THE SUPERCONDUCTING CYCLOTRON AND BEAM LINES OF PSI'S NEW PROTON THERAPY FACILITY "PROSCAN"

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Abstract

The PROSCAN project involves a major expansion of the proton therapy program at PSI into a facility consisting of a dedicated 250 MeV superconducting cyclotron, new beam lines to the existing gantry, to a new gantry and to a new area for eye treatments. Quick beam-energy changes for range modulation are possible with a fast degrader and laminated magnets in the beam line.

This year the cyclotron has been shipped to PSI and is now ready for commissioning. Most of the components of the beam lines are ready for installation and the first beam-line section with the degrader is ready for beam. Here a brief overview of the facility is presented.

INTRODUCTION

A major disadvantage of the existing proton therapy facility at PSI is the parasitic use of the beam from the large 590 MeV proton cyclotron in a multi-user environment, with shut down periods of about four months per year. Therefore PSI decided to expand the proton therapy activities and launched the so-called PROSCAN project. The project's objectives are: 1) further development of the PSI Spot-Scanning technology into a new Gantry, which can be implemented in a hospital environment (i.e. with faster scan methods to deal with the organ-motion problem), 2) optimisation of the treatment methods, including treatment of mobile tumours, and 3) transfer of the technology and of the know-how to industry and to radiation therapy centres, including education and training of specialised personnel.

The new facility (fig. 1) consists of a dedicated cyclotron, energy degrader, beam lines, therapy equipment (the currently existing gantry, a new gantry and a new eye treatment facility) and a beam line for experiments. It has been designed to be capable of providing reliable stable beams of varying energy during the whole year.

In May 2001 PSI signed a contract for the delivery of the 250 MeV superconducting cyclotron COMET. The cyclotron is based on a design of H. Blosser, NSCL, (USA) and has been manufactured and delivered by ACCEL Instruments GmbH (D) to PSI this year (2004).

FACILITY LAYOUT

The whole facility has been built within an existing PSI experimental hall. Where possible, use is made of moveable concrete elements, so that crane access is possible at all sites. An important boundary condition

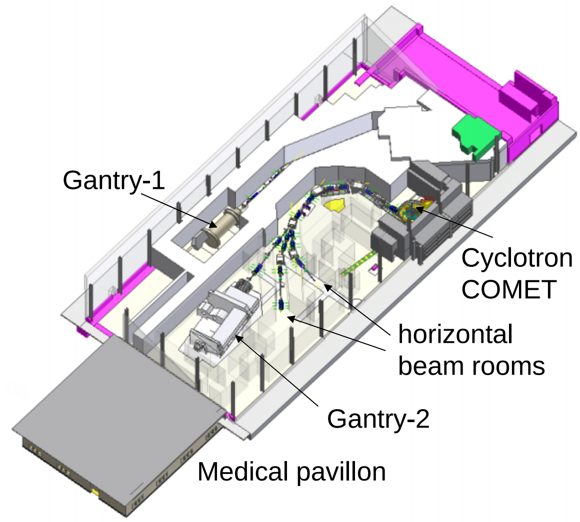

Figure 1: Layout of PSI's new dedicated proton therapy facility *PROSCAN*. Gantry-1 and Gantry-2 are the existing and the new gantry, respectively.

during the various construction phases is the continuation of the program of the existing gantry, which is located in the same hall. The patient treatment program with the existing gantry will continue until the end of 2005, using the beam from the 590 MeV cyclotron.

The beam extracted from the new cyclotron, will be adjusted onto the axis of the beam line with two xy-steering magnets. A quadrupole triplet focuses the beam onto a degrader, which has been designed for fast beam-energy changes. In order to limit the emittance of the degraded (and scattered) beam, and to define the acceptance of the beam transport system, the degrader is followed by two collimator systems. Behind the collimators, an analysing system selects the beam momentum, with a maximum spread of ±1.2%. The analysing magnet together with the momentum selection slit are part of an achromatic beam transport system, so that the beam transport to the treatment room is almost insensitive to small deviations from the nominal magnet settings. A point-to-point imaging with intermediate images transports the beam to so called *checkpoints* at the entrances of the user areas. The beam optics has been designed such that the lens settings are independent of the specified beam characteristics. All magnet settings scale similarly with beam energy, which can be done sufficiently fast by using laminated magnets. The beam size is set by the collimator apertures only.

