CONTROL SYSTEM STATUS OF SuperKEKB INJECTOR LINAC

M. Satoh#, I. Satake, H. Sugimura, Y. Seimiya, F. Miyahara, T. Natsui, Y. Enomoto, T. Suwada, K. Furukawa, KEK/ SOKENDAI, Tsukuba, Japan

Y. Mizukawa, K. Hisazumi, T. Kudou, S. Ushimoto, Y. Kuroda, S. Kusano, Mitsubishi Electric System & Service Co., Ltd, Tsukuba, Japan

H. Saotome, T. Ohfusa, M. Takagi, Kanto Information Service, Accelerator Group, Tsuchiura, Japan

Abstract

The SuperKEKB injector linac provides the electron and positron beams of different properties for the four independent storage rings. The required beam energy is from 2.5 GeV to 7 GeV, and the amount of bunch charge is from 0.3 nC to 10 nC. Especially, the injection beam to SuperKEKB electron and positron storage rings require the low emittance and high intensity beams for the nano beam scheme operation for aiming at the luminosity of $8\text{x}10^{35}$ cm^{-2} s^{-1}, 40 times higher than the luminosity record of previous KEKB project. The Phase I beam commissioning of SuperKEKB has been already conducted from February to June in 2016. The injector linac has successfully delivered the electron and positron beams to the SuperKEKB main rings. The linac beam studies and subsystem developments have also been intensively going on together with the daily normal beam injection to both rings of the SuperKEKB and two light sources.

Towards Phase II and III beam commissioning of SuperKEKB, the key issues are the fine beam control for the low emittance beam transport, the high intensity positron generation with the flux concentrator, the pulsed quadrupole and steering magnets for the four ring simultaneous top up injection, and the low emittance photo cathode rf gun. For the stable beam operation with the newly developed accelerator subsystems, the robust control system is strongly required. In this paper, we report the control system status of SuperKEKB injector linac.

INTRODUCTION

The SuperKEKB injector linac is a linear electron positron accelerator with the total length of about 600 m [1]. Figure 1 shows the schematic layout of injector linac. Two straight sections of 120 m long and 500 m long are connected with the 180 degree bending section. The both electron sources of thermionic and photo cathode rf gun are situated at the most upstream end. The thermionic electron gun is utilized for the light source injection with bunch charge of about 0.3 nC and the primary electron of positron generation with bunch charge of 10 nC. The photo cathode rf gun is required for the low emittance electron beam injection to the SuperKEKB electron high energy ring (HER). Eventually, the electron beam with the vertical normalized emittance of less than 20 mm· mrad is required for getting the high peak luminosity in Belle II physics experiment. The low emittance electron beam transport without damping ring is one of key issues of injector linac operation. Both of the fine component alignment and the beam orbit manipulation are crucial issues for the success of SuperKEKB project. The beam studies related to these issues are now on going. The main parameters required for SuperKEKB operation are summarized in Table 1 together with ones for the former KEKB project [2, 3, 4, 5].

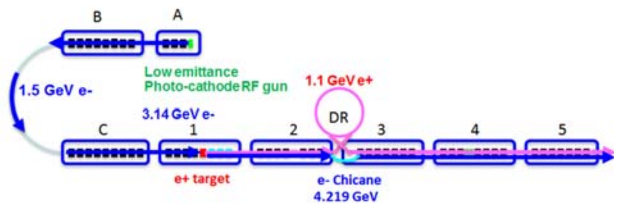

Figure 1: Schematic layout of the SuperKEKB injector linac. It comprises two strait sections of 120 m and 500 m long. They are connected 180 degree bending section. The both electron sources of thermionic and photo cathode rf gun are situated at the most upstream end of the injector linac.

PREVIOUS CONTROL SYSTEM

At the beginning of KEKB project, the injector linac control system was based on the library software developed in house. They have been implemented by C language and conducted on the Tru64 UNIX server computers. As the data storage system, the RAID system has been used, and it was connected to the server computer of HP DS20 alpha server via SCSI interface. The operator interfaces (OPIs) were designed by the Tcl/Tk scripting language and displayed on the X terminals, Macintosh, and Windows PC via X server software. For the local controllers of magnet, vacuum, and safety systems, the programmable logic controller (PLC) were utilized since its robustness are suitable for the stable accelerator control. For the beam monitor of beam position monitor and profile monitor, the VME bus based system were in operation. The timing delay modules have been also developed as the VME bus module board.

masanori.satoh@kek.jp

Table 1: Main Parameters of KEKB and SuperKEKB Injector Linac.

