Heidelberger Ionenstrahl-Therapiezentrum

EXPERIENCE AT THE ION BEAM THERAPY CENTER (HIT) WITH 2 YEARS OF CONTINUOUS ECR ION SOURCE OPERATION

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ABSTRACT

Radiotherapy with heavy ions is an upcoming cancer treatment method with to date unachieved precision. It associates higher control rates particularly for radiation resistant tumour species with reduced adverse effects compared to conventional photon therapy. This paper will provide an overview about the project, with special attention given to the two 14.5 GHz electron cyclotron resonance (ECR) ion sources. The HIT ECR ion sources are routinely used to produce a variety of ion beams from proton up to oxygen. The runtime of these two sources are 330 days per year 24 h 7 days a week operation, our experience with two years of continuous operation will be presented, with special emphasis on stability and breakdowns of components. In addition, an outlook of further planned developments at the HIT ECR ion sources will be given.

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).

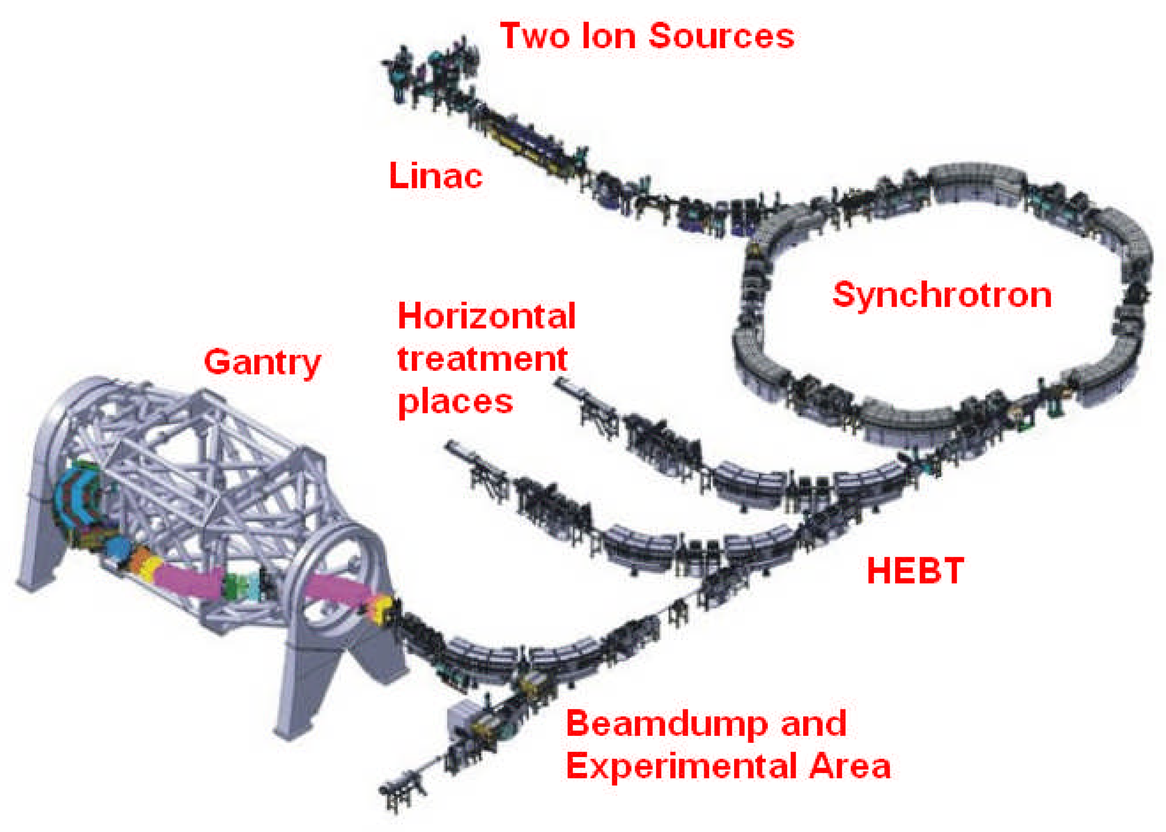


Figure 1: Overview of the HIT accelerator facility

Over the last two years the HIT accelerator [2,3] was commissioned by GSI Darmstadt [4,5,6], while the technical systems were operated under the responsibility of the HIT operating team. In parallel the implementation of the medical equipment took place.
