FIRST SIMULTANEOUS TOP-UP OPERATION OF THREE DIFFERENT RINGS IN KEK INJECTOR LINAC

M. Satoh#, for the IUC*
Accelerator Laboratory, High Energy Accelerator Research Organization (KEK)
1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

The KEK injector linac provides beams with four different rings: a KEKB high-energy ring (HER; 8 GeV/electron), a KEKB low-energy ring (LER; 3.5 GeV/positron), a Photon Factory ring (PF; 2.5 GeV/electron), and an Advanced Ring for Pulse X-rays (PF-AR; 3 GeV**/electron). In original operation, the beam injection of the PF ring and PF-AR had been carried out twice daily. The injection of the KEKB rings had been operated in every 90 minutes. In such operation scheme, the stored beam current decreases until next beam injection, and it results in the heavy drop of integrated luminosity and brilliance. In 2004, we has started the KEK injector linac upgrade project aiming at the simultaneous top-up operation for three different rings (KEKB HER, LER, and PF).

In the simultaneous top-up operation, the common DC magnet settings are utilized for the beams with different energies and amount of charges, whereas the different optimized settings of RF timing and phase are applied to each beam acceleration by using a fast low-level RF (LLRF) phase and trigger delay control up to 50 Hz. With this noble operation scheme, a simultaneous top-up operation for different three rings was successfully achieved for the first time over the world, and has been stably in operation since April 2009. We report the operation scheme and status of simultaneous top-up operation in detail.

INTRODUCTION

The lepton accelerator complex in KEK Tsukuba campus consists of four storage rings and one injector linac as shown in Fig.1. The maximum beam repetition of the linac is 50 Hz. In the original operation, the beam injection for each ring was sequentially carried out since the four rings share only one injector linac with. The beam properties required for each ring injection are much different. The required beam energy is from 2.5 GeV for PF to 8 GeV for KEKB HER, and the required amount of beam charge is from 0.1 nC for PF to 10 nC for positron production of KEKB LER. For each ring injection, we should use the different optimized linac parameters which are the settings of trigger delay, RF phase, magnet power supply, and other subsystems. The linac parameter switching took a several minutes in original operation.

Figures 2 and 3 show the typical one day stored beam current at KEKB and PF, respectively. Here, about 16 times beam injection of the KEKB was carried out daily in every 90 minutes. The PF and PF-AR injections were operated twice daily on scheduled time. For increasing

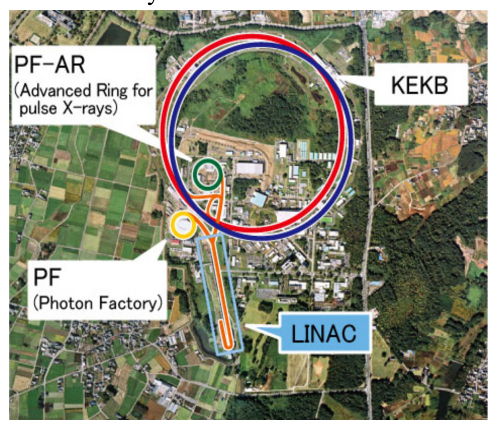

Figure 1: Accelerator complex in KEK Tsukuba campus.

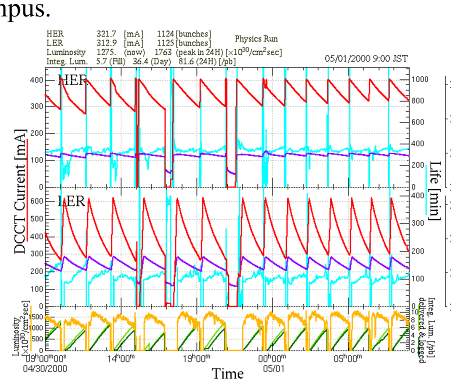

Figure 2: Stored beam current of HER (top), LER (middle), and luminosity (bottom) of KEKB in the original injection operation (24 hours).

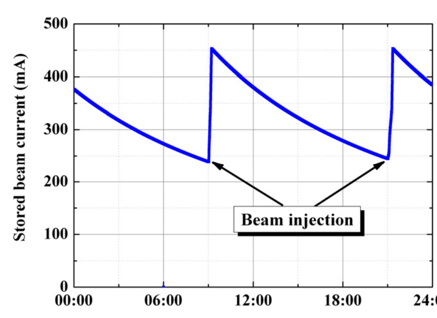

Figure 3: Stored beam current of PF in the original injection operation (24 hours).

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masanori.satoh@kek.jp

* Injector Upgrade Committee: Cross-functional team for the injector upgrade from PF/ KEKB and Linac members.

