OVERVIEW OF THE MedAustron DESIGN AND TECHNOLOGY CHOICES

Michael Benedikt[1], Johannes Gutleber[1], Marcus Palm[1],
Werner Pirkl[1], Ulrich Dorda[2], Adrian Fabich[2] (For the MedAustron team)
[1]*CERN, 1211 Geneva, Switzerland,* [2]*EBG MedAustron, Wr. Neustadt, Austria*

Abstract

MedAustron is a synchrotron based accelerator facility for cancer treatment to be built in Wiener Neustadt, 50 km south of Vienna, Austria. It is currently in the development phase at CERN, Geneva. The design is based on the PIMMS study [1] and the CNAO [2] synchrotron. The accelerator will provide proton and carbon ion beams for clinical application and non-clinical research in the fields of medical radiation physics, radiation biology and experimental physics. The differences to other medical accelerator-based facilities will be elaborated, specifically the used source technologies and configuration, which allows for a later upgrade to ion species up to neon, and the online verification of all relevant beam parameters. Finally the current project status is presented.

INTRODUCTION

The MedAustron project for a cancer therapy treatment centre with clinical and non-clinical research facilities has been planned in collaboration with all of the Austrian University Clinics and Departments for Therapeutic Radio Oncology. The centre comprises an accelerator facility based on a synchrotron for the delivery of protons (p) and carbon ions (C^{6+}) to irradiation stations for cancer treatment and for clinical and non-clinical research. In full operation it is foreseen to treat up to 1200 patients per year. The centre will also provide infrastructure installations for non-clinical research together with a comprehensive support service for researchers coming from national and international research institutes and from industrial companies. The main research activities will be in the fields of medical radiation physics, radiation biology and experimental physics [3, 4].

FACILITY LAYOUT

The MedAustron facility will at the initial stage contain four irradiation rooms, IR1-IR4, of which IR1 is dedicated to research and IR2-IR4 to treatment (see Fig. 1). With the exception of IR4, which is equipped with a proton gantry, carbon ions and protons can be delivered to all rooms using fixed beam lines. The particle energy ranges are presented in Table 1. Protons with energies beyond clinical needs can be delivered to IR1 (up to 800 MeV). IR2 is equipped with two beam lines: one horizontal (H) and one 90° vertical (V).

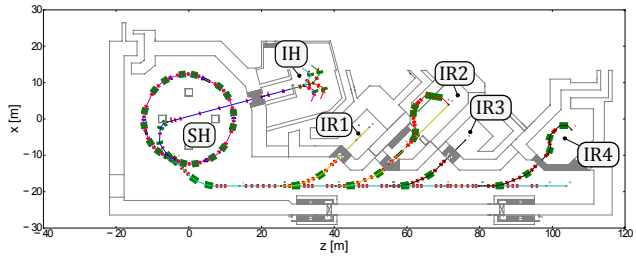

Figure 1: The accelerator layout of the MedAustron facility, showing the synchrotron hall (SH), injector hall (IH) and the four irradiation rooms IR1-IR4. (The vertical beam line in IR2 is a projection.)

BASELINE PARAMETERS

The performance of the synchrotron is dictated by medical needs, but goes beyond these for non-clinical research (see Tab. 1). Active scanning will be used in the three treatment rooms. In depth, the target will be irradiated layer by layer in steps of typically 5 mm, using different extraction energies. Each layer is divided into spots spaced by 1/3 of the beam width and irradiated spot by spot without interrupting the beam while jumping from spot to spot. In the horizontal beam lines the distance between scanning magnets and iso-center (IC) is about 7 m and thus provides quasi-parallel scanning. In the vertical beam line and in the gantry, quasi-parallel scanning is achieved with the optics settings. The beam can be turned off in less than 300 μs by a fail-safe chopper system [5].

Table 1: MedAustron synchrotron parameters and scanning specifications for medical use. Numbers within parentheses indicate extended range for non-clinical research.

