STATUS OF THE ACCELERATOR CONTROL SYSTEM (ACS) FOR THE THERAPY FACILITY HIT

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Abstract

Shortly before first tumor patients will be treated with high-energy ions at the Heidelberg Ion Therapy Center (HIT) we give an overview of the ACS special characteristics and present status. The ACS was designed and implemented by an all-industrial partner following functional specifications from GSI [1]. At each of the three therapy rooms more than 20000 combinations of beam energy, intensity and focus can be requested by the therapy control system (TCS). The commissioning for carbon and proton ion beams has already been successfully conducted by GSI [2]. We show how different operating conditions are implemented. Experimental research is possible while beam properties already verified within medical test procedures cannot be altered without following predefined work flows. All system and device parameters as well as all set values that possibly could change beam properties for patient treatment are securely locked or integrated into checksums. We also focus on functionality that had to be implemented to conform to the requirements that originated by the risk assessment of the ACS.

FRAMEWORK OF THE ACS

The HIT ACS was designed solely for the facility in Heidelberg where cancer patients will be treated with heavy ion irradiation (ions up to Neon with energies up to 430 MeV/u). The accelerator (Fig.1) consists of two dc ion sources, LINAC, Synchrotron and beamlines to two horizontal treatment rooms, the gantry structure (where the beamline can be rotated 360° around the patient), an additional room for medical research and one beamdump. In total the ACS controls about 500 components [3].
The ACS is realized on few standard industrial computers (OS Windows 2k) and most communication takes place via TCP/IP and broadcast messages. An ORACLE-Database holds all relevant accelerator data. Core of the ACS is the so-called maincontrol (C++) process which together with a couple of other processes controls all activity of the accelerator [4].
Where real-time control of accelerator equipment is necessary (mainly power supplies, rf-systems and trigger channels for beam diagnostics), it is realized with special front-end controllers (FECs) based on a Motorola PowerPC processor (64 MB RAM, 32MB flash) and an Altera Stratix FPGA. For normal operation mode all necessary device data are stored in the FECs RAM while nonvolatile memory (flash) is used for therapy settings. The whole accelerator comprises 170 FECs[1]. The ACS provides μs timing of all beam guiding components and timing is provided using a delay-compensated real-time bus (RTB) with few signals and individual device delays. All events are generated by one special FEC unit (timing master).
The whole concept is based on a virtual accelerator (VAcc) concept, namely groups of devices with associated set-values. In total 255 different VAccs can be defined where only ten of them (according to all possible combinations of ion source and beam target) are used by the (TCS) for patient treatment and provide set values for the whole parameter space. One special VAcc runs continously with 10 Hz and provides stability pulses for the Linac rf components.

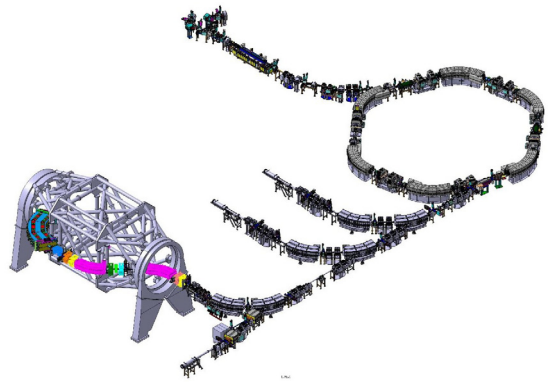

Figure 1: View of the facility: Two ion sources, LINAC, Synchrotron and four beam targets including the gantry.

SPECIFICS OF THE ACS, INTERFACES TO THE TCS

The TCS delivered by Siemens Medical Solutions holds all responsibility for patient treatment and physical integrity using its own totally independent systems for e.g. treatment plans, patient positioning or safety interlocks. Its interface to the ACS mainly consists of one direct digital connection arbitrated from one of the local therapy control units to the ACS timing master. Using this interface the TCS requests beam from the ACS, switches ACS modes of operation or quit power supply interlocks generated by the TCS itself.

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[1] Some of them have special hardware: (i) One timing master generates timing events (ii) Some FECs provide up to 32 different TTL trigger pulses each for the beam diagnostic system (iii) 21 FECs have an additional interface to the TCS (communication, interlocks).