** The injected beam is accelerated up to 6.5 GeV for user experiment.

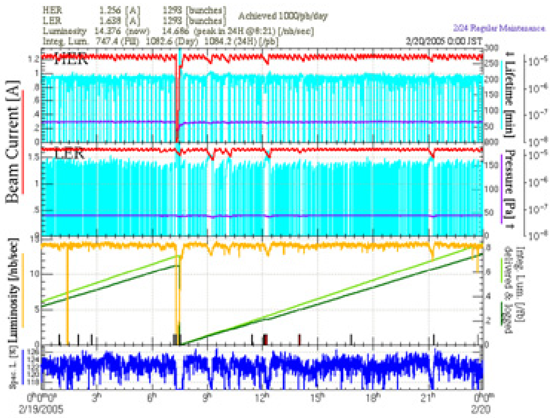

Figure 4: Stored beam current of HER (top), LER (middle), and luminosity (bottom) of KEKB in continuous injection operation (24 hours).

the integrated luminosity, we started the continuous injection operation for KEKB in 2005 [1]. It is a quasi-top-up operation, where the linac parameters should be frequently switched for KEKB HER and LER injection. The much more stability of stored current was demanded, whereas the continuous injection improved the integrated luminosity of KEKB very much in comparison with the original operation scheme. In addition, the demand for PF top-up operation was glowing up from the experimental user community. For these reasons, we started the injector upgrade aiming at the simultaneous top-up operation of three different rings [2, 3, 4, and 5].

OPERATION SCHEME FOR SIMULTANEOUS TOP-UP

In the new operation scheme toward simultaneous top-up, we change only the minimum linac parameters related to timing signals and LLRF phases. Almost all the remaining parameters including the DC magnet settings are never changed even for the different ring injection. Figures 5 and 6 show the schematic drawing of the beam energy variation along linac in the original operation and simultaneous top-up operation schemes, respectively. In original operation, the different electron guns (GUN #1 and #2) were used for the KEKB and PF injections, and the energy differences between KEKB HER and PF were very large at each position along linac.

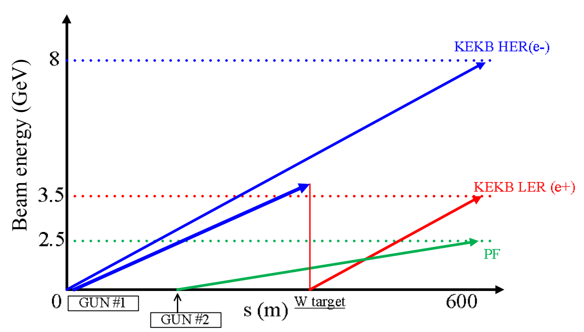

Figure 5: Beam energy variation along linac in the ordinary operation scheme.

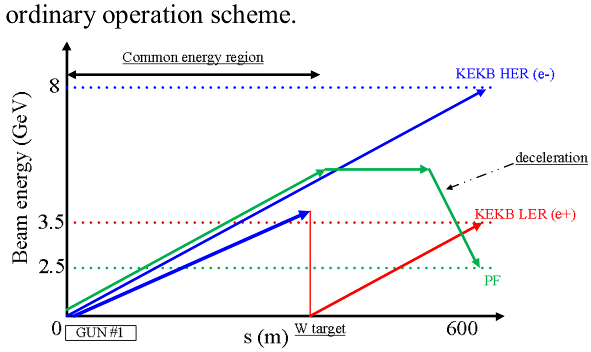

Figure 6: Beam energy variation along linac in the simultaneous top-up operation scheme.

In the simultaneous top-up operation, GUN #1 is utilized also for the PF injection instead of GUN #2. The PF beam is accelerated up to about 5 GeV which is much higher energy required for the PF injection. In the middle of linac, it is transported without any acceleration. Finally, the PF injection beam is decelerated down to 2.5 GeV in the end of linac. By using such scheme, the common magnet settings can be utilized for all of three different beams (KEKB HER, LER, and PF) since they are transported with almost same energy in first half of the linac. In downstream of the linac, the happy-medium settings of magnets are utilized for transporting the beams with different energies [6].

