EXPERIENCES WITH AN INDUSTRIAL CONTROL SYSTEM: TRACEABILITY OF SPECIFICATIONS, COMMISSIONING SUPPORT AND CONCLUSIONS FROM THE HICAT PROJECT

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Abstract

While the accelerator for HICAT (Heavy Ion Cancer Therapy) was designed by GSI, most components and systems were supplied by industrial partners. Despite of thorough and detailed specifications for the control system (CS) the concept allowed a rather high degree of freedom for the industrial partner regarding the implementation. The challenge of this combination established a good understanding of the necessary functionalities by our industrial partner. Firstly we describe the process of implementation starting by the specifications made, sum up the tracing of the development and show how we assured proper functionality ab inito and necessary steps since then. Secondly we describe problems ranging from software bugs to demands regarding acceptance tests for other components and state how we managed to solve these problems with our industrial partner on a short time-scale. Lastly we show what can be learned from our experiences. Especially we discuss where it is more efficient to describe all necessary physical dependencies to the industrial partner instead of defining a proper interface where the programming can be done by accelerator experts and concentrate on areas that led to problems with the time schedule.

INTRODUCTION

Scope of the HICAT Control System

The HICAT control system was designed solely for the facility in Heidelberg where in the final stage about 1300 cancer patients each year will be treated with heavy ion irradiation with energies up to 430MeV/u. While ions up to Neon can be used in the facility at present the commissioning is done with carbon and protons. The layout includes two horizontal rooms, one gantry where the beamline can be rotated 360° around the patient and an additional room for medical resarch.

The accelerator consists of two dc ion sources, LINAC, Synchrotron and the beamlines to the different rooms. In total the CS has to control about 500 components to accelerate, monitor and analyze the ion beam.
Main demands to the CS are:

- μs timing of all beam guiding components; for some devices 100ns timing is necessary. Optimization, monitoring and analyzing tools in realtime.
- Different energies, intensities and foci from pulse to pulse
- High reliability and stability for at least 25 years
- A huge parameter space for patient treatment has to be filled consisting of all combinations of 255 energies, 6 foci and 15 intensities (EFI) for each target room[1] and ion type. Beam properties have to be verified and all settings safeguarded and well protected.
- In normal operation mode only two operators must be able to control and supervise the whole accelerator.
- Different operation modes for commissioning, quality assurance and therapy.

Industrial Partner, Operating Company

The industrial partner Eckelmann AG (EAG) is a company with about 300 employees and has a history of several decades in control system design for e.g. process automation or production control, but no experiences in accelerator physics so far. The companies location in Wiesbaden is less than 100 kilometers away from both GSI and the facility in Heidelberg. EAG developed the front end controllers, the accelerator control system (ACS) itself and in addition to that delivered the core of the personal safety system (PSS) and the vacuum control system (VCS) including hardware and stand-alone control equipment.

EAG has yet another contract with Siemens Medical Solution and developed the therapy control system (TCS) as well which has the advantage that the interface between TCS and ACS is controlled by EAG itself.

While the accelerator including the ACS has been designed by GSI and also the commissioning is done by GSI, operating company is the "HIT company" (Heidelberg Ion Therapy), a wholly owned subsidiary of the clinic. Therefore stepwise handovers and instructions have/had to be accomplished parallel to acceptance tests.

DEVELOPMENT OF THE CS

Proposal and Level of Detail Ab Inito

While extensive and detailed functional requirements had been written by GSI the industrial partner was allowed to choose OS platform, programming SW and designed the front-end controllers. Comprehensive functional specifications were created by the industrial partner, then verified and approved by GSI. While on one hand not all necessary functions could be specified right from the start like algorithms for setting ramp generation it was clear on the other hand that a lot of adaptations would have to be performed during commissioning since the whole system was a prototype of an individual item.

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[1] Multiplied by 36 supporting points for the angle dependency of the Gantry.

