TRIGGER CONTROL SYSTEM WITH BEAM GATE AT SUPERKEKB INJECTOR LINAC AND DAMPING RING

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Abstract

Accelerator control system is indispensable for the beam handling. Especially, a timing control is much important tool for SuperKEKB project [1]. In the SuperKEKB project, the timing control system became more complex than previous KEKB project, because a Damping Ring (DR) was newly constructed. The DR is located at the middle of injector Linac. Positron beam is delivered from Linac to DR at the energy of 1.1 GeV, and is made lower emittance there. After being stored during 40 ms, the positron beam is returned to Linac. To control the beam injection and extraction at DR, we made two different timing at main timing system. In the DR, it is necessary to control the timing in the various situation, storage mode that is only injection, extraction only mode after optics measurement and so on. To satisfy this situation, "Beam Gate" handling system was embedded in the timing system. We also adopted beam gate handling at injector Linac. This system is very useful not only machine inhibit control but also identification the beam is transported or not.

INTRODUCTION

The SuperKEKB accelerator which is located in Tsukuba Campus, KEK, is aiming at the world highest luminosity to $8 \times 10^{35} \mathrm{cm}^{-2}\mathrm{s}^{-1}$. The injector Linac supplies electron and positron beam to SuperKEKB main ring at the energy of 7 GeV and 4 GeV, respectively for asymmetric collision at $\sqrt{s}$ =10.58 GeV. The Damping Ring (DR) is newly constructed for reducing positron emittance, and is located at the middle of injector Linac as shown in Fig. 1.
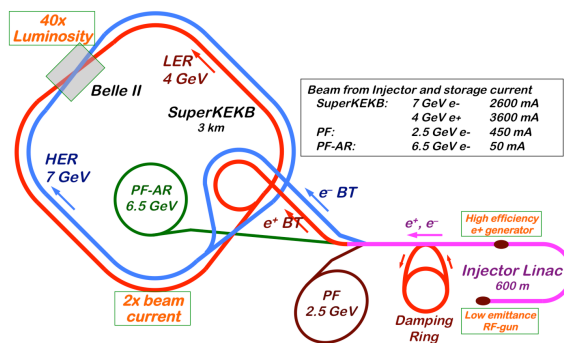

Figure 1: SuperKEKB Accelerator.

The positron beams are generated by irradiating electron beams on a tungsten target. The beams are gathered

through Flux Concentrator (FC). Bunch charge is going to be reached up to 4 nC. After accelerated at 1.1 GeV, the positron beams are delivered to beam transport line, and injected to the DR. The emittance before DR is about 3 mm in normalized emittance. When stored for 40 ms, it will be 92 μm in the horizontal direction and 7.3 μm in the vertical direction, respectively. Key parameters are listed in the Table 1.

Table 1: Key parameters of Damping Ring

Parameters	Value	Unit
Energy	1.1	GeV
Repetition frequency	50	Hz
Circumference	135.5	m
RF frequency	508.9	MHz
Harmonic Number	230	

Four bunches can be stored in DR at maximum when 2-bunch and 2-pulse mode is operated as shown in Fig. 2. Time difference between two bunches is kept 96.3 ns because injection chance comes up at the rate of 10.38 MHz. Where, frequency of 10.38 MHz is derived from common frequency 508.9 MHz in DR, MR and 2856 MHz in Linac. In the case of 2-pulse storage mode, first pulse and second pulse should be kept more than 100 ns because pulses of the Kicker magnets are active before and after 100 ns of trigger timing. Therefore, it is limited to inject second pulse since first pulse (in 2-bunch) is occupied (100 + 96.3 + 100) ns. The trigger control system calculates which timing is enabled to inject or not using this occupancy criteria.
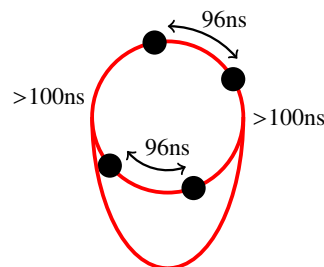

Figure 2: 2-bunch and 2-pulse operation mode at DR.

