TIMING SYSTEM FOR MULTIPLE ACCELERATOR RINGS AT KEK e+/e- INJECTOR LINAC

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Abstract

The KEK e+/e- injector linac is operated in multiple beam modes that can be switched every 20 ms for e+/e- beam injection to five different circular accelerators, SuperKEKB High Energy Ring (HER), Photon Factory (PF) ring, PF-AR, positron damping ring (DR) and SuperKEKB Low Energy Ring (LER). Because those accelerators have different ring energies and radio frequencies, the linac is required to have a timing system which supports multiple modes and synchronization system to the circular accelerator. Those systems to fulfil multiple injections to independent circular accelerators are described in this paper.
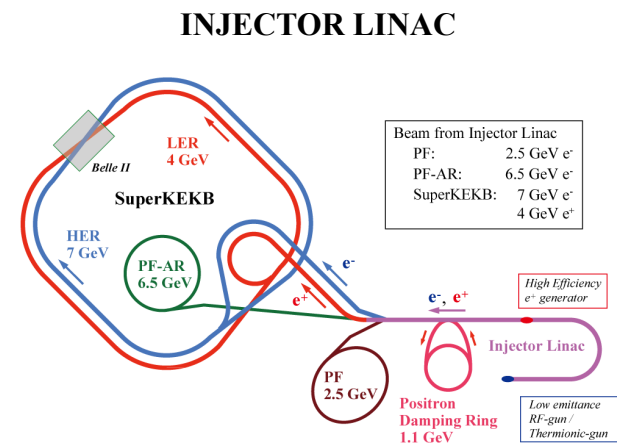
INJECTOR LINAC

Figure 1: Schematic view of the e+/e- injector linac and accelerator rings at the KEK.

The KEK e+/e- injector linac and five different rings are depicted schematically in Fig. 1. The HER requires low emittance electron beam, thus the photocathode rf-gun [1] is used for HER beam injection. High charge (~10 nC) electron bunches for positron production and electron beams for PF, PF-AR are given by the thermionic gun. The linac consists of 8 sectors (A-C, 1-5) which have 8 high power RF units except for injector (rf-gun, thermionic gun and bunching section) and positron production section. The RF unit provides RF power to 4 accelerating structures. The beam energy at the end of the linac is controlled by RF phase of the unit. In order to set optimum beam optics for each the beam mode, 28 pulsed quadrupoles and 36 steering pulsed magnets were installed in last year [2]. Parameters such as accelerating RF

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phases and the currents pulsed magnets can be changed every beam pulse by employing the event timing system.
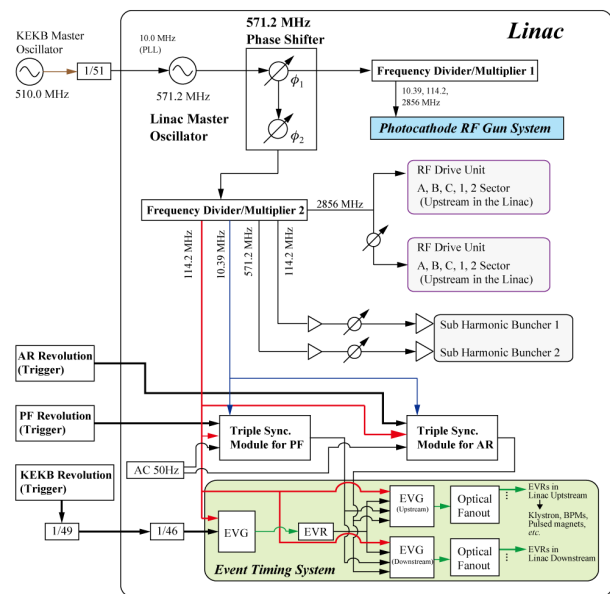
TIMING SYTEM OF THE LINAC

Figure 2: Timing system of the linac.

