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BEAM GATE CONTROL SYSTEM FOR SUPERKEKB

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Abstract

SuperKEKB is an electron-positron collider at KEK. Its phase-1 operation is successfully carried out in 2016. We develop the new Beam Gate control system for the ongoing phase-2 operation. The synchronization of injection hardware control is improved. In addition, the "Delayed Synchronization" function is installed to operate the newly constructed damping ring. The new system accepts the control from Bucket Selection. We proceed the phase-2 commissioning of SuperKEKB with the sophisticated Beam Gate control system.

INTRODUCTION

SuperKEKB [1,2] is an electron-positron collider with the center-of-mass energy of 10.58 GeV. It consists of the injector linac (LINAC) [3], damping ring (DR) for positrons, and two main rings (MRs). The MRs for electrons and positrons are called High Energy Ring (HER) and Low Energy Ring (LER), respectively.

The phase-1 operation of SuperKEKB was successfully carried out in 2016 [4, 5]. The beam doses at LER and HER are 780 Ah and 660 Ah, respectively. The vacuum scrubbing of beam pipes was smoothly proceeded. The beam commissioning was implemented.

The phase-2 operation is started from March 2018. The positron-pulses generated at LINAC are once stored into DR to suppress the beam emittance and injected into LER in phase-2 while they were directory injected in phase-1. We successfully realized this injection scheme. Further commissioning of beams and accelerators is ongoing. We observed the first collision event on April 26th.

The Beam Gate system is one of important items for the commissioning of SuperKEKB. Figure 1 is an example of beam operation. The Beam Gate quickly switches "beam delivery" and "pause" of beam injection system. During the accelerator studies, we iterate above process with changing lots of machine parameters. So the quick switching makes the studies efficient. Besides, SuperKEKB has an automatic process to keep beam current at MRs. The software process monitors beam currents of two MRs. It opens (closes) Beam Gate when the MR beam current becomes low-limit (high-limit). It helps vacuum scrubbing in the machine commissioning.

The upgrade of Beam Gate is required for the phase-2 operation. More precise synchronization of injection hardware is required. The delayed synchronization to control injection and extraction components at DR is necessary.

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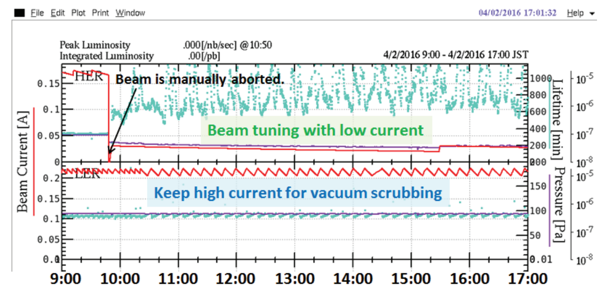

Figure 1: Example of beam operation: the beam currents at LER and HER are plotted. The high beam current at LER is kept by iterating the open and close of Beam Gate.

REQUIREMENTS TO BEAM GATE

We prepare the Beam Gate system for LER and HER separately. They control (enable or disable) trigger delivery to the injection hardware, such as electron gun, septum and kicker magnets. The operation of kicker magnets slightly affect to the stored beams. Therefore we should stop the trigger deliveries when we do not perform the injection to MRs. It is important for the septum and kicker magnets to avoid unnecessary operation also in terms of their lifetime.

Since the Beam Gate in the phase-1 operation inaccurately synchronize the controls of injection hardware, it caused a lot of accidental beam abort at the early stage of operation. The trigger delivery to the MR-injection septum is stopped much earlier than that to electron gun when we closed Beam Gate. More than ten beam-pulses hit the septum wall in the absence of bending field. Then the beam-loss monitor at MR requested the beam abort. The precise synchronization of injection hardware control is required to the new Beam Gate system.

The "Delayed Synchronization" function described the later section is necessary to control DR components together with LER components.

EVENT TIMING SYSTEM

We leave the basic functions of Event Timing System to somewhere Ref [6]. In this section we describe the module configuration at SuperKEKB and its important function, Distributed Bus Bit, for the Beam Gate system

Configuration at SuperKEKB

The basic configuration of Event Timing System is as follows: the master module is configured with Event Generator (EVG) and is connected with more than one slave modules, Event Receivers (EVRs) via dedicated optical network.

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We mainly utilize the EVG and EVR modules developed by MRF [6]. Those developed at SINAP are partially install at MR. They configure sub-station to provide injection triggers to MR hardware.