DEVELOPMENT OF SUBSYSTEMS

Fast Event Based Timing Control System

In the old timing system, about 150 timing delay modules based on VME-bus (TD4V) and CAMAC (TD4)

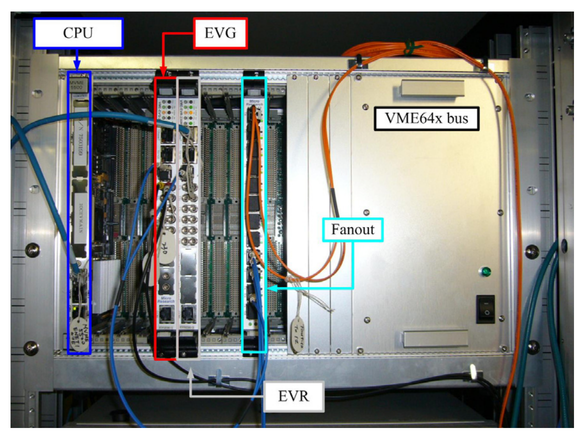

Figure 7: Photograph of the new event based timing system.

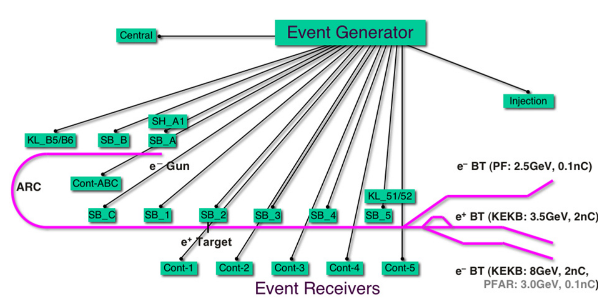

Figure 8: Schematic drawing of the connection between the event generator and receivers.

were used for controlling the timing signals distributed to the many different types of local controllers. The timing system upgrade was indispensable since it was not feasible for the old system to realize a fast timing control up to 50 Hz.

The event generator and receiver (EVG/EVR) system based on VME64x-bus has been adopted as a new timing system. Its photograph is shown in Fig. 7 [7, 8]. In the new system, one EVG and twenty one EVRs are connected via optical fibre on star topology as shown in Fig. 8. The event information, RF clock (114 MHz), timestamp and data buffer can be quickly transferred from EVG to EVR. Twelve DAC modules based on VME-bus are utilized for a fast LLRF phase control. The control software was developed by using EPICS system on VxWorks.

EVR can output the timing signal corresponding to the event id set on EVG. Associating each event id with specific trigger delay settings, the beam energy and rf phase can be immediately changed to the optimized setting in every 20 ms by switching event id on EVG. In addition, the total number of used module for the timing system can be drastically reduced by using the EVG/EVR system. This can gratefully increase the reliability of timing system and beam operation.

Construction of the New PF-BT Line

In the original PF-BT line, the standardization of the energy compensation system (ECS) bends were required for switching the beam injection between PF and other rings since PF-BT was branched off at downstream of ECS. Such procedure took several minutes because it needed to change a current of large bends slowly for keeping its hysteresis cycle.

In order to avoid standardizing ECS, a new PF-BT line with 60 m has been constructed as shown Fig. 9 [9]. The new PF-BT is branched off at upstream of the first ECS bend. Only the PF injection beam can be selectively kicked toward the new PF-BT since the new pulsed bend and its power supply have been developed and installed as mentioned in next subsection. After the construction of new PF-BT, the constant settings of ECS are available during the simultaneous top-up injection.

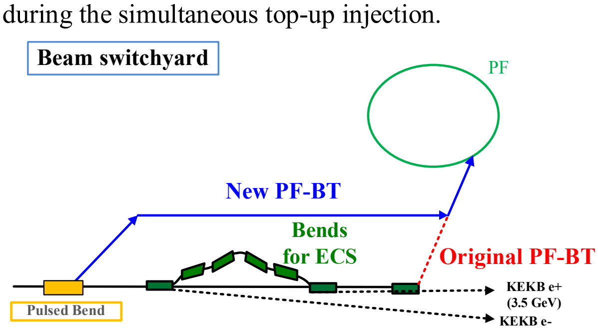

Figure 9: Schematic drawing of the new PF-BT at beam switchyard of linac end.

Pulsed Bend System

For the new PF-BT line, we have developed the new pulsed bend system comprising of the pulsed bend, the pulsed power supply, and the ceramic chamber. Table 1 shows the main parameters of the pulsed bend system [10, 11]. The photograph of pulsed bend and power supply are shown in Figs. 10 and 11, respectively.

Though the electron beam with 2.5 GeV is required for the PF injection, the pulsed bend system has been designed for the beam operation up to 3 GeV for the future demand. The maximum repetition rates are 25 Hz and 18 Hz for the beams with 2.5 GeV and 3 GeV, respectively. Its output current has the half-sinusoidal shape with 200 μs duration. The both at long and short term stability of power supply output current is satisfied less than 0.1%.

