RECOMMISSIONING OF THE MARBURG ION-BEAM THERAPY CENTRE (MIT) ACCELERATOR FACILITY

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Abstract

The Marburg Ion-Beam Therapy Centre (MIT), located in Marburg, Germany, is in clinical operation since 2015. MIT is designed for precision cancer treatment using beams of protons or carbon nuclei, employing the raster scanning technique. The accelerator facility consists of a linac-synchrotron combination, developed by Siemens Healthcare/Danfysik, that was in a state of permanent stand-by upon purchase. With support from its Heidelberg-based sister facility HIT, the MIT operation company (MIT Betriebs GmbH) recommissioned the machine in only 13 months, reaching clinical standards of beam quality delivered to all four beam outlets. With the first medical treatment in October 2015, MIT became the third operational hadron beam therapy centre in Europe offering both proton and carbon beams.

INTRODUCTION

Since 2009, the University Hospital of Heidelberg (Germany) operates the Heidelberg Ion-Beam Therapy Centre (HIT) [1], which was the first dedicated facility to offer tumour therapy with protons and carbon ion beams in Germany. In order to add redundancy and enhance the capacity in numbers of patients, the Marburg Ion-Beam Therapy Centre operation company was founded in 2014 jointly with Rhön-Klinikum AG.

MIT acquired the existing particle therapy facility in Marburg (Germany), which had been developed by Siemens Healthcare GmbH, but had operated only as a technical prototype and test centre until September 2013. With the end of the Siemens test and certification program, a possible final shut-down of the site could be avoided, as MIT stepped in to bring the facility into clinical operation.

Only 13 months after foundation of MIT, the first medical treatment was performed in October 2015.

THE MIT ACCELERATOR

The MIT accelerator (cf. Fig. 1) was designed by Siemens Healthcare/Danfysik [2–4], based on the existing layout of the HIT facility [1]. Like all European proton/carbon facilities, MIT makes use of the raster scanning method originally developed at GSI [5] as part of the precursor studies to HIT. The machines operating at CNAO [6] and MedAustron [7] differ in their use of a slightly different synchrotron concept [8].

The accelerator design is driven by the need to reproducibly deliver a wide range of energies, intensities, and beam widths of two different ion types (protons and $^{12}C^{6+}$) to three horizontal and one semi-vertical (45°) medical beam outlets (cf. Fig. 1).

The required penetration depth in human tissue of 20 to 300 mm defines the range of necessary beam energies, which reaches up to 430 MeV/u in case of $^{12}C^{6+}$ and up to 220 MeV for protons.

Layout

In parallel operation, two ECR ion sources ((1) in Fig. 1) continuously produce the two different precursor beams (H_3^+ and $^{12}C^{4+}$) for the linear accelerator, so that fast switching between the two medical ions is possible.

The linear accelerator consists of an RFQ (2) accelerating the different primary ions to 0.4 MeV/u, followed by an IH drift-tube structure (3) accelerating to 7 MeV/u. Foil-stripping and charge-to-mass selection in the following medium energy transport line (4) produces protons and $^{12}C^{6+}$ ions for further acceleration.

The main acceleration stage is a light-ion synchrotron (5). It accumulates the particles by 10-fold multi-turn injection and ramps their energy from 7 MeV/u (equivalent to a rigidity of 0.38 Tm) to the final value requested by the Safety and Therapy Control System (STCS)—up to 221 MeV (2.42 Tm) for protons and up to 430 MeV/u (6.62 Tm) for carbon nuclei.

Slow extraction of the high-energy beam is performed by third-order resonant knock-out (KO) excitation. Maximum values of 3×10^{10} protons or 7×10^{8} carbon ions can be accelerated and extracted in spills of up to 8 s duration. In case of malfunction, the spill can be interrupted by a fast ($\sim 200\ \mu s$) kicker magnet (6) in the extraction beam line.

Horizontal (7) and vertical (8) high-energy beam transport (HEBT) lines lead to the four medical treatment rooms of MIT: The first three are equipped with horizontal beam outlets while the last features a semi-vertical (45°) port.

Clinical Operation

In therapy operation, the accelerator is under direct control of the STCS, which applies the calculated dose distribution by requesting a sequence of predefined beam configurations (ion type, energies, pulse intensities, and beam widths) from the data sets of the Accelerator Control System (ACS).

