UniversitätsKlinikum Heidelberg

HIT Heidelberger Ionenstrahl-Therapiezentrum

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

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

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 radiological university hospital in Heidelberg (Radiologische Universitätsklinik Heidelberg, Germany). 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 of the LEBT, 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.

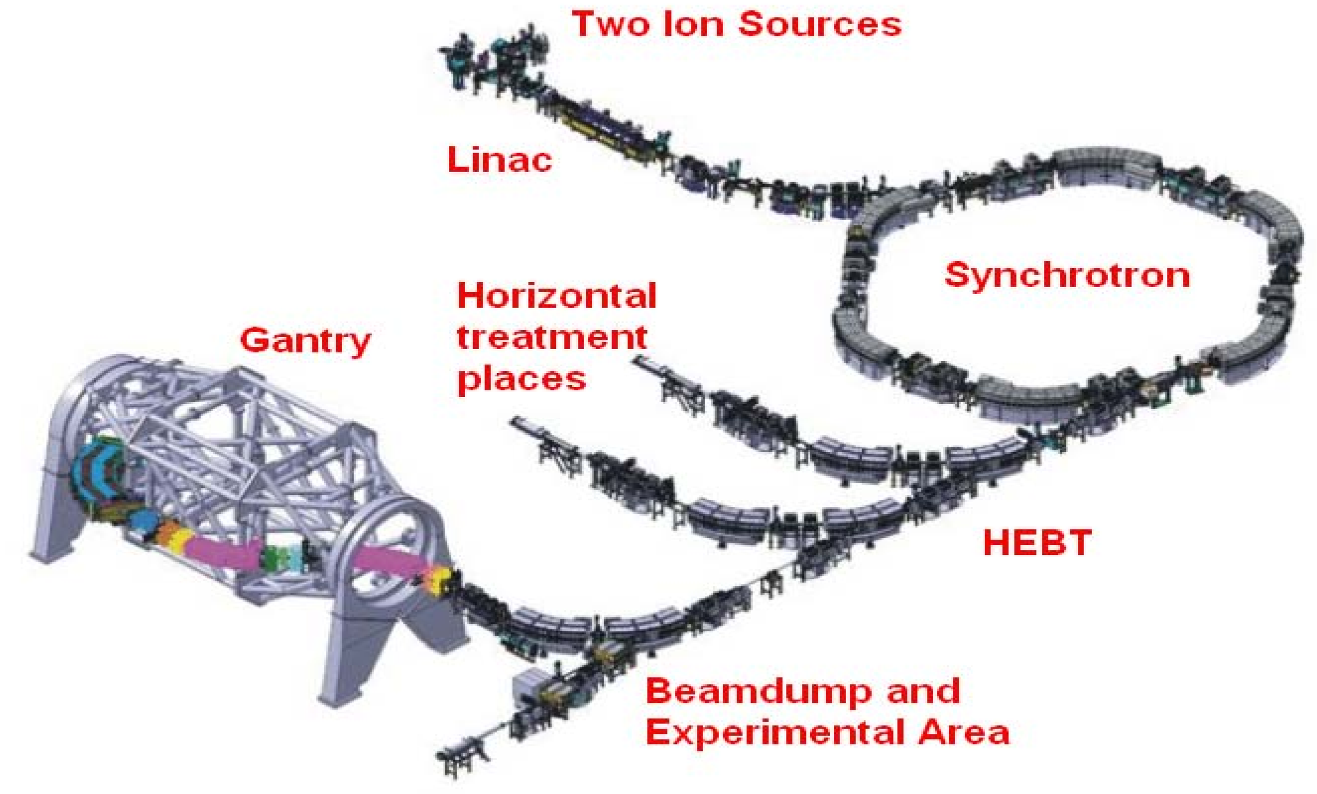

Figure 1: Overview of the HIT facility

The maximum available beam intensity at the patient treatment place are $4{\cdot}10^8$ ions/spill for carbon and $1.6{\cdot}10^{10}$ 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: $1{\cdot}10^9$ ions/spill, p: $4{\cdot}10^{10}$ ions/spill). Taking into account the variable spill-length, the intensity has to 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 a better beam quality and a better source components durability. Therefore we integrate a frequency variable microwave in a narrow range of 250 MHz around the 14.5 GHz center frequency [8]. Furthermore we designed a new extraction system.

