DEVELOPMENT OF THE BEAM GATE SYSTEM USING THE WHITE RABBIT AT SUPERKEKB

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Abstract

In the SuperKEK, the beam gate is a system that turns the beam supply from the injector to the main ring on and off. Since the beam gate signal is shared with the abort system, the signal is delivered asynchronously with the operation frequency. The beam gate system, on the other hand, must start/stop each component of the accelerator working at the time of injection in a defined sequence. For reliable operation, we currently allow one blank firing to the kickers and others. A beam-gate system with WRs can stop blank firing.

INTRODUCTION

The e-/e+ SuperKEKB collider continues to update the world's highest luminosity [1]. Figure 1 shows a schematic of the SuperKEKB accelerator, which consists of two main rings for e-/e+ and the injector. To increase the integrated luminosity, the top-up filling operation is carried out. To keep the beam current, the beam supply from the injector frequently switched between "on" and "off". The trigger signals to each component are delivered with a precisely defined time delay from the operating frequency using the event timing system [2]. Injection is started and stopped by controlling the trigger signals to each component (electron gun, injection/excursion kicker, septum magnets, etc.) that work during beam injection by the beam gate system.

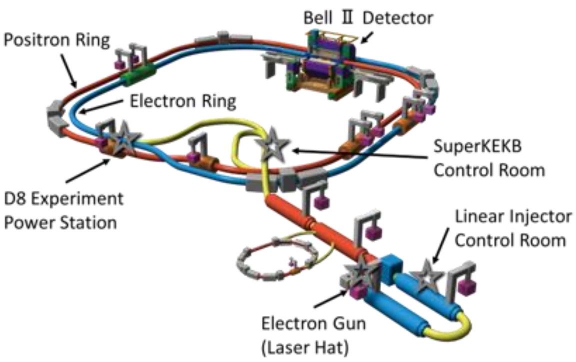

Figure 1: Schematic of the SuperKEKB accelerator.

The photo cathode RF gun used at the injector is turned on and off by opening and closing the physical shutter for the intense laser beam. To avoid laser irradiation during the shutter operation, which takes about 20 ms, the beam gate signal is input to the pulse delay module together with the trigger for laser irradiation, and the trigger signal is sent to the shutter after waiting for one laser irradiation. The beam gate signals are delivered asynchronously with the operating frequency. Therefore, as shown in Fig. 2, the time width between the beam gate signal and the output of the trigger for the shutter varies depending on the timing of the beam gate signal. This makes it difficult to turn on/off the kicker, septum, etc. at the correct timing.

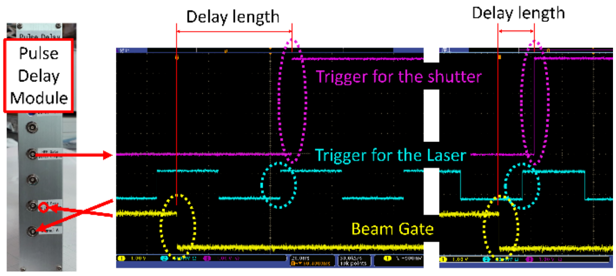

Figure 2: Waveforms of triggers for the shutter, triggers for the laser, and beam gate signals.

TRIGGER TRANSFER USING THE WR

White Rabbit (WR) is a technology with properties such as sub-nanosecond accurate time synchronization between modules separated by kilometers, scalability, and Gigabit data communication [3]. This technology information is freely available in the Open Hardware Repository (OHWR) [4] in accordance with the CERN Open Hardware License. In this work, we used the Simple PCIexpress Carrier (SPEC), an FPGA Mezzanine Card (FMC) carrier board, and an FMC-DIO card. These were plugged into the PCIe slot of a PC (Ubuntu 20.04LTS) and set up as WR nodes.

KEK uses EPICS for the control system of the accelerator. The development to control the SPEC and FMC-DIO with EPICS has already been done at KEK and has been operated at SuperKEKB [5]. The WR nodes set up this time can send and receive time-stamped trigger events via the WR network using EPICS software (3.15.8). These WR nodes were installed in the laser hut and in the D8 Experiment Power Station (D8) where the event receivers (STD-EVE) that distribute the triggers to the kicker and others are located, respectively. FMC-DIO has 5-channel TTL signal input/output connectors and can record input/output time stamps. When the EPICS software on the WR node detects the rising or falling edge of the signal, it sends a time stamp (T0) when the signal change is detected, the set delay time (Td), and the signal status to the programmed destination node. When the destination WR node receives the trigger information, it outputs a signal at T0 + Td. If its own clock has already passed T0 + Td, it outputs the signal immediately.

