BUCKET SELECTION FOR THE SuperKEKB PHASE-3 OPERATION

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Abstract

Bucket Selection is one of the most important components at SuperKEKB. It manages the timing of injector linac so that we can select the RF-bucket at main ring to be injected beam-pulse. We upgrade the software after the successful phase-1 operation. Bucket Selection manages the positron injection with the newly constructed damping ring. The system works smoothly and robustly in the entire phase-2 period. We discuss the future upgrade which is required for the phase-3 operation.

INTRODUCTION

The SuperKEKB accelerator is an electron-positron collider [1, 2] which is built at KEK. The 7 GeV of electrons and 4 GeV of positrons are stored into two main rings (MRs) called HER (High Energy Ring) and LER (Low Energy Ring), respectively.

One of its challenges is the timing management of injector linac (LINAC) [3]. The difference in the RF frequencies of 2856 MHz (LINAC) and 508.89 MHz (MR) makes timing management complicated. Besides, from phase-2, we must consider also about the newly constructed damping ring (DR) with the RF frequency of 508.89 MHz.

The Bucket Selection system [4] works for the injection management as well as the timing management. It decides lots of operation parameters including the injection timing and provides them to the Event Timing System [5, 6].

The both hardware and software of Bucket Selection work excellently in the phase-1 operation. However we need the upgrade of software to satisfy the new requirements for phase-2. The new functions must be developed for the DR operation.

In this report, we explain the general specification of Bucket Selection in the phase-2 operation. Then we describe the upgrade plan for phase-3.

BUCKET SELECTION

In this section, we introduce the overview of Bucket Selection. Then we describe the logic for the LER injection in the phase-2 operation [4] since it is quite different from that in phase-1.

Overview

Bucket Selection controls the LINAC operation timing so that the beam pulse is coincided with the injection RF-bucket at the injection point. The LINAC timing is changed in every pulse since we change the injection RF-bucket in every injection. The hardware of Bucket Selection is described in Ref [4].

The operation phases of LINAC and MR are not always coincide since their RF frequencies are different (2856 MHz and 508.9 MHz, respectively). The coincidence happens in every 96.3 ns. It is the common frequency of 10.385 MHz.

In the HER injection case, we adjust the LINAC timing in range of 0-493 μs. The one of RF-buckets at HER can be selected with this timing range. Note, the harmonic number of SuperKEKB is 5120 and one cycle of coincidence condition is $96.3 \times 5120 = 492922$ ns.

This logic is utilized for both LER and HER in the SuperKEKB phase-1 and the entire KEKB era.

Bucket Selection for LER in Phase-2

The logic to determine the LINAC timing for the LER injection becomes complicated from phase-2 since we operate DR. Note, the positron-pulses are once stored into DR for radiation damping. Then, they are extracted from DR and transferred to LER. In this case, we must consider the RF frequencies and the harmonic numbers of both DR and LER in the new Bucket Selection logic.

There is no degradation of Bucket Selection in terms of the RF frequency. The RF frequency is 508.89 MHz at DR. Therefore the common frequency among LINAC, DR, and LER is 10.385 MHz.

The problem is in the harmonic number. The harmonic numbers for DR and LER are 230 and 5120, respectively. There are 23 kinds of coincidence combinations of RF-buckets. The LINAC timing range to take care of all Bucket Selection condition becomes longer since we must consider all combinations of RF-buckets between DR and LER.

The one cycle of coincidence conditions is $96.3 \times 5120 \times 23 = 11339336$ ns (= 11.34 ms). It is longer than the timing range of 0-2 ms which is allowed from the LINAC hardware. Therefore, it is impossible to realize all combinations between DR and LER. On the other hand, in every pulse, there are 4 DR-buckets which can deliver the positron pulse into the requested LER-bucket.

Bucket Selection choose one of 4 allowed DR-buckets and determine the LINAC timing in the phase-2 operation [6]. It is no problem when we operate the only one pulse at DR.

