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INTEGRATION OF BEAM DIAGNOSTICS DEVICES FOR A THERAPY ACCELERATOR

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Abstract

MedAustron is a synchrotron based accelerator complex, used for cancer treatment as well as for non-clinical research, and is situated in Wiener Neustadt, Austria.

Cosylab has been working closely with MedAustron to develop the core accelerator control system and is now also working on on-site integration of beam diagnostics (BD) devices. These devices are critical for commissioning of the accelerator as well as later during regular operation to ensure high up-time of the machine. Beam instrumentation devices are fully integrated into the Front End Controller Operating System (FECOS) of the accelerator. FECOS is a custom designed control system framework implemented in LabVIEW, which provides unified interfaces and core services to all software components in the system. The Master Timing System component provides configurable real-time events distribution (triggers), essential for measurement and control in sections where the beam is bunched and device actions need to be synchronized. Both companies, MedAustron and Cosylab also developed user interfaces that are designed to be intuitive, while maintaining a level of flexibility for physics research.

INTRODUCTION

MedAustron will primarily treat different cancer indications with proton and carbon ion beams. Additionally it will provide beams for non-clinical research. Installation and commissioning of the accelerator is well under way and the first patient treatment is planned for end of 2015 [1].

To commission an accelerator the properties of the ion beam need to be measured. The beam is measured and diagnosed using more than 150 beam diagnostics devices, installed along the MedAustron accelerator.

These sensors are effectively the operator's "eyes" on the particle beam along its path from ion source to the patient.

In some cases, the beam properties are measured by insertion of a specific device (e.g. Faraday Cup) into the path of the beam. Since the beam is bunched in several sections of the accelerator, the measurement on the beam diagnostic devices must be synchronized to the passing of the beam pulse. This synchronization is provided by the MedAustron timing system.

MEDAUSTRON CONTROL SYSTEM

Front End Controller Operating System

The control code for all accelerator front-end controllers (FECs), including those for the timing system, power converter and beam diagnostics is written in the custom developed Front End Controller Operating System (FECOS) [2].

FECOS is a light-weight, custom-developed, programming framework with real-time support that allows users of the MedAustron control system to write control code for accelerator components. One of the key purposes of FECOS is the standardization of software interfaces and partial standardization of behaviour, e.g. FECOS enforces a state machine that is implemented by every component. FECOS also provides standard functionality like error reporting, logging, timing system support and watchdog and host health-status monitoring, providing a mechanism for configuration, control and supervision. FECOS runs on all FECs and each FEC is able to run multiple applications (application components) [2,3].

FECOS and all device-support software are implemented through object-oriented programming (known as LVOOP) in National Instruments' LabVIEW [2]. Presently FECOS is running on a variety of devices along the MedAustron accelerator structure, including power converters for about 300 magnets, RF systems, ~150 beam diagnostics devices and ion sources.

Master Timing System

The MedAustron Timing System, called the Real-time Event Distribution Network (REDNet) is based on off-the-shelf timing equipment from Micro Research Finland (MRF) with a redesigned FPGA firmware that extends the MRF high-logic services above the transport layer, as required by the specifics of the MedAustron accelerator.

The timing system comprises a real-time and a non-real-time link. The real-time link is based on the MRF transport layer and custom logic in FPGA, whereas the non-real-time link is based on Gigabit Ethernet [4].

REDNet uses a deterministic network protocol for real-time operation, has reliable distribution of events/data and has fast response times from the timing system master to about 300 controlled devices. It provides a 1 μs real-time control loop resolution, 100 ns timestamp resolution and support for 250 000 different accelerator cycles [3].

REDNet comes with National Instruments' LabVIEW-based software support, ready to be integrated into PXIe based FECs [3].

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MEDAUSTRON BEAM DIAGNOSTICS

Beam Diagnostics Component Architecture

The BD devices in the accelerator are arranged into Low Energy Beam Transfer (LEBT), Medium Energy Beam Transfer (MEBT), Synchrotron ring (SYNC) and High Energy Beam Transfer (HEBT) monitors. All BD devices are part of the distributed control system in which each device class corresponds to its own FECOS component and each beam monitor to its own instance of the component class (Table 1).

For developer efficiency as well as software maintainability reasons, MedAustron added an extra layer of common functionalities, contained in the High Level Component (HLC) FECOS component (Fig. 1). HLC is a parent class to any BD component, already capable of dealing with common operations, used by all BD components, such as: data buffering and publishing, post-processing of data, data analysis, timing system interface support and common error handling.

This software layer also provides a uniform interface to motion system and high voltage controllers associated with various BD components (e.g. Faraday cups use both systems).

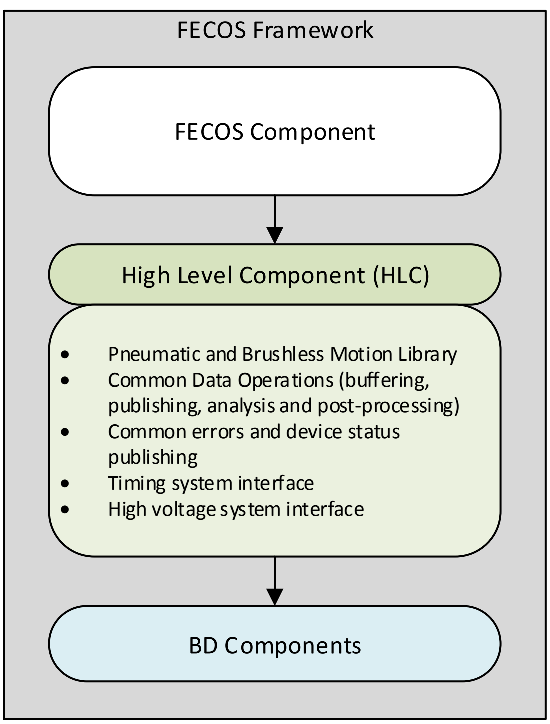

Figure 1: BD components class hierarchy.

