BEAM QUALITY ASSURANCE FOR PROTON CLINICAL BEAMS AT MEDAUSTRON

L. Penescu†, F. Farinon, A. Garonna, M. Kronberger, T. Kulenkampff, C. Kurfürst, S. Myalski, S. Nowak, F. Osmic, M. Pivi, C. Schmitzer, P. Urschütz, A. Wastl,
EBG MedAustron, Wiener Neustadt, Austria

Abstract

The commissioning process of the MedAustron Particle Therapy Accelerator (MAPTA) has delivered the configurations providing the requested beam parameters in the first irradiation room to be used for proton clinical treatments, and at the same time it identified the critical points where a performance drift can appear. The strategy for Beam Quality Assurance (QA) has therefore two components: testing the specific parameters of the beam delivered to the irradiation room, and testing for any drifts that might appear at the critical points.

We present here the monitoring strategy, the observed limitations, the tools employed and the long-term statistics of the beam quality assurance for proton clinical beams.

MEDAUSTRON BEAMS

The MedAustron proton clinical beams commissioned at this time covers the full energy range (from 60 to 250 MeV, in 255 steps) for one spill length (5s), one spot size and four intensity levels, delivered to one Irradiation Room (IR3, with horizontal beam line).

The clinical specifications are setting acceptance ranges on position (±0.5mm for spill average and ±0.25mm for intra-spill variation), size (≤1mm between planes and intra-spill variation below ±5%) and range (±0.3mm for spill average and ±0.15mm for intra-spill variation).

The commissioning process [1-4] has delivered hardware configurations generating beams that fulfil all these requirements. The beam QA process assures the reproducibility and stability of the beam performance commissioned for the Clinical operation of MAPTA. It also identifies the needs for further performance improvement.

BEAM QA AT MEDAUSTRON

There are several QA stages to be done before the beginning of any patient treatment: (a) the Accelerator QA, using the accelerator beam diagnostics to validate the performance conformity of the beam delivered at the isocenter in the irradiation room; (b) the functional test of MAPTA, using the scanning magnets in the irradiation room to test the delivery of a full treatment plan; (c) the Clinical QA, done by the medical physics team and validating the entire beam delivery chain. In this paper we only describe the first QA step.

The "visible" part of the Beam QA process (Fig. 1) is the dedicated test done at each handover of the accelerator to a user. But the success of this test relies on a proper configuration control and on a well-defined setup procedure. And ultimately, the reliability of the entire process is sustained by a solid basis for accurate, stable and reproducible performance, provided by the state-of-the-art accelerator components and by the sum of results providing information on the accelerator performance and limitations (which must be always kept up-to-date).

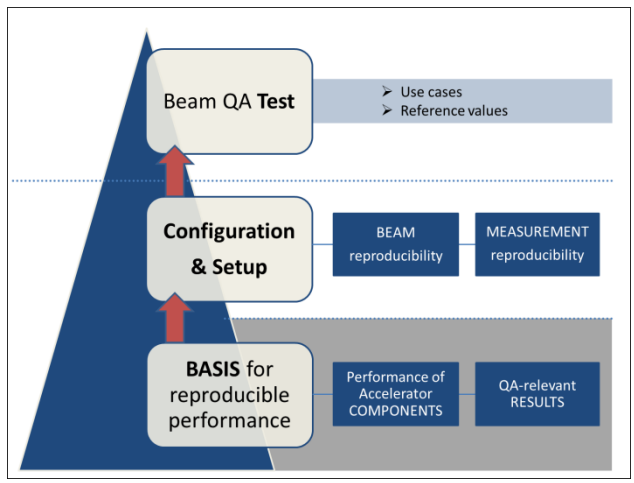

Figure 1: Overview of the Beam QA process.

Description of the Beam QA Test

There are two types of planned QA tests, covering different types of risks: (a) The Daily QA test, covering the risks of an error in the accelerator setup and of a performance drift (and therefore executed each time the user of the accelerator is changed); (b) The Extended QA, covering the risk of a change of accelerator performance (and therefore executed after a release of new configurations, after a maintenance of the accelerator, after an unsuccessful Daily QA and at regular intervals).

The goal of any QA test is to validate the machine performance, section by section (from the ion source to the irradiation room), through specific measurements aimed at providing sufficient information to identify the faulty component in case of non-conformity. The Daily QA measurements (marked with * in Table 1) focus on validating the performance of the High Energy Beam Transfer line (HEBT), while for the other accelerator sections it only acquires non-destructive beam intensity measurements. If successful, this is sufficient to fully qualify the beam quality at the irradiation room, and if unsuccessful, any type of drift in one of the machine sections will lead to a decrease in the transport efficiency for that section

† Liviu.Penescu@medaustron.at

ISBN 978-3-95450-147-2

and therefore point to the location where more investigations are needed (via an Extended QA).

