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PLANNED OPTIMIZATION OF THE ION SOURCES ON THE HIT TEST BENCH

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Abstract

The Heidelberg Ion Beam Therapy Center (HIT) is a hospital-based treatment facility in Germany. Since the first treatments in 2009, more than 8,500 patients have been irradiated with protons or carbon ions and since July 2021 with helium ions. At HIT, three supernanogan ion sources from Pantechnik are in operation 24/7 for therapy up to 335 days a year. A fourth supernanogan ECR ion source is installed at the HIT test bench. The test bench is currently being prepared for a measurement campaign that will start in October. The aim of the investigations is to obtain more beam current for the carbon ions used in the therapy by feeding two microwave frequencies in parallel. We expect this experiment to lead to a better understanding of the ionization process in the ion source. In the first step, we will feed 14.5 GHz and an additional frequency close to the resonance frequency of 14.5 GHz ± 0.5 GHz and in the second step 14.5 GHz and 18 GHz are injected.

To characterize and evaluate the beam quality in this setup, we use the Pepperpot as a 4D emittance meter. In addition, it is possible to measure the beam current and the beam profile on the test bench.

INTRODUCTION

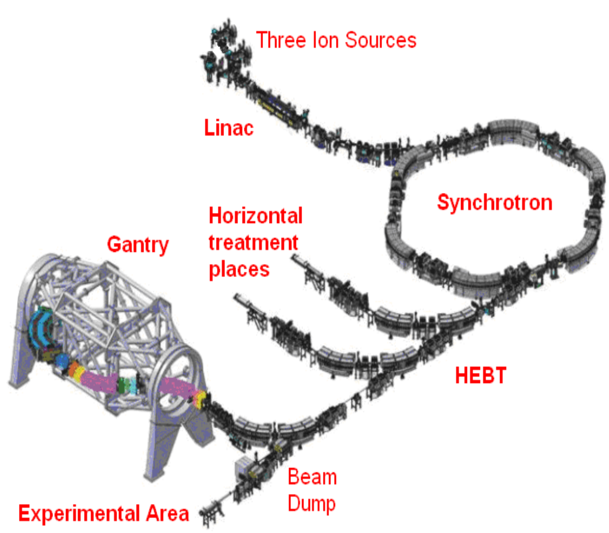

Figure 1: Overview of the HIT facility.

The beam production at HIT (see Figure 1) consists of three ECR Supernanogan ion sources [1] for the routine operation of proton, carbon and helium beams at 8 keV/u.

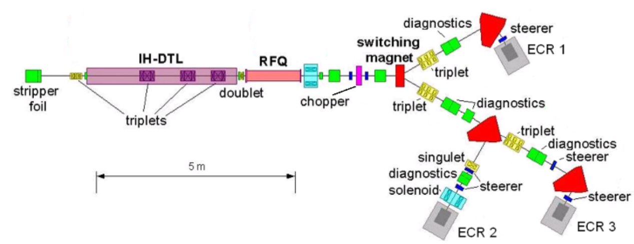

Figure 2: Low energy beam line (LEBT) and the linear accelerator (LINAC).

The compact 217 MHz linear accelerator (LINAC) consists of a radio frequency quadrupole accelerator (RFQ) and an IH-type drift tube linac (IH-DTL) with the end energy of 7 MeV/u for all ions; a foil stripper directly located behind these cavities produces fully stripped ions (see Figure 2). A synchrotron of 65 m circumference accelerates protons, helium, carbon and oxygen to predefined end energies e.g. for carbon ions from 89 to 430 MeV/u in 255 steps.

In order to minimize the already very short downtimes at the ion source (Figure 3), we started testing the 14.5 GHz solid-state amplifier (R&S PKU100) some years ago [2]. Until then, only tube amplifiers were used in clinical operations at HIT. After testing and checking the beam quality, the tube amplifiers were gradually replaced by solid-state amplifiers.

