THE ELBE CONTROL SYSTEM – 10 YEARS OF EXPERIENCE WITH COMMERCIAL CONTROL, SCADA AND DAQ ENVIRONMENTS

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Abstract

The electron accelerator facility ELBE is the central experimental site of the Helmholtz-Zentrum Dresden-Rossendorf, Germany. Experiments with Bremsstrahlung started in 2001 and since that, through a series of expansions and modifications, ELBE has evolved to a 24/7 user facility running a total of seven secondary sources including two IR FELs. As its control system, ELBE uses WinCC on top of a networked PLC architecture. For data acquisition with high temporal resolution, PXI and PC based systems are in use, applying National Instruments hardware and LabVIEW application software. Machine protection systems are based on in-house built digital and analogue hardware. An overview of the system is given, along with an experience report on maintenance, reliability and efforts to keep track with ongoing IT, OS and security developments. Limits of application and new demands imposed by the forthcoming facility upgrade as a centre for high intensity beams (in conjunction with TW/PW femtosecond lasers) are discussed.

THE ELBE ACCELERATOR FACILITY

The electron accelerator ELBE is a multiple user facility (see fig. 1) that delivers an electron beam between 5.5 and 33 MeV (pc) with a broad range of temporal schemes, ranging from single sub-pC bunches to a 1 mA cw beams with 13 Mhz repetition rate. Electrons are produced by a 250 kV thermionic d.c. gun and accelerated by two cryomodules, each comprising two 9-cell TESLA-cavities at 1.3 GHz. Until September 2011, the electron beam was alternately delivered to a bremsstrahlung facility, two IR FELs (5…280 µm), a site for channelling X-rays, cell irradiation and detector analysis, a neutron time-of-flight source, a position source and a preliminary electron-laser interaction. Additionally, a well noted superconducting RF gun making progress towards delivering bunch charges of up to 1 nC with significantly decreased transverse emittance. Thus, ELBE is able to address a wide range of scientific disciplines and programs within the Helmholtz community and above.

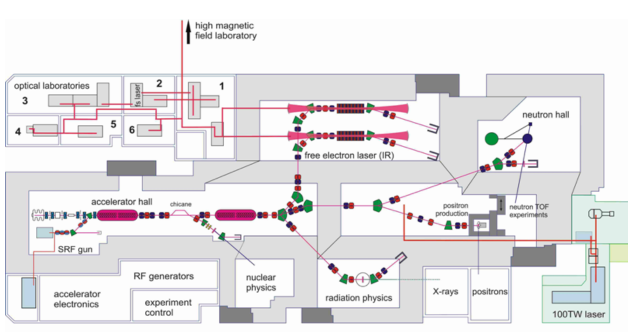

Figure 1: ELBE facility overview.

THE ELBE CONTROL SYSTEM

The ELBE project started in 1999, where the decision was made to use commercial industrial control technology as its control system (CS). Due to its project size, ELBE was sort of a pilot project in electron accelerator technology at the former Forschungszentrum Rossendorf. So this decision was in parts the result of balancing in-house expertise in industrial control systems versus the advantages of systems specifically developed for accelerators. As a multifunctional facility, ELBE has not been built all at once (or better: within few years), but rather grew proportionally with the installed beam lines and user labs.

Looking at the system architecture (fig. 3), the ELBE CS is a mostly straight-forward implementation of the automation pyramid as known from IEC 62264 [1] and depicted in fig. 2. On layers 0…2 we find different branches addressing specific needs of accelerator control: machine control and supervision, machine protection system and data acquisition. On layers 3 & 4 there are web based applications with no direct integration into the ELBE control system.

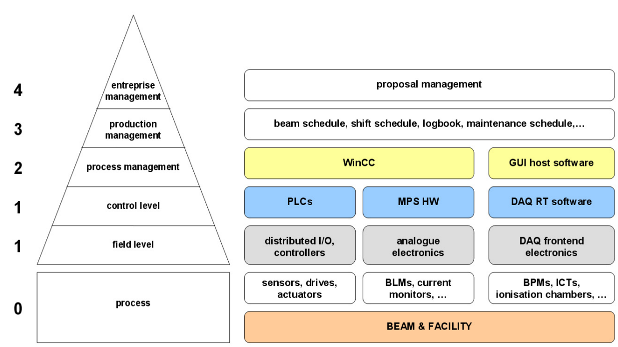

Figure 2: ELBE control system classification.

