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TOWARDS A NEW CONTROL SYSTEM FOR PETRA IV

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Abstract

At DESY, an upgrade of the PETRA III synchrotron light source towards a fourth-generation, low emittance machine PETRA IV is currently being actively pursued. The basic concept of the control system of PETRA IV is to exploit synergies between all accelerator facilities operated by DESY. The key figures of PETRA IV's new accelerator control system include the DOOCS control system framework, high-end MTCA.4 technology compliant hardware interfaces for triggered, high-performance applications and hardware interfaces for conventional slow-control applications compliant with industrial process control standards such as OPC UA, and enhanced data acquisition and data storage capabilities. In addition, the suitability of standards for graphical user interfaces based on novel Web application technologies will be investigated. Finally, there is a general focus on improving quality management and quality assurance measures, including proper configuration management, requirements management, bug tracking, software development, and software lifetime management. The paper will report on the current state of development.

INTRODUCTION

With PETRA III, DESY operates one of the best storage ring X-ray radiation sources in the world. PETRA III is a 2300-metre-long storage ring feeding 24 user beamlines. It is operated either in brightness mode (480 equally distributed bunches, 120 mA stored beam) or in timing mode (40 equally distributed bunches, 100 mA stored beam). Research groups from all over the world use the particularly brilliant, intense X-ray light for a variety of experiments - from medical to materials research.

DESY plans to expand it into a high-resolution 3D X-ray microscope for chemical and physical processes. PETRA IV [1] will extend the X-ray view to all length scales, from the atom to millimetres. Researchers can thus analyse processes inside a catalyst, a battery or a microchip under realistic operating conditions and specifically tailor materials with nanostructures. PETRA IV also offers outstanding possibilities and optimal experimental conditions for industry.

PETRA IV will replace the PETRA III facility and will be housed by the existing PETRA III buildings. An additional experimental hall will provide space for additional 18 user beamlines. In addition, a new synchrotron (DESY IV) will serve as booster between the existing electron source LINAC II and PETRA IV.

In 2020, a preparatory phase for the future project PETRA IV was initiated with the aim of submitting a Technical Design Report by mid-2023. Construction work is scheduled to begin in early 2026, followed by a commissioning phase in 2028.

The following chapter will describe the baseline of the accelerator control system of the future PETRA IV facility.

CONTROL SYSTEM DESIGN BASELINE

The development and implementation of the future PETRA IV accelerator control system will be embedded in a long-term process to consolidate the whole accelerator control system landscape at DESY and to take advantage of synergies between the accelerator facilities operated by DESY. The accelerator control system of PETRA IV will closely follow the control system concept implemented at the European XFEL. Consequently, support and maintenance of the existing control system framework used at PETRA III will not be continued beyond its expected lifetime.

Control System Framework

The Distributed Object-Oriented Control System (DOOCS) [2] will form the basis of the future control system of PETRA IV. DOOCS is the established control system framework at FLASH, European XFEL and other conventional accelerator facilities operated by DESY, as well as advanced accelerator projects based on plasma wake field acceleration.

DOOCS is based on a distributed client-server architecture combined with a device-oriented view. Each control system parameter is made accessible via network calls through a device application. Its transportation layer is based on the standardized, industrial RPC protocol. The DOOCS framework is written in C++ and supports a variety of fieldbus and hardware interfaces via device classes. These are accessible through additional libraries which can be linked as needed individually to the server core library. Libraries for creating client applications in C++, Java, Python or MATLAB are available either as a separate implementation or as C-bindings. Through the client API DOOCS provides access to multiple popular control system such as EPICS and TANGO. At DESY, EPICS is used for facility control (electrical power and water distribution, ventilation and air conditioning) and control of the cryogenic systems, while TANGO is the standard control system for operating the beam line components and the experimental equipment.

The initial development of DOOCS dates back to 1993. Since that time, it has steadily developed into a powerful, reliable and versatile control system. Recently, a roadmap was established to meet the increasing user demands over the next decade and to continue to keep pace with the rapid developments in IT technologies.

