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CONTROL SYSTEM PROJECTS AT THE ELECTRON STORAGE RING DELTA

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Abstract

Data logging and archiving is an important task to identify and investigate malfunctions during storage ring operation. In order to enable a high-performance fault analysis, large amounts of data must be processed effectively. For this purpose a fundamental redesign of the present SQL database was necessary.

The VME/VxWorks-driven CAN bus has been used for many years as the main field bus of the DELTA control system. Unfortunately, the corresponding CAN bus I/O-modules were discontinued by the manufacturer. Thus, the CAN field bus is currently being replaced gradually by a more up-to-date Modbus/TCP-IP communication (WAGO), which largely supersedes the VME/VxWorks layer. After hard- and software integration into the EPICS environment, several projects have been realized using this powerful field bus communication.

The server migration to a 64-bit architecture was already carried out in the past. By now, all client programs and software tools have also been converted to 64-bit versions.

In addition, the fast orbit feedback system project, using a in-house FPGA-based hardware, has been resumed.

This report provides an overview of the developments and results of each project.

INTRODUCTION

DELTA is a 1.5-GeV electron storage ring operated as a synchrotron light source by the TU Dortmund University [1]. Since 2011, a short-pulse facility for coherent sub-picosecond light pulses in the vacuum-ultraviolet (VUV) and Terahertz (THz) regimes has been established [2], [3]. In order to reach shorter wavelengths, an upgrade applying the so-called echo-enabled harmonic generation (EEHG) scheme is under preparation [4], [5]. Further upcoming upgrades like the installation of a new superconducting wiggler magnet (SCW) as well as the associated expansion of the storage ring RF-System (integration of a EU-type-cavity [6]) increase the need for a number of control system hardware and software innovations.

REDESIGN OF THE EPICS-LOG DATABASE

All important actual machine data is stored in EPICS records, collected by a logger daemon (linux systemd service) and archived in the open-source object-relational database management system (ORDBMS) PostgreSQL [7].

Usually, typical data logging tables become quite extensive over time, compared to the working memory (RAM) of DB servers. To improve query performance in such large tables the basic table partitioning functionality of PostgreSQL is used [8]. Partitioning refers to splitting what is logically one large table into smaller physical pieces. PostgreSQL supports partitioning via table inheritance (see Fig. 1).

For each month (*mXX*) of yearly (*yXXXX*) logged data, there is a separate data table (*log_yXXXX_mXX*) that inherits from the base table *log* (see Fig. 1, blue arrows). A *sql-SELECT* command on the base table automatically accesses all the monthly tables. Only the tables that are in the time slot of the *sql-WHERE* condition are searched which significantly accelerates data access.

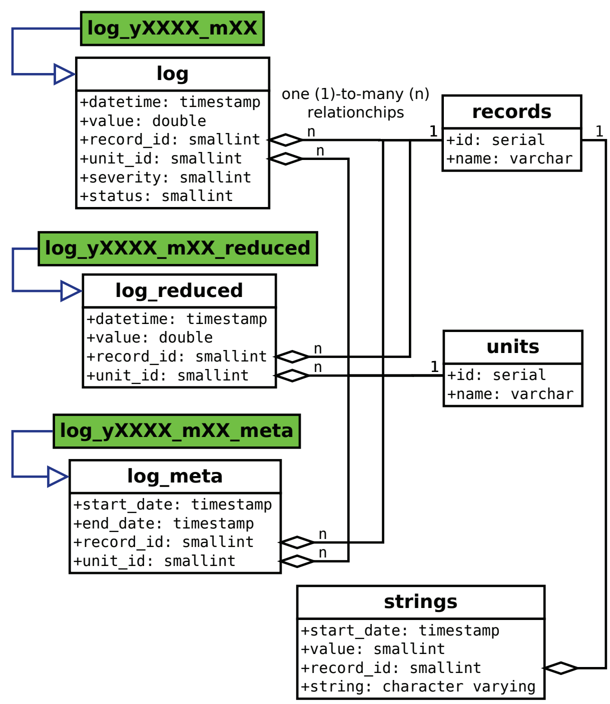

Figure 1: Epics-Log DB inheritance scheme (class diagram in UML notation [9]).