Time Synchronization

If there is an error ΔT in time between the sender and the receiver node, the actual time at which the signal is output

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at the receiver is T0 + Td + ΔT. Therefore, both nodes need to be synchronized correctly, and WR uses the extended PTP protocol to perform high-precision time synchronization. At that time, the standard transmission medium for WR is 1000BASE-BX10, which is a bi-directional transmission of two wavelengths in a single-mode (SM) optical fiber supporting Gigabit Ethernet. However, only multi-mode (MM) optical fiber is installed from the location of the WR Grand Master Switch (WRGM) to the D8. Therefore, we checked the accuracy of time synchronization between the WR node and WRGM using MM optical fiber. The latency at signal output and at signal input were set to the same values as when using the SFP module for SM fiber. The asymmetry of the transmission rate due to the signal transmission direction of the optical fiber was set to zero. The time difference of the PPS signals from both modules, obtained with a digital oscilloscope, is shown in Fig. 3. The length of the optical fiber was approximately 1.2 km.

Since time synchronization was done with sufficient accuracy (sub-nanosecond), it was decided to use MM fiber between WRGM and the WR node in the D8.

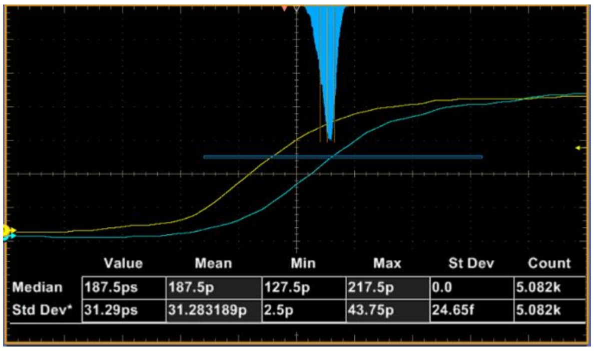

Figure 3: Comparison of the two PPS signals from the WR node and WRGM.

Trigger Transfer Test

Next, trigger transfer tests were performed between the WR nodes located in the laser hat and the D8.

A square wave of 12.5 Hz, duty ratio 1:1, 4 Vpp, and offset +2 V from a function generator was input to the WR node in the laser hat. The actual path between WR nodes is shown in Fig. 4. The WR node in the laser hat recorded T0, and the node in the D8 recorded the time it actually output the transferred trigger. The time difference distribution recorded at both WR nodes for each Td is shown below (Fig. 5).

At each Td setting value, 1.5 million transfers were made. The peak value in the distribution with a Td of 0 ms was approximately 700 microseconds. Most of the measurements when Td was 1 or 2 ms resulted in signal output at the set Td value, but in rare cases delays occurred. Over the two weeks of measurements, no transfer took more than 5 ms or failed. The number of beam gate signals transferred corresponds to approximately one year of operation.

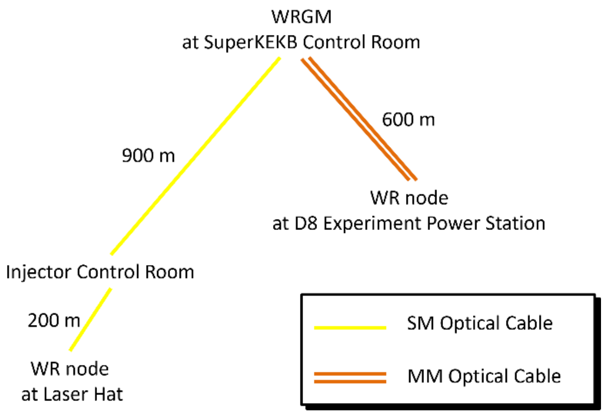

Figure 4: Diagram of the optical fiber path.

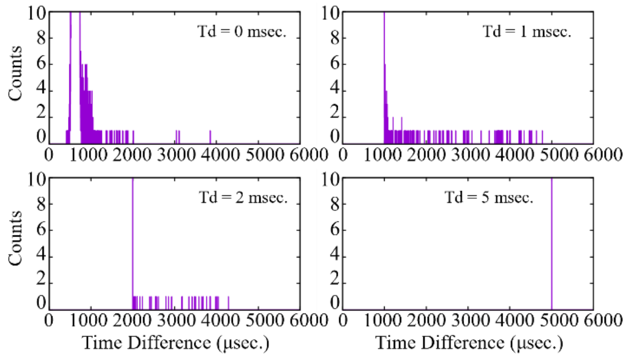

Figure 5: Time difference distributions for each Td.