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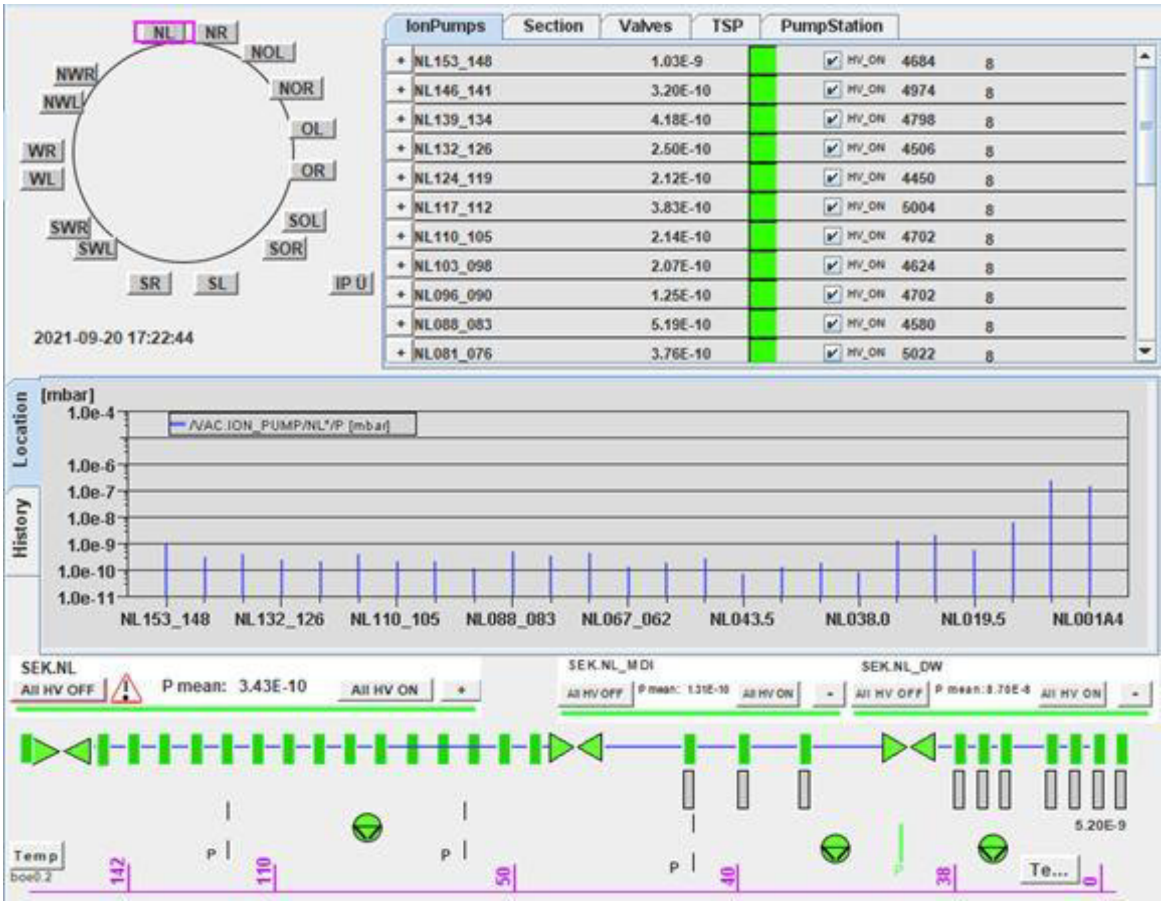

Figure 1: Sample JDDD display.

Graphical User Interfaces

The proven Java DOOCS Data Display (JDDD) [3] is chosen as standard user interface. JDDD is a Java application and follows a thin-client approach with a functional and rich set of widgets. Individual UI components can be easily created through a versatile editor IDE without the knowledge of any programming language (Fig. 1).

While JDDD is the tool of choice for the standard beam operation as well as operating technical accelerator devices and systems, Python is increasingly becoming the preferred programming language for rapid prototyping and visualization of scientific procedures and data.

Even if JDDD also provides a secure, HTML5-based Web interface, with the advent of modern Web standards such as Progressive Web Apps (PWA) other promising alternatives to design graphical user applications seem to be available. PWA are multi-platform, browser-based applications with a look-and-feel of versatile classical desktop applications. The potential of graphical user applications based on the React [4] JavaScript framework is currently investigated.

Hardware Interfaces

In general, the hardware interfaces for triggered, high-performance applications (e.g. beam diagnostics, injection / ejection system, feedback systems, timing / synchronization system, machine protection system, RF control) will be compliant with the high-end MTCA.4 technology [5]. MTCA.4 is the accepted long-term standard for the DESY accelerators and is enjoying growing popularity within the accelerator community and the related industry. The operating system for server hosts running within the MTCA.4 platform will be Linux.

