INSTALLATION AND COMMISSIONING OF NEW EVENT TIMING SYSTEM FOR SuperKEKB

H. Kaji, K. Furukawa, M. Iwasaki, E. Kikutani, T. Kobayashi, F. Miyahara, T.T. Nakamura, M. Satoh, M. Suetake, M. Tobiyama, KEK, Ibaraki, Japan
Y. Iitsuka, T. Okazaki, East Japan Institute of Technology, Ibaraki, Japan
T. Kudou. S. Kusano, Mitsubishi Electric System & Service Co. Ltd., Ibaraki, Japan

Abstract

The new Event Timing System was installed in 2014. The parameters of new system to operate LINAC were optimized through the commissioning which was based on the trigger-monitoring and the experimental beam operation. The necessary functions for the Main Ring injection were additionally integrated in 2015. Finally we performed the study of long-term stability and confirmed the soundness of new system. The new Event Timing System is ready for the injection into Main Ring.

INTRODUCTION

The Event Timing System is one of the most important components to succeed the SuperKEKB project [1, 2]. This system has already been installed at LINAC [3] for implementing Pulse-to-Pulse Modulation (PPM), which made the operations of both KEKB [4, 5] and the light sources compatible.

The new Event Timing System was designed to satisfy the new requirements for SuperKEKB [6]. It was installed in the 2014 spring.

The commissioning of new system was performed through the trigger-monitoring and the experimental beam operations in the 2014 autumn. We successfully operated LINAC in October and injected beam-pulses into two light source rings in November.

We increased the system in the first half of 2015. The time-to-digital converter (TDC) was installed for "roughly" synchronizing the injection trigger of Main Ring (MR) with power-supply frequency of 50 Hz (AC50). The Bucket Selection system [7, 8] was integrated with the installation of distributed shared memory.

We introduce the above activities in the following sections.

EVENT TIMING SYSTEM FOR SuperKEKB

The module configuration in the Main Timing Station[1] part of Event Timing System is upgraded for the SuperKEKB project. The new configuration is reported elsewhere [6, 9]. In this section we explain more details which cannot be described in the previous documents and updates which were carried out during the installation and the commissioning.

[1] It was called as Main Trigger Station during the KEKB era.

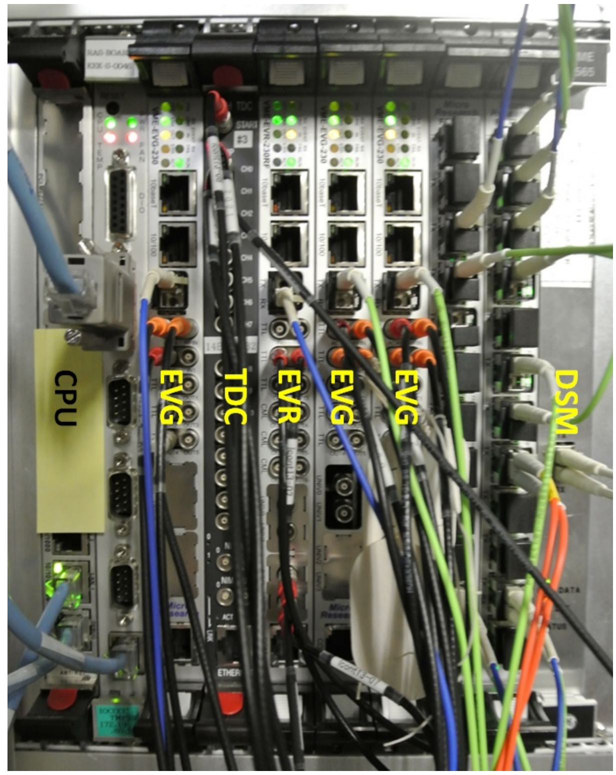

Figure 1: Picture of Event IOC: the system is based on VME64x sub-rack. From left, the CPU, RAS, upper-EVG, TDC, middle-EVR, two lower-EVGs, two fanout modules, and distributed shared memory are installed.

Configuration of EPICS IOC

Figure 1 is a picture of the Main Timing Station part of Event Timing System. The system is constructed as the VME64x based EPICS IOC [10] since it is the standard for the accelerator components at KEK. Three Event Generators (EVGs) and one Event Receiver (EVR) [11] are installed into the new Event IOC.

