CONTROL SYSTEM OF THE KEKB ACCELERATOR COMPLEX

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Abstract

The KEKB collider complex consists of high- and low-energy rings, and an 8-GeV Linac. Some of the resources were inherited from the previous TRISTAN project, and also they are shared with the Photon Factory and PF-AR light sources. In order to realize the long lifespan of the system, de-facto and international standard technologies were employed since the early stage, which have been efficiently operated. Several gateway methods were implemented in order to integrate heterogeneous sub-systems, which are gradually converted into EPICS. Scripting languages are employed for high-level applications. The ever-evolving control system has enabled flexible and reliable beam operations at KEKB for a long period.

INTRODUCTION

The KEK B-factory (KEKB) asymmetric electron-positron collider complex was built for the study of CP violation. Since the KEKB is a factory machine, it requires stable and robust operation. At the same time, it has many active operation parameters to improve the machine quality. Hence, the control system is important.

The control systems at the KEKB ring and Linac have different histories and architectures in the past. The number of accelerator components and control points of the KEKB rings are approximately four times larger than those of the Linac. This difference leads to slightly different strategies in effective use of the resources.

Furthermore, during the upgrade of the accelerators towards the KEKB project, Linac had only a five-month shutdown period, while the rings had a five-year shutdown period. In reality the Linac control system had to perform rejuvenation due to discontinuous support of the main computers and networks just before the machine was upgraded. This caused discrepancies between rings and Linac.

Nevertheless, both the control systems have evolved in order to meet the advancing requirements.

In the following sections, the KEKB and Linac control systems are described briefly. Subsequently, several aspects of their evolutions are described by comparing Linac and KEKB rings.

KEKB AND LINAC CONTROLS

There have been several control systems in KEK. The KEKB and Linac control systems are described here.

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KEKB Control System

The KEKB is a 3-km dual ring asymmetric collider consisting of 8-GeV electron and 3.5-GeV positron rings. In order to achieve a higher luminosity, improvements are made daily and therefore the requirements to the control systems have changed.

The KEKB control system is a standard EPICS system (experimental physics and industrial control system) with approximately 100 VME-based IOCs (I/O controllers) [1]. For the field interfaces, 200 VXI mainframes through MXI-2 interfaces, 50 CAMAC crates through serial highways, and 200 ARCNet segments are installed in addition to the VME frames. Many GPIBs, RS232C devices, and PLCs are also employed. Control services are provided by different types of Unix computers such as HP-UX, Tru64 Unix, Solaris, Linux, and MacOSX. MacOSX computers manage most of the data processing tasks and graphic displays.

Because of a five-year gap between the previous project TRISTAN and the KEKB project, a majority of the software and hardware resources was reconstructed, whereas some CAMAC resources were reused.

The software for EPICS R3.13 and R3.14 applications is developed using various EPICS development tools. Approximately 250,000 EPICS records are distributed across 100 IOCs. While many of the established hardware-related algorithms are programmed in dedicated record types or as record links, most of the control and operational algorithms are implemented using scripting languages such as SADscript/Tk and Python/Tk.

Linac Control System

The electron/positron Linac has been in operation since 1982; it was upgraded for the KEKB injection from 1994 through 1997 with 8-GeV electrons and 3.5-GeV positrons. Its length is 600 m and it has 60 high-power RF stations and 400 magnets. As it was operational for the PF injection during the upgrade, it continued to utilize many components from the previous projects.

The Linac provides beams with different characteristics to the KEKB, PF, and PF-AR rings, and the beams are switched more than 300 times a day. Because these rings are factory machines, the upstream Linac is required to carry out reliable and stable beam injection and to precisely control the beam characteristics such as Twiss parameters, timing, and charge. Furthermore, new operational beam modes have been added almost every year [2].

The Linac control system was revived between 1991 and

1993 just before the approval of the KEKB project, and minor and gradual modifications were made during its upgrade for use in the KEKB. The control system comprises 30 VMEs, 150 PLCs, 15 CAMACs, 30 VXIs, 24 intelligent oscilloscopes, many Unix computers, and redundant Ethernet/IP networks.

