STATUS REPORT AT THE HEIDELBERG ION-BEAM THERAPY (HIT) ION SOURCES AND THE TESTBENCH

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Abstract

Since October 2009 more than 2000 patients were treated at HIT. In a 24/7 operation scheme two 14.5 GHz electron cyclotron resonance ion sources are routinely used to produce protons and carbon ions for more than 8000 hours per year. The integration of a third ion source into the production facility was done in summer 2013 to produce a helium beam. This paper will give a status report of the ion source operating experience and statistics and will summarize the enhancement activities, which were undertaken at an in-house ion source testbench.

INTRODUCTION

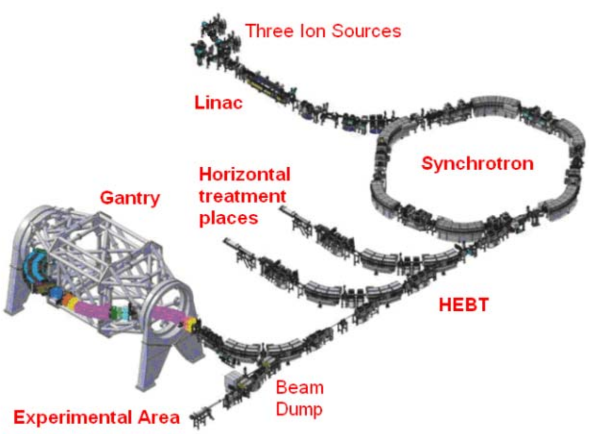

Figure 1: Overview of the HIT facility.

The beam production at HIT consists of two ECR Supernanogan ion sources [1] for the routine operation of proton and carbon beams at 8 keV/u; a third Supernanogan ion source is integrated (see ECR3 in Figure 2) for ion species like helium and oxygen for experiments at the experimental area (see Figure 1) and for the therapy in the future.

The compact 217 MHz linear accelerator (LINAC) consists of a radio frequency quadrupole accelerator (RFQ) and an IH-type drift tube linac (IH-DTL) with the end energy of 7 MeV/u for all ions; a foil stripper directly located behind these cavities produces fully stripped ions (see Figure 2).

A synchrotron of 65 m circumference accelerates protons, helium, carbon and oxygen to predefined end energies e.g. for carbon ions from 89 to 430 MeV/u in 255 steps.

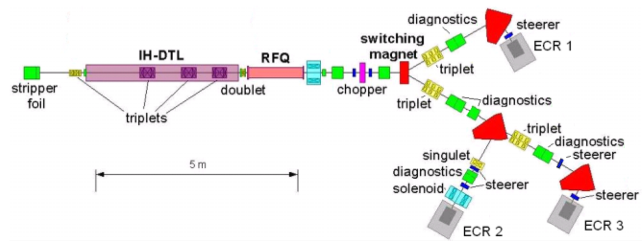

Figure 2: Low energy beam line (LEBT) and the linear accelerator (LINAC).

OPERATION EXPERIENCE

During the last years of operation mainly carbon ions were used by 58 %, followed by hydrogen (39 %), helium (2 %) and oxygen (1 %). The continuous operation runtime of the two sources are about 340 to 360 days per year in a 24h-operation! The operation-statistics since 2008 of the accelerator is shown in Figure 3. The sources in 2013 are in operation for 358 days per year, 7 days for planed maintenance shifts and 4 hours in 2013 are the "off time". The "off time" between 2008 and 2010 is caused by multiple RF amplifiers breakdowns [2].

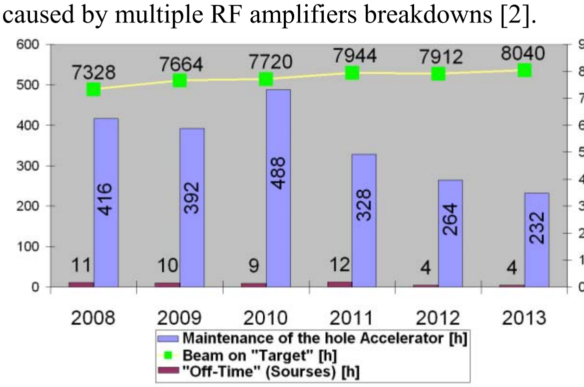

Figure 3: operation-statistic of HIT (2008- 2013).

The peak of the ion source "Off-Time" in 2011 is caused by numerous failures of the extraction system. The pollution of the extraction ceramic led to sparks in that region and generated an isolator ceramic replacement about every 3 weeks. This unfavorable situation could be remedied by the new construction and installation of the extraction system in winter 2011 at the therapy sources.