Machine Control and Supervision

At field level, we use distributed I/O systems interconnected by Profibus DP [2], such as Beckhoff field bus terminals [3], Simatic ET200 [2], or Profibus supporting field devices. "Intelligent slaves" are embedded here to source out specific control tasks from control level.

Control level is represented by Simatic PLCs [2], distinguished by their major areas of functionality, such as personal safety system (PSS), beam generation & beam control, vacuum & media control, beam dump control and cryogenics. This separation was chosen to achieve an optimum match between tasks and technology of the central hardware and firmware. The software is developed in-house using IEC 61131 languages within the Step7 environment [2]. The CPUs are interconnected by Profibus communication to share main machine parameters. Most of them are within one single project.

For supervisory data acquisition and control (SCADA), we use WinCC, a Windows based system [2], in the form of a server-client architecture. Graphical user interface, alarm handling, data logging & trend display and management of machine settings are implemented. For specific systems, additional standalone WinCC stations or operator panels are available to ensure access independently from the main server. WinCC client stations communicate via LAN with the server.

DAQ Systems

Data acquisition for beam diagnostics, demanding fast triggering and high temporal resolution are realized with National Instruments PXI crates and PC DAQ components [10]. Application software programmed using LabVIEW or LabWindows™/CVI [4], running real time or Windows systems. They mainly use shared network variables for data exchange between host applications and acquisition systems. To interface PXI, PCs or user systems (NIM, VME) with the PLC world, we use OPC [5], specifically the Simatic Net OPC server [2], with defined access rights. Different data engines translate OPC item access into shared variables or telegram based TCP/IP communication, where OPC implementation is not available or inconvenient.

Machine Protection System

The MPS consists of a fast and a slow signal chain. The fast chain is realized with hardware electronics, including beam loss detection, vacuum inrush detection & prevention and the RF system interlock with a total reaction time below 2 milliseconds, using PLC interrupt techniques. Hard-wired data exchange with the main PLC enables altering the MPS functionality according to the current beam option, as well as a diagnostics interface. The slower branch of the MPS is spread all over the PLC code units, ensuring beam shutoff within 2 seconds due to technical failure or operational mistakes.