In the intermediate tables *log_yXXXX_mXX_reduced* (green), which inherit from *log_reduced*, the values of the records of the associated monthly table are averaged over one minute intervals. This is useful for evaluating larger time periods. In the intermediate tables which inherit from table *log_meta*, the time intervals of the associated monthly table are stored in which a record has a specific unit (e.g. mm, mA, V, etc.). The *strings* table stores the mapping of ENUM values to record values for individual EPICS records

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(e.g., mbbi or bi records). These entries are valid beginning from *start_date*. The tables *records* and *units* contain the assignments of the text values to the corresponding IDs.

PostgreSQL optimizations as well as creation and updating of the intermediate DB tables (*log_reduced*, *log_meta see*, see Fig. 1) are performed automatically by supporting scripts (e.g. maintenance and backup services).

The DB-data can be read out via the in-house command line tool *epicslog* which is based on standard SQL commands and a Python library [10], [11]. For more comfortable use of the Epicslog-DB a graphical user interface (GUI) is in progress. It will combine the properties of an in-house developed TCL/TK-based data display program (*TimeLog* for archived data) and the Epics StripTool [12] (for real-time data).

HARDWARE UPGRADES

TCP/IP-based Field Bus Extensions

Controlling of DELTA accelerator components is accomplished in many places via the Control Area Network (CAN) field bus. A variety of different types (e.g. D-IN/OUT, A-IN/OUT) of CAN I/O-modules (so called CAN knots) can be connected to VME-CAN-cards which are driven by VME-VxWorks/EPICS servers. In the medium-term this extensive VME-middle layer will be replaced by a dedicated, less complex TCP/IP-based network.

After comparison and testing various suppliers, three projects have been realized using the DIN-rail-mountable, modular extensible and compact WAGO-I/O system [13]. This product is intended for building and industrial automation. It provides a wide selection of multi-channel digital and analog in/out-modules for various signal types as well as intelligent stepper motor controllers. In addition, it is field bus independent and supports numerous communication protocols (e.g. Profibus, CANopen, EtherCAT, MODBUS) and industrial Ethernet standards. DELTA controls applies an Ethernet field bus coupler (Type 750-352) which is designed for communication in both Ethernet/IP and MODBUS networks. In order to communicate with the WAGO modules/terminals, the MODBUS protocol [14] is used, which is encapsulated in the TCP/IP protocol (Modbus over Ethernet, Modbus-TCP) [15], [16].

The field bus coupler detects all connected I/O terminals and creates a local process image. This process image may include a mixed arrangement of analog (word-by-word data transfer) and digital (bit-by-bit data transfer) modules. In-house developed GUI software tools enable general setup, configuration and diagnostics (e.g. port mappings and offset definitions) of individual composed field bus I/O assemblys (coupler and terminals), which can be stored in non-persistent memory (EEPROM) on the coupler. The link to the EPICS interface is realized by using the Modbus package [17] (TCP/IP with Modbus) over an asynchronous device driver support (asynDriver framework [18]).

The following projects were implemented using this new I/O system.

