STATUS OF COMMISSIONING OF GANTRY 3 AT THE PSI PROSCAN FACILITY

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Abstract

Paul Scherrer Institute currently extends its PROSCAN facility with a third gantry treatment room – Gantry 3, which is realized in the framework of a research collaboration with Varian Medical Systems (VMS).

The main research goals at the PROSCAN facility include further development of precise spot scanning and optimized beam delivery with low dead-time for treatment of moving targets. Consequently Gantry 3 is designed to feature advanced pencil beam scanning technology with a large scan field size of $30 \times 40\,\mathrm{cm}^2$, integrated cone beam CT functionality and will in the future allow fast energy layer switching.

The main challenge in realizing Gantry 3 is the integration of the Varian Gantry into the existing PROSCAN control system environment, allowing seamless beam operation. Installation of the additional treatment room has started in summer 2015 followed by the integration and technical commissioning phases of the Gantry in 2016, all during full operation of the existing treatment areas at our facility. We report about the special challenges and achieved performance results during commissioning of the Varian Gantry system in combination with the PSI PROSCAN facility.

INTRODUCTION

The PROSCAN facility [1] [2] [3] at PSI and its research and clinical capabilities are extended by a third irradiation room, Project Gantry 3 [4]. The technical concepts and detailed specifications have been reported previously [4] [5], see also Table 1. The ambitious goal of this research collaboration with VMS is to achieve comparable system performance as accomplished on Gantry 2 [6], using Varian's standard Gantry design as a base. Fig. 1 shows the currently finished treatment room Gantry 3 (touch-up finishes pending). We report about the experiences, approaches and solutions employed to accomplish the required system performance and the present project status.

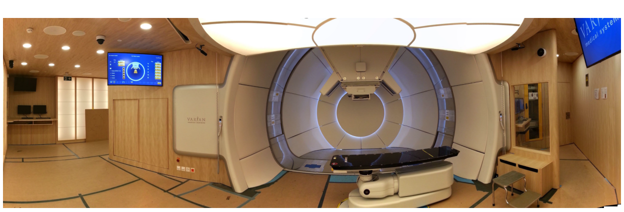

Figure 1: Gantry 3 treatment room. January 2017.

Table 1: Gantry 3 Main Performance Specifications

Energy range	70 – 230 MeV
Energy resolution	< 0.1 MeV
Beam momentum spread	< 1%
Layer switching time	< 200 ms
Beam FWHM at ISO (in air) @ 230 MeV	8.5 mm
Lateral beam position precision (ISO)	1 mm
Field size	$300 \times 400\,\mathrm{mm}^2$
Dose delivery	2 Gy/liter/min

COMMISSIONING CHALLENGES & EXPERIENCE

In this project different design philosophies meet, which was taken care of by careful interface specification. During commissioning however it is inevitable to find that the devised solutions needed adjustments due to workflow issues or unanticipated challenges and technical issues. The requirements on beam stability implied a beam optics revision in this respect, see the following section.

Special care has been taken to bring the two system-architectures (PSI, Varian) via common physical and control system interfaces together. Control system integration has been successfully completed and commissioning equally successful finalized by an intensive verification & validation phase, owing to the early, extensive and careful design and implementation activities from both collaboration partners. During the commissioning several challenges had to be faced:

- Configuration management – twice the # of systems that need to be controlled by different experts
- Two system worlds – twice # of error sources
- Two system worlds – multiple # of measurement equipment – multiple results
- Error message/signal "loops"

Interface matching and coordination is key in mastering these real-life challenges. Additionally it was extremely helpful to have an automated test system for the quality assurance of the patient safety system in place, see for the subsequent section.

Of note, the entire commissioning phase of Gantry 3 was done without interruption of clinical operation of the PROSCAN facility. Naturally, this posed two main challenges:

- Limited beam time availability, due to patients throughput,
- Commissioning in night shifts over long periods.

Due to the limited off-hours availability of specific system experts involved in daily clinical operation, definitely more

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time needs to be anticipated for error analysis and resolution. Detailed logs and shift reports played an important role, however most helpful were dedicated commissioning sessions with all relevant system experts present at the same time.