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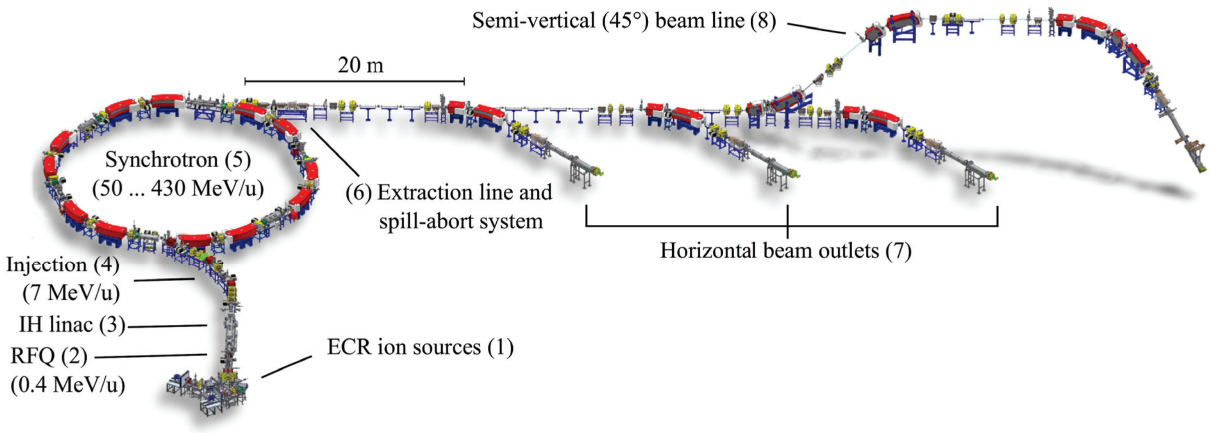

Figure 1: Overview of the MIT accelerator and high energy beam transport lines. The figure is modified from [3].

During irradiation, the STCS controls the extracted particle rate by applying an active feedback loop to the amplitude of the synchrotron KO noise kicker [9]. This allows fast variations of the particle rate within a single spill.

RECOMMISSIONING

While the accelerator had been in operation prior to purchase by MIT, it had been used only as a technical test facility by Siemens Healthcare. Upon foundation of MIT, the facility had been in stand-by for more than a year. In addition to beam recommissioning, an extensive technical overhaul was necessary as a preparation for clinical routine operation.

As reported in these proceedings [10], experienced personnel from HIT played a decisive role in recommissioning of the facility as well as in the required training of the newly employed MIT accelerator crew.

Ion Sources and Linear Accelerator

Mass-analysed precursor ion beams of H_3^+ and $^{12}C^{4+}$ are extracted from the two permanent-magnet ECR sources (Pantechnik Supernanogan) at approximate intensities of 800 μA and 180 μA, respectively.

During recommissioning, optimisations regarding the gas pressure balance in the source were performed, based on long-time experience with the same source type at HIT. Also, the familiar continuous (DC) mode of beam extraction was adopted from HIT, although a special pulsed mode of operation had originally been foreseen for the MIT sources. An improved extraction electrode geometry, reducing wear of the high voltage insulators, has been developed at HIT and is planned to be adapted to the MIT sources.

After mass analysis, the DC ion beams are chopped to fit the length of the linac radio-frequency (RF) pulses. As the linac transmission is critical in reaching the design beam intensities, the RF of the IH structure was carefully matched to the beam pulse from the RFQ in phase and amplitude (cf. Fig. 2). The optimum working points found in the experiments are practically identical to those used by the previous operator.

Synchrotron Knock-out Extraction

For the multi-turn injection and acceleration in the synchrotron, only slight adjustments have been done with respect to the parameters that had been used in the test operation of the machine.

More efforts were undertaken to optimise the settings related to feedback-controlled KO extraction. The STCS requires the ability to vary the extracted particle rate in a wide dynamic range during a single spill of the synchrotron. A prompt response of the particle rate to a fast increase or decrease of the set-point is considered more important than a perfectly homogeneous spill in absence of active control (cf. Fig. 3). Energy-dependent shifts of the machine tune were introduced for both ions in order to optimise that response.

