ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF004

STATUS OF THE MEDAUSTRON BEAM COMMISSIONING WITH PROTONS AND CARBON IONS

C. Kurfürst*, L. Adler, A. De Franco, F. Farinon, N. Gambino, G. Guidoboni, G. Kowarik, M. Kronberger, S. Myalski, S. Nowak, M. Pivi, C. Schmitzer, I. Strasik, P. Urschütz, A. Wastl, EBG MedAustron, Wr. Neustadt, Austria
L. Penescu, Abstract Landscapes, Montpellier, France

Abstract

MedAustron is a synchrotron-based Particle Therapy Accelerator located in Wiener Neustadt, Austria, which is delivering beams for medical treatment since end of 2016. The accelerator provides clinical proton beams in the energy range 62-252 MeV and is designed to provide carbon ions in the range 120-400 MeV/n to three ion therapy irradiation rooms IRs, including a room with a proton Gantry. Proton beams of up to 800 MeV will be provided to a fourth room dedicated to research. Presently, proton beams are delivered to the fixed horizontal beam lines of three rooms. Beam commissioning of the vertical beam line of the second IR is being completed and the beam line is in preparation for clinical treatment. Commissioning of the accelerator with carbon ions is advancing and first clinical beams have been sent to the IRs, while the preparation for the Gantry beam line is ongoing. A slow extraction 3rd order resonance method is used to extract particles from the synchrotron between 0.1-10 seconds to favor control of the delivered dose during clinical treatments. The main characteristics of the accelerator and results obtained during the latest commissioning activities are presented.

INTRODUCTION

MedAustron is a synchrotron based hadron therapy and research center. Its design originates from those of PIMMS [1] and CNAO [2]. The therapy accelerator comprises three ECR ion sources feeding a 400 keV/n RFQ and a 7 MeV/n IH Drift tube linac. The facility provides medical proton and carbon beams via slow resonant extraction spills [3]. For non-clinical research purposes, proton beams with energies of up to 800 MeV/n can be provided. The transfer line transports the beam into four irradiation rooms (IRs): IR1 with a horizontal beamline for non-clinical research, IR2 with a horizontal and a vertical beamline, IR3 with a horizontal beamline and IR4 with a Gantry for protons. The general status of the beam lines and the particle types is summarized in Table 1. The major topics on the accelerator side are the V2 beam line commissioning, the carbon commissioning, the machine performance increase and the machine stability for clinical treatment.

At this stage the patient treatment is performed with protons in two rooms. In the beginning of 2017 only 1 to 2 daily fractions were applied, but with a continuous ramp up over the year 22 ± 1 daily fractions could be achieved leading to in total 2779 applied fractions in 2017. In January and February 2018, 26 patients have been treated, with a weekly machine uptime during clinical operation between 90% and 97%.

* christoph.kurfuerst@medaustron.at

Table 1: MAPTA commissioning status (BC: Beam Commissioning, MC: final Medical Commissioning).

Beam line	Proton	Carbon
IR1	Research	BC after IR2-H
IR2-H	Treatment	BC ongoing
IR2-V	MC	BC after IR1
IR3	Treatment	BC after IR2-V
IR4	Construction	n.a.

VERTICAL BEAM LINE

The vertical beamline of IR-2 is a 90° angle beam line, which focuses the beam at the same isocenter position as the horizontal beam line. The first part of the vertical beamline is in common with the horizontal beamline. A first set of dipole magnets bend the beam vertically upwards by 45° angle, while a second set of dipoles bends it by 45° angle parallel to the horizontal beam line. The last vertical bending dipole bends the beam by 90° downwards to the isocenter.

