THE BEAM QUALITY ASSURANCE OF THE MEDAUSTRON PARTICLE THERAPY ACCELERATOR

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Abstract

The delivery of clinical beams for patient treatment at the MedAustron Ion Therapy Center requires extensive accelerator performance verifications, which are performed in several steps. In first instance, the key parameters of the beam delivered to the irradiation rooms (beam position, spot size, energy and intensity) are verified via measurements performed with beam diagnostic devices distributed along the accelerator. The second verification step consists in testing the full functionality of the therapy accelerator, including the medical frontend: scanning magnets performance, intensity monitoring and safety features. The final verification step is the quality assurance (QA) done by the medical department. An extended set of reference measurements assures the fast identification of the faulty components in case of a performance deviation, and the totality of the accumulated data allows in-depth analysis of the accelerator performance. We present here the trends and correlations observed during the first verification step for the most important parameters, as well as the lessons learned through all the implementation stages of the beam quality assurance.

INTRODUCTION

The accelerator performance verification which is the closest to the real workflow of patient treatment is the verification done by the medical department (stage 3 in Figure 1), by testing the beam range, the deposited dose and the spot maps for treatment plans delivered via the medical frontend. But to minimize the risk of identifying a performance deviation at this stage, and to assure a swift troubleshooting when needed, two other verification stages are performed on a daily basis: (1) the Accelerator QA, which focuses on verifying the key beam parameters delivered at the treatment room's isocenter for a relevant selection of beam configurations and (2) the MAPTA (Medical Accelerator Particle Therapy Accelerator) functional and safety tests, which verify the reliable performance of the medical frontend and of the safety systems.

The number and content of verification stages is subject to further optimization, as the facility commissioning for all combinations of irradiation rooms and beam species is still ongoing [1]. We present here the strategy and the results as valid at 6 months after the treatment of the first patient.

The basis for reproducible performance is assured by a reliable configuration control: the configurations for all hardware components are found (or validated) via the commissioning activities and controlled via the MedAustron quality assurance processes. For each beam-related verification, reference values and acceptance thresholds are associated to each configuration, and they are reviewed (and possibly updated) at each configuration change.

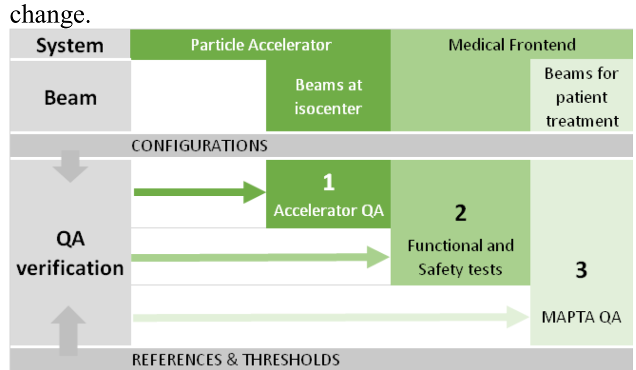

Figure 1: The three stages of beam quality assurance verification at MedAustron.

THE ACCELERATOR QA

The acceptance conditions for the accelerator QA focus exclusively on the key beam parameters at the irradiation room: (a) beam position: verified on the last 2 position monitors; (b) beam size: verified on the last 2 position monitors; (c) beam energy: verified (indirectly) via the frequency of the synchrotron RF system at the time of the beam extraction; (d) beam intensity: verified on the nozzle monitor. The test is done for several beam cycles, to best cover the accelerator performance over the entire set of medical cycles (energy, intensity and spill length ranges).

Additional beam parameters are monitored (but not affecting the acceptance) along the accelerator during this verification step, to serve the purpose of in-depth accelerator performance monitoring [2]. During the daily QA, the additional measurements are only non-destructive, to save time. During the extended QA sessions, the measurements performed cover all information required for performance troubleshooting in any accelerator section.

Daily Accelerator QA

The daily QA is mostly automated: a framework called Operational Applications [3,4] assures the verification of the applied accelerator configuration, the performance of the measurements, the processing of the measurement data and the comparison with the corresponding

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thresholds. For each parameter, two thresholds are defined, corresponding to two action levels: the first one allowing the acceptance of the QA verification with a warning (if crossed) and the second one preventing the patient treatment and triggering immediate troubleshooting (if crossed). These thresholds are static and their values are chosen in consistency with the thresholds used during the MAPTA QA.