Figure 2 shows the linac timing system with the fundamental RF signals. The master frequency of 571.2 MHz is generated with a signal generator which is synchronized with the SuperKEKB oscillator via a 10 MHz reference signal [3]. The 571.2 MHz phase shifter set the linac whole RF phase according to the beam mode. The phase of ϕ_1 and ϕ_2 correspond to the HER and the LER injection phase, respectively. In case of the PF and the PF-AR injection, the ϕ_2 is set to zero. Because large phase shift accompanying beam mode change makes the laser system for the rf-gun unstable, the laser system always synchronized with the HER.

The trigger signals to various components are distributed by the MRF event system [4] which consists of event generators (EVG) and event receivers (EVR). The event timing system has three EVGs [5]. The first EVG-EVR set makes a trigger timing signal for the HER/LER injection. The trigger timing signal for the PF/PF-AR injection is sent from a special module to make a synchronized signal with the circular accelerator. The EPICS IOC program for the event system selects a corresponding trigger for 2nd EVGs of the beam mode. Then, the 2nd EVGs distribute an event code which corresponds to the beam

mode and a data buffer including some parameters such as a the HER/HER/PDR injection RF bucket number, setting current of pulsed magnets. Because the external RF clock used in the event system depends on the beam mode, the phase of the event system could be varied every pulse.

BEAM INJECTION TO A CIRCULAR AC-CELERATOR WITH DIFERENT RF
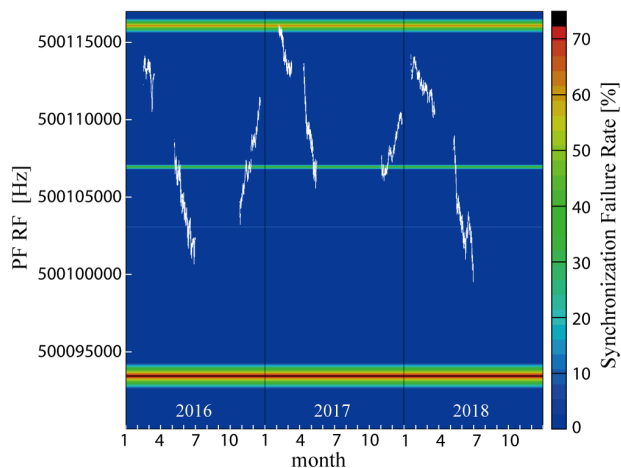
Synchronization System

Figure 3: Variation of the PF radio frequency and the synchronization failure rate. White dots show the PF RF in the past 3 years. The colour band represents the synchronization failure rate at the frequency which was estimated by a simulation in a condition of synchronization width of 500 ps and 114.237423 MHz of the linac RF.

Since the event system uses the 114.2 MHz clock which is generated by the linac RF system that uses common sub-harmonic frequency of the 10.39 MHz, the linac beam timing synchronized with HER/LER revolution timing periodically. However, the PF and the PF-AR are not synchronized to the linac because the two accelerators use independent RFs. In that case, to generate the RF for the linac from the RF of the circular accelerator [6] in every pulse is one of the ways. We plan to use the rf-gun for the beam injection to the PF/PF-AR. In that case it is difficult to adopt the way in our system because the laser system requires stable radio frequencies. Thus, we take the way to use chance synchronization of the linac RF and the PF/PF-AR revolution frequency. The triple sync module shown in the Fig. 2 outputs a signal to the event system on a timing when the linac RF (114.2 and 10.39 MHz) is synchronized with a revolution timing of the circular accelerator every 20 ms. The width of synchronization (Γ_{syc}) can be changed. Because the synchronization probability depends on the linac and the circular accelerator RFs, there could be no chance event in a certain period of time. In order to operate the klystron stably, a regular interval of the trigger (20±2 ms in our case) is required. In case of no synchronized event in a waiting time (~0.9 ms) from the 50 Hz trigger input, the module

send a trigger output to the event system and a veto signal to the thermionic gun. Figure 3 shows the variation of the PF RF and the synchronization failure rate. The annual variation of the PF RF is about 15 kHz owing to the circumference compensation of the ring. The RFs and variations in a day/year are summarized in Table 1. A very low synchronization probability region is found around 500.093 MHz, but there is no such a region in the operating frequency. We can enlarge the probability of the synchronization by increasing the Γ_{syc}, but it is trade-off for the beam injection phase jitter.