The base configuration of a MTCA system includes a power-supply, a Management-Controller Hub (MCH), a CPU as an Advanced Mezzanine Card (AMC), a Timing System AMC, and optionally a Timing System Rear Transition Module (RTM) if required.

Based on the existing MTCA.4 timing module used at the European XFEL, a successor model is currently being developed at DESY. This module will function either as a transmitter or as a receiver. The module will distribute the RF reference signal, provide low-jitter clocks and trigger signals as well as beam-synchronous data such as a timestamp, revolution counters, beam modes, bunch pattern and bunch current via a dedicated optical fibre network. Storage ring, booster and linac will each be equipped with central timing system components, synchronized across the overall facility. Beamline experiments can make use of the same MTCA-based timing system hardware to exploit all accelerator-provided timing system information.

Dependent on the location in the accelerator, the MTCA systems will be equipped with additional digital I/O AMC modules for specific read-out, measurement and control tasks, e.g. interface boards to the beam position monitor

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front-end electronics or feedback controllers as well as ADC boards to acquire measured bunch current pulses or HV-pulses generated by the injection and ejection elements.

All of these modules can be managed remotely via Intelligent Platform Management Interface (IPMI) interfaces and the MCH. Linux drivers with hot-swap support allow for PCIe access of the various AMC and RTM modules from applications running on the CPU AMC.

Likewise, the hardware interfaces for conventional slow-control applications (e.g. magnet power supplies, vacuum system) will be compliant with industrial process control standards preferably providing a well-established and widely-used industrial API.

Special emphasis will be put on the OPC UA interface technology [6]. All power converters for magnets as well as power supplies for getter pumps of the vacuum system will implement an OPC UA server. DOOCS provides a generic bridge server, which seamlessly integrates OPC UA devices into the accelerator control system.

Front-end hardware systems based on the Beckhoff controller technology (EtherCAT / OPC UA) will also be used in many cases, e.g. to control the motors of the insertion devices or of the movable girders supporting all accelerator components. In addition, classical PLC system have to be interfaced. In both cases, generic bridge servers to the accelerator control system are available.

Data Acquisition and Archiving

Systems and tools for data acquisition, data archiving and data providing will be implemented with domain-specific interface standards and technologies. Both, time series data as well as snapshot data have to be considered.

Time series data include data from fast data streams in synchronism with the beam revolution frequency (130 kHz) such as single-turn orbit data, and data from slow data stream updated asynchronously with less than 100 Hz. These include e.g. multi-turn orbit data or magnet currents.

Snapshots are measured and stored once and are triggered either by a value change (e.g. in case of a device error), by a specific event (e.g. at beam injection), or by an operator request (e.g. while performing a study).

For both cases, versatile visualization and analysis tools have to be provided. Particular emphasis will be placed on the capability to support data science applications operated in either online (e.g. learning feedbacks, learning tuning procedures) or offline (e.g. failure prediction, predictive maintenance forecast) mode.

High-Level Control Applications

A team of controls experts and accelerator physicists has been already established to interface specific needs of beam commissioning and operations and implement corresponding tools and applications.

The well proven MATLAB Middle Layer library suite [7] supplemented by procedures developed for PETRA III operation will be adapted for further use at PETRA IV. In addition, novel control concepts based on advanced machine learning algorithms are being developed and tested at PETRA III. Resulting applications to be intended afterwards for regular standard operations will be transformed to well-behaved operator panels or server applications.

Similar to the so-called Virtual European XFEL Accelerator [8] a Virtual PETRA Accelerator infrastructure is being set-up. It will be used to test new concepts, enhancements or just modified and improved applications before they will be put into the field which can potentially save significantly commissioning and machine studies time.

Quality Assurance

High availability is a key parameter of modern synchrotron light sources. This must also be reflected in the availability and quality of the software and hardware components of the control system.

Various quality assurance measures are being set-up. These include a revision of the issue and bug tracking workflow and a proper management of requirements for the control system during the preparatory, construction, commissioning and operating phase of PETRA IV. A template has been worked out to document the requirements for the control system which will be regularly reviewed and adapted if needed. Training courses for application developers covering various topics, e.g. application software development, graphical user interface design, software testing etc., are being organized.

The control system of PETRA IV will consist of a huge number of software artefacts. In contrast to PETRA III, also the number of hardware components is significantly larger. A comprehensive configuration management of software and hardware components has to be provided during all stages of the PETRA IV life cycle, e.g. by maintaining a configuration management data base or by well-defined workflows and processes for change and release management.

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