BUCKET SELECTION SYSTEM FOR SuperKEKB

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Abstract

Bucket Selection enables us to select an arbitrary RF-bucket of SuperKEKB main ring as the target in each injection process. This is one of the key tools for the SuperKEKB commissioning. The three EPICS IOCs placed in the injector linac and main ring are consolidated to realize Bucket Selection. The operation-timing of the injector linac is adjusted, in 96.3 ns step, into the timing of the RF-bucket to be injected. The different schemes for timing-adjustment for two main rings are explained, separately. Then, the constraint to Bucket Selection and the upgrade plan to solve it are reported.

INTRODUCTION

The Bucket Selection system of the injector linac (LINAC) [1] at KEK enables to select an arbitrary RF-bucket of SuperKEKB main ring (MR) [2, 3] as the injection-bucket, into which LINAC injects $e^{\pm}$ beam-pulses. This system can change the injection-bucket, on pulse-by-pulse, in 50 Hz.

Bucket Selection is originally developed for the KEKB accelerator [4] and we upgrade it for the SuperKEKB project since more intelligent scheme is required. The storage currents in the two MRs of SuperKEKB are twice larger than those of KEKB. Besides, we use the damping-ring (DR) for the injection of e^{+} beam-pulses.

The collaborative works between LINAC and MR are carried out for Bucket Selection. LINAC slightly adjusts the timing of its operation to select the injection-bucket while the next injection-bucket should be considered and decided at MR. Therefore, the hardware of system extends over the two accelerators.

In this report, we introduce the hardware configuration of Bucket Selection, the detailed scheme for selecting injection-bucket, and the plan for future upgrade.

HARDWARE CONFIGURATION

The hardware configuration of Bucket Selection consists of three nodes which are located at LINAC Main Timing Station (MTS), the D7 hall, and KEKB Central Control Building (CCB). Figure 1 shows locations of three Bucket Selection nodes, as well as accelerators at the KEK-Tsukuba campus.

The individual nodes are the EPICS IOCs [5] which have the distributed shared memory module, VMIVME-5565 [6]. The modules are connected via the optical cables and they form dedicated triangle network. Figure 2 is schematic view of three IOCs. They all have the CPU modules which are processed and play their own roles respectively. However all processes are consolidated as Bucket Selection by using the data synchronization and the network interruption of the distributed shared memory modules.

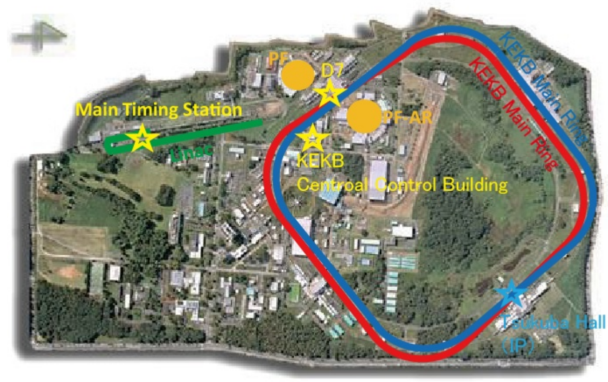

Figure 1: Location of Bucket Selection nodes at the KEK-Tsukuba campus.

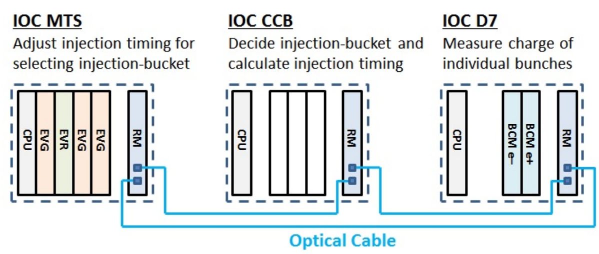

Figure 2: Schematic view of three IOCs for the Bucket Selection system: the MTS IOC is placed in the LINAC area while the CCB and D7 IOCs are placed in the MR area. They are connected via dedicated optical network.