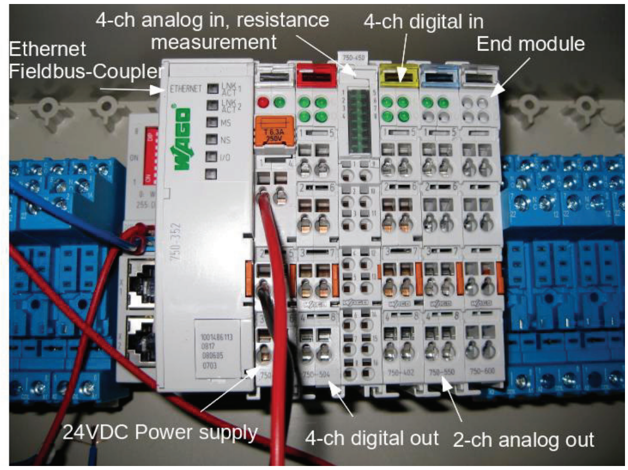

Figure 2: WAGO-I/O system (here: RF watercooling control).

- In conjunction with the new superconducting wiggler magnet (SCW) an extension of the DELTA RF-system is necessary. To compensate for the higher energy loss, caused by the SCW, an additional EU-type-cavity [6] must be installed. The water cooling control for this device is build in-house. Data exchange will be provided by standard WAGO analog and digital in/out-terminals (see Fig. 2). The system monitors and regulates different signals, sensors and devices like: injection pump, valve states, interlock signals, temperature sensors as well as a variety of water flow monitors. The high level control will be performed by an EPICS server.

- Intense sub-picosecond light pulses in the vacuum ultraviolet regime are generated based on the so-called coherent harmonic generation (CHG) principle scheme [2], [3]. In this process, a laser-electron interaction generates a dip in the longitudinal electron distribution which causes coherent emission of terahertz (THz) radiation [19]. These THz pulses modulate the refractive index of an electro-optically active crystal. After passing the crystal, the modulation of the Yb-laser pulse can be detected and serves as a direct measure for the temporal shape of the dip in the electron distribution. The electro-optical setup of such a fiber laser system consists of various polarizers, mirrors, grating compressors and fiber stretchers (see Fig. 3). For remote control and automatic feedback loops, some of these components are equipped with motorized linear or rotation stages. The quarter- & half-wave plates (QWP, HWP) are driven by rotation stages whereas mirrors and the grating compressors are moved by translation stages. All six motorized units are connected to the WAGO I/O-system via motor stepper controllers (Typ 750-671). The 750-671 module is an intelligent stepper controller with on-board power driver designed to control 2-phase stepper motors up to 24V/1.5A [13].

- As an extension of the CHG facility towards smaller wavelengths the implementation of EEHG (echo-

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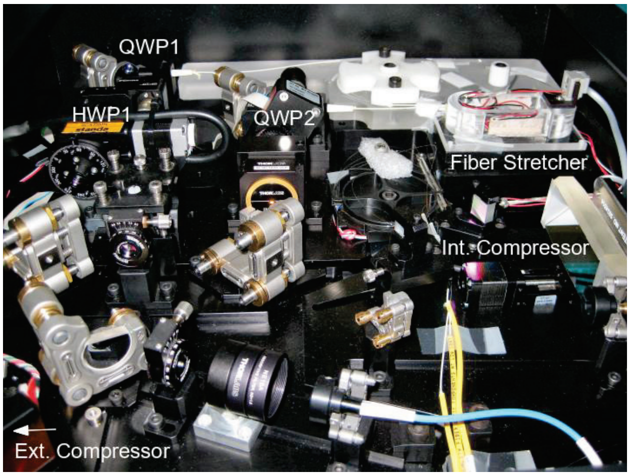

Figure 3: Fiber laser system.

enabled harmonic generation) is presently in preparation [4], [5]. The EEHG scheme requires additional undulators (U200) which have already been delivered. The magnet power supply (PS) interlock system, taking into account the magnet cooling water flow, coil temperature and emergency stop switch, is realized with the WAGO I/O system too. Here common digital in/out-modules are installed.

Client-Server and Network Updates

For more flexibility and performance as well as for security aspects the complete control network has been reorganized to VLAN (virtual local area network). Now each remote TCP/IP device connected to a managed control system switch can be assigned seamlessly to any subnetwork (e.g. controls, office, user, management, testbed) without hardware rewiring.

