design, to correct the missalignment and to optimize beam transport to the IH-DTL. The aim is to achive a sufficient overall linac transmission above 60%. Since August 2008 the new RFQ is at a test setup in Risø, Danmark. There a test bench comprising a full ion source and LEBT setup to commission the RFQ has been installed by Danfysik.

INTRODUCTION

The commissioning of the injector Linac [5] shown in Figure 1 was performed in three consecutive steps for the LEBT, the RFQ, and the IH-DTL.

Because of the low transmission (~30 %) achieved for the injector Linac an upgrade program was initiated in 2007. The timeline of the commissioning and the upgrade program is given in Table 1.

Table 1: Timeline of the HIT Linac Commissioning and the Linac Front-end Upgrade Program

2006 Apr.-Dec.	HIT Linac commissioning
2007 Aug.	RFQ design study measurements and solenoid exchange
2007 Nov.	New stiffened tank copper plated
2007 Dec.	RFQ input radial matcher design ready and approved
2008 May	Machining of the electrodes at NTG workshop
2008 Jun.	Assembly and RF tuning at the Univ. of Frankfurt
2008 Sep.–Oct.	Rebuncher adjustment and commissioning in Risø, Danfysik
Outlook	
2009	Integration of the new RFQ at HIT

LINAC FRONT-END UPGRADE

As a result of the Linac commissioning and excessive beam dynamics simulations the reasons for the low RFQ transmission were found to be:

- The poor performance of the ion sources,
- field errors of the Solenoid matching the beam to the RFQ,
- RFQ input radial matcher section and
- the deformed electrodes due to mechanical stress on the tank.

As first the Solenoid matching the beam to the RFQ has been exchanged and the result is shown in Figure 3.

During this solenoid exchange a measurement campaign was performed to obtain sufficient data for optimization of the input radial matcher design.

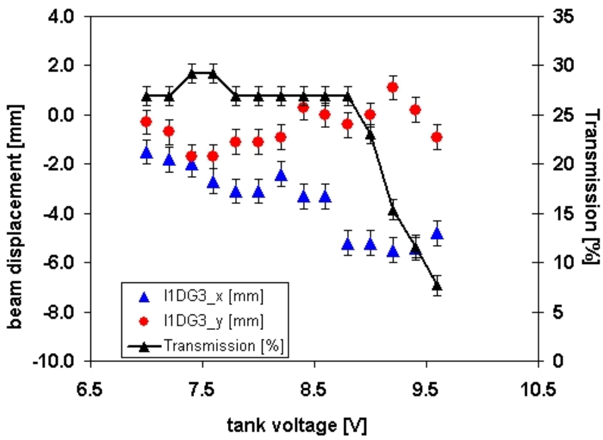

Figure 2: Transmission and beam displacement of the RFQ measured during commissioning in 2006.

Yet, because of unstable conditions of the ion sources this data could not be used. Instead, from the emittance measurements of the commissioning in 2006 a particle distribution was generated (Figure 4) and used for simulation with the simulation code Dynamion [6].

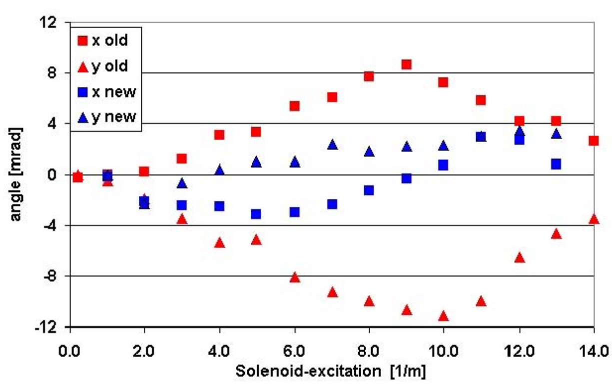

Figure 3: Steering of the beam behind the old and new Solenoids depending on their field strengths.

