FIRST YEAR OF OPERATION OF PSI'S NEW SC CYCLOTRON AND BEAM LINES FOR PROTON THERAPY

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Abstract

At PSI's Center of Proton Radiotherapy the worlds first SC cyclotron for proton therapy and new beam lines have been commissioned and patient treatments have started in February 2007. An extensive measurement program has been carried out to study the characteristics of the cyclotron and the beam lines. We report on the acceptance tests and the first year of experience with the cyclotron and the beam lines.

INTRODUCTION

A new stand-alone proton therapy facility started patient treatment at PSI in February 2007. The heart of the new facility is a novel 250 MeV superconducting cyclotron. Originally designed at NSCL (MSU), it was built by ACCEL instruments GmbH (Varian), in close collaboration with PSI. The collaboration ensured that the stringent medical and operational requirements could be achieved. An intensive program of beam commissioning and acceptance tests of cyclotron and beam lines confirmed that essential specifications had been met, including high extraction efficiency (>80%), fast (kHz) beam-intensity control, reliability and efficient maintenance. Dedicated beam diagnostics and control systems have been developed to provide high performance quality and safety. Patients are now being treated at *Gantry-1.* The facility is planned to be completed in 2008.

LAYOUT AND PERFORMANCE

The PROSCAN facility (fig. 1) has been built within an existing experimental hall at PSI in which Gantry-1 had been using the beam from PSI's 560 MeV ring cyclotron. The extracted beam from the cyclotron is focused onto an energy degrader that sets the beam energy between 70 and 250 MeV. In order to obtain a well defined beam emittance behind the degrader, it is followed by collimators and an analyzing system (dp/p < ±1%). The beam is then transported to the existing Gantry-1, or to a new Gantry-2 [1], or a new eye treatment room OPTIS-2, or a vault for experiments.

Cyclotron acceptance tests

After the delivery and commissioning, the cyclotron had been subject to a rigorous test program. In 2004 PSI had defined 37 acceptance tests. In December 2006, 33 of the tests had been performed successfully, and PSI could formally take over of the cyclotron. These tests and the final commissioning of the cyclotron were performed in close collaboration with the ACCEL team. Apart from many tests on beam characteristics also the reliability of the cyclotron was tested. As an example, figure 2 shows the number of unscheduled beam interrupts of different lengths, during a 10 hours run. The number of long interrupts (2) and the total time without beam (3 min.) were well within the specifications.

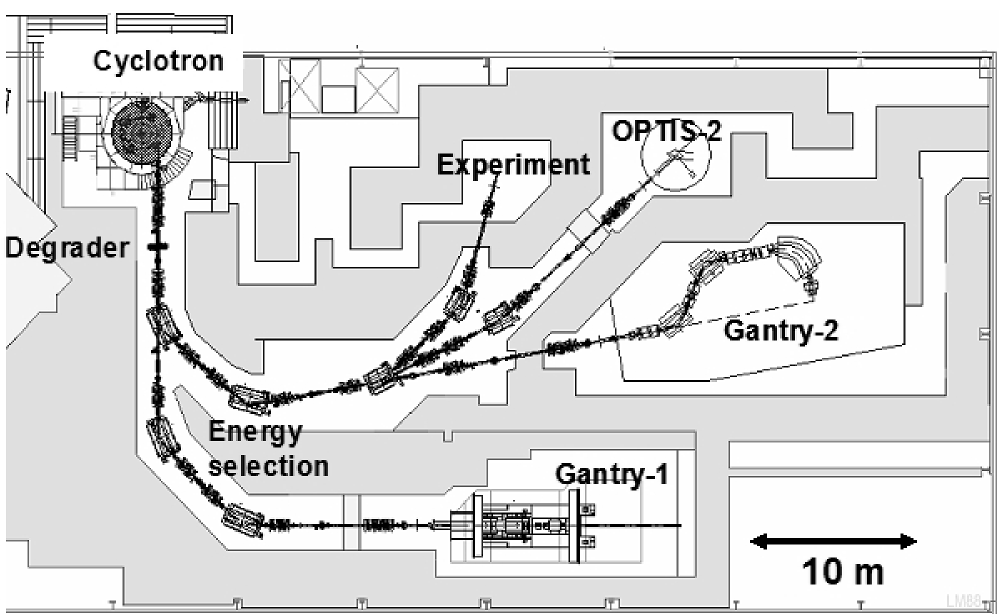

Figure 1. The proton therapy facility at PSI, with the SC cyclotron and beam lines to three treatment areas and one area for experiments.

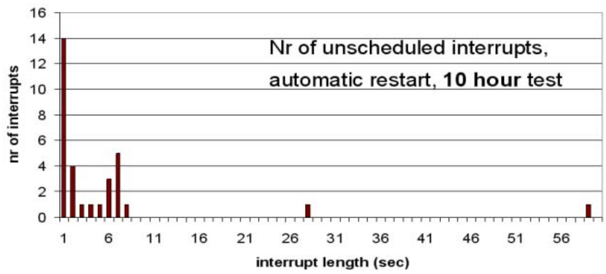

Figure 2. Unscheduled interrupts during a test of 10 hours running time.