The decision on the next injection-bucket is made at the CCB node. This node schedules injection-buckets to realize the requested filling-pattern from the operator. The filling-pattern are uploaded as an ascii file which includes “whether the RF-buckets are used for the operation or not” for both MRs. The charge rate of individual bunches also are designated with this filling-pattern file.

The CCB node changes the injection-bucket on pulse-by-pulse. Therefore, every time, it calculate the timing of injection and upload it into the distributed shared memory.

The D7 node has bunch current monitors which measure charge of individual bunches for both MRs. The measured charges are uploaded into the distributed shared memory and they are utilized when the CCB node decides the next injection-bucket.

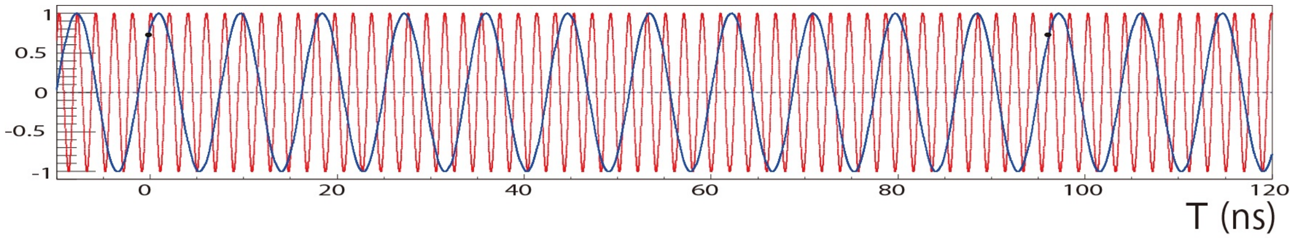

Figure 3: Time, T, evolution of RF phases in case of 114.24 MHz (blue) and 508.89 MHz (red): the black points indicate the coincidence of stable phases between two frequencies. The only once in the 49 stable phases of 508.89 MHz can be coincided with those of 114.24 MHz. it is once in every 96.3 ns and its rate is 10.385 MHz. This discussion should be done with 2856 MHz and 508.89 MHz for LINAC and MR while we discuss with 114.24 MHz and 508.89 MHz for good appearance. However there is no problem since the conditions of coincidence in these two cases are equivalent.

The MTS node is actually the main IOC for Event Timing System of SuperKEKB [7–9]. This node works for adjusting the operation-timing of LINAC. Firstly, it launches the network interruption towards the CCB node to decide the next injection-bucket and downloads the necessary timing information. Then, the timing is set on the Event Generators [10] to realize the requested injection.

Note, the entire processes are managed at the MTS node by using network interruptions while the decision of next injection-bucket is made at the CCB node. This collaboration well represents the authorities of LINAC and MR.

SCHEME FOR SELECTING INJECTION-BUCKET

The selection of injection-bucket is realized by adjusting the injection-timing and by coinciding the LINAC beam-pulse and the injection-bucket at the injection point. In this section, we summarize the scheme for timing-adjustment of Bucket Selection. Firstly, we introduce the RF frequencies of LINAC and MR since it is necessary to understand the condition of coincidence between the beam-pulse and the injection-bucket. Then, the scheme for timing-adjustment is explained for two MRs, High Energy Ring (HER) and Low Energy Ring (LER), separately. We also introduce the constraint to the LER Bucket Selection.

RF frequency

The RF frequency and operation clock of LINAC are 2856 MHz and 114.24 MHz[1], respectively. Their common frequency with the RF frequency of MR is 10.385 MHz. This is also the frequency that the stable phases of RF cavities are coincided between LINAC and MR.

Figure 3 shows coincidence of stable phases between two different RF frequencies. The injection is performed only on this coincidence, otherwise beam-pulses cannot be transferred from LINAC to MR.

Timing-Adjustment for HER

The scheme of timing-adjustment for HER is simple and it is same as that in the previous KEKB accelerators. The selection of injection-bucket is realized by adding the delay to the reference timing based on the MR revolution. The example delay values and corresponding injection-buckets of HER are summarized in Table 1.