Pulse to Pulse Variation of Beam Properties

For the execution of patient treatment plans it is necessary that all beam properties can be changed from pulse to pulse. Combinations of 255 energies, 6 foci and 15 intensities ("EFI"-combinations) are possible for each of the four ion types at all treatment rooms. Consecutive pulses can vary in ion type, EFI and beam target. The device settings for all combinations are stored in each front end controller where some of the devices even have to provide different settings for different rooms. However, not all dependencies apply to each single device.

Assignment of Authorization and Beam Requests

Several submodes of operation exist for the ACS as well as for the TCS while possible main system states of the ACS are "TCS", "ACS" or "IDLE" with equivalent modes for the TCS. Change of the overall operation mode by request is only possible if the system in charge of authorization deallocates ("IDLE") whereupon the new state is engaged with no active operational submode (e.g. "TCS/IDLE").
From the ACS all beam paths can be locked separately regarding the execution of therapy accelerators upon beam requests by the TCS (or even the ACS). Changing the mode of operation affects only devices along enabled beam paths. All FECs possess several possible operational modes themselves and those along enabled beam paths have to switch to their correct individual submode. All remaining FECs can be controlled manually by the ACS as long as they are not locked by e.g. medicine or personal safety interlocks.
Upon request of a specific submode a lot of fully parameterizable necessary preconditions dependent on the submode itself are verified before this mode is activated. Possible submodes are e.g. "experimental ACS", "quality assurance ACS" or "patient treatment TCS". For the latter the highest set of necessary conditions applies. In this case all FECs have to switch to their correct submode and individual checksums as well as device status information have to fulfill patient treatment conditions.[2]
While beam requests from within the ACS are initiated manually via procedures ore standalone, beam requests from the TCS are routed through the ACS timing master unit to the maincontrol process of the ACS. At any rate each beam request is sent as a broadcast message containing among other information EFI combination and ion type. The reply message of each single device contains the devices status and the index of the requested EFI combination in the FEC. In case of a discrepancy the beam request is aborted.

[2]In addition to quality assured accelerator set values this includes all device settings that could affect beam properties: Device software and firmware version, interface settings, IP-address etc.

Reservation Queue and Allocation of Beam Paths

Besides the personal safety system and its interlocks another interlock system governed by the TCS is installed, namely the ASD ("Arbitration, Safety and Dispatching Unit"). It triggers hardware interlocks to all dipole magnets in the high energy beam transport section that guide the ion beam to the target rooms. Only one of the control systems (ACS or TCS) is allowed to allocate a beam path to only one room at a time. This constriction is not intrinsic to the ACS and some adaptations had to be made for correct handling of these interlocks, especially regarding status, surveillance and feasibility of virtual accelerators. Handling of this allocation is performed by the so-called reservation queue governed by the TCS. The ACS can only quit these interlocks if in addition to an correct reservation queue entry the TCS is switched to "remote ACS".

BAMS, Scanner Magnets and Spill Abort Devices

The TCS has direct access to several power supplies of the accelerator (communication or interlocks), namely scanner magnets and devices for fast and safeguarded interruption or abort of beam extraction. In patient treatment mode scanner magnets are solely controlled by the TCS to deflect the beam and scan one isoenergetic plane during irradiation. Beam extraction out of the synchrotron is stopped or interrupted[3] by the TCS with direct fiber optic connections to special power supplies in form of spill pause or medical interlocks. In addition it is signaled to the ACS via direct digital connection to the timing master directly generating corresponding RTB events thus triggering necessary action inside the ACS.
In addition to its own beam diagnostic devices with about 70 measurement units in 40 diagnostic chambers the ACS has access to measured data from the "Beam Accelerator Monitoring System" (BAMS) in experimental mode. The BAMS situated at the end of each beamline consists of a set of multiwire proportional and ionisation chambers used by the TCS during patient treatment to monitor and supervise irradiation. Furthermore it is a critical component of the TCS interlock system thus categorized as a medical device.

