A CONTROL SYSTEM FOR THE ESRF SYNCHROTRON RADIATION THERAPY CLINICAL TRIALS

C. Nemoz, G. Berruyer, T. Brochard, Hervé Gonzalez, Ricardo Hino, M. Renier and P. Berkvens, ESRF, Grenoble, France
H. Elleaume, INSERM, Grenoble, France
J.F. Adam, UJF, Grenoble, France

Abstract

The bio-medical beamline of the European Synchrotron Radiation Facility (ESRF) located in Grenoble, France, has recently started the Phase I-II Stereotactic Synchrotron Radiation Therapy (SSRT) clinical trials targeting brain tumours. This very first SSRT protocol consists in a combined therapy where monochromatic X-rays are delivered to the tumour pre-loaded with high Z element. The challenges of this technique are the accurate positioning of the target tumour with respect to the beam and the precision of the dose delivery whilst fully assuring the patient safety. The positioning system used for previous angiography clinical trials has been adapted to this new modality. 3-D imaging is performed for positioning purpose to fit to the treatment planning. The control system of this experiment is described from the hardware and software point of view with emphasis on the constraints imposed by the Patient Safety System (PASS).

INTRODUCTION

The ESRF ID17 beamline is dedicated to investigate the medical applications of x-rays produced by an electron synchrotron. A 1st clinical trial took place during period 2000-2003 and was dedicated to coronary angiography [1]. The technical success of the trials has shown that it was possible to treat a patient with very good patient safety and patient comfort conditions. The medical interest was then oriented to exploit the special properties of synchrotron x-rays to radio-therapy. Nowadays the gold standards to treat deep cerebral tumours are based upon MV accelerators producing a quasi-uniform photons spectrum coupled with chemotherapy. It was proposed by the medical community to adapt the existing ID17 imaging system to Stereotactic Synchrotron Radiation Therapy [2],[3],[4].

SSRT PRINCIPLE

SSRT consists in loading the brain tumour with a high atomic number element, such as iodinated contrast media and irradiating it with the monochromatic x-rays beam tuned at an optimal energy in stereotactic conditions (the patient is rotated in the beam). The high-Z element selectively accumulates in the tumour tissue through the locally impaired blood brain barrier. The highly conformal irradiation geometry and the increase in the photoelectric cross sections produce a localized dose enhancement restricted to the tumour. This leads to improved dose distributions when compared to conventional high energy treatment. The patient is sitting on a positioning device (PPS) developed for the coronary angiography trials [5] as shown on Fig. 1.

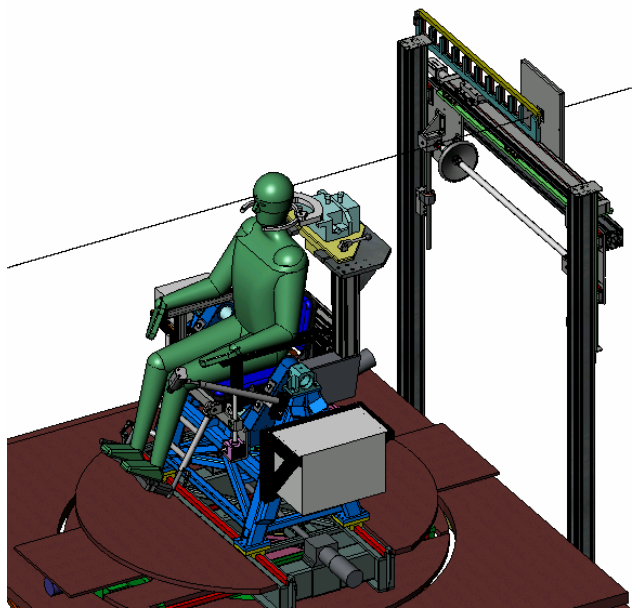

Figure 1: SSRT principle.

The patient can rotate in the horizontal plane and the positioning adjustment is made by X, Y axis located above the rotation plate. The whole platform can move vertically in such a way the photon beam sweeps the patient. The dimension of the photon beam at the patient level is 150x2mm^2. A set of 10 Cerobend collimators are aligned upstream of the patient in such a way conformal irradiation is possible. For each collimator, the lateral Y position and an angular position defines an irradiation "port", according to a pre calculated conventional treatment planning. 36 switches located under the rotating platform permits to ensure that the angle is correctly set in correspondence with the Y position.

CONTROL SYSTEM

To achieve a patient treatment at a synchrotron the control system must be robust and user friendly.