Two layers are configured with three EVGs. Two EVGs (lower-EVG) are placed in the downstream of another EVG (upper-EVG). The EVR (middle-EVR) is placed for connecting two EVG layers. It receives Events from upper-EVG and delivers TTL level triggers to lower-EVGs. The parallel configuration of two lower-EVGs is required from the Damping Ring (DR) operation. One lower-EVG manage the LINAC beamline before DR while the other lower-EVG manages that after DR. These two beamlines are operated separately when we inject e^+ beam-pulse into MR.

In addition to the modules of Event Timing System, the time-to-digital converter (TDC) and the distributed shared memory are installed in the IOC. The roles of these modules are explained the later section.

For the CPU module, we adopt MVME6100 [12] not MVME5500 [13], which is the standard CPU module for SuperKEKB. The faster bus clock of new CPU makes PPM more stable. We consider it is necessary also for future upgrades.

Firmware upgrade

The firmware version of EVG and EVR is upgraded from version-3 to version-5 even though we use same types of hardware as those of KEKB. The new functions of version-5 firmware are necessary to satisfy the requirements of PPM at SuperKEKB.

The other reason for firmware upgrade is the upgrade of EPICS version. We adopt the EPICS version of 3.14.12 for the accelerator components of SuperKEKB. The new Event Timing System is operated with this EPICS version and the device/driver version of mrfioc2 [14]. It causes the Event modules the firmware upgrade.

Trigger Line

Figure 2 is the schematic view of the injection trigger lines at the Event IOC. In the configuration for SuperKEKB, lower-EVG receives three kinds of inputs to launch the Events. They are the injection triggers for MR and two light source rings (PF [15], and PF-AR [16]).

The **ACIN** channel of lower-EVG receives the trigger from middle-EVR. Upper-EVG and middle-EVR are functioned with the division of MR revolution. Therefore, this trigger line can be used to launch Events for the MR injection. The revolutions of PF and PF-AR are put into extra input channels, **IN0** and **IN1** of lower-EVG, respectively.

For the "simultaneous" top-up filling operations into more than one rings, the PPM operation of SuperKEKB needs switch of trigger lines among MR, PF, and PF-AR. It is realized by just switching input channels of lower-EVGs among **ACIN**, **IN0**, and **IN1**, on pulse-by-pulse. This is one of the benefits of firmware upgrade.

INSTALLATION

The installation of new Event IOC was implemented in the spring of 2014. The new IOC was installed without removing the currently operating Event IOC.

The Event Timing System of LINAC becomes redundant. This is important since even during the installation and commissioning of new IOC, LINAC must deliver e^- beam-pulses into PF and PF-AR. Note following works are performed without disturbing any LINAC operations.

During the installation, the optical network for Event Timing System were bundled up to be two by changing the configuration of Event fanout modules [9]. Totally 4 fanout modules were installed in the optical network for Event Timing System. Two of these fanouts are connected under one lower-EVG which delivers Events towards the EVRs on the beamline before DR. Other two fanouts are connected under the other lower-EVG. This arrangement is necessary to operate the beamlines before and after DR, separately.

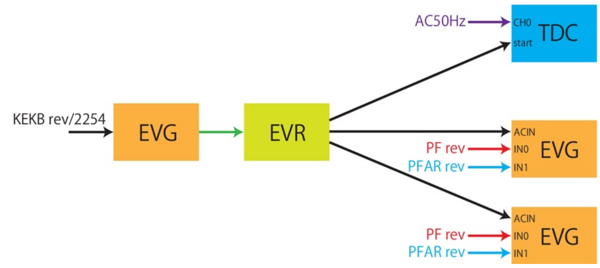

Figure 2: Trigger lines of Event Timing System: the sequence of upper-EVG is triggered by the division of MR revolution. Lower-EVGs have three input channels. The revolutions of light source rings are put into two of them. The signal from middle-EVR is put into the last channel. The input channels of lower-EVGs can be switched in 50 Hz. The TDC also receives signal from middle-EVR.

COMMISSIONING

The machine commissioning of new Event Timing System was performed through the trigger-monitoring and the experimental beam operation. The detailed parameters for operation of this system were optimized. Besides, the function to synchronize MR trigger with AC50 and the Bucket Selection system were integrated on this IOC. We introduce these activities in the following subsections.

Trigger-Monitoring

The trigger-monitoring was performed on each time during the second half of 2014 and the first half of 2015 for checking the soundness of new Event Timing System.