Table1: RF and Its Variation in a Year/Day

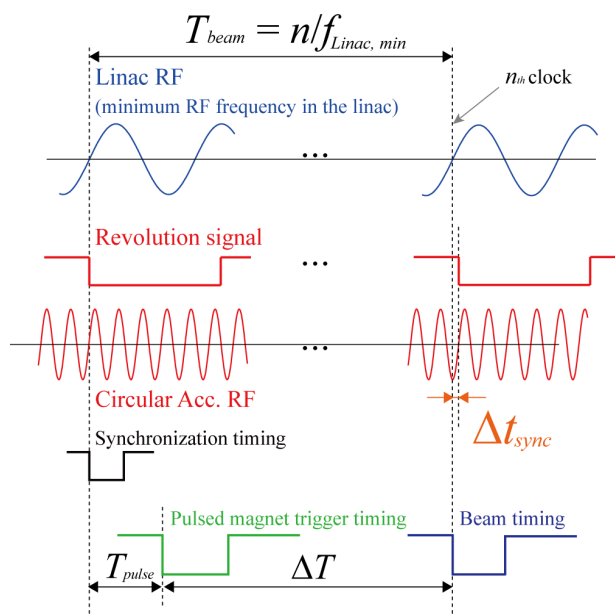| Ring Accelerator	Frequency	Annual Variation	Variation in a day
SuperKEKB	508.88 MHz	~300 Hz	~10 Hz
PF	500.11 MHz	~15 KHz	~1 kHz
PF-AR	508.57 MHz	~1.5 kHz	~200 Hz

Resynchronized Delay

Figure 4: Layout of papers.

To keep reproducibility of the current to the pulsed magnet, the power supply of the magnet requires precise trigger timing which is 3 ms before the beam arrival time. Then, the trigger should be the first timing in the timing system and it is generated by the chance synchronization in case of PF/PF-AR beam injection. Because the RF used in the event system is different from the PF/PF-AR one, a simple 3 ms delayed beam trigger leads to injection to outside the separatrix or an unexpected RF bucket. Thus, we have developed the way finding a synchronized timing after arbitrary delay from the first synchronized timing. Figure 4 shows the relation of trigger signals (the output of the triple sync module, the pulsed magnet, the beam timing), the RF of the linac and the revolution signal from

the circular accelerator. If we can know the resynchronized delay longer than the required interval (3 ms), the beam timing is synchronized with the revolution timing and the interval can be fixed. The delay T_{beam} which has a jitter less than Δt_{sync} is given by Eq. (1),

$$\left| n \frac{f_{Circ,Rev}}{f_{Linac,min}} - \text{int}\left(n \frac{f_{Circ,Rev}}{f_{Linac,min}} \right) \right| < f_{Circ,Rev} \Delta t_{sync} \ , (1)$$

where, n is the number of clock cycles, int(x) stands for the integer part of the x. The $f_{linac,min}$ and the $f_{Circ,Rev}$ are the minimum fundamental frequency used in the linac and the revolution frequency of the circular accelerator. In the operation, the 114.2 MHz of the linac RF and the 500.11 MHz of the PF RF (508.57 MHz of the PF-AR), are monitored by using the same frequency counter with the resolution of 10 digits per second. The delay and the synchronization probability are calculated every second to follow the changing of the RFs. We can easily find the n, and the timing control is implemented by EPICS. The maximum injection timing jitter is given by $\Gamma syc + \Delta t_{sync}$, and the jitter is less than 0.6 ms for the beam injection to

the PF. The system using the way has been working since autumn of 2017 without any trouble.

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