CONTROL SYSTEM ACHIEVEMENT AT KEKB AND UPGRADE DESIGN FOR SUPERKEKB

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Abstract

SuperKEKB electron-positron asymmetric collider is being constructed after a decade of successful operation at KEKB for B physics research. KEKB completed all of the technical milestones, and had offered important insights into the flavor structure of elementary particles, especially the CP violation. The accelerator control system was led by the combination of scripting languages at the operation layer and EPICS at the equipment layer to a successful performance. The new control system in SuperKEKB will continue to employ those major features of KEKB, with additional technologies for the reliability and flexibility. The major structure will be maintained especially the online linkage to the simulation code and slow controls. However, as the design luminosity is 40-times higher than that of KEKB, several orders of magnitude higher performance will be required at certain area. At the same time more controllers with embedded technology will be installed to meet the limited resources.

INTRODUCTION

KEKB B-Factory was designed as an asymmetric electron/positron collider in order to study the violation of CP symmetry in B-meson system. It consisted of double storage rings of 8-GeV electron (HER) and 3.5-GeV positron (LER) with a diameter of 1 km, and a full energy injector linac of 600 m. It achieved twice as the design luminosity and led to the Nobel Prize of Kobayashi and Maskawa for the theory of quarks and the CP symmetry violation.

After a decade of successful operation at KEKB a new electron/positron collider, SuperKEKB, is being constructed to commission in 2014. It aims at a luminosity of $8 \times 10^{35} cm^{-2} s^{-1}$, 40-times higher than that of KEKB, in order to study the flavor physics of elementary particles further, by mainly squeezing the beams at the collision point. The control system should be utilized to the utmost for the goal.

KEKB was constructed and operated almost the same time as PEP-II at SLAC with the same scientific goal. It provided a friendly competition between these two machines and brought many collaborative efforts. New projects SuperKEKB at KEK and Super B at INFN will be constructed in parallel again. It is hoped to exchange ideas between these projects.

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LESSONS AT KEKB CONTROLS

Success of the high performance operation of KEKB owed much to the control system. It was designed more than 15 years ago and had started the beam operation in 1998. While it inherited a part of resources from the previous project TRISTAN, it restructured most of the software and hardware components. It employed the EPICS (experimental physics and industrial control system) toolkit for the low-level control mechanism and scripting languages for high-level operational applications. The combination provided the flexible and robust operational environment.

Lower-level Controls with EPICS

Before KEKB, projects in the institute repeated the development of its own control system. As technologies such as Unix, VME and TCP/IP became de-facto standards at the end of 1980s, it was considered to share control systems among projects. After the Superconducting Super Collider chose EPICS as the main control toolkit, EPICS became a candidate for future controls at KEK [1]. It was decided to employ EPICS for the KEKB ring controls and the previous software resources were not employed. On the other hand EPICS gateways were constructed for the linac injector to make a bridge from the existent control system [2]. The main reason for that was the ring could shutdown the accelerator completely for 4 years, but the linac had to continue the operation for light sources even during the upgrade construction towards KEKB.

The KEKB ring employed several fieldbuses such as VME, VXI, CAMAC, GPIB and ARCNET depending on the purposes. Approximately 100 VME systems with VxWorks operating system served as EPICS I/O controllers (IOCs) for all the hardware devices including 200 VXI mainframes, 50 CAMAC crates and 200 ARCNET segments [3].

At the linac most of the devices employed IP-network-based controllers. Before the KEKB project network-based PLCs and CAMAC crate controllers, and VMEs were managed by middle-layer software on Unix servers. During the upgrade construction for KEKB, those network-based controllers were shared between old control software and EPICS gateways. Gateways were implemented with portable channel access server (PCAS) at the beginning, and were eventually replaced by soft IOCs as EPICS started to support Unix IOCs [4].

Number of EPICS process variables was approximately 300 thousand, and that of archived ones was 150 thousand. They were distributed over 150 VME-based and Linux-based EPICS IOCs.