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EVENT TIMING SYSTEM FOR ACCELERATOR CONTROL

Overview

The timing system calculates various trigger generation timing and distributes it to many equipment. There are many timing parameters in the Linac because it provides beam for four multi-purpose ring, SuperKEKB two main ring, PF, PF-AR, and also DR with different energy and different particle. Therefore, it is necessary to identify which shot is for which ring. To satisfy in this requirement, event timing system is introduced. We chose event timing system produced by MRF's company [2]. MRF's event timing system consists of a pair of "Event Generator (EVG)" and "Event Receiver (EVR)". The EVG sends event information to EVRs for each devices. Originality of the event timing system is that the system is able to deliver not only timing signal but also shot information via optical fiber cable. The timing has 8-bit information which is called "event code", and is transferred after 8B10B encoding. 2 bytes of information are transmitted to EVR in synchronization with RF wave of 114 MHz. The first 1-byte is assigned as event code, and the second 1-byte is shared by the distributed bus bit and synchronous data buffer alternatively. The distributed bus bit has 8-bit and can send 8 kinds of HI or LOW bit state to EVR. By using this function, we are sending Beam Gate information. The detail is described next section. The data buffer is enabled to be included 2 kB information at most. We are packing shot number, event code information, RF phase etc. in the data buffer.

System Setup on EPICS IOC

We have developed on EPICS base R3.14.12 for SuperKEKB event timing system [3]. Under this version, MRF's device support in the version of mrfioc-2.0.2 or 2.0.3 is embedded [4]. Since the original MRF's device support is omitted read out of distributed bus bit, we modified to be able to read it. Hardware settings are also made at each locations. Main timing station of EVG is located at the center of injector Linac [5] and each sub-system is working at DR [6] and MR [7]. The sub-system is originally made and re-made trigger according to receive it from main timing station.

BEAM GATE CONTROL AT DAMPING RING

DR operation started from February 2018. We have constructed sub-timing station at control room at DR. There are several operation method in DR, continuous injection mode, one-shot and storage mode, only extraction mode, and so on. Considering various operation mode, the control method of injection and extraction kicker and septum became difficult. And also, it is necessary to switch beam gate quickly for incoming and outgoing positron in DR. The beam gate handling method is usually processed via EPICS PV. However, it is not suitable for pulsed-like control such as kicker and

septum magnets. So, we decided to transmit beam gate via event timing system network by using distributed bus bit. Since the distributed bus bit sends bit information at the frequency of 57 MHz, the response speed is about 17 ns. The bit status can be monitored with EPICS PV, and each EVRs can process according the status. The beam gate bits for DR injection and extraction kicker and septum is assigned in 8 bit distributed bus. Totally 4 kinds of bit information are used as shown in Table 2.

Table 2: Assigned Beam Gate Bit in Distributed Bus Bit

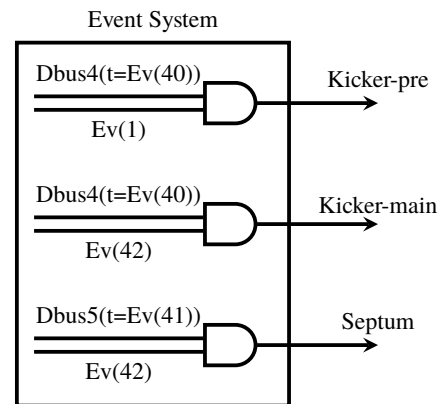| Category	Dbus bit
DR Injection Kicker	Upstream DbusBit4
DR Injection Septum	Downstream DbusBit5
DR Extraction Kicker	Upstream DbusBit4
DR Extraction Septum	Downstream DbusBit5
HER LER Beam Gate OR	Both DbusBit6

Figure 3: Beam gate logic structure.