Table 1: The Content of the Daily* and Extended QAs

Section	QA Verification
Ion Source	Intensity and stability*
LEBT	Transport efficiency* Beam trajectory and size Twiss match to RFQ Beam pulse length*
LINAC	Transport efficiency* Beam matching to stripping foil Beam energy
MEBT	Transport efficiency* Beam trajectory and size
SYNC	Capture and acceleration efficiency* Beam positions (H and V)* Extraction timing and flux
HEBT	Spill quality* Beam trajectory and size* Intensity at irradiation room*

Several cycle codes (beam configurations) can be tested, according to the estimated risk of non-conformity (depending mostly on the machine history).

The trajectory and size are measured in the Low Energy Beam Transfer (LEBT) section via wire scanners; in the Medium Energy Beam Transfer (MEBT) section via profile grid monitors, and in the HEBT section via scintillating fiber monitors (SFX). The beam intensities are measured via one Faraday cup (at the ion source), current transformers (in LEBT, LINAC, MEBT, SYNC) and by the Dose Delivery System (DDS) at the irradiation room. The matching to the RFQ is verified via emittance measurement [5]. The matching to the stripping foil is verified by position and size measurement at the foil position. The beam energy out of the LINAC is verified through the position of the beam after the MEBT bend (on a scintillating plate) or via a phase probe measurement (not integrated into the control system at this time). The efficiency of capture and acceleration in the synchrotron is calculated using the beam intensity at flat-top. As the Synchrotron RF (SRF) system has an active loop to maintain the configured beam radial position [2], the validation of this stage requires the logging of both the measured radial position and of the SRF frequency contributions from all the regulation loops. The extraction flux is verified via the measured decrease of intensity in the synchrotron. The quality of the extracted spill (flat intensity distribution, low peak-to-mean) is verified via a high-resolution intensity monitor.

The reference measurement values are applicable only if the reproducibility conditions (Fig. 2) are fulfilled, both for the beam and for the measurement.

A change of any of the reproducibility conditions triggers a review/update of the reference measurement values. To assure a reliable maintenance of the QA test, the reference values and the reproducibility conditions are stored in a version-controlled xml file. Most of the beam measurements and verifications versus references are automatized using a framework called Operational Applications [6].

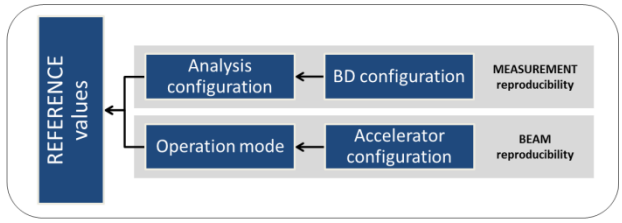

Figure 2: The reproducibility conditions for the reference measurement values (version-controlled).

Troubleshooting

A reliable accelerator QA test assures the success of the following QA stages (validating the clinical treatment), as well as any performance deviation observed by a user of the accelerator has its root cause in the faulty performance (or drift) of an accelerator component. Therefore by identifying and solving all the accelerator limitations via the beam QA process, the risk of a failed clinical QA or of a treatment stopped by an interlock is reduced to a minimum.

In case of a failed QA test, the triggered troubleshooting relies on an up-to-date base of QA-relevant results (detailed in the dedicated section).

PERFORMANCE OF ACCELERATOR COMPONENTS

Hardware Performance

Behind all the applied configurations, the accelerator hardware assures the actual command execution with the required accuracy. Reaching the proper reaction times, ramp rates, configuration times, synchronicity and parameter stability was one of the big challenges of the design, procuring and commissioning stages.

Any further limitation observed on the hardware side during the accelerator operation will have to be taken into account for the QA process, until solved.

Control System Functionalities

Many of the accelerator performance aspects rely on functionalities of the control system: the configuration settings are handled via cycle codes mapping to user-relevant parameters; the synchronized and exclusive operation of relevant groups of accelerator hardware is assured by using predefined “virtual accelerators”; the configuration and preparation for operation of the accelerator hardware is done via generalized state machines; the hysteresis cycle of the magnets is fully reproduced through automated actions included in the operation workflow; the choice of operation in fully controlled configuration (clinical) or in commissioning mode is enabled by having several modes of operation available.

