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Ion Sources for *Med*Austron

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Abstract

The *Med*Austron Ion therapy center will be constructed in Wiener Neustadt (Austria) in the vicinity of Vienna. Its accelerator complex consists of four ion sources, a linear accelerator, a synchrotron and a beam delivery system to the three medical treatment rooms and to the research irradiation room.
The ion sources shall deliver beams of H_3^{1+}, C^{4+} and light ions with utmost reliability and stability.
This paper describes the features of the ion sources presently planned for the *Med*Austron facility; such as ion source main parameters, gas injection, temperature control and cooling systems. A dedicated beam diagnostics technique is proposed in order to characterize ECR ions beams; in the first drift region after the ion source, a fraction of the mixed beam is selected via moveable aperture. With standard beam diagnostics, we then aim to produce position-dependant observables such as ion-current density, beam energy distribution and emittance for each charge states to be compared to simulations of ECR e-heating, plasma simulation, beam formation and transport.

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Ion Sources for MedAustron[a]

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I. INTRODUCTION

The MedAustron[1] ion-therapy facility is scheduled for first beam in 2013 and test operation will start in 2014. MedAustron is based on the PIMMS study[2] and has a collaboration agreement with the National Centre of Oncological Hadrontherapy (CNAO)[3] in Pavia and CERN. It will be equipped with three patient irradiation rooms. The first treatment room, equipped with a horizontal irradiation port, and the second with horizontal and vertical irradiation ports will be operating carbon ions and protons. The third treatment room will be equipped with a proton gantry. An additional irradiation room will be dedicated to research with light ions from protons to oxygen. The main components of the accelerator complex delivering these beams are four ion sources delivering beams of H_3^{1+}, C^{4+} and light ions, a beam chopper, a linear accelerator composed of a Radio-Frequency Quadrupole (RFQ) followed by IH drift tube linac (IH-DTL) accelerating structures at the end of which stripping of the H_3^{1+} to 3 protons and of C^{4+} to C^{6+} will take place prior to injection into the synchrotron. The main parameters of the accelerator for medical treatment are presented in table 1 and The low energy beam transport section of the injector is presented in FIGURE 1.

TABLE I. The MedAustron accelerator; Main parameters for medical treatment.

Ions	Protons	C^{6+}
Beam energy	60 to 250 MeV/u	120 to 400 MeV/u
Pulse intensity	2×10^{10} ions	1×10^{9} ions
Extraction time	1.1 to 1 s (max 10 s)	
Repetition rate	0.5 Hz (max 1 Hz)	

In order to meet MedAustron's ambitious goal of 1200 patients per year, highest availability of all elements of the accelerator chain is mandatory. In this paper, the main features of the four ion sources of the MedAustron facility are described and ways towards reproducible, reliable and stable operation are sketched.

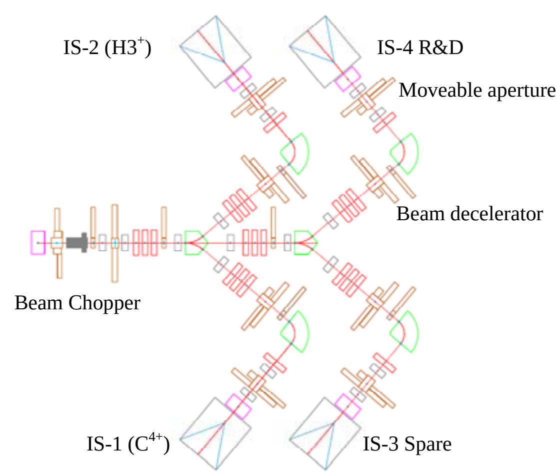

FIG. 1. Layout of MedAustron's ion sources and low energy beam transport. Beam elements (color codes) starting from the ion source: solenoid (magenta), steerer (grey), diagnostics (brown), quadrupoles (red) and dipole magnets (green). The beam chopper and specific beam diagnostics are indicated.

II. MedAustron ION SOURCES

The operation schedule of MedAustron will evolve with time and should be independent from installed hardware; in this respect, specialization of the ion sources to ensure simultaneous availability of the C^{4+} (IS-1) and H_3^{1+} (IS-2) beams is proposed.

