LONG-TERM OPERATION EXPERIENCE WITH TWO ECR ION SOURCES AND PLANNED EXTENSIONS AT HIT

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Abstract

The HIT (Heidelberg Ion Beam Therapy Center) is the first treatment facility at a hospital in Europe where patients can be treated with protons and carbon ions. Since the commissioning starting in 2006 two 14.5 GHz electron cyclotron resonance ion sources are routinely used to produce a variety of ion beams from protons up to oxygen. The operating time is 330 days per year, our experience after three years of continuous operation will be presented. In the future a helium beam for patient treatment is requested, therefore a third ion source will be integrated. This third ECR source with a newly designed extraction system and a spectrometer line will be installed at a testbench to commission and validate this section. Different test settings are foreseen to study helium operation as well as enhanced parameter sets for proton and carbon beams in combination with a modified beam transport line for higher transmission efficiency. An outlook to the possible integration scheme of the new ion source into the production facility will be discussed.

INTRODUCTION

The facility of the Heidelberg Ion Beam Therapy Center (HIT) [1] is the first dedicated proton and carbon therapy facility in Europe. HIT is located at the university hospital in Heidelberg (Universitätsklinik Heidelberg, Germany).

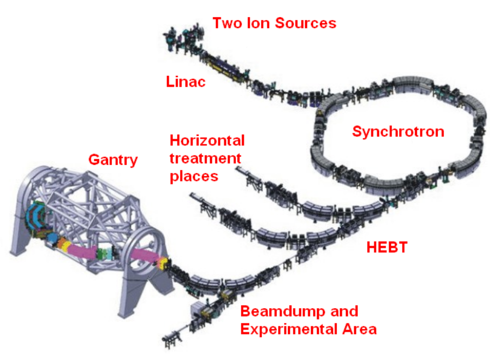

Figure 1: Overview of the HIT accelerator facility.

The beam production at HIT consists of two 14.5 GHz permanent magnet ECR ion sources from PANTECHNIK [2]. The 7 MeV/u injector linac [3] comprises the LEBT (Low Energie Beam Transport), a 400 keV/u radio frequency quadrupole accelerator (RFQ) [4,5], and a 7 MeV/u IH-type drift tube linac (IH-DTL) [3,4,5]. The linac beam is injected in a compact 6.5 Tm synchrotron [6] with a circumference of about 65m to accelerate the ions to final energies of 50 – 430 MeV/u, which is the key to the enormous variety of beam parameters provided by the HIT accelerator.

The maximum available beam intensity at the patient treatment place are 4·108 ions/spill for carbon and 1.6·1010 ions/spill for protons. With respect to the patient treatment, these intensities are sufficient, but for an effective quality assurance it will be important to reach the design parameters (C: 1·109 ions/spill, p: 4·1010 ions/spill). Taking into account the variable spill-length, the intensity shout be increased by a factor of 2.5 for carbon and protons.

The main contribution of particle losses is caused by the suboptimal transmission of the beam through the RFQ. Therefore the upgrade programme concentrates on a redesign of the RFQ [7]. In parallel we start to optimize the ion source performance for an improved brilliance to achieve a better adaption. Therefore we integrate a frequency variable microwave in a narrow range of 250 MHz around the 14.5 GHz center frequency. The frequency tuning is a method to optimize the electron cyclotron resonance ion source performances to maximize the extracted beam current and lower the beam emittance [8, 9, 10]. Furthermore for higher beam brilliance we designed a new extraction system.

LONG-TERM OPERATION EXPERIENCE

During the first three years of operation mainly carbon ions were used by 60 %, followed by hydrogen (38 %), helium (1 %) and oxygen (1 %). The continuous operation runtime of the two sources are 330 days per year 24h-operation!

Our challenge in the first three years of operation was the enhancement of the source components durability to stretch the time between maintenance intervals [10].

The operation-statistics (see Fig. 2) since summer 2007 of the two ion sources are: 97% of the time in operation, 2.9% of the time for planed maintenance shifts and 0.1% of the time are the “off time” caused by multiple RF-amplifier breakdowns. The time to exchange the defect amplifier by a spare part took mostly just one hour. By installing 3mm μ-metal shielding this instability is resolved in the meantime.