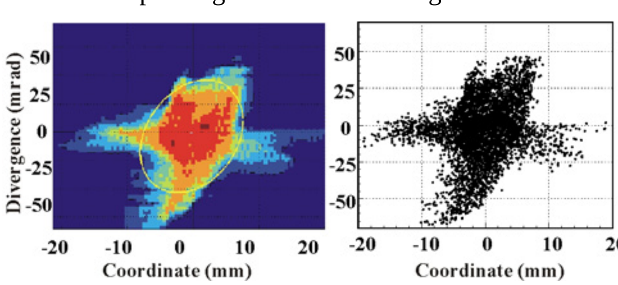

Figure 4: Measured $^{12}C^{4+}$ emittance at the RFQ entrance (left) and generated particle distribution to be used for simulation.

This distribution was transformed backwards through the solenoid. By varying the field strength in the transformations forward it was found that it is not the total emittance but the mismatch of the Twiss-parameters that leads to the beam losses. The possible improvement changing the input radial matcher is shown in Figure 5.

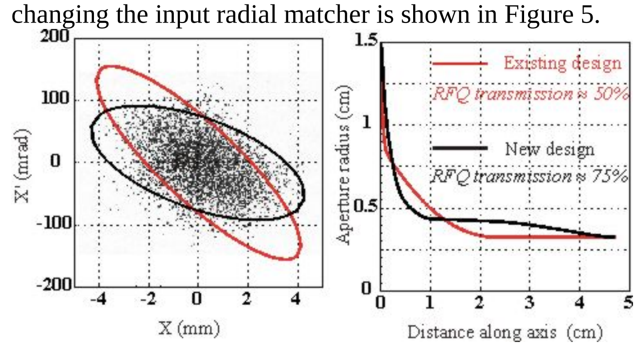

Figure 5: Dynamion simulation of the transmission improvement through the old and the new input radial matcher design using the particle distributions generated from the measured emittances (Figure 4).

During commissioning the alignment of the electrodes has been checked and a strong bending due to mechanical stress on the structure was found. A measurement of this deformation is shown in Figure 6 for the CNAO RFQ [7], a copy of the HIT RFQ. This deformation most likely happened during the alignment procedure and is of the same order of magnitude for both RFQs. A new stiffened tank design with thicker walls (6 mm instead of 4 mm), extra supports and 3 instead of 4 fixation points should solve this problem for the new RFQ design.

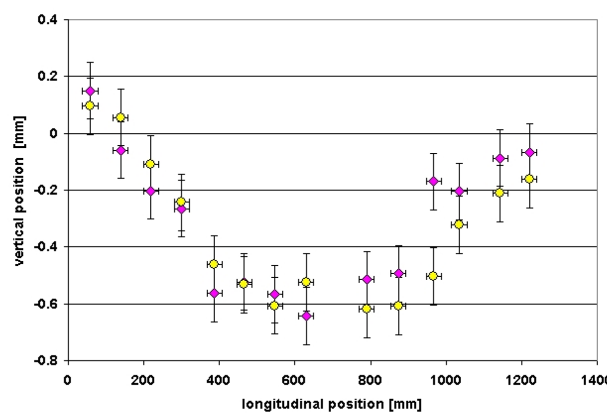

Figure 6: Vertical deformation of the CNAO RFQ electrodes measured on the upper and lower rods for a fixed (red) and loosened (yellow) tank.

Before the electrodes for the new design of the RFQ were machined, test pieces have been prepared to check the machining procedures for their feasibility. After the whole RFQ has been assembled, aligned and RF tuned it was shipped to a test setup of Danfysik in Risø, Denmark. This type of RFQ has an integrated rebuncher section (Figure 8) which has to be adjusted in a first commissioning step as described in [8]. The adjustment of the rebuncher voltage, which is a necessary prerequisite to commission the RFQ, has highest priority.

Besides an investigation of the high energy end of the RFQ is foreseen. The data obtained during commissioning in 2006 indicates that there might be particle losses also in the rebuncher section.

Figure 7: Final test piece of the RFQ radial matcher section to check the production procedures.

Beam losses definitely occurred in the doublet following the RFQ. Yet this fact does not allow for simulating the data further back as at this point all information about the transversal beam properties are lost.

