ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME001

COMMISSIONING AND OPERATION OF THE MEDAUSTRON INJECTOR

L. Penescu, M. Kronberger, T. Kulenkampff, F. Osmic, P. Urschütz, EBG MedAustron,
Wiener Neustadt, Austria
W. Pirkl, CERN, Geneva, Switzerland

Abstract

The MedAustron facility [1, 2] is a synchrotron-driven hadron therapy and research center presently under construction in Wiener Neustadt, Austria. In its final outline, the facility will provide H^+ beams with kinetic energies ≤250MeV and C^{6+} beams of ≤400MeV/u for clinical applications, and H^+ of up to 800MeV for non-clinical applications. At a later stage of the project, beams of other species can be generated with similar optics. First patient treatment is foreseen for the end of 2015.

This contribution presents the results of commissioning and operation of the injector of the MedAustron accelerator. A comparison with the baseline optics and with the design error studies is given alongside with an overview on the operational experience, with emphasis on the system reliability, stability and reproducibility.

THE MEDAUSTRON INJECTOR

The layout of the MedAustron injector, as commissioned, is presented in Figure 1.

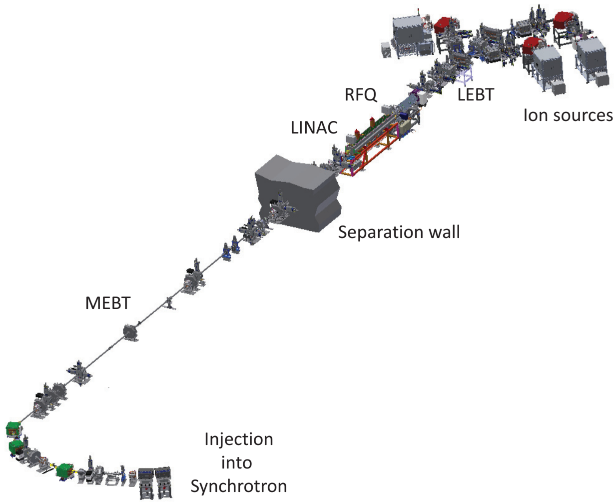

Figure 1: The MedAustron injector.

The primary particle beams (H_3^+, C^{4+}) are generated in continuous mode at 8keV/u by two ECR ion sources (one for each particle type). A third ion source is used as backup and can be tuned for both ion species, and at a later stage for other light ions. All three ion sources are connected by individual transport lines to a common LEBT comprising a fast electrostatic deflector for beam pulse length adjustment. From there, they are transported to the RFQ for acceleration to 400keV/u. An inter-tank matching section (IMS), encompassing a Buncher (BU) RF cavity, two quadrupole doublets, and two steerers, matches the beam to the entrance plane of an IH-mode DTL (KONUS) that accelerates the particles to 7MeV/u before they are stripped to, respectively, H^+ and C^{6+}, debunched and transported to the injection plane of the synchrotron. The Linac RF system is operated with 10Hz repetition rate and a maximum pulse length of 500µs. A beam dump located after the stripping foil allows operating the source lines, LEBT and the Linac even when installation works are taking place inside the synchrotron hall, which increases availability for beam commissioning.

The beam diagnostic (BD) devices available for beam characterisation in the Injector involve [3]: profile grids (PGX), wire scanners (WSX; only in the source lines and LEBT, where the beam is continuous) and slits (SLX) for transverse profile and emittance measurements, current transformers (CTAs) and Faraday Cups (FCs) to measure the beam current, Phase Probes (PHPs) for beam energy measurements, and a four-button probe to determine the beam position at the entrance plane of the IH-tank.

The injector commissioning was started in 2012/12 using the H^{3+} beam from ion source 1 (IS1). First H^+ beam was seen on the injection plane of the synchrotron in 2014/03.

INJECTOR COMMISSIONING STRATEGY

The injector of the MedAustron accelerator has been commissioned in a stepwise process in order to fully characterize the beam for each section of the injector, by making use also of two temporary installations of beam diagnostics. Due to the tight time constraints, the commissioning strategy was optimized to allow the acquisition of sufficient data with only one ion beam species (H_3^+), from one ion source (S1). Based on this commissioning data, the injector can be commissioned for any new beam, even though the temporary test benches are no longer available.

The commissioning stages are described in the following.

Ion Sources

The MedAustron ion sources have several operational parameters that affect directly the emittance and the Twiss parameters of the generated beam. The commissioning goal was to find at least a set of source parameters providing a beam within the specified requirements [4] and to identify on which beam property each ion source parameter is acting on.

A notable dependence, integrated into the strategy of the next commissioning stages, is the possibility to tune the Twiss parameters of the beam after the spectrometer magnet via the electrical potential on the middle extraction electrode of the ion source ("Focus" electrode). The dependence of α and β in the horizontal plane is presented in Figure 2; in the vertical plane, the influence on α and β is considerably weaker.