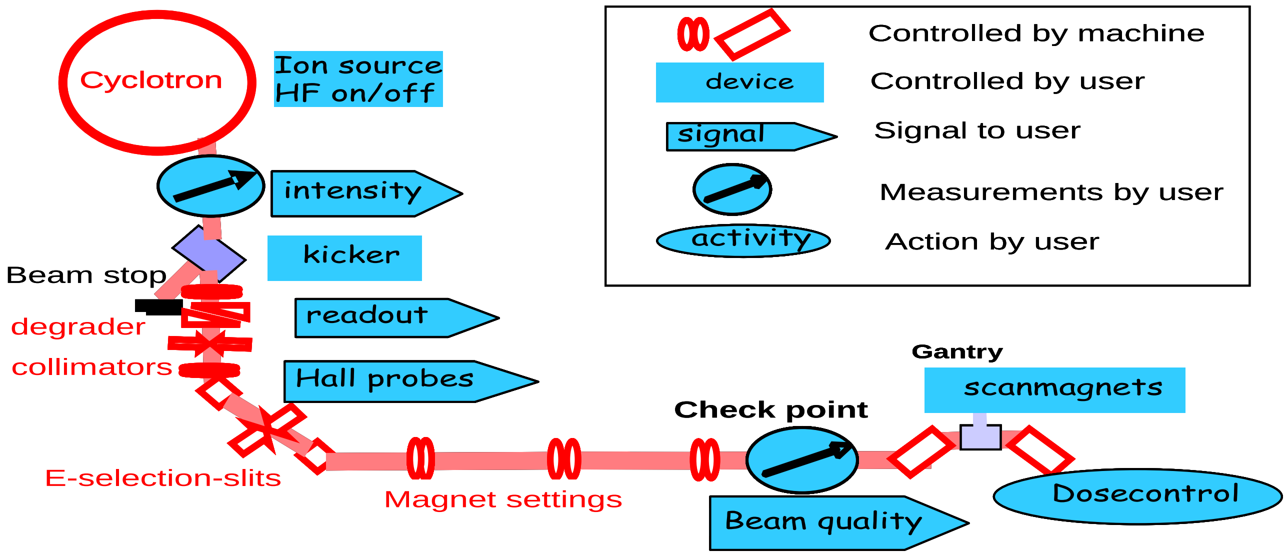

Figure 2: The separation of responsibilities between the "machine" and the "user" is an important design aspect in the PROSCAN facility.

During a test phase, the reliability and performance of the cyclotron will be evaluated using a beam line up to the entrance of the new gantry area. A research program to test new beam-scanning concepts, dedicated dosimetry equipment for beam scanning, and control aspects will also be carried out in this phase. At the end of 2005, the existing gantry will be connected to COMET. Shortly after that, the installation of the new gantry and the eye treatment room will commence.

SHARING OF RESPONSIBILITIES

An important design aspect in PROSCAN is a rigorous separation of the cyclotron and beam lines from the treatment equipment. This decouples the tasks and responsibilities of the "machine" as beam delivery system and a "user" who decides whether the beam is accepted or not for a treatment. Before each treatment room, a so called checkpoint has been defined, where the beam should comply with specifications on energy, position, direction, emittance and intensity. For each beam energy, the "machine" will use a predefined setting of the beam line (a "tune") and, by means of collimators and dedicated beam diagnostics at the checkpoint (plus dedicated read back from energy defining elements), the user has to verify if the beam characteristics satisfy the user's needs (fig. 2). This separation is also present in the control system architecture. A "Machine Control System" (MCS) controls the accelerator and beam lines and it only checks the machine performance itself. Each user area has its own "User Control System" (UCS), which decides to take the beam or not. Each UCS communicates with the MCS via an allocation system. When the beam is allocated to a certain user area, its UCS will obtain the so called "mastership" over the facility. The Master-UCS will then ask the MCS to set a tune and independently of the MCS it will start, verify, use and stop the beam.

COMPONENTS

Cyclotron

The cyclotron COMET has been designed to deliver 500 nA of 250 MeV protons. An important specification is the high extraction efficiency (>80%), to minimize the amount of radioactivity in the machine. This aspect is important for the other important specification, a high availability, similar to normal radiotherapy equipment. An intensive collaboration between ACCEL and PSI, led to a design that aims to fulfil these requirements.

Design aspects are e.g. extensive diagnostic tools in the HF system. All cooling circuits in the cavity are separately monitored with a flow switch and a temperature sensor. Furthermore, the exchange of service-sensitive components has been made relatively easy, and in the commissioning phase the last iteration steps will be done after exercising with PSI's service staff.

We expect that, in addition to the advantages of the high magnetic field from the superconducting coil, a stabilization of the room temperature and a relatively low temperature rise in the cavity cooling-circuits, will lead to a very reproducible magnetic field, which is a primary requirement for the reproducibility of the beam line tune.

The (micro-)spark detection circuits [1] in the low level part of the HF-amplifier, are provided by PSI and operate analogous to those for the 590 MeV cyclotron. Due to the possibility of distinguishing so called micro-sparks from larger discharges, the HF need not switch off completely at every spark. It is expected that this will also enhance the availability of the beam. A rigorous set of acceptance tests will start in the fall of this year. In addition to the beam and technical parameters, also aspects regarding service and availability will be subjected to tests.