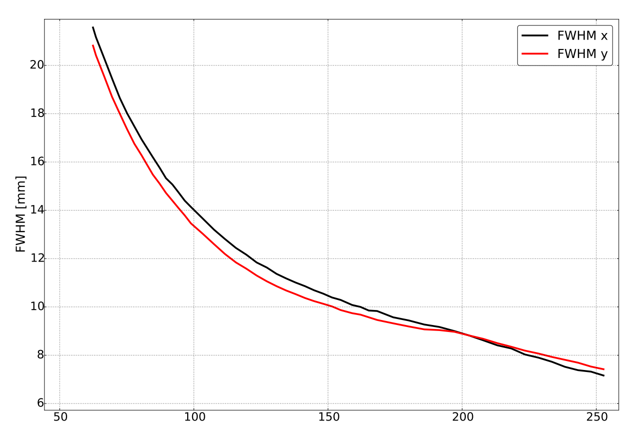

Figure 1: FWHM measured for 50 energies at the isocenter of IR2-V.

The commissioning is performed starting with the highest and the lowest beam energies. For these energies, the accelerator settings, e.g. strength of the magnets, are defined during the commissioning work. For further intermediate

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF004

energies, accelerator settings might be adjusted to fulfill the medical requirements. Finally the magnet settings for all other 255 beam energies are obtained by interpolation.

A tuning of the vertical beamline optics is performed to obtain the required symmetric beam size at the isocenter for 20 energies. The optics tuning is done via MADX matching with the use of seven quadrupoles due to the high number of optics constraints. The resulting spot sizes at the isocenter are shown in Fig. 1. Dispersion effects are measured to be within tolerance margin throughout the spill.

At the maximum dispersion location of the vertical beam line, vertical beam position differences up to 0.8 mm are measured for different beam intensity settings, while these position differences vanish at the isocenter. To explain this vertical beam position difference, space charge effects can be indicated: with different intensity settings, space charge effects in the synchrotron result in different emittances. Due to the extraction mechanism summarized by the Steinbach diagram [4], different beam emittances imply different extracted momentum spreads. This difference in extracted momentum spread in turn causes a different beam position in a region with high dispersion. The design vertical dispersion D_y reaches 7 m, which is unique in the transfer line. The vertical dipoles open the vertical dispersion, which is then closed downstream at the end of the 90° dipole. A difference in the extracted momentum spread as small as dp/p = 1.15e-4 can cause the observed 0.8 mm position difference. Thus, particular care is taken to properly align the beam vertically for different degrader settings both at the location with maximum vertical dispersion, close to the scanning magnets, as well as at the isocenter.

When scanning the irradiation field by the use of scanning magnets upstream the 90° bending dipole, a high order magnetic field component, sextupolar in nature, forces the beam positon distribution from a quadratic to a slight trapezoidal shape. This effect is measured and can be reproduced by simulations. Countermeasures to compensate for the high order component are being investigated.

CARBON COMMISSIONING

In parallel, the carbon commissioning is in progress [5] and the amount of machine time dedicated to it increases. So far a stable high intensity source setting and 54 % transmission through the LINAC could be reached. While the optimization through the further accelerator stages continues, preparatory tests have been performed, showing that a 400 MeV/n carbon beam is successfully accelerated at ramp rates of the dipoles of up to 3 T/s. Furthermore the carbon intensity reached at this early stage of commissioning is of 1.5e9 ions in the room. The achieved intensities throughout the accelerator are shown in Fig. 2. The corresponding transmissions are summarized in Table 2.

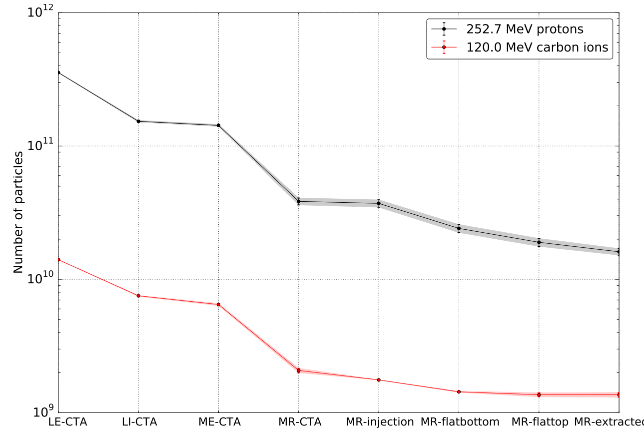

Figure 2: Intensities throughout the accelerator.

