DEVELOPMENT OF TIMING AND CONTROL SYSTEMS FOR FAST BEAM SWITCH AT KEK 8 GeV LINAC

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Abstract

The 8 GeV Linac at KEK provides electrons and positrons to Photon Factory (PF) and B-Factory (KEKB). Simultaneous top-up injections have been considered for both PF and KEKB rings in order to improve the injection efficiency and the experimental stability. Therefore, fast beam-switching mechanisms are being implemented, upgrading the timing and control systems. While the old timing system provides precise timing signals for 150 devices, many of the signals are now dynamically switched using an event system. A new scheme has been developed and tested to enable double-fold synchronization between rf signals. Fast controls of low-level rf, beam instrumentation, kickers, a gun, and beam operation parameters are also upgraded for fast and precise tuning of those parameters. The system has been developed since 2006, and is being deployed under the beam operation in 2008.

INTRODUCTION

The KEK Linac injects electron and positron beams with different characteristics into four storage rings, KEKB-HER, KEKB-LER, PF and PF-AR. It takes 30 seconds to 2 minutes in order to switch the beam modes, depending on the magnet standardization [1]. When the beam development study is performed at PF ring for example, the experiment at KEKB is disturbed. Especially with the crab cavities installed at KEKB, the luminosity tuning is sensitive to the constant beam conditions at the both HER and LER rings and simultaneous injection to those rings is preferable. At the same time, the top-up injection is increasingly demanded at the PF ring in order to achieve higher-quality experimental data.

Thus, the fast beam-mode switching system has been designed and implemented [2]. In the system many hardware pieces of equipment are installed including pulsed magnets, fast rf system, and so on. Beam optics development is also performed in parallel to support the wide dynamic range of beam energy and charge, namely 3-times different energy and 100-times different charge.

Control and timing systems is upgraded as well to meet the requirement of the beam-mode switch in 50Hz (20ms). In order to notify the switching event globally along the 600-m Linac, an event system has been introduced [3]. It has been tested since 2006 and installed for the operation in autumn 2008. The system enables fast switching of many parameters of timing-signals, magnets, microwave systems, and beam instrumentations.

FAST BEAM-MODE SWITCHING

There are a few beam modes defined at the Linac. It took more than 30 seconds for more than 20 items to switch. And it is considered important to switch at least following beam modes.

- 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.

Here, 2 bunches in a pulse are separated by 96 ns. A fast switch of those beam modes is challenging because the dynamic range of the beam characteristics is very large. An adaptive beam optics scheme is being developed. In order to enable this scheme several hardware components had to be improved. And following parameters are changed within 20ms.

- Magnet: a pulsed bending magnet, several pulsed steering magnets, and a pulsed positron capture coil.
- Microwave: phase and timing of low-level rf, timing of high-power rf.
- Gun: grid-pulser selection, bias voltage, pico-second timing.
- Beam instrumentation: synchronized and fast beam-position-monitor read-out, pulse selection for wire-scanners and streak-cameras.
- Injection: selection of septa and kickers, interface to bucket selection systems.
- Operation: beam stabilization feedback, beam mode sequence pattern generation, mode-dependent parameter manipulation and archiving.

In order to achieve synchronized controls over Linac and beam transport lines for KEKB and PF, a global event notification system has been installed. Errors are not allowed because of safety reasons as the beam power varies 10 to 100 times [4]. The parameters for each mode have to be manipulated easily to optimize the beam tuning and the physics experiment conditions. It almost corresponds to building of three virtual accelerators.

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EVENT DISTRIBUTION SYSTEM

In the old system beam-modes were notified through two mechanisms. Four separate cables were connected to important control stations in order to indicate four independent pulse characteristics, such as the beam existence and the synchronized beam measurement. More detailed information was transferred via normal control features through control networks. Timing signals were transferred to 15 timing stations through a coaxial cable, which provides a 50 Hz pulse and a 571 MHz clock [5].

When the beam mode was changed, more than 500 parameters were changed. It took more than 30 seconds mainly because many magnets had to be standardized.

In the new system, it was decided to introduce the series-230 event system that was developed for Diamond light source [6]. With an event generator (EVG230) installed at the central station, event receivers (EVR200/EVR230RF) can receive information through an optical fiber connection. EVRs can provide,

- Sequence of programmed events in a pulse,
- Regenerated clock signal (114.24 MHz in our case),
- Up to 14 delayed timing signals (with precision less than 10 ps),
- Shared data buffer up to 2 k bytes.

Because they are transferred through a single fiber connection, the maintenance is expected to be straightforward.

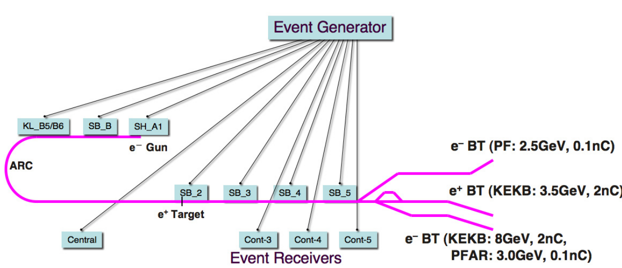

Figure 1: Layout of new event system.

Figure 1 shows 11 EVRs installed along the Linac. They are believed to be enough to control three beam-modes. Seven of those EVRs reside close to the existent timing stations, whose functionalities are being moved to EVRs. The number of components is reduced as an EVR can generate 14 precise delayed timing signals. Thus, most of the remaining old timing stations will be replaced by EVRs near future. Some devices, such as streak cameras, require better timing precision, so that a precise re-synchronization module is being developed.