The master EPICS IOC [7, 8] for Event Timing System consists of three EVGs and one EVR. They are connected to form three-layers. The two EVGs installed in the lowest layer work for controlling the 1st half and 2nd half of LINAC, respectively. The detailed specification of master IOC is described elsewhere [9–11].

Distributed Bus Bit

We utilize the Distributed Bus Bit (Dbus) function of Event Timing System for delivering Beam Gate information towards individual injection hardware. The Dbus system monitors the input TTL level signals at EVG and delivers them toward all downstream EVRs. The information is delivered via Event network without disturbing machine operation with the Event delivery.

In more detail, the Dsub accepts 8 TTL inputs. They are converted into one byte data packet and transfered toward EVRs. Therefore we can deliver 8 different level signals simultaneously via the single optical cable. The input sampling rate is one or half of Event clock, it depends on operation parameters of EVG. It is 57 MHz in case of SuperKEKB.

By upgrading the device/driver of MRF modules [8], the transfered information can be used in two ways at individual EVRs. The status of individual Dbus bits can be outputted as the NIM or TTL level signals. They can be monitored also via the EPICS PV.

INJECTION CONTROL

General Specification

The Beam Gate system receives inputs from the individual MRs. The electron gun at LINAC, injection and extraction hardware at DR, and injection hardware at two MRs are controlled with these inputs.

Totally 8 kinds of control signals are provided with Beam Gate main software. They are summarized in Table 1. The LER Beam Gate input controls the LER and DR components while the HER input controls the only HER components.

Figure 2 is the schematic view of Beam Gate control system at main Event IOC. The control signals of electron gun are outputted from EVG module and delivered to the nearby circuit which generates triggers to electron gun. All other control signals are newly developed for the SuperKEKB phase-2 operation. They are delivered with Dbus toward remote IOCs. As written in the previous section, the Dbus utilizes the Event network which has already been configured and Therefore we increase the control signal without cabling new optical lines.

The electron gun at LINAC is controlled with both LER and HER gun control signals. The gun circuit receives two control signals. However it accepts only LER (HER) control

Table 1: Summary of Beam Gate Signals: note, the LER Beam Gate controls LER and DR components while the HER Beam Gate controls the only HER components. The injection kicker and septum for HER (LER) are controlled with only one signal labeled ”Injection Hardware”.

Components	Latency (ms)	Dbus
LER Gun	20	None
DR Injection Kicker	0	EVG1 bit4
DR Injection Septum	20	EVG1 bit5
DR Extraction Kicker	T_{str}	EVG2 bit4
DR Extraction Septum	$T_{str} + 20$	EVG2 bit5
LER Injection Hardware	$T_{str} + 20$	EVG2 bit1
HER Gun	20	None
HER Injection Hardware	20	EVG2 bit3

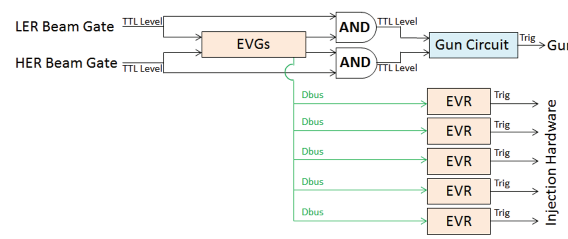

Figure 2: Schematic view of Beam Gate circuit: the output for electron gun is provided as the level signal while others are provided as the Dbus.

signal when LINAC performs LER (HER) injection.[1] The by-pass lines connect between input and output for electron gun works as the “immediate close”. For example, when the MR is aborted, the Beam Gate is closed the abort trigger system. The “immediate close” function is able such kind of cases.

The other injection hardware is controlled by the EVR modules. The EVRs provide injection triggers to the injection hardware, such as the septum and kicker magnets. They switch the enabling and disabling of trigger output with the Dbus information when they receive the Event interruption.

The core part of Beam Gate system (labeled as “EVGs” in Figure 2) is software process. We newly develop main software of Beam Gate. It receives the Beam Gate control signal and provide the 8 kinds of output control signals which are listed in Table 1.

Even though the individual injection components are controlled by different EVRs, we can precisely synchronize their switching processes since the main software controls the Dbus information.

The main software intendedly makes latency between input and output. We can set different latencies listed in Table 1 to the individual outputs so that the delayed synchronization of Beam Gate is realized. The details of delayed synchro-

[1] The gun circuit is developed in the former KEKB project. The Beam Gate signal is directory inputted into this circuit in that period. The same control is implemented also for the light source ring on this circuit.

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nization and main software itself are described in following subsections.