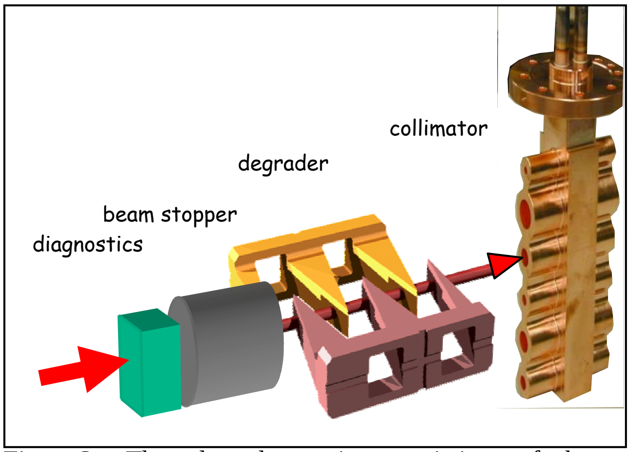

Figure 3: The degrader unit, consisting of beam diagnostics, a mechanical beam stopper, the degrader pair of multi-wedges and a collimator system.

Degrader

In the new gantry, a fast beam-scanning technique in three dimensions will be applied: two lateral scans by fast steering magnets and one scan in depth by adapting the beam energy. This will be accomplished by a degrader and laminated magnets in the beam transport system. A range change of ~5 mm in water (this corresponds to a beam-momentum change of ~1%) has to be set within 50 ms. The degrader consists of a pair of multiple wedges, (fig. 3) covering a energy setting in the range of 70-238 MeV. It has been mounted in a vacuum box, which also contains a beam stopper (before the degrader) and a beam size defining collimator, immediately behind the degrader. To allow short service times, but also because these components and material in their environment will become radioactive, special handling tools and transport systems have been constructed. The need to limit the radioactivity due to activation has led to a careful choice of materials and a minimization of the amount of material.

Beam interruption concept

The beam will be switched on and off by the user. In a first phase of the project, the main switch will be a fast kicker magnet that can deflect the beam within 50 µs. In a later phase, use will be made of a deflector mounted in the cyclotron center. When activated, this will stop the beam in the first few orbits. For longer interruptions, also the HF will be set to a reduced power. Since then no beam is accelerated, excessive activation is prevented. Furthermore, for safety reasons, the ion source must be switched off before staff can enter the vault.

Beam diagnostics

Several beam diagnostic systems will control the beam parameters in the different modes of operation. Ionisation chambers and secondary emission monitors will be used as current monitors and, in a multi-strip configuration, as profile monitors for the beam lines. Thin monitors, which will always be in the beam, will be used for continuous measurements and “thick” monitors will be inserted in the beam for tuning purposes only. To prevent a patient treatment with a monitor still left in the beam, the thickness of these monitors has been chosen such that the beam cannot reach the patient.

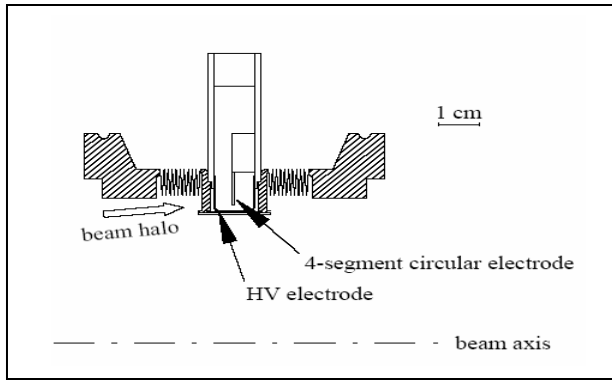

Figure 4: Sketch of the Beam-halo monitor

Beam-halo monitors (fig. 4) will be placed at locations in the beam line where the beam size is large. These devices are integrated in special bellows in the beam line. They provide a very sensitive indication for detection of beam-positioning errors.

For fast measurements of the beam energy and momentum spread, a multi-layer Faraday cup has been developed and tested. A copper version will be mounted on an actuator in the beam line and an aluminium version will serve as a “table-top” device for the commissioning of the cyclotron and degrader.

New VME-based electronics for the diagnostics have been developed. Remote verification whether the detector is intact is possible via the connected electronics. In order to allow quick access and minimal deterioration due to radiation damage, all electronics are placed outside the vaults.

CONCLUSIONS AND OUTLOOK

A prototype facility for hospital based proton therapy is under construction at PSI. The design especially aims for a high availability of the system. We expect to start tests with beam in the beginning of 2005.

We would like to acknowledge the ACCEL crew for the very fruitful and open collaboration and the PSI staff for the enthusiastic involvement.

REFERENCES

[1] P.Sigg et al., Proceedings of the RF Systems Users Group Meeting APS, Argonne National Laboratory, March 2002