Conference Poster

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Dose verification of fast and continuous scanning in proton therapy

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Purpose

The interplay between organ motion and pencil beam scanning impairs the homogeneity of the delivered dose distribution [1]. Applying the same field multiple times with proportionally reduced dose – so-called rescanning – can average out such interferences [1,2]. However, rescanning accumulates dead time when irradiating in a discretized ‘step-and-shoot’ manner. Thus, fast and continuous scanning could be desirable for such cases, which necessitates a dedicated beam monitoring and verification system to ensure safe treatment.

Steps

1. Aim: monitor beam current and beam position during patient irradiation to fulfill current safety standards

   - Level 1: Real-time verification to prevent radiation accidents
     (a) continuous monitoring of the beam current with nozzle dose monitors as well as
     (b) continuous monitoring of the beam position with Hall probes in the scanner magnets

   - Level 2: Online verification to assess and examine delivery accuracy
     validation of line profiles with the nozzle strip monitor after the application of each line

What is line scanning?

- Scanning the beam continuously along straight lines without turning it off yields a significant reduction in dead time compared to spot scanning [4].
- We modulate the dose [5] by adjusting (a) the scan speed v and (b) the beam current I.
- Regions of low dose correspond to a high local v/I or low I (cf. figure 2).
- The delivery of highly modulated fields requires an exceptionally high frequency of speed and current modulation.
- The verification system must be able to react on the same time scale.

Real-time verification – monitoring beam current and position

- Beam current: signal of the primary dose monitors in the gantry nozzle
- Beam position: signal of the Hall probes in the scanner magnets

Online verification – validating integral line profiles

- Step 1: A single line is delivered under real-time verification before its integrated signal in the strip monitor is read out.
- Step 2: The expected line profile is calculated from the speed and current modulation contained in the delivery tables.
- Step 3: Measured and predicted profiles are compared (e.g. strip sum, center of gravity, residuals, 1D y analysis) [6].

Conclusion & Outlook

- We consider line scanning well-suited for efficient rescaning of moving targets because of its minimized dead time.
- The combination of real-time and online verification ensures safe beam delivery.
- Clinical integration of the prototype verification system requires precise synchronization of beam delivery and monitoring. Additionally, strategies on how to resume after interlocks triggered during and after line application must be implemented (cf. figures 9 and 10).

References


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Figure 1: Gantry 2, image of Paul Scherrer Institute ( PSI).

Figure 2: Schematic comparison of spot and line scanning.

Figure 3: MAM concept of spot and line scanning.

Figure 4 and 5: Planned beam current (left) and measured position (right) during the application of a modulated line (cf. figure 6 for the corresponding dose distribution). The beam current remains con- stant, while the beam position changes according to the modulated current profiles. The delivered current is monitored by means of a 1D fast current monitor placed at the nozzle (cf. figure 6).

Figure 6: Measurements of dose delivered to two different line scanning profiles on the left and the corresponding measured profile on the right. The measured profile is represented by a thin line, the other lines represent different dose levels: 0 (black), 10% (blue), 20% (red), and 50% (green) of the original dose level.

Figure 7 and 8: Comparison of measured and generated calculated dose profiles for the two described in figure 6. The data are presented as a percentage of the measured dose level measured on the left, and the corresponding calculated dose level on the right. The measured and calculated dose profiles on the right correspond to the measured dose profiles on the left. The dose levels are represented by the same color coding as in figure 6.

Figure 9: Demonstration of the influence of the line scanning on the delivered dose. The beam current is sampled at a rate of 20 kHz. The interval is propagated to the electronics and the calculation is aborted.

Figure 10: Example to show how the system reacts to a remaining fault after the application of a line. The delivery is aborted and the magnet is closed. The interval is propagated to the control system and the treatment is paused.

Figure 11: Example to show how the system reacts to a remaining fault after the application of a line. The delivery is aborted and the magnet is closed. The interval is propagated to the control system and the treatment is paused.