CONTROL SYSTEM OF THE KEKB ACCELERATOR COMPLEX

K. Furukawa*, A. Akiyama, N. Kamikubota, T. Nakamura,
J. Odagiri, M. Satoh, T. Suwada, N. Yamamoto
High Energy Accelerator Research Organization (KEK)
Tsukuba, Ibaraki, 305-0801, Japan

Abstract

The KEKB collider complex consists of high-energy and low-energy rings, and 8-GeV Linac. Some of the resources were inherited from the previous TRISTAN project, and also they are shared with 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 to integrate heterogeneous sub-systems, which are gradually converted into EPICS. Scripting languages are employed for higher-level applications. The ever-evolving control system has enabled flexible and reliable beam operations at KEKB throughout the long period.

INTRODUCTION

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

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

Furthermore, during the upgrade of the accelerators towards the KEKB project, while the rings had 5-year shutdown period, Linac had only 5-month shutdown. Actually Linac control had to perform rejuvenation just before the machine upgrade because of the discontinuity of the support of main computers and networks.

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

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

KEKB AND LINAC CONTROLS

There have been several control systems in KEK. KEKB and Linac control systems are briefly described below.

KEKB Control System

KEKB is a 3-km dual ring asymmetric collider with 8-GeV electron and 3.5-GeV positron rings. In order to achieve a higher luminosity, improvements are made daily and, as a result, requirements to the control system have been 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, majority of the software and hardware resources was reconstructed, while some CAMAC resources were reused.

Software for EPICS R3.13 and R3.14 applications is developed with various EPICS development tools. Approximately 250,000 EPICS records are spread over the 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 SAD-script/Tk and Python/Tk.

Linac Control System

The electron/positron Linac has been in operation since 1982; it was upgraded for KEKB injection in the period of 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 in operation for PF injection during the upgrade, it continued to utilize many components from the previous projects.

Linac provides beams with different characteristics to 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 a 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

* <kazuro.furukawa@kek.jp>

1993 just before the approval of KEKB, and minor and gradual modifications were made during its upgrade for use in KEKB. The control system comprises 30 VMEs, 150 PLCs, 15 CAMACs, 30 VXIs, many Unix computers, and redundant Ethernet/IP networks. 24 oscilloscopes with built-in 3-GHz computers were just introduced in 2006.

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

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

Operation of KEKB and Linac

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

SADscript is a Mathematica-like language whose processor is written in Fortran and has built-in interfaces to 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 SADcore, a full accelerator modeling engine including symplectic beam tracking and beam envelope capabilities [6].

SAD and SADscript are designed to carry out almost all tasks related to 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 just after the proposal. Virtual accelerators are also built with SAD in order to analyze the behavior of accelerators with new operational parameters.

COMMUNICATION NETWORK

At Linac most of the communication links had to be fiber-optic, because the electro-magnetic interference from high-power rf modulators are not negligible. Home-grown fiber-optic networks with several different speeds were developed since around 1982. However, some of them often failed because the fiber-optic technology was not mature yet. Furthermore, the diagnosis was time-consuming as the network topology was a loop.

During the control upgrade at 1993 it was decided to employ commercially-available technologies, namely exclusive use of fiber-optic Ethernet/IP networks. The decision enabled us to concentrate on other important areas. The IP network also enabled us to make transition from slow technology to improved one without software modifications.

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

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

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

EQUIPMENT CONTROLLERS

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

After the control upgrade in 1993 PLCs (programmable logic controller) were employed and attached with fiber-optic Ethernet. 150 PLCs are utilized now.

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 WindowsXP 3GHz computers were introduced for 100 BPMs. This new oscilloscope enabled 10GS/s 50Hz acquisition with local processing of 20 calibration parameters.

At the ring, CAMAC was the interface to 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, PLC for interlocks.

TRANSITION TO EPICS

At the Linac control upgrade in 1990 to 1993, we replaced old software with home-grown RPC software. It was an unpleasant timing just before the KEKB upgrade.

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

At first, realtime processing computers which serve both Linac RPC and EPICS IOC were investigated and developed. LynxOS was chosen as the platform and the Linac RPC implementation was tested immediately. EPICS R3.12 implementation was almost done with pthread and posix services in 1995. However, it was found that the funding was not available because the upgrade in 1993 was performed just before.

Then gateways between Linac controls and 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 was installed. Then more efficient portable channel access server (PCAS) of EPICS-3.12 is used since 1995. Several IOCs with a device support layer to Linac RPC were installed since 2002.

Real IOCs are also increasing such as Linux IOCs to serve 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 EPICS during the KEKB upgrade, because 5-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, EPICS was the only choice because the international collaboration was attractive and there was no man-power for the system software development. The choice of EPICS at SSC project was also a motive force.

SCRIPTING LANGUAGE

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

At Linac Tcl/Tk language began to be 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 replacing Windows environment in 1997. Since then SADscript/Tk, Python/Tk and Tcl/Tk were utilized for the operation.

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

POSSIBLE FUTURE ENHANCEMENTS

SADscript will be maintained because KEKB and Linac won't work without it. However, newer operating environment such as XAL - CSS should be evaluated for the future.

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

There are more areas where PLCs can be used. Because its software management can be an issue in the future, IEC61131-3 standard for the PLC software is being investigated.

FPGA will be also utilized more and more. It will serve as a favorable platform for embedded controllers and instrumentations.

Although the complete downtime of the control system is quite low and less than one percent, the partial availability is occasionally compromised. Thus, more reliability study is required.

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

SUMMARY

While Linac had slow and gradual modernization because of a lack of long shutdown for 25 years, KEKB made a large and effective transition during 5-year shutdown period with an enormous help from EPICS community. They 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. Also large and small installations may require different solutions.

EPICS and scripting languages have brought a great success to the both KEKB and Linac beam operations. 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.

REFERENCES

[1] N. Akasaka *et al.*, "KEKB Accelerator Control System", Nucl. Instrum. Meth. **A 499**, 2003, p. 138.

[2] I. Abe *et al.*, "The KEKB Injector Linac", Nucl. Instrum. Meth. **A 499**, 2003, p. 167.

[3] K. Furukawa *et al.*, "Accelerator Controls in KEKB Linac Commissioning", *Proc. of ICALEPCS99*, Trieste, Italy, 1999, p. 98.

[4] K. Furukawa *et al.*, "Implementation of the EPICS Device Support for Network-based Controllers", *Proc. of ICALEPCS2001*, San Jose, U.S., 2001, p. 197.

[5] K. Akai *et al.*, "Commissioning of KEKB", Nucl. Instrum. Meth. **A 499**, 2003, p. 191.

[6] `<http://acc-physics.kek.jp/SAD/sad.html>`.

[7] M. Satoh *et al.*, "Fast BPM DAQ System Using Windows Oscilloscope-based EPICS IOC", *these proceedings*.

[8] K. Furukawa *et al.*, "Timing System Upgrade for Top-up Injection at KEK Linac", *Proc of EPAC2006*, Edinburgh, UK, 2006, p. 3071.