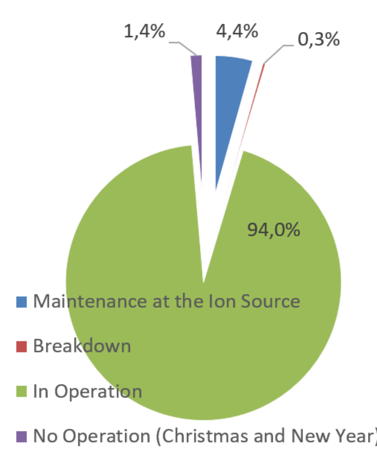

Figure 3: Statistics of the three ion sources in 2023.

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The future use of multi-energy operation [3] requires the synchrotron to be filled as quickly as possible. In order to achieve this efficiently, the existing RFQ will be replaced by a newly designed and optimized version [4]. By increasing the transmission of the linac from the current 30% to about 70% - 80%, efficient fast filling of the synchrotron can be ensured.

In order to achieve a stable source setting with an extracted beam current of 250 eμA C^{4+}, we will begin testing the coupling of two frequencies [5,6,7] on the test bench in autumn this year.

An increase in output would be particularly desirable for the therapeutically used carbon ion. For protons (H_3^+) and helium ($4He^{2+}$), the intensity and stability are sufficient with the mechanical changes to the plasma lens made to the ion source in the past [8].

COUPLING OF TWO FREQUENCIES

The plasma chamber of the ECR ion source has multiple excitations of different modes in the presence of non-magnetized homogeneous plasma. This leads to the generation of different resonance modes when electromagnetic waves are injected into the chamber.

Due to the complex magnetic field topology generated by hexapole and solenoid magnetic fields, plasma electrons are also heated outside the intended resonance surfaces. To achieve this, they must oscillate at the frequencies of the excited modes within the plasma chamber [9].

Since multiple modes are generated in the plasma chamber when heated at one frequency, it is suspected that superimposed multimodes are excited when the ECR ion source is operated in heating mode at different frequencies.

To investigate this phenomenon, we start with the following setup (Figure 5): A TWT amplifier capable of delivering 13.75 GHz to 14.75 GHz is connected to one of the RF ports, while a solid-state amplifier capable of delivering 13.75 GHz to 14.75 GHz is connected to a second RF port (see Figure 4).

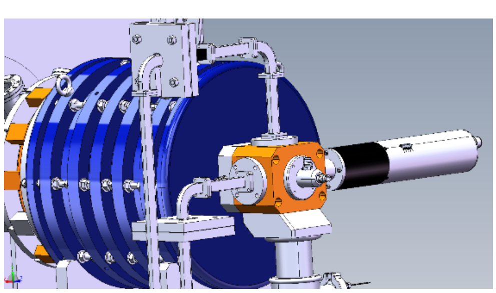

Figure 4: 3D model of the ion source with two waveguide connections on the copper cube.

Both RF systems are equipped with circulators, vacuum windows, dummy loads and high voltage insulators. Finding the two optimal frequencies that provide the highest stable current for C^{4+} will certainly require some iterations given the strong dependence on the tuning bulb position.

In a second setup (Figure 6) we will investigate how to increase and improve the beam intensity and beam quality for C^{4+} by using two far apart frequencies (14.5 GHz and 18 GHz).

The coupling is also done via the second flange in the copper cube of the SuperNanogan ion source, as in the experiment with the nearby frequencies, see Figure 4.

It is expected that the interference of two microwaves with far apart frequencies will lead to complex phenomena and the highly charged ion currents will generally tend to increase. Despite this complexity, we hope that the second frequency will increase plasma stability and thus improve beam quality for C^{4+}.

The beam quality is measured on the test bench using a pepperpot [10]. In addition, we have an RFQ on the test bench (see Figure 7), with the help of which the measured transmission also allows conclusions to be drawn about possible beam-improving properties.

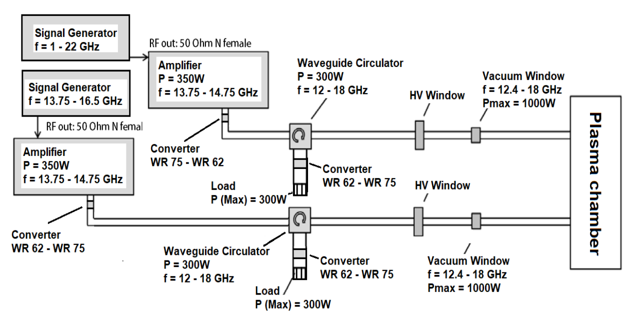

Figure 5: Schematic drawing of the two-frequency heating system (14.5 GHz & 14.5 GHz).