Performance on Phase-2

Here we introduce the performance of Bucket Selection in the phase-2 operation. The several kinds of MR operations with different filling patterns including the luminosity run are carried out in this period.

Figure 1 shows the bunch currents at LER in the operations with typical two filling patterns. We perform the luminosity run with 789 bunches. The number of operation bunches becomes larger and to be 1567 bunches when we perform the vacuum scrubbing with the large beam current.

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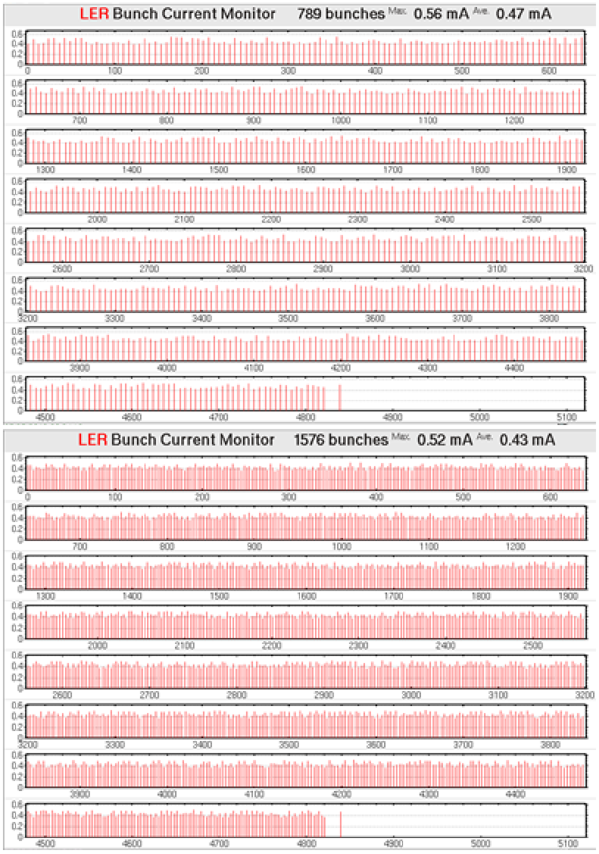

Figure 1: Bunch Currents at LER: the results from bunch current monitor at LER are shown. The upper and lower plots show the results in the 789 and 1576 bunches operations, respectively. The former is the typical filling pattern for the luminosity run. The later pattern is utilized for the vacuum scrubbing in both the phase-1 and phase-2 operations.

Bucket Selection works excellently and realizes the various requirements of filling patterns in compliance with the beam commissioning. Even though the injection scheme for LER becomes complicated, the injections are quite smooth and robust in the entire phase-2 period. Besides the bunch currents are properly equalized.

UPGRADE TOWARDS PHASE-3

In the phase-3 operation, the beam current at MR will be gradually increased to enlarge the luminosity. The designed beam currents are 3.6 A and 2.6 A for electrons and positrons, respectively. The upgrade of Bucket Selection is necessary since the more frequent injections are required. In this section, we explain the requirements, issues, and upgrade plan of Bucket Selection for phase-3.

Requirements for Phase-3

In phase-3, the beam life time with the large beam current operation is estimated to be ~5 minutes at LER. We must perform the LER injection in > 25 Hz.

On the other hand, there is the other requirement to the DR storage time (damping time). The minimum DR storage time of 40 ms is required for positrons to guarantee enough radiation damping.

The storage time becomes shorter than 40 ms with the > 25 Hz injections when we carried out the one pulse operation like phase-2. The damping time is determined as the interval of the LER injections in the one pulse operation.

In phase-3, the two pulses operation at DR will be performed when the LER injection rate become larger than 25 Hz. The positron-pulses are injected and extracted with the fast-in-fast-out rule. The damping time becomes twice of the injection interval. We can realize the 40 ms damping in the 50 Hz LER injection.