<table>
<tr><th>Project</th><th colspan="2">KEKB***</th><th colspan="2">SuperKEKB***
(Phase I)</th><th colspan="2">SuperKEKB****
(Phase II)</th><th colspan="2">SuperKEKB****
(Phase III)</th></tr>
<tr><th>Beam</th><th>e-</th><th>e+</th><th>e-</th><th>e+</th><th>e-</th><th>e+</th><th>e-</th><th>e+</th></tr>
<tr><td>Beam energy (GeV)</td><td>8</td><td>3.5</td><td>7</td><td>4</td><td>7</td><td>4</td><td>7</td><td>4</td></tr>
<tr><td>Stored current (A)</td><td>1.1</td><td>1.6</td><td>1</td><td>1</td><td>-</td><td>-</td><td>2.6</td><td>3.6</td></tr>
<tr><td>Beam lifetime (min.)</td><td>200</td><td>150</td><td>100</td><td>100</td><td>-</td><td>-</td><td>6</td><td>6</td></tr>
<tr><td>Bunch charge (nC)</td><td>1</td><td>1 (10*)</td><td>1</td><td>0.4 (8*)</td><td>1</td><td>0.5 (10*)</td><td>4</td><td>4 (10*)</td></tr>
<tr><td>Normalized vertical emittance (mm·mrad)</td><td rowspan="2">310</td><td rowspan="2">1400</td><td>300
130**</td><td>1200</td><td>150</td><td>40</td><td>20</td><td>15</td></tr>
<tr><td>Normalized horizontal emittance (mm·mrad)</td><td>160
200**</td><td>1000</td><td>150</td><td>200</td><td>40</td><td>100</td></tr>
<tr><td>Energy spread (%)</td><td>0.125</td><td>0.125</td><td>0.5</td><td>0.5</td><td>0.1</td><td>0.16</td><td>0.07</td><td>0.16</td></tr>
<tr><td>Bunch length (mm)</td><td>1.3</td><td>2.6</td><td>1.3</td><td>2.6</td><td>1.3</td><td>0.7</td><td>1.3</td><td>0.7</td></tr>
<tr><td># of bunch</td><td colspan="2">2</td><td colspan="2">2</td><td colspan="4">2</td></tr>
<tr><td>Maximum beam repetition (Hz)</td><td colspan="2">50</td><td colspan="2">25</td><td colspan="4">25 / 50</td></tr>
<tr><td>Top up injection</td><td colspan="2">3 rings (HER, LER*****, PF)</td><td colspan="2">n/a</td><td colspan="4">5 rings (HER, LER*****, DR, PF, PF-AR)</td></tr>
</table>

*: Primary electron beam for positron production.
**: Results with the photocathode rf electron gun.
***: Achieved values.
****: Design values.
*****: Low energy ring of KEKB and SuperKEKB.

The server computers, OPI, and local controllers were connected via Ethernet up to 100 Mbps data transfer speed. For the high availability operation, we adopted the redundant network connection between the core and edge network switches. Moreover, the core switch system itself is also the redundant system since it is one of the key component of the injector linac control system.

PRESENT CONTROL SYSTEM

EPICS based Control System Software

In the middle stage of KEB project, the injector linac control framework has been gradually migrated from the system developed in house to the experimental physics and industrial control system (EPICS) based one [6]. The KEKB and PF-AR ring control systems have been already developed with the EPICS environment from the beginning of the operation. Later, the PF ring control system was also replaced by the EPICS based one. The EPICS framework can provide the large number of driver software, archiver tool, alarm software, and so on. It can drastically accelerate the development cycle of control and commissioning software. In addition, it can also provide the good affinity between the ring and injector control system. Since we can conduct the quick and easy data analysis to find some correlation between the ring and injector related parameters, it can eventually bring the

Table 2: Number of EPICS IOCs for each subsystem.