Table 1: Main parameters of pulsed bend system

Pulsed bend:		
	Beam bending angle:	7 deg. (up to 3 GeV)
	Max. magnetic field:	1.36 T
	Gap:	157 x 30 mm (W x H)
	Coil:	1 turn
Power supply:		
	Max. current:	32 kA (12.5 Hz)
		27 kA (25 Hz)
	Pulse width:	200 μs (half-sinusoidal)
	Stability:	0.1%
Ceramic chamber:		
	Length:	1200 mm
	Coating:	Ti (1 μm)

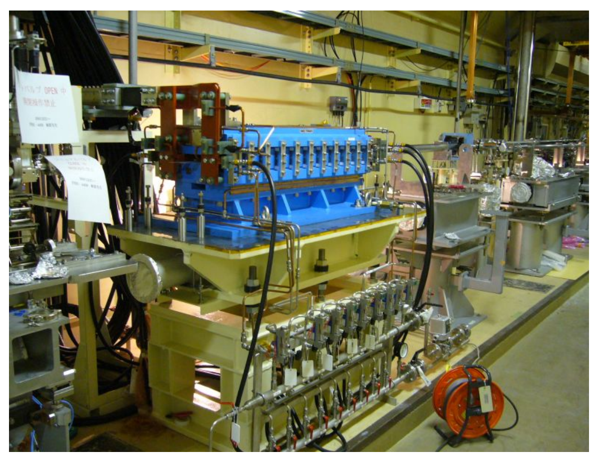

Figure 10: Photograph of the pulsed bending magnet for the new PF-BT.

Figure 11: Photograph of the pulsed power supply.

The 1200-mm-long ceramic chamber has been also developed and installed. Its cross-section is a race track-shaped. To avoid the heating, the inner wall of ceramic chamber is coated with 1-μm-thick Ti.

New Positron Production Target for e-/e+ Fast Switching

In the original operation scheme, the positron production target was controlled by extracting or inserting a target holder. For the fast switching between electron and positron operations, we have developed the new positron target [12]. In the new operation scheme, the new target is fixed at the centre of beam line even for the electron operation.

The new positron production target is a tungsten target with a hole as shown in Fig. 12. A centre of a hole is placed 5.2 mm apart from that of the tungsten target. The diameter of a hole is about 5 mm. The electron beam can go through the inside of a hole for the electron injection, whereas the primary electron beam with 10 nC collides the center of target during the positron injection.

The result of machine study by using the new target shows that the beam loss is less than 5% at the hole in comparison with an original operation as shown in Fig.13. It was confirmed that this scheme is applicable to the practical beam operation. For a fast control of the bump orbit, the several pulsed steering magnets have been installed at both of upstream and downstream of the target.

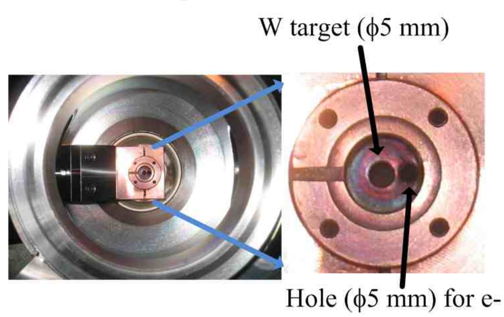

Figure 12: Photograph of the new positron production target with a hole.

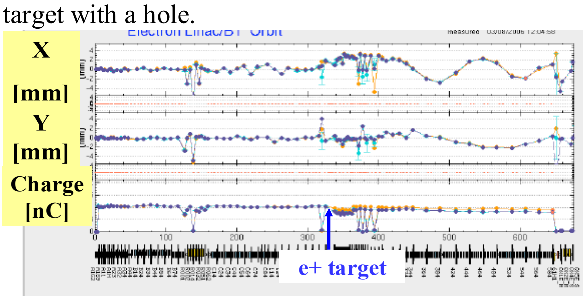

Figure 13: Machine study result of the new positron target. The horizontal (upper), vertical (middle) beam orbit and beam charge (bottom) are shown along the linac. The blue and orange dots mean the results of original and new scheme, respectively.

Beam-Charge Interlock System

Toward the simultaneous top-up operation, a new PLC-based beam-charge interlock system has been also developed for radiation safety [13]. This system restricts a regulated amount of integrated beam charges traversing through at several locations for machine protection, and it also monitors the amount of integrated beam charges delivered to the four different storage rings at the linac beam switchyard.

