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DEVELOPING CONTROL SYSTEM SPECIFICATIONS AND REQUIREMENTS FOR THE ELECTRON ION COLLIDER*

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Abstract

An Accelerator Research facility is a unique science and engineering challenge in that the requirements for developing a robust, optimized science facility are limited by engineering and cost limitations. Each facility is planned to achieve some science goal within a given schedule and budget and is then expected to operate for three decades. In three decades, the mechanical systems and the industrial IO to control them is not likely to change. In that same time, electronics will go through some 4 generations of change. The software that integrates the systems and provides tools for operations, automation, data analysis and machine studies will have many new standards. To help understand the process of designing and planning such a facility, we explain the specifications and requirements for the Electron Ion Collider (EIC) from both a physics and engineering perspective.

INTRODUCTION

The Electron-Ion Collider (EIC) is being built to research the high energy spin-polarized particle beams in order to quantify contribution of the intrinsic spins, orbital momenta of quarks, anti-quarks and gluons to the characteristic spins of observe particles [1]. High collision luminosity 10^{33}-10^{34} cm^{-2} s^{-1} over a broad range in center-of-mass energies (ECM) from 20 GeV to 140 GeV will enable precise determination of the confined momentum and spatial distributions of the sea of quarks and gluons in nucleons and nuclei. One of the most challenging tasks is to obtain high luminosity. The EIC consists of electron and hadron accelerators with an interaction region to produce collisions of electron and proton beams with high intensity (shown in Fig. 1). The electron injection scheme includes: a 400 MeV LINAC, a Rapid Cycling Synchrotron (RCS) with energy ramp from 400 MeV to 18 GeV, and an Electron Storage Ring (ESR) with operation at 5 GeV, 10 GeV and 18 GeV energies. The average current of the electron beam at 5 GeV and 10 GeV is $I_{av} = 2.5$ A within $M = 1160$ bunches with a $\sigma_s = 7$ mm bunch length. The average current at 18 GeV is much smaller, $I_{av} = 0.23$ A. The standard vacuum chamber for ESR has an elliptical profile with 80 mm x 36 mm (copper). The Ion Injection Scheme is based on the existing RHIC accelerator complex, where the proton beam will be accelerated to 41 GeV, 100 GeV and 275 GeV energies. The entire complex includes a 200 MeV LINAC, Booster, Alternating Gradient Synchrotron (AGS) and a Hadron Storage Ring (HSR) with more aggressive beam parameters as $I_{av} = 0.69$ A within $M = 290$ bunches with a $\sigma_s = 60$-mm bunch length. The present RHIC vacuum system will be fully updated, and it includes amorphous carbon (aC) and copper (Cu) coated stainless steel beam screen chambers, which are actively cooled [2]. To achieve 10^{34} cm^{-2} s^{-1} luminosity, the strong hadron cooling concept (SHC) is being developed.

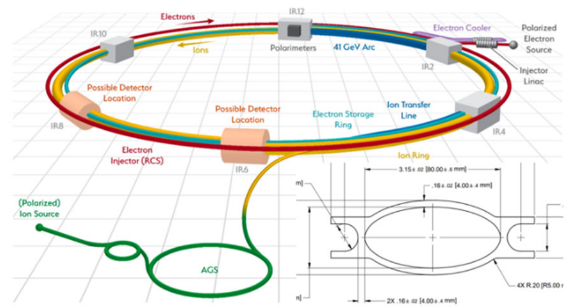

Figure 1: EIC layout with profile of the vacuum chamber for the electron storage ring.

This paper focuses on e activity to capture the control system specifications. These specifications include the integration of all instrumentation to meet the needs of the facility for construction, implementation, integration, subsystem commissioning, beam commissioning and operations. Developing these specifications for a new accelerator facility requires a broad range of skills to determine both the necessary capabilities and the potential capabilities to improve efficiency throughout the life cycle of the project.

CONTROL SYSTEM COMPONENTS

The control system includes a broad range of functionality. The lowest level the control system provides electrical and computer interfaces to all instrumentation for control and monitoring. It also includes the standard network and the commercial computer hardware for all hardware integration. It includes the middle layer services to collect, manage and provide aggregated data such as time series archives and configuration data such as the lattice. The controls group provides the operator stations and storage to provide Supervisory Control and Data Acquisition (SCADA) functionality. For accelerators, there are a special set of requirements for control and monitoring Infrastructure that support the synchronization of control and data acquisition of beam-related instrumentation.

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One important aspect of the control system is the Application Programmable Interfaces (APIs) to provide access to all applications for test, commissioning, operations and maintenance. A physics research project has a unique requirement compared to industrial control system in that the facility continually evolves. The ability to develop new applications for data collection, machine control and data analysis is an important aspect of the control system.