For the same reason, a SAN (storage area network) concept has been introduced (see Fig. 4). SAN is a high speed storage network which provides access to hard disk arrays as block level data storage. In combination with virtual machines (here: KVM-based VMs) SANs provide a perfect method to share centralized data (e.g. EPICS log) and to guarantee high server availability. For this purpose all servers and services (e.g. EPICS soft-iocs) must be virtualized. The SAN unit provides two fiber channel (FC) IO-cards with four FC-SFP connectors, respectively. Since the DELTA control system consists of four servers at maximum, each equipped with two FC connectors, redundant wiring is possible without an optional SAN switch (see Fig. 4).

After server migration to 64-bit Linux (debian 8, [20]), now all clients are prepared for 64-bit (debian 8) operation, too. Therefor, more than 200 applications and scripts had to be adapted. Additionally, the Qt-based K Desktop Environment (KDE) [21] is replaced by the open source desktop environment Xfce [22]. Xfce is easy to use, fast and lightweight. It is based on standards like the GTK widget toolkit and uses the Xfwm window manager.

At Delta, all client PCs are booting the operating system (OS) as well as the control system software over the network (PXE, TFTP, NFS) [23]. The separation of client specific settings is realized by symbolic links which has proved to be error-prone and cumbersome. For this reason a union mount file system has been introduced. This kind of file system allows to stack different file systems one on top of each other, whereby only the top layer is writable. The files of the lower layers are visible, but changes are only stored in the top layer. Since low-level changes are reserved for system administrators only, maintenance and stability of the client system are significantly improved. All Delta client PCs use OverlayFS which is merged into the Linux kernel since version 3.18 [24].

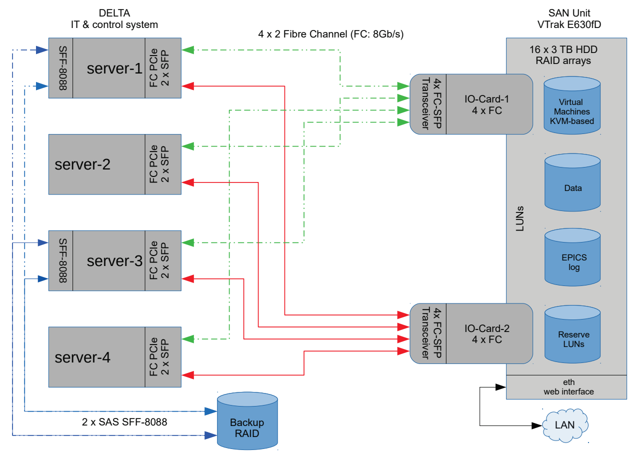

Figure 4: SAN concept at DELTA.

NEW SUPERCONDUCTING WIGGLER MAGNET (SCW)

The fault-prone (18 years in operation) 5.5 Tesla superconducting asymmetric wiggler (SAW) will be replaced by a 7 Tesla superconducting wiggler magnet with 11 sin-like periods (SCW) [25]. This new device will generate five times higher photon fluxes in the hard X-ray regime (@25 keV). The magnet is already ordered and delivery is expected in 2018. Although, the SCW operates as a stand alone device with a local control system, integration into the DELTA control system is madantory.

The central unit of the SCW controls is a so called "junction box" (JB) build and provided by the manufacturer of the SCW [26]. The JB is the central data acquisition device which low level controls and monitors all main components of the SCW, e.g. hardware interlock, watchdog, compressors, magnet- and cryo-sensors as well as I/O data collection (see Fig. 5). The JB is connected to an IOC via RS232/Ethernet. The IOC, consisting of an embedded computer system running Linux-OS & EPICS, supports various I/O-interfaces, e.g. CAN, LAN, RS232 as well as USB and VGA for field site monitoring (local GUI-client). Moreover, it acts as an EPICS server and handles the high level control, e.g. steerer and main magnet power supply ramping,

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magnetic field adjustment and software interlock. The more complex high level control is performed by an EPICS sequencer [27] whereas the EPICS server provides all relevant EPICS records to the DELTA client operator interfaces (OPI) for SCW remote control.