LONG-TERM OPERATION EXPERIENCE

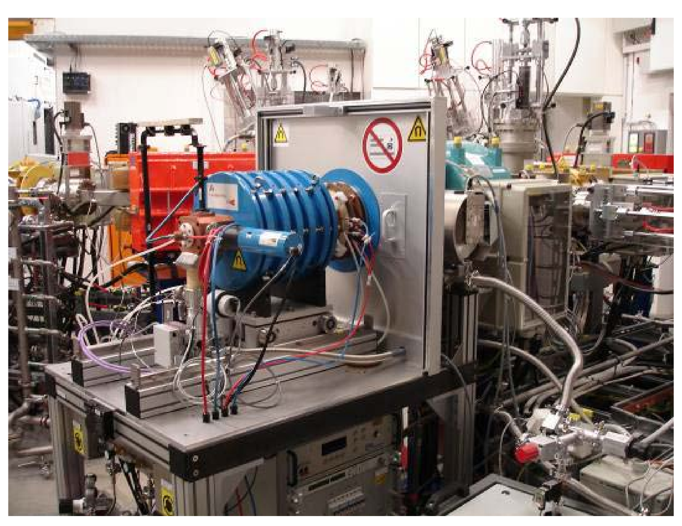

Figure 2: The 14.5 GHz high-performance permanent magnet ECRIS SUPERNANOGAN. This source was developed at GANIL, and is commercially available from PANTECHNIK, France [2].

Operating frequency	14.5	GHz
RF power	≤ 2	kW
Plasma chamber inner ∅	44	mm
Magnets for axial field	Permanent (FeNdB)	
Yoke outer length	324	mm
Yoke outer ∅	380	mm
Length of magnetic mirror	≈ 145	mm
$B_{max, Injection}$	1.2	T
B_{min}	0.45	T
$B_{max, Extraction}$	0.9	T
$B_{Hexapole}$	1.1	T
Measured ion currents:		
C^{4+}	200	μA
H^{+}	≥ 2.1	mA
H_2^{+}	1.0	mA
He^{1+}	1.1	mA
O^{6+}	300	μA

Table 1: Main parameters of SUPERNANOGAN

Ion	I / eμA Used current	I / eμA Reachable current	Usource / kV
H2+	1200	1500	16
3He1+	500	500	24
12C4+	160	200	24
16O6+	150	150	21.3

Table 2: Specified ion species and intensities behind the 90 analyzing system.

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

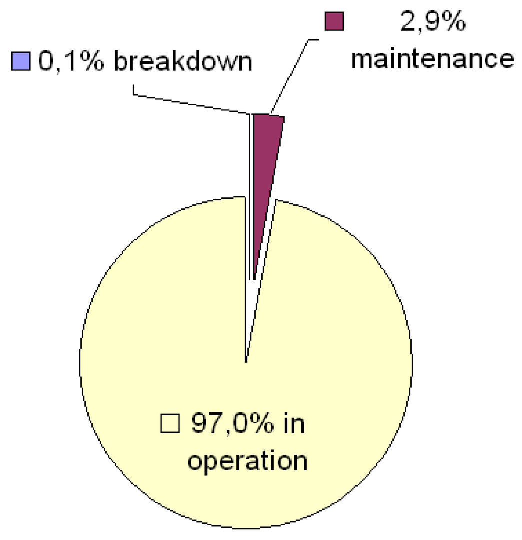

Figure 3: The failure probabilities (Ion Sources at HIT, since summer 2007)

Our challenge in the first three years of operation was the enhancement of the source components durability to lower the time of maintenance intervals[10]. The failure probabilities since summer 2007 of the two 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.