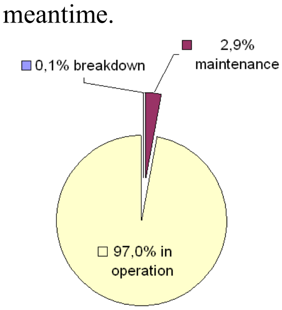

Figure 2: operation-statistic of the two ion sources at HIT, since summer 2007.

The required intensities given in table 1 were very stably achieved.

Table 1: Routinely used ion species and intensities behind the 90° analysing system.

Ion	I / eμA Used current	I / eμA Reachable current	U_{source} / kV
H_2^+	1200	1500	16
$^3He^{1+}$	500	500	24
$^{12}C^{4+}$	160	200	24
$^{16}O^{6+}$	150	150	21.3

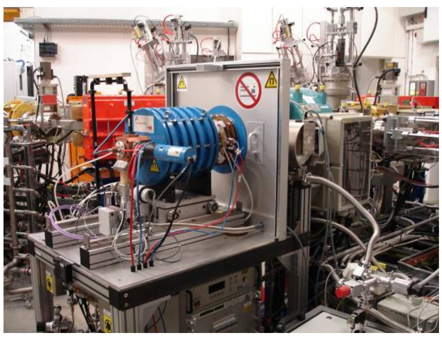

Figure 3: The 14.5 GHz high-performance permanent magnet ECRIS SUPERNANOGAN. This source was developed at GANIL, and is commercially available from PANTECHNIK S.A., France [2].

THIRD ION SOURCE

Presently the LEBT is designed for ion energies of 8 keV/u. At the moment there are two independent spectrometer lines (one for each ion source), a switching magnet which allows fast switching between the ion beams, a macro pulse formation and matching of the beam parameters to the entrance of the RFQ (Fig.4).

In 2009 it was decided to install a third ion source at HIT to offer Helium beam regularly for patient treatment in near future (Fig. 5).

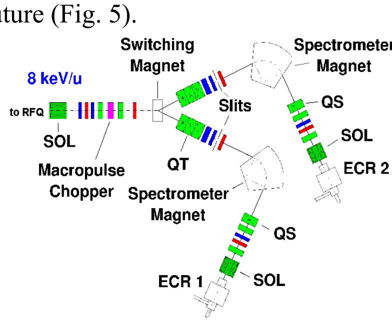

Figure 4: The existing low energy beam line (LEBT). SOL = solenoid magnet, QS = quadrupole singulet, QT = quadrupole triplet. Green: focusing and steering magnets, red: profile grids and tantalum screen, blue: beam current monitors

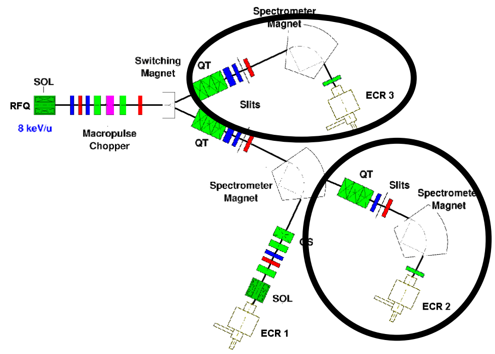

Figure 5: Possible schematic design of the LEBT including three ion sources.

All parts are delivered and will be pre-tested at a testbench.

The motivation for the shorter new design of the LEBT beam line is founded by lower space charge effects and by the geometry of the available LEBT space.

To test the "short" set up of the new spectrometer line (without Solenoid and Quadrupol (marked in Fig. 5)) a test bench is set-up now.

In May 2010 the factory acceptance tests (FAT) for the third ion source (SUPERNANOGAN) at Pantechnik has been started. For this test Pantechnik integrated in the acceptance test bench the new extraction system designed by HIT. We chose for the FAT a similar electrode design to the "old" Pantechnik extraction system with a 3mm smaller gap between plasma lens and puller electrode; another change to the original extraction system is the possibility to bias all three electrodes. After a week of conditioning the source fulfilled all tests. Pantechnik has begun in July the source installation at the HIT-Test-Bench.

