REQUIREMENTS AND COHERENT REALIZATION OF THE HICAT CONTROL SYSTEM FUNCTIONALITY FOR TEST, COMMISSIONING AND OPERATION

T. Fleck*, R. Bär, M. Schwickert, GSI, Darmstadt, Germany

Abstract

The control system for the HICAT project comprises several rather different functionalities for the whole range of demands starting from tests of single components up to the specified operation mode where the accelerator has to deliver a beam of high-energy ions with requested energy, focus and intensity for tumor treatment. We outline the concept and realization of this system which is capable of fulfilling all those needs within the implemented functions and GUIs. The range of functionality spans from test environments and trace-possibilities for single front-end controllers up to complete integrity tests of the whole accelerator for the designed operation mode. E.g. for commissioning of the LINAC division the control system utilizes a 5 Hz mode while typical synchrotron cycles last for several seconds and can be used with similar adjustments. In normal operation mode diagnostics like beam current are only evaluated at special times in a cycle, but it is possible to monitor and record these data at high sampling rates in a continuous mode over several hours. Furthermore it is possible to accomplish long-term stability tests of single components during normal operation.

CONCEPT AND REALIZATION OF THE CONTROL SYSTEM

The HICAT control system was designed solely for the facility in Heidelberg where, in the final stage, about 1300 cancer patients will be treated each year with heavy ion irradiation with energies up to 430 MeV/u and ions up to Neon. The layout includes two horizontal treatment rooms, one gantry where the beamline can be rotated 360° around the patient and an additional room for medical research.The accelerator consists of two dc ion sources, Linac, synchrotron and the beamlines to the different rooms. About 500 components have to be controlled including slow controls like vacuum components.

The control system has to provide μs timing for all beam guiding components. Energy, intensity and focus of the beam need to be changed from pulse to pulse. The parameter space for patient treatment consists of all combinations of 255 energies, 6 foci and 15 intensities. Beam properties have to be verified and all settings safeguarded and well protected. Different operation modes for commissioning, quality assurance and therapy must be possible where in therapy mode the control system has to be locked against parameter changes that affect beam properties. While all specifications have been written by GSI, the whole control system was implemented by an industrial partner.

* t.fleck@gsi.de

TEST FUNCTIONALITIES

Single Front-End Control Units

The front-end controllers (”device control unit”: DCU) developed and produced by the industrial partner can be used for extensive tests without any control system (CS) via a serial connection and e.g. hyper terminal. A lot of test functions for the DCU's processor and FPGA are implemented and proper functionality for updated SW/FW versions can easily be verified. Bus communication with up to five interface cards of the power supply units can be tested as well as the power supplies themselves with e.g. predefined data ramps or control of single register values. All this developer tools are accessible while a operator normally doesn't need this interface at all.

Integration of DCUs in the CS and Network

While the first two byte of a DCUs network address have to be set by direct communication and are correctly preset the last two byte are set with bit switches on the backplane to assure error free address assignment. As soon as a DCU is identified by the control system, automatically up to three reboots are initiated to set the correct DCU device class and current SW and FW versions to comply with the database settings for that individual IP-address. The DCU then receives all necessary data including master data, parameters, accelerator device settings and definitions about interface cards and register settings automatically from the control system. The control system also detects whether defined interface cards have been moved to another slot and in that case reconfigures the DCU. Proper connection of the real-time bus can be tested and the parameters of the interface cards configured regarding e.g. command register or interface calibration with nominal current and voltage.

Beam Diagnostic Device Tests

First beam diagnostic (BD) device tests can be performed with stand-alone application software for manual control developed by the industrial partner. Inside the CS BD elements can be individually parameterized and tested in a free run mode or participating in accelerator cycles. In the latter case TTL trigger pulses to BD elements provided by special DCUs can be adjusted. Furthermore test functions of some BD elements are possible as well.