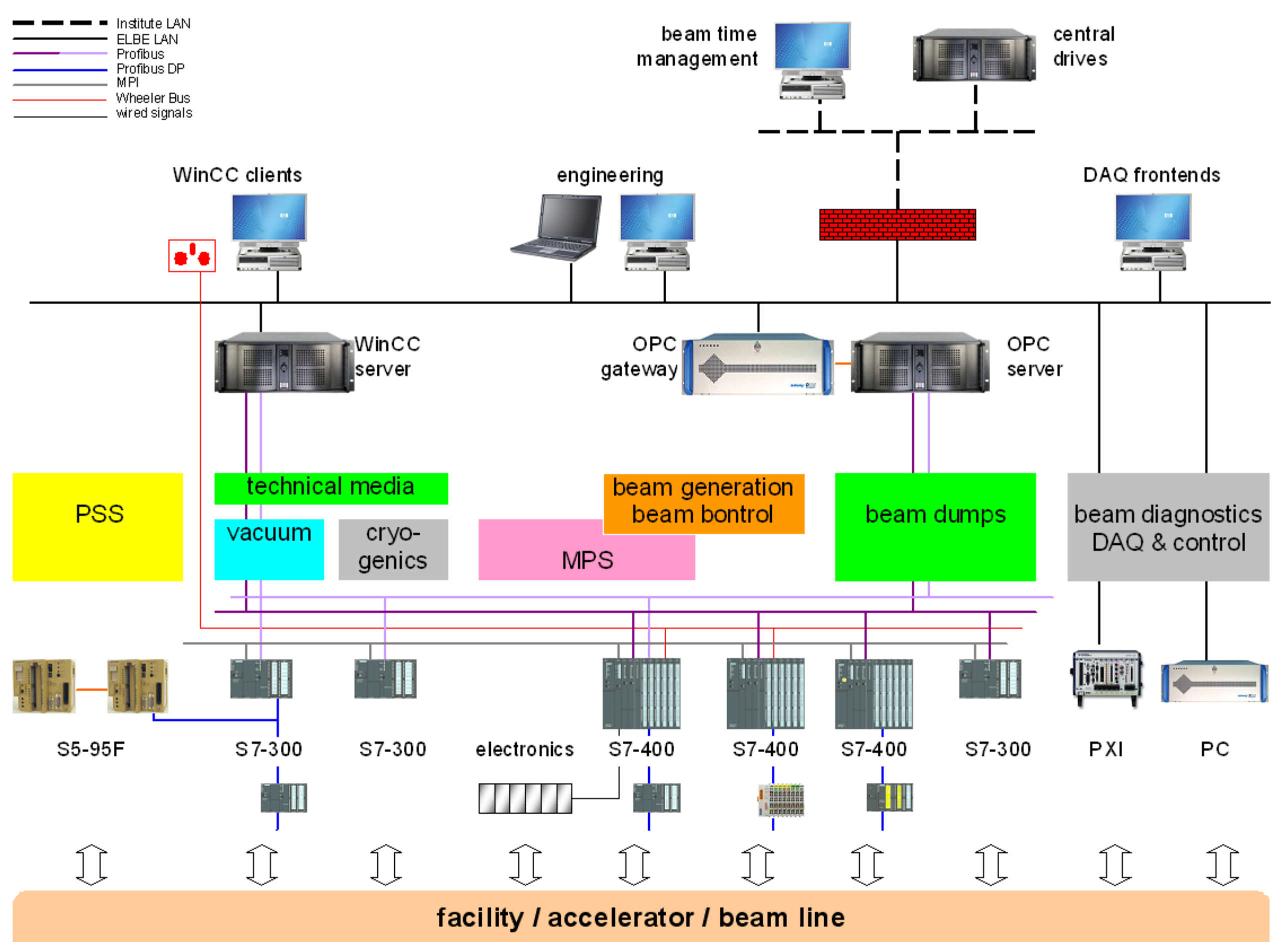

Figure 3: ELBE control system architecture.

Operational Management

ELBE operation is organized by a web based infrastructure like beam time schedule, shift schedules, a logbook with features like failure tracking and user response and a WIKI supporting the operator staff. The overlying administration of experimental proposals is a centralized service of the Helmholtz-Zentrum Dresden-Rossendorf. Integration of these tools into the machine control system is not yet available.

System Key Figures

As all pictures show only exemplarily the system characteristics, a few key number are given in the below table:

Table 1: ELBE Control System Key Figures (Rounded)

PLC CPUs	12
PLC data points	4500
PLC plain machine code	1.5 MB
PLC development software	Step7 V5.5
MPS fast channels	80
WinCC process tags	7000
WinCC client PCs	25
WinCC software	V7.0
OPC items	250
LabVIEW development software	2009
PC / PXI DAQ systems	10
PC / PXI DAQ applications	15
MPS fast hardware channels	80

OPERATIONAL EXPERIENCE AND SYSTEM MANAGEMENT

System Availability and Stability

As a measure for system availability, one can simply monitor the failure or unavailability rate of servers, PLC units, communications and other systems. As ELBE is a single beam linear machine, at least downstream the accelerator subsystems are not permanently needed to deliver beam. In fact, it is a special advantage that for beam time statistics, a critical failure scenario can often be compensated by changing the schedule. Thus, availability is more a result of managing infrastructure, system maintenance and implementing a proper failure monitoring to be one step beyond.

Hardware Management

Usual failure scenarios with few recurrences a year involving CS components are:

- PLC hardware failure, really rare if operational conditions are maintained as specified (this is in terms of radiation exposure not always possible)
- field bus components failure, can occur under hard EMC conditions
- PC & PXI system hardware failure, likely for standard PCs

To meet hardware and communication difficulties, a monitoring system has been established during the last three years to permanently check hardware, field devices (i.e. magnet power supplies, drives), field bus communication, serial connections, as well as CPU operation by means of PLC alarm handling and software diagnostics. Malfunctions are reported to WinCC, enabling statistical analysis within its alarm system. This often helped to detect sub system failure well before the specific components are needed for beam delivery. Commercial PLC technology has been experienced as ideal for implementation of simpler control functionality with a high demand on availability and physical robustness. The advantage of commercial hardware in general is that staff does not have worry about electronics design, availability of parts or firmware compliance, if good manufacturer support is provided.