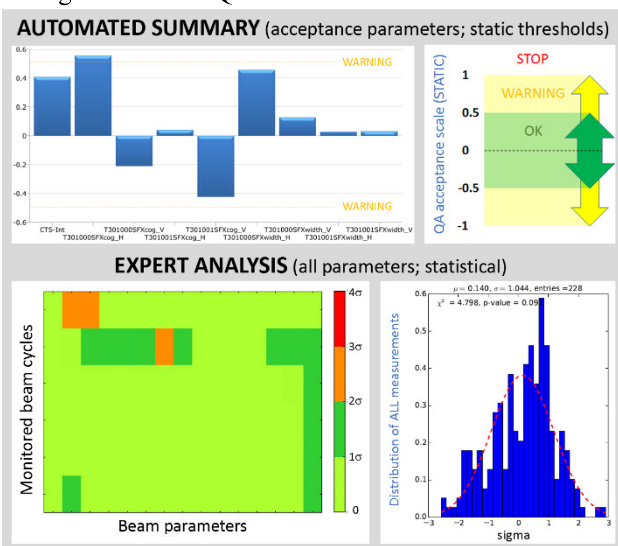

Figure 2: Top: Automated summary with deviations of measured parameters on the static acceptance scale. Bottom: Statistical analysis of all parameters.

The automated analysis is generating for each investigated beam cycle a report containing a summary acceptance plot, where the measurement deviation for each beam parameter is represented on a normalized scale from -1 to +1 (see Figure 2).

For the expert summary of all the measured parameters, an analysis framework (programmed in Python) was developed internally [5]. This framework allows, among others, the statistical analysis of the accumulated data; each new measurement is evaluated not according to a static threshold, but to the standard deviation scale defined by all the past measurements corresponding to the same configuration. On longer term, this statistical analysis also allows the review and refinement of the static thresholds.

Troubleshooting Strategy

A reliable troubleshooting relies on an up-to-date set of reference measurements covering the key beam parameters in all accelerator sections. The troubleshooting can be then executed in several steps: (a) identify the accelerator section where the transport efficiency is deviating from the reference; (b) in the identified section, find the location where the beam optics or trajectory deviates from the reference; (c) identify the component generating the deviation; (d) find the reason for the change in the component performance.

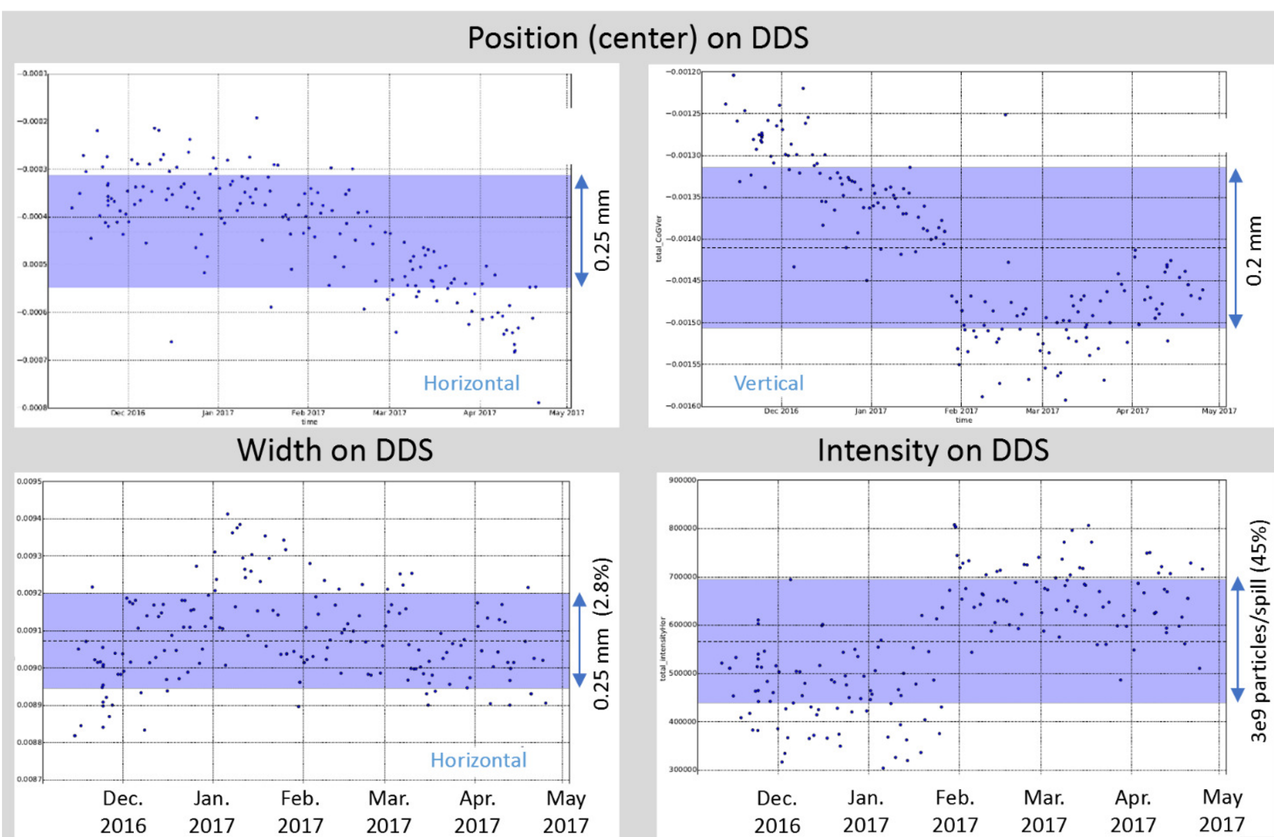

Figure 3: The six-months trend analysis of the beam parameters on the nozzle monitor (for one energy). The blue range represents the ±σ of the statistical distribution. The relevant dimensions on y-axis are indicated by line arrows.