During the summer shutdown of KEK accelerators in 2014, we connected the new Event IOC with all EVRs which belong to the LINAC beamline. Then we studied the long-term stability of triggers with the trigger-monitoring system, which is equipped at the LINAC beamline. This trigger-monitoring system measures the interval of triggers which are delivered to the LINAC components and counts up when the interval is not to be "20 ± 1 ms"[2]. We did not observe any loss of triggers with this system.

The same study was repeated after integrating additional functions on Event IOC. We introduce its results in the later subsection.

Experimental Beam Operation

The further tuning of operation parameters was performed through the experimental beam operation in October and November of 2014. We confirmed whether "Events delivered from lower-EVGs did not have a miss". Then we optimized the delivery timing of all Events.

[2] This condition is required from hardware at the LINAC beamline.

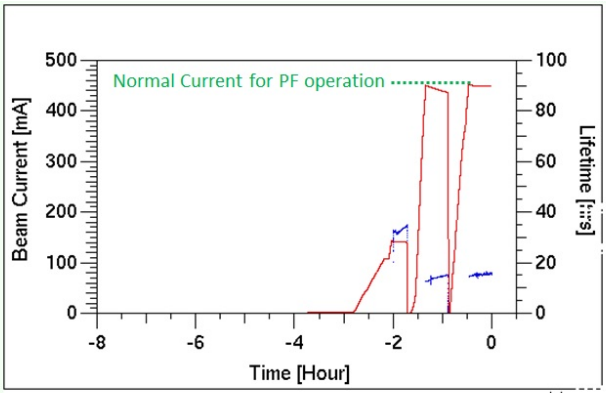

Figure 3: Storage current of PF during experimental beam injection: the increase of current which is caused by injecting e^- beam-pulses with the new Event Timing System are seen.

During the LINAC operation, we successfully produced e^- beam-pulses for both PF and PF-AR. Especially, it is the important achievement that these two kinds of beam-pulses are produced in turn. The productions of beam-pulses for both PF and PF-AR in the same LINAC run were realized for the first time while those for PF and MR have already been realized in the same LINAC run during the KEKB operation. It is one of important mile stones for the top-up filling into PF-AR, which has not been performed in the KEKB era.

After the commissioning at LINAC, the produced e^- beam-pulses were injected into PF and PF-AR in November 2014. The injections into PF-AR and PF were performed on November 13 and November 20, respectively. These days were machine study days. We successfully carried out the injections with only a few hours of allocated time. We achieved this important mile stone with the careful preparation and the redundancy of Event IOC. Figure 3 shows the storage current at PF during the PF injection. The e^- beam-pulses were injected definitely and accumulated up to 450 mA, which is the normal current in the PF operation.

Synchronization with Power-Supply Frequency

The TDC module [17] was installed on the new Event IOC for monitoring AC50 and synchronizing the MR injection-trigger with it. To stabilize the performance of LINAC, the injections are implemented on the same phase of AC50. Therefore, all injection-triggers from Event Timing System must be launched with the coincidence between AC50 and the revolution of ring to be injected.

For the injection into light sources, we make the coincidence between AC50 and the revolution of PF (PF-AR) in advance, and put those signals into the channel **IN0** (**IN1**).

For the injection into MRs, we must use the 2254 times division of revolution (rev/2254) as the input of upper-EVG. The period of this signal is longer and to be 22.68 ms, so that we cannot coincide it with AC50 in every time.

We developed the "rough" synchronization system for MR injection with TDC. As shown in Figure 2, upper-EVG is triggered by rev/2254. Then it launches Events for more

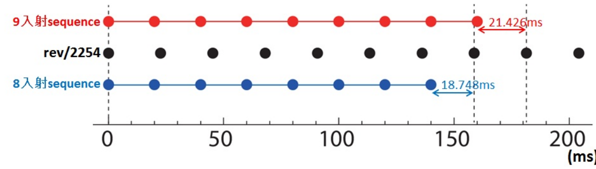

Figure 4: Timing relation among 8 injections, 9 injections, and rev/2254: the relation when the sequence is triggered on time "0" is shown in cases of 8 injections and 9 injections. The interval between the end of sequence and the next trigger are different between these cases.