The acceptance tests with beam started in 2006, when sources, low energy beam transport system (LEBT) and the linear accelerator (LINAC) were commissioned [4], followed by synchrotron [5] and high energy beam transport system (HEBT) in 2007 and 2008. The first turn in the synchrotron was achieved in February 2007, the first beam in the treatment place was seen in March 2007. Beam performance for protons and carbons had reached a level enabling patient treatment at the two fixed beam patient treatment places by December 2007, at the experimental area by April 2008. Gantry commissioning started at January 2008 [6].
The beam production at HIT consists of two 14.5 GHz permanent magnet ECR ion sources from PANTECHNIK [7]. The 7 MeV/u injector linac [3] (Figure 2) comprises of the LEBT, a 400 keV/u radio frequency quadrupole accelerator (RFQ) [8,9], and a 7 MeV/u IH-type drift tube linac (IH-DTL) [3,8,9]. The linac beam is injected in a compact 6.5 Tm synchrotron [10] 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 beam is distributed by the high energy beam transport line (HEBT) to the four beam stations. There are two horizontal fixed beam stations for patient treatment. In station three the beam is guided along an isocentric gantry. The fixed beam station for quality assurance is dedicated to development and research activities. All places are fully equipped for a 3D rasterscan volume conformal irradiation.

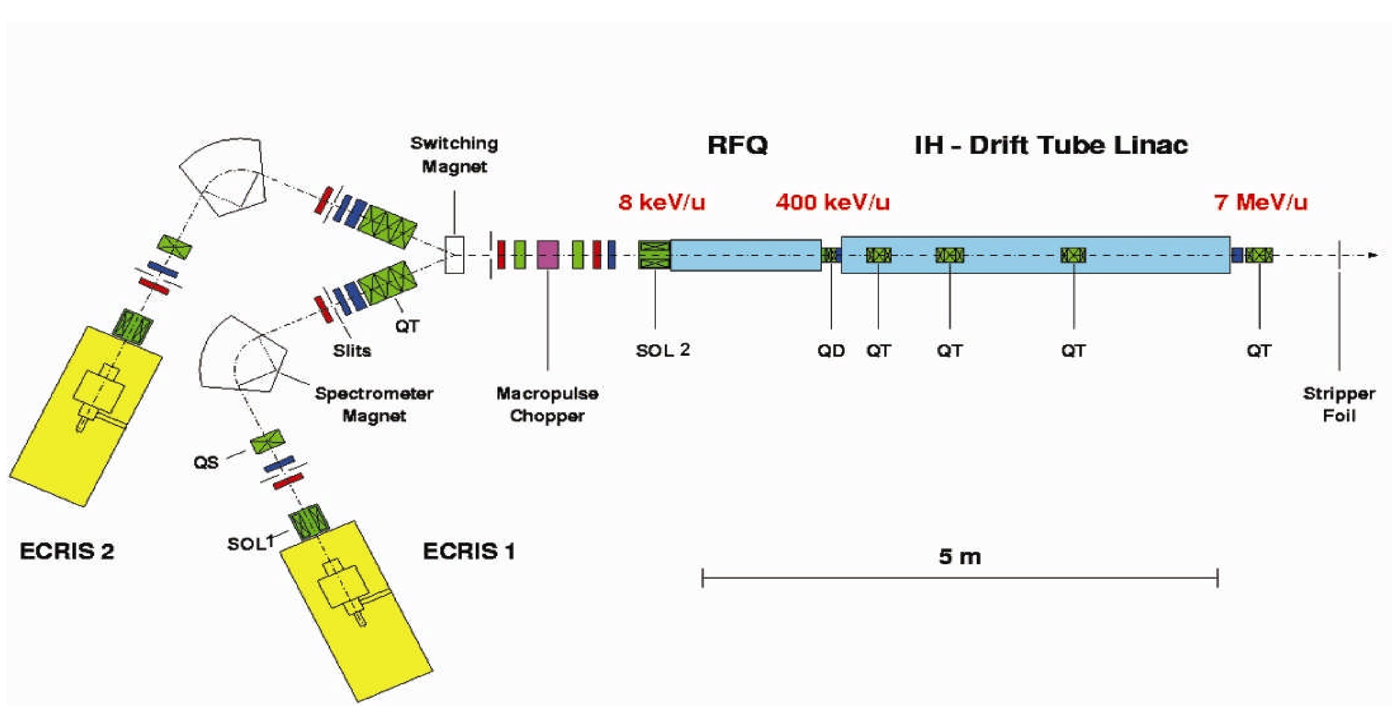
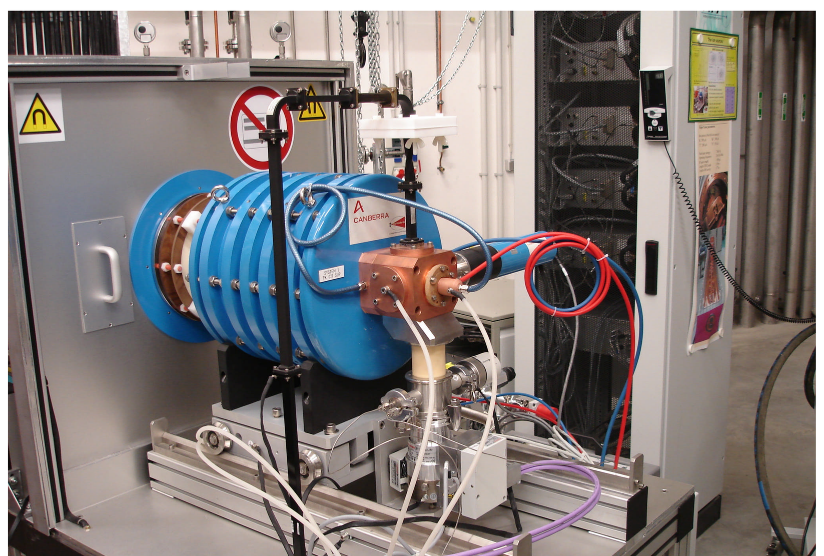