Table 2: Comparison of main transmissions, in percent, for 252 MeV protons and carbon ions 120 MeV/n.

Particle type	LINAC	Injection	Acceleration
Proton	43	27	79
Carbon	54	32	95

PERFORMANCE IMPROVEMENT PROJECT

Machine developments at MedAustron are ongoing to reduce the treatment time. The first development being implemented is the 'cycle abort at end of slice', with a decrease of the beam on time of 3-40 %, depending on the actual treatment plan. Initially, the extraction time was fixed via a pre-programmed sequence at 5 s. When the dose is reached for an iso-energy slice, no further beam is required. So far the unused beam went via deactivating a trajectory bump into a beam dump for the time left out of the 5 s extraction. Typical treatments contain slices for which only a part of the spill is required, leading to unnecessary dead time. To avoid this dead time, the cycle abort to end the cycle and trigger the next one is being implemented. The effect is visible on the current transformer in the synchrotron, as shown in Fig. 3, where the first and the third cycles are with cycle shortening, while the second and fourth are without cycle shortening. This measure is expected to enable to apply an additional fraction per day.

Further topics in progress are the RF channeling and RF knock out [6]. One of the next steps for a direct reduction of the treatment time is to smoothen time profile of the extracted beam in order to allow safe operation at full intensity, which is at the moment artificially reduced to 20 %.

MACHINE PERFORMANCE OBSERVATIONS

Beam property measurements are regularly performed to evaluate the status of the machine and verify the proper beam characteristics for patient treatment [7]. The data is

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF004

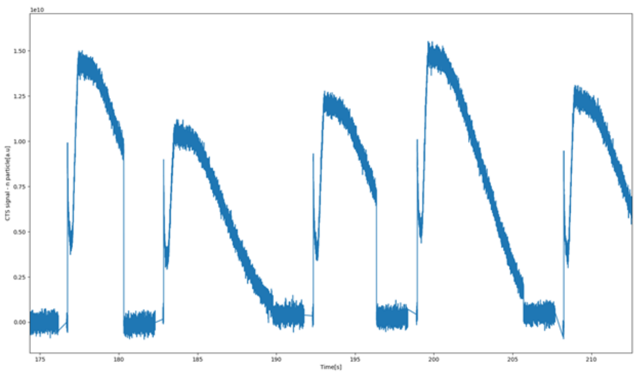

Figure 3: Main ring current transformer measurements. The effect of cycle shortening is visible on the spills where only a fraction of the intensity is required.

furthermore used to understand patterns, investigate drifts and ideally act before downtime occurs.

An intensity drop over several weeks was observed last year, which lead to a recommissioning of the source. The recommissioning brought the required intensity back and allowed to achieve an excellent stability of the beam in the injector: intensity fluctuations of ± 10 % were reduced to below ± 3 %. The intensity variations further lead to the observation of related variations of the vertical FWHM throughout the high energy transfer line. The corresponding correlation plot is shown in Fig. 4.

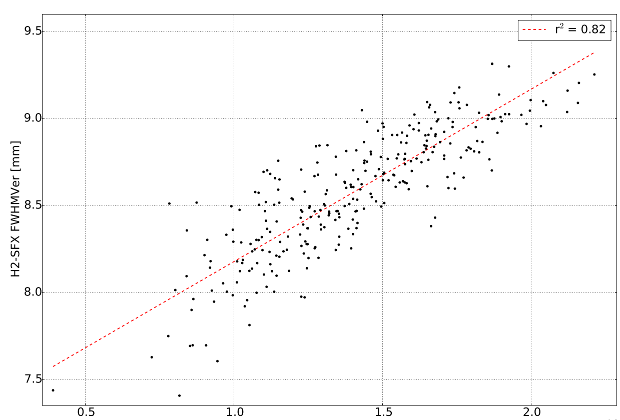

Figure 4: Correlation between intensity and FWHM directly before the IR.