BEAM GATE SYSTEM

Currently, in SuperKEKB and injectors, beam gate information is distributed to individual hardware using the Distributed Bus Bit (Dbus) function of the event timing system [6]. If the beam-gate system stops the septum magnets before the laser stops, the injection electron beam will strike the septum wall and beam loss will be detected. Since this would lead to the beam abort system dumping the stored beam in the ring, the system has a safety margin that allows one blank firing for the kicker and other components. However, it is desirable to minimize the kicker and septum magnet blank firing, since they disrupt the beam in the main ring and lead to a decrease in luminosity.

Layout of Beam Gate System Using the WR

If the delayed trigger signal for the shutter from the pulse delay module is input to the FMC-DIO in the laser hat, the trigger signal can be output at any time from the FMC-DIO in the D8. The STD-EVE is equipped with an INHIBIT input connector that can control the ON/OFF of the trigger output. By outputting the transferred trigger signal to the INHIBIT connector, the trigger delivery to the kickers and others can be operated without excess or deficiency. The layout of the beam-gate system using the WR is shown in Fig. 6.

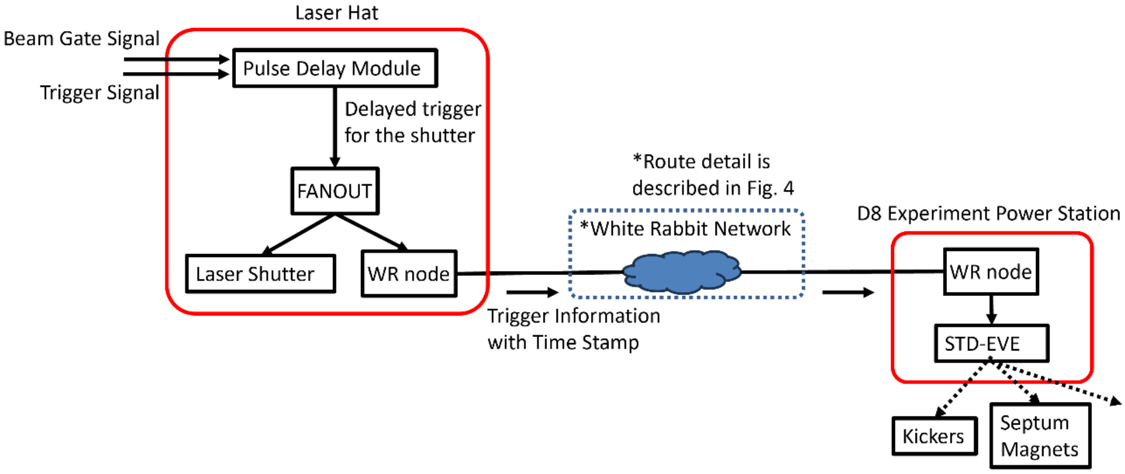

Figure 6: Layout of the Beam gate system.

Finally, we checked to see if they worked correctly as Beam Gates. The event receiver can be set to control the trigger output by the INHIBIT signal for each output channel. The settings were made so that the INHIBIT control of the event receiver is effective for triggering the kickers, etc. Figure 7 shows the beam gate system in operation.

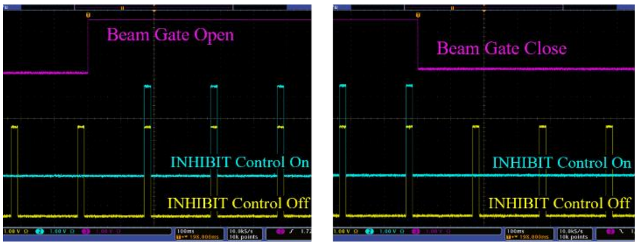

Figure 7: Picture of the beam gate system in operation.

CONCLUSION AND DISCUSSION

The beam gate system using WR was developed. The control signal of the laser shutter of the RF gun is transferred to the kicker trigger circuit via the WR network. In the transfer test, we confirmed that the signal transfer is sufficiently reliable when we apply 5 milliseconds of delay. We plan to install the new beam gate system based on the WR system. It will start being operated after the long shutdown which finishes in December 2023.

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