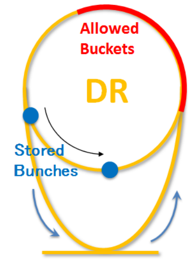

Figure 2: Schematic view of allowed RF-buckets at DR in the two pulse operation: it indicates in the case when the two bunches spacing 49 RF-buckets are stored. The two positron bunches in the one LINAC pulse occupy in this way. The next positrons can be injected into the 80 RF-buckets in the opposite region. This means only 31 RF-buckets can be selected as the first bunch of next positron-pulse and this becomes the constraint of Bucket Selection.

Constraint to Two Pulse Operation

There is the constraint when we select the DR-bucket in the two pulse operation. It is demonstrated in Fig. 2. Bucket Selection can select only 31 DR-buckets when the previous positron pulse has already occupied some of DR-buckets. We cannot inject the new pulse into those DR-buckets. Besides, the ±50 buckets from them must be vacated since those are the timing for the rising and falling edge of kicker magnets.

There is the other constraint in the selection of DR-buckets. Only 4 of 23 combinations can be realized in the 2 ms range of LINAC timing adjustment, as we described in the previous section.

As the result of above two constraints, Bucket Selection is deteriorated hardly. We cannot choose more than half of LER-buckets in every pulse. The bunch current equalization is quite difficult in this situation.

RF phase shifting at LINAC

We plan to modulate the RF phase in the LINAC section between DR and LER (2nd LINAC). By controlling the RF phase in pulse-by-pulse, we can realize the coincidence of operational phases among LINAC, DR and LER in more 11 times [4]. The entire time range to select all combinations between DR-buckets and LER-buckets becomes shorter than

2 ms which is allowed in terms of the LINAC hardware. The possible RF phase is listed on Table 1.

Bucket Selection needs to provide the RF phase at 2nd LINAC as well as the operation timing. The RF phase is delivered on the data buffer transfer of Event Timing System while the operation timing is instructed on the timing of Event delivery.

One of concerns in this new scheme is the timing difference between the trigger timing from Event Timing System and the RF phase. They are also summarized on Table 1. In principle, the trigger timing also is coincided with RF phases at LINAC, DR, and LER on the normal operation timing. However, in new scheme, we modulate the RF phase at 2nd LINAC to make different kinds of coincidences with those at DR and LER. The coincidence with the clock of Event Timing System is broken in those cases. The timing of trigger is slightly detuned with respect to the beam pulse and the RF phase. It becomes at most 900 ps as shown in Table 1.

If some hardware at 2nd LINAC does not accept above difference, we must assign the fine delay output channel of Event Receiver (EVR). This channel has 20 times finer delay function based on the GTX technology. However, number of fine delay channels are limited. The replacement of EVR can be considered if necessary. The EVR developed at SINAP [7] has fine delay functions on all 8 output channels.

We must distinguish the LINAC components which require the precise timing trigger and check number of such kinds of components. We develop and install the software to control the fine delay function on EVR.

Table 1: The normal and additional RF phase at 2nd LINAC: the additional phases are realized by modulating 2856 MHz RF phase with listed values. It makes the synchronization with the different RF-buckets at LER. On the other hand, the synchronization with the clock of Event Timing System is broken. It makes the timing difference between beam and trigger.

RF Phase (degree)	Timing Difference (ps)
±0	±0
+161.6	−893
+183.7	+179
+345.3	−715
+7.3	+357
+169.0	−536
+191.0	+536
+352.7	−357
+14.7	+715
+176.3	−179
+198.4	+893

CONCLUSION

The Bucket Selection manages the injection timing at the SuperKEKB collider. Its hardware and software work excellently in the phase-1 operation. The software is upgraded to satisfy the new requirement in the phase-2 operation.

The upgraded Bucket Selection realizes the LER injection with DR. It is operated smoothly and robustly in the entire phase-2 period.

The two pulse operation at DR is planned in phase-3. It needs further upgrade of Bucket Selection. The RF phase modulation is necessary and it also is managed by Bucket Selection.

There is the concern about the trigger timing. We must consider it before the phase-3 operation.

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