Since this time we do not have any insulator ceramic contaminations and no "hardware" problems with the sources. These replacements ensure an off time of just 4 hours per year (2012 and 2013). These 4 hours per year of "not usable" and instable therapy beam are used e.g. to find new and stable setting parameters, can be bridged by

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the usage of the second source for the therapy. Additional to this advantageous situation, we finalized in summer 2013 the integration of a third identical ECR ion source in the LEBT to disposal and respond quickly to possible ion source failures. The third source is also used for the production of helium and oxygen ions for experiments at the experimental area (see Figure 1).

All these measures led to smooth operation without ion source induced therapy down time since October 2009.

TESTBENCH

The activities described in this paper on the in-house ion source testbench can be divided into two fractions:

- Investigation of new designed plasma electrode for the therapy used ECR ion source type
- Investigations of the transmission through the RFQ with an EBIS ion source.

Plasma Electrode

The design with a tube is substantially different from the standard plasma electrode, where the electrode thickness is minimal close to the axis. Figure 4 shows the schematic construction and the axial magnetic field of the ECR ion source.

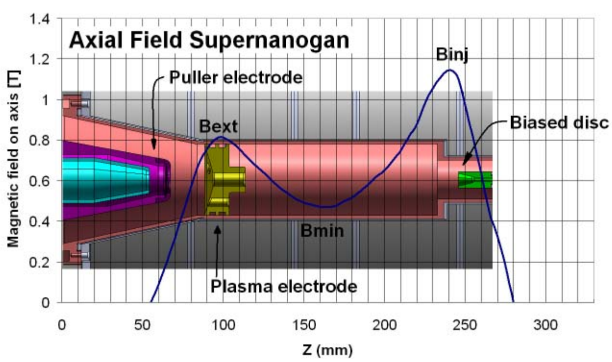

Figure 4: Axial magnetic field of the ECR ion source.

For an improvement of the vacuum in the region between the plasma electrode and extraction puller three additional holes were drilled in the "new" plasma electrode (see Figure 5, left). This creates the opportunity to reduce the distance between plasma electrode and puller electrode, without sparking, originally from 4 cm to 2 cm, leading to an improvement of the beam quality.

Figure 5: Used plasma electrode (left) and ion deposition in the tube after a year's operation in the ECR ion source for C^{4+} (right).

Figure 6 shows a comparison of the different extraction holes (3 and 7 mm) in a "standard" plasma electrode and the new 6 mm extraction "tube" hole with respect to the transmission between the first and the second Faraday cup at the test bench for H_3^+ and C^{4+} beams. The structure of the test bench is comparable to Figure 9, except for the source, for this measurement the EBIS was replaced by the ECR. With the requirement to the active redundancy of the mechanical source set up for all sources, this new design allows up to 220 eμA C^{4+} for carbon operation and up to 1.3 emA H_3^+ for the therapy with protons.

The measurement of the beam profile behind the dipole (Figure 7) shows a smaller beam profile with the new plasma lens at the same ion source settings.

This tube facing the plasma serves as an aperture for magnetic field lines. These field lines are not going through the extraction aperture and shields therefore ions coming from a loss line. Figure 5 (on the right side) shows the deposition of ions [3], in the tube, they are not entering the extraction aperture.

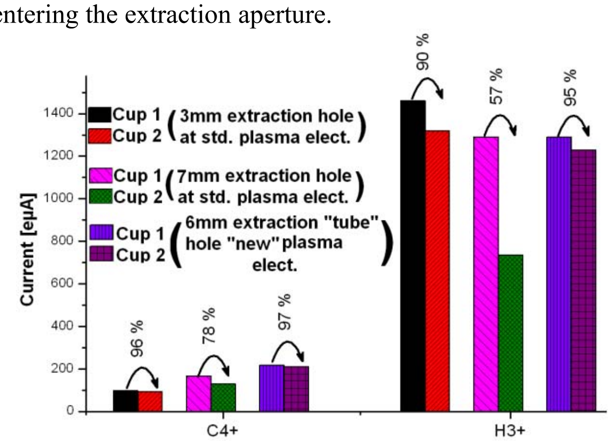

Figure 6: Transmission measurements at the test bench with different plasma electrodes (3 and 7 mm standard and 6 mm new designed electrode).

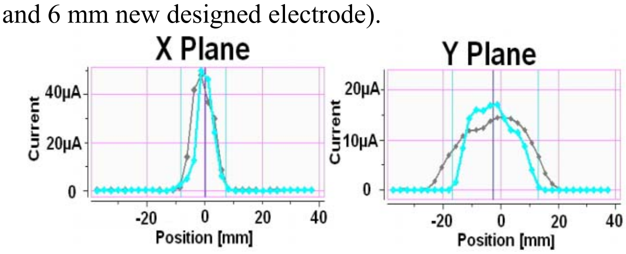

Figure 7: C^{4+} beam profile behind the dipole with different plasma electrodes (7 mm standard (gray) and 6 mm new designed electrode (cyan)).