The beam charges delivered from an electron gun are measured with the beam-charge interlock system. This system consists of the wall-current monitors, beam-charge integration circuits, and a PLC-based control system. This system sends the beam abort signals directly to another radiation safety system with hard-wire cables when the amount of the integrated beam charges is beyond the prescribed threshold level. In addition, the system logic of radiation safety at KEKB, linac, and PF have been replaced by new one from the old exclusive logic for the simultaneous top-up operation.

PF-AR INJECTION

In this upgrade, the PF-AR injection is still based on the old scheme which takes a several minutes for the linac parameter switching. The full energy top-up injection of PF-AR with 6.5 GeV is very difficult since the transport beam energy at AR-BT is limited up to 3.1 GeV. In addition, a large part of BT is shared by both of KEKB and PF-AR as shown in Fig. 14. The construction of a new dedicated AR-BT line is not feasible because of a tight tunnel space. In the next coming SuperKEKB, the beam lifetime will be about 10 minutes. For this reason, even PF-AR injection of 15 minutes twice daily will cause a serious problem for the stable SuperKEKB operation. In the SuperKEKB, the beam energy of positron (electron) will be changed from 3.5 GeV (8 GeV) to 4 GeV (7 GeV). We are planning the simultaneous injection of four rings including PF-AR. In this plan, the positron beam for KEKB LER injection will be also used for the PF-AR injection. The new switching pulsed bend will be installed at the end of common BT. In the dedicated BT for PF-AR, all quadrupole magnets and vacuum chambers will be remodelled for increasing magnetic field. The detailed design will be reported elsewhere in the near future.

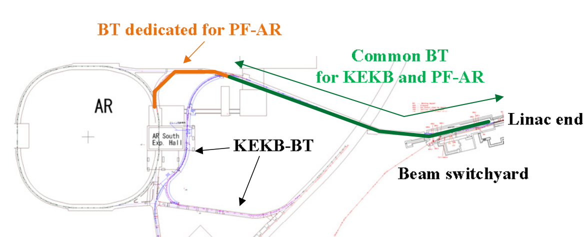

Figure 14: Schematic drawing of BT for KEKB and PF-AR.

SIMULTANEOUS TOP-UP OPERATION

Eventually, the simultaneous top-up operation of three different rings was successful for daily operation in April 2009. Figures 14 and 15 show the stored beam current of KEKB and PF during simultaneous top-up operation, respectively. The stored beam current variation of KEKB and PF are about 0.05% and 0.01%, respectively. These results are far superior to the original operation performance of around 50% drop in stored beam current, and significantly improve the experimental performance at both of KEKB and PF.

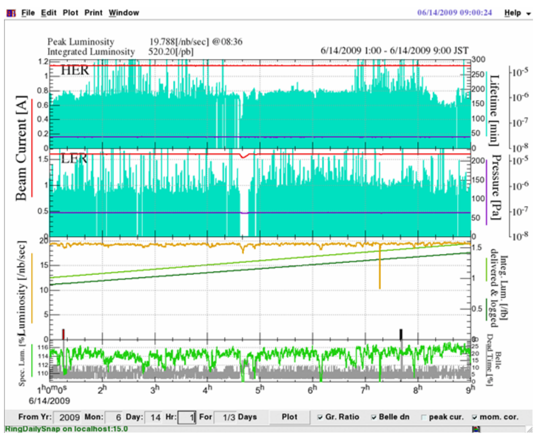

Figure 15: Stored beam current of HER (top), LER (middle), and luminosity (bottom) of KEKB in the simultaneous top-up operation (24 hours).

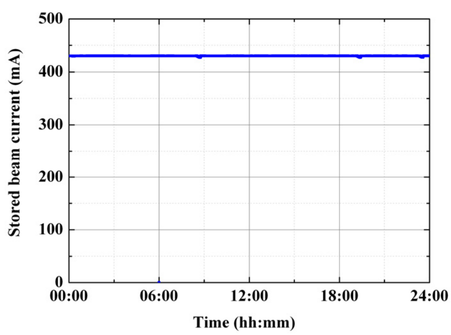

Figure 16: Stored beam current of PF in the simultaneous top-up operation (24 hours).

SUMMARY

We have succeeded the KEK injector upgrade aiming at the simultaneous top-up injection of three different rings in April 2009. Towards the simultaneous top-up, we developed the many subsystems; new event based timing system, pulsed bend and power supply, ceramic chamber, construction of the new PF-BT, radiation safety system upgrade and so on. The achievement of this milestone has been brought through the grate effort of all members of linac, KEKB, and PF groups. In the simultaneous top-up operation, the stored current variation of KEKB and PF are about 0.05% and 0.01%, respectively. Such high current stability can bring the improvement of experimental efficiency to both of KEKB and PF.

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