In summary, we were faced with more challenges than anticipated during the technical commissioning phase, which have been mastered successfully and we are now in the phase of customer acceptance testing. The timelines of the latter had to be adjusted accordingly.

BEAM POSITION STABILIZATION

The stability of the beam center position at the isocenter (ISO) is one of the essential criteria for the clinical operation of the gantry. Hence, during the commissioning year 2016 several arrangements have been made in order to achieve as high level of beam iso-center stability as possible. These included the two following measures.

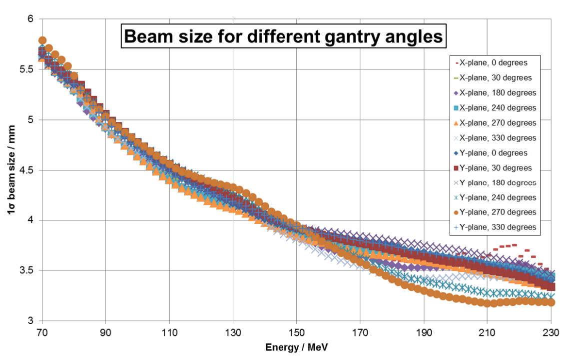

Figure 2: Beam size at the iso-center as a function of energy for different gantry angle settings.

Beam Optics Optimization

The optimization of gantry quadrupole settings (tunes) has been performed in order to achieve as good as possible imaging from the coupling point collimator to the iso-center.

The R_{12} and R_{34} parameters of the current tunes are < 0.1. These have been calculated with Transport software and later tested experimentally. For this test, the beam has received different deflections in X and Y directions via the steering magnets located near the coupling point. The beam position change at iso-center has been recorded as a function of the deflection angles and it has been found that the angles of 1 mrad at the coupling point result in less than 0.1 mm beam position offset at iso-center. As a side-effect of the new optics implementation, we accept smaller beam sizes at iso-center for the high energies even below the previously specified level (see Fig. 2).

Beam Position Stabilization

The magnification factors (R_{11} and R_{33}) for the imaging from the coupling point collimator to the gantry iso-center are in the order of 1.6. This implies that the beam position errors at the coupling point location result in 1.6-fold errors at the iso-center location. In order to ensure the beam position stability at the coupling point, an alignment procedure with automated software has been developed. This procedure includes the centring of the beam after the cyclotron with the first quadrupoles switched off and is performed every morning during the standard alignment routine.

The measured beam position variation at the coupling point before the gantry is in the order of 0.1 mm during the daily operation. The beam between the degrader and Gantry 3 coupling point has been re-aligned with steering magnets following this procedure. The steering magnets settings have been included into the Gantry 3 tunes. The gantry optics with an optimized imaging, the automated alignment procedure and the new beamline tunes have been used for the fine steering of the gantry.

SCANNING COMMISSIONING RESULTS

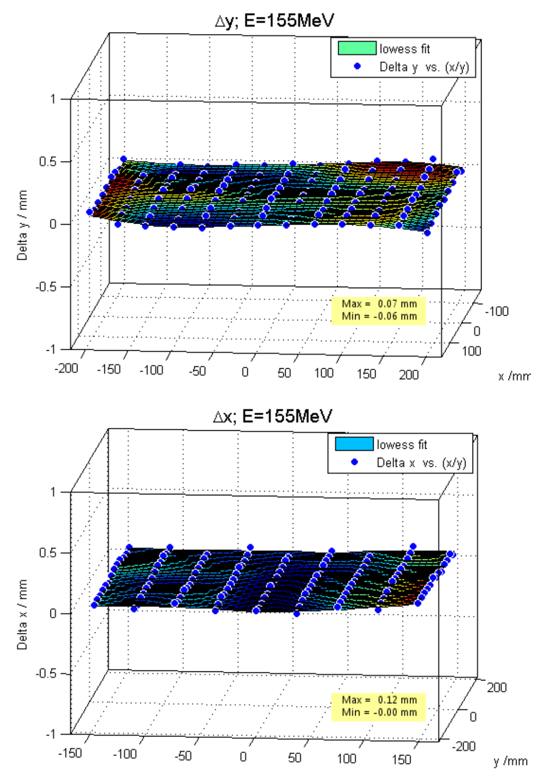

Figure 3: Beam offset in x-plane (bottom) and in y-plane (top) as a function of the scanned beam deflection.