The event rate is chosen to be 114.24 MHz, which is same frequency as the first sub-harmonic buncher and 1/25 of the main Linac frequency. The rf signal of 114.24 MHz is fed into EVG and used to transfer events and other data to EVRs in a star-like topology. Most of the EVR stations are connected through fan-out modules with multi-mode optical fibers, which were laid more than 10 years ago. Some of further stations are connected with single-mode optical fibers, replacing small-form-factor pluggable (SFP) modules at the fan-out module and EVRs.

The EPICS driver software is employed, and is extended to support new features of the series-230 system. The CPUs and the operating system of the VME computers are MVME5500 and VxWorks-5.5.1, respectively. The combination was chosen to satisfy the realtime performance requirements to the system and to enable the maximum coherence of the resources in KEK and EPICS community [7].

BEAM MODE PATTERN GENERATION

Approximately 50 event codes are defined so far. Some of them are directly related to one of the beam modes, and some others are related to one of the accelerator equipment. Each beam pulse, every 20 ms, is accompanied with a sequence of several event codes, which contains at least an event related to the beam mode of the present pulse and that of the next pulse. Some event codes received at an EVR system trigger EPICS software to control equipment connected.

Some of the equipment can respond to 50 Hz controls, however, others impose restriction rules in choosing pulses. The beam repetition request from each ring may vary depending on the beam and experimental conditions in the ring. Thus, it is complicated to arbitrate and design the pattern of the beam-mode pulse train. At the same time, however, it should be flexible.

As the modification of the software on the EVG system may interrupt the beam operation, it was decided to generate the pattern in a separate program. The present pattern generation scheme is developed in a scripting language for rapid prototyping.

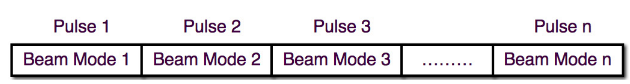

Figure 2: Beam-mode pulse pattern. A certain beam mode is assigned to each beam pulse, and several event codes accompany each beam mode.

The pattern such as Fig. 2 is designed in the program. The length of the pattern can be any number less than 500 (10 seconds), and it can be downloaded any time into the EVG system. Once it is loaded, it repeats forever until the next one is loaded, then the previous one is replaced at the end of the pattern. The EVG system generates a related event code sequence automatically following the pattern.

EQUIPMENT CONTROLS

EVR modules directly drive timing signals, responding to event codes. The pulse widths are normally fixed, however, the timing delays are modified dependent on the event codes that correspond to one of the beam modes. Those timing signals are connected to devices such as pulsed magnets, low-level rf, high-power sources, beam instrumentation, and injection systems in order to switch the beam and to adjust the beam characteristics.

The phase values in the low-level rf systems (LLRF) are essential in order to define the profile, absolute value and spread of the beam energy. At the end of each pulse LLRF parameters are changed to prepare the next LLRF pulse as in Fig. 3.

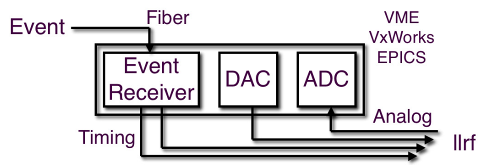

Figure 3: Six LLRF stations are controlled by EVR systems.

Currently, six pulsed magnets are installed in Linac, a bending magnet to feed the beam to the transport lines, a pulsed coil to efficiently capture the positron, and pulsed steering magnets to create a beam orbit bump to guide a beam around the positron target. They are separately triggered by timing signals from nearby EVR systems depending on the beam modes.

Beam instrumentations are also important to ensure the beam properties. Approximately 100 beam-position monitors (BPM) are utilized to monitor, stabilize and analyze the beam [8]. The old system reads the information only once a second. However, it is required to read every pulse if we switch the beam.

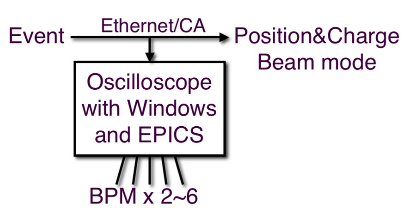

Figure 4: 24 oscilloscopes are installed to read 100 BPMs in 50 Hz distinguishing the beam modes.

The new system employs 24 oscilloscopes (Tektronix DPO7104) [9]. EPICS software is embedded on to those oscilloscopes with Windows. They can acquire the BPM signals in 10 Gsample/s and analyze the beam properties applying more than 20 coefficients per BPM. They can process the signals every pulse recognizing the beam modes and distinguishing two bunches 96 ns apart. Because the event system cannot be embedded on oscilloscope, events are delivered through the normal control network.

For some of the beam instrumentations such as streak cameras that do not recognize 50 Hz switched signals, a timing signal for only a selected beam mode is delivered.

RF SYNCHRONIZATION

Both of the ring rf frequencies are independently and continuously adjusted in order to compensate the ring circumference variations. KEKB and Linac frequencies have a common source because the tolerance of the injection timing jitter is less than 30 ps. For PF ring, double-fold synchronization module was developed to choose a timing that synchronizes within a certain jitter between PF revolution frequency and Linac frequency. Currently, the jitter is set to 300 ps.

CONCLUSION

The features of this new event-based control system is being validated under the beam operation. It is proved to satisfy the fast switch requirements. The system is expected to realize a sensitive and stable tuning of KEKB with crab cavities for a higher luminosity and a top-up injection at PF ring, simultaneously. More software development may be needed to support the beam operation with those three virtual accelerators enabled by the event system. An integrity monitor of the system is being developed as well to ensure the correct operation.

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