The Present Performance and Future Upgrade of the KEKB Electron Linac

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Abstract

The KEKB linac injects 8-GeV electrons and 3.5-GeV positrons into the KEKB asymmetric collider rings designed for B-physics studies. KEKB has recorded the highest luminosity records to which the linac contributes with advanced operational stability. In order to further improve the luminosity, new schemes of dual-bunch injection and continuous injection have been studied and adopted. It is also planned to upgrade KEKB for a luminosity of $10^{35}\ /cm^2/s$ with exchanged beam energies (3.5-GeV electrons and 8-GeV positrons). The upgraded linac is being designed and studied with a higher acceleration gradient and others to realize such a super B factory.

1 INTRODUCTION

The performance of KEKB [1] has gradually improved, and recently it has recorded an integrated luminosity of 399/pb/day and a peak luminosity of $7.35 \times 10^{33}\ /cm^2/s$. Such a high luminosity reinforces the achievement of important results in the study of CP-violation with the Belle detector [2].

The injection rate from linac also had to be improved, and it has been planned to adopt a higher beam quality control and advanced operation modes, which include dual-bunch injection and continuous injection.

With such a success in B-physics studies, it was proposed to build an upgraded factory machine, SuperKEKB, with a 10-times higher design luminosity of $10^{35}\ /cm^2/s$ [3]. This is the major challenge for the linac because both the positron energy and the beam charge must be upgraded. It is planned to study the upgrade possibilities at first with a C-band high-gradient scheme [4].

2 OPERATION STATUS

The linac has been operating very stably these days, and it seems that such difficulties as a discharge issue have been overcome, which we experienced in the bunching section and the positron target section [5].

2.1 Statistics

Table 1 gives the operation statistics during the past three years, where a machine down means that the machine was not ready, including rf trips and short maintenance work between injections; a beam loss means that the machine was not available while an injection was being requested.

Table 1: Linac operation time (hours).

	FY1999	FY2000	FY2001
Operation Time	7297	7203	7239
Machine Down	768 (10.5%)	601 (8.3%)	385 (5.3%)
Beam Loss	74 (1.0%)	54 (0.8%)	22 (0.3%)

Table 2: Four beam modes of the linac.

Ring	Energy (nC)	Charge (GeV)	Injection (/day)	Inj. Time (min.)
KEKB e^-	1.28	8.0	∼14/18	∼1.5
KEKB e^+(1)	.64×1	3.5	∼14	∼8
KEKB e^+(2)	.64×2	3.5	∼18	∼4
PF e^-	0.2	2.5	1	∼5
PF-AR e^-	0.2	2.5/3.0	12	∼4

KEKB e^+(1), (2) denote single- and dual-bunch operations.

The linac injects beams into the Photon Factory (PF) and the PF-AR as well as the KEKB rings. Table 2 gives the typical beam mode parameters for four storage rings. The beam modes are switched about fifty times a day, without any beam quality degradation. Recently, we started 3-GeV injection into PF-AR instead of 2.5 GeV, which seems to have cured the instability issues in the ring.

2.2 Beam and Machine Quality Control

Because of the characteristics of the factory machines, especially at KEKB, continuous operation of the rings and the linac through the year is crucial. Thus, in order to maintain the beam quality, we routinely monitor several machine and beam parameters. Here are some examples of such parameters:

- Number of rf-trips and the reason for each klystron (every week).
- rf phasing at each klystron (every other week).
- Twiss parameters and matching condition Bmag (every day).
- Energy spread (every day).

If those parameters are not optimal, machine tuning is carried immediately. For example, if a matching condition parameter Bmag for a certain location is large, beam optics matching is carried out using a Twiss-parameter measurement by wire scanners. Figure 1 shows that the number of

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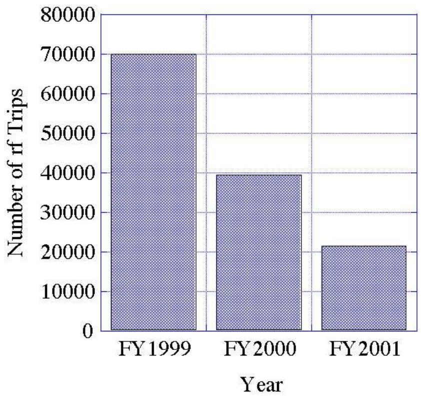

Figure 1: Number of rf trips per year.

rf trips per year is decreasing rapidly. The reason is mainly because we gradually began to choose the optimum high-voltage values for the klystrons, besides quality improvements of the klystrons and pulse modulators.

2.3 *Dual-Bunch Acceleration*

During beam injection to the KEKB rings, an experiment cannot be performed. Most of the injection time is used for positrons, since the stored current is larger and the lifetime is shorter in the ring.

Thus, in order to double the positron injection efficiency dual-bunch acceleration had been studied [6] and necessary equipment had to be installed [7, 8]. During this year we tried this injection scheme for more than a one-month period, and were successful.

However, because of the common frequency between the linac and the ring, bunch selection in the ring is restricted. That led to heating of the beam pipes in the rings, and also affected the luminosity tuning. While we may need some more studies concerning those issues, the luminosity increased by 4 to 8%.

2.4 *Continuous Injection*

As the stored beam currents in the rings decrease between injections, the luminosity decreases accordingly. In two rings the positron beam reduction is larger since the lifetime is shorter. Thus, we started to study the continuous injection of the positrons during physics experiments after careful tests against detector noises. In this scheme, positrons are injected continuously at 5 to 10 Hz instead of a maximum rate of 50 Hz. As shown in Fig. 2, the positron current was kept almost constant and the reduction of the luminosity was relaxed. A beam-current reduction before each injection was caused by a PF-AR injection.

