

# STATUS OF MEDAUSTRON

## THE AUSTRIAN ION THERAPY AND RESEARCH CENTRE

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### Abstract

MedAustron is the Austrian center for hadron therapy and non-clinical research. The accelerator design is based on the PIMMS study [1] and features proton beams of up to 800 MeV and carbon ion beams of up to 400 MeV/u. The accelerator is currently being installed and the beam commissioning has started early 2013. The injector comprising three ECR sources, an RFQ and an IH-mode structure has already been qualified; the synchrotron commissioning started in March 2014. Certification of the therapy accelerator following the European Medical Device Directive (MDD) is well under way with strong partners from industry involved in the process. The status of the overall facility including an overview of the recent commissioning results will be presented in this paper.

### THE MEDAUSTRON ACCELERATOR COMPLEX

The beam produced by one of the three ion sources is selected and transported by the low-energy beam transport (LEBT) system to the LINAC. The LINAC consists of a radio frequency quadrupole (RFQ), a matching section and an IH-mode drift-tube LINAC (DTL). The RFQ accelerates the particles to 400 keV/u, the injection energy into the synchrotron of 7 MeV/u is achieved by the DTL. After the LINAC, the particles are conditioned by electron stripping with a thin carbon foil and guided by the medium energy beam transport (MEBT) system to the synchrotron. A multi-turn injection is carried out in order to accumulate the beam in the synchrotron. Subsequently, the beam is captured and accelerated by means of an RF cavity. Extraction of the beam proceeds using a slow extraction scheme at a third

order resonance driven by a betatron core. The high energy beam transfer line (HEBT) delivers the extracted beam from the synchrotron to one of the four different irradiation rooms. The main parameters are shown in Table 1.

Table 1: MedAustron Main Parameters

Parameter	Value
Proton energy range:	60 – 800 MeV/u
Carbon energy range:	120 – 400 MeV/u
Beam size (FWHM at isocenter in vacuum):	4 – 10 mm
Extraction time:	1 – 10 s
Maximum number of p/C extracted:	$1 \cdot 10^{10} / 4 \cdot 10^8$
Intensity variation:	0,01-1
Ion species:	p, C <sup>6+</sup>
Transverse field for scanning:	200 × 200 mm <sup>2</sup>

MedAustron features a horizontal (H) beam line for non-clinical research, one horizontal and vertical (H+V), one horizontal (H) beam line and a proton Gantry for patient treatment. Figure 1 shows the layout of the beam lines at the MedAustron complex.

The particle therapy accelerator delivers beams using the active pencil-beam scanning method. The beam is scanned over the tumor volume in the transverse plane by means of fast scanning magnets. The scanning field covers an area of 200 x 200 mm<sup>2</sup>, allowing the irradiation of large size tumors. The penetration depth is adapted from spill to spill by changing the extraction energy of the synchrotron, covering a range from about 3 – 30 cm in human tissue. The beam with selectable diameter in the range of 4 to 10 mm (size in vacuum) is positioned with a precision of ± 0.5 mm.