LIBC Interface

In the "List of Ion Beam Characteristics" (LIBC) all relevant beam properties for all ion types are defined in physical units and the beam commissioning that was exclusively executed by GSI had to meet this values. The LIBC is stored in a separate ORACLE database that belongs to the TCS. However restricted access for the ACS is granted for the following essential tasks:
(i) Upon each beam request from the TCS the ACS translates the physical units from the beam request to its corresponding indices of set values with the LIBC.

[3]This allows for repositioning of the beam during one extraction cycle (spill pause) whenever large displacements are necessary.

(ii) Daily test procedures with adequate sample measurements are run by the ACS users to ensure correct beam properties. As a result all EFI combinations have to be released or blocked by the ACS users using reasonable blocs in the space of beam parameters. This information is directly written to the LIBC database and has to be evaluated by the TCS before the start of a treatment plan.
(iii) All changes within the ACS that could change beam properties are logged not only in the ACS but also in the LIBC as necessary information for the medical personnel to decide whether and which quality assurance measurements are necessary after changes within the ACS.

MODES OF OPERATION

Calculation of Device Control Data

In "**experimental research**" submode, the accelerator is completely governed by the ACS and all beam properties are adjusted to specified values using a sophisticated physical machine model using high level machine parameters. Within this model it is not only possible to calculate one specific EFI combination and monitor its results during continuous beam executions; furthermore the whole EFI parameter space can be interpolated generating device set values for all combinations. In this mode all beam diagnostic devices can be used without any restrictions. Also all freely programmable experimental VAccs can be defined, parameterized and run in this mode [5].
As soon as beam properties match therapy requirements, all interpolated device set values can be copied from all FECs RAM to its flash memory, but only in a special "**adjustment**" submode to be safeguarded and well protected against unintentional change. At that instant all set values are stored in the database together with all necessary checksums and LIBC entries for each single device are created for the affected ion type. With this backup it is possible to switch the calculation base to therapy settings whenever realignment is necessary since the (experimental) set values in the FECs RAM do not have to correlate with therapy settings in the flash memory.

Verification of Beam Properties

To verify beam properties prior to patient treatment[4] automated procedures (therapy protocols) are defined that execute beam with different representative sample measurements regarding energy, intensity and focus at all treatment rooms for both ion types in use. Not only the therapy protocols but also its presentations can be defined in a meaningful way e.g. defining tolerances for measured data or using relative scales. As a result of these protocols either beam properties have to be realigned or EFI combinations blocked for TCS beam execution.
Therapy protocols have to be run from the FECs flash memory which is achieved with a special "**quality assurance**" submode where not only flash set values are used but further requirements to the execution of VAccs have to be met (set-values for slits, vacuum valve positions, certain device properties etc.) that match TCS mode as best as possible.

[4] irrespective of the TCS's own quality assurance measurements

ACS FUNCTIONALITY ORIGINATING FROM RISK ASSESSMENTS

Even though the ACS is on no account responsible for the patients physical integrity, a lot of time has been spent for the risk assessment. All possible ACS problems that in TCS mode could lead to treatment with wrong beam properties had to be excluded. In the following some examples of corresponding functionality are given:
(i) All changes inside the ACS that possibly could change beam properties have to be logged in the LIBC change log to inform the TCS personnel.
(ii) In the LIBC two IDs of different severity are assigned to each ion type. Each single device and a multitude of parameters can be marked to be relevant to one of those IDs. Upon change the corresponding ID as well as one of the devices checksum is incremented. Patient treatment mode only can be activated again after this checksum has been written to the FECs flash memory.
(iii) Some additional redundancies have been implemented: In TCS mode e.g. neither FEC downloads nor most of the device commands are allowed. Additionally the FEC itself blocks these commands in its therapy submode and the submode cannot be changed in global TCS mode.

CURRENT STATUS AND OPEN ISSUES

By now the ACS is not fully completed, but most of its functionality is implemented. Functions have been tested during machine commissioning and extensive test shifts. From the technical point of view the ACS is ready to be used for patient treatment. However, about hundred minor open issues - missing functionality and known bugs - are listed that have to be eliminated by the industrial manufacturer of the ACS. Final functional and safety compliance tests still have to be performed. Patient treatment is expected to start early 2009 after certification of the TCS.

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