The trigger for Kicker and Septum magnet is controlled with AND circuit in the event timing system as shown in Fig. 3. Kicker-pre is the timing for charged trigger, and the original event code is No. 1. This trigger is controlled by the beam gate of Dbus4. Kicker-main is the timing for discharged trigger, and the original event code is No. 42. It is controlled by same logic of Kicker-pre. Septum timing is numbered event No. 42 and controlled by the beam gate of Dbus5, which is different timing with Kicker.

Timing chart of beam gate is shown in Fig. 4. The beam gate via distributed bus is pulse like structure which width is about 20 ms. Which event code to be transmitted is informed before 2-shots. We numbered event code No. 40, 41, 42 on the positron beam. The code of No. 42 indicates the delivered positron beam timing, and No. 41 indicates preparation event timing transmitted before 1-shot (20 ms), and No. 40 indicates also preparation event timing transmitted before 2-shot (40 ms). Each beam gate is output so as to overlap with event timing at No. 40 and 41, respectively. The trigger for Septum magnet is output at the timing of event No. 42. To control this output, beam gate sta-
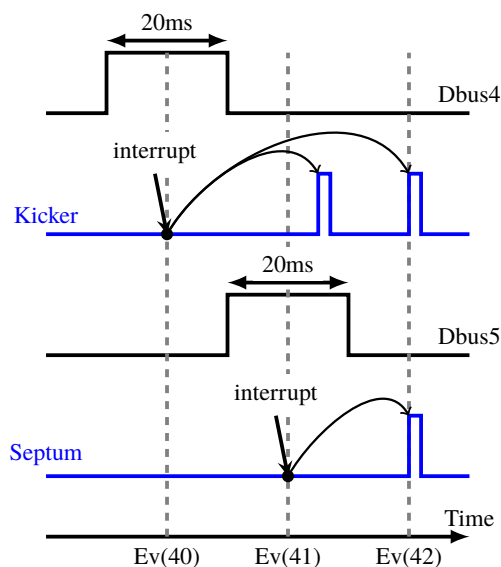
Figure 4: Timing chart of beam gate at DR.

tus is checked at the timing of event No. 41. The triggers for Kicker magnet are output at the timing of event No. 42 for discharged trigger and the timing of event No. 42 before 12 ms for charged trigger, respectively. To control this output, beam gate status is checked at the timing of event No. 40.

Selection of operation mode using beam gate

Since the beam gate is assigned individually as shown in Table 2, various operation mode can be supported. Especially, injection and extraction at DR is designed to be fired simultaneously by assuming 50 Hz continuous injection with storage time of 40 ms. In addition, storage operation mode and low repetition injection mode are necessary for optics study. These operation mode can be categorized like Table 3.

Table 3: DR operation mode according behavior of beam gate

Mode	Beam Gate (inj/ext)	Use
KBP	○ / ○	continuous injection
KBPu	○ / ×	first-shot after B.G open, storage mode
KBPd	× / ○	extraction after T_{max}, last-shot before B.G close

We call operation mode of positron beam for SuperKEKB Main Ring as "KBP" mode. The KBP mode is normally used for continuous injection. We assigned "KBPu" and "KBPd" as additional mode in DR. The KBPu mode means that positron beam is delivered to DR, but not extracted the stored beam at the same time. On the other

hand, the KBPd mode means that stored positron beam is extracted, but not injected to DR. These mode of KBP, KBPu, and KBPd is same event code. The beam gate combination makes these differences. An upper limit is set for storage time, T_{max}, so as to prevent the timing from shifting with long storage time. If the injection interval is longer than T_{max} by low repetition rate, the beam is extracted after passing T_{max}. At this time, the beam is handled with a pair of KBPu and KBPd mode. Including 1-pulse and 2-pulse mode, the storage time calculation is described in [8].

