INTEGRATION OF A THIRD ION SOURCE FOR HEAVY ION RADIOTHERAPY AT HIT

T. Winkelmann, A. Büchel, R. Cee, A. Gaffron, T. Haberer, J. Mosthaf, B. Naas, A. Peters, J. Schreiner, Heidelberger Ionenstrahl-Therapie Centrum (HIT), D -69120 Heidelberg, Germany

Abstract

HIT is the first European hospital based facility for scanned proton and heavy ion radiotherapy. In 2009 the clinical operation started, since then more than 1000 patients were treated in the facility.

In a 24/7 operation scheme two 14.5 GHz electron cyclotron resonance ion sources are routinely used to produce protons and carbon ions.

In the near future a helium beam for regular patient treatment is requested. The modification of the low energy beam transport line (LEBT) for the integration of a third ion source into the production facility was done in winter 2011. For beam quality improvement with a smaller emittance at the same current we designed and tested a new extraction system at the testbench and equipped the source for protons and helium with this optimized system. This paper will present results of the LEBT modification and give an outlook to further enhancements at the HIT ion source testbench.

INTRODUCTION

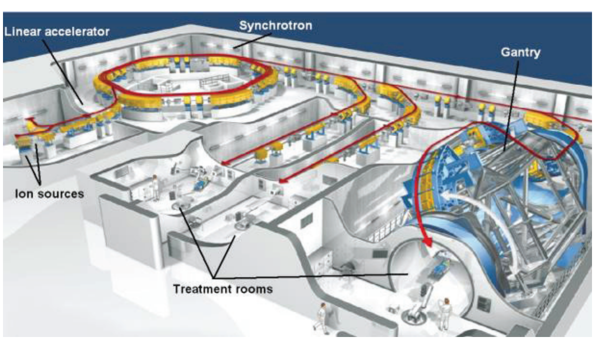

Figure 1: Overview of the HIT facility.

Since November 2009 more than 1000 cancer patients have been treated at HIT (see Fig.1) with carbon ions and protons [1, 2]. The increasing interest in the treatment with helium ions, especially for paediatric tumours [3], in addition with the requirement for fast switching between carbon ions, protons and helium ions triggered the design of a third independent spectrometer line and a new ion source.

LEBT MODIFICATION

The motivation for the new design of the LEBT beam line is based on the desire for higher beam brilliance and thus increased intensities for the upcoming clinical applications. The geometry of the available LEBT-room and the necessary space for a third source was an additional reason. Figure 2 and 3 is the status shown before winter 2011.

Figure 2: The existing low energy beam line (LEBT) before winter 2011.

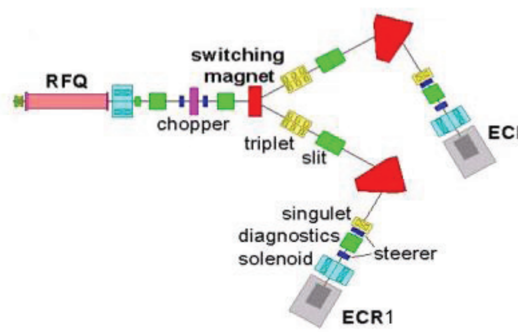

Figure 3: Schematic drawing of the LEBT before winter 2011.

The major improvement is motivated by the large emittance and the resultant poor transmission for the low LET beams especially protons through the LEBT.

TESTBENCH

To improve and test the possible LEBT setup with the requirement to integrate a third ion source in the production facility we build up a testbench with the following setup (Fig. 4): ECR ion source with extraction system (einzel lens), horizontal/vertical pair of steerers, 90° double focusing analyser dipole, beam diagnostics chamber with profile grid and Faraday cup, DC transformer, emittance measuring system (slit/grid) and Faraday cup. The emittance measurement analyser is a

ISBN 978-3-95450-123-6

loan of GSI Darmstadt and consists, amongst the data acquisition electronics and software, of two chambers, the first one housing the slits, the second one the profile grids. It is capable to measure the horizontal as well as the vertical beam emittance [1, 2]; [4, 5].

Without a magnetic focusing element between source and analyser dipole the plasma lens (extraction aperture) is placed in the focus of the dipole a difference to the existing (long) LEBT with a solenoid generating a beam focus in this section.

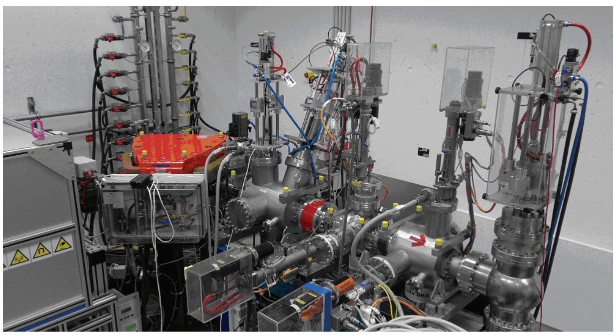

Figure 4: Test bench setup with a slit grid emittance measurement device.