Investigations of the RFQ Transmission

The objective of the work at the testbench was also determined in recent times by the further investigation of the non-optimal transmission through the RFQ [5]. To the often mentioned beam quality of the ECR source as a cause for the suboptimal transmission through the RFQ, we integrate, together with DREEBIT GmbH [4], a superconducting electron beam ion source (EBIS-SC) into the ion source testbench [6].The EBIS-SC was set on a high voltage platform providing up to 20 kV positive potential additional to the potential of the drift tubes,

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which defines the energy of the extracted ions. The extraction energy of the ions without the platform potential is about 6.9 keV. To reach the injection energy of 8 keV/u for the RFQ the HV-platform was set on 17100 V. The full setup of the testbench with the EBIS ion source is shown in Figure 9. The beam transmission (through the RFQ) of the generated EBIS pulsed beam of 19,8 eμA peak in a 20 μs pulse, $12C^{4+}$ at 8 keV/u showed that the improvement of the beam emittance by a factor 9, in comparison to the beam from the ECR [7], has just minor influences of 10% improvement for the transmission through the RFQ (Figure 8).

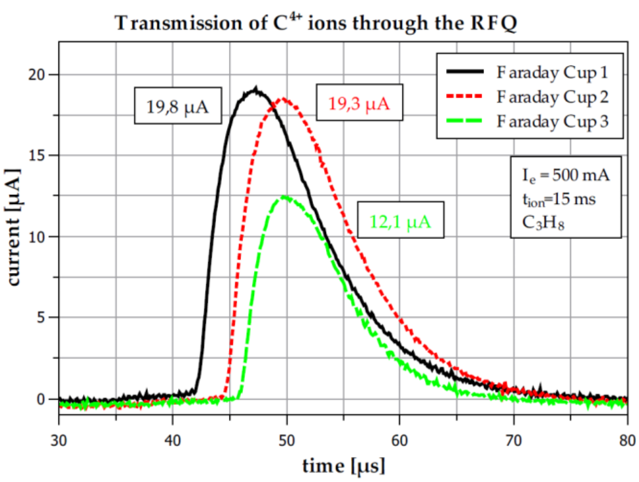

Figure 8: Transmission of a C^{4+} ion pulse from Faraday Cup 1 (black solid line) to Faraday Cup 2 (red dotted line) passing the RFQ to Faraday Cup 3 (green dashed line).

By this low beam quality influence of the transmission through the RFQ it is understandable why we do not see a transmission improvement with the reached emittance (4 x rms) enhancements at the ECR beam [7].

The measurement result implies that a desired time reduction for patient irradiation, by more injected synchrotron beam current, can be achieved only by improving the RFQ structure.

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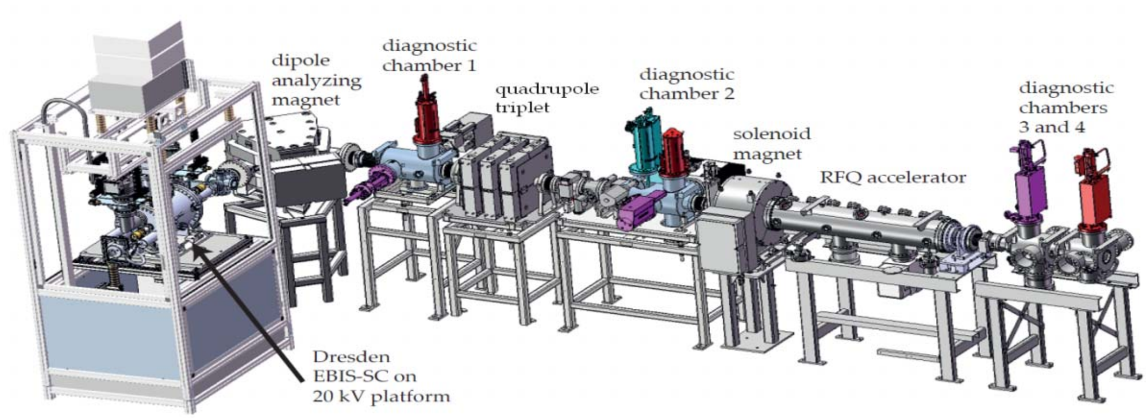

Figure 9: 3D CAD model of the testbench with the EBIS ion source (from left: EBIS-SC with 20 kV-platform, dipole analyzing magnet, diagnostic chamber one with profile grid 1, analyzing slits and Faraday cup 1, quadrupole triplet, diagnostic chamber two with pepper pot, profile grid 2 and Faraday cup 2, solenoid magnet, RFQ accelerator, diagnostic chamber three and four with a set of 3 phase probes, profile grid 3 and Faraday cup 3). The Faraday cups are colored in red, the grids profile monitors are colored in purple and the pepper pot is colored in cyan.

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