PSI GANTRY 3: INTEGRATION OF A NEW GANTRY INTO AN EXISTING PROTON THERAPY FACILITY

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Abstract

Paul Scherrer Institute extends its proton therapy facility PROSCAN by a third gantry. It is delivered by Varian Medical Systems (VMS) as part of a joint research project. Gantry 3 is equipped with a cone beam CT and allows 360 degrees of rotation while occupying a 10.5 m diameter.

The integration of a gantry into the existing PSI system typically being designed for a complete Varian system is a challenging project, since also the certification is to be maintained. Especially the interfaces between the PROSCAN control system and the one of Gantry 3 have been a major development. Gantry 3 is designed to deliver proton beam of up to 8 nA with an accuracy better than a mm, while having a high level of over-current protection. This comprises a new current monitoring unit, several levels of interlock controllers and a beam energy dependent intensity compensation concept. One challenge concerns the specified layer switching time of 200 ms, required to reduce the treatment time to enable for repainting. After technical commissioning, acceptance tests and hand over, the clinical commissioning is foreseen in the second half of 2016 with the first patient treatment in December 2016.

INTRODUCTION

PSI expands its PROSCAN facility [1] [2] [3], depicted in Fig. 1, by a further Gantry treatment room [4]. The project is funded by the Swiss Canton of Zurich and is part of a research collaboration of PSI with Varian Medical Systems (VMS).

Table 1: Gantry 3 project timeline

Civil engineering start	Begin 2014	✓
Start infrastructure	End 2014	✓
PSI beamline commissioned	May 2015	✓
Gantry mechanics installation	July 2015	✓
1st beam, new PSI control system	1st Dec 2015	✓
1st beam through Gantry 3	24th Jan 2016	✓
Integration & Commissioning	Feb-May 2016	(✓)
Validation & Verification	May-Jul 2016	–
Acceptance testing	Jul-Aug 2016	–
Clinical commissioning	Aug-Dec 2016	–
1st patient (provisional)	Dec 2016	–

The gantry installation follows a tight schedule in order to permit the start of the patient treatment in minimum time. Table 1 summarizes the timeline of the project and status of individual phases and milestones.

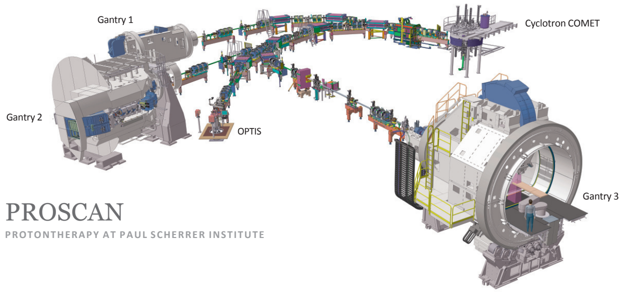

Figure 1: Layout of the PROSCAN facility beam lines including the new Gantry 3 area.

The main challenges in the Gantry 3 project are the attainment of performance comparable to Gantry 2 [5] and in particular the integration of two system environments with different design background. The relevant technical concepts have been reported in [4] and the technical properties for beam operation are highlighted again in Table 2.

Table 2: Gantry 3 main performance specifications

Energy range	70 – 230 MeV
Energy precision	< 0.1 MeV
Beam momentum spread	< 1%
Layer switching time	< 200 ms
Beam FWHM at IC (in air)	8.5 mm
Lateral beam position precision (IC)	1 mm
Field size	300×400 mm^2
Dose delivery	2 Gy/Liter/min

INSTALLATION PHASE

After successful completion of the civil engineering works in 2014 and installation of general and technical infrastructure in the first half of 2015 up to the interface points with the Varian Gantry system, July 2015 marked the beginning of the Gantry installation phase. The thoroughly planned and organized installation sequence by Varian, the just-in-time delivery of the large mechanical parts and the good weather lead to a rapid and successful initial rigging of the Gantry mechanics, see also Fig. 2. The subsequent install of beamline elements including the nozzle was equally facilitated by Varian's strategy to deploy pre-assembled, pre-aligned and pre-tested modules, cf. Fig. 2, leaving the rest of the time for cabling, fitting connections and hardware testing.

Technical installation was ready for beam operation by end of 2015. The work on the interior of the patient treatment room has progressed and will be finished soon.