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).
The motivation for the shorter new design of the LEBT beam line is founded by lower space charge effects and the geometry of the available LEBT (space). To test the "short" set up of the modified spectrometer line (without Solenoid and Quadrupol (marked in Fig.5)) a test bench is built-up now (Fig. 8).

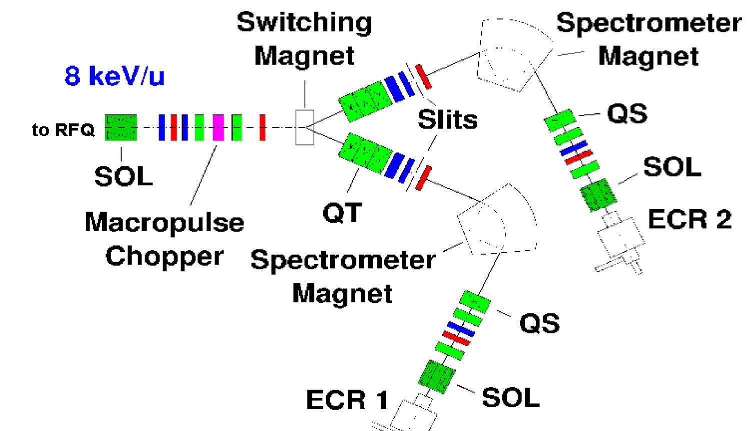

Figure 4: The existing low energy beam line (LEBT)
SOL = solenoid magnet, QS = quadrupole singulet,
QT = quadrupole triplet. Green: focusing and steering magnets,
red: profile grids and tantalum screen,
blue: beam current monitors (Faraday cups and beam transformers).

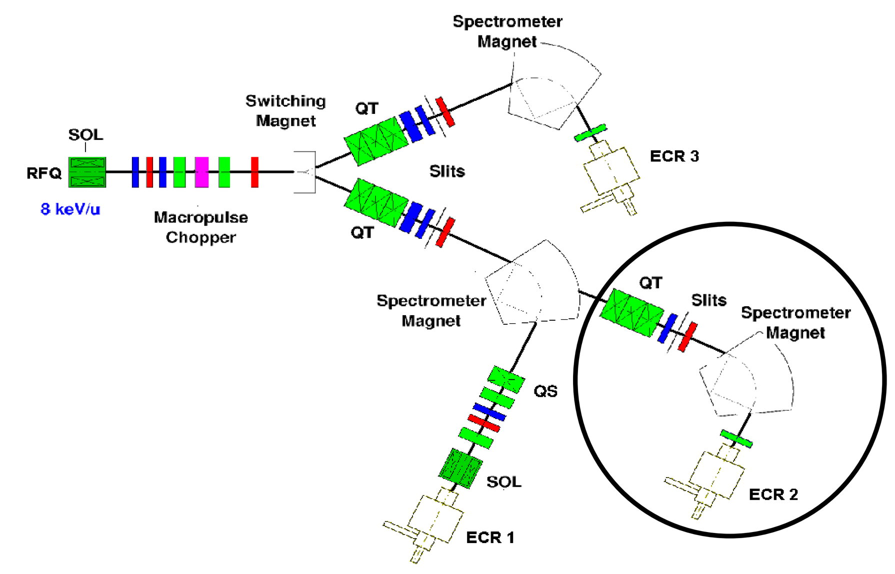

Figure 5: Possible schematic design of the LEBT including three ion sources.
SOL = solenoid magnet, QS = quadrupole singulet, QT = quadrupole triplet. Green: focusing and steering magnets,
red: profile grids and tantalum screen,
blue: beam current monitors (Faraday cups and beam transformers).

