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CARBON COMMISSIONING OF THE MEDAUSTRON THERAPY ACCELERATOR

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Abstract

The MedAustron therapy accelerator[1,2] is intended to treat cancer patients with proton and carbon beams of 62-252 MeV and 120-400MeV/u respectively. The accelerator features three Supernanogan ECR ion sources, a 400keV/u RFQ and a 7MeV/u interdigital H-mode Linac. A middle energy beam transfer line also serves as injector into a 77m synchrotron from which the beam may be transferred to 4 different irradiation rooms, 3 of which are dedicated to medical treatment. The therapy accelerator is in clinical operation since end 2016 [2] and is currently solely configured for the use of protons. After activation of a new vertical beam line the next clinical objective is to enable treatments using C6+ ions which triggered the carbon commissioning of the accelerator in 2017. This paper will discuss the ongoing carbon commissioning in the different sections of the accelerator, achieved efficiencies and outlook on future carbon activities.

CARBON COMMISSIONING

As the beam commissioning is tackled while parts of the machine are already in clinical use for proton therapy, the respective beam time is rather limited. Yet there is an important advantage to this situation which is that one profits from comfortable preparation and anylsis times in between dedicated beam commissioning shifts. Therefore a commissioning strategy was chosen as to preliminary test different parts of the machine as early as possible under different situations to identify and mitigate complications already at an early stage. The presented commissioning performance is preliminary results from the first tests of the MedAustron accelerator complex with carbons.

Ion Source

Three identical Supernanogan electron cyclotron resonance ion sources (ECRIS) are installed at MedAustron. Source 1 is driven with hydrogen gas for “proton” production (H_3^+) whereas Source 2 is tuned for carbon ($^{12}C^{4+}$) and uses a CO_2 and He gas mixture. Source 3 serves as a spare source and will be commissioned with multiple ion types for non-clinical research and to allow a swift substitution if need be.

The commissioning of the second ion source for medical treatment with carbon beam is almost finalized. Stable source settings have been found which allow to reach the nominal carbon current for medical treatment (on the order of 150 μA). Long term stability tests of the extracted beam current showed only single deviations of the nominal current <5% within 45hours periods. The installation of an overpressure valve between gas bottle pressure reducer and injection mass flow controller mitigates a pressure build up in the CO2 line and improved plasma stability considerably. Commissioned source settings for optimal performance are summarized in Table 1. A more detailed description of the source commissioning can be found in [2].

RF Freq. [GHz]	**14.464**
RF FWD [W]	**190**
Gas Mixing (CO2/He)	**1.4**
DC Bias Voltage [V]	**350**
Puller Voltage [V]	**2200**
Focus Voltage [V]	**1525**
Source Voltage [V]	**24000**

Table 1: Detailed source settings of the Supernanogan ECRIS for carbon usage.

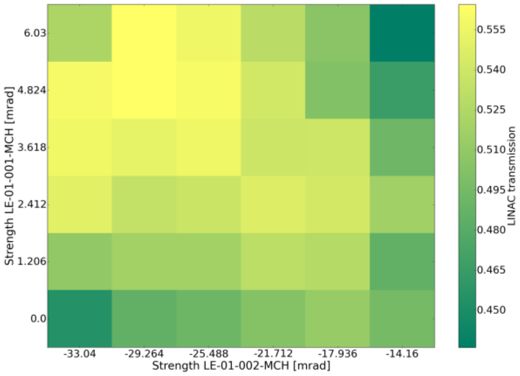

Figure 1: Two dimensional corrector strength scan of the last horizontal correctors before the RFQ.

Linac & MEBT

As the ion sources deliver the same charge to mass ratio independent of the used particle type (H_3^+ or $^{12}C^{4+}$) the Linac is optimized for exactly this situation. Thus the electromagnetic field strengths and phase delays barely need adjusting in respect to proton operation as foreseen by design. The main commissioning effort concerning the

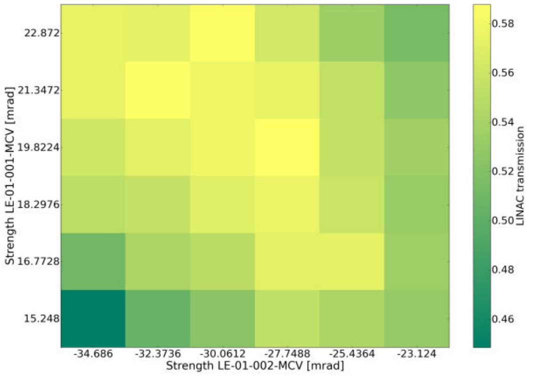

Figure 2: Two dimensional corrector strength scan of the last vertical correctors before the RFQ.