BEAM GATE CONTROL AT LINAC

Overview

Trigger from event timing system is generated to be kept duration within (20 ± 2) ms because the Flux Concentrator (FC) and the Klystron must be maintained in equal spaced trigger with 20 ms even when beam is stopped. The event timing system is calculated to generate at around commercial 50 Hz under FC and Klystron criteria. However, the timing is sometimes generated out of 2 ms due to initialization of timing calculation sequence, then the hardware is interlocked. To avoid trigger lost in this situation, trigger switch method is introduced.

Trigger Switch for Flux Concentrator

The concept of trigger switch is shown in Fig. 5. FC input trigger is selected either the trigger from event system or commercial 50 Hz according switching gate level. The interval of commercial 50 Hz trigger hardly change, so that FC input is sent this trigger during event system initialization.

Timing chart of the trigger switch is shown in Fig. 6. The switching gate is made from the delayed timing signal of Event No. 41. The switching gate status is originated from beam gate (Dbus4) status at the timing of Event No. 40, namely event system is used for FC input when beam gate opened, and 50 Hz trigger is used when beam gate closed. The switching gate timing is adjusted 10 ms before Event No. 42.
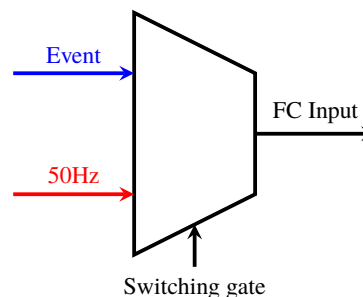

Figure 5: Trigger switch logic.

Trigger Switch for Klystron

Trigger switch method is also developed for Klystron. The principle is almost same as FC trigger switch method.
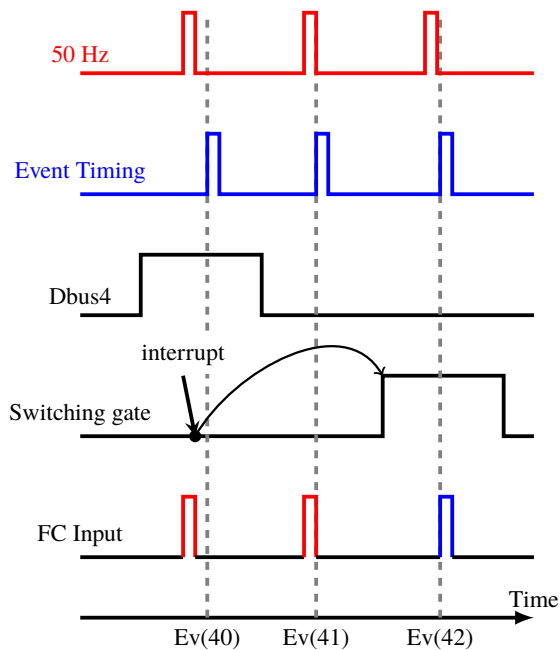
Figure 6: Timing chart of the trigger switch for FC.

The Klystron is operated with the interval of 25 Hz or 50 Hz. We improved trigger switch system by incorporating commercial 50 Hz trigger as the "Event code", and also 25 Hz trigger was made from the 50 Hz trigger by pre-scaling. The switching gate status is originated from Dbus6 status which is Beam Gate OR of HER and LER as listed in Table 2.

SUMMARY

We developed injection and extraction control system at Damping Ring by using beam gate via event timing system. It became useful function by separating injection and extraction control, with Distributed Bus Bit technology. This method was applied to trigger switch in the event timing system at injector Linac. The trigger switch method was able to compensate for trigger-lost of event timing calculation method during initialization of event timing system. This function is adopted to devices required for equal spaced trigger such as the FC and Klystron.

SuperKEKB Phase-2 project started from February 2018, and finished in July this year. The DR operation was successfully finished with no serious event timing problems. Phase-3 project is scheduled to start in February 2019 to attempt to update the world highest luminosity record and obtain new particle physics events by Belle2 experiment [9].

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