Figure 2: Layout of the Injector Linac [2]. SOL = solenoid magnet, QS = quadrupole singulet, QT = quadrupole triplet. Green: focusing and steering magnets, red: profile grids and tantalum screen, blue: beam current monitors (Faraday cups and beam transformers).

OPERATION OF THE ION SOURCE

During the first two 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! During the commissioning, the required intensities given in table 2 were very routinely achieved for hydrogen, helium and oxygen. For carbon we cannot achieve the specified intensity at the moment, we are looking forward to reach the specified intensity after a next general cleaning of the plasma chamber.



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

Ion	I / eµA Reachable current	I / eµA Specified current	U_{source} / kV
H_2^+	1000	1000	16
$^{3}He^{1+}$	500	500	24
$^{12}C^{4+}$	150	200	24
$^{16}O^{6+}$	150	150	21.3

Table 2: Specified ion species and intensities behind the 90° analysing magnet.

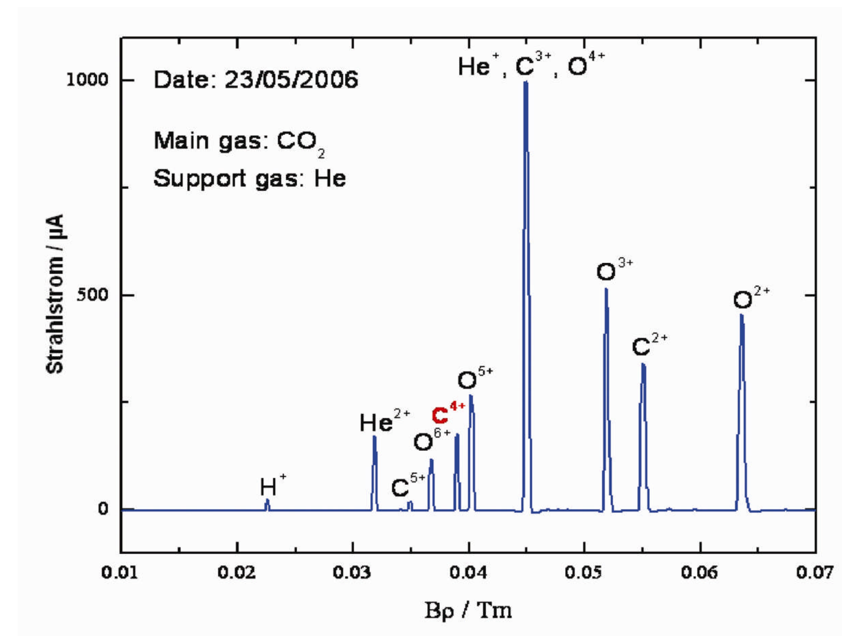


Figure 4: Spectrum of one of the ECR ion sources. The peak at Br = 0.0386 Tm corresponds to the desired $^{12}C^{4+}$, for carbon operation.

DEVELOPMENTS

After 2 years of permanent operation the ceramic isolator showed relevant evaporation. Pantechnik supplied us with a longer first electrode (puller electrode) to make an overlap of 3mm to minimize the evaporation, see Figure 7.
In order to increase the life time of the extraction system components we are presently running particle optics simulations for a reduction of evaporation.

