ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPWI016

GANTRY 3: FURTHER DEVELOPMENT OF THE PSI PROSCAN PROTON THERAPY FACILITY

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Abstract

PSI and its Center for Proton Therapy (CPT) is extending its research capabilities in the field of proton therapy and pencil beam scanning technology. Gantry 3 will be an additional treatment room at the PROSCAN facility at PSI, Villigen, Switzerland. It will feature a 360° scanning Gantry delivered by Varian Medical Systems. The Gantry design is based on Varian technology, which will be combined with advanced PSI active scanning technology.

The further development of fast energy switching as well as precise spot and continuous line scanning irradiation modes are main research topics at the PROSCAN facility. A major challenge with Gantry 3 is the link of the existing PSI PROSCAN system with the Varian ProBeam system, while retaining the system integrity and high performance level. Additionally, Gantry 3 will be installed and commissioned while keeping the other treatment rooms (Gantry 1, Gantry 2, Optis 2) in full operation.

The current development and project status is presented.

INTRODUCTION

PSI has a long-standing successful history in the development and application of irradiation technologies for treatment of cancer. With the inauguration of Gantry 1 in 1996 [1], PSI has pioneered the irradiation technique using actively scanned pencil proton beams. In 2007 the world's first 250 MeV superconducting cyclotron for proton therapy COMET was installed at PSI's PROSCAN facility [2].

Spot scanning, the proton-dose delivery technique developed at PSI is being further developed for fast re-painting and precise spot scanning on Gantry 2 [3] which is treating patients since 2013. The Optis 2 irradiation room allowing for accurate treatments of eye melanoma using passive scattering technology complements the PROSCAN facility.

PSI takes a further step by extending the research and treatment capabilities with an additional Gantry treatment room sponsored by the Swiss Canton of Zurich. Gantry 3 is realized in collaboration with Varian Medical Systems (VMS), which continues the fruitful research collaboration with Varian that has led to the development of the superconducting cyclotron COMET.

The main goal of the Gantry 3 project is to realize an additional scanning Gantry by 2016 with performance and capabilities comparable to PSI Gantry 2.

Figure 1 shows the layout of the PROSCAN facility with the cyclotron and the beam lines delivering the proton beam to the treatment areas Gantry 1, Gantry 2, Optis 2 and the new area Gantry 3. The new Gantry 3 will be installed behind a newly built extension of the existing fixed beam line for experiments.

PROSCAN BEAMLINE

Extracted beams from COMET are focused on a degrader, which can decrease the energy of the proton beams to the patient to any value in the range of $70-230$ MeV. The degrader is followed by collimators and an energy selection system to obtain a well-defined beam emittance (max.30π mm mrad), and a maximum beam momentum spread of $\pm 1.0\%$.

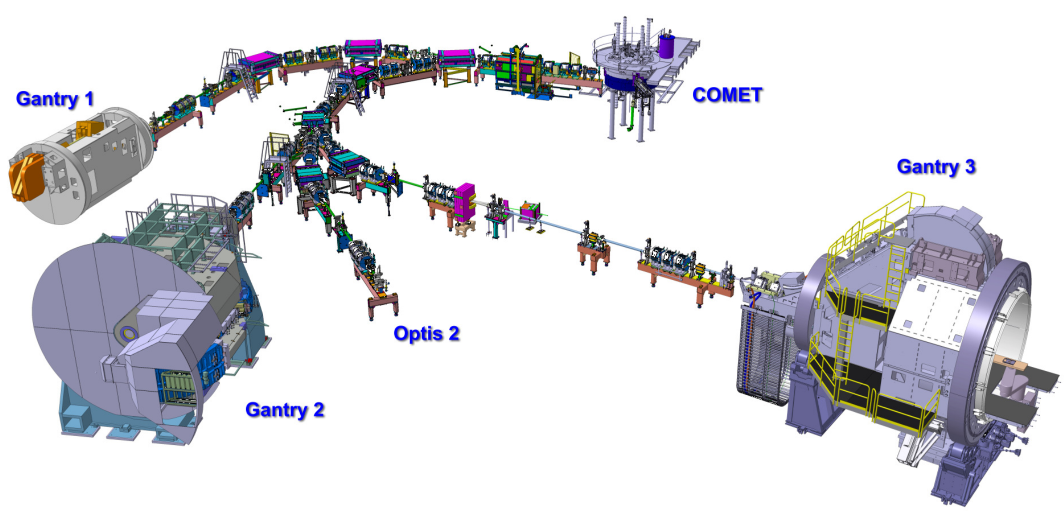

Figure 1: Layout of the PROSCAN facility beam lines including the new Gantry 3 area.

