EVENT-BASED TIMING AND CONTROL SYSTEM FOR FAST BEAM-MODE SWITCHING AT KEK 8-GeV LINAC

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Abstract

The 8-GeV linac at KEK provides electrons and positrons to several accelerator facilities. A 50-Hz beam-mode switching system has been constructed to realize simultaneous top-up injections for Photon Factory and the KEKB high- and low-energy rings, which require different beam characteristics. An event-based timing and control system was built to change the parameters of various accelerator components within 20 ms. The components are spread over a 600-m linac and require changes to a total of 100 timing and control parameters. The system has been operated successfully since the autumn of 2008 and has been improved upon as beam operation experience has been accumulated. It is expected to enhance the quality of the experiments at KEKB and PF. We describe the details of this new and improved control system and present status of the accelerator operation.

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]. Crab cavities were installed at KEKB to achieve higher luminosity. However, it was found that luminosity tuning is sensitive to the constant beam conditions at both the HER and LER rings. At the same time, the need to maintain stable experimental conditions led to an increasing demand for top-up injections at PF. Thus, a simultaneous injection system for the three rings was constructed, which provided the following beams:

- KEKB HER: 8-GeV electron, 1.2-nC, 2 bunches.
- KEKB LER: 3.5-GeV positron, 1.2-nC, 2 bunches (10-nC primary electron).
- PF ring: 2.5-GeV electron, 0.1-nC, 1 bunch.

Thus, a fast beam-mode switching system has been designed and implemented [2]. Several sets of equipment are installed, including pulsed magnets and a fast microwave (RF) system. 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.

The control and timing systems are upgraded to meet the required beam-mode switching rate of 50 Hz (20 ms). An event system has been introduced for global notification of an imminent switching event along the length of the 600 m linac. It has been tested since 2006 and was commissioned in the autumn of 2008. The system enables the fast switching of many parameters for timing-signals, magnets, microwave systems, and beam instrumentation [3].

FAST BEAM-MODE SWITCHING

A linac beam pulse is generated every 20 ms (50 Hz). Each beam pulse can currently be assigned to one of five different beam modes, namely KEKB-HER, KEKB-LER, and PF from an electron gun called GU_A1, and PF-AR and PF from another gun, GU_CT. For the KEKB injection modes, each pulse normally contains two beam bunches 96.3 ns apart.

The new system can assign any one of the beam modes to a pulse. Thus, the beam pulse stream is a train of different beam modes. However, there are several pulsed power supplies that require equally separated pulses for stable operation. Thus, each beam mode is assigned an equally separated pulse train. And the beam pulse stream becomes overlapped trains of beam modes, or a beam mode pattern. Such a pattern is often dynamically changed to meet the beam status at the ring and to improve luminosity and the quality of the experiment.

In order to control the generation of the beam mode pattern, an event control system was introduced.

EVENT NOTIFICATION SYSTEM

The event system comprises an event generator (EVG) station and several event receiver (EVR) stations. They contain EVG230 and EVR230RF modules from Micro-Research Finland [4], an MVME5500 CPU from Emerson, and other VME components. Other types of event receivers are also connected.

Event Generator Station

The EVG station is placed at the main timing station near the linac's master oscillator. The bucket selection for the

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KEKB and PF rings is outside the EVG. A bucket selection timing is selected by the EVG and is used as a timing fiducial. The master oscillator provides the 114.24-MHz clock signal to the EVG, which is used as the event clock. While the clock signals at KEKB are directly synchronized with certain integer relations, the clock signals at PF do not have a common base with the linac.

This is explained by the clocks being continuously and independently adjusted at both rings for circumference compensation, with the KEKB requiring tight synchronization tolerances of less than 30 ps. Thus, an accidental synchronization with a certain jitter tolerance is searched for in the PF revolution clock. Currently, the tolerance is set to 300 ps, which is smaller than the injection acceptance of 700 ps.

The EVG is loosely synchronized to a 50-Hz AC power line before being fed the timing fiducial. While the accidental synchronized timing for the PF is normally about 10 kHz, it can be lower if the clock frequencies become close to an integer relation. Thus, the signal is always monitored to maintain a sufficient rate. Thereafter, all the timings and events generated are based on this 50-Hz fiducial and the 114-MHz clock.

The generated event stream signal is transmitted from a small form-factor pluggable transceiver (SFP) on the EVG to many EVRs through optical fan-out modules in a star-like topology.

Event Receiver Stations

EVR stations are installed at six sub-control rooms to replace old and static timing systems [5], and also at the beginning of linac sectors to provide fast equipment controls. The EVR receives the event stream though a SFP connector. While multi-mode fibers are used for most stations, a single-mode fiber and SFPs are used for an EVR station at a distance of 400 m.

The EVR generates timing and gate signals based on the event code provided by the EVG in order to drive the equipment. Timing signals are assigned some delay from the fiducial. Gate signals are started at the end of the previous pulse and are stopped at the end of the next pulse.

The event also triggers an interrupt on the VME bus and then invokes EPICS device-support software [6]. Analog signal controls are performed using DAC and ADC modules through a CPU module.