Synchrotron circumference	77.6 m
Number of dipoles	16
Energy range [MeV/n]	p: 60-250 (800) C^{6+}: 120-400
Max. number of ions per spill	p: 1×10^{10} C^{6+}: 4×10^{8}
Spill duration	1.0(0.1) - 10 s
Repetition rate	$<$ 1.0 Hz
Intensity variation (min:max)	1:100
Horizontal tune	1.666
Vertical tune	1.72
Field size (fixed beam lines)	200×200 mm^2
Beam FWHM at IC	4, 6, 8 or 10 mm
Lateral beam position precision at IC	0.3 mm
Time to move between spots	$<$ 200 μs

As far as possible, the nozzles will be identical in all treatment rooms and house the following elements:

- Ridge filters for C^{6+} and low energy p
- Range shifter for irradiation of superficial tumours
- Two redundant beam intensity monitors
- Two redundant beam position and profile monitors

INJECTOR

The injector hall can host up to four independent source arms together with the individual and common low energy beam transport line (LEBT) working at 8 keV/nucleon. The acceleration to the synchrotron injection energy of 7 MeV/nucleon is performed by a linear accelerator housed in a separate Linac bunker enclosed by concrete shielding walls (see Fig. 2).

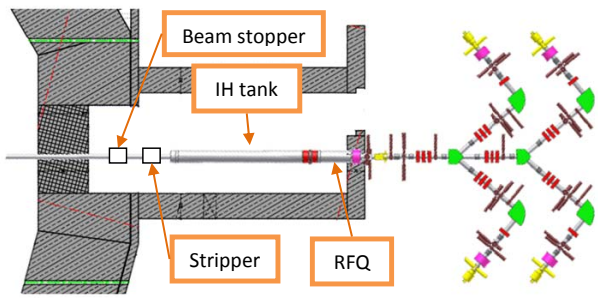

Figure 2: Schematic layout of the injector. On the left: Linac bunker. On the right: LEBT with four source arms.

Each source arm up to the selector switching magnet is equipped with a 90-degree spectrometer magnet, magnetic quadrupoles and steerers together with extensive diagnostics. Electron Cyclotron Resonance (ECR) sources are foreseen that can be tuned to deliver any of the required particle species. Their nominal charge-to-mass ratio is 1/3, namely H_3^+ for protons, $^{12}C^{4+}$ for carbons and an approximative close figure for light ions. In a 4-source scenario two sources will cover proton and carbon operation respectively, with the remaining ones used as hot spares. Other scenarios with simplified dedicated sources for proton operation are under investigation. There are further diagnostics, an electrostatic beam chopper and a final focusing solenoid for injection into the linear accelerator (Linac). In the common beam transport part downstream of the selector switching magnets there are further diagnostics, an electrostatic beam chopper and a final focusing solenoid for injection into the linear accelerator (Linac).

The first modules at the Linac input are a Radio Frequency Quadrupole (RFQ) for bunching and acceleration up to 400 keV, followed by a short intertank section with Radio Frequency (RF) buncher. These elements have been identified as critical for beam transmission in the existing medical centers and shall be entirely redesigned. Acceleration up to the final energy of 7 MeV/nucleon is provided by an Inter Digital H-mode (IH) structure. The complete IH tank together with its inner and outer quadrupoles will be delivered by industry identical to the design used by HIT [6] and CNAO. The last element of the injector, a debuncher cavity, is installed in the synchrotron hall.

The operating frequency of the Linac is 216.8 MHz. Pulsed RF amplifiers of 250 kW and 1600 kW equipped with tetrode tubes feed RFQ and IH tank, semiconductor amplifiers the bunching and debunching cavities. Servo electronics are provided for resonator amplitude, phase and tuning state.

A stripper tank with a set of stripper foils and associated diagnostics followed by a beam stopper are installed at the end of the bunker. The Linac can thus be tuned independently while the synchrotron hall is fully accessible. Bunker walls of 1-m concrete shield the Linac hall from X-rays generated by the IH tank as well as radiation stemming from the synchrotron.

SYNCHROTRON

The synchrotron consists of 16 2 m long dipoles, 24 quadrupoles grouped in 3 families and 4 lattice sextupole in 2 families and one resonance sextupole.

The beam is injected using multi-turn injection in the horizontal plane. Intensity fluctuations during a spill are specified to be within maximum $\pm 10\%$ in order to avoid local regions of over- and under-dosage in the tumour. This will be achieved by a betatron core driven third-order resonant extraction. If further smoothing of the spill is required, RF-channeling could be used.

