TWO-BUNCH OPERATION OF THE KEKB LINAC FOR DOUBLING THE POSITRON INJECTION RATE TO THE KEKB RING

Y.Ogawa, A. Enomoto, Y.Funakoshi, K. Furukawa, T. Honda, N. Iida, N. Kamikubota, T.Kamitani, E. Kikutani, M. Kikuchi, H. Kobayashi, H. Koiso, T. Matsumoto, Y. Ohnishi, S. Ohsawa, K. Oide, T. Suwada, KEK, Tsukuba, Japan

Abstract

A high-intensity, two-bunch acceleration scheme in the primary electron beam for positron production has been introduced at the KEKB linac for doubling the positron injection rate to the KEKB ring. The KEKB linac has until now injected single-bunch positron beams with an injection rate of about 1.4 mA/s (50 Hz) into the KEKB ring, requiring several minutes of topping-off time. Therefore, two-bunch operation could eventually halve the injection time, resulting in an efficient accumulation of the integrated luminosity of collisions. The results of two-bunch operation tests at the linac are reported.

1 INTRODUCTION

KEKB (KEK B Factory [1,2]) has been accumulating integrated luminosity with an unprecedented velocity since the Belle-detector roll-in in May, 1999. By July 2001, the total integrated luminosity had reached over 30 pb^{-1}, being comparable with that of PEPII in SLAC. Although the accelerator performance, itself, has already surpassed that of PEPII in various aspects, such as in the peak luminosity, the daily integrated luminosity, etc., more efficient accumulation of the integrated luminosity would be required in order to contribute to physics experiments [3]. In practice, the peak luminosity must be primarily raised by increasing the stored currents as well as elaborating collision-tuning, while the injection time should also be minimized. In Fig. 1, the daily KEKB performance is shown, indicating about twenty-times

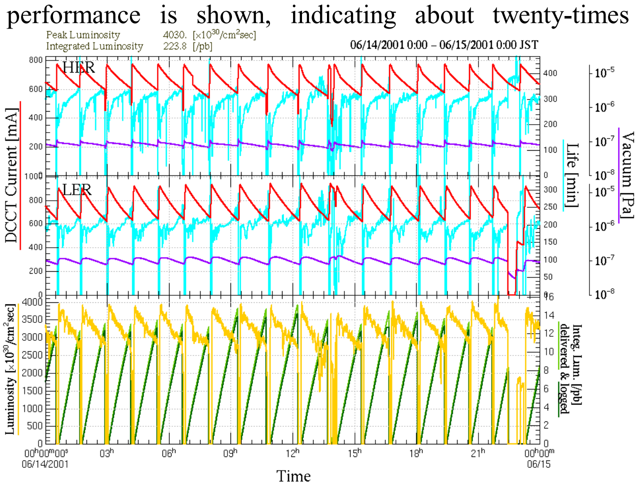

Figure 1: Daily snap shot of the KEKB ring.

injection in one day with a few minutes of each injection time, which corresponds to more than two hours for injection per day. Since the present injection time is mainly determined by that of a relatively low-intensity positron beam, it is quite natural to increase the positron intensity in the linac for minimizing the injection time. The single-bunch intensity of the positron beam in the KEKB linac, however, has almost amounted to the maximum value, simply because the charge of a high-intensity, single-bunched primary electron beam for positron production has almost approached the beam blow-up threshold due to single-bunch transverse wake-field effects. Therefore, we have adopted a two-bunch acceleration scheme for doubling the positron intensity [4, 5]. The present status of two-bunch acceleration as well as various experiences concerning the stable acceleration of high-intensity two-bunched beams is reported.

2 TWO-BUNCH ACCELERATION SCHEME

In the KEKB linac, a high-intensity single-bunched electron beam is generated through a bunching section comprising two subharmonc bunchers (SHB1: 114 MHz and SHB2: 571 MHz) and subsequent S-band bunchers (prebucher and buncher), giving a 10-nano-Coulomb, single-bunch beam with a bunch length of 10 ps (FWHM). The beam is accelerated to the positron production target at an energy of 3.7 GeV. The generated positron beam is accelerated to the end of the linac at an energy of 3.5 GeV and directly injected into the KEKB ring. Major constraints and issues for doubling the bunch number in the KEKB linac are the following:

- The bunch separation should be an integer multiple of a common period (96.29 ns) among the linac and ring frequencies (Table 1).
- Two bunches must be accelerated during the same rf pulse, signifying that the bunch separation should be comparable with the width of the SLED gain curve, in which the energy gain does not change very much (Fig. 2).
- Beam loading compensation between two bunches could be carried out by utilizing the SLED gain curve (Fig. 2).
- Beam blow-up due to multi-bunched transverse wake-field effects must be suppressed by fine and elaborate orbit tuning.

