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, 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).

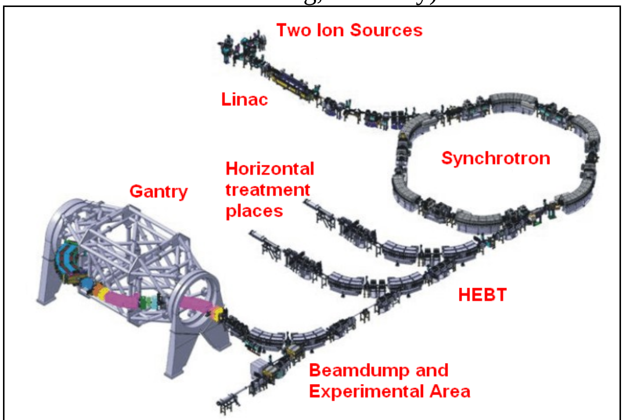

Figure 1: Overview of the HIT accelerator facility

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].

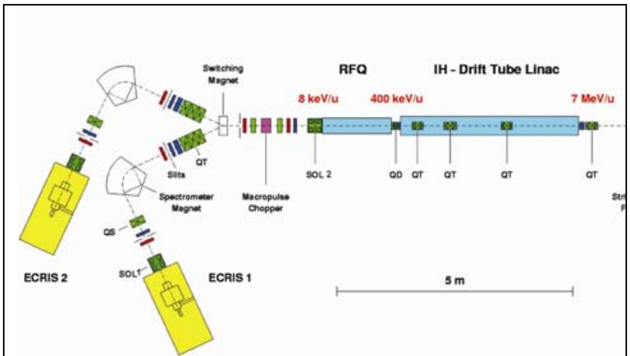

Figure 2: Layout of the Injector Linac [2]. SOL = solenoid magnet, QS = quadrupole singulet, QT = quadrupole triplet. Green: focusing and steering magnets, red: profile grids and tantalum screen, blue: beam current monitors (Faraday cups and beam transformers).

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.

The maximum available beam intensity at the patient treatment place are $8 \cdot 10^7$ ions/s for carbon and $3.2 \cdot 10^9$ ions/s 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: $5 \cdot 10^8$ ions/s, p: $2 \cdot 10^{10}$ ions/s). Taking into account the variable spill-length, the intensity has to be increased by a factor of 2.5 for carbon and by a factor of 4 for protons.

The main contribution of particle losses is caused by the poor transmission of the beam through the RFQ. Therefore the upgrade programme concentrates on a redesign of the RFQ [11]. In parallel we start to optimise the ion source performance.

ION SOURCE

We are operating two ECR Supernanoguns. During the commissioning of the LEBT the design values for the beam emittance could not be fully reached, especially for the proton beam [12].

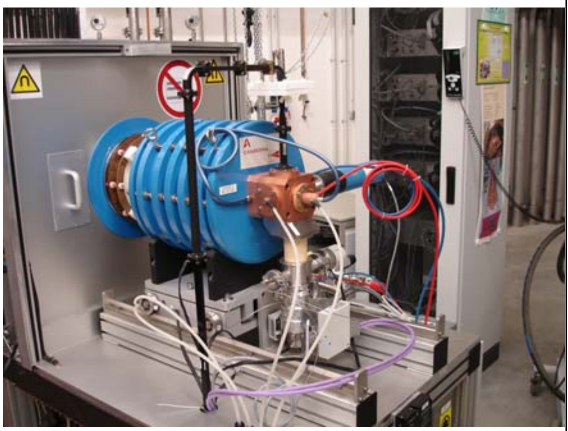

Figure 3: The 14.5 GHz high-performance permanent magnet ECRIS SUPERNANOGAN. This source was developed at GANIL, and is commercially available from PANTECHNIK S.A., Caen, France [7,13].