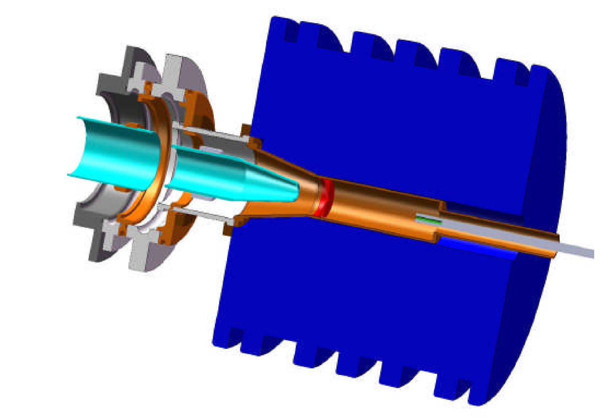


Figure 5: 3D-Model of the first extraction system that HIT bought with the source, design by PANTECHNIK S.A., Caen, France [7].

Figure 6: Isolator after 3 weeks of CO_2 operation of the first extraction system that HIT bought with the source (e.g. Figure 5)

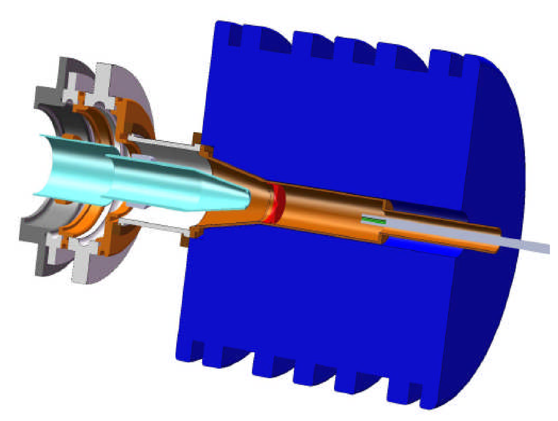


Figure 7: The new design of the extraction system by PANTECHNIK S.A., Caen, France [7]. The puller electrode got an overlap with the focus electrode.

Based on particle optics simulations performed by HIT a new extraction system was designed. As a next step COBRA simulations will be performed jointly with GSI to study the properties of the new design. The goal for this new design is a better long time stability in combination with extended maintenance intervals. The beam transport with a smaller emittance and better isolator shielding could be achieved by simulations. This new design will also allow an optimized position of the pumps, we found out that the durability is better when the turbo pump run in vertical plane.

At the tip of the extraction we changed the puller electrode material (Figure 8), we also changed the material of the bias cap (Figure 9), with these changes we reach long-therm stable operating conditions with extended maintenance intervals.

Figure 8: Left the new design of the titanium puller cap after 6 months of operation, right the old design made of steel after the same time of operation (broken).

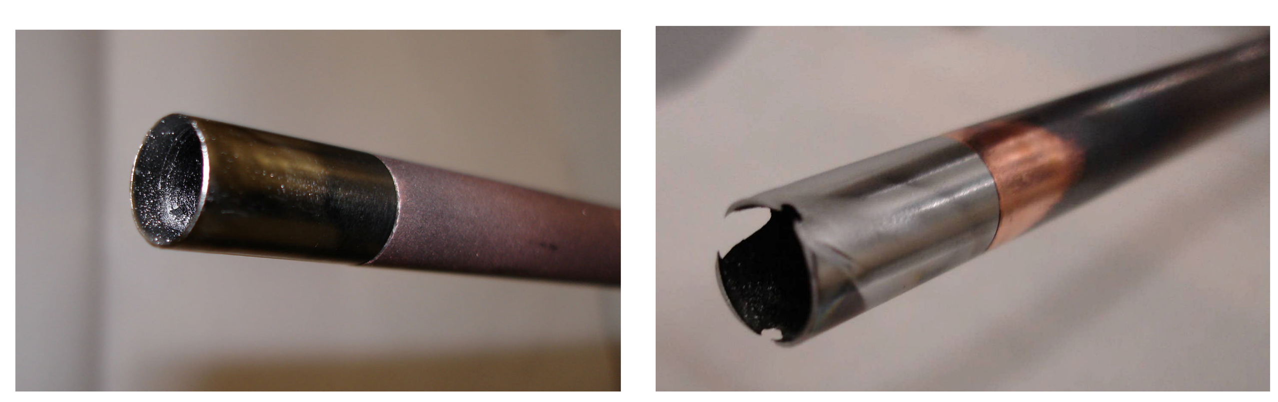


Figure 9: Left the new design of the titanium bias cap after 6 months of operation (still o.k.), right the old design made of molybdenum after 3 months of operation (broken).

OUTLOOK

The following developments are planned:

- A new extraction system for a stable beam and better focusing will be build.
- Intensity gain can be obtained by varying the microwave frequency within a narrow range around the centre frequency.