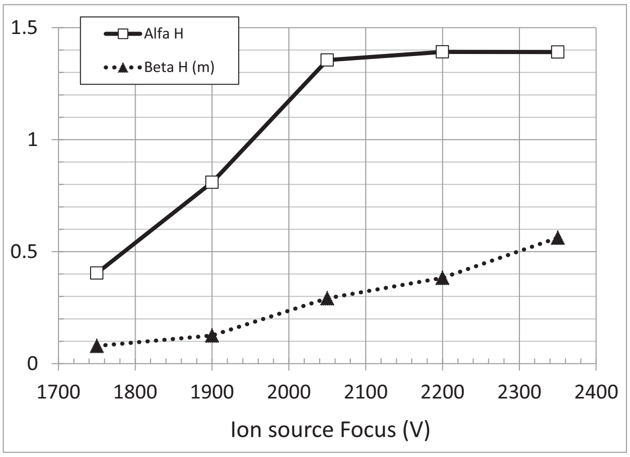

Figure 2: Dependence of the horizontal Twiss parameters after the spectrometer on the potential of the Focus electrode.

LEBT and TB1

Matching the beam to the RFQ entrance plane was achieved by means of a test bench (TB1) installed temporarily at the location of the RFQ and allowing to measure the beam current and the transverse emittance at the RFQ entrance plane position.

The commissioning goal of the TB1 stage: to find a baseline for the LEBT magnets that provides the matching of the beam from the ion source to the acceptance parameters of the RFQ.

In order to be able to determine the beam properties at the RFQ entrance plane even after removal of the TB1, a reference plane (RP) was defined in the LEBT at the closest beam diagnostic tank allowing for emittance measurements. Consequently, a perfectly matched Linac can be assumed for any new beam with the same Q/M that is matched to the RP.

RFQ, IMS and TB2

The optimization of the RFQ performance and the preparation of the beam for injection into the IH tank have been achieved by means of a second test bench (TB2), sharing the functionality as TB1, with additional PHPs for beam energy measurements and hardware testing. The goals of the TB2 stage: (a) to measure the RFQ beam energy; (b) to reduce the length of the RFQ beam bunches by optimizing the phase of the Buncher; (c) to find the transversal matching to the IH of the longitudinally matched beam.

IH-DTL and Stripping Foil

The IH-DTL transmission was optimized by finding the setpoints of the integrated quadrupole triplets via Trace3D simulations and by experimentally tuning the phase and amplitude of the transmitted RF pulse. Generally, the transmission of the DTL was found to be relatively insensitive on the quadrupole settings, but strongly dependent on the RF amplitude and phase settings.

Matching of the IH-DTL output beam to the stripping foil was achieved primarily by tuning the strengths of the quadrupole triplet situated between the IH and the foil. Additional tuning parameters are the RF amplitudes and phases of the IH-DTL and of the BU cavity (Figure 3).

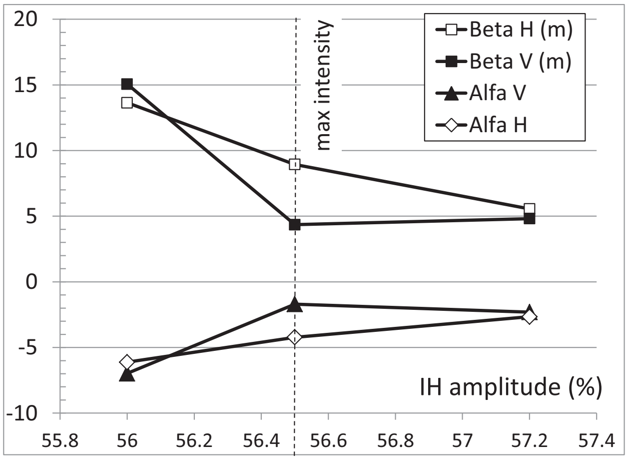

Figure 3: Beam matching to the stripping foil by the IH-DTL RF amplitude. Similar curves are obtained when tuning the IH phase, and the BU amplitude or phase.

MEBT

The MEBT baseline optics assumed a beam at the foil with a very low β (design value: 0.2m), in order to minimize the losses and the emittance increase. This value could not be achieved experimentally, therefore the MEBT had to be re-matched (via MAD-X) to the real beam parameters (β=0.6m). Emittance and beam profile measurements are possible at different positions in the MEBT to assure that the MAD-X simulations match the beam transport.

COMMISSIONING CHALLENGES AND CURRENT PERFORMANCE

During the commissioning period, the uptime of the injector during beam commissioning shifts increased from ≈20% during LEBT and RFQ commissioning to >50% (2014-06), while setup times decreased from several hours to less than 1h thanks to the availability of new software tools and to the improved stability of the used software and hardware.