Group	# of IOCs
Safety	2
Monitor	48
RF	57
RF monitor	41
Magnet	19
Vacuum	1
Timing	52
Utility	2
Operation	3

Table 3: Number of EPICS PVs registered to the channel and CSS archivers.

Group	# of IOCs
Beam monitor	29803
Injector	787
Timing	8268
RF	2206
RF monitor	9991
Magnet	17204
Vacuum	499
Operation	8977
Safety system	940
Utility	324

Figure 2: Screen shot example of EPICS IOC running inside of vncserver.

operators some useful information to fix the problem and improve the beam quality. The beginning of migration in the linac control system, the wrapper software for the existing control software to EPICS has been developed and deployed. After then, the whole system was migrated to the pure EPICS control system. Table 2 and 3 show the number of EPICS IOCs and PVs registered to archiver, respectively. The total number of archived parameter is around 70000, and the large parts of them are the beam monitor and magnet parameters. The both of channel and CSS archiver systems record the large number of linac parameters. As show in Fig. 2, the large parts of EPCIS IOCs are conducted in the vncservers which are running on two Linux virtual machines provided by the VMware vSphere. Almost all OPIs are migrated from the Tcl/tk based ones to the Python scripting language ones. Recently, NI LabVIEW programming environment is also utilized to develop the control software for the flux

Table 4: Number of local controllers for each subsystem.

Controller type	Accelerator component type (# of accelerator components)	# of controllers
VME 64x	Event timing generator	4
	Event timing receiver	50
	BPM (94)	94
PLC	DC magnet (363)	59
	Vacuum (333)	26
	Klystron (5)	5
	Profile monitor (116)	39
	TDC (40)	40
	Charge integration interlock (5)	3
Network attached power supply	DC magnet (105)	105
Embedded Linux	Klystron (66)	66
Data logger	Temperature and humidity (720)	26
PXI express	Pulsed magnet (74)	13
	Event timing receiver for pulsed magnet (13)	13

concentrator and pulsed magnet. It is also effective for the rapid OPI development.

Control System Hardware

The previous server computers were replaced by the new Linux based blade type server machines. The new servers are four ProLiant BL460c cards based on the c7000 enclosure. The utilization of blade type server computers helps to increase the operational reliability since the enclosure has the five power supply modules and ten cooling fan units to make sure the redundancy. The Linux distribution used in the injector linac is mainly CentOS 6.8 x86_64 for the control system software. In addition, the Linux CentOS 7.3 x86_64 is utilized for the backend utility software like the LDAP, Web, and PostgreSQL services.

For the injector linac control network environment, the core redundant network switch of Cisco C4506 was replaced by the Cisco C3750-X. Around fifteen edge switches situated in the klystron gallery were migrated from Cisco C2950 to C2960-S. The fiber link between the core and each edge switch is also redundant connection for the high operational availability. The replacement in this time, the network speed is improved from 100 Mbps to 1 Gbps. However, some local devices are still operated via the 10 Mbps ethernet speed. In the future, they will be replaced by the new high speed one since the such slow speed network device has the low vulnerability to the large number of network packets. The core switch can be upgraded to the 10 Gbps network transfer by replacing the transceiver modules.

Table 4 shows the number of local controllers for each subsystem. The device types used as the local controllers are mostly VME 64x and PLC based ones. It is a similar situation with the former injector linac control system. Recently, the PXI bus based system is also included for the pulsed quadrupole and steering magnets control systems. In addition, the event receiver cards based on the PXI bus are also implemented for the pulsed magnet timing system. Through the development of pulsed magnet control system, we can get the much expertise about the PXI bus system, and it is applicable to the future control system development or improvement.

SUMMARY AND FUTURE PLAN

The control system status of SuperKEKB injector linac is summarized together with the former control system outline. Towards SuperKEKB Phase II and III commissioning, the more advanced beam control software will be developed to aim at the general search engine for finding the optimized linac parameters by using the machine learning scheme. These machine study results will be presented elsewhere in the near future.

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