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A spare carbon or hydrogen molecular ion-beam (IS-Spare) will be available in the event of an ion source failure. Light ions beams will be relying on a single ion source (IS-R&D). All ion sources will be operating in parallel according to patient irradiation requirement during day time and to the R&D program over night and Sundays. The accelerator shut-down has to be as short as achievable; by making use of the ion source redundancy, some of the yearly maintenance of the four ion sources could be done during standard operation provided that access is granted into the low energy room for extended period. Furthermore, it is likely that regular access will be necessary for short interventions and adapting the R&D ion source to new light ion-species. The low duty factor of the injection into the synchrotron allows pulsed operation of the ion source that could improve its mean time between maintenance and proportionally reduce ECR's X-rays emission. However, precise beam diagnostics and ion source tuning are more efficient using cw beams.

Beam intensity (within emittance): C^{4+} H_3^{1+}	200 µA 500 µA
Emittance (95%)	180 π mm mrad
IS-HT, energy spread	30 kV, < 1%
24h Beam Stability (peak to peak) : Intensity and Emittance	 < 4%
Reproducibility of all beam parameters after restart before tuning	5%
Maintenance interval Duration (1 ion source)	> 12 month < 2 weeks
Synchrotron injection	< 100 µs

TABLE I. Main ion source parameters for medical application.

A. H_3^+ Ion source

Molecular hydrogen ECR ion sources that are successfully used at HIMAC (H_2^+), CNAO (H_3^+) and HIT have appropriate ion current and emittances for MedAustron (500 µA, 180 π mm mrad). A filament volume ion source operated at IAP as proton linac injector could be considered provided that long term stability is demonstrated.

B. Carbon Ion source

ECR ion sources are successfully used at HIMAC, CNAO and HIT, a common feature of CH_4 or CO_2 is the deposition of thin carbon layers that is correlated with a slow evolution of the beam intensity. It must be underlined that MedAustorn's emittance requirement (180 π mm mrad) is challenging for most available ECR ion sources. Pulsed operation of the ion sources requires dedicated timing that must be optimized, the time constant for thermal stabilization in pulsed or cw mode will be measured.

C. Light ions Ion source

Light ion beams in the range between 50 and 250 µA within an emittance of 180 π mm mrad will be dedicated to research activities. For the production of light ions with charge to mass ratios higher than 1/3, ECR and Electron Beam ion sources (EBIS) are considered. The gaseous Hydrogen, Helium, Nitrogen, Oxygen and Neon can be directly injected into the ion-sources. For Lithium, Beryllium, Boron and Carbon; vapors, volatile compounds or single charge state injection techniques are required. The choice of an EBIS implies the use of specific beam diagnostics and a pulse duration of the order of 100 µs to match the multi-turn injection into the synchrotron.

D. Temperature control

Ion sources are often located in a rarely visited cellar and benefiting from air conditioning; these stable temperature conditions are one of the keys to the stability of the ion source. In the MedAustron low energy room, frequent accesses are expected and may influence the stability of the gas injection or ion-source temperature. The effect temperature on gas injection and therefore on the beam stability shall be minimized. Furthermore, the source must deliver the same beam parameters while restarting at nominal settings after a stop; this is the figure of merit of the ion source's reliability. MedAustron's gas injection relies on a precisely temperature controlled leakage valve (piezo for fast response or thermo-mechanic), its temperature and pressure will be monitored in order to regulate the density of the injected gas.[4]

The body of the ion source, the RF injection wave guide and the extraction are water cooled at a stability of 0.5°C as illustrated in FIG. 2.

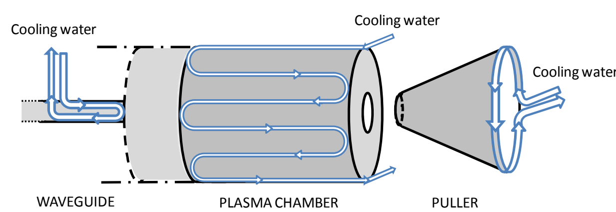

FIG. 2. ECR ion source cooling systems of the RF injection wave guide, the body of the ion source and the ion extraction.

E. Modeling and Beam diagnostics

The ECR ion sources resonance region is defined by multipole and coils magnetic configuration. The ions produced in these regions will follow preferentially the field lines and contribute to the complexity of the observed beam profiles[5]. Simulation tools exist for electron heating (TrapCad[6]) plasma dynamics (Vorpal[7]) ion-extraction and beam formation (KOBRA[8], IGUN[9]).