Responsibility and System Specifications

The industrial partner took full responsibility for

- SW development of the whole ACS
- HW design and production of the front-end controllers
- HW delivery for the ACS and parts of PSS, VCS and TCS.
- Integration of all beam diagnostic devices into the ACS with additional independent controls.
- Separate control systems for vacuum and access control as well as interfaces to this systems
- SW for the TCS and interfaces to the ACS
- Documentation, instructions, time management in agreement with the scheduling of the whole facility.

Developments Preceding the Commissioning

More than one year before the first components were installed in the building, a test facility was build at GSI (to put into operation the Radio Frequency Quadrupole for the LINAC) where the first implementation of the CS could be tested with first components and beam diagnostic devices. This CS and mainly the communication with the controllers and their properties were intensely tested by GSI. Regular updates upon further developments (functionality and GUIs) have been performed by EAG since then.

Previous to that prototypes of the controller units had been build and delivered to the manufacturers of the power supply units and acceptance test had been performed. Because of concerns regarding the electrical interference of the data communication between controllers and interface cards the backplane bus was re-designed. EAG built a test facility at their site with about 100 FE-controllers to test the operation of the CS as close to reality as possible. During the development EAG could work with interface cards, single beam diagnostic devices and the PXI systems of the beam diagnostic (BD).

First Steps of Commissioning

At the end of 2005 the CS was installed in Heidelberg, the network set up and first power supplies integrated. Early in 2006 the ion sources and the low energy beam transport section had to be controlled by the CS and their proper behavior checked with the CS including the first BD classes profile and current measurements as well as optical diagnostics.

Following that till the end of 2006 the whole LINAC section was commissioned with different ions. In this step the timing of the CS became important and was intensely tested since the ion sources deliver DC ion currents and the first devices with real timing requirements were the high frequency units and one chopper to cut out beam packages of about $300\mu s$ length for LINAC injection.

For this part of commissioning a 5Hz mode had originally been specified for fast adjustments and beam requests with changing device data on a short time scale were performed. At that time it became clear that it wasn't possible to integrate the BD devices (extended to phase probes) properly in the accelerators timing and this problem couldn't be solved till spring 2007 when it was first possible to definitely correlate measured data of the BD to performed beam cycles.

Changeover to Operation Mode

Since the Start of 2007 the Synchrotron and the beamlines to the first two target rooms have been commissioned including all BD device classes and about two third of all final devices have been included into the CS. The CS had to fulfill all specifications regarding timing and consistent data calculation of devices with real time-dependencies. Furthermore beam requests with all possible EFI-combinations had to be correctly calculated and pulse to pulse variations of these values have been necessary since then. All verified beam properties have to be transferred to nonvolatile controller memory (flash) to be requested and verified by the therapy control system.

By now all components are included into the ACS and most of the above mentioned functions are working rather reliable. However still work has to be done regarding the creation of e.g. automate test procedures and the analysis of beam properties via standardized protocols.

SUPPORT, DIFFICULTIES AND TIMESCALE

Support from the Industrial Partner

Throughout the whole project the industrial partner proved good cooperation and working atmosphere. He mostly showed a high degree of flexibility and helpfulness regarding unforseen problems or necessary adaptations and expansions of the CS's functions. A lot of on-site support has taken place and mostly questions could be directly answered by appropriate developers. A lot of minor problems have been analyzed and solved on a short timescale. On a regular base a copy of the database mirroring the actual system is imported at EAG company site where problems are analyzed. Traces and error logs of problems can be evaluated by the partner as well. A remote login to the system is realized and proofed to be an absolute necessity for commissioning. Since this week the industrial partner attends each commissioning shift while at least one daily delegate has been at the facility during the last months. Additional telephone support is given and also foreseen in the maintenance agreement that still has to be agreed upon.

Expansions and Clarifications

Necessary expansions during the commissioning have been implemented on short timescales by the industrial partner like acceptance tests of the ion sources for 24 hours (trending of current measurements) that hadn't been specified, ventilation supervision, additional inspection of discrepancies between set and real values or additional visualizations of measured online-data.

