THE CONCEPT OF THE PROSCAN PATIENT SAFETY SYSTEM

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Abstract

PSI is developing a new multi-area facility for biomedical treatment of patients with proton beam, called PROSCAN. For this facility secure patient handling in pre-selected areas must be guaranteed. A safety system for this purpose is now under development. The requirements and layout of this Patient Safety System (PaSS), and the embedding into the entire system are reported.

INTRODUCTION

Proton therapy of tumours has a long tradition at PSI [3]. Patients have been treated for eye cancers in the existing facilities since 1984. In 1996, treatments started with a new method called spot scanning. Encouraged by the results and to overcome limitations in beam time availability from the existing accelerators, a project to build a dedicated facility (Proscan) for proton therapy was started in 1998 [1].

The irradiation of patients in Proscan (as well as in the existing gantry) is done with a method called spot scanning, where the beam is applied to the patient as localized spots. The beam is steered with a bending magnet and between the spots the beam is switched on and off using a fast kicker magnet. One treatment consists of a number of spots that are applied in sequence. Future developments will require continuous scanning where the beam is continuously swept over an area while simultaneously modulating the beam intensity before switching it off.

The Proscan facility has multiple areas for patient treatment [2]. They share the beam from a superconducting cyclotron (COMET) that accelerates protons up to 240 MeV, with currents up to 500 nA. There is shared equipment for beam energy selection (degrader), beam switching (kicker), size manipulation (collimators) and so on. From the common section the beam is directed into one of four beamline branches. The Machine Control System (MCS) is responsible of controlling the beamlines from the cyclotron to the user area start point.

To make efficient use of the facility and the shared resources it is required be able to switch the beam between areas within one minute.

A secure patient handling in a pre-selected area must be guaranteed. Each of the areas has its own treatment setup and the corresponding control system, called User Control System (UCS). A system that ensures that the switching happens correctly and securely and that the local UCS is able to use the beam during the assigned time without causing problems in the other areas is needed.

The safety system has also to be able to react fast; the faster the beam is switched off in case of a failure, the smaller is the unnecessary dose that the patient gets.

LAYOUT OF THE SYSTEM

General Requirements

The main task of the PaSS is to act as a safety supervisor that guarantees safety of operation in an environment where the beam is switched between areas. The PaSS has to act independently of the machine and user control systems (MCS, UCS.) However, it needs to be aware of the beamline reservations to be able to arbitrate the access and to verify the correct sequence of beam operation. The reservations and the part of information of the beamline settings (‘tune’) that is relevant to the patient safety are communicated to the PaSS through the machine control system (MCS.)

Signals from beamline devices that are crucial to a safe operation are directly fed to the PaSS; it has also direct access to some components to switch off the beam. It has no other control functionality than switching off the beam through these devices when an anomaly has been detected.

The PaSS has to fulfil stringent reliability requirements before patients can be treated in the Proscan facilities.

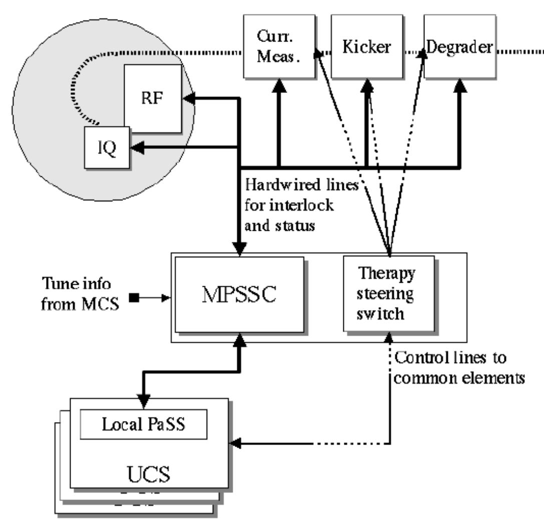

Figure 1: Schematic diagram of Patient Safety System.

The components of the PaSS

The PaSS has the following subcomponents:

Main Patient Safety Switch and Controller (MPSSC) monitors the interlock status of all areas. It enables the main user to switch on the kicker and monitors its interlock status. It monitors the main user area arbitration and the operation of the beam interrupting elements: ion source (IQ), RF system (HF), beam blocker before degrader (BMA1) and the first beam blockers at each area

(BMx1). To enhance reliability, the MPSSC has a redundant configuration.

