NEW EVENT-BASED CONTROL SYSTEM FOR SIMULTANEOUS TOP-UP OPERATION AT KEKB AND PF

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Abstract

The 8-GeV linac at KEK provides electrons and positrons to three ring accelerators of KEKB-HER, KEKB-LER and Photon Factory. Simultaneous top-up injections to those rings are carried for the ultimate experimental results at the both KEKB and PF facilities.

An event-based fast control system was newly constructed overlapping the existent EPICS control system. The new system controls the distant equipment globally utilizing event modules from MRF and several other techniques. The event system enables fast controls from picosecond to millisecond range, and the conventional EPICS system covers slower controls. More than 100 parameters are driven globally by the event system every 20ms pulse in order to generate beams with three-times different energies and 100-times different charges. And more than 500 parameters are observed synchronously to ensure the beam operation. The system enables the future accelerator complex such as SuperKEKB as well.

This paper describes the detailed design of the hardware and software structures, and beam operation experiences.

INTRODUCTION

The KEK 8-GeV linac injects electron and positron beams with different characteristics into four storage rings: KEKB high-energy ring (HER), KEKB low-energy ring (LER), Photon Factory (PF) and PF-AR. It took from 30 s to 2 min to switch the beam modes, depending on the magnet standardization and other equipment controls [1]. It became necessary to realize simultaneous top-up injections to three rings, KEKB-HER, KEKB-LER, and PF in order to improve the physics experiments at those rings [2].

Several sets of pulsed equipment are installed. Beam optics development is also performed in parallel to support the wide dynamic range of beam energy and charge needed, namely, 3-times different energies and 100-times different charges.

A new event-based control system was introduced in order to achieve global and fast controls, where many equipment parameters which spread over 1km have to be updated within 20ms. The system has been designed since 2005, and the hardware installation was performed at the summer of 2008 [3]. Recently, we have started the pulse-to-pulse beam switching operation with these event-based synchronized controls.

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FAST BEAM-MODE SWITCHING

The linac provides S-band single- or dual-bunch beam at 50Hz. In order to control the charge and the energy of the beam, we have to change many equipment parameters globally. For the energy change, fast low-level microwave (LLRF) controls were installed. Most of the 60 high-power microwave stations are used to accelerate 8-GeV electron beams for KEKB-HER injection, while 1/3 of them are used to decelerate the high-energy beams for PF injection with very different LLRF configuration. As beam charges for PF injection and positron generation are 100-times different, those longitudinal wakefield have to be compensated by LLRF configuration as well. Thus, LLRF parameters are switched every 20 ms.

Because parameters for magnets with iron yokes cannot be changed within 20 ms, more than ten pulsed air-core steering magnets are installed. They are used to absorb the difference of the beam orbits between different beams. A pulsed bending magnet was also installed to switch the beam to the PF beam transport line. Other magnets share the same parameters to have compatible beam optics between three beam modes.

Beam charges are controlled by high-voltage power supplies and picosecond timing triggers for the electron gun.

RF synchronization schemes for KEKB and PF are different as they have separate circumference compensation systems, and also bucket selections for those three rings are separate. Thus, those systems should be tightly connected. Injection parameters such as kickers, septa, and RF phase offsets should be controlled respectively pulse-by-pulse.

For the beam instrumentations, beam position monitors (BPM) have to perform pulse-to-pulse 50-Hz measurements with calibration parameters corresponding to beam modes. Streak cameras, wire scanners and RF monitors also need to be modified to measure only for the target beam mode.

TIMING SYNCHRONIZATION

Fundamental clock (event rate) for the event system was chosen to be 114.24MHz. This clock is used for a subharmonic buncher and has an integer relation to KEKB ring RF clock. This was selected because the tolerance for the KEKB injection jitter is as small as 30ps. The brief relation is described in Fig. 1 (A). PF has a larger acceptance, and the injection timing is generated based on an accidental coincidence as in Fig. 1 (B). Those two synchronization schemes are switched pulse by pulse by the software.