Integration of Further Devices

Vacuum control system, rf generators or the ion sources fieldpoint controllers comply to industrial standards like PLC and communication is realized via profibus or OPC. Integration into the control system is realized by gateway systems. All set and read values of these gateways can be shown in real-time but normally these systems are controlled solely from within the GUIs where data is updated either about every two seconds or upon change.

Verification of Calculated Device Data

One process of the control system, the data supply module (DSM), calculates all necessary device settings for a group of components, e.g. all necessary settings to accelerate ions from one ion source to one treatment room with predefined beam parameters. About 1000 physical input parameters are used for the DSM and whenever a parameter is changed all dependent device settings are calculated. Typical device settings are current or voltage values or ramps and timing information relative to the start event of a cycle. All calculated data can be visualized for verification. For commissioning and testing purposes it is possible to run the DCUs in simulation mode where the power supply interface cards are reset and ignored. In this mode the DCUs FPGA sets read values to set values. Correct timing and synchronization can thus be tested, monitored and visualized.

FUNCTIONALITIES FOR COMMISSIONING

5 Hz LINAC Operation

Normal accelerator cycles have a duration of several seconds: About one second for Linac acceleration, injection and acceleration in the synchrotron followed by some seconds of beam extraction and in a last step all synchrotron magnets can be driven up to their nominal currents and back to injection currents to get rid of remanence effects. Since Linac commissioning can be performed with higher frequencies this section allows for beam requests with 5 Hz. In between stability cycles without beam with up to 10 Hz assure temperature stability of the rf generators.

Normal beam requests are initiated by an standard ethernet broadcast telegram and before the start event is generated, all devices in the virtual accelerators group have to respond correctly by sending their present status. In the case of the 5 Hz mode only one broadcast is send at the beginning and then the timing master periodically generates start events. In this mode DCUs react on events only.

Experimental Virtual Accelerators

User-defined combinations of devices can be grouped, calculated and supplied with according set values to check their proper functionality or to commission only parts of the accelerator. Relevant accelerators for therapy are defined with all elements along the beam line from one ion source to one treatment room. In contrast to therapy accelerators that contain all device settings for all combinations of beam parameters experimental virtual accelerators only have one set of parameters.

Stability Tests for the Ion Sources

To perform long-time stability tests of the DC ion sources lasting several hours experimental virtual accelerators can be used. Although all necessary devices have to have constant values during this time continuously identical beam requests are performed. Online measurements of necessary BD systems are performed and definable averages of this data can be saved to files.

Implementation of a Parallel Test System

For e.g. first synchronized commissioning tests of synchrotron devices with real timing a parallel CS with independent database can be installed in the same network. The concept of the CS allows this mode and all user-interfaces and components can be assigned to different control systems. Thus parallel commissioning of Linac and synchrotron section is possible at the same time. An additional timing master is needed for this parallel test system that can be connected to the synchrotron real-time bus while the first timing master is connected to the real-time bus of the Linac section.

Tracing Possibilities

The core of the control system, the so called maincontrol, can be used to directly communicate with every single device without the need of the user interfaces and most of the possible commands are available. This can be used to identify errors in the user applications. Additionally detailed traces can be saved for error analysis at the developers site. An additional trace server is implemented where detailed information about single DCUs can be gathered. Each DCU can be parameterized to send all accessible information to this trace server like communication status or the setup-time described below.

TIMING AND GLOBAL SYSTEM ADJUSTMENTS

Global Settings

The system can be configured to a very high extend by system parameters. For example the maximum extraction time for the synchrotron can be set, the whole communication can be switched from broadcast to unicast or the data type of all used parameters can be changed as well as their units. For each single device it is possible e.g. to define its dependencies of beam parameters, whether or not device settings may be downloaded during a cycle or if device settings shall be downloaded automatically after a reboot.