For protons, the mean frequency of the KO excitation spectrum has been shifted from resonance with transverse ion motion, which results in a improved response to very

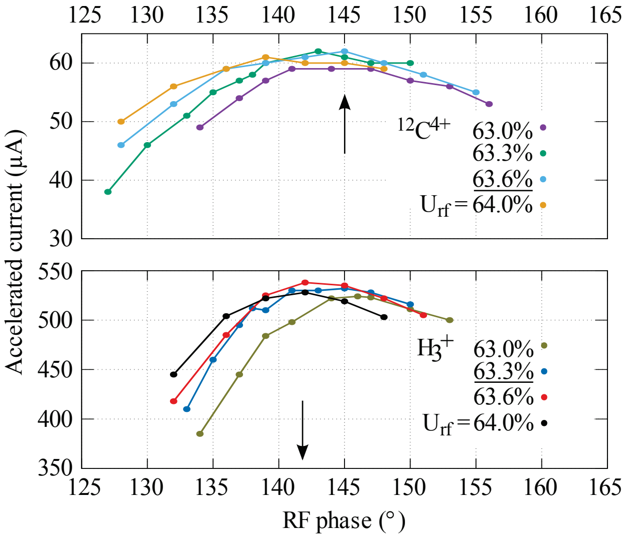

Figure 2: Transmitted current of the IH accelerator as a function of RF amplitude and phase shift for both primary ion beams. The final working points are highlighted.

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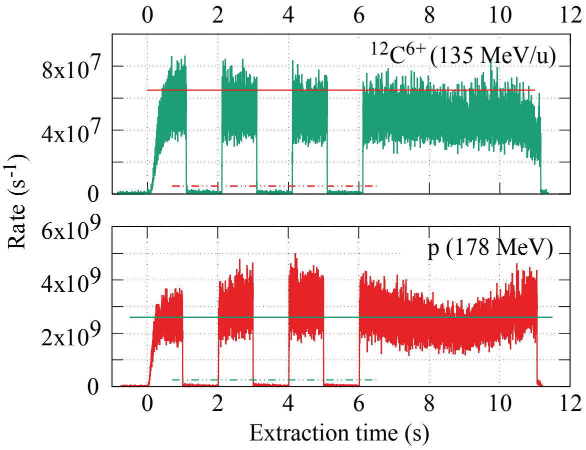

Figure 3: Spill pause intervals: The solid lines indicate the nominal particle rates (the active spill control was switched off in these measurements). The dash-dotted lines indicate the maximum allowed spill rates in the breaks.

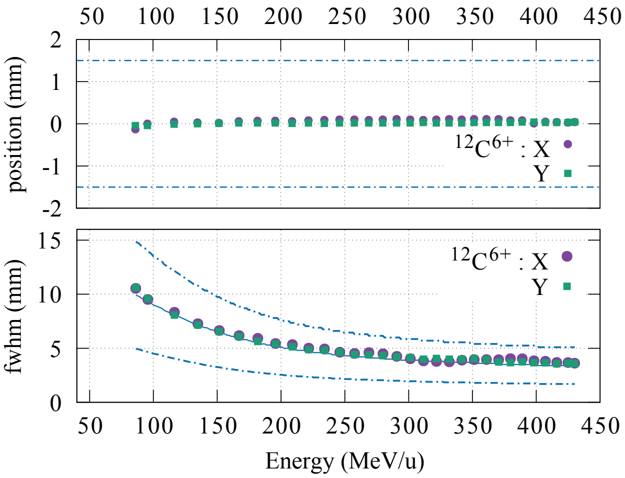

Figure 4: Beam properties for ^{12}C^{6+} at the isocentre of treatment room 1 (horizontal). The clinical precision requirements are indicated by the dash-dotted lines.

low intensity set-points. The reason for this behaviour is under investigation.

Clinical Beam Alignment

The raster scanning technique [5] requires careful alignment of the ion beam to the isocentre of each treatment room over the entire energy range. In addition, the beam widths have to match the lateral dose distribution used in computation of the irradiation plans.

Figure 4 shows the properties of a ^{12}C^{6+} beam delivered to the first horizontal treatment room. The alignment and focussing precision that has been achieved during recommissioning exceeds the medical requirement by far. The long-time stability of the beam properties are routinely monitored as part of the medical quality assurance program.

SUMMARY

MIT, the second hadron beam therapy centre in Germany to offer treatment with protons and carbon ions, went into clinical operation in October 2015. In only 13 months of technical overhaul and machine recommissioning, the accelerator facility was tuned to the required standards of beam quality.

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