We also integrate in the extraction system a fourth extra electrode with an independent power supply to accelerate or decelerate the ions in the puller-electrode gap. This fourth electrode improves the beam brilliance caused by a clearing effect (electrons) in this very "sensitive" area (Table 1). The beam line contraction between ion source and spectrum magnet optimized also the space charge compensation.

Table 1: Emittance and beam current output setup with the fourth electrode and without (in brackets).

Ion	Emittance [π ·mm·mrad]		Current [eμA]
	Horizontal	Vertical	
H_2^+	133 (147)	124 (160)	927 (902)
H_3^+	65 (85)	77 (103)	1490 (779)
$4He^{2+}$	64 (65)	64 (72)	746 (577)
$12C^{4+}$	98 (67)	110 (92)	166 (206)
$16O^{6+}$	74 (102)	53 (86)	188 (165)

LEBT MODIFICATION (STEP 1)

To realize the LEBT modifications during the operation we divided the mechanical work in two steps (Fig. 5 and 9). At the first step we change the 90° double focusing analyser dipole in the beam line to ECR 1 with a new dipole. These magnets get in addition to the same optical characteristic for the deflection angle of 90° (ECR 1) the possibility to pass the beam straight through (T_ Magnet).We contract also in the winter 2011 the LEBT for ECR 2 and remove the quadrupol Singulett, one pair of steerer, the diagnostic box and the solenoid. After this we installed the ion source (ECR2) with the implemented einzel lens extraction system.

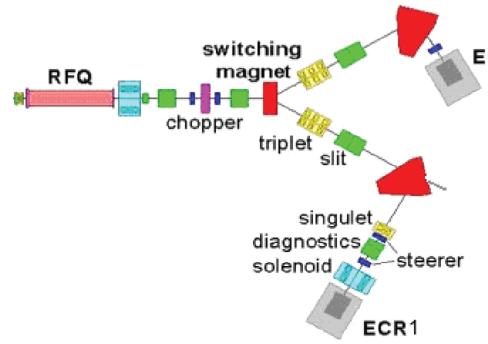

Figure 5: Schematic drawing of the LEBT after winter 2011.

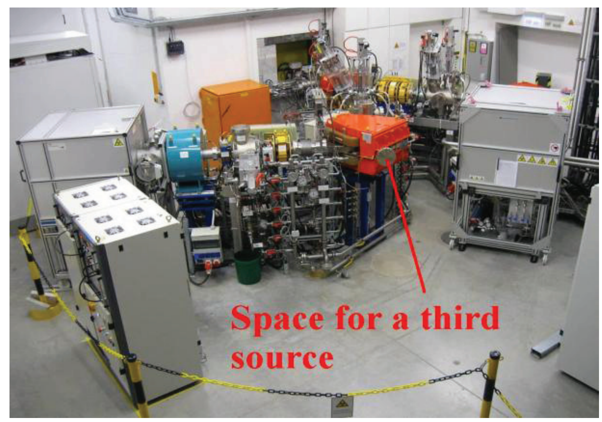

Figure 6: The low energy beam line (Step 1).

OPERATION EXPERIENCE AND RESULTS OF THE LEBT MODIFICATION

During the first five years of operation mainly carbon ions were used by 59 %, followed by hydrogen (39 %), helium (1 %) and oxygen (1 %). The continuous operation runtime of the two sources are 330 days per year 24h-operation!

The operation-statistics (see Fig. 7) since summer 2007 of the two ion sources are: 98.75% of the time in operation, 1.2% of the time for planed maintenance shifts and 0.05% of the time are the "off time" caused by multiple RF-amplifier breakdowns in the first two years.

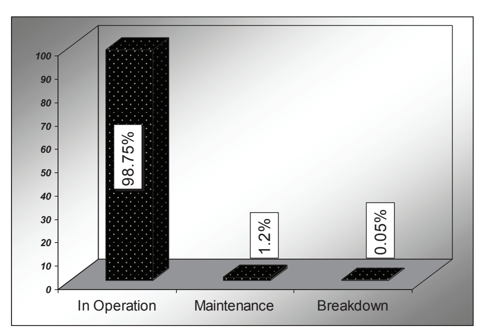

Figure 7: operation-statistic of the two ion sources at HIT, since summer 2007.

ISBN 978-3-95450-123-6

With the new set-up we reach nearly 100% transmission through the LEBT, and we have now the ability to operate the ion source gently to reach the same requested H3+ intensity behind the LEBT. That leads to a reduction of the extraction current from 7mA to 2,5mA. The benefit of that are lower wasting and a longer durability especially for the ceramics in the ion source. The beam shapes are comparable to measurements that we have done at the testbench [5] and looks much smaller than the shapes in the "old" set-up (see Fig. 8).