As shown in Figure 3, the coincidence comes in every 96.3 ns, so that the delay must be set in 96.3 ns step. The injection-buckets at HER is skipped 49 buckets every time. However, the number of skipping buckets, 49, and the MR harmonic number of 5120 are prime numbers each other. Therefore, opportunities for all RF-buckets occur by turns and the latest opportunity occurs with the delay of 493 μs, which is 5120 times of 96.3 ns.

Table 1:Example of Delay Values for HER Bucket Selection

Opportunity	RF-bucket	delay (ns)
1	0	0
2	49	96.3
3	98	192.6
...	...	...
105	1	10014
106	50	10111
...	...	...
5120	5071	492922

Timing-Adjustment for LER

The scheme for LER becomes more complicated since we must consider the selection of RF-bucket of DR (DR-bucket). We use DR for the LER injection to suppress the emittance of injection e^+ beam-pulse.

The example delay values for LER Bucket Selection are summarized in Table 2. The DR-bucket to be utilized is also shown here. For example, in the first and 5121th opportunities, we can inject e^+ beam-pulse into the **#0**-bucket of LER. However the utilized DR-buckets are different between these two opportunities.

The range of timing-adjustment must cover all combinations between DR-bucket and LER injection-bucket. There are 23 kinds of combinations. Therefore, the range becomes 23 times of 493 μs and to be 11.34 ms.

[1] 25 times division of RF frequency.

Table 2: Example of Delay Values for LER Bucket Selection

Opportunity	**RF-bucket** LER	DR	**delay (ns)**
1	0	0	0
2	49	49	96.3
3	98	98	192.6
...	...	...	...
5120	5071	131	492922
5121	0	180	493019
5122	49	229	493115
...	...	...	...
10240	5071	81	985941
10241	0	130	986038
...	...	...	...
...	...	...	...
117760	5071	181	11339336

Constraint to LER Bucket Selection

There is the constraint to LER Bucket Selection. It is caused by the synergistic effect of following two conditions.

The timing-adjustment of Bucket Selection is limited within 2 ms even though the range of 0−11.34 ms is necessary for LER Bucket Selection. Because of the hardware requirement, LINAC must be operated periodically in 50 Hz and only 2 ms width of fluctuation is accepted. Therefore, in each time, only 4 of 23 combinations between DR-bucket and injection-bucket can be utilized in LER Bucket Selection.

The other limit to the usage of DR-buckets appears when we inject the beam-pulse into LER in the rate >25 Hz and the injections into LER are implemented for more than one pulses in succession.

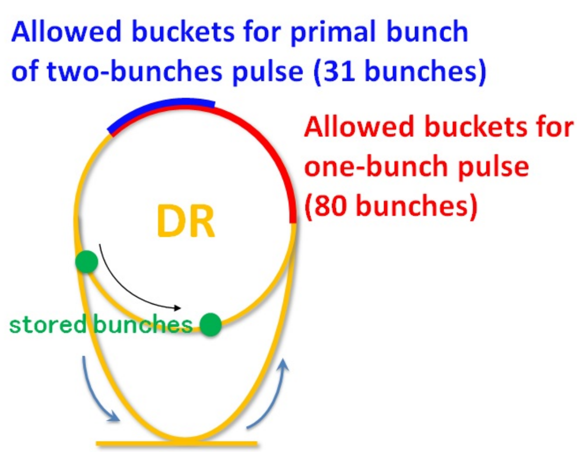

Figure 4: Schematic view of allowed DR-bucket when some of them have already been occupied: in the case two bunches have already been stored as the previous pulse are shown. The occupied buckets and the buckets between two occupied buckets cannot be utilized for the next beam-pulse. Besides, the buckets whose time distance from the occupied buckets is smaller than 100 ns are also restricted.

