

# THE KEKB BUCKET SELECTION SYSTEM - RECENT PROGRESS AND THE PLAN IN THE NEAR FUTURE

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## Abstract

The KEKB bucket selection system, which enables us to realize a variety of bunch fill-patterns in the KEKB rings, has been working well since the start of the commissioning of KEKB in Dec. 1998. Although the hardware of the system has not changed since the start of the machine-operation, its software is continuously evolving, in order to meet the requirements from the view-point of more sophisticated machine operation. In this paper, we will describe recent progress in the software, as well as the plan for the near future, upgrading it to be able to handle two bunches accelerated in one pulse of the injector linac. With this upgrade, the injection time of the positron beam into the low energy ring will remarkably be shortened.

## 1 INTRODUCTION

The KEKB collider at KEK in Japan is a *B*-meson factory consisting of a 3.5 GeV positron-ring and an 8 GeV electron ring with their injector. The injector is actually a linac-complex which can provide the collider with both electron and positron beams. At the end of 1998, commissioning of KEKB started and the machine performance has been progressing since then, and the peak luminosity reached  $4.5 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  in July 2001. In order to obtain high luminosity, the number of bunches stored in the rings is chosen to be very large. At present, the number of bunches per ring is 1153 in daily physics-experiment operation, and the number will be increased to make the luminosity still higher. The fill pattern, that is, which bucket is filled with beam and which not, is one of important parameters for operating storage rings under such a high-current/multi-bunch condition. Then, a sophisticated fill-pattern-managing system or a bucket selection system is required.

The KEKB bucket selection system has been working well since the start of commissioning. Machine parameters concerning the bucket selection are summarized in the Table 1. While the hardware system has not been changed since then, the software has been continuously evolving to meet operational requirements. In the previous paper[1] published in late 1999, we described the system architecture and experiences up to that time. In the present paper, we review the system and discuss the recent progresses as well as the plan for the near future.

## 2 A BRIEF REVIEW OF THE KEKB BUCKET SELECTION SYSTEM

Since KEKB has no damping/accumulation rings, the beams are directly injected from the linac to the rings. At injection time, the rf systems of the linac and the rings are

Table 1: Machine parameters concerning the bucket selection system

rf frequency	509MHz
harmonic number of the rings	5120
repetition rate of the injection	50Hz
minimum bunch spacing	2ns

tightly synchronized, and which bucket is occupied by the injected bunch is determined by the relative timing between the revolution signal of the ring and a trigger signal for the linac gun. By controlling this timing (or more concretely by giving a suitable delay to the gun-trigger-signal), we can fill the bunch into a desired bucket.

The KEKB bucket selection system consists of three parts; (1) a part that actually sets the delay explained above, (2) a part which communicates with accelerator operators, and (3) a bunch-current monitor part. The bunch-current monitor is indispensable to precise control of the relative bunch-currents over the buckets. These three parts are connected with a high-speed dedicated communication system based on optical fiber cables, since the three parts are installed in separate buildings. Figure 1 schematically explains the connection of the three parts of the system.

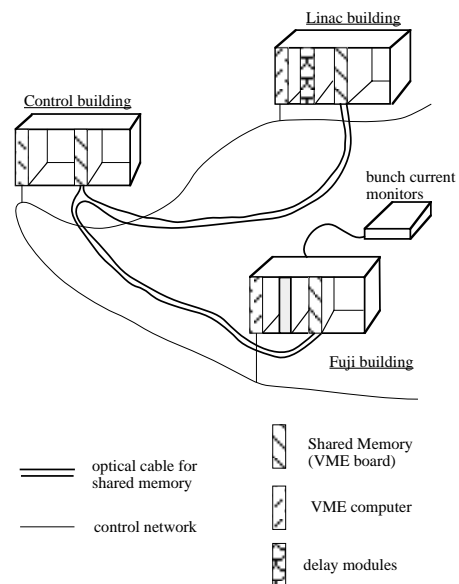


Figure 1: Three parts of the KEKB bucket selection system and their connection.

### 3 RECENT PROGRESSES

#### 3.1 Generation of arbitrary fill-patterns

The operator-communication part provides us with a tool for generating standard fill patterns. The term “standard” means that the fill pattern is made up of a number of bunch trains with equal spacing, where the number of the trains should be a measure of the harmonic number of the rings, 5120. An operator can specify (a) the number of the trains, (b) the number of bunches per train, and (c) the bunch spacing. Then the system generates the pattern corresponding to the specified parameters and loads it to the hardware pattern-table when requested. In ordinary physics-experiment operation, we use this pattern generator system.

