

# Bucket Selection of KEKB and its Possible Reconstruction for SuperKEKB

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## Abstract

Last year, the KEKB bucket selection system, which generates appropriate bunch-filling patterns in the KEKB rings, was reconstructed to accomplish the “ simultaneous injection ” to the three rings, the low-energy and the high-energy rings of KEKB, and the PF ring. In this paper, we describe the main point of the reconstruction. In addition, we discuss the possible extension to this system to the SuperKEKB rings.

## INTRODUCTION

In storage rings for colliding experiments or light sources, often a very large number of bunches are stored to obtain high luminosity or high-brilliance photon beams. One example of these cases is the KEKB collider at KEK in Japan. It is an energy-asymmetric double-ring collider for B-physics. KEKB consists of an 8 GeV electron ring (HER), a 3.5 GeV positron ring (LER) with an injector linac (LINAC) which provides these rings with electron and positron beams.

It is expected that coupled bunch instabilities will occur in rings, when a large number of bunches are stored with very short spacings. In principle, strengths of these instabilities can be evaluated based on an estimated impedance of the rings. However, from practical point of view, the growth rate of the instabilities varies depending on conditions, even with the same total beam-current. One of the important conditions which determines the strength is a filling pattern, that is, how the RF buckets are occupied by beam bunches.

We designed and constructed a system for realizing any desired filling pattern in the HER and LER, as a part of the KEKB timing system. Essentially, the central hardware of the system is a variable delay which manipulates the trigger timing the electron gun of the injector. The delay time is determined by an intelligence implemented in the system. We call this system “*Bucket Selection System*”[1].

## ARCHITECTURE OF THE BUCKET SELECTION SYSTEM

As explained above, the bucket selection system is a sub-system of the KEKB-LINAC timing system. Like all the components of KEKB, this system is working under the EPICS environment. One VME Input/Output controller (IOC) is assigned to this function. We call this IOC “*Delay IOC*”. In this subrack, VME digital programmable delay modules (named TD4V) are installed and they determine the trigger-timing in LINAC. A software program is run-

ning in this IOC under Vx-Works, and it determines which bucket should be filled in the next shot of LINAC beam and set the delay value into the delay modules. The program runs synchronizing with injection, i.e., the gun-trigger signal is accepted by Vx-Works interrupt mechanism.

The decision, which bucket should be filled, is done based on the following information:

1. the filling pattern which the operator gave to the system,
2. bunch current information of whole ring,
3. the bucket address last filled.

Brief explanations for first two items of information will be given below. The fill pattern information is loaded in the system prior to the operation. The loading is done by an operator manually and the man-machine communication is organized by an IOC named OP-IOC. Bunch current information is used for equalizing bunch-charge per bunch and it is delivered by the Bunch Current Monitor IOC (BCM IOC). This IOC controls a bunch-by-bunch current monitor, which is made of a wide-band flash ADC (509MHz, 8-bit) and a series of memory. This is a by-product of the KEKB bunch-by-bunch feedback systems and closely described in reference[2]. With this monitor, digitized bunch-current information of each bunch is obtained in one revolution time ( $10\mu\text{s}$ ).

To summarize, three IOCs, namely Delay IOC, OP-IOC and BCM-IOC are taking part in this system. They are connected with fiber cables which are independent of standard TCP/IP communication system. The speed of this networking system is 250 Mbit/s. A fast and stable transfer of the bunch current information from BCM IOC to Delay IOC is essential. The connection of these IOCs is schematically depicted in Fig. 1.

## A BRIEF HISTORY OF THE KEKB INJECTION SCHEME

### *Traditional operation and continuous injection*

At earlier stage of the operation of KEKB, beam-current plots was like a saw-tooth, that is, experiment run with decaying currents and at the moment when the currents went down to some critical values, the beam was added. During the injection, data taking was stopped to avoid the damage of detector components by injected beam particles. Since 2004, the injection scheme was converted to “*continuous injection scheme*”<sup>1</sup>, in which the detector continued data-taking except just a few milliseconds after the injection.