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Software Environment

The ESRF standards TACO/TANGO device servers have been used to build the control system. The experiment sequencer has been written in SPEC [6] and is driven by a Graphical User Interface (GUI) developed in Python/Qt with the help of the ESRF Framework system. An example of the GUI panel is presented on Fig.2

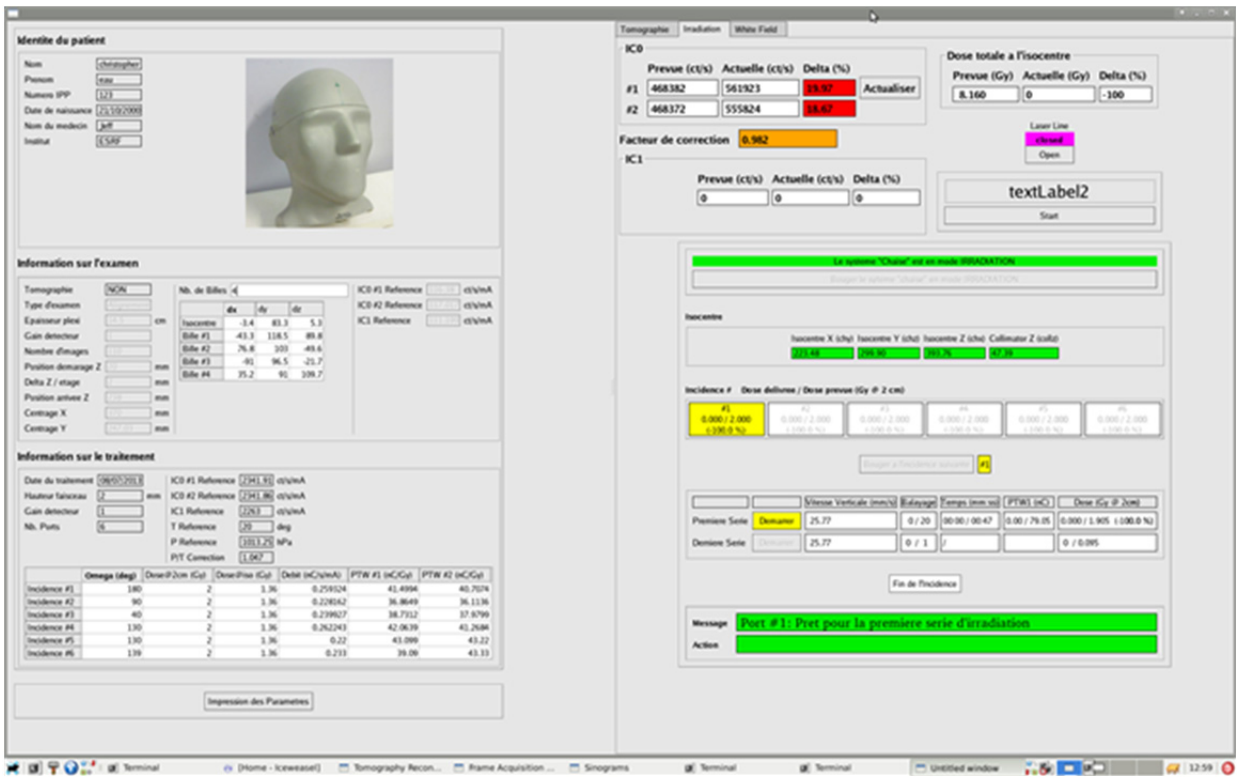

Figure 2: The Graphical User Interface used to perform the patient irradiation.

The low level software to control the PPS is hosted on PLCs and is based upon basic system designed by the Trio Motion System Company. The Patient Safety software interface is located on MUSST IO modules designed at ESRF. These modules are measuring the dose rate and the speed of the chair by means of counter encoders at low and high frequency. The two outputs are sent to the PASS.

Experiment Components

The PPS can operate either in Imaging mode or in Irradiation mode. The Imaging mode permits to perform 3D scanner of the patient head for alignment purpose. The patient is rotated at 90 degrees per seconds and the photons are collected by a one-dimensional germanium semi-conductor pixel detector in synchronisation with the rotation. To achieve the record of the full volume, the patient is also translated vertically at each turn of the PPS. The incident beam is monitored by ionisation chamber (IC0) and can be open and shut within 15 ms time. The vertical axis of the PPS must be laterally displaced during this tomography in order to perform "half- acquisition" on 360 degrees. Indeed, reconstructing the images on 180 degrees permits to virtually double the field of view of the detector from 150 to 300 mm which correspond to a standard human head. Switching from imaging position to irradiation centred position takes almost 5 minutes. In irradiation mode, the collimator tray is moved up on a vertical axis connected to the chair platform in such a way the collimator is centred in front of the tumour isocenter. Some limit switches ensure that the collimators are present and are well positioned. During the irradiation the germanium is collecting the residual photons in such a way the real delivered dose can be estimated spatially. Some dedicated gaseous transparent and calibrated chambers (PTW) permits to measure the dose entrance into the patient.