Local Patient Safety System is a system for each area that is embedded in the corresponding UCS and monitors all the signals connected to the local system (interlocks, warnings and "Beam Ready".) It generates and monitors the pre-programmed "Kicker Off/On"-Signals for the spot scanning and monitors the switching of the beam in case of a local interlock. In case of an error in switching off of the beam (kicker failure, etc.) a "Beam Off" command will be sent to the MPSSC, which then generates a global switch off.

Through the separate connection "Emergency Beam Off" the local system can generate a global beam switch off independently of the beam reservation.

Emergency OR is a switch off system with a permanent hardwired connection to each area. The system is independent of MPSSC and user status and can initiate a global switch off. The "Emergency OR"-module has a simple logic function with no processors; the details of implementation are yet to be defined.

In addition there are modules that read out, digitize, process and distribute safety relevant signals. These modules perform simple tasks that are implemented in low-level soft- or firmware and they operate independently of the control system (except for being informed of the current requested tune.)

ACHIEVING THE PROTECTION GOALS

The PaSS gets information from and can act on a number of *patient safety* devices. These are accelerator components that either can be used to quickly and reliably switch off the beam or have been shown in simulations to be effective in detecting discrepancies from the desired beam parameters. The components that are involved in switching off the beam have direct and separate hardwired connections to the PaSS; for the components in the common section (degrader, first beam blocker, etc.) the signals go directly to MPSSC.

The hardware-based security logic in PaSS cannot directly deal with analogue values, which however are required for fulfilling the safety goals. The measurements in safety devices that have tune-dependent settings are done with dedicated elements that have a simple and robust low-level soft- (or firm-) ware implementation and are not dependent of the control system. When a measurement result from one of these devices exceeds a defined (possibly tune-dependent) limit, a signal to switch off the beam will be generated and fed to PaSS logic.

In cases where the decision is done by the local user rather than globally the measurement results have to be available in the local PaSS. Having a direct connection from the shared components to each of the areas is not feasible, because of the difficulty of distributing very weak signals over long distances to multiple destinations (the user areas.) For this reason, the digitizers need to be connected to receiving components in the user areas.

Beam intercepting devices

The **kicker** is used as a fast steering element for the regular on- and off-switching of the beam during scanning. The magnet current and as an independent check, the Hall probe voltage are read out at a rate 0.05-0.1 ms.

The **beam stoppers** can be moved into the beam fast, although slower than electrical devices (see table 1.) They have (multiple) end switches that indicate that the stopper has reached a safe (beam intercept) position.

A **RF level indicator** is a digital signal that indicates the level of the Dee-voltage. It is read out by PaSS (MPSSC.) The RF is in safe state when the level indicator tells that RF power is off (or low.)

The **ion source** has a status indicator to PaSS (MPSSC) that tells when it is off (safe state.)

Devices that have a tune-dependent setting

Measurements on these devices can be used to detect deviations from the set tune. The signals are read out by separate, hardwired signal cables.

Beam intensities are available from therapy monitors 1 and 2, beam current monitors before degrader (ionization chamber and secondary emission foil) and at the entrance to the gantries.

Degrader has a 2-fold position readout from which the beam energy can be calculated.

Hall probes at bending magnets indicate the correct beam direction. They are read out at a rate of about 1ms and propagated to the local controllers in the areas.

The collimator defining the beam acceptance after the degrader has a redundant position readout. This is only checked in one special mode (radiography.)

The reaction times of the elements and the dose errors as a result of them in a normal therapy dose rate and by maximal beam current are shown in Table 1.

Table 1: The beam intercepting devices, their reaction times and the corresponding dose errors.

Device	Response time	Dose (at 5Gy/s) (0.2 nA)	Dose (500 nA)
Kicker	50 μsec	0.025 cGy	63 cGy
Beam blocker at area entry	60 msec	30 cGy	750 Gy
Ion source	20 μsec	0.01 cGy	25 cGy
HF	20 μsec	0.01 cGy	25 cGy
Beam blocker after kicker	≤ 1 sec	≤ 500 cGy (= 5% Tot.dose)	≤ 13 kGy
Beam blocker at beamline entrance	≤ 1 sec	≤ 500 cGy (= 5% Tot.dose)	≤ 13 kGy

HARDWARE REALIZATION

The PaSS hardware

The hardware platform used in local PaSS and MPSSC is the HYTEC Industry Pack Carrier board with a SHARC DSP (VICB8003). The logic to switch off the beam is embedded in Industry Pack (IP) modules mounted on the carrier boards.