The current explanation is an intensity dependent instability in the ring [8], which causes oscillations in the vertical plane and therefore blows up the beam vertically. The current hypothesis is that this vertical instability originates from effects related to the impedance of the ring. The range of variation of the spot size, especially at the isocenter, is acceptable.

Due to seasonal variations of the beam position a temperature dependency was formulated. Such trends could be observed for the main ring pick-ups as well as in the transfer line towards the irradiation rooms for the profile monitors. The position on a profile monitor in the transfer line together with the temperature in the hall is shown in Fig. 5.

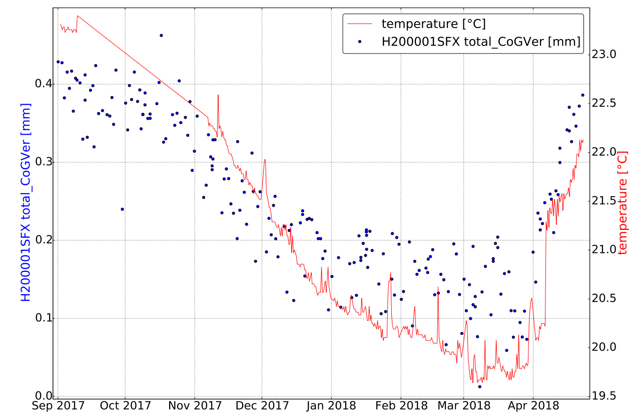

Figure 5: Position changes in the transfer line and temperature variations over several months.

CONCLUSION

Since December 2016, patient treatment at MedAustron is ongoing with proton beams, with a continued ramp up in the number of patients. Proton beams are available for medical commissioning in IR2-V and patient treatment is expected to start in May. The further commissioning of the facility is focusing on carbon ions, for which promising results, especially in terms of high transmissions and in room beam intensity, could already be achieved. A number of performance improvement projects are ongoing, like the cycle abort taking effect in May. The further commissioning milestones are the carbon commissioning in the rooms IR2-H, IR1, IR2-V, IR3 and the Gantry with protons.

ACKNOWLEDGEMENT

These results would not have been possible without the support of all the members of MedAustron's Therapy Accelerator Division. The authors would furthermore like to acknowledge the important contribution of M. Pullia and A. Garonna as well as the support of the TE-ABT and the Magnets group at CERN.

REFERENCES

[1] P. J. Bryant *et al.*, "Developments in the design of proton and ion accelerators for medical use", Proc. of EPAC'98, paper FRX01A (1998).

[2] U. Amaldi and G. Magrin, eds., "The path to the Italian national centre for ion therapy", ISBN 978-88-95522-44-9, TERA Foundation (2010).

[3] T. Kulenkampff *et al.*, "Extraction commissioning for MedAustron proton operation", Proc. of IPAC'16, paper TUPMR036 (2016).

[4] M. Pullia *et al.*, "Betatron core driven slow extraction at CNAO and MedAustron", Proc. of IPAC'16, paper TUPMR037 (2016).

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAF004

[5] C. Schmitzer *et al.*, "Status of Carbon Commissioning of the MedAustron Therapy Accelerator", Proc. of IPAC'18, paper MOPML027, these proceedings (2018).

[6] A. De Franco *et al.*, "Slow extraction optimization at the MedAustron ion therapy center: implementation of front end acceleration and RF knock out", Proc. of IPAC'18, paper MOPML025, these proceedings (2018).

[7] L. Penescu *et al.*, "Beam measurements in the MedAustron synchrotron with slow extraction and off-momentum operation", Proc. IPAC'17, paper THPVA078 (2017).

[8] A. Garonna *et al.*, "Status of the proton beam commissioning at the MedAustron ion beam therapy centre", Proc. IPAC'15, paper MOBB1 (2015).