Beam profile

The extraction process will yield a bar-of-charge in the horizontal phase space (x) and a Gaussian beam distribution in the vertical phase space (y). Projected onto the x-axis, the beam profile will be trapezoidal and its Full Width at Half Maximum (FWHM) at IC can be varied by rotating the bar-of-charge, while in y the FWHM at IC is varied by the focusing strength [1, 7]. The FWHM in x and y can be set independently from 4 to 10 mm in steps of 2 mm.

CONTROL SYSTEM ARCHITECTURE

Application of accelerators for ion-therapy calls for a strict separation of the control system into an accelerator control system (ACS) and a beam delivery control system (BDCS). The BDCS is part of a medical device and is seen as an accessory to a patient record and verify system (PRVS) that traditionally acts as the master in radiotherapy. Upon request of the PRVS, the BDCS requests accelerator cycles from the ACS that describe the beam characteristics (energy, beam dimensions, intensity, particle type and spill length). Strategic, architectural and design choices are an outcome of an ISO 14971 risk management process for medical devices as required by the regulatory authorities.

We chose an industry-standard multi-tier architecture [8, 9] (see Fig. 3) relying on commodity electronics and soft-

ware where possible. Presentation and processing tiers carry out non real-time monitoring, control, alarming, trending tasks and regulate concurrent access to devices by reading and writing to data structures that represent the controlled hardware and software components. Currently a survey is carried out to select one out of several supervisory control and data acquisition (SCADA) products that are in use in other facilities. The equipment tier comprises a number of Front End Controllers (FEC) that interact with the technology dependent Front End Devices (FED). Software components are implemented using an in-house developed, light-weight toolkit for the NI Labview Real-Time environment. It provides a uniform interface for control, generation of events, error reporting and logging. Each component implements a standardized state-machine. FEDs reside in a front-end tier that is managed by the individual accelerator subsystems. The clear separation of responsibilities as well as the uniform software infrastructure and the standardized way of operation ease integration during installation and commissioning.

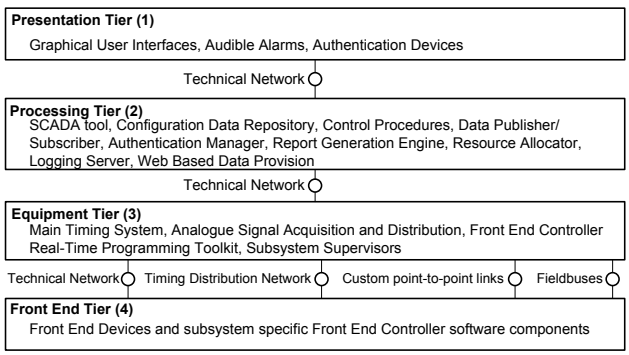

Figure 3: Control system architecture, standardized communication interfaces link the individual tiers together.

The equipment tier features a Main Timing System which is the heart of the ACS. Its sequencer broadcasts timing events to FECs in real-time. FECs and FEDs perform their actions such as generation of waveforms for power converters and triggering of beam monitoring measurements based on this system. A well proven and robust technology will be deployed [10].

A Beam Interlock System based on commercial PLC technology is foreseen to reduce the risk of equipment damage and injury. It follows the IEC 61508 standard for functional safety. A separate system built from radiation-tolerant watchdogs, counters and logic evaluation elements can be arranged in a modular safety matrix. It controls beam activation to protect the patient from malfunctioning beam delivery components or situations that would cause a violation of the maximum dose and irradiation time at a single spot. In order to be able to roll out a system within a predictable schedule, we established an "off-shoring" project management process: A small core team collaborates with a team of experts from an external company that has been granted a framework agreement as a result of an EU tendering process. The development lifecycle is carried out according to an ISO 9001 compliant process.

STATUS

MedAustron is currently in collaboration with PSI for the development of the proton gantry and with CNAO for the technical systems and layout of the medical facility (the CNAO and MedAustron synchrotrons are both based on the PIMMS study). The accelerator development and design and the parts procurement are carried out in collaboration with CERN.

- In beginning of 2010 a contract was signed for the procurement of 700 tons of magnets steel. The magnet steel for the whole MedAustron accelerator is purchased in one lot to assure uniform steel properties across production for magnet families. Steel will be delivered on demand to future magnet producers.
- The tender phase for the main dipole production is ongoing and a final contractor will be awarded during summer 2010.
- The application documents for the Environmental Impact Assessment as requested by Austrian authorities will be submitted by June 2010. Approval is expected by the end of 2010.
- First patient treatment is planned in 2014.

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