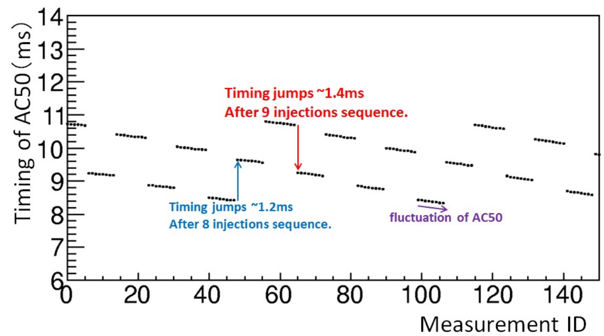

Figure 5: TDC measurement of AC50: the measurements are performed with the configuration shown in Figure 2. The timing jump at the boundary of sequences can be seen. Totally 150 measurements are shown in turn. Note, we put the signal from middle-EVR into the start channel of TDC and monitoring AC40. Therefore the direction of timing jump becomes opposite way from the discussion in the text.

than one injections with the longer sequence. All triggers generated in this sequence precisely relate with the inputted revolution and are synchronized with MRs.

We manage upper-EVG with two different lengths of sequences. They are 8 injections sequence and 9 injections sequence. By switching these sequence, MR triggers can "roughly" be synchronized with AC50.

Figure 4 explains the relation of these sequence and rev/2254. When upper-EVG processes an 8 injections sequence, it receives the next trigger on 18.748 ms after the end of sequence. It means the next sequence is launched ~1.25 ms earlier than the usual 20 ms periods. The opposite thing is happen on a 9 injections sequence. The next sequence is launched 1.4 ms later than usual periods.

We manage the length of sequence for keeping the TDC measurement of AC50. Then, the MR injection-triggers are synchronized with AC50. Figure 5 shows the TDC measurements during the operation of new Event Timing System with the management of sequence length. By switching the length of sequence, we keeps the TDC measurement to be 10 ms. Therefore we can deliver the MR injection-triggers on the same phase of AC50. Note these triggers are, of course, synchronized with rev/2254.

In Ref [6, 9], we described the sequence length of upper-EVG is to be ~100 injections. However we decided more shorter sequence length. This is because we understand

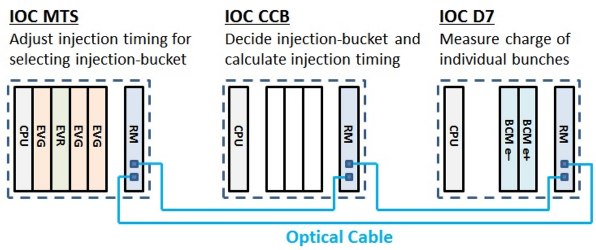

Figure 6: Schematic view of three IOCs for Bucket Selection: the one of nodes is integrated in the Event IOC while remaining two nodes are placed in the MR side. They are connected via dedicated optical network.

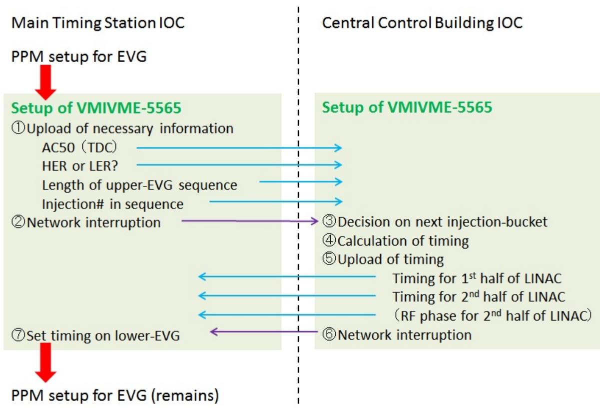

Figure 7: Schematic diagram of communication between the Event IOC node and the CCB node: the processes of two nodes are in parallel. However they are consolidated with the data synchronization and the network interruptions.

from the trigger-monitoring that the fluctuation of AC50 is larger than that we expect and we should apply more frequent correction. After several tests and considerations, we optimized them to be 8 injections and 9 injections from many possible combinations.

Bucket Selection System

The new Event IOC works also for Bucket Selection [7,8]. The distributed shared memory module, VMIVME-5565 [18], was installed for this purpose.

The VMIVME-5565 module is connected with those at KEKB Central Control Building (CCB) and the D7 hall via the dedicated optical network. The Event IOC receives the delay value based on the MR revolution from the CCB node and adjusts injection-timing into the RF-Bucket to be injected beam-pulse (injection-bucket). This timing-adjustment is managed at two lower-EVGs.