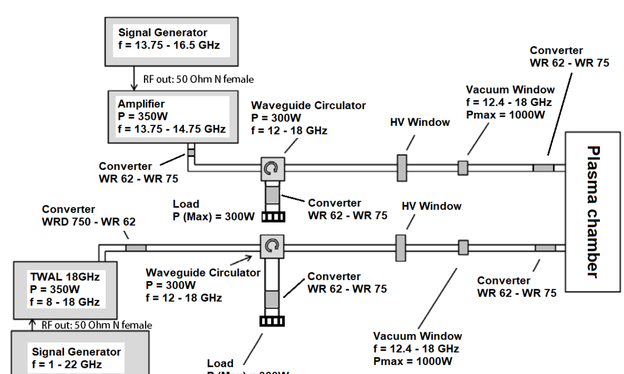

Figure 6: Schematic drawing of the two-frequency heating system (14.5 GHz & 18 GHz).

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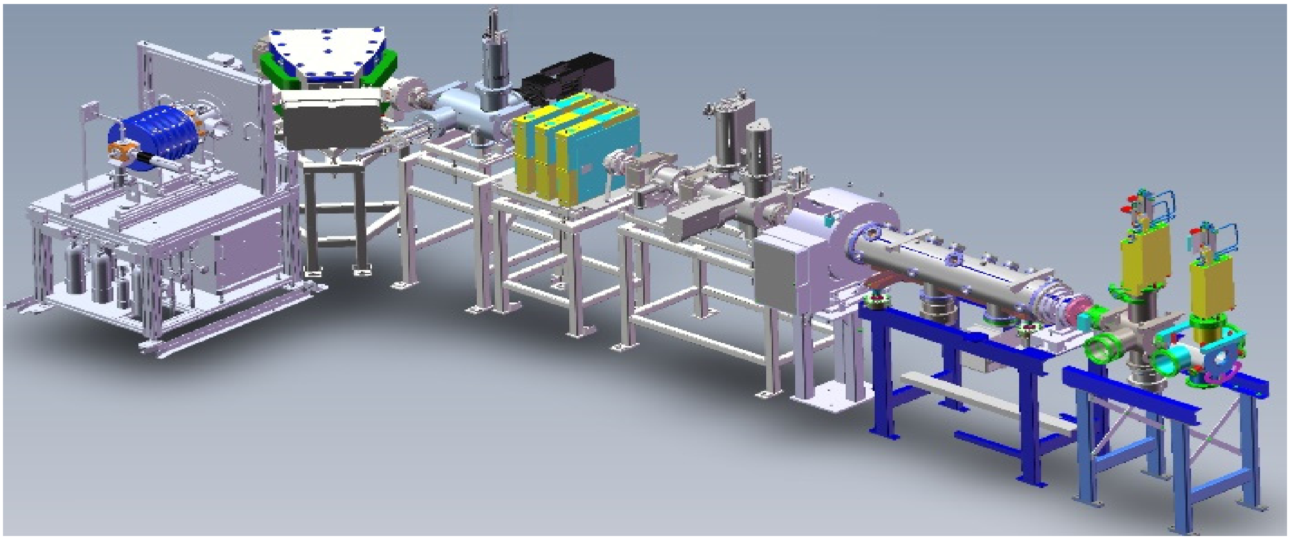

Figure 7: 3D CAD model of the testbench with the Supernanogan ion source (from left: ion source, dipole analyzing magnet, diagnostic chamber one with profile grid 1, analyzing slits, and Faraday cup 1, quadrupole triplet, diagnostic chamber two with pepper pot, profile grid 2, and Faraday cup 2, solenoid magnet, RFQ accelerator, diagnostic chambers three and four with a set of 3 phase probes, profile grid 3, and Faraday cup 3).

ACKNOWLEDGMENT

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