Linac is to obtain the proper emittance from the source and optimum entry position and angle of the beam for both particle types. Two horizontal (see Figure 1) and two vertical corrector magnets (see 2) are scanned to identify the working point.

The Solenoid magnet positioned at the RFQ entry remains untouched. The overall observed Linac transmission of the RFQ, Buncher and IH-tank ensemble was 64% which exceeds any expectations based on Hydrogen operation.

In the middle energy beam transfer line, connecting the Linac to the Synchrotron, only minor losses have been observed which has been neglected in the first stage of carbon commissioning. A debuncher cavity situated in the first sector of the MEBT aids to minimize the momentum spread injected into the synchrotron. The cavity is operated at the unstable fixed point with nominal power levels of 10kW. To quantify the momentum spread the beam is injected into the synchrotron and an empty bucket measurement is performed at flat bottom. Figure 4 clearly shows a reduced momentum spread for stronger field gradients which is expected as the debuncher operates after the stripping foil which yields bare $^{12}C^{6+}$ ions (or p^{+} in hydrogen operation) resulting in a lower charge to mass ratio.

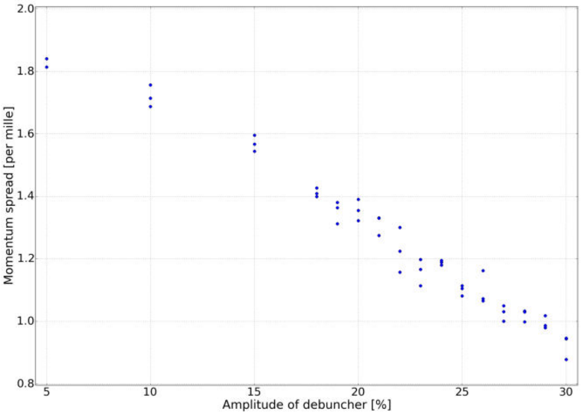

Figure 4: Reduction of momentum spread measured in synchrotron while increasing MEBT debuncher voltage.

Synchrotron

During the first stage of carbon commissioning, capture process and multiturn injection into the synchrotron were only crudely set up as to enable acceleration and extraction tests as fast as possible. This results of course in reduced observed particle numbers in the synchrotron and irradiation room. Nonetheless acceleration tests with dipole ramp rates of 2-3 Tesla/s were successfully performed. Careful adaptation of the programmed B-field, to improve power converter precision, and RF voltage ramp together with beam regulation loop tuning of the RF system lead to stable low loss acceleration. Figure 5 shows particle intensity and revolution frequency of a typical cycle with a capture voltage of 210V which is ramped adiabatically over 205ms at an RF frequency of 469.8kHz. The presented ramp rate of 2.5T/s requires an RF voltage of up to 1770V. Throughout the entire cycle the beam is kept on an off momentum orbit at an 20mm offset towards the centre of the synchrotron.

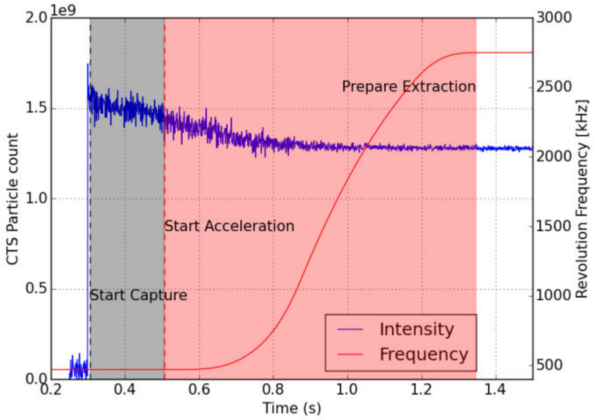

Figure 5: Current transformer signal and revolution frequency of carbon accelerated to 400MeV/u showing losses <18% during (not optimised) capture and acceleration.

Irradiation Room

The synchrotron extraction process[5,6] is currently not optimized yet after preliminary tuning of electrostatic and magnetic extraction septa as well as orbit corrections in the high energy beam transfer line (HEBT) first carbon beam in MedAustron's irradiation room 2 (IR2) was observed. Most recent commissioning efforts resulted in the first carbon beam of maximum energy at 400MeV/u in IR2. Even though the transfer line to IR2 still needs proper optimization the observed intensities are very promising.

CONCLUSION

Commissioning efforts of the MedAustron Therapy Accelerator team is currently focused on carbon commissioning. Ion source optimisation is finalized resulting in very stable $^{12}C^{4}$ beam of ≈150 μA. An overall RFQ, Buncher and Linac transmission of 64% was achieved. Debuncher tuning for momentum spread optimisation shows expected behaviour and potential for improvement. Acceleration setup of the synchrotron is in a final stage whereas multiturn injection and slow resonant extraction remain untuned. The overall carbon performance of the facility is very promising.

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