UPGRADE OF EVENT TIMING SYSTEM AT SUPERKEKB

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Abstract

SuperKEKB is the upgrade of KEKB. The designed luminosity is 40 times larger than the KEKB achievement. One of key items for this luminosity enhancement is twice larger storage beam current. Injector Linac is required more efficient injections although the injection control becomes complicated. The Event Timing System at Main Trigger Station is upgraded. We perform the basic study for the new configuration of Event Timing System and confirm it satisfies the SuperKEKB requirement.

SUPERKEKB

SuperKEKB[1, 2] is the electron-positron collider at KEK, Japan and will be started the commissioning in early 2015. This is the upgrade of KEKB[3, 4] which achieved the world's largest luminosity for colliders[5]. The energy of electron (positron) beam is 7.0 GeV (4.0 GeV) so that the center of mass energy is on the Υ(4S) resonance of 10.58 GeV. The designed luminosity is set to be $8 \times 10^{35}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and 40 times larger than the KEKB achievement. This luminosity upgrade project is realized by two parts. One is 20 times smaller vertical beta function at the interaction point. The other is, related to this report, twice larger storage beam current at both main rings (MRs).

INJECTION CONTROL

Injector Linac[6] plays more important roles in the SuperKEKB project. The beam current at two MRs is doubled and it must be kept with the top-up injection. Besides injection scheme becomes complicated for positrons because of the newly constructed Damping Ring (DR). In this section, Linac is explained briefly. Then the injection controls at SuperKEKB are described.

Injector Linac

Linac provides beams into four rings, namely, KEKB HER (High Energy Ring), KEKB LER (Low Energy Ring), PF[7], and PF-AR[8]. Positrons are injected into KEKB LER while electrons are injected into other three rings. The beams provided by Linac are summarized in Table 1.

Table 1: Beams provided by Linac

Direction	Particle	Eneragy	Charge
KEKB HER	e^-	7.0 GeV	5.0 nC
KEKB LER	e^+	4.0 GeV	4.0 nC
PF	e^-	2.5 GeV	0.2 nC
PF-AR	e^-	6.5 GeV	5.0 nC

There are new features at SuperKEKB. Positrons are once stored into DR for at least 40 ms and injected into KEKB LER. The top-up injection for four rings[1] are performed after finishing the construction of new beam transport line for PF-AR.

Injection control is performed by Main Trigger Station[2], which is described in the later section, and the star-type optical network. The Event Timing System[9] is used in this system.

Ring Selection

One of the injection controls is Ring Selection. To realize top-up injection into more than one ring simultaneously, the injection ring must be changed frequently. However Linac needs different operations for the individual injection rings.

Linac arbitrates the requests from four rings and schedules operations for a next couple of seconds. Injections are performed with this schedule and the injection ring is changed pulse-by-pulse. At SuperKEKB, more than 150 of Linac parameters are changed every injection pulse, typically with 50Hz.

Injection scheme of positrons becomes complicated. It must be processed in a part of long term schedule. A few examples of schedules for the Linac operations are shown in Figure 1. The injection process of positrons at SuperKEKB cannot be finished before the next beam pulse is launched. The positrons are stored into DR for at least 40 ms and the storage time depends on the injection rate.

More than one process is implemented in parallel. The electrons are injected while the positrons are damping. Besides, in case of positrons, the first and second halves of Linac work separately. The first (second) half works for injecting positrons into DR (MR).

Ring Selection at SuperKEKB requires the upgrade of Main Trigger Station. The new system should have the capability to control more than one process simultaneously. The injections must be performed with knowing the long-term injection schedule for positrons.

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[1] Top-up injection for three rings (KEKB HER, KEKB LER, and PF) has already been realized in the KEKB era.

[2] We call it also Main Timing Station.

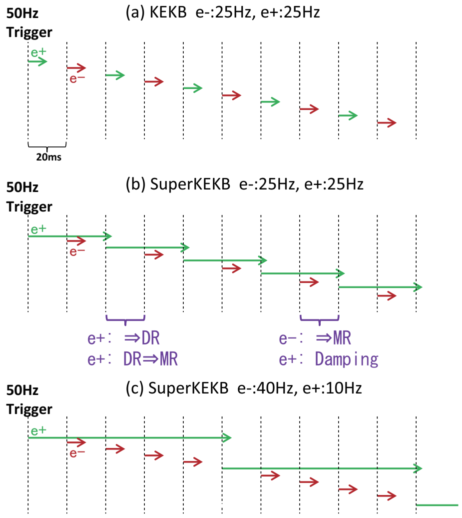

Figure 1: Examples of injection schedule. In cases of 25 Hz (e^-) : 25 Hz (e^+) at KEKB, 25 Hz : 25 Hz at SuperKEKB, and 40 Hz : 10 Hz at SuperKEKB are shown. The brown and green arrows indicate electron and positron injections, respectively.