The main sources of accelerator downtime have been: software issues, hardware shortcomings or failures and infrastructure unavailability.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME001

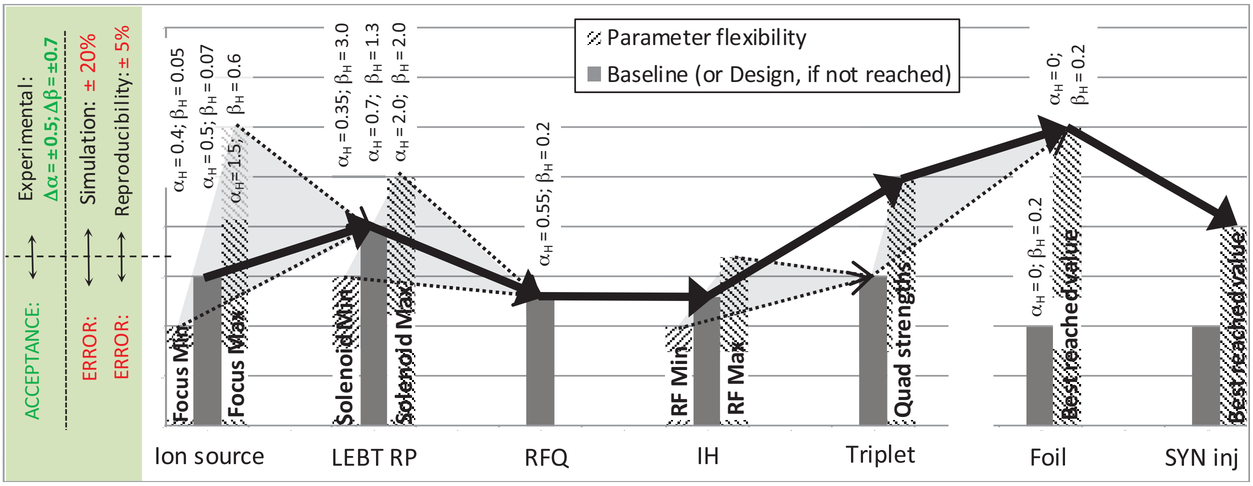

Figure 4: The design flexibility of the MA injector (see text).

The current performance of the MedAustron injector is summarized in Table 1. The numbers show that the Linac section after the RFQ is currently the bottleneck in terms of transport efficiency, indicating that the IMS and IH-tank settings are not yet fully optimized.

Table 1: Beam Energy and Transport Efficiency for Different Sections of the Injector

Location	I_{beam} [uA]	Beam Species	Transport efficiency [%]	Beam energy [keV/u]
Ion Source	500	H_3^+	-	8
LEBT	500	H_3^+	100	8
RFQ	400	H_3^+	80	385
IMS	280	H_3^+	70	385
IH	160	H_3^+	60	6840
MEBT	300	H^+	65	6840
Full injector			20	

DESIGN FLEXIBILITY

A design which can accommodate variations in the input parameters is a critical aspect of an accelerator, starting from the commissioning stage and continuing with any new beam to be developed, as well as with any hardware development that will follow.

The results of our investigations on the flexibility of the MedAustron injector are presented in Figure 4. The "handover" points have been already presented in the previous sections.

- The beam provided by the ion source can be tuned via the ion source Focus and we could find via Trace 3D a match to the same parameters at LEBT RP for the entire range provided by this parameter.
- If needed, the beam parameters at LEBT RP can be different and via the solenoid we can still find a match to the same beam parameters at RFQ input. The variation range of the horizontal Twiss parameters is presented in the figure. This represents the extent of the solenoid transfer map measured during the TB1 stage.
- The quoted errors represent (a) the variation over time of the measured Twiss; (b) the difference found between the applied quadrupole strengths and those provided by Trace3D matching.
- The quoted acceptance represents the variation of the input Twiss parameters (from the ion source) which experimentally still provides a beam transport with less than 20% additional losses by the IH-DTL exit.

ACKNOWLEDGMENTS

We acknowledge the extensive support of our colleagues from all MedAustron work packages, who continuously helped us understanding the unexpected behaviours and to solve the bugs and failures inevitable to the commissioning activities.

REFERENCES

[1] U. Dorda et al., "Status of the MedAustron Ion Beam Centre", IPAC 2012, THPPR046, New Orleans, USA (2012); CERN-ATS-2012-109.
[2] F. Osmic et al., these proceedings, WEPRO081, IPAC 2014, Dresden, Germany.
[3] F. Osmic et al., "Overview of the Beam Diagnostics in the MedAustron accelerator: Design Choices and Test Beam Commissioning", IPAC 2012, MOPPR002, New Orleans, USA (2012); CERN-ATS-2012-110.
[4] J. Lettry et al., Rev. Sci. Instrum. 81(2), 02A328 (2010).