<sup>1</sup>At PEP-II, they call this scheme the “trickle injection”

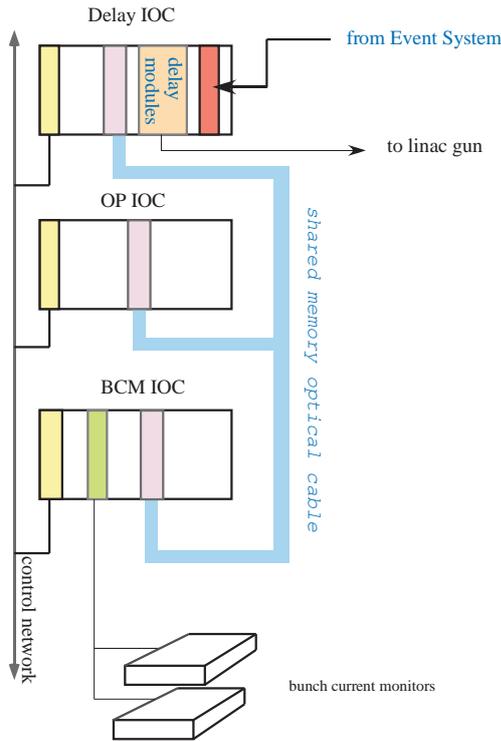


Figure 1: Connection of the IOCs. The delay IOC plays the central role in the bucket selection. The BCM IOC sends the bunch-current information to Delay IOC through "Shared Memory optical cable".

This scheme enabled us to increase the integrated luminosity per day. In addition, decreased dynamic range of the currents enabled us to tune the machine easily.

### "Simultaneous" injection

However, functions of LINAC is not only providing the KEKB rings, but also providing PF ring and PF-AR, which are light-source rings at KEK. Table 1 summarises the requirements of beams, beam species, energy, intensity[3] from each ring. Naturally, during the injection to PF and PF-AR, the KEKB rings were not able to inject beams and currents went down for a few to ten minutes.

Table 1: The beams which required to deliver to the rings. The positrons are produced by bombarding a target with high-intensity electron beam.

op. mode	particle	energy	charge	# of bunches
HER	$e^-$	8.0 GeV	1.2 nC	1 or 2
LER	$e^+$	3.5 GeV	0.6 nC	2
LER*	$e^-$	4.0 GeV	10 nC	2
PF	$e^-$	3.0 GeV	0.1nC	1
PF-AR	$e^-$	3.0 GeV	0.1nC	1

In order to compromise the requirements of these rings, we pursued the possibility of "simultaneous" injection scheme. By *simultaneous injection* we mean that the beams

are injected to several rings without any pause due to changes of energy, beam species etc.

After many efforts[4], in 2008, we succeeded to start the simultaneous injection.

- LINAC gun is fired every 20 milli seconds (i.e. 50Hz)
- each shot of the LINAC beam is delivered to one of the rings listed above
- the event system[3] supervises which operation mode is selected

## RECONSTRUCTION IN THE BUCKET SELECTION SYSTEM

For the realization of the simultaneous injection, a triggering scheme of the bucket selection system was changed. Before the start of the simultaneous injection, electron injection and positron injection were done in two different operation modes of LINAC. It means, although the common resource was used for the both beams, the injection of each beam were independent operation, conceptually.

Figure 2 shows a simplified flow-chart of the software. It runs in synchronizing with the beam injection timing. When one action ended it stops to run and waits for the next injection. By the `semTake` function provided by Vx-Works, the software restarts the action.

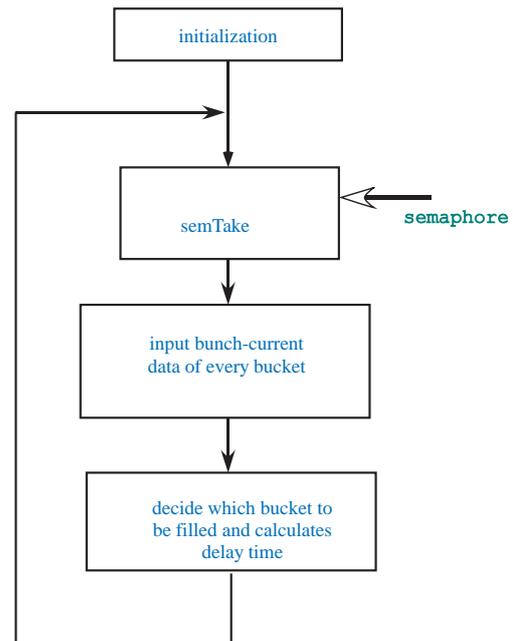


Figure 2: Simplified flow chart of the software. The program run in synchronizing with the beam injection and it is done with the Vx-Works real-time functions.