TESTBENCH

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

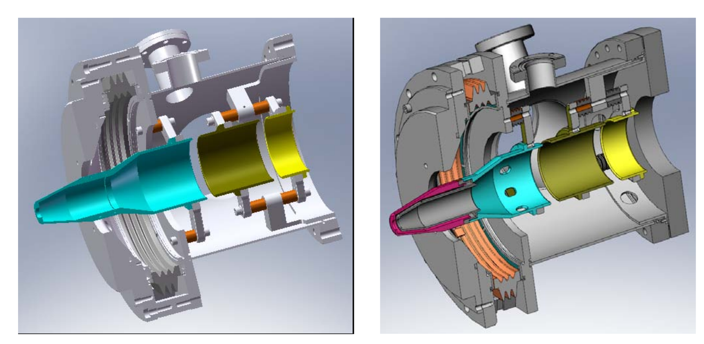

Figure 6:
left: Extraction system for the ion source factory acceptance test at Pantechnik;

right: The accel-decel extractionsystem, consisting of 4 electrodes set up for the HIT-Testbench

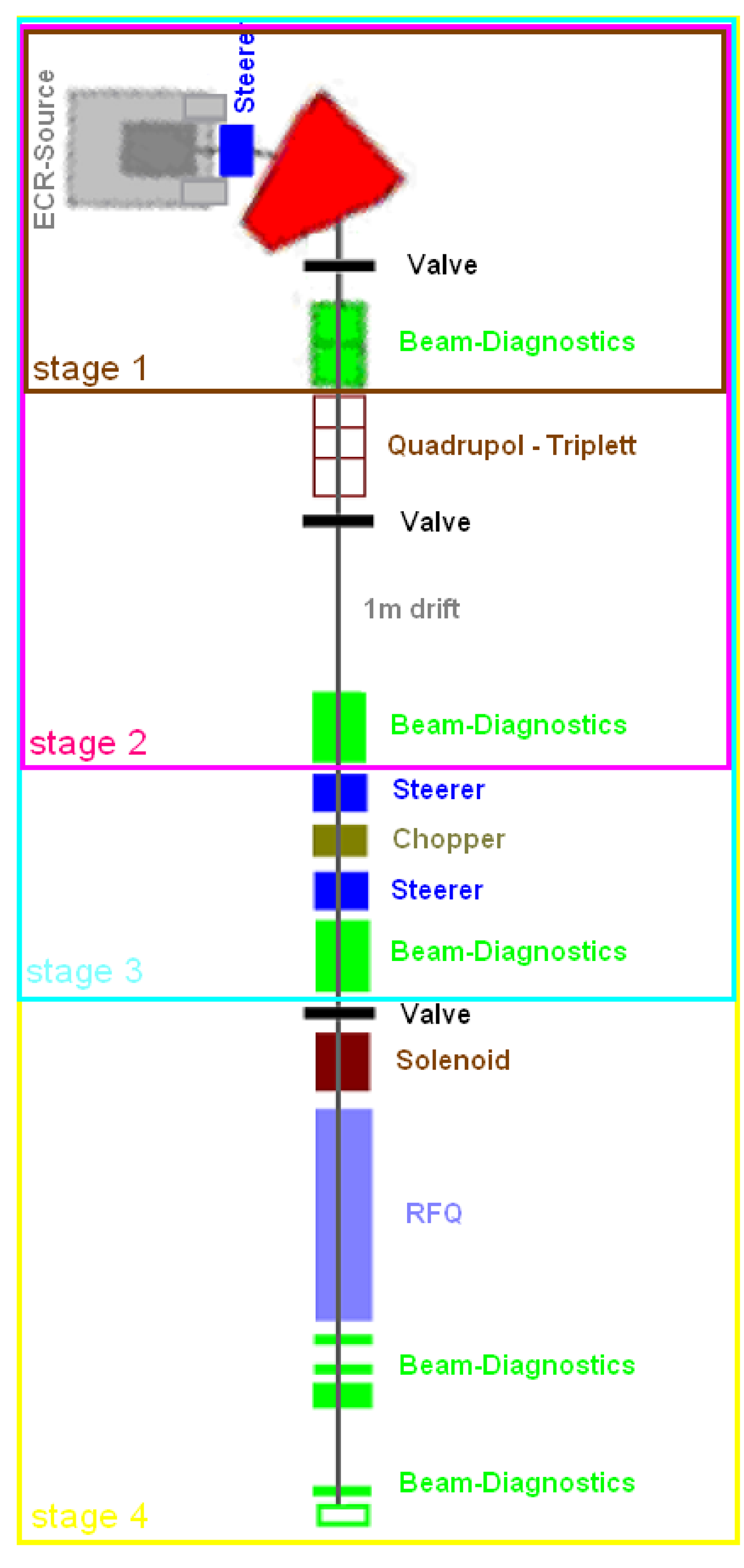

Figure 7: Test-Bench in 4 stages of expansion after every stages we integrate a slit grid-emittance measurement device.

Aims for the different setups:

Stage 1:
- Test of the optic for the new LEBT set up
- Acceptance test for the ion source with the new extraction system
- Acceptance test for the T-Magnet and the test of the zero field compensation
- Parameter sets for helium beams (risk mitigation measurement) (see Helium operation)