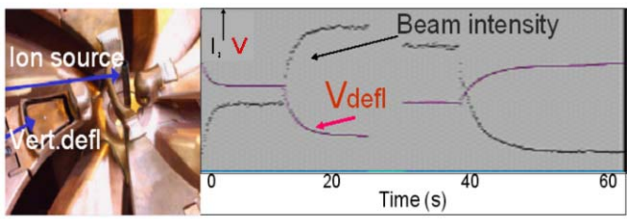

Figure3. The vertical deflector used for intensity control and beam on/off switching.

A vertical deflector in the centre of the cyclotron can be used for beam-intensity control (fig. 3) or as a fast on/off switch (40 μs). In order to allow fast intensity modulation at the new pencil beam scanning technique applied in Gantry-2, sufficient stability of the beam intensity at kHz bandwidth has been achieved in a dedicated program [2].

An important property of the cyclotron is the high extraction efficiency (>80%). After one year of operation, this has paid off in a low activation of COMET amounting to only a few mSv/h immediately after 500 nA and <0.4 mSv/h, after 24 hours without beam (extracted total beam integral 72 μA.h). This considerably simplifies maintenance work.

Beam transport

The beam optics is based on a point-to-point imaging with intermediate images from the degrader exit to "checkpoints" at the entrances of the four areas (fig. 4). There beam diagnostics is checking crucial beam parameters on-line. The beam optics has been designed such that all magnet settings scale similarly with the beam energy.

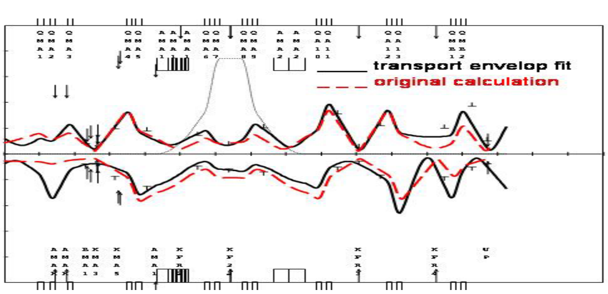

Figure 4. Calculated [3] and measured beam envelopes and dispersion (dotted) of the undegraded 250 MeV beam. Above the horizontal axis the vertical beam size is shown, below indicates the horizontal beam size. The "T" symbols indicate the measured beam widths.

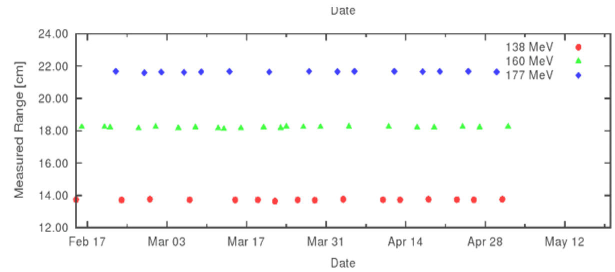

Figure 5. Results of the daily QA checks of ranges of 138 MeV, 160 MeV and 177 MeV protons at Gantry-1. The measured ranges are constant within a standard deviation of 0.3 mm, 0.4 mm and 0.4 mm (courtesy Jürgen Salk).

Technically beam switching between the areas can be done within a few seconds. Presently, however, the interface for the users of the control system is still under development to acquire more practical experience, so that safety checks and actions to be taken by the operators still need a few minutes.

Degrading the beam energy

Figure 5 shows the very good reproducibility of the measured proton range in water for three proton energies, which indicates an energy reproducibility of σ<0.05% (cyclotron energy and magnet settings).

To enable rapid variation of the proton range for new fast pencil-beam scanning techniques, the degrader and the beam-line magnets have been made to allow energy changes of 2%, corresponding to 5 mm range change in water, in 50 ms (fig. 6). The large multiple scattering in the degrader, allows an optical decoupling at the degrader so that the beam size is set by the collimator apertures only. Due to the increase of multiple scattering with energy degradation, the accepted beam intensity decreases with decreasing energy (fig. 7). For OPTIS-2, where the treatment time is limited to ensure an accurate treatment, this required a novel design of the eye-treatment nozzle for an efficient use of the beam intensity.

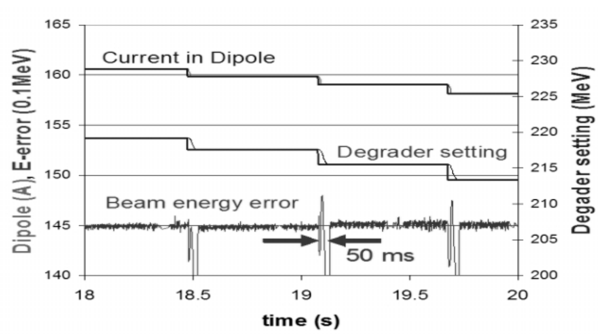

Figure 6. A fast sequence of beam energies is shown. The energy set by the degrader is given on the right axis and on the left axis the magnet current in the analyzing magnet and the beam position at the dispersive focus are shown. The latter has been expressed as the energy mismatch in units of 0.1 MeV (displayed with an offset of 145 MeV). During an energy change the beam is switched off, causing the wiggles in this signal.