Although a part of the detector needs some more preparation against injection noise and heating, the integrated luminosity may increase by 20% with this scheme as a rough estimate. However, if we inject positrons in this scheme, the measurements and corrections to maintain the beam quality may become a issue. This is discussed later.

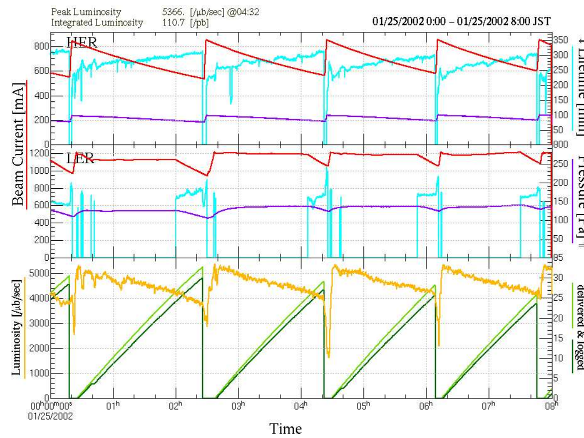

Figure 2: Continuous injection to keep the positron beam constant.

After those successful adoptions of both dual-bunch injection and continuous-injection schemes, we will further utilize them in the coming operation periods.

3 UPGRADE FOR SUPERKEKB

Based on the success of the KEKB, the new project SuperKEKB was proposed to study the B-meson system parameters precisely and to search for new physics, such as the super-symmetry. The new machine should provide a ten-times higher luminosity, $10^{35}\ /cm^2/s$, while the design luminosity of KEKB is $10^{34}\ /cm^2/s$. In the new design a factor of ten is achieved by squeezing the beta function at the interaction region and by increasing the stored beam currents in the rings, both of which should provide a factor of 3.2.

However, because of the electron cloud in the beam pipe of the positron ring, the luminosity may be limited. Thus, in order to cure this issue, energy exchange is planned, where the energies of the electrons and positrons should be 3.5 GeV and 8 GeV. A positron injection energy of 8 GeV is the major challenge at the linac as well as the increase of the injection rates. The machine design is being carried out in two schemes, one of which we have already started development.

3.1 *High-Gradient C-Band Scheme*

Since the linac site is limited, the energy upgrade of the positron beam from 3.5 GeV to 8 GeV needs restructuring of the linac. After investigating several possibilities, two options are being considered. The first option is to employ C-band structures to double the energy gain at a part of the linac and a damping ring to lower the emittance, as shown in Fig. 3.

A damping ring is necessary not only for the smaller aperture of the C-band structure, but also to relax the design criteria of the improved interaction region at the ring. It will be installed after the positron capture section, where

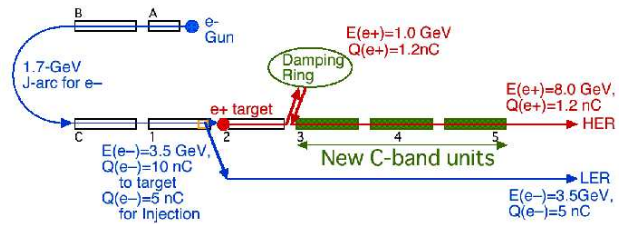

Figure 3: Energy upgrade with high-gradient structures as a first option.

the positron energy is 1 GeV.

C-band structures will be installed in the 24 units after the damping ring. Currently, each unit contains a 40-MW klystron, a SLED pulse compressor and four 2-m long S-band structures, which provide an energy gain of 160 MeV (21 MeV/m). It will be replaced by two 40-MW C-band klystrons, two rf-pulse compressors and four C-band structures, with which the energy gain will be 320 MeV per unit (42 MeV/m). The maximum positron energy will be 8.7 GeV.

The C-band technology will be based on development by the JLC C-band group [9]. However, the components are being optimized and simplified for our needs, since we don't need multi bunches, and we want to simplify the maintenance. In the first design, the klystron will be a non-PPM type, the pulse compressor will be a LIPS type and the accelerating structure will be just a scale-down of the current S-band structure without HOM damping. Those components have been designed and are being fabricated. Their high-power tests and beam tests will be carried in 2003.

3.2 Recirculation Scheme

Another scheme being considered utilizes a recirculation in which generated low-energy positron will be kept in a damping ring for the next rf pulse and will be recirculated from the head of the linac. There can be several variations in this scheme. Although it does not require any new accelerating components, very different beams have to be accelerated in the same pulse and several bypass lines and kickers have to be installed. Thus, the operation and maintenance will be complicated.

3.3 Beam Measurement

Since continuous injection was adopted, and it will be more important in SuperKEKB, the beam quality control will be impossible, which is currently performed during 1-hour periods between injections. Thus, a non-destructive beam measurement would be crucial. To that end, a stealth-bunch measurement is considered, in which a bunch between injection bunches will be used to measure the characteristics and will be removed by a kicker at the end of the transport line. This scheme requires the following components to be developed:

- Fast actuators, like phase shifters, to be scanned in the measurement.
- Fast and synchronous data-acquisition system.
- Fast kicker.
- Timing system modifications.

Some of these items are being developed for other purposes, like a fast beam-feedback system [10]. The development will be continued, since beam-quality control is indispensable.

4 SUMMARY

The KEKB linac has been stably operated and has contributed much to improve the KEKB luminosity with its improved operation, which includes beam quality control and advanced injection modes, dual-bunch injection and continuous injection. On the other hand, in order to meet the injection specifications of the newly proposed SuperKEKB project, several upgrade schemes are considered and designed. The development has started for one of the schemes, which is an upgrade with a higher gradient by C-band structures. Beam quality control for the future is also planned with a better beam measurement scheme.

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