Besides FECs, MedAustron also developed a GUI framework, which similarly to FECOS, provides the developer with out-of-the-box libraries, effectively streamlining the development process for GUIs. At the same time, the framework enforces the developer to conform to the foreseen software architecture.

From a software architecture point of view, BD components can be split into two major categories.

The first group are components that measure a continuous beam. These controllers start and stop their signal acquisitions upon user commands.

The second group are components that deal with devices measuring a pulsed or bunched beam, here synchronization is crucial. The latter, start and stop their acquisitions in real-time, triggered by timing events provided by the REDNet.

Table 1: Current Operational Beam Diagnostics Components

Monitor type	Number of instances	Purpose
Faraday Cup	8 in LEBT, 3 in MEBT	Measures beam intensity
Slit Plates	7 in LEBT, 3 in MEBT	Collimator, emittance and beam halo
Wire Scanner	14 in LEBT	Measures beam profile, position, emittance
Faraday Cup Cylindrical	1 in LEBT	Measures beam intensity
Profile Grid Monitor	1 in LEBT, 6 in MEBT	Measures beam profile, emittance and position
Current Transformers	1 in LEBT, 2 in MEBT, 2 in SYNC, 1 in HEBT	Measures beam intensity and number of particles
Position Pick-Ups	1 in MEBT, 20 in SYNC	Measures beam position
Degrader	3 in MEBT	Regulates beam intensity
Stripping Foil	1 in MEBT	Strips the particles of electrons
Luminescent Screens	2 in SYNC	Measures beam position and intensity
Scintillating Fiber Hodoscopes	29 in HEBT	Measures beam profile and position
Qualification Profile Monitor	1 in HEBT	Measures beam profile, position and intensity

Synchronized Measurement Devices

With devices measuring pulsed or bunched beams, the measurement must be synchronized to the passing of the beam.

At MedAustron, there are three different solutions to device triggering, software interrupt triggering, real-time triggering and custom hardware real-time triggering.

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Software Interrupt Triggering

Some devices, like the Scrapers, have to be moved on certain timing events in soft real-time. These software interrupt events are broadcasted by the Main Timing Generator (MTG) over the optical fiber network to the Main Timing Receiver (MTR) component in the PXI system. Using a custom event-driven form of inter-process communication, called FECOS Events (FE), this event is processed by the MTR component and a software interrupt is internally broadcasted to all subscribed components.

If configured, the component (e.g. Scraper) will process such a software event and then drive the actual monitor towards or away from the predefined end position.

This particular solution does not guarantee the amount of time passing between generating, broadcasting, and receiving such a software event in the target component. Typical times range anywhere from 10 ms up to 200 ms.

Real-Time Triggered Devices

In some cases, however, such high response times are not acceptable and for that reason the MTR firmware may skip the software component and immediately generate a pulse on a predefined slot on the backplane, providing hard real-time trigger signals from the MTG through the MTR FPGA directly to individual slots.

These Star Trigger Line (STL) triggers directly trigger readout on the Commercial Off-the-Shelf (COTS) NI DAQmx or NI-Scope data acquisition cards. This solution provides a 1 μs timing event repetition rate with ~30 ps trigger accuracy and is used anywhere along the accelerator structure where a bunched beam is measured.

Custom Hardware Real-Time Triggered Devices

In some cases, data has to be acquired not only on timing events, but also on an external (i.e. frequency accelerating) sampling clock. An alternative solution to Direct Diode Detection principle [5] for measuring the beam tune in the synchrotron, custom development was done. NI FlexRIO FPGA card was used to cope with the continuously increasing sampling frequency (300 kHz to 3 MHz). At each pulse of the sampling clock, the FPGA acquires up to 16 samples, averages them into 1 sample, and adds it in the on-board RAM, thus limiting data bandwidth requirements significantly.

To take pictures of the scintillating fibers in the HEBT, a custom circuit and software component were designed to split the trigger signal and distribute the triggers to some 15 cameras at the same time. The initial trigger again comes via the PXI backplane.

SUMMARY AND CONCLUSIONS

Currently there are approximately a hundred operational BD components, being used for beam commissioning at MedAustron, with the remaining ones well under way (Table 1).

There was considerable integration effort spent, mainly on dealing with many different interfaces, for both custom and COTS hardware and efficient GUI design, the latter of which is still on-going and is being further improved.

With on-site presence of engineers, Cosylab and MedAustron successfully combined the expertise of both companies. The MedAustron BD team contributed with the core expertise of beam diagnostics including the past experience from developments for MedAustron Injector Test Stand (ITS) [6], while the Cosylab team contributed to efficient device-integration having experience with prior control-system development.

ACKNOWLEDGMENT

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