Bucket Selection

The other important control is Bucket Selection[10]. This is implemented only when a beam is provided into the KEKB MRs. There are 5120 RF-buckets in each MR. The operator send a request to Linac about the fill pattern into the RF-buckets. The Bucket Selection system controls the injection RF-bucket to realize the requested fill pattern.

The injection RF-bucket is controlled with changing the delay time of Linac operation. In the individual 20 ms periods, the Linac operation is synchronized with the reference signal which is made from the revolution of injection ring. In case of MRs, Linac is operated with adding delay time to this reference signal. In this method, the injection RF-bucket is determined with the delay time. For example, if Linac is operated after 96.3 ns longer delay time, the beam pulse is injected into the 96.3 ns later RF-bucket.

The delay time is set to be 0–493 μs with 96.3 ns step. For considering the RF frequencies of Linac (2856 MHz) and MRs (508.9 MHz), an opportunity of injection comes every 96.3ns. After 5120 opportunities, it takes 493 μs, all RF-buckets have their own injection opportunities. The 493 μs cycle of reference signal is used at KEKB.

In case of the positron injection at SuperKEKB, the delay time for Bucket Selection becomes longer and to be 0–11.34 ms with 96.3 ns step since the DR-bucket also must be considered. All of MR-buckets can be selected in the 0–493 μs delay time. However, the DR-bucket coupled with injection MR-bucket changes every 493 μs period. We choose the harmonic number of 230 for DR so that there are 23 kinds of combination between DR-bucket and MR-bucket. Then, the delay time for selecting both DR-bucket and MR-bucket becomes at most 11.34 ms ($= 493\,\mu\mathrm{s} \times 23$).

Main Trigger Station needs the upgrade also for Bucket Selection. All triggers must be synchronized with the reference signal for selecting the RF-bucket with the above mentioned delay time method. At KEKB, the analog coincidence of injection trigger and reference signal is performed in 50 Hz. However, it becomes difficult since the cycle of reference signal is expanded to be 11.34 ms.

We choose the different approach to synchronize triggers with the reference signal. The new configuration of Event Timing System for SuperKEKB is developed.

EVENT TIMING SYSTEM AT SUPERKEKB

We use the Event Timing System at Main Trigger Station. The timing trigger and the instruction for actions in the next injection are delivered from this system to the Linac local devices. In this section, the Event Timing System and its new configuration at SuperKEKB is introduced.

Event Timing System

The Event Timing System is composed of optical network connections between an Event Generator (EVG) and an Event Receiver (EVR). The EVG sends 1 byte data named Event-Code. It is encoded with 8B10B encoding so that the delivered Event-Code indicates precise timing. One optical cable can be considered as 256 cables of trigger line since the Event-Code is distinguished into 256 types. The EVR receives the Event-Code and activates the programmed action, such as the NIM/TTL signal production, on the Event-Code timing. The action can be programmed for the individual Event-Code types and the CPU interruption also is possible.

At the SuperKEKB project, we use the MRF products, VME-EVG-230 and VME-EVR-230RF[9]. We have knowledge and experience to operate these modules from the KEKB project. The EVG is installed at Main Trigger Station. The operation is synchronized with the 114.24 MHz of RF clock at Linac. Therefore, the Event-Code is delivered with the timing in units of 8.8 ns ($=$ 96.3 ns/11). The EVRs are installed with the local devices along with the Linac beamline. They interrupt the CPU to change the configuration of local devices. The preparation for the injections to the individual rings has been programmed at the local EVRs in advance.

Configuration at Main Trigger Station

Main Trigger Station is placed the vertex of optical network and connected with the local devices. The EVG delivers two kinds of Event-Code. One is used for the timing trigger and the other is for the instruction to the local devices about the actions in the next pulse.

We upgrade the Event Timing System at Main Trigger Station to satisfy the complicated requirements of SuperKEKB injection. Figure 2 is the new configuration. The two-layers configuration of EVGs is developed.