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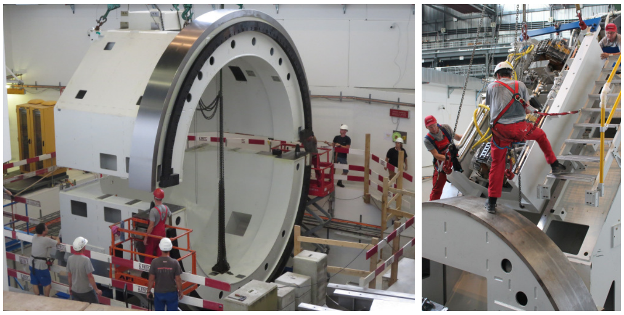


Figure 2: Installation phase, July 2015. *Left*: Front ring. *Right*: Installation of pre-assembled beamline girder.

INTEGRATION

The Gantry usually resides as a subset in a consistent Varian facility environment. The key concept to integrate it into PSI's PROSCAN facility is the minimization of interfaces. The building interfaces (mechanical, electrical, general infrastructure) are mostly pre-defined, yet a thorough change management has been applied and the entire installation checked employing a 3D CAD integration model.

The chosen architectural approach for the control system integration is the encapsulation of the two system environments (PSI, Varian) and expose the necessary interfaces only at newly created adaptors [4], on PSI side these are the TCS (Treatment Control System) and PaSS (Patient Safety System) adapters.

TCS Adapter: The TCS adapter development is based on a detailed specification of the network interface to the VMS control system and a functional specification describing the actions on the PROSCAN side. The software development is covered by unit tests and extensive system tests. Each interface command is backed up by a test case covering success and failure modes. For running the test cases, a TCS adapter installation is interfaced to simulations of the external systems like the VMS control system, the PROSCAN beam allocator and IO signals from the safety systems. Automated system testing in this environment is supported by a subordinate control instance driving the test cases. A smooth and timely system integration without major issues was the result of these efforts.

PaSS Adapter: The integration of the Gantry 3 safety system follows PSI's concept with local (specific to one treatment room) and central (shared by the facility) components. The PaSS Adapter constitutes the interface between the Varian (local) and PSI (central) systems. A state-of-the-art platform was chosen for the logic controller, the IFC1210 developed jointly by PSI and IOXOS [6]. It features a user programmable Virtex 6 FPGA chip and contains the safety system logic which after system startup is totally autonomous. Two additional Power PC CPUs running SMP Linux provide a standardized EPICS communication interface. This is used by the Graphical User Interface which provides access to the safety logic and automated actions like logging and statistics, see Fig. 3.

A generic platform, the so called Signal Converter Box (SCB) jointly developed by PSI and SCS [7], supports the interconnection of IO signals from and to all subsystems.

Development of the safety logic followed an established process. It comprises extensive verification and validation steps to ensure the correctness and integrity of the logic. Once connected to the Varian adapter, the integrated system worked smoothly with minor technicalities quickly rectified.

An additional benefit of the new platform is the possibility to automatize performance measurements of the safety system (logic and final elements). These measurements are required for the acceptance and the technical QA of Gantry 3. It is expected to save approx. 10 man days of work each year. The continuous monitoring will allow the prediction of failures by ageing of components and organize their replacement before delays in the clinical program would arise.

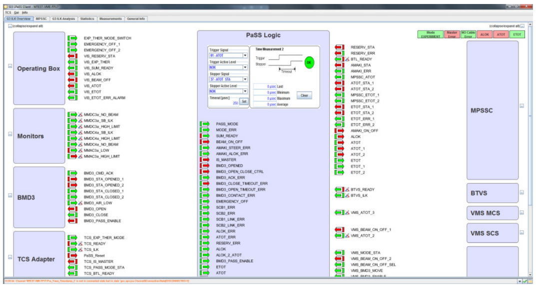


Figure 3: PaSS Adapter – GUI.

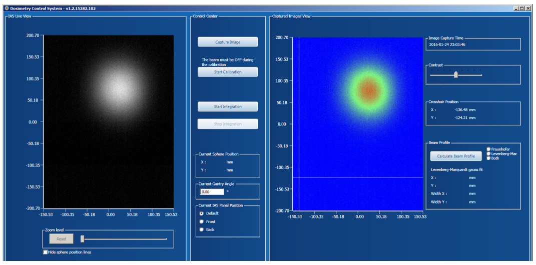


Figure 4: First beam at iso-center of Gantry 3, Jan 24th 2016.

COMMISSIONING

Gantry 3 is realized without interruption of the PROSCAN patient treatment schedule. All integration and commissioning activities acting on common safety systems or requiring beam are therefore conducted during night shifts.