- Parameter sets for proton and carbon beams
- Test to optimize the C^{4+} output by different gases like C_2H_2
- 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].

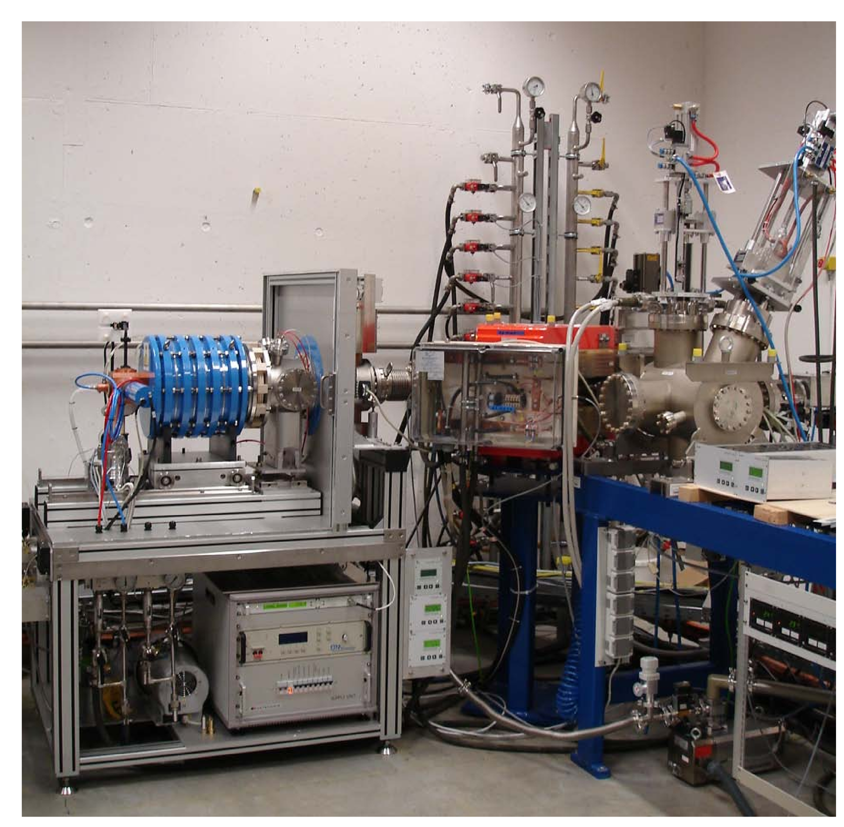

Figure 8: Test bench at HIT (stage 1)

HELIUM OPERATION

In the HICAT Technical Proposal [13] the use of ^{3}He was recommended, but there are strong medical arguments to use ^{4}He 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 $^{12}C^{6+}$ and $^{16}O^{8+}$ 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 "contaminating" output of $^{12}C^{6+}$, $^{14}N^{7+}$ and $^{16}O^{8+}$ (same A/Q) at the "normal" operation setting for He.

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