The upper-layer EVG is operated with the long term sequence. This is triggered once a few second by the analog coincidence of injection triggers (20 ms period, 50 Hz)

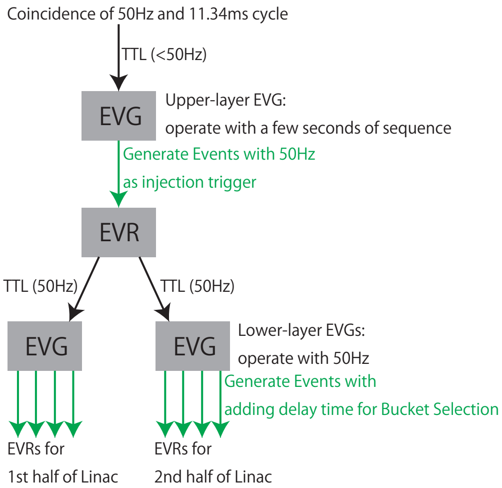

Figure 2: Configuration of Event Timing System at Main Trigger Station. Two layers of EVGs are composed. The upper-layer EVG is operated with a few seconds of sequence and generate Event-Codes in 50Hz. The lower-layer EVGs are operated with the 50Hz trigger and generate Event-Codes with adding delay time for Bucket Selection. The transmission of Event-Code is shown by green arrow. The signal lines for PF and PF-AR are omitted on this figure. Subsequently, they will be described in the separate paper.

and the reference signal (11.34 ms). The injection schedule is programmed on this EVG and the Event-Codes for timing trigger are delivered to the lower-level in 50 Hz. The positron injection via DR is possible since its longer injection process can be programmed on this EVG as a part of long term schedule.

There are two lower-layer EVGs. The first and second halves of Linac are separately controlled by them. They are operated in 50 Hz and delivered Event-Codes to the local devices with adding the delay time for Bucket Selection. The calculation of delay time is possible since the time relation between every input trigger and the reference signal is precisely controlled by the upper-layer EVG.

PERFORMANCE STUDY

The performance study for the new configuration of Event Timing System is carried out. Although we continue to use the same model of Event Timing modules since the KEKB project, there is no experience for us about two key elements in the new configuration. One is the two-layers configuration of EVGs. The other is the EVG operation with long term sequence, such as a few seconds, by one input trigger. We study whether the new system satisfies timing accuracy of $O(100)$ ps, which is the requirement for the timing trigger in the SuperKEKB injection.

The setup of performance test is shown in Figure 3. The two-layers configuration of EVGs is produced. The most downstream EVR should be placed distantly with the Linac local devices in the real operation. However, in this test, it

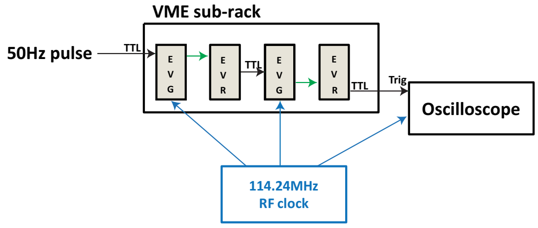

Figure 3: Test setup. The two-layers EVGs configuration is produced. The timing accuracy of output trigger is examined as a reference of RF clock. The transmission of Event is shown by green arrow.

is inserted in the same VME bus and controlled from the same CPU as other Event modules for simpleness. We use the sampling oscilloscope and the accuracy of timing measurement is better than 1 ps. The EVGs are synchronized with the 114.24 MHz of RF clock. The timing of same RF clock is measured with triggering by the Event System.

Figure 4 is an example of measurements. The mean and standard deviation of measurements are checked and they are defined as trigger-timing and jitter, respectively.

The effect to the accuracy of trigger-timing is studied when the upper-level EVG is operated with the long term sequence. The results are shown in Figure 5. The upper-layer EVG is operated with different length of sequence from 8.8 ns (one RF clock) to $\sim$2 s (2×10^8 RF clocks) and generates an Event-Code at the end of sequence. We confirm the two-layers configuration works well. The trigger provided by this setup is accurate and its jitter is to be always $\sim$10 ps. There is no significant difference in the resultant jitters when we change the length of sequence up to $\sim$2 s.

We study also the long term stability. Figure 6 is the re-

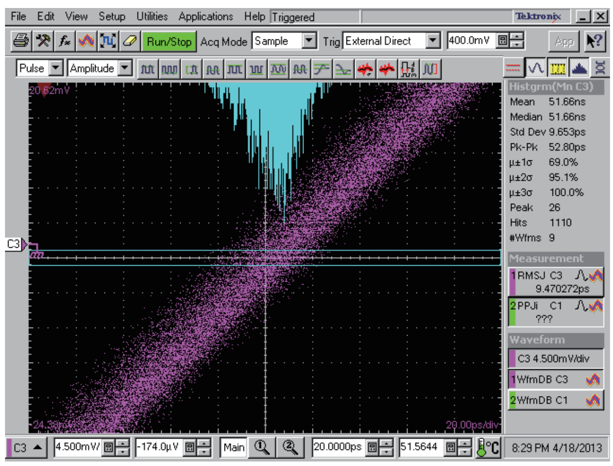

Figure 4: An example of timing measurement. The timing on phase zero of RF clock is measured by the oscilloscope. The mean and standard deviation is determined statistically after collecting 1000 samples. They are determined as the trigger-timing and jitter, respectively.