ISBN 978-3-95450-182-3

LONG-TERM STATISTICS

The accumulated beam measurements are only comparable as long as no significant change was brought to the configuration used for beam generation. Until the first patient, the rate of configuration changes (triggered by the commissioning and by solving various limitations) did not allow a long-term statistical analysis. Since the treatment of the first patient, only a few changes affecting the beam have been implemented; the changes in the beam parameters have been small enough to keep all measurements comparable, but some of them big enough to show cross-dependencies. We detail in the following the observed statistics, for a duration of six months.

Trend Analysis

The statistical analysis of primary importance to assure the long-term reliability of the accelerator performance is the search for any trends in the beam parameters, and especially in the QA acceptance parameters (beam at isocenter). The Figure 3 shows the observed trends for one beam configuration. A significant change in behaviour can be observed at end of January, when the resonant behaviour of the IH drift tube LINAC was improved.

The same figure indicates that at the present time there is an ongoing position drift of the horizontal center of gravity of the beam measured on the nozzle monitor (DDS). The small drift velocity will allow a few additional months to identify the reason.

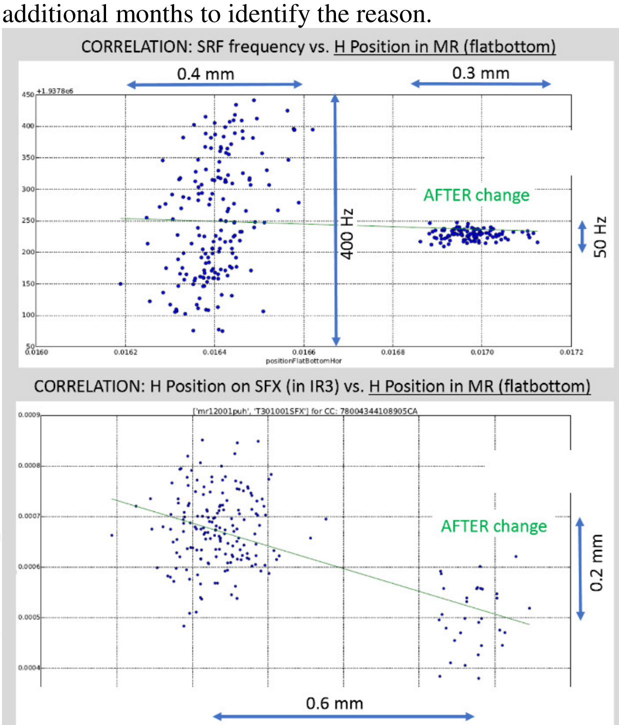

Figure 4: Effects of changing the gain of the ORB monitor: the statistical variation of the SRF frequency is decreasing, leading to a smaller statistical variation of the H beam position on the last profile monitor before the irradiation room. The relevant dimensions are indicated by line arrows.

Correlation Analysis

The Python analysis framework also allows to plot correlations between any two beam parameters measured at the same time (which is the case for all non-destructive measurements, plus maximum one destructive measurement at a time). This approach allows using the statistical fluctuations to identify eventual dependencies between the beam parameters.

The Figure 4 illustrates how the correlation analysis could explain a quite unexpected effect: using a high gain for the beam monitor measuring the beam orbit in the synchrotron (ORB) was generating a high fluctuation in the frequency of the synchrotron RF (SRF) system, via the regulation loop for radial beam position. This higher fluctuation of the SRF frequency was increasing the fluctuation of the beam position getting to the irradiation room (as visible in Figure 4), and was also increasing the rate of interlock generation by the energy verification system, which monitors the total frequency of the SRF.

SUMMARY AND CONCLUSIONS

The Accelerator QA passed through several stages from the beginning of the beam commissioning until the daily patient treatment. In the early phases, most of the deviations originated in the imperfect application of the configurations, either due to an incomplete procedure or to parameters not yet fully controlled. Later on, the QA data became the main support in identifying faulty components and thus allowed acquiring valuable experience in accelerator debugging. Now, the long-term statistics allows revealing fine operational effects. A next step for the future is to have an on-line database with beam measurements and accelerator hardware parameters saved parasiticaly, thus enabling extensive analysis for trends and correlations.

ACKNOWLEDGEMENTS

We acknowledge the contributions of our colleagues from the MedAustron Controls group for their support with the automation of the Accelerator QA via the OpApp framework.

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