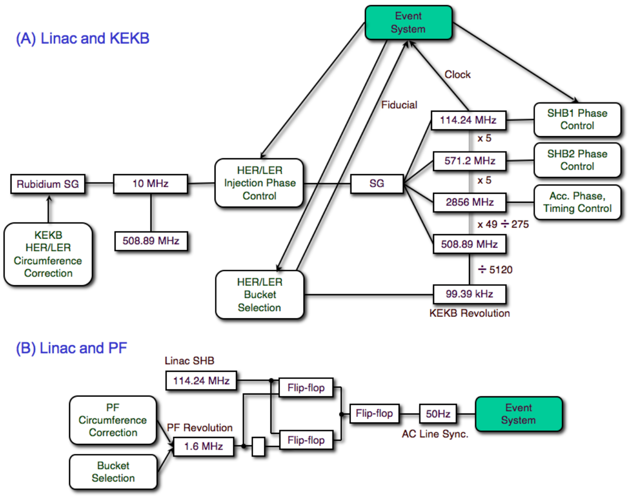

Figure 1: RF and timing synchronization schemes (A) between linac and KEKB which has integer relations for low jitters, and (B) between linac and PF. Those two schemes are switched pulse by pulse.

EVENT SYSTEM ARCHITECTURE

Event generator and receiver stations are operated with EPICS control software release 3.14.9 and vxWorks 5.5.1 [4]. Several event receiver stations have been added recently, and the system now comprises an event generator station and 17 event receiver stations as shown in Fig. 2.

Event Generator Station

The generator station is operated with an event generator (EVG230) from MRF [5], a CPU (MVME5500), optical event fanouts and a VME64x subrack. 114MHz RF clock and 50Hz synchronization signals are fed into the generator. The application software on the generator builds a stream of events every 20ms, and they are sent to 17 receiver stations through SFP optical transceivers.

Event Receiver Stations

The receiver station is composed of an event receiver (EVR230RF) from MRF, a CPU (MVME5500) and some I/O modules such as DACs and ADCs depending on the connected hardware systems. A single width EVR230RF can generate up to 16 signals, and several stations which need more than 16 signals accommodate multiple EVR230RFs. Those signals are used to generate LLRF signals and to drive pulsed magnets and beam instrumentations. Analog modules are driven by synchronous software on the CPU that is triggered by an interrupt signal generated by an event received from the event generator.

If it is difficult to embed event receiver hardware into monitoring stations, network connections are used. For example, beam position monitors are read by 26 DPO7104 oscilloscopes with embedded-EPICS, which receive events over Ethernet network [6, 7]. It was found that 50Hz events through the channel-access protocol over linac network are lost less than once in million times.

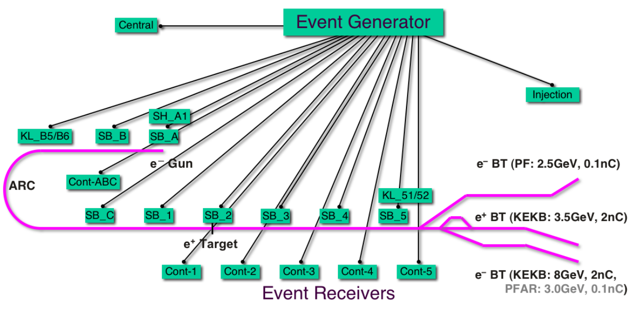

Figure 2: Overall configuration of the event-based control system. 17 event receiver stations cover 1km facility.

Timing Signals at Receiver Stations

The timing jitter of the signals at an event receiver station is better than 10ps relative to the RF clock (114.24MHz) at the event generator station as shown in Fig. 3. If the temperature changes, the timing drift is not small, but still it satisfies our needs for most of 150 timing signals other than triggers for electron guns and beam bunch monitors. Thus, most of the timing control system, which was developed during the KEKB linac upgrade, was replaced with this event control system [8].