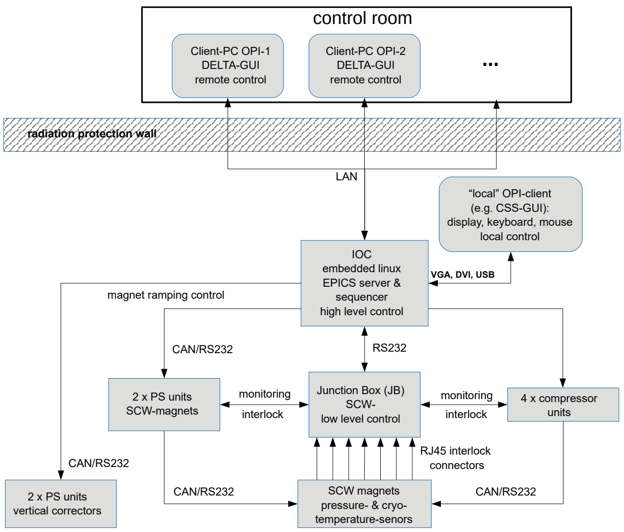

Figure 5: Integration of the SCW control system.

FAST ORBIT FEEDBACK

Further progress has been made in setting up the global fast orbit feedback system (FOFB). The FOFB will supplement the global slow orbit feedback (SOFB) with a cut-off frequency below 10 Hz to more than a few 100 Hz. At DELTA, a total of 54 BPMs are read out by a mixture of I-Tech Libera (Brilliance, Electron) and Bergoz MX-BPM electronics [28]. For the FOFB all Bergoz MX-BPMs are connected to the in-house developed FPGA based digital frontend Extender-3000 [29], [30].

Due to synchronization problems among the read-out electronics, the FPGA design of the Extender-3000 was replaced by a new one. This design implements a packet-based synchronization mode additional to the common clock-based synchronization mode that is part of the diamond communication controller (DCC [31]). A stable network topology is necessary to obtain a well working, fault-tolerant orbit feedback, which is given by the optimized ring topology proposed by diamond [31], which is now utilized at DELTA.

Now, fast global data exchange can be captured synchronously within a time frame of about 1/10kHz. The complete orbit correction system (see Fig. 6) including the additionally installed fast corrector magnets (21 vertical and 19 horizontal steerer magnets) is in a test phase. First BPM time series measurements indicate valid functionality. Also first response matrix measurements show promising results.

CONCLUSION AND OUTLOOK

The projects described in this paper are either underway or in preparation. The Epics-Log DB was completely revised and a corresponding GUI interface is currently in progress.

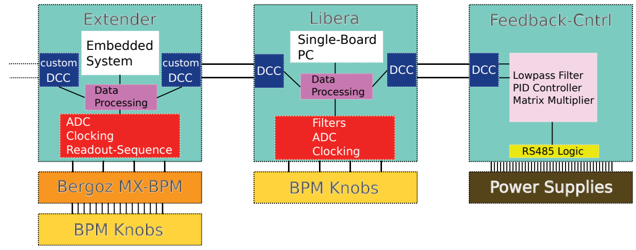

Figure 6: General layout of the FOFB at DELTA.

A SAN (storage area network) has been installed. After virtualization, all servers must be migrated to this network storage. The OverlayFS for the 64-bit client PCs has been in the test phase for several months now. The new superconducting wiggler magnet will be delivered soon. Integration into the DELTA control system is being prepared. The new TCP/IP-based field bus system is already available. Three different controls have been successfully installed. The fast orbit feedback system was able to carry out promising initial test measurements and is about to be completed.

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