To support the continuous evolution of the system applications, providing services to manage configuration data, time series archive data, snapshot data, alarm logs, save/restore sets, directory, electronic logs, etc., allows the development of applications to leverage off robust, well-defined functionality. A production quality service may also have mature clients to support the configuration, runtime viewing, and access to all service data.

The controls system provides the tools, performance and capabilities for controlling and monitoring a complex machine with many interacting subsystems. Careful consideration of the needed performance at each stage of the project is critical to the successful delivery of the project. An in-depth look at the potential tools and capabilities that can be brought to bear can be used to improve the schedule during implementation, integration, commissioning and operation. EIC is investing in a series of workshops to explore the requirements, specifications, and design to provide control capabilities in a timely fashion to support all aspects of the project.

CONTROL SYSTEM ARCHITECTURE

The EPICS controls system architecture includes a broad range of functionality (Fig. 2). It consists of multi-layer network connections, where the signal from diagnostic elements is propogated to an I/O controller through the beam instrumentation devices. Similar CS architecture has been applied to desing the NSLS-II control system [3].

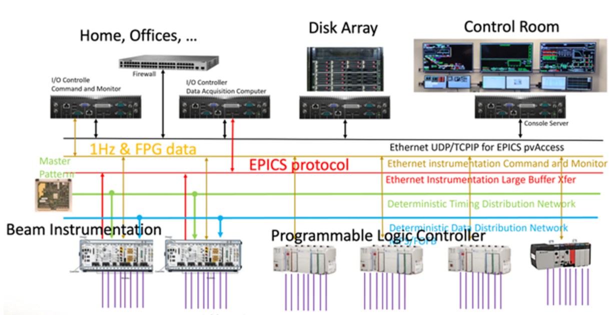

Figure 2: Control system hardware architecture.

The EPICS based controls sytem software arcitecture, shown in Fig. 3, consists of Accelerator Physics High Level Aplications (HLA), Channel Access Gateway, Control System Studio [4], and it provides access to: e-log book, machine protection system, channel finder, save restore data, archive appliance, inventory, synchronized Data Acquisition System (DAQ), etc.

DEVELOPING SPECIFICATIONS

There are several critical questions that need to be answered while developing the control system specifications. They are the following: What is asked from the project? How do we provide the project with the capabilities to meet the Key Performance Parameters (KPP)? What has been achieved by recent similar projects? What has been learned and developed in the most recent projects? What has not been achieved by recent similar projects and what were the consequences? Are there lessons to learn from shortcomings of similar projects? What can be reasonably accomplished as they have been demonstrated elsewhere? What approach provides the best solution with the given or likely resources? There are a limited number of resources in the scope of a construction project. The project plan should include what is absolutely required to meet the project goals. It can also include capabilities that improve the execution of other aspects of the project. Some capabilities are easier to consider at the onset of development of the system that improve the mission of the facility. These are not necessarily a requirement, but they can greatly improve the project mission with relatively little incremental effort.

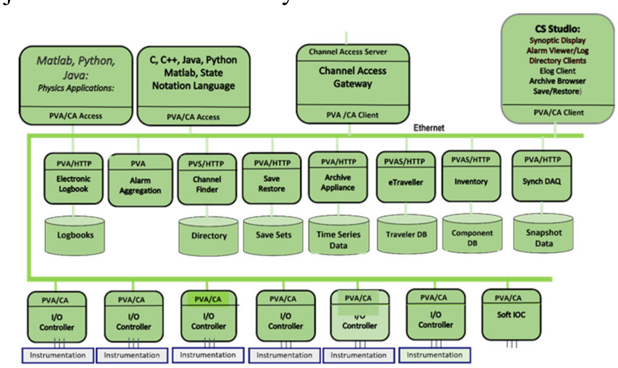

Figure 3: Control system software architecture.

COLLECTING REQUIREMENTS – SOURCE OF REQUIREMENTS

The collection of requirements is a multi-directional exercise from many different sources for different subsystems including the low level for main RF system, Crab Cavities, Diagnostics, Vacuum, Magnets, Power supplies, Interaction point, Detector, Machine protection, Safety and global accelerator control. The source of these requirements can be specified: 1) Accelerator Control and Monitoring → Instrumentation → Controls. 2) Physics Studies → Instrumentation → Controls. 3) Physics Applications → Controls → Instrumentation. 4) Operations → Controls. 5) Facility Control and Instrumentation → Controls.