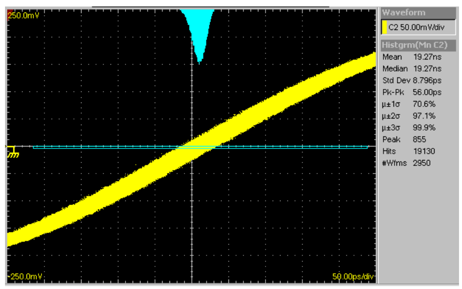

Figure 3: Timing jitter of output signal from an event receiver is just less than 10ps relative to the original RF clock at the event generator.

OPERATIONAL SOFTWARE STRUCTURE

With the introduction of event-based control system, any beam injection modes can be assigned to every 20-ms beam pulse. Depending on the experimental situations at the rings, beam mode assignment requests change frequently. However, fast software on event stations cannot be replaced during the operation because that may interrupt the beam pulse stream. Thus, we have designed fast software on event stations which accept a beam mode pattern [9].

Processing on Event Generator and Receivers

Each element of a beam mode pattern corresponds to a beam mode which specifies certain beam characteristics.

A beam mode pattern can be loaded any time at the event generator station from external software. The length of the pattern can be any length up to 500, which corresponds to 10 seconds.

Once a beam mode is specified as an element of the pattern, a preparation event is sent to receiver stations over the fiber-optic event links at the end of a pulse, and the receiver stations set their corresponding hardware variables of analog and delay values for the next pulse. This preparation event is also used to select one of the RF synchronization schemes shown in Fig. 1.

From the beginning of the next pulse several events are sent in sequence to specify the signal timings for hardware equipment. Approximately 50 different events are defined. Some of them correspond to specific devices at certain receiver stations, and others correspond to one of the beam modes and they drive many different devices.

Currently 120 independent fast variables are defined for delays and analog values. And each of them has independent values for ten different beam modes. Those 120 variables are replaced every pulse being triggered by the preparation event as described above.

The processing on event generator and receiver stations is performed in EPICS environment, and is expressed as links between approximately 5000 EPICS process variables.

Operational Software

The operational software that generates the beam mode pattern has to be flexible, and is written in Python scripting language. There are many versions depending on the purposes. The most commonly used software accepts requests from remote software at the downstream rings through the channel access protocol, or from human operators through graphical user interfaces. It arbitrates those requests based on the ring priorities for the shift, and it finds the best beam mode pattern that satisfies restrictions for hardware devices such as pulsed magnets.

BEAM OPERATION

The new system has been operated for simultaneous top-up injections without any issues. It enabled these controls.

- 17 EVR stations
- voltages and picosecond-timing controls for an electron gun
- LLRF timing and phase controls for 14 RF stations
- high-power RF timings for 60 RF stations
- 14 pulsed magnets and solenoids
- 26 linac and BT beam position monitor stations for 150 BPMs
- 4 RF monitor stations
- injection RF phase controls for KEKB rings
- injection bucket selections for KEKB rings

Adaptive beam optics developments were also performed to support simultaneous injections to three rings with the same parameters for static magnets [10]. Many parameter optimizations were performed for the magnet fields, RF powers, and LLRF timings in order to achieve the beams with smaller optics mismatching and lower energy spreads.

The simultaneous top-up injections are performed since April 2009. Under the typical operation the beam repetition rates for PF, KEKB-HER, and KEKB-LER were 0$\sim$0.5Hz, 0$\sim$12.5Hz and 0$\sim$25Hz respectively. The beam mode pattern was regenerated every 10 seconds based on the requests from the rings, and was downloaded to the event generation station. The beam current was kept at 450mA with fluctuations less than 0.1mA at PF ring. The fluctuations at KEKB rings with the beam currents of 1.1 $\sim$ 1.6A were 1mA. Those stable operations enabled an exceptional KEKB luminosity tuning with sensitive crab cavities.

CONCLUSION

A new event-based control system was developed. And it was proven to be robust and to satisfy the fast switching requirements under the injection operation to three rings. The system has realized a sensitive and stable tuning of KEKB with crab cavities for improved luminosity and also higher-quality experiments simultaneously at the PF ring. It is expected to support future SuperKEKB operation with more complicated configurations.

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