Software Management

More often, due to permanent modification of the facility during the last years, we experience several types of software problems:

- programming errors in PLC code, WinCC scripts and other software that appear in unlikely and unforeseen system states
- WinCC server failures, i.e. due to project modification during system runtime or communication errors
- communication problems between DAQ components and applications
- malfunction of application software

Dealing with these problems requires (beyond the pure code verification) software and IT management measures. To become independent from overall IT policies (which are usually forced on any system that connects to the general IT infrastructure), the ELBE control system has been segregated from the overall IT network by an own domain behind a firewall (see fig. 3). Dedicated access rights and trusted relations for accounts and groups enable access to central services and drives.

For NI or Siemens application and development software, compatibility of operating systems, development software, hardware components and IT policies has to be checked carefully. Proven and tested configurations are made in-house standards. WinCC itself already offers log files for its own components, such as compiler, script monitoring, runtime software or connection management.

While PLC code usually has a durability of 10 years plus and is nearly independent from the development suite version and the OS, this is not necessarily the case for higher level programming, including LabVIEW. Therefore, we limit the changeover of releases to what is absolutely necessary. Further, software projects are managed using professional versioning tools running on central IT resources, in combination with routine backup copies.

To give some numbers, table 2 shows renewal and upgrade rate we have experienced or can expect in all conscience:

Table 2: Renewal and Upgrade Rates

PLC hardware	> 10 yrs *
PLC application software	~ 10 yrs *
PLC development software	~ 3 yrs
WinCC server and client PCs	~ 5 yrs
WinCC application software	> 5 yrs **
WinCC development software	~ 3 yrs
NI hardware (PC)	~ 5 yrs
NI hardware (PXI)	> 5 yrs ***
NI application software	~ 2 yrs
NI development software	~ 3 yrs

* few PLC systems have been completely replaced by now, they run between 3 and 10 years

** driven by new software options, WinCC applications were reworked in parts

*** PXI system are involved for about 5 years, no complete replacements so far

OUTLOOK: FUTURE CENTRE FOR HIGH INTENSITY BEAMS

From October 2011 on, parts of the ELBE beam lines and user facilities are being dismantled to give room for new installations addressing the scientific needs of our users or improvement of their experimental sites. Including a building extension, we will install a new THz source and laboratory, the revised neutron production target and the revised interaction chamber for high brightness laser beams with ELBE electrons.

For the ELBE CS, this is an ideal opportunity to keep track with recent and already proven developments:

- The aged out S5 system of the PSS is currently replaced by S7 technology. This system will be expanded to the ne building, including interfaces to personnel access management.
- New beam lines will be equipped with newer PLCs, including extensive re-engineering of the PLC software towards better object orientation and efficiency.
- Profibus Technology will be partly replaced by ProfiNET (an industrial Ethernet standard) to provide more convenient data connections between PLCs and the PC/PXI world based on TCP/IP, as well as to improve the coupling performance of the WinCC system.
- As an in-house pilot project, an optical beam line will equipped with EPICS control. Interfaces to WinCC are realized with TCP/IP communication via PLCs.
- The machine protection system fast chain will be completely redesigned in-house, applying pure hardware logics with PLC interface. The overall reaction time will be decreased below 1 ms, according to the demands of the beam power upgrade (64 kW maximum). PLC interrupt handling is limited to about 1.5 ms and will not be involved in this system anymore

SUMMARY

When looking at implementation time and maintenance, the ELBE control system with its mainly commercial components and in-hose developed software is a good choice for a facility of this size with around 25 staff members running in full 24/7 user operation. The price of this is a large variety of interfaces and system constraints to be managed, and the lack of tools specifically designed for accelerator physics. The aimed future role of ELBE as a facility with > 50 % external users demands more system openness and data availability than we can provide by now, and will more and more involve industrial and office IT.

REFERENCES

[1] IEC 62242-1 “Enterprise control system intzegration – Part 1: Models and Terminology”, Geneva, Switzerland, 2003 (http://www.iec.ch)
[2] http://www.automation.siemens.com
[3] http://www.beckhoff.com/
[4] http://www.ni.com
[5] http://www.opcfoundation.org/