KEY SPECIFICATION IDENTIFIED

Here we highlight some of the specifications. Turn-by-turn data needs to be collected from any BPMs around the ring with data samples at different location. For Machine Learning (ML), one would need to sample/transfer data with 1 kHz speed. For the ESR, to mitigate beam excursions from the defined orbit and dump the beam needs to be within ~100 microseconds (~8 turns). The data updates

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to the operator must achieve 10 Hz with up to ~1000 chosen parameters. The timestamp value is work in progress and the preliminary value is 48-bit representing seconds/nanoseconds with a precision of microseconds, which may be augmented. Every sixth RF bucket is going to be filled in ESR with M = 1160 bunches at 591 MHz RF frequency, where the harmonic number h is 7560. The filling pattern monitor needs to provide stable and accurate fill pattern data. In this case, a bunch-by-bunch reading is specified with high-speed of 8 GS/s and high-resolution of 16-bit. The feedback on spot size for collision is required 80 % noise suppression for steering magnet on controlling the interaction region with sampled 3 kHz data. There are ~1500 magnets and ~500 BPMs in the ESR over 3833.9 m circumference. Machine availability for EIC is based on the RHIC experience and performance. RHIC availability is ~80% and RHIC time at store is ~60% [5]. Since the EIC is a complex project with cryogenic systems (magnets, RF, etc.) the controls system availability should be 85%.

REQUIREMENTS - PRIORITIES

All requirements must meet and support: 1) Project Key Performance Parameters, 2) Construction, installation, integration and testing (considering best return on investment), the Instrument Readiness Review (IRR) required to turn on the equipment and the Accelerator Readiness Review (ARR) required for operation with beam, 3) Operation with basic controls, mean time to repair (MTTR), mean time between failures (MTBF), and mean time to failure (MTTF) required to meet overall reliability goals and protect against obsolescence of software, FPGA, hardware and Network Hardware, 4) and contain the costs of construction and support the availability of controls staff, 5) Commissioning goals to achieve and demonstrate the specified requirements and minimize/optimize the commissioning schedule.

REQUIREMENTS IMPACT SCHEDULE

The impact of production and software development on schedule can be considered as following: 1) New hardware boards require 3 years to develop, 2) New software tools require 2 years to develop, 3) Software applications require 9 months to develop, 4) New device integration into a Supervisory Control And Data Acquisition (SCADA) system requires 2 months. All schedule work can be estimated backwards from the critical decision days (CD1, CD2, … CD4) and start of the commissioning.

USE CASES AS A MECHANISM TO DEVELOP REQUIREMENTS

An example of a physics use case is Machine Learning (ML), which is a type of Artificial Intelligence (AI). For the machine-learning process, ~3000 PVs, related to beam instrumentation, need to be collected continuously at 1 kHz. In a case of the present RHIC facility, there are many accelerator-physics High Level Applications (HLA) written within the last two decades. As a part of the HLA development program, we need to revisit the existing HLAs and provide an AP interface to the control system that supports Physics Name references to all controls system Process Variables (PV). From an operations perspective, the machine protection is one of most important tasks. To avoid accelerator related equipment damage, the design of the machine protection system needs to be well established. As a part of the machine protection system, the electron beam needs to be dumped within 8 turns, with the revolution period of 12.8 microseconds.

EIC APPROACH TO DEVELOP REQUIREMENTS

To collect the requirement and specification list, we lead bi-weekly meetings with representatives of the Vacuum, Diagnostics, Collimator, Detector, RF, Controls and Accelerator Physics groups on requirements and specifications for control and data acquisition and HLA development. In addition, we invite speakers from other facilities, to discuss their experience and listen to their opinions. Y. Hidaka, Y. Hu and A. Derbenev (all BNL/NSLS-II) give talks on "Accelerator Physics Python HLA Development & Experiences at NSLS-II", "NSLS-II User Interface (UI) and Accelerator Physics High Level Applications (APHLA)" and "EPICS Through Time and Space" respectively. G. Shen (ANL/APS) shared his expertise on "Use Case Study Online Model and Its Python Environment".

CONCLUSION

The EIC project is a complex facility with two injector, pre-Cooler and SHC systems. Collection of the CS requirements needs multi-discipline contributions and must be done at earlier stage of the project, before CD2. Bi-weekly meetings on requirements and specifications for control and data acquisition helps to discuss and collect the list of the requirements and specification for different subsystem of the EIC project. Experience at other facilities is helpful in design of the EIC controls system and all these discussions have produced results in capabilities to inform the controls system for custom built beam instrumentation, timing, and applications software. We have a good start on requirements and specifications that support the design of the hardware and software architecture. Our early work has also identified several applications that need to be selected, modified, and developed.

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