Table 1: Various frequency relations.

	Multiple	Frequency [MHz]	Period [ns]
Common Frequency	1	10.385454	96.289
SHB1	11	114.240	8.754
SHB2	5*11	571.200	1.751
Linac	5*5*11	2856.000	0.350
Ring	7*7	508.887	1.965

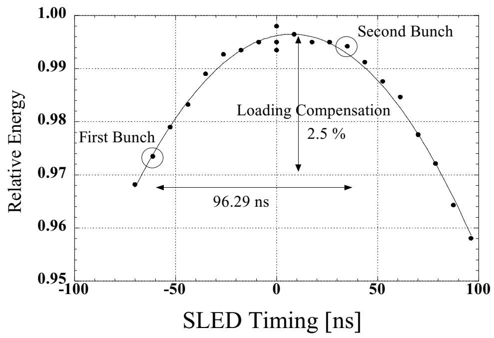

Figure 2: SLED gain curve.

The first constraint comes from complex relations among the linac and ring frequencies (Table 1), giving the most severe requirement regarding the bunch separation in the linac. Taking account of the second constraint as well, the bunch separation is uniquely determined to be 96.29 ns, corresponding to just the common period. Figure 3 shows a block diagram of two-bunch generation and acceleration.

Several issues concerning the bucket selection system for the injection of two-bunch beams into the KEKB ring with this bunch separation are described elsewhere [6].

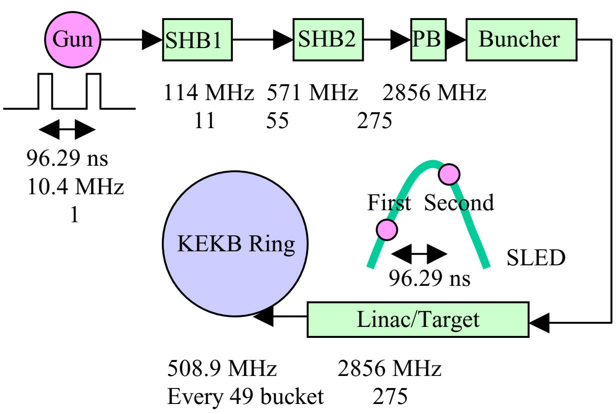

Figure 3: Two-bunch acceleration scheme.

3 ACCELERATION OF A HIGH-INTENSITY, TWO-BUNCHED ELECTRON BEAM

3.1 Two-Bunch Generation

Two high-voltage pulses with a time interval of 96.29 ns are produced by combining the outputs of two independent grid pulsers with a pulse width of about 1 - 2 ns each, in which both the amplitude and pulse timing are adjustable. They are applied to an electron gun with an acceleration voltage of 200 kV, and immediately fed into two SHBs and an S-band bunching section, generating a high-intensity two-bunched beam with a charge of 10 nano Coulomb and a bunch length of 10 ps (FWHM), respectively. The main concern in the high-intensity, two-bunch generation is how to accommodate both pulses with the same bunching conditions by adjusting the pulse height and the relative time delay of the grid pulsers:

- The S-band pre-buncher and buncher comprise travelling-type accelerator sections with rf-filling times of 8 ns and 48 ns, respectively, which are quite short compared with the bunch separation of 96.29 ns. This means that there is no beam-loading effect due to multi-bunch longitudinal wake-fields. Single-bunch longitudinal wake-field effects, however, could cause an energy difference between two bunches unless the intensities of the two pulses are the same. Therefore, we must assure the same bunching conditions for two bunches by equalizing both charges.
- Vary the relative time delay of two pulses and acquire an optimum value so that the energies of two bunches at the exit of the buncher are equalized with each other. The energy is measured by utilizing beam-position monitors and steering magnets (Fig. 4).

The observations of the bunch profiles at the exit of the bunching section showed that the bunch profiles for the two bunches are almost identical, confirming the above tuning procedures.

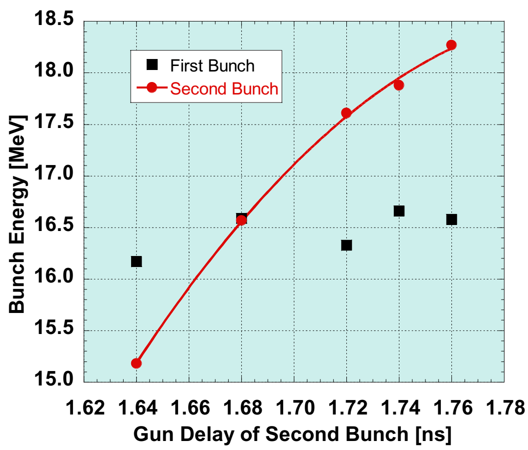

Figure 4: Energy equalization at the buncher.