The functionality of control systems, interlocks and hardware has been examined in dry run tests prior to first beam. These system integration tests allowed to identify and correct minor issues which would otherwise have caused difficulties and delays during the first beam tests. As a result, on Jan 24th 2016 the first beam has been successfully directed through Gantry 3 to the iso-center detector at the very first shot (see Fig. 4).

The Varian and PSI parts of the control system have proven to work with each other in a reliable way. Requesting specific beam energies, beam currents and switching the beam on/off via the adapter interfaces performed flawlessly.

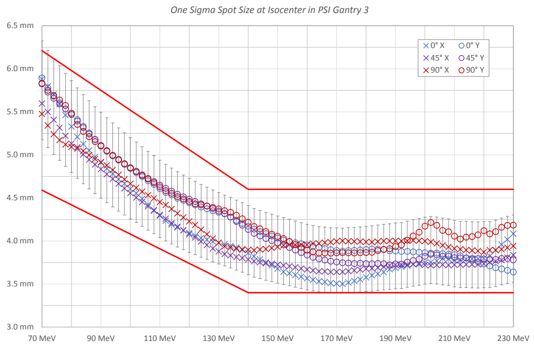
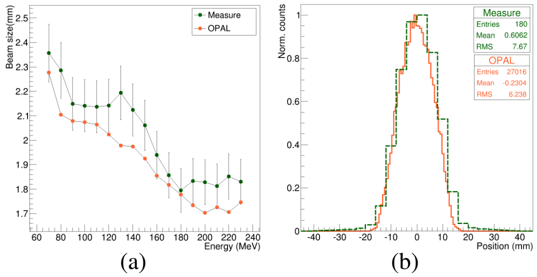


Figure 5: Measurement of the beam size at the iso-center of Gantry 3 for the full clinical energy range 70 – 230 MeV and different gantry rotation angles.

During the ongoing beam commissioning phase, optimized magnet settings are established on the Gantry. The beam optics shall be independent of gantry rotation angle, while angle-dependent corrections should solely involve the steering magnets. Beam sizes at the iso-center within the tolerance limits have been achieved for all energies 70 – 230 MeV at 0.1 MeV resolution (see Fig. 5).

The beam optics of the beamline from the COMET cyclotron to the coupling point at the entrance to Gantry 3 has been developed with various beam optics and particle tracking codes. Realistic simulations that allow for precise predictions of beam profiles, losses at collimators and transmitted intensity, are possible on the basis of a (simplified) model of the graphite degrader. The OPAL [8] framework has been used, a parallel open source C++ library for generic particle accelerator simulations developed at PSI, which combines beam dynamics with particle matter interactions.

For the intensity compensation strategy, collimators and apertures play an important role and have to be considered. OPAL includes multiple scattering, beam collimation as well as fringe field and non-linear effects and allows to precisely predict the beam profiles and intensities at various positions along the beamline up to the iso-center of Gantry 3. Figure 6a shows results of simulated vs. measured beam size at the last profile monitor before the coupling point. In this way, the beam dynamics model has been benchmarked against profile measurements, as shown in Fig. 6b.



(a) (b)

Figure 6: Comparison between the OPAL model and the beam profile measurements. (a) 1σ beam size (x/y averaged) vs. energy at the coupling point monitor. (b) Beam profile at 150 MeV at an upstream monitor.

STATUS & OUTLOOK

Gantry 3 has been successfully installed and integrated into the PROSCAN facility. The installation phase was planned in much detail by Varian and will soon be finished with the last design elements being mounted in the Gantry 3 treatment area. The control system integration and beam commissioning has progressed equally well. Nominal beam parameters have been established and the two control systems perform reproachlessly so far.

Integration and commissioning is not finished yet. Presently the scanning system as the last step of beam commissioning is under way. The imaging system, the pencil beam scanning system and the nozzle still have to be commissioned and thoroughly tested, the latter activity requiring also proper energy and dose monitor calibrations.

The commissioning phase will be finalized by a period of system validation & verification followed by acceptance tests by summer 2016. The subsequent clinical commissioning phase is the last major step towards first patient treatments on Gantry 3, anticipated for end of 2016.

In parallel to the customary project activities, an R&D programme has been established in order to reach the 200 ms energy layer switching goal. A test stand, including dipole magnet, power supply, real time control system and data acquisition system, has been set up at PSI to measure and optimize the dynamic behaviour of the magnetic field of the beamline elements for typical clinically used layer steps in the order of 1 – 3% in energy. This joint activity of Varian and PSI has lead to design improvements which will be further tested and then implemented on Gantry 3.

ACKNOWLEDGMENT

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