TESTBENCH

A challenge for the installation planning was the integration of the new designed accel-decel-extraction-system (Fig. 6).

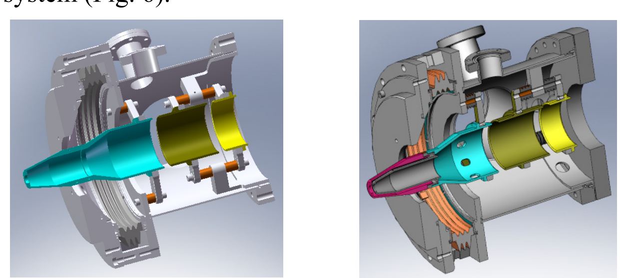

Figure 6: left: Extraction system for the ion source factory acceptance test at Pantechnik; right: The accel-decel extractionsystem, consisting of 4 electrodes set up for the HIT-Testbench

A goal for this set up (with a new extraction system and a "short" LEBT) is higher beam brilliance in comparison with the existing LEBT especially for the low LET-beams like helium and protons.

In the HICAT Technical Proposal [13] the use of 3He was recommended, but there are strong medical arguments to use 4He because of the less lateral straggling. In addition, the operation of a third ion species with the same A/Q = 2 value behind the stripper like for 12C6+ and 16O8+ will be much more efficient for keeping excellent accelerator settings for all ion species. For the risk mitigation measurement it is necessary to simulate a leak in the source and measure the potential "contaminating" output of 12C6+, 14N7+ and 16O8+ (same A/Q) at the "normal" operation setting for He.

A schematic design of the testbench is given in Fig. 7. The different testbench setup stages are also shown.

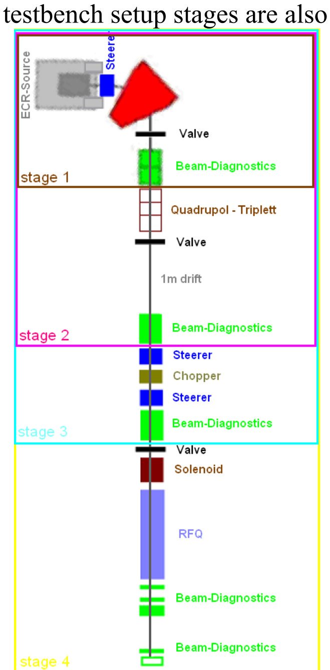

Figure 7: Test-Bench in 4 stages of expansion after every stages we integrate a slit grit emittance measurement device.

The aims for the different setups are:

Stage 1:

- Test of the optic for the new LEBT set up
- Acceptance test for the ion source with the new extraction system
- Parameter sets for helium (risk mitigation measurement), proton and carbon beams
- Improvement of the beam brilliance by changing the µ-Wave frequency [9]

Stage 2 and 3:

- Integration, and test, of a new designed pepper pot emittance scanner [11].

Stage 4:

- Investigation of the new RFQ with an enhanced electrode design and optimized alignment [12].

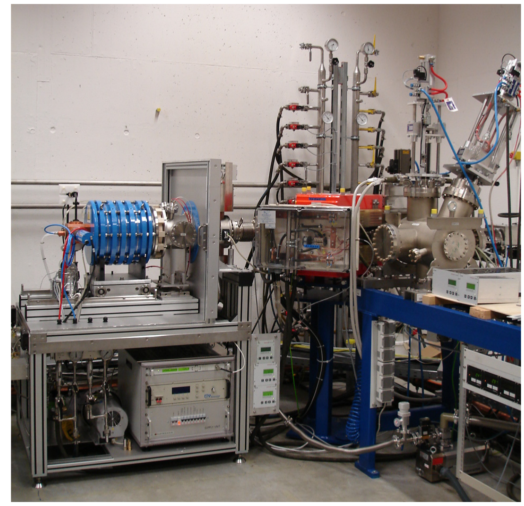

Figure 8: Test bench at HIT (stage 1)

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