In the old system, the interrupt signal was delivered by the bunch-current monitor, which measures the charge in each bucket just before the injection. As shown in Fig. 1, the Delay IOC and BCM IOC was connected with a high

speed optical cables, and the interrupt signal was transferred through this cable. Two bunch current monitors are prepared for the two rings and each of them are motivated to measure changes by the trigger signal of the injection kicker in each ring.

After the reconstruction, the interrupt signal is delivered by the Event System. This system sends the trigger signal to the bucket selection system, and additionally it provides the information showing in which mode LINAC will be operated, just 20 milli seconds before the actual injection. The bucket selection system read this information and if it is "HER" or "LER", the bucket selection action is done. For this purpose, new interrupt access port was prepared. (a red module in Delay subrack in Fig. 1.)

In parallel with the change of the hardware, the flow of the bucket selector was changed. Before the change, the flow was branched when the particle species (i.e. trigger source) was detected.

## PERSPECTIVE TO SUPERKEKB

### *Fill-pattern editing*

Through the ten-years history of KEKB operation a large number of fill patterns have been tried and some of them were used for actual operation for physics experiments. Since the start of the operation in 1998, the number of bunches has been increased step by step, to get higher luminosities. On the other hand, from a view point of studies of accelerator physics, other types of fill patterns have been used, some of them were similar to that for physics experiments and others were not.

The bucket selection system provides operators with a function of generating a standard "bunch-train pattern", in which operators can specify, (1) the number of trains, (2) the number of bunches in a train, (3) bunch spacing in a train. The system can generate also an arbitrary fill pattern. In this case, operator should specify *on* or *off* for each RF bucket. In KEKB rings there are 5120 RF buckets and a 5120-line ASCII files (we call it "pattern file") is used to inform the system of the fill pattern. Operators can edit the pattern file with standard editors like Emacs. It is sufficient enough for present operation, but in future a more convenient GUI might be necessary. It can manipulate standard filling pattern components, such as the abort gap, or the pilot bunches.

### *A Dynamic decision-making based on bunch charge information*

The mission of the bucket selection system is to realize the fill pattern specified by an operator. This means that the system is informed of only static information. Then, in what order the buckets are fed by bunches from the injector should be decided by the system itself.

In the present system the order is decided in two different methods. One is to alter the target bucket with some algorithm, with which a bunch will be injected to a bucket far

from the bucket last filled. It will avoid a pile-up of the betatron oscillation due to the injection. The second method is to fill the beam into the bucket with the least bunch charge. This method can regulate the bunch charges among the all occupied buckets. We call this function *Bunch Current Equalizer* (BCE). Through experiences we learned that this scheme is very powerful for practical operation.

At present, the program in Delay IOC, which is coded in the C-language, is executing the BCE task. In SuperKEKB, the Event System will be used and the intelligence implemented in the system can do this task. In this case, the bunch current monitor should be connected to the Event System more tightly than the present case. This should not be straightforward and if the flexibility with the C-language program can be preserved or not is not clear at present. We will continue discussing what architecture is hopeful for the new bucket selection system.

## SUMMARY

The operation scheme of LINAC was upgraded to realize the "simultaneous" injection, in which KEKB HER, LER and the PF ring are fed continuously. For the timing manipulation, the Event System was introduced for this purpose. The bucket selection system was reconstructed to meet the requirement of this new injection scheme. In future SuperKEKB, the timing system will be based on this Event System. We will continue the design works for the new bucket selection system for SuperKEKB.

## REFERENCES

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