Figures 6 and 7 are the schematic pictures of hardware and those processes in the PPM operation. The LINAC node uploads the necessary information to decide the next injection-bucket on the memory and launches the network interruption to the CCB node. The CCB node decides the next injection-bucket with the necessary information. Then this node calculates the delay value, upload them on the memory, and returns the network interruption.

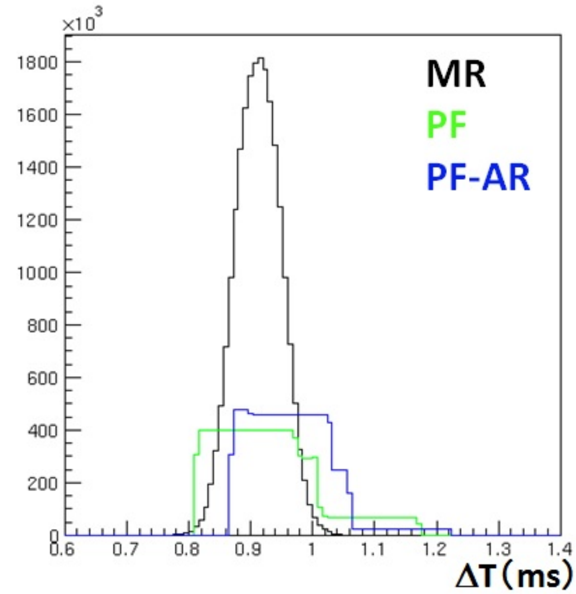

Figure 8: Difference of TDC measurements, ΔT: the distribution of timing difference between AC50 and outputs from the temporal EVR are shown. The TDC measurements are collected in 50 Hz for 242 hours. The results of PF (green), PF-AR (blue), and MRs (black) modes are shown separately.

The entire process of Bucket Selection is managed at the Main Timing Station node with the network interruption while the decision on the injection-bucket is made at CCB node. They well represent the authorities of both LINAC and MR.

Study of Long Term Stability

We studied the long-term stability after integrating the synchronization system and the Bucket Selection system. We put the temporal EVR at Main Timing Station and connected it with one of lower-EVGs. Then, the output NIM signals from this EVR were measured.

During this study, we set the schedule of injections into PF, PF-AR, and two MRs to be equally 12.5 Hz. Therefore two lower-EVGs were switching inputs in the PPM operation. Actually, the switch of trigger-line makes timing fluctuation of LINAC operation and it is one of the concerns for new Event Timing System. Therefore, we studied the size of this fluctuation.

For Bucket Selection of MRs, we chose the provisional mode. In this mode, the CCB node always returns the nominal timing, which is always matched with the AC50 measured by TDC. Note, in real operation, Bucket Selection is implemented by adjusting timing within ±1 ms from this nominal timing.

We put the outputs from temporal EVR into the TDC and compare timings between it and AC50. Figure 8 shows the distribution of difference between two TDC measurements. We can confirm the stability of injection-triggers from the new Event Timing System as a reference of AC50. Even though the new Event IOC delivers triggers with three kinds of inputs, like the revolutions of PF/PF-AR and rev/2254, the triggers were stable and periodically delivered within the 400 μs fluctuation. The fluctuation satisfies the hardware requirement of <2 ms. Also it indicate we have the enough timing-window which we utilize for Bucket Selection.

The long-term stability was studied also with the trigger-monitoring system which we described before. The monitoring was performed at the same time as the TDC measurements and we did not observe any loss of triggers during the test.

CONCLUSION

The Event Timing System at Main Timing Station was upgraded for the SuperKEKB project. The two-layers of EVGs are configured for the new Event IOC. The new system was installed redundantly with the current operating system. The activities after installation were smooth because of this redundancy.

The parameters of new system to operate LINAC were optimized through the commissioning. During this commissioning, the study of long-term stability and the experimental beam operations were performed. As the experimental beam operation, the injections into PF and PF-AR were carried out successfully.

After the experimental beam operation in 2014, we integrated the synchronization system and Bucket Selection system. All system for the MR injection were actualized at the new Event Timing System. The soundness of system was confirmed in the further study of long-term stability. The fluctuation of injection-triggers delivered from the new Event Timing System satisfies the requirement from the LINAC hardware.

In conclusion the Event Timing System was successfully upgraded for SuperKEKB. The new system is ready for the operation of MR injections.

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