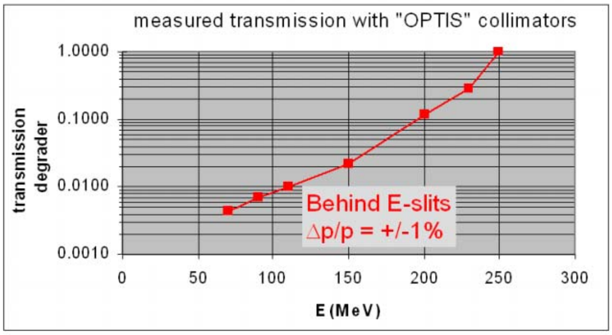

Figure 7. Measured transmission from cyclotron exit to treatment room as a function of energy.

This design is based upon a novel dual scattering technique. Using a multi-ring foil as a second scattering foil (fig. 8), the proton beam will be used 20-50 times more efficiently than in the current OPTIS setup. Therefore, despite the much lower beam intensity, we can keep almost the same treatment times as before.

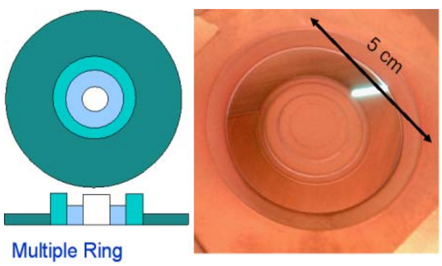

Figure 8: A foil consisting of multiple rings is used as second scattering foil (courtesy Marc-Jan van Goethem). The foil is made by laser ablation at the Fachhochschule Aargau (CH).

OPERATION EXPERIENCE

Although the facility has been running too short to collect accurate statistics, the operation experience allowed to draw some preliminary conclusions on the availability and identification of the major problems. The availability of the system has been defined as: 1-UDT/UT, in which UDT is the unscheduled down time, during which no beam was available for patient treatment and UT is the total amount of hours that the cyclotron and beam line were ready to deliver beam or did deliver beam (defined as HF on and source on). Due to a planned shut down in June 2007, in order to connect the beam lines to Gantry-2, OPTIS-2 and the experimental area, as well as due to the cautious start-up, only 18 patients have been treated until the end of May 2007. However, since the machine was on between the patient treatments, statistics could be collected over a substantial amount of machine hours (UT=961) and an availability of 95% was obtained for the cyclotron and beam lines. Figure 9 shows the uptime and availability per week and figure 10 shows the systems that caused the 5% unavailability. Some mechanical problems occurred in a HF-power transformer and there were cooling water problems due to parallel installation activities.

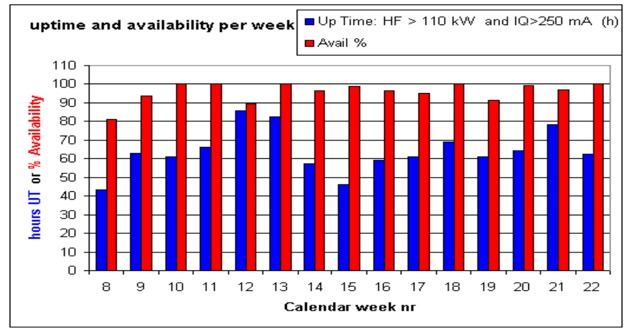

Figure 9. Uptime and availability of the cyclotron and beam lines during the first 15 weeks of patient treatment at Gantry-1

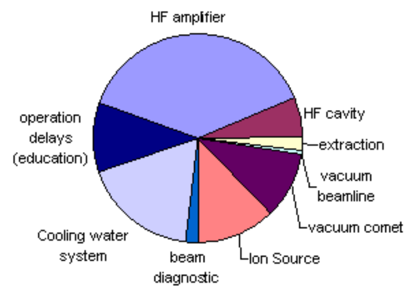

Figure 10. The subsystems causing unscheduled down time during the patient treatment period Feb.-May 2007.

Another important cause of down time is the learning curve of the PSI operation crew. It is remarkable that most of the problems have occurred in the auxiliary devices and not in the cyclotron itself. Also the big problems were always recognized in the early morning, before patient treatment had started.

The cyclotron is started up within 15-30 minutes every day around 4 AM, to allow ample time to react on problems and to reach a stable operation mode when the daily QA-checks are made at 6:30 AM. During day time the few operator interventions are related to slight corrections of the drifting magnetic field of the cyclotron, caused by heating of the magnet by the HF cavity.

After the recommissioning program following the planned shutdown, patient treatment at Gantry-1 has resumed in August 2007. Installation and commissioning of the other areas are in progress and expected to be completed by late 2008.

ACKNOWLEDGEMENTS

We would like to thank the ACCEL/Varian crew for the excellent collaboration during the installation, commissioning and acceptance of the cyclotron.

REFERENCES

[1] E. Pedroni et al., Z. Med. Phys. 14 (2004) 25-34
[2] J.M. Schippers et al, these proceedings
[3] PSI Graphic Transport by U. Rohrer based on a CERN-SLAC-FERMILAB version by K.L. Brown et al.