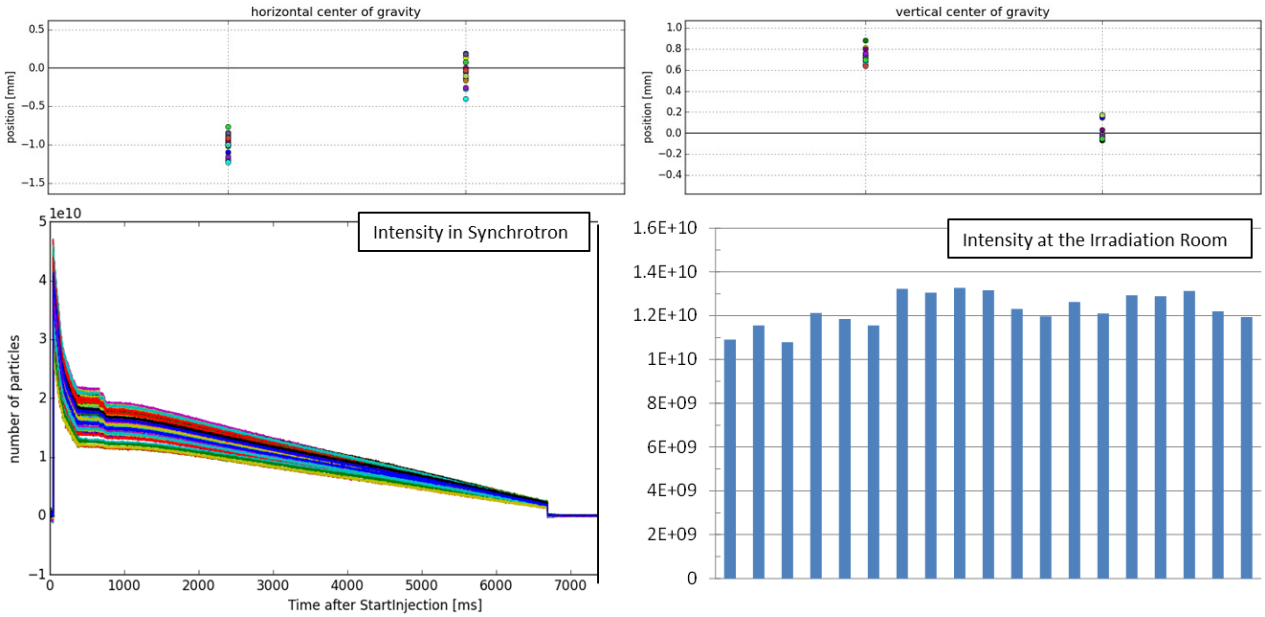

Figure 3: Two-week statistics of Beam QA measurements; CoG on the last 2 SFXs and intensities in SYNC and IR3.

QA-RELEVANT RESULTS

Results of Beam Commissioning

The beam commissioning demonstrated that the accelerator performance is within the clinical specifications and is providing the QA reference measurements for any new configuration. It also proved that it is possible to generate all the machine settings based on normalized values with interpolation between a few energies. For this reason the QA process is also testing only a small number of relevant cycle codes.

The knowledge of the limitations which are not yet addressed is also very important for setting up realistic QA goals. For example, the CoG provided by SFX measurements is only to be used for relative measurements [4].

Operation History

The operation history relevant for the beam QA is of several types: (a) past troubleshooting and underlying root causes; (b) recommissioning experience needed to address maintenance or drift effects; (c) performance limitations observed via long-term statistics over the beam QA measurements.

Up to now, there has been continuous improvement of the beam performance in the SYNC and HEBT [1], therefore there is limited statistics for constant settings. Nevertheless, a two-week performance statistics (Fig. 3) could point out that: (a) the beam parameters at IR3 are stable and reproducible; (b) the beam matching to the synchrotron can be further improved (for stable injector currents there are fluctuations of the captured beam, inducing small variations in IR3).

Longer statistics are available for the injector, where no recommissioning was needed since the performance was optimized at end-2014.

Special Tests

To actively prepare for efficient troubleshooting sessions before they actually are needed, several QA-dedicated tests are being carried out: (a) test of the design assumptions (e.g. the decoupling between the injector and the HEBT); (b) test of the efficacy of the parameters to be used for different types of recommissioning; (c) periodic scans to detect radiation damage on the SFX monitors.

ACKNOWLEDGEMENTS

We acknowledge the contributions of all our colleagues and collaborators who participated during all the project phases to reaching today's design, performance and configuration control.

REFERENCES

[1] A. Garonna *et al.*, "Status of proton beam commissioning of the MedAustron Particle Therapy Accelerator", presented at IPAC'16, Busan, Korea, May 2016, paper THOAB01.

[2] C. Schmitzer *et al.*, "MedAustron Synchrotron RF commissioning for medical proton beams", presented at IPAC'16, Busan, Korea, May 2016, paper MOPOY001.

[3] T. Kulenkampff *et al.*, "Extraction commissioning for MedAustron proton operation", presented at IPAC'16, Busan, Korea, May 2016, paper TUPMR036.

[4] C. Kurfürst *et al.*, "HEBT commissioning for horizontal beamline proton treatments at MedAustron", presented at IPAC'16, Busan, Korea, May 2016, paper TUPMR035.

[5] L. Penescu *et al.*, "Commissioning and operation of the MedAustron Injector", in *Proc. IPAC'14*, Dresden, Germany, Jun. 2011, paper THPME001, pp. 3202-3204.

[6] A. Wastl *et al.*, "title", in *Proc. IPAC'15*, Richmond, VA, USA, paper MOPHA002, pp. 773-776.

ISBN 978-3-95450-147-2