The design concept of this system was based on the use of de-facto standards such as Unix, VME, and TCP/IP and the use of optical Ethernet/IP networks for all device controllers without any special field networks [3]. This concept was inherited by J-PARC controls, while the use of EPICS was inherited from KEKB controls [4].

Most of the communication in the control system is achieved by a locally developed RPC (remote procedure call). The overall system is multitiered; the lower level is controlled by the UDP-RPC or simple UDP protocols in order to recover failures promptly. The upper level is controlled by the TCP-RPC, and a network-wide software-based shared memory system is provided for read-only information. The Linac API (application program interface) provides a transparent access to the UDP-RPC, TCP-RPC, and shared memory.

It also has communication links to console systems, utility facilities, and downstream accelerators including EPICS gateways. The EPICS gateways are implemented in several methods such as soft-IOCs, portable CASs (channel access servers), and dedicated IOCs with gateway programs. Currently, the EPICS gateways are utilized for most of the data archiving operations using an EPICS channel archiver and a KEKBlog and for operational alarms using a KEKB-alarm.

Operation of KEKB and Linac

Most of the operational panels are developed using scripting languages, and those for beam operations are written using SADscript [5].

SADscript is a Mathematica-like language whose processor is written in Fortran and has built-in interfaces for EPICS channel access (asynchronous and synchronous), Tk X11 widgets, CanvasDraw, Plotting, KBFrame graphic libraries on top of Tk, numerical data processing such as fitting and FFT, inter-process communication, and SAD-core, a full accelerator modeling engine including a symplectic beam tracking method and beam envelope capabilities [6].

SAD and SADscript are designed to perform almost all tasks related to the accelerator and beam operation. The Mathematica-like list-processing functions of SADscript enable the rapid development of online operational software. Many novel concepts have been tested using such rapid prototyping soon after the proposal. Virtual accelerators are also built using SAD in order to analyze the behavior of accelerators with new operational parameters.

COMMUNICATION NETWORK

At the Linac, most of the communication links had to be fiber-optic links, because the electromagnetic interference from high-power RF pulse modulators is significant. Since 1982, home-grown fiber optic networks with various speeds were developed. However, some of them often failed because the fiber-optic technology was not yet established. Furthermore, the diagnosis was time-consuming as the network topology was a loop topology.

In 1993, during the control upgrade, commercially available technologies were employed, namely, exclusive use of fiber-optic Ethernet/IP networks, without any special field networks. This step enabled us to concentrate on other important areas. The IP network also enabled us to make a transition from slow (10 Mbps) technology to an improved one (1 Gbps) without software modifications.

During the upgrade towards the KEKB project, a redundant technology was introduced at 40 fiber-optic Ethernet links, which ensured continuous operation of the accelerator. Employed technologies were redundant transceivers at first, and subsequently the standard protocols of rapid spanning-tree and HSRP/VRRP.

On the other hand, at the ring, the TRISTAN project employed a token ring network between minicomputers and CAMAC serial highways for equipment.

For the KEKB project, the IP network was introduced for the EPICS. Also introduced there were more than 200 ARCNet segments for various equipment controllers, 20 segments of MXI-2 interconnect for VXI mainframes, and CAMAC serial highways.

EQUIPMENT CONTROLLERS

At the Linac approximately 300 microprocessor-based controllers were used from 1982 to 1997. They were linked with home-grown fiber optic networks.

After the control upgrade in 1993, PLCs (programmable logic controllers) were employed and attached to the fiber-optic Ethernet link. Currently, 150 PLCs are utilized.

During the Linac upgrade since 1995, 30 VXI mainframes for RF measurement, 5 VMEs and 10 CAMAC crates for timing, and 20 VMEs for beam monitors were installed. In 2006, 24 oscilloscopes with embedded Windows-XP 3GHz computers were introduced for 100 BPMs. These oscilloscopes enabled 10 GS/s 50 Hz acquisitions with local processing of 20 calibration parameters.

At the ring, the CAMAC served as the interface to the equipment during the TRISTAN project.