Delayed Synchronization

In principle, the trigger deliveries to all injection hardware are controlled synchronously. The new Beam Gate system precisely synchronize the EVR processes with main software and Dbus.

There is another important feature on the Beam Gate main software. It works when we control the LER Beam Gate. The positron pulse is once stored at DR to damp the beam emittance. The DR storage time and entire period of LER injection becomes longer than one LINAC operation period of 20 ms. In this case the trigger delivery is controlled from upstream to downstream. Therefore the delayed synchronization is implemented with the arbitrary latency of individual outputs.

The delay of the DR-extraction and LER-injection from the DR-injection depends on the positron storage time at DR, T_{str}. The latency of output signals for DR-extraction and LER-injection are T_{str} ms longer than the DR-injection components. The T_{str} is defined as follows:

$$T_{str} = \min(T_{MAX}, 1000 \cdot N_{pulse}/f_{inj}), \qquad (1)$$

where the f_{inj} and N_{pulse} are injection frequency of LER and the operation pulse of DR. The T_{MAX} defines the maximum storage time. It is decided to be 200 ms owing to the specification of trigger circuit. Therefore, for example, the T_{str} becomes 40 ms when we perform LER injections with $f_{inj} = 25$ Hz and $N_{pulse} = 1$. Note, the T_{str} value is defined in 20 ms step.

The delayed synchronization is important. For example, when we close LER Beam Gate, if we stop trigger delivery to the DR-extraction components earlier than schedule, the positron pulse remains at DR. On the other hand, if we stop the delivery later than schedule, they are fired unnecessary. It makes their lifetime shorter.

Main Software

The main software is configured on the EPICS process. Figure 3 is the flow chart of Beam Gate core process. We develop the new software record named "bgate". Two software PVs are provided for LER and HER, separately.

The bgate has one input field and eight output fields. The Beam Gate status is once converted to the EPICS PV which is linked with the input field of bgate. It is transfered into output field after waiting the latency defined as follows.

The bgate record has an internal counter. The counter is incremented when the PV is processed and initialized when the input status is changed. The PV is processed in 50 Hz by the interruption of Event Timing System.

The latency listed in Table 1 is set to the delay field in unit of this counter. For example, we set "1" to the delay field when the latency is 20 ms. Then the bgate transfers the input status to the output when the internal counter equals to the value of delay field.

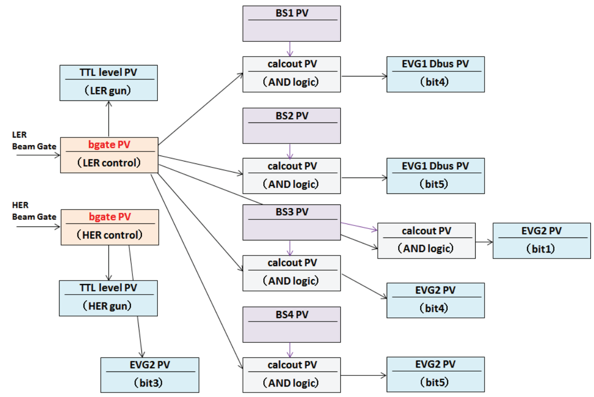

Figure 3: Flow chart of Beam Gate core process on EPICS IOC: it consists of bgate PVs, reflective memory PVs, and calcout PVs configured as "AND" logic.

The Event Timing System launches interruptions precisely between injections of LINAC[2]. Therefore the delayed synchronization of Beam Gate control is realized precisely even though it is the software process.

Input from Bucket Selection

As seen in Figure 3, We put the "AND" logic PV which receive inputs from the bgate PV and the reflective memory PV (BS PV). The Dbus PV for DR and LER components are controlled with this "AND" PV.

By using this "AND" logic we can control injection hardware also from Bucket Selection. For example, during DR commissioning, we can store beam pulse at DR when the BS1 and BS2 PVs are "HIGH" and all others are "LOW". We can throw beam from DR with the opposite condition.

Bucket Selection manage such kind of control by using the reflective memory PVs.

CONCLUSION

We develop the new Beam Gate system for the phase-2 operation of SuperKEKB. The controls of trigger delivery to individual injection hardware are precisely synchronized with the new system. Besides, the "Delayed Synchronization" function is installed for the LER injection which includes the operation of newly constructed DR. The injection hardware can be controlled also with Bucket Selection. It makes the beam commissioning efficient.

The DR is commissioned successfully in February 2018, before the phase-2 operation. The phase-2 operation is ongoing with the sophisticated Beam Gate system.

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