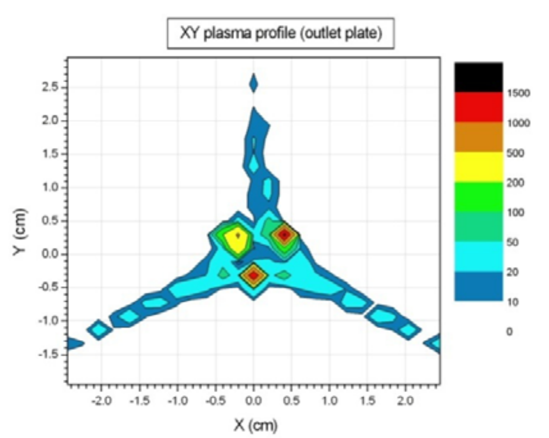

FIG. 3. Electron loss Profile from an ECR ion source (hexapole magnetic configuration) as simulated with TrapCad.

We propose to implement a moveable aperture (FIG. 4) located in a beam drift region after the first solenoid (FIG. 5) that allows selecting a fraction of the mixed elements and charge states passing through a diamond or square surface. A mobile faraday cup will be located behind the aperture system to integrate the transmitted beam. Using standard beam diagnostics in the magnet's focal plane, the charge state distribution, emittance and integrated current are accessible for each beamlet. In order to measure the beam energy distribution, a decelerating device coupled to a faraday cup is located in the focal plane of the magnet. This system was used at Jyväskylä[10] and ISOLDE[11] and provides complementary information to the ion beam's phase space.

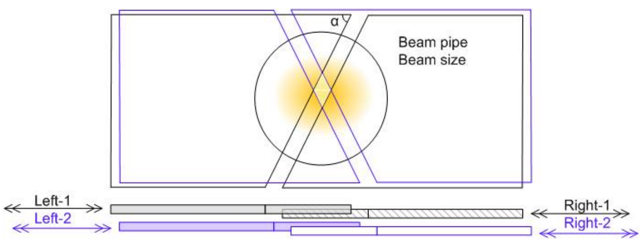

FIG. 4. Selection of a fraction of the beam via four plates. The size and position of the diamond or square aperture is tunable.

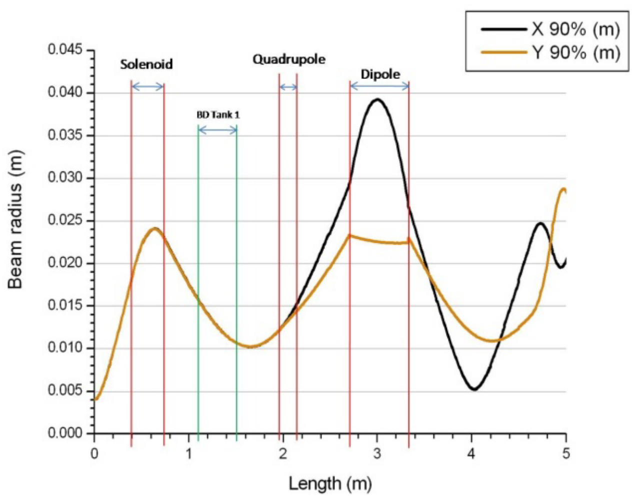

FIG. 5. Ion-beam envelope at nominal beam optics settings.

Modeling and ion-beam phase space measurements should be done before the commissioning of the accelerator; they are time consuming and would hugely benefit from a dedicated test period.

E. Mechanics and alignment

The redundancy of the ion sources for medical application (spare unit) may allow some time for the maintenance. However, the intervention time shall be minimized via specific design of the ion-source design in matter of assembly, maintenance and alignment. For the final alignment, a three feet structure is expected. The vibration induced by mechanical pumps has to be damped.

III. CONCLUSION AND OUTLOOK

Ion sources were identified that match most of the presently planned beam requirement of the MedAustron facility. Rooms for improvement were identified concerning mean time between failure, operation stability and maintenance that are crucial for medical applications. Simulations of plasma heating, ion-transport within the ion source, ion extraction and beam transport are mandatory to fully grasp the complexity of the ion-injection. Specific beam instrumentation is proposed to validate the simulation results. These dedicated measurements would be an optimum training for MedAustron's technical staff. Stabilization techniques are proposed for MedAustron ion sources, their commissioning could be achieved prior to the final installation at Wiener Neustadt provided that a test stand is assembled at CERN.

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