Besides this standard fill-pattern generator, a new pattern generation system is developed. An operator can input an arbitrary fill pattern via an ascii-based fill-pattern file. The data in the file is in 5120-line, 2-column format, as shown in Fig. 2. This “read-in pattern” system is very useful in operating the rings in the machine-study mode.

0	1
1	0
2	0
3	0.8
4	0
⋮	⋮
5119	0

Figure 2: An example of the fill-pattern file. The first column is the bucket id and the second column indicates the relative bunch intensity as explained in the following.

#### 3.2 Intentional uneven filling

Usually, bunch-currents of all the filled buckets are controlled to be the same among them, since the evenness of the “fill shape” is essential for the stable operation of the rings. To ensure evenness, the bucket selection system is equipped with the *bunch-current equalizing* (BCE) function. When the BCE switch is on, the system checks out the relative bunch currents and sends the linac beam into the bucket that has the smallest bunch current.

Sometimes, however, we are required to fill bunches intentionally un-evenly, for beam-studies. Due to these non-standard fill-patterns, unusual power spectra arise in each part of the rings. This can be helpful for us to identify impedance-sources by carefully checking the response of the beam. To use this option we can use the fill-pattern file we described above. We put the figure 1 in the second column for the standard bunch current. On the other hand, when we want to store a smaller current, 90% of the other buckets for example in some specific bucket, we must put the figure 0.9 in the 2nd column of the corresponding line.

### 4 TWO-BUNCH ACCELERATION IN THE INJECTOR LINAC

#### 4.1 Motivation and the principle

In the usual operation of the injector linac, only one bunch is accelerated within one linac-pulse. If multiple bunches are accelerated in one pulse, injection time will be shortened, and as a result, the accumulation rate of the luminosity will be effectively increased. This is the motivation of the multi-bunch acceleration in the linac, particularly for the positron beam.

However, the realization of this idea is not a simple task. The complexity comes from the relation between the rf frequencies of the linac and the rings. The rf frequency of the linac is 2856MHz and that of the rings is 509MHz. Since these frequencies have the common divisor of 10.38MHz, they are made by multiplying this common frequency, by multipliers 275(55 × 5) and 49 for the linac and the rings, respectively. Figure 3 shows this frequency relationship and the basic idea of the bucket selection.

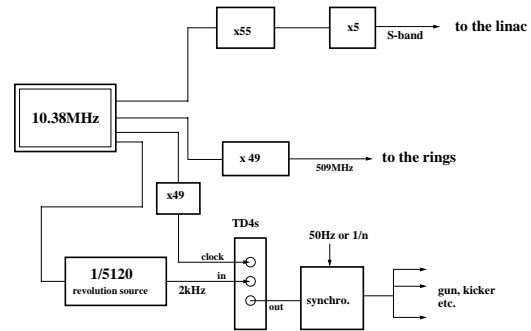


Figure 3: Basic idea of bucket selection. The rf signals of the linac and the rings are made by multiplying the common frequency, 10.38MHz, by 275 and 49, respectively. The linac-gun is triggered by the timing signal delayed by the TD4V module appeared in this figure.

From the frequency relationship, we find that two beam-bunches can sit on the same rf phase only if they are separated by 49 times of the one cycle of the ring rf-frequency (~ 98ns) or its multiples. That is, if we inject beam from the linac to the ring with best injection efficiency, two bunches should be positioned, for example at bucket #1 and bucket #50, in the ring. This is a very tight constraint for the choice of the fill patterns.

#### 4.2 Considerations on the fill-pattern

At present time we operate the rings with a bunch spacing of 4 rf buckets. However, it is clear that we can not use this fill-pattern due to the constraint. From many experiments we have learned that the 5 rf-buckets-spacing is harmful because of a heating-up problem at the interaction-region chamber installed inside the physics detector. We have also learned that the 3-bucket-spacing introduces a very strong coupled-bunch instability, and that the luminosity is not

increased as we expected even though the number of the bunches (and also the total current) is increased. Thus, in the 2-bunch acceleration scheme, we must use a fill-pattern whose spectrum is similar to the 4-bucket spacing and not similar to the 3-bucket nor 5-bucket spacing.