High-level Application with Scripting Languages

At the linac Tcl/Tk scripting language was effectively employed for its commissioning [5] after the language had been utilized for testing tools for long time. Later for the both the ring and linac Python was employed as it had more strong points [6]. Many of the device control software were written in those two languages, as well as MEDM.

For the beam operation SAD (Strategic Accelerator Design Program) was extended to have an interpreter, SADscript, which emulated most part of Mathematica language [7]. It provides most of the functionalities which is required by accelerator operation such as linear beam optics, symplectic beam tracking, many of non-linear analysis, optimization, list processing, numerical manipulation, EPICS channel access, and graphical user interface.

During the normal operation it is required to measure the beam response on certain parameter changes, and then to optimize those parameters. Such a process can be interactively carried by SADscript, and then turned into a graphical user interface that is performed routinely. New ideas for luminosity optimization were often proposed in the morning meeting, and corresponding operational tools were realized within a day or two. Some of the ideas turned out to be favorable, and the tool became utilized routinely. As many ideas were proposed, rapid tool development was crucial and SADscript played a significant role. Actually it was difficult to name a single mechanism that enabled the high performance of KEKB, however, for example hundred of rapid one-percent improvements provided twice the performance.

Rejuvenation During a Project

As an upgrade of a control system needs considerable effort, it is preferable to maintain the same environment during a project. However, an accelerator project can span more than ten years, and related software, hardware, persons, companies, and their policies may change substantially during that period. It is necessary to introduce advanced technologies to improve the machine even during the project. On the other hand existent components are often found to be difficult to accommodate new technologies. If a component is modified to accept them, others may have to be modified.

Actually, during the KEKB project new operation schemes were introduced almost every year. As most components in the control system were kept the same, it was rather difficult to catch up with the requirements at the later period. One modification might trigger another, and several modifications had to be performed at the same time. Because the shutdown period in a year is limited, if the extent of modifications exceeded the limit, it became very hard.

Thus, we should be prepared to accommodate small upgrades each year not only for application programs but also for control system infrastructure including base software and hardware components in order to manage a project for a long period.

SUPERKEKB CONTROL SYSTEM

The next project SuperKEKB should follow the existent KEKB control system, which featured with EPICS and scripting languages. It is planned to incorporate new technologies to rejuvenate hardware and software components, which do not change the architecture much. However, two new concepts are considered promising, namely channel access everywhere and dual-layered control system that are described below.

Channel Access Everywhere

The accelerator control architecture in KEK evolved in several steps in the past. Some time ago several control systems were standardized with a combination of several fieldbuses, VME field computers, and Unix computers. In order to consolidate the efforts on the development and maintenance some of the fieldbuses were gradually removed and many controllers were directly attached on to IP networks.

At the same time EPICS control software framework was employed at several control systems at KEK. Eventually, many controllers evolved to embed the same EPICS IOC software as on VME field computers as illustrated in Fig. 1. Common IOC software communicates with others using a common protocol called Channel Access (CA), which realizes unified application development environment from the top to the bottom. We call this embedded EPICS framework as “CA Everywhere”, and it enabled the both rapid development and smooth maintenance [4, 8].

Different kinds of controllers have been developed in the framework of CA Everywhere, and they greatly reduced the control efforts and improved the reliability. They include following controllers. Many of them were re-

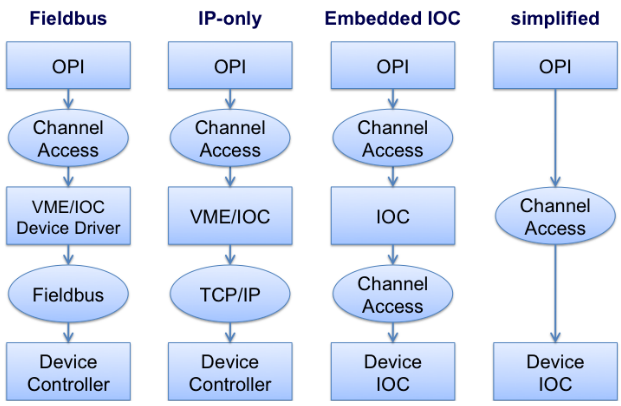

Figure 1: Evolution of device controllers from a fieldbus device towards CA everywhere with embedded IOC.

alized employing FPGA (Field Programmable Gate Array) [9, 10].