Several methods are used to enhance reliability. First, two modules (Carrier board plus the logic IP's) are programmed to provide the same functionality, but are implemented in inverse (one in positive, one in negative) logic. The DSP program continuously checks the decisions of the logic (XILINX FPGA) modules (Inputs to Outputs). The two modules compare their decisions by exchanging data through the SHARC serial ports. That is, the decisions are made in hardware and the software on the boards provides a more powerful way of supervising the logic.

The Local Controllers and their role

A number of *local controllers* are used to implement fast local feedback loops and do signal digitizing. A local controller can be considered as a sophisticated amplifier, filter, ADC and memory. It can also be used to distribute signals via its serial link ("*signal digitiser*"). Its on board CPU also provides the possibility to check the signals against limits (comparator) and to produce interlocks.

The communication to distribute the data between the controllers will be done by using SHARC serial links in a bussed, time-division multiplexing (TDM) mode. In this mode the transmission delays are deterministic; each node on the link has a defined time slot to put its data to the link. All other nodes can receive the data by reading the data in the timeslot of interest.

The local controllers relevant to the functioning of PaSS are:

Energy and Intensity Controller is located in a Machine Control System (MCS) crate and is a part of MCS. It controls the degrader position (from tune info) and beam intensity regulation (Deflection Plate and Ion source) as a function of degrader setting and tune info. For the regulation feedback the current measurement just before degrader (MMAC3/4) is used.

Energy and Intensity Digitizer is another board that is a copy of EIC, but uses only the *signal digitiser* part on the board digitises the signals and forwards them to local controllers in user areas.

A **local controller** that is a part of the UCS of each user area compares these readouts against tune dependent limits. It is a part of UCS of the corresponding area. It reads and evaluates the following: current before degrader, degrader position, Hall probe x, beam position at checkpoint and current at the checkpoint.

CONNECTION TO THE CONTROL SYSTEM(S)

Based on the therapy flow, the medical users reserve the beamline in Beam Allocator (BALL.) BALL is a software package that arbitrates the user requests for mastership for each area. The BALL grants the main user area control system exclusive access to the corresponding beamline, the degrader, the control of the kicker and the right to give Beam On/Off commands.

The BALL transmits the beam reservation to the "Machine Run Permit System" (MRPS) through MCS. The MCS sets the corresponding MRPS operation mode. The MPRS then informs its ready status for the reserved area through the MPSSC.

- MPSSC, which then sets its operating mode according to a defined sequence including the following steps:
  1. Enable the beam stopper in the master area, disable the beam stoppers in the other areas.
  2. For the reserved area, open the following connections: Beam On/Off (Interlock), Kicker On/Off.
  3. For the not reserved areas: close the connections. The exclusivity of the granting of the area will be checked.
  4. The consistency of the Ready signal of the MRPS and the reservation through the MPSSC are verified.

After this sequence, the UCS that has acquired the mastership can access the shared facilities

STATUS AND OUTLOOK

The commissioning of the COMET cyclotron and the first section of the beamline, including the most essential control elements (kicker magnet, degrader, etc.) is planned to start in early 2004. The plan is to be ready to switch the existing Gantry to the Proscan facility (from the PSI 590 MeV cyclotron) in the shutdown of 2005.

The hardware for the PaSS is for most parts defined and ready, although there is still work to be done in the communication link hardware and firm- plus software development.

The concepts have to be tested and verified to see that the planned system fulfils the safety and performance requirements. The testing work is about to start and the first test results should be available within a few months.

REFERENCES

[1] H. Reist et al., Project study for Proscan. PSI Scientific and Technical Report 1999, VI, p.22-23.

[2] M. Schippers et al, Architectural Overview of the PROSCAN beam lines. Review Document F, P00/SJ85-109.2 (Internal)

[3] More information about the PSI medical research is available under http://www.psi.ch/index_e_human. shtml