We are hence planning to adopt modifications resulting from recent experiments with ECR ion sources to reach a better emittance [14]. They have shown that a remarkable intensity gain can be obtained by varying the microwave frequency within a narrow range around the centre frequency. Furthermore we intend to investigate the performance of an extended extraction system. In Fig.4 you can see the extraction system that we bought two years ago with the ECR- Source from Pantechnik.

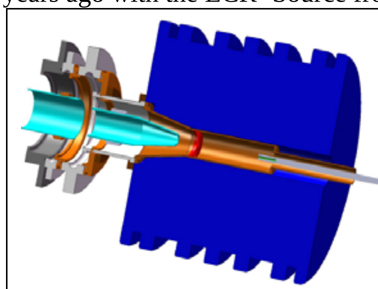

Figure 4: 3D-Model of the first extraction system design by PANTECHNIK S.A., Caen, France [7,13].

After 2 years of permanent operation the ceramic isolator showed relevant evaporation.

Figure 5: Isolator after 3 weeks of CO_2 operation of the first extraction system that HIT bought with the source (e.g. Figure 4).

Pantechnik supplied us with a longer first electrode (puller electrode) to make an overlap of 3mm to minimize the evaporation, see Figure 6.

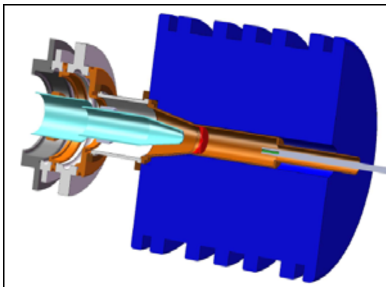

Figure 6: The new design of the extraction system by PANTECHNIK S.A., Caen, France [7,13]. The puller electrode got an overlap with the focus electrode.

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 vertical plane position of the pumps.

OPERATION OF THE ION SOURCE IN THE LAST TWO YEARS

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 1 were very stable 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 the next general cleaning of the plasma chamber.

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

Table 1: Specified ion species and intensities behind the 90° analysing magnet.

At the tip of the extraction we changed the puller electrode material (Figure 7), we also changed the material of the bias cap (Figure 8), with these modifications we reach long-therm stable operating conditions with extended maintenance intervals.

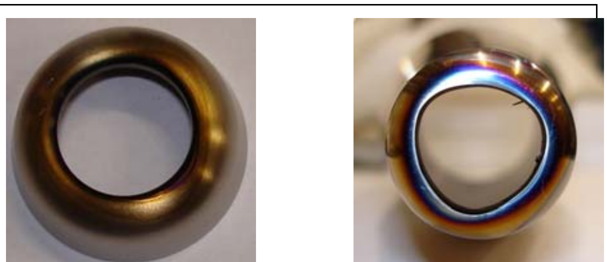

Figure 7: Left the new design of the titanium puller cap after 6 months of operation, right the old design made of steel after the same time of operation (broken).

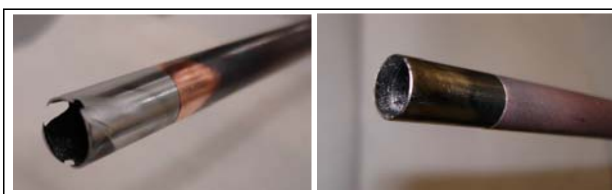

Figure 8: Left the new design of the titanium bias cap after 6 months of operation (still o.k.), right the old design made of molybdenum after 3 months of operation (broken).

The main problem during the two years of continuous operation were due to the RF-amplifier breakdown which occurred 11 times within the last 2 years. The time to exchange the defect amplifier by a spare part and to restart the source for operation took mostly just some hours.

We spent a lot of time to investigate this insufficient durability of the RF-amplifiers. We tried a better magnetic shielding and a better grounding system, but it seems that the problem is still not solved.

OUTLOOK

To summarize, 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.
- Problems with the short life time of the RF-Amplifiers have to be solved

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