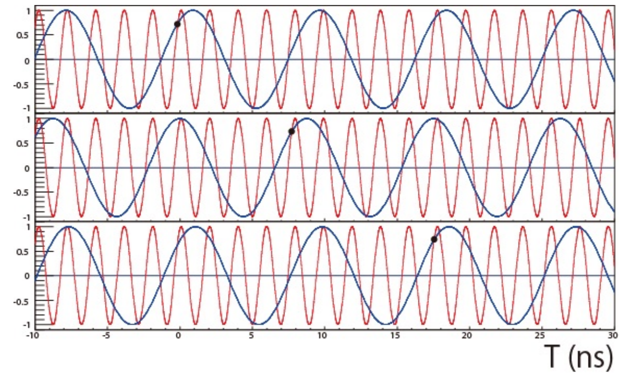

Figure 5: Comparison of the coincidence of stable phases between 114.24 MHz (blue) and 508.89 MHz (red) in three different phases of 114.24 MHz: the different stable phases of 508.89 MHz are coincided with that of 114.24 MHz when we shift the RF phase of 114.24 MHz. We discuss with the frequencies of 114.24 MHz and 508.89 MHz rather than 2856 MHz and 508.89 MHz, again.

When we inject beam-pulse into LER two times in succession, some of DR-buckets have already been occupied with previous beam-pulse since the storage time at DR is at least 40 ms. Figure 4 schematically shows the allowed DR-buckets in this situation. In addition to the occupied buckets, we need the 100 ns of timing-separation from these buckets for the rise/fall time of kicker and septum magnets which work for injection and extraction. Therefore only 31 of total 230 DR-buckets can be utilized for the primal bunch of next two-bunches injection. The allowed DR-buckets are increased to be 80 buckets when we consider one-bunch injection. However still the limit remains there.

By the synergistic effect of two kinds of limits to the usage of DR-bucket, the ∼3000 of total 5120 LER RF-buckets cannot be injected in case of two-bunches injection. This constraint to LER Bucket Selection is inconvenient in terms of beam commissioning. However we cannot avoid it in the current LINAC machine.

FUTURE UPGRADE

In this section we introduce the future upgrade of Bucket Selection. This upgrade has already been scheduled after the phase-1 or phase-2 of SuperKEKB for the purpose of solving the constraint to LER Bucket Selection.

We plan to shift the phase of RF cavities. Figure 5 shows the coincidence of stable phases between two different RF frequencies in cases of normal phase (same as Figure 3) and two shifted phases. The alternative coincidence appears in the cases of shifted phase. It indicates we can provide additional opportunities of injection by shifting the RF phase. By changing the phase of cavity on pulse-by-pulse, the opportunities of injection can be increased substantially.

After the consideration of feasibility, we decide the phase-shifting scheme in the following way. We shift the phase of cavities at LINAC rather than those at DR. The cavities at beamline between DR and MR are shifted on pulse-by-pulse. We implement 10 kinds of phase-shifting. The opportunities to select injection-bucket becomes 11 times more than those in the current system. All combinations between DR-bucket and injection-bucket can be realized more earlier. Even though we need to analyze and decide details of this upgraded method, we expect the necessary range of timing-adjustment becomes shorter and to be <2 ms.

The R&D for both Event Timing System and Low Level RF for the upgrade of Bucket Selection is on-going.

CONCLUSION

The hardware configuration and the scheme of Bucket Selection are summarized.

The hardware consists of three distributed shared memory modules which are separated each other. Three nodes are processed in parallel. However they are consolidated as Bucket Selection by using the data synchronization and the network interruption.

The selection of injection-bucket is realized by adjusting injection-timing into the injection-bucket at the injection point. The timing must be adjusted in 96.3 ns step because of the difference of RF frequencies between LINAC and MR. The timing range of 0-1134 ms is needed for the LER injection while that of 0-493 μs is enough for the HER injection. The longer range of timing-adjustment is needed for LER Bucket Selection since we must cover all combinations between DR-bucket and injection-bucket.

There is the constraint to LER Bucket Selection. The ~3000 of 5120 RF-buckets cannot be selected as the next injection-bucket when we inject e^+ beam-pulse into LER two times in succession. The synergistic effect of two kinds of limits to the usage of DR-buckets causes this constraint.

The future upgrade of Bucket Selection to solve the constraint to LER Bucket Selection is explained. We plan to shift the phase of cavities at the LINAC beamline between DR and LER on pulse-by-pulse. The R&D for both Event Timing System and Low Level RF for this upgrade is ongoing.

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