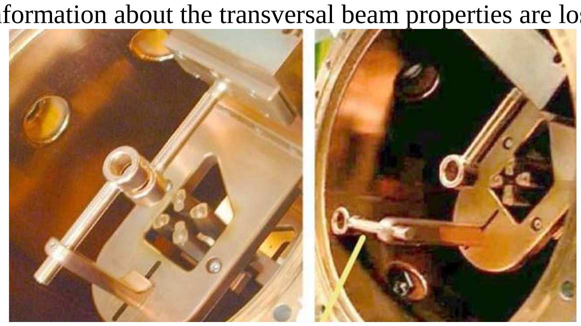

Figure 8: Rebuncher structure as mounted for operation (left) and in a dummy position to measure the output energy of the RFQ itself (right).

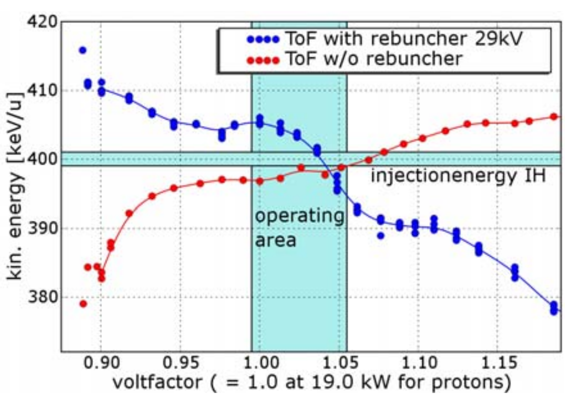

Figure 9: Measurement to adjust the rebuncher gap voltage [6].

The measurement campaign in Risø has started in September 2008 and for the first part the test bench shown in Figure 10 is equipped with three pickups a profile grid and an end cup for electron suppression. With this equipment the first energy scan without the rebuncher section shown in Figure 11 could be obtained.

Presently the rebuncher is adjusted to the design position continuing the beam energy measurements. After the rebuncher setting is fixed it is foreseen to change the test bench setup to allow for beam current and emittance measurements. Due to narrow apertures in front of the pickups it is not possible to do so with the provided setup for energy measurements.

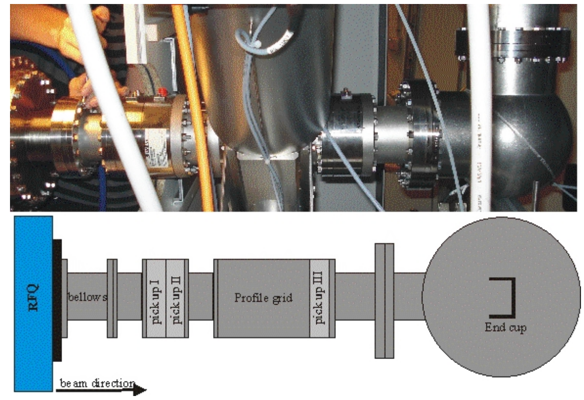

Figure 10: A photo of the diagnostics test bench as currently installed at Risø for RFQ energy measurements (top) and a schematic drawing (bottom).

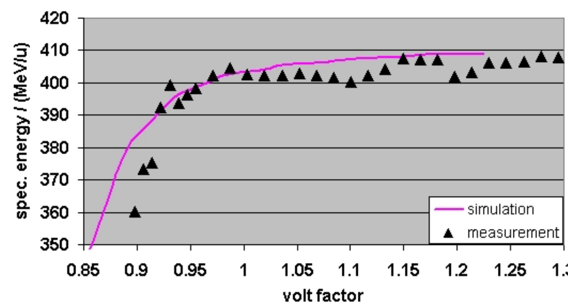

Figure 11: The RFQ energy scan with the rebuncher in the dummy position (blue) and the theory curve (red).

The planed second setup will consist of a beam current monitor, an emittance scanner and an end cup.

OUTLOOK

After the commissioning of the RFQ at the test bench in Risø in autumn 2008 it will be shipped to Heidelberg and included in the system during the first available shutdown period. A significant improvement in the overall Linac transmission up to 60% is expected.

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