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Table 1: 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	$300 \times 400\,\mathrm{mm}^2$
Dose delivery	2 Gy/Liter/min

To modulate the Bragg peak over the tumor depth the degrader is used and all magnets in the beam line downstream of it follow these changes synchronously. A typical step of 1% in momentum is made within 100 ms.

Since the commissioning of Gantry 2 an energy dependent correction of the beam intensity at the Gantry entrance is in use (intensity compensation scheme). The transmission through the degrader system varies two orders of magnitude in the energy range 70 – 230 MeV. Therefore it is advantageous to adjust the beam intensity as a function of degrader setting, to treat the patient with an almost energy independent beam intensity of typically 0.5 – 1 nA.

The obtained intensity has shown to be very reproducible, therefore the intensity compensation scheme has become an integral part of the standard beam line settings to Gantry 2 and a similar method will be applied for Gantry 3.

Figure 2 shows the beam optics along the PROSCAN beam line in the direction of Gantry 3 simulated in TRANSPORT software. The horizontal axis represents the z-position along the beam from cyclotron to coupling point. The vertical axis above zero indicates $2\sigma_y$ vertical beam size (green), below zero indicates $2\sigma_x$ horizontal beam size (blue). The red dotted line shows the dispersion trajectory for a momentum offset of $\Delta p/p = 1\%$. Two pairs of dipole magnets form achromatic bending sections, up- and downstream of which the beam dispersion is zero. The intensity compensation for the higher energies is partially performed by defocussing the beam on the collimators before and after the degrader (shown in light green).

A circular collimator at the coupling point to the Gantry makes sure that an unwanted beam misalignment, wrong

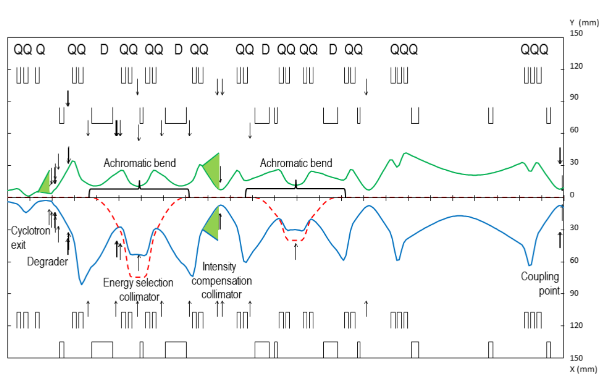

Figure 2: Simulated beam optics of the PROSCAN beam line up to the coupling point of Gantry 3.

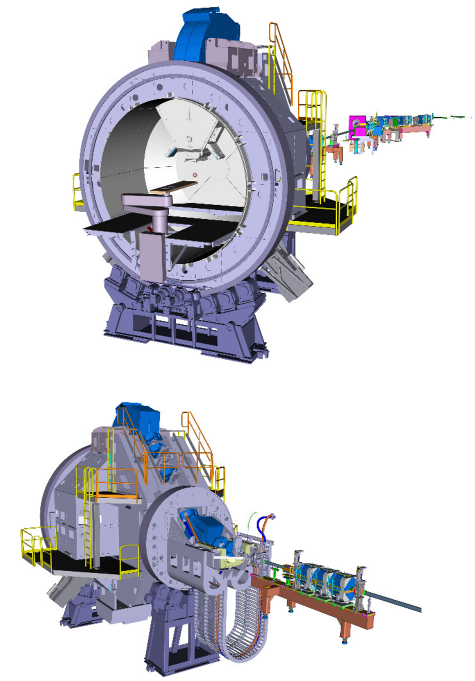
Figure 3: Front and rear view of Gantry 3.

focusing or beam asymmetry only causes a change in beam intensity (dose rate) at the patient and not an error in the location of the dose delivery.

GANTRY 3

Mechanically, Gantry 3 is an implementation of the ProBeam Gantry by Varian [4]. It rotates full 360° and has a total weight of 270 t. The rotating parts have an envelope diameter of 10.5 m and a length of 10 m. The beam is deflected from the rotational axis by a 45° dipole and bent towards the iso-center through a 135° dipole. Five quadrupoles and three orbit correction magnets are used to set the beam optics. Two additional quadrupoles have been introduced at the entrance to the Gantry in order to facilitate beam matching between the PSI and VMS beam lines and to enhance the transmission through the Gantry beam transport system.