Software Receiver Stations

Some observation stations receive events over a TCP/IP network because such hardware cannot accommodate an EVR module. The failure rate with our current network configuration was confirmed to be less than 1 ppm. The hardware includes oscilloscopes with Windows embedded and a VME system. Although the failure rate is low, the use of this scheme is restricted to observation stations. EVRs are utilized to control equipment.

Hardware Receiver Stations

Some of the existent subsystems receive events through hardwired cables. The EVG station also has an EVR module to provide gate signals for subsystems such as the bucket selection system and the ring injection systems. The systems use the gate signals to determine the local parameters.

SOFTWARE STRUCTURE

The entire event related stations run EPICS software R3.14.8.2 or R3.14.9. These include one EVG, 13 EVRs, and 27 software stations. EVG and EVR stations also run V2.4.1 of their device support software with modifications made for new hardware features.

Beam-mode Pattern Generation

In order to generate the beam mode pattern explained above, an external program to the EVG station is used. This is explained by the fact that the operation requirements may change frequently and a flexible system is required. Programs in scripting languages are utilized for rapid prototyping. The event control system together with several hardware system installations and beam optics developments are performed simultaneously. Thus, the pattern generation algorithm is modified almost daily.

The length of the pattern can be any number less than 500 (10 s), and it can be downloaded at any time into the EVG station as an EPICS waveform record. Once it is loaded, it repeats forever until the next pattern is loaded, then the previous one is replaced at the end of the pattern.

There are several pattern generator programs. One of the programs accepts requests from other programs and human operators, and tries to arbitrate them automatically. Thus, this program is the one most frequently used. Another manual pattern generator is also utilized, depending on the operation modes.

Event Code Generation and Processing

Every 20 ms, the EVG station reads one element from the beam mode pattern, to generate a sequence of event codes.

Linac may provide five different beam modes as described above. Each beam mode has a backup called a study mode and sometimes a pulse does not have a beam. Thus, a total of eleven beam modes are defined.

Three events are assigned at least for each beam mode, one for the preparation and two others for the beam and equipment triggers. The preparation event at the end of an event code sequence invokes EPICS process-variables (PVs) at the EVR stations to assign delay values to the EVR itself and analog values to the DAC modules, and also to generate gate signals. The other two events at the next pulse generate actual timing pulses for the corresponding beam mode, as set by the preparation event.

Some devices such as pulse magnets need dedicated treatments at the EVR stations, and they have corresponding event codes. The number of event codes is approximately 50, with approximately 120 dynamic equipment parameters. Each dynamic parameter PV has eleven corresponding PVs tagged with the beam modes. In total, approximately 4000 EPICS PVs drive the event system and the numbers are evolving for new operation features[1].

Event Transmission over Network

For each pulse, the beam event code is also transmitted from the EVG station over a TCP/IP network using EPICS channel access (CA) protocol. Software receivers accept the beam event code and decide the operation based on the delivered code and update the observed values. EPICS PVs tagged with eleven beam modes are prepared for each observation value. All of the beam position monitor (BPM) stations are driven under this scheme [7].

COMMISSIONING AND OPERATION

The event system was installed in the summer of 2008, replacing the hardware element of the slow beam-switching system. The new system was utilized with static parameters and operated statically in the autumn of 2008.

Each piece of the newly installed equipment was individually tested with the event system. We generally have a four-hour maintenance period every other week during which time new EPICS IOC software was installed and new hardware was connected. During the commissioning stage, running until the spring of 2009, fast controls were confirmed for these devices and sub-systems.

- 13 EVR stations
- voltages and picosecond-timing controls for an electron gun
- low-level RF timing and phase controls for 11 RF stations
- high-level RF timings for 60 RF stations
- 12 pulsed magnets
- 24 linac beam position monitor stations for 100 BPMs
- 2 beam-transport line monitor stations for 50 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 [8]. During that period, operational software written in scripting languages was enhanced on a daily basis in order to meet the requirements stemming from daily discussions. The programs include the beam mode pattern generators, dynamic parameter manipulators, beam-mode dependent display panels, data archivers, etc.

[1]PVs for the observation stations are not counted.

Actual simultaneous injection for the three rings started in the middle of April 2009. Although the operational parameters are not yet optimal, the beam current at the PF ring is kept within 0.1 mA, and those of KEKB rings are kept within 2 mA. Such stable beam conditions should enhance the beam quality at the rings.

Some of the observation stations do not recognize 50-Hz beam-mode switching yet, including streak cameras, beam wire-scanners and RF monitors, for which a timing signal only for a selected beam mode is delivered.

Missing pulse detectors are installed at several locations, and no anomalies have been observed during normal operation. An integrity timing monitor for the system is being developed to ensure correct operation. Since the summer of 2008, one of the EVR stations unexpectedly stopped working on two occasions, forcing a reboot. Electronic noise elimination is considered for this.

CONCLUSION

The new event-based control system was validated under the beam operation. It was proven to satisfy the fast switching requirements. The system is expected to realize a sensitive and stable tuning of KEKB with crab cavities for improved luminosity and higher-quality experiments simultaneously at the PF ring. Further software development is planned to support the beam operation with the three virtual accelerators enabled by the event system.

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