Following this principle, we listed three candidates of the fill-pattern for the two-bunch acceleration scheme:

1. Basically the bunch-spacing is 4 rf-buckets. But every 98 th rf-bucket, there is an irregular spacing (5 or 1),
2. Basically the bunch-spacing is 4 rf-buckets. But every 49 bucket, there is an irregular spacing (5 or 1),
3. The third fill-pattern is made up with repetitions of a train of 7 bucket-length each of which is divided into 3 and 4 spacing as show below. The number 7 is good for our situation where the buckets of two linac bunch is separated by 7 x 7 buckets.

1001000 | 1001000 | 1001000...

Prior to the actual two-bunch acceleration, we stored the beam with these three patterns and compared the performance, such as the injection efficiency, the luminosity and so forth. The experiment was done with usual one-bunch acceleration of the linac and is purely for the fill-pattern study. The results from the experiment are as follows:

- \* The fill patterns 1 and 2 are almost the same as the usual 4-bucket spacing operation.
- \* The fill pattern 3 is worse than the former 2 patterns, particularly, the injection efficiency for this fill pattern is about 1/3 of the usual pattern. More injection tuning might increase the efficiency, but we did not try it because it would take a very long time.

#### 4.3 Injection procedure

Up to the present time, only one bunch in a pulse is accelerated and the BCE switch is almost always ON from the start to the end of the injection. However, the BCE system compares the bunch-currents bucket to bucket, not bucket-pair to bucket-pair where bunches in each of pair are distanced by 49 rf-buckets. Hence, the BCE does not function correctly unless the intensity of the linac bunches are completely the same. In addition, even if the intensity of linac-bunches are exactly controlled to be equal, problems will remain. For example, when we top-off the beam, the remaining beam-current is not regularly distributed over the buckets, in general.

Considering this variety of cases, we find it is reasonable to divide the injection procedure into two steps. In the first step, the two-bunch acceleration is used and the injection rate is tuned as high as possible. In this step the BCE is switched off. After the beam-intensity reaches some fraction of the full-current, 80%-90% depending on various conditions, the injection comes to the second step, where the BCE switch is turned on and acceleration mode is changed from two-bunch to one-bunch.

#### 4.4 Trial of the two-bunch acceleration

After the fill-pattern investigation, we tried actual two-bunch acceleration and injection into the both rings. The experiment was performed just before the summer shut-down of 2001. The fill pattern 1 (explained in Section 4.2) was used for the experiment. Figure 4 shows the bunch-current distribution in this experiment.

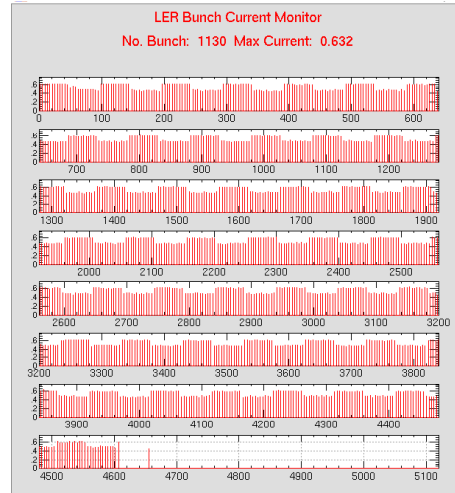


Figure 4: The filled pattern with the two-bunch acceleration mode. We successfully accelerated the bunches and stored them in the ring. In the pattern, we see an irregular pattern due to the imbalance of the first and second bunches in one linac-pulse. After careful adjustment, this problem will be solved.

## 5 SUMMARY

The KEKB bucket selection system has been working well since the start of the commissioning at the end of 1998. The software of the system has been continuously evolving to meet the operational requirements. An arbitrary fill-pattern with individual intensity control was newly devised. In addition, the software system is now reconstructed to incorporate the two-bunch positron-bunch acceleration in the linac. In the summer 2001, we performed the experiment of the two-bunch acceleration and injection into the rings.

## 6 REFERENCES

- [1] E. Kikutani *et al.*, "Bucket selector system for KEKB", Proc. ICALEPCS99, Trieste, October 1999.
- [2] Y. Ogawa *et al.*, "High-Intensity, Two-bunch Acceleration for Doubling Positron Production at the KEKB Linac" to be appeared in the Proc. of the 18-th International Conf. on High energy Accelerators (HEACC2001), Tsukuba, 2001.