3.2 Two-Bunch Acceleration

After exiting the bunching section, two bunches are accelerated in the regular accelerator sections, where the multi-bunch beam-loading effects are the main concerns. The energies of both bunches must be equalized by the following methods, depending on with or without SLED (beam-loading compensation):

- For the case without SLED, put the first bunch into the accelerator sections during the rf-filling time so as to gain a lower energy than that of the second bunch, thus compensating for the beam-loading effects.
- For the case with SLED, equalize the energies of the two bunches by adjusting the SLED timing, as mentioned in section 2.

The energy equalization is verified by measuring the energy difference of the two bunches, for instance, at the middle of the J-arc section, where the dispersion function is finite, or by observing the phase difference of betatron oscillations for two bunches.

3.3 Orbit and Optics of Two Bunches

When the energies for the two bunches become definite along the linac, orbit and optics corrections are required for two-bunch beam transport without any beam loss. Since the beam characteristics of the two bunches at the exit of the bunching section are the same, optics corrections and matching only for either the first bunch or the second bunch should be sufficient, in principle. On the other hand, orbit corrections might be carried out for each bunch by introducing a new algorithm, for instance, a method involving the average minimum of two-bunch orbits. This is because the transverse wake-field generated at the first bunch due to a misalignment of the accelerator sections and quadrupole magnets might deteriorate the second bunch, leading to beam blow-up. The observed beam orbits for two bunches are quite similar (Fig. 5), indicating that suppression of the transverse wake-field effects may be satisfactory.

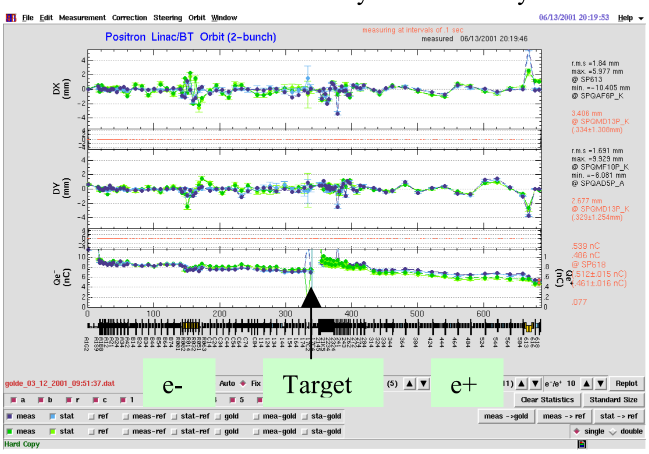

Figure 5: Orbit and charge of two bunches measured by bpm. The dense line indicates the first bunch.

4 CHARACTERISTICS OF TWO-BUNCHED POSITRON BEAMS

Positrons are produced at a tungsten target, on which high-intensity, primary electron beams impinge. Passing through the positron capture section comprising a pulse coil, a solenoid coil and high-field accelerator sections, the positron beam is accelerated to the end of the linac at an energy of 3.5 GeV. The energy spread is almost halved by an energy compression system (ECS) installed at the end of the linac, thus minimizing the beam loss due to the energy tail along the beam-transport line to the KEKB ring. We could accelerate two-bunched positron beams with a charge of about 0.5 nano Coulomb having a good beam quality; the observed energy spread for two bunches is almost identical and the measured twiss parameters are also quite similar to each other. We have also succeeded to inject two-bunched positron beams into the KEKB ring in special filling patterns [6] as well as in leading them to the end of the beam-transport line.

5 CONCLUSIONS

Two-bunch operation tests of the KEKB linac for doubling the positron injection rate to the ring have been successfully carried out, giving promising results concerning possible normal operation. We expect to obtain stable operation of two-bunch injection into the KEKB ring in FY2001.

REFERENCES

[1] K. Oide, “Status of KEKB B-Factory”, HEACC2001, Tsukuba, March 2001.

[2] S-I. Kurokawa, “B-Factory Commissioning and First Results”, PAC’01, Chicago, June 2001.

[3] K. Abe *et al.*, “Observation of Large CP Violation in the Neutral B Meson System”, Phys. Rev. Lett. 87, 091802 (2001).

[4] Y. Ogawa *et al.*, “High-Intensity, Two-Bunch Acceleration for Doubling Positron Production at the KEKB Linac”, HEACC2001, Tsukuba, March 2001.

[5] S. Ohsawa *et al.*, “Increase of Positrons by High-Intensity Two-Bunch Acceleration Scheme at the KEKB Linac”, PAC’01, Chicago, June 2001.

[6] E. Kikutani *et al.*, “The KEKB Bucket Selection System – Recent Progresses and a Plan in the Near Future”, in these proceedings.