- MicroTCA LLRF controller with FPGA and Linux
- Yokogawa FAM3 PLC with Realtime Linux
- Oscilloscope for 50-Hz measurement with Windows
- Timing TDC with Linux
- Microwave power modulator with FPGA and Linux
- Libera BPM readout at 50 Hz with FPGA and Realtime Linux
- NI Compact-RIO with CAS and FPGA

Dual-layered Control System

For higher experimental performance at KEKB and the light sources, it was favorable to inject beams in top-up mode into all the storage rings. In the Photon Factory (PF), a stable beam current would provide precise experimental results. In KEKB, a stable beam current was desired for a sensitive beam collision tuning to increase luminosity.

To that end, simultaneous top-up injection had been established for three storage rings at the KEKB HER and LER, and PF since 2009. Electron and positron beams with very different characteristics, charged from 0.1 nC to 8 nC and with energies of between 2.5 GeV and 8 GeV, were exchanged at a rate of 50 Hz (20 ms). As a result, stored beam stabilities of 0.05 % (1 mA) at the KEKB HER and LER, and 0.01 % (0.05 mA) at PF, were achieved, improving the quality of experiments.

Global and fast controls have been established for such a beam modulation. As the existing control system, based on decade-old hardware and conventional software, was inadequate for controlling the beam within 20 ms, a new event-based control system, capable of regulating over a hundred parameters at 50 Hz, was installed. This system covered the controls of the low-level RF, high-power RF, pulsed magnets, an electron gun, injection systems, and beam instrumentation, whose devices were spread over a 1-km length. While the event-based control system was supervised by the EPICS control software, it had a dedicated communication link for fast, global, and robust controls [11, 12].

An event generator sends timing signals and control data to 17 event receiver stations arranged in a star-like topology. Each link between the event generator and a receiver is carried over a single optical fiber. It provides both synchronized timing signals, with approximately 10 ps precision, and synchronized controls through a realtime software mechanism, at about 10 μs precision. Recent technological advances in FPGA and SFP (Small Form factor Pluggable) enabled reliable controls in this configuration.

The same dual-layered control system with a conventional EPICS control and an event-based control will be essential in SuperKEKB as well. Simultaneous injection will be maintained, as the beam lifetime will be more limited at the SuperKEKB HER and LER. Many more parameters have to be managed precisely in order to realize lower-emittance beams for higher luminosity.

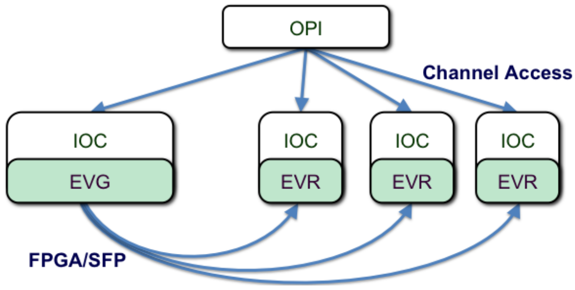

Figure 2: Dual layer controls with EPICS channel access at the top and fast event synchronized control at the bottom.

The event-based control layer manages global, fast controls in the pico- to microsecond range. The EPICS control layer covers slower parameter controls as well as existing conventional controls. Such a layered control system is optimal for the next generation of accelerator systems as depicted in Fig. 2.

CONCLUSION

The design of SuperKEKB controls is being finalized based on the achievement in the KEKB project and the discussion with each sub-group. Control components are constructed preserving EPICS and scripting languages from KEKB and enforcing two additional concepts of “channel access everywhere” and “dual-layer controls”.

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