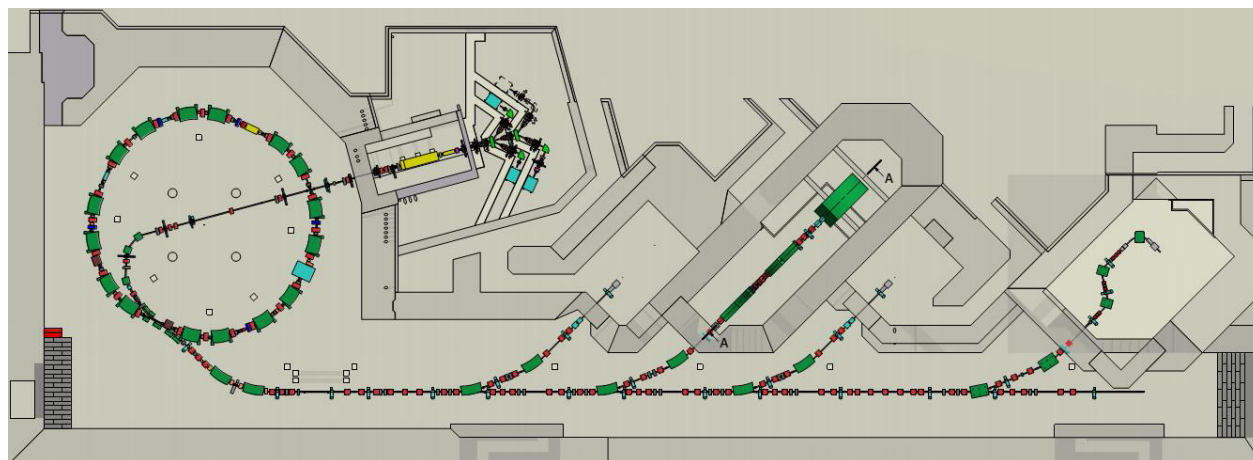


Figure 1: Beam line layout of the MedAustron accelerator complex.

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Figure 2: MedAustron synchrotron – fully installed and operational. The injection/extraction region can be seen in the front.

In order to ensure that the dose is applied as prescribed, beam parameters are online monitored and controlled during the entire treatment process. Beam intensity, position and size are supervised by redundant means in front of the patient. In case of deviations from the nominal values, the beam is switched off within less than 1 ms, ensuring the safety of the patient.

## STATUS OF THE ACCELERATOR AND ITS COMPONENTS

### *Injector*

The MedAustron injector complex has already been installed and commissioned with protons last year. For detailed results on the injector commissioning please refer to the 2<sup>nd</sup> MedAustron contribution to this conference [2].

### *MEBT and Synchrotron*

The MEBT beam line and the synchrotron have been fully installed with beginning of the year and final component integration and beam commissioning of the synchrotron is currently ongoing (see below). Figure 2 shows the synchrotron and the MEBT beam line where the densely occupied injection/extraction region is shown in the foreground.

### *HEBT*

The HEBT is presently being installed with focus on the third irradiation room (IR3) with a horizontal beam line, the first room to go into clinical operation.

### *Accelerator Components*

95% of components needed for the beam line up to the IR are already available at MedAustron and are successively being installed, parallel to the beam commissioning. One remaining dipole and a dozen of corrector magnets are in the pipeline for magnetic measurements at CERN and will be available by end of June, in time for beam commissioning. The last components to be delivered will be the scanning magnets.

A few components in the synchrotron still need to be commissioned with beam, the tune kicker, the RF cavity, the betatron core and the B-train. All, but the B-train, shall be available for beam commissioning before end-June. B-train will follow in July.

### *CERN Activities*

CERN remains a strong partner to MedAustron with clear defined projects. All magnet tests are carried out at the MedAustron test stand at CERN. The synchrotron RF system is a common development. A similar system is presently being commissioned at CERN in the PS booster. The CERN RF group is consequently heavily involved in the commissioning of the RF cavity at MedAustron. The prototype tests of the scanning magnet power converters are also done at CERN.

### *Timeline*

The schedule remains very tight, with the first patient to be treated by end of 2015. Until the end of this year the accelerator shall be fully commissioned with protons in IR3 at all energies. After that the medical physicists and doctors will start with the medical integration and validation.

## SYNCHROTRON COMMISSIONING

MedAustron beam commissioning follows a staged approach concept: Stage A is the exploration phase where the accelerator complex and its equipment are tested with beam for the first time. This stage focuses on progressing as quickly as possible to test new hardware and operation modes while establishing basic functionality. At this stage there is no intention to reach nominal performance, but rather sufficiently stable and detectable beam conditions. Subsequently Stage B (optimization) and Stage C (fine tuning) are run through. Currently Stage A is still ongoing for the Synchrotron.