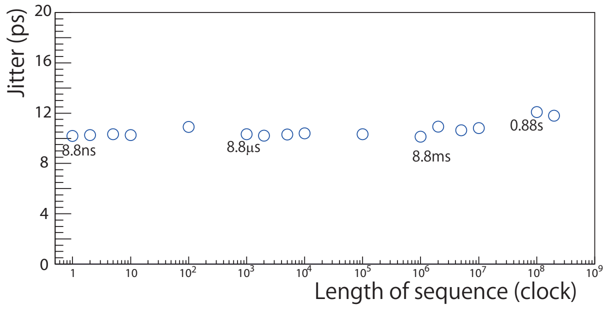

Figure 5: Results of the two-layer setup test. The length of sequence at the upper-layer EVG is shown in RF clock unit. That at the lower-layer EVG is fixed to be 8.8 ns, one RF clock, during the measurements.

sults of five days of measurements. The measurements for 1 min-period are carried out continuously with monitoring the room temperature. We clearly observe the timing dependence in temperature.

We determine the magnitude of drift of trigger-timing from the 2D histogram in Figure 7. It is evaluated from the slope of distribution to be 18 ps/degree. This is reasonably small and no problem when we operate the Event Timing System with keeping the temperature within ± 1 degree by the air conditioning.

CONCLUSION

We upgrade the Event Timing System at Main Trigger Station to satisfy the requirements of SuperKEKB injection. The positrons are injected via DR and it makes the entire operation of Injector Linac complicated. The two-layers of EVGs is configured at Main Trigger Station.

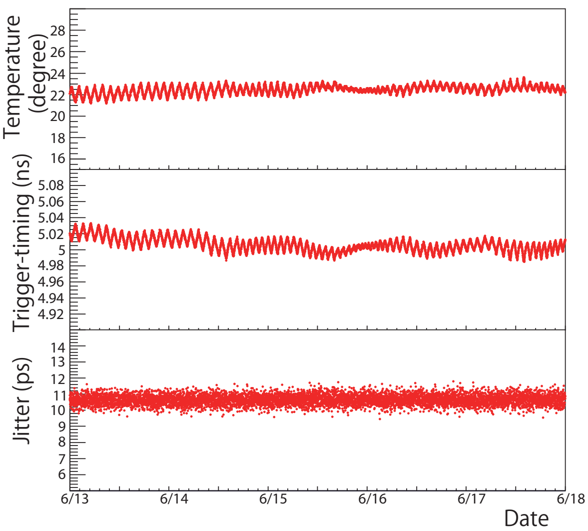

Figure 6: The five days of measurements during Jun13–Jun17 in 2013. The timing is measured every one minute together with room temperature.

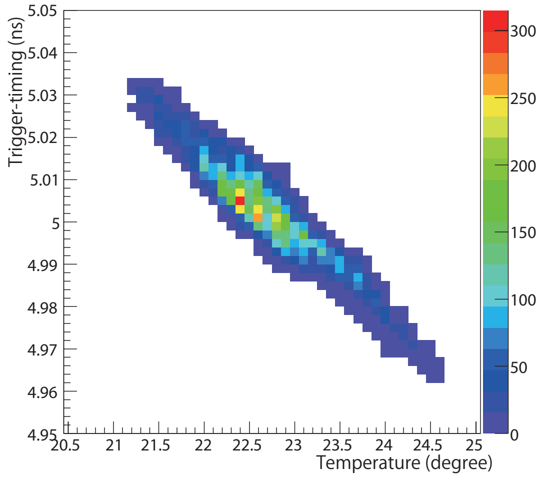

Figure 7: Timing vs temperature. The 2D plot made with results in Figure 6. The slope is evaluated by fitting with 1D polynomial function to be -18.00 ± 0.16 ps/degree.

We perform the basic studies for the new configuration. The accuracy of timing with the new configuration is determined to be 10 ps and there is no significant difference in the length of sequence at the upper-layer EVG. The accuracy satisfies the requirement for the SuperKEKB injection.

We observed the drift of trigger-timing by the change of room temperature. The magnitude is determined by the study to be 18 ps/degree. The influence on accuracy is reasonably small when we operate the Event Timing System with air conditioning.

We conclude there is no problem in the new configuration of Event Timing System for SuperKEKB.

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