Device Synchronization

In a special mode signal propagation times from the timing master to each single DCU are measured to be properly taken into account. The longest measured propagation times are about $2\mu s$. Upon beam requests each DCU compensates this signal propagation time. Devices with data ramps have set values every $32\mu s$ and the DCUs FPGA interpolates between this values and sets values every single μs. Some devices (injection bumpers) even need a data rate of 100 ns which also is provided by the FPGA with a special firmware version and device class.

Setup-Time for Slow Magnets

Because beam properties have to be changed from pulse to pulse, sometimes it is necessary to delay the start event in order to wait until all slow magnets have reached their set values. The magnets current therefore has to be measured as a function of time and fitted with exponential functions. This has to be done from the minimum to the maximum nominal value and vice versa. With every beam request the DCU reads the magnets present current and calculates the time necessary to reach its set value. The time difference between the start event and the time when this magnet must have reached its set value is subtracted and the start event delayed by the maximum setup-time of all devices.

Control of Proper Device Status

For each single device inside a virtual accelerators group necessary settings for successful beam requests can be defined for different operation modes like commissioning, quality assurance or patient treatment. In the latter case for example all settings that may influence beam properties are locked and e.g. pneumatic actuators have to be in defined positions.

NORMAL OPERATION MODE FUNCTIONS

Measurement of Spectra, Transmission and Beam Properties

It is possible to take two different kinds of m/q-spectra of the ion sources: In the low energy beam sections the ion beam is still continuous, and the first dipole is operated with steplike set values to measure a complete spectrum while further elements can be mastered as well. The second type of spectrum can be performed with the $300\mu s$ beam behind the Linac section. The transmission of the ion beam can be measured throughout the whole accelerator using non-destructive beam diagnostic devices along the beamline and e.g. one faraday cup at the end of the sections of interest. Depending on the devices used and the sections to be measured the transmission can either be calculated from beam currents or particle numbers. To be able to do this, correct timing information is needed since the beam is chopped from DC to 300 μs first and to 30 μs before injection into the synchrotron where the particles velocity has to be taken properly into account as well.

Beam properties are measured with about 70 single beam diagnostic devices allowing e.g. energy measurements in the Linac section with phase probes, width and center of mass measurements along the whole beamline with MW-PCs or optical diagnostics.

Beam Requests with Pulse to Pulse Variations, Automated Test Procedures and Protocols

When experimental accelerators are used, or one set of beam parameters for therapy is commissioned or optimized, beam requests of this single set of device settings can be continuously performed with an specified delay between the end of one cycle and the start of the next one of less than 250 ms. Parameters can be changed and as soon as all dependent devices received this new settings the next cycle is started.

To verify different beam properties procedures can be defined with several beam requests and control of all beam diagnostic devices; especially it is possible to define procedures where different pneumatic actuators can be moved to measure the beams center of mass along the beamline with subsequent beam requests. Results of these procedures are visualized in so-called therapy protocols that can be customized for automated quality assurance tests with identical visualization or print functions.

Offline Diagnostics of Accelerator Data

While online data of DCUs and beam diagnostic devices have to be measured manually in real-time each of these components can be parameterized to send up to two set and read values at two significant times in a cycle that cannot be changed manually but move relative to the start event when timing is changed. The snapshot time for e.g. all magnets behind the synchrotron is set to the begin of extraction. These data are single read values for the magnets while for beam diagnostic devices different kinds of averaging can be defined.

All snapshot data are stored in the database for offline diagnostics where either all snapshot data of one specific cycle can be displayed or the time development of a single device can be shown and analyzed.

PATIENT TREATMENT MODE

During patient treatment the therapy control system requests beams with different properties while the accelerator control system is locked against user interference and can only be used to monitor proper behavior of the accelerator. Should any error occur the accelerator control system has to be given full control again to eliminate it. The therapy control system can pause the synchrotron extraction, perform fast beam cutoffs and control the DCUs of the fast scanning magnets to position the beam inside the tumor region.