Due to the optimized beam stability at the coupling point a high level of the beam spot positioning accuracy at the iso-center has been achieved. This has resulted in relative beam position deviations below 0.1 mm when the beam is scanned over the full range of the scanning field (see Fig. 3). Such a stability yields a dose homogeneity $< 3.5\,\%$ for the full range of the scanned beam. The example of the beam dose distribution for 90 MeV beam energy and 0° gantry angle is presented in Fig. 4.

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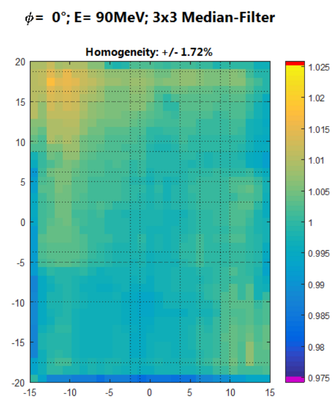

Figure 4: Dose distribution for a full scan field with an applied mono-energetic layer of 90 MeV. The color-wash scale is indicated on the right hand side of the figure.

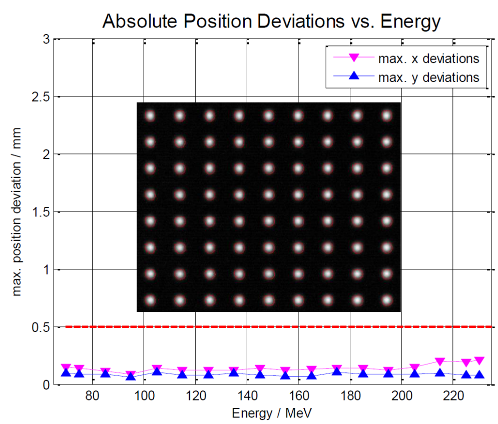

Figure 5: Absolute deviation of beam position in x and y as a function of beam energy and an example of measured distribution of the scanned beam.

CONTROL SYSTEM INTEGRATION TESTING & QA STRATEGY

Key of the architectural concept of control system integration is the encapsulation of the two system environments. Necessary interfaces are only exposed at newly created adaptors [4] [5].

The PaSS (Patient Safety System [7]) adapter constitutes the interface between the Varian scanning and safety system and the central PSI safety components. In order to prevent non-optimal beam delivery, it can interrupt the treatment if any sub-system reports an error. The logic is implemented on a FPGA which connects to the real world via a flexible hardware interface (Signal Converter Box [8]).

The PaSS adapter needs to be thoroughly tested as part of the regular quality assurance (QA) as well as after each change. These QA procedures typically required weeks of work in the past, extensive beam usage and could not always cover all possible failure modes. With the opportunity of the installation of the new Gantry 3, an automated PaSS test stand was developed that can emulate the rest of the facility. It consists of a NI PXI chassis with virtually unlimited IOs that are synchronously stimulated or sampled at 1 MHz, a set of adapters to connect each type of interfaced signal and a runtime environment. Also, a VHDL based formal language was developed to describe stimuli, assertions and specific measurements. The correct functioning of the test stand was validated by repeating a number of measurements on the facility itself using oscilloscope traces for time measurements.

With this new system it is possible to perform the complete set of unit tests automatically within a few hours.

STATUS & OUTLOOK

Gantry 3 technical commissioning has been concluded and we are now in the phase of acceptance testing. The system shows extremely good scanning performance and the elaborate control system integration phase has led to smooth operation conditions (few interlocks).

Due to a necessary intervention on our COMET cyclotron after more then 10 years of operation, beam related-activities can only resume after a shut-down of 8 weeks. This time will be used to finish the non-beam related acceptance tests on the imaging and positioning system. After resuming beam operation extensive QA checks will be necessary, followed by the finalization of acceptance testing and the subsequent clinical commissioning phase. First patient treatments on Gantry 3 are anticipated earliest for the end of 2017.

ACKNOWLEDGMENT

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