PRE-INJECTOR OF THE KEKB LINAC

S. Ohsawa, A. Enomoto, K. Furukawa, M. Ikeda, K. Kakihara, T. Kamitani, H. Kobayashi,
Y. Ogawa, T. Oogoe, A. Shirakawa, T. Suwada, T. Urano, S. Yamaguchi, KEK, Tsukuba, Japan

Abstract

The pre-injector of the KEKB linac has been completed and is in operation. 10-nC electron bunches, without satellite bunches, are created and used for producing positrons, while 1-nC electron bunches are directly injected into the KEKB 8-GeV ring. Observed bunch widths are typically 10 ps (FWHM) or less. The high-intensity beam is stably accelerated to a positron production target with a transmission efficiency of greater than 90%. Major efforts to stabilize the beam and their results are described.

1 INTRODUCTION

Since 1994, the KEK electron / positron linac has been upgraded in order to inject 8-GeV electrons and 3.5-GeV positrons directly into the KEKB rings. The major goals of the linac upgrade have been to increase the accelerating energy from 2.5 to 8 GeV and to increase the positron intensity by about 20 times. One of the most important points at issue has been to stably accelerate a high-density single-bunch beam of 10 nC to the positron-producing target without loss. Fundamental characteristics of the beam are strongly dependent on the performance of the pre-injector, which makes a high-density, short bunch of 10-ps width (FWHM) from a 200 keV low energy beam of 2-ns width.

The linac was extended upstream and 19 accelerator modules were newly installed in a new building. The first 12 accelerator modules including the pre-injector were completed by the end of September 1997. The beam commissioning was initiated on October 7th, 1997 before completing the 180°-bending section. After having combined the old and extended linacs at the end of March 1998, the beam was transported through the entire linac. The linac rf repetition rate has been raised from 25 pps up to 50 pps since operation started in September 1998.

We have carried out the commissioning step by step while gradually increasing the electron beam intensities [1]. By precisely tuning the rf phases and beam orbit, about 10 nC electron bunches accelerated by October 1998. But, as was expected, it was difficult to switch beams to deliver to one of four different rings at every injection. In the linac system some very old components that have been used since the start of operation in 1982 are still in use. After completion of the upgrade, we immediately started a project to improve the reproducibility of the beams. In September 1999, the linac reached the stage wherein a high intensity beam of 10nC bunches could be accelerated stably to the positron production target with a transmission rate of greater than 90%.

The main elements of the pre-injector had been moved except for two accelerating sections from the previous pre-injector of the old linac. Some parts of the pre-injector were improved step by step so as to make beams more stable in the high current region. A cavity of the first sub-harmonic buncher (SHB1) that had been utilized from 1985 was replaced with a newly designed one in May 1998. There was a problem with the cooling performance of the cavity at high power. In August 1999, a solid-state amplifier replaced an old planar-triode-type rf amplifier for SHB1. At the same time a newly designed SHB2 cavity was installed, the shunt impedance of which was improved two times in order to relax power requirement for its power amplifier.

As the beam charge increased, it became difficult to maintain some equipment within tolerance limits for keeping the beams stable without feedback systems. Some software feedback loops were added during the commissioning. They cover the gun accelerating voltage, the gun-beam trigger timing and the power levels of the SHBs [2].

2 SYSTEM CONFIGURATION

The pre-injector consists of an electron gun, a bunching system and two accelerating sections with focusing, vacuum and monitor systems. The electron gun is a triode-type thermionic gun with a 1cm^2 cathode. The bunching system is composed of two SHBs with frequencies set at the 25th and 5th sub-harmonics of 2856 MHz, and a prebuncher (PB) and a buncher.

The SHB frequencies are chosen from sub-harmonics near 100 MHz and 500 MHz with the condition that each frequency should be a multiple of the linac/ring common frequency of 10.385 MHz, which is a 25x11th sub-harmonic of 2856 MHz.

Table 1: Operation parameters

Element	Frequency	(Power)
Gun	50 Hz	200kV
SHB1 (standing wave)	114 MHz	11 kW
SHB2 (standing wave)	571 MHz	7 kW
Prebuncher(travelling wave)	2856 MHz	1 MW
Buncher (travelling wave)	2856MHz	23 MW
Accelerating sections (travelling wave)	2856MHz	12 MW x 2

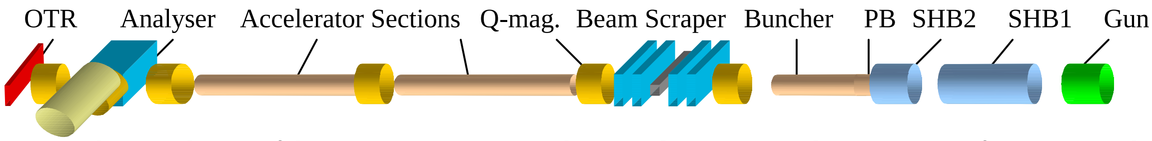

Figure 1: Schematic layout of the pre-injector. ORT is the optical-transition-radiation monitor for measuring bunches.

The klystron for the pre-injector is a special one that has a generating capacity of 60 MW. Since the buncher rf power was doubled, the bunching performance was improved especially in the high intensity region, as was expected from computer simulations [3].

3 PERFORMANCE OF MAIN ELEMENTS

2.1 Gun grid pulser

We introduced a new grid pulser in September 1999 to deliver stable and short electron beams from a triode-type thermionic gun. Its time jitter is remarkably small (σ~4 ps) , with a pulse width (FWHM) as small as 1ns. We designed the new pulser to be divided into two parts. The pulse generating part is installed in the conical portion of the gun body to avoid degradation of the pulse-characteristics from transmission over long cables. The other part is composed of power supplies and voltage control circuits, which are assembled in a NIM crate. Another feature of the pulser is that it has an electric analog time-delay unit that continuously varies the trigger timing over a 3-ns range. This function is useful for controlling the beam timing with a feedback system, which is described in the section 2.3.