For the correct implementation of device interfaces to e.g. high frequency devices or the therapy control system clarifications sometimes have been very hard to achieve or still are under way. Disregarding the workload of the industrial partner a high adjustability for necessities could an can be observed despite all above mentioned problems.

Problems with the Industrial Partner / Timescale

The above mentioned situation of a daily present on-site support originates from grave problems with the CS that prevented and to a certain amount still prevent proper commissioning of the accelerator. While concerns about available manpower and the time schedule have repeatedly been expressed unfortunately still assured and already delayed deadlines cannot be kept. Mainly this seems to be a matter of underestimation of the complexity or misinterpretation of required functionalities.

In June 2006 a revision of the CS time schedule coordinated with commissioning milestones has been carried out. At present the delay in commissioning of the accelerator is about six weeks but the CS's functionalities are about five months behind schedule even though the revised new time schedule implied considerable additional time for the industrial partner. Referencing the new schedule by the end of this year the whole contract should be fulfilled but a conservative guess points to midsummer 2008. Although the industrial partner developed a surprisingly fast and broad understanding of accelerator physics the consequences of supposedly minor specifications sometimes led to great obstacles. Noteworthy for this is the correct implementation of EFI device dependencies in the calculation of device data. Furthermore we state that the industrial partner valued essential functions according to his impressions at the facility instead of taking concerns serious enough - especially regarding milestones in the commissioning accompanied each time by an increase of the necessary functional range within the original specifications.

Difficulties and Frequent Errors

Most problems and errors so far can be assigned to the following issues:

Integration and data supply of the BD systems, especially reliable (online-) measurements from pulse to pulse without interruption and definite assignment to accelerator cycles.

Performance of the whole system regarding real-time optimization of device data, offline-analysis, BD systems and especially calculation of all device data for patient treatment: Interpolation of all EFI data for one ion type and one source-target combination together with the data supply of the components should be possible in about 20 minutes. While actually this goal is nearly reached at the time when this functionality was first needed the CS took about one day to perform all necessary steps.

Stability of the system: Constantly necessary system updates to satisfy the specifications often lead to new problems while known problems repeatedly take a lot of time to be eliminated. The step-wise enhancement of the system by more components, supervision or realized specifications predictably led to new problems.

Lacking time for documentation, briefing and user-friendly implementation of the GUIs led to precious few CS experts able to deal with common problems and errors.

The commissioning teams have to deal with lots of trivial errors, report them to the industrial partner and have to classify overdue functions to different priorities.

EXPERIENCES AND CONCLUSIONS

While a strategy to further prepone CS milestones comes into mind it may not help much as long as the urgency and complexity of necessary functionalities lying long ahead cannot be made clear to the industrial partner. At any rate comprehensive test procedures should have been specified in more detail and especially this tests must not only follow the commissioning starting with integration of single components but already have to cover final operation scenarios as far as possible. Furthermore the question has to be answered about reasonable instruments that can be integrated in the case of non-performance. Partial or delayed payment of several parts alone could not be sufficient.

From the beginning a situation must be reached where the industrial partner knows about his debts and claims outstanding specifications. Also from the beginning a mechanism must be implied where the provider of the CS automatically informs about achieved developments and performed tests while no changes to the system whatsoever are possible without proper description. Objective criteria for the overall system performance and stability have to be defined that can be tested and stored with every new version on a short but meaningful timescale. During commissioning large time blocks must be defined for extensive tests of the CS. This times must not be reduced nor confined by necessary works on e.g. single components, i.e. the CS must be able to operate the facility in operation mode. User aspects especially regarding predefineable commissioning workflow and operability of the GUIs must be given high priority from the beginning.

Assignment of Complex Issues to the Industrial Partner

In the course of the project it became clear that it could have been easier and less work to just define a proper interface to get proper calculated device data instead of defining all functional dependencies. The necessary documentation was a time-consuming task and sometimes even had to be written in pseudo-code. Also necessary changes or error eliminations were dependent on implementation time from the industrial partner.