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 ECR source will be integrated. This third ECR source with a newly designed extraction system and a spectrometer line will be installed at a test bench to commission and evaluate this system. 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 a 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 (HI-DTL) [3-4]. 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.

LONG-TERM OPERATION EXPERIENCE
The maximum available beam intensity at the patient treatment place are 4 x 10^9 ons/cm² and 1 x 10^8 ons/cm² 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 x 10^9 ons/cm², p: 4 x 10^9 ons/cm²). 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.

Table 1: Main parameters of SUPERNANOGAN

<table>
<thead>
<tr>
<th>Ion</th>
<th>T / eA Used current</th>
<th>I / eA Reachable current</th>
<th>Voltage / kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD+</td>
<td>1200</td>
<td>1100</td>
<td>16</td>
</tr>
<tr>
<td>38He+</td>
<td>500</td>
<td>500</td>
<td>24</td>
</tr>
<tr>
<td>12C4+</td>
<td>160</td>
<td>200</td>
<td>24</td>
</tr>
<tr>
<td>16O8+</td>
<td>150</td>
<td>150</td>
<td>21.3</td>
</tr>
</tbody>
</table>

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.

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 planned maintenance phases and 0.1% of the time are the "off time" caused by multiple RF-amplifier breakouts.

The motivation for the shorter new design of the LEBT beam line is found 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 build-up new (Fig.8).

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

- Stage 2 and 3:
  - 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-AngleT and the test of the zero field compensation
  - Parameter sets for helium beams (risk mitigation measurement) (see Helium operation) for the HIT-Testbench.

- Stage 4:
  - Investment, test, and sale of a new designed deuterium ion emittance scanner[11].

HELIUM OPERATION
In the HICAT Technical Proposal [13] the use of 4He was recommended, but there are strong medical arguments to use 3He because of the less lateral straggling. In addition, the operation of a third ion species with the same A/Q and "off line" 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 12C6+, 14N7+ and 16O8+ (same A/Q) at the "off line" operation.

REFERENCES
[1] T. Winkelmann et al., "The Heidelberg Ion Therapy Center,” Radiology and Oncology, Vol. 73 (Supplement), P43.05, 2006
[8] WORK Microwave GmbH (http://www.work-microwave.de/work_home.htm)
[12] T. Winkelmann et al., "The Heidelberg Ion Therapy Center,” Radiology and Oncology, Vol. 73 (Supplement), P43.05, 2006
[14] HIT-Testbench In the HICAT Technical Proposal [13] the use of 3He was recommended, but there are strong medical arguments to use 3He 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 "C2H2" and "O2" 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 12C6+, 14N7+ and 16O8+ (same A/Q) at the "off line" operation setting for the HIT-Testbench.