Several steps had been defined for the exploration stage for the synchrotron: dry-run tests, first turn, circulating beam w/o RF, multi-turn injection, RF capture,

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acceleration, basic lattice optimization, extraction first beam.

Synchrotron dry-run is ongoing with first successful cycling of the three quadrupole families, and are still continued with cycling tests of more components integrated to the system continuously.

Beginning of April'14 the first turn was achieved in the synchrotron after 1.5h by one-to-one steering using horiz. correctors and the horiz. pick-up  $\Delta/\Sigma$ -signals seen via the analog signal distribution system (SADS). A  $1\mu\text{s}$  proton pulse at 7MeV from the injector was used, which had been shaped to a pencil beam using slits in the MEBT, see Figure 3. Not utilizing injection kickers, the injection bump was created using orbit correctors. The main dipole field was adjusted to minimize the overall orbit offsets. Applied corrections were small and consistent with expectations. No polarity or alignment errors could be seen so far.



Figure 3: First turn seen on the beam screens MR-00-001-SLU (injection) and MR-00-000-SLU (after one turn).

Succeeding the first turn, the injection kicker system was set-up and commissioned and by mid-April'14 the first circulating beam could be established. Beam position signals showed circulating beam for more than 1ms.

After a period of bug-fixing and system improvements, which were necessary to operate the synchrotron RF system, the beam could be captured via the RF cavity in a non-adiabatic way (fixed voltage) at a fixed frequency of 469kHz, see Figure 4. A following orbit correction reduced maximum offsets from less than  $\pm 1\text{cm}$  down to less than  $\pm 1.5\text{mm}$ .

Multi-turn injection preliminary tests show a promising increase of circulating beam current by a factor of 2.5, using a  $2\mu\text{s}$  and  $20\mu\text{s}$  pulse from the injector.

The next major steps of the exploration stage comprise first acceleration, basic lattice measurements and tuning, and finally first extraction. Only after achieving these milestones, the next Stage B (Optimization) will be started and focus on the tuning of the Synchrotron.

## MEDICAL CERTIFICATION

The MedAustron Particle Therapy Accelerator is classified as a IIb medical device and thus subject to a certification process according to the MDD requiring the involvement of a notified body. To this end a full quality management system needs to be established. The relevant processes are agreed and are presently being implemented. In addition to the technical challenges of the commissioning, all aspects related to risk management, the fulfillment of standards and laws and the creation of the technical documentation are treated in parallel.

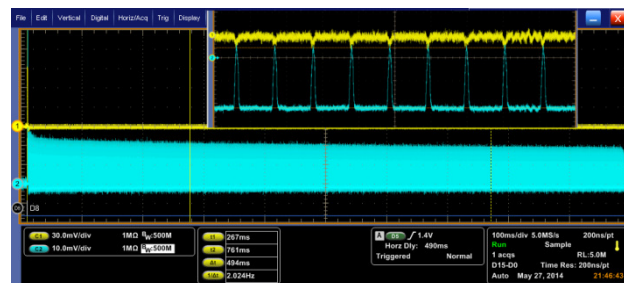


Figure 4:  $\Delta/\Sigma$ -signals (yellow/cyan) of captured beam in synchrotron (orbit corrected) at 7MeV and 1s pulse.

## CONCLUSION

Current activities at MedAustron are focused on the beam commissioning in the Synchrotron and the component installation of the HEBT line. The goal is to conclude with the proton beam commissioning until end of the year to allow for a first patient treatment in December 2015. To reach this, different disciplines within MedAustron, accelerator, medicine and medical physics are carefully coordinating their efforts. A close collaboration with the notified body on the certification process is established.

## ACKNOWLEDGMENT

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## REFERENCES

- [1] P. J. Bryant et al., "Proton-Ion Medical Machine Study (PIMMS), 2," Aug 2000.
- [2] L. Penescu et al., "Commissioning and Operation of the MedAustron Injector", IPAC 2014.