Gantry 3 is a downstream, divergent raster scanning system. The scanning magnets are placed after the last 135° dipole and allow maximum field sizes of 30×40 cm.

One major goal for Gantry 3 is to achieve overall system performance comparable to Gantry 2. Table 1 lists the main performance parameters of Gantry 3. One goal of the development collaboration with Varian is an energy layer switching time of 200 ms. This includes modifications on the beam line hardware as well as adaptions and new developments on the control system side.

Gantry 3 will be equipped with a 360° co-rotating X-ray system. A further collaboration development effort is the upgrade of the X-ray system to a cone beam CT (CBCT).

Figure 3 shows a visualization of Gantry 3 including the beam lines and the patient positioner.

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CONTROL SYSTEM INTEGRATION

The challenge for the control system integration is to merge two quite different worlds, namely Varian's ProBeam scanning system and PSI's existing control and safety systems. The PSI systems ensure that during therapy sessions exclusive access to accelerator and beam line components is granted to just one room. The safety system relies on central components for the logic and for the final elements to switch off the beam (e.g. cyclotron RF, ion source, beam blockers in the central part of the beam line). The Varian scanning system needs access to these components to control the beam during scanning and in case of an interlock.

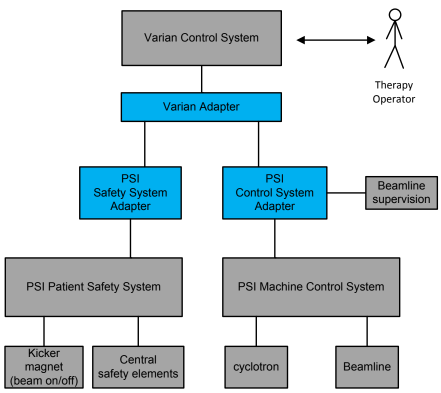

Figure 4: Gantry 3 controls architecture.

The chosen architecture leaves most of the existing systems untouched, but connects them with newly developed interfaces, see Fig. 4. The Varian system controls the scanning (scanning magnets, dose monitors), positions the Gantry and patient table and sets the beam line on the Gantry itself. The PSI systems control the upstream part of the beam line, the cyclotron and the central components of the PSI safety system. On PSI side two interface components are added, the TCS and the PaSS adapters:

TCS adapter: Communicates with the Varian system over a network API and serves as a gateway to PSI's machine control system. Typical commands are requests for treatment room reservation, beam energy and intensity. It also supervises the correct setting of the energy selection system. The adapter is implemented as a VME system with a Motorola SBC running VxWorks.

PaSS adapter: The hardware interface between Varian and PSI, transmitting signals like beam on/off and interlocks. It makes the connection to the central components of PSI's safety system. Besides providing the electrical conversions it contains logic supervising the safety status of the facility, ie. it can trigger interlocks. The logic is implemented on the IFC1210 FPGA controller developed jointly by PSI and IOxOS Technologies [5].

CIVIL ENGINEERING TECHNICAL INFRASTRUCTURE

The relocation of a mechanical workshop and experimental test stands to free the space for Gantry 3 marked the beginning of the civil engineering works. All dusty construction works (excavation of the Gantry 3 pit) were executed under a low-pressurized tent, to avoid dust emissions on sensitive user's equipment in normal operation in the experimental hall. Figure 5 shows the area during construction works in summer 2014.

Figure 5: Gantry 3 civil engineering works.

As far as possible the infrastructure has been installed up to the interface points with the Varian systems. The electrical supply required upgrade to a new transformer station including a new medium voltage switchboard. The existing cooling circuit was adjusted and a new air conditioner installed for the HVAC system. The access and safety system was extended and tested to include the new area.

STATUS & OUTLOOK

The Gantry 3 project is well on track. The major civil engineering work and installation of technical infrastructure was completed at the end of 2014. Commissioning the beam line up to the coupling point has been the focus in early 2015 and is currently being finalised.

In a next step, the area will be prepared for the installation of the Varian Gantry, to be delivered to PSI in July 2015. The mechanical installation will take place in parallel to the integration and initial tests of the control system.

With all sub-system in place, the technical commissioning and system performance tests of the complete Gantry 3 can start in late 2015. The clinical commissioning will be the last phase before patient treatments can start at the end of 2016.

ACKNOWLEDGMENT

We would like to thank the Varian team engaged in the development and realization of Gantry 3 for the fruitful and beneficial collaboration and their great commitment.

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