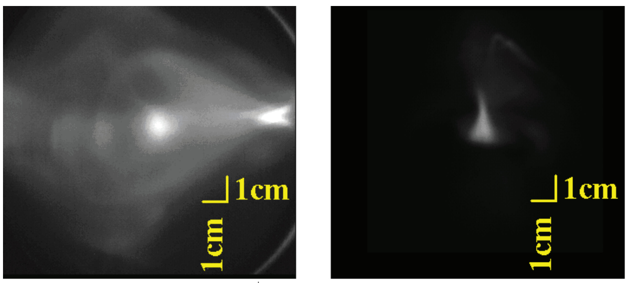

Figure 8: Shape of H_3^+ beam at a glass viewing screen (Herasil) behind the switching magnet. Left figure: Before LEBT modification (2emA) - Right figure: Status now (700eμA).

LEBT MODIFICATION (STEP 2)

The start of the third source implementation in the LEBT room starts in winter 2012.

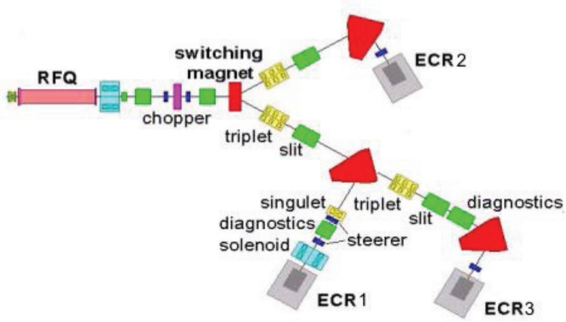

Figure 9: Considered design of the LEBT including three ion sources (planned in winter 2012) (Setup 2).

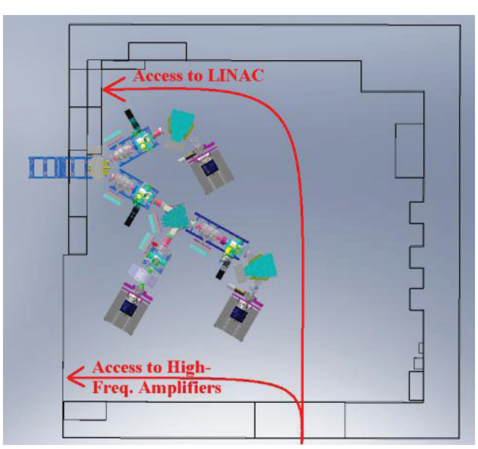

Figure 10: Considered design of the LEBT including three ion sources in the LEBT room.

OUTLOOK

The next measurement campaign takes place at the moment to analyse the poor RFQ transmission. The test bench configuration is installed and contains the LEBT, including quadrupole triplet, macro pulse chopper, solenoid, and the RFQ with a dedicated test beam line at the high energy end. These beam diagnostic components are: three phase probes, an AC transformer, a viewing target, a profile grid and a pepper pot screen with mirror plus CCD-camera and a Faraday cup in the end (see Fig. 11).

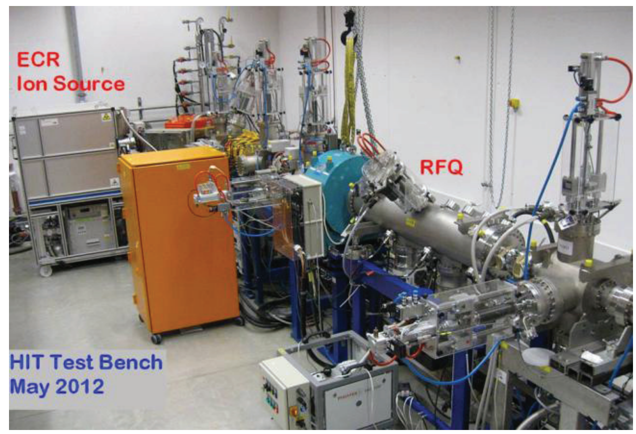

Figure 11: Test bench set up to analyse the RFQ output parameter.

REFERENCES

[1] A.D. Jensen, M.W. Münter, J. Debus, "Review of clinical experience with ion beam radiotherapy" British Institute of Radiology, doi:10.1259/bjr/71511359; Publ. 03/2011.

[2] A. Peters et al., "Five years of operation experience at HIT", IPAC'12, New Orleans, USA, May 2012, TUOAB03.

[3] T. Haberer "Charged particle therapy steps into the clinical environment" Int. J. Modern Physics E, Vol.16.

[4] R. Cee et al., "Status of the Ion Source and RFQ Test Bench at the Heidelberg Ion Beam Therapy Centre",IPAC'11, San Sebastian, Spain, September 2011,WEPS044, p. 2586 (2011).

[5] T.Winkelmann et al., "Test Bench to Commission a Third Ion Source Beamline and a New Designed Extraction System", ICIS'11, Catania, Italy, September 2011, Rev. Sci. Instrum. **83**, 02B904 (2012).

ISBN 978-3-95450-123-6