EXPERIMENT SEQUENCE

The parameterisation of the control system is performed by a dedicated GUI: The treatment planning, the positions of the isocenter, the number of images are entered in the system at this level. This application is then closed and in normal case is not reopen anymore for this patient. The operation application is the open. All the parameters are displayed but cannot be modified at this level. The precise dosimetry measurements and the pre-alignment of the PPS are performed the morning before the arrival of the patient. When these operations are completed, all the motors and devices which are physically controlling the beam characteristics are switched off. A signal is then sent to the PASS to confirm this switch-off.

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Imaging Sequence

The PPS is positioned in Imaging mode. As soon as the patient enters the experimental hutch, the PASS keys are turned from "Test" mode to "Patient Imaging" mode. The hutch is then searched and closed. The software operator initiates the sequence and the control system is then waiting for external events. The safety officer pushes the "Acknowledge Stable Beam Button". The slow shutters are open automatically, the PPS is brought to start position and the start button dedicated to the medical doctor is enabled. When this button is pushed, all the sequence is executed until the end of Imaging. The operator reconstructs the 3D volume and a system of external markers permits to establish the coordinates of the isocenter within the frame of the PPS. The system is then brought to the isocenter irradiation position, and the hutch is again searched and closed. The X,Y alignment motors of the PPS are then switched off. A new imaging sequence is initiated for only one slice to confirm that the isocenter position has been reached. The PPS is then brought to the irradiation position for the 1st irradiation port.

Irradiation Sequence

During the movement of the system, the injector is prepared and the PASS system is positioned from "Patient Imaging" mode to "Patient Irradiation" mode. The hutch is the searched and closed. The software operator initiates the sequence and the control system is then waiting for external events. When the safety officer pushes the "Acknowledge Stable Beam Button", the intensity (ImA) of the storages electron ring is measured and the vertical speed and the number N of sweeps are computed as a function of ImA. The slow shutters are open, the patient is injected thanks to the injector remote control and the permit is given to the medical doctor to push the start button. When the system is started, a series of N-1 vertical sweeps is performed to deliver the major part of the dose. At the end, the dose is measured on the PTW and the system is then adjusted to complete the dose delivery with a newly computed speed for only one or two sweeps. The irradiation for one port lasts almost 2 minutes; the total sequence lasts 30 minutes. The patient does not stay in the hutch more than 45 minutes.

PATIENT SAFETY SYSTEM - PASS

The PASS logic is divided in 3 units, the slow safety unit, the low frequency monitor and the high frequency monitor.

Slow Safety

The slow safety units deliver the permit to the medical doctor push button and check the following things:

- The motors and devices are switched off
- The collimators are IN/OUT depending Imaging or Irradiation mode
- The collimators horizontal and the PPS rotation angle position correspond
- The position of the PPS is in Imaging or in Irradiation mode.
- The hutch is closed
- The "Acknowledge Stable Beam Button" is pressed
- The MUSST modules has returned a "ready" status.

Low Frequency Monitor

The low frequency monitor will enable the permit for the last sweep dedicated to dose fine adjustment and check the following things on the MUSST with a 20 ms sampling time:

- Chair vertical/rotational speed within +- 2%
- Dose rate within -10% +2%.
- Vertical displacement of the PPS during Imaging.

In addition the integrated dose will send a signal if the measurement on the PTW exceeds 2%.

High Frequency Monitor

The high frequency monitor will close all the shutters and send an RF trip signal to the electron storage ring within 5 ms. It checks the following things on the MUSST with 1 ms sampling time:

- Chair vertical/rotational speed higher than -50% of the nominal value.
- Dose rate does not exceed +15% of the nominal value.

The PASS system is redundant. All coders, circuits and signal are duplicated in two independant systems.

STATUS AND PERSPECTIVES

The clinical trials started late 2012. Until now 5 patients have been treated. It is relatively difficult to put in adequation the beamline schedule and the recruitment of a patient corresponding to the protocol selection criterions.

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The delivered dose at the synchrotron is today only 15% of the total delivered dose at the hospital. From the 6th patients, the facility will be authorized to deliver up to 50% of the dose.

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