For the KEKB project, various platforms were introduced, such as 100 VME/IOC without analog processing, 200 VXI/MXI mainframes for 900 BPMs, 50 CAMAC crates for RF and vacuum, ARCNet boards for magnet, GPIB for measurement, and PLC for interlocks.

TRANSITION TO EPICS

During the Linac control upgrade from 1991 to 1993, we replaced old software with home-grown RPC software. It was an unpleasant timing soon before the KEKB upgrade.

After the EPICS was chosen at the KEKB ring, several facilities were employed to connect the Linac controls with the EPICS.

At first, real-time processing computers, which served both Linac RPC and EPICS IOC, were investigated and developed. LynxOS was chosen as the platform and the Linac RPC was implemented immediately. EPICS R3.12 implementation was almost completed using pthread and posix services in 1995. However, it was found that the funding was not available because the control upgrade in 1993 had just concluded.

Then, gateways between the Linac controls and the EPICS were developed in several ways. At first, a software-only IOC as an EPICS record container and a gateway program that talks the both EPICS CA and Linac RPC protocols was installed. A more efficient PCAS (portable channel access server) of EPICS-R3.12 was used since 1995. Since 2002, several IOCs with a device support layer for the Linac RPC were installed.

Real IOCs are also increasing such as Linux IOCs for serving PLCs for RF, magnet, and vacuum systems, Windows IOCs embedded in oscilloscopes for BPMs [7], and RTEMS/VME for LLRF and event timing [8].

At the ring, the Nodal control environment at TRISTAN was completely replaced with the EPICS during the KEKB upgrade because the five-year construction time could be utilized to upgrade the system without any beam operation. RPC/CORBA and reflective memory hardware were the candidates as a basis of the control system replacement as well. However, the EPICS was chosen because international collaboration was desirable and there was no manpower for system software development. The choice of the EPICS at the SSC project was also a motive force.

SCRIPTING LANGUAGE

Both the Linac and KEKB heavily utilize scripting languages for the rapid prototyping of the beam operation.

At the Linac, Tcl/Tk language was used as a test tool on Unix computers since 1992. It was chosen as a main beam operation tool for the commissioning of the KEKB injection, thereby replacing the Windows environment in 1997. Since then, SADscript/Tk, Python/Tk, and Tcl/Tk have been utilized for the beam operation.

At the ring, the Nodal interpreter was utilized for the TRISTAN operation. For the KEKB, Python/Tk covers many areas such as dynamic graphical user interfaces or object-oriented programming, which is not covered by MEDM. SADscript is used by operators and physicists. During the commissioning, it was necessary to test novel ideas within a short time. As only a few ideas are effective, rapid prototyping is the most important and the SADscript environment plays a significant role.

POSSIBLE FUTURE ENHANCEMENTS

SADscript will be maintained because the KEKB and Linac cannot work without it. However, new operating environments such as XAL-CSS (control system studio) should be evaluated in the future.

For the EPICS, we still have hopes left to be realized. We are working on some of them such as redundancy.

There are more areas where PLCs can be used. The IEC61131-3 standard for the PLC software is being investigated because it may solve the software management issue in the future.

The FPGA will also be utilized increasingly. It will serve as a favorable platform for embedded controllers and instrumentation.

Although the complete downtime of the control system is quite low and less than 1 %, the partial availability is occasionally compromised. Hence, a more reliability study is required.

Integration of the control systems is expected to advance in order to increase the reusable resources and reduce the redundant efforts. In spite of the above challenges, the basic control system is stable and mature, so that the extension of the operation software would be desirable in order to achieve rapid improvement of the accelerator.

SUMMARY

While the Linac had slow and gradual modernization because of a lack of long shutdown for 25 years, the KEKB made a huge and effective transition during a five-year shutdown period with an enormous help from the EPICS community. The both systems run without much modification ever since. We learned that the design of the accelerator control system required a balance between several different aspects, some of which are investigated. In addition, large and small installations may require different solutions.

The EPICS and scripting languages have brought tremendous success to both the KEKB and Linac beam operations. The KEKB and Linac groups are expected to continue the enhancement in order to have ever-evolving control systems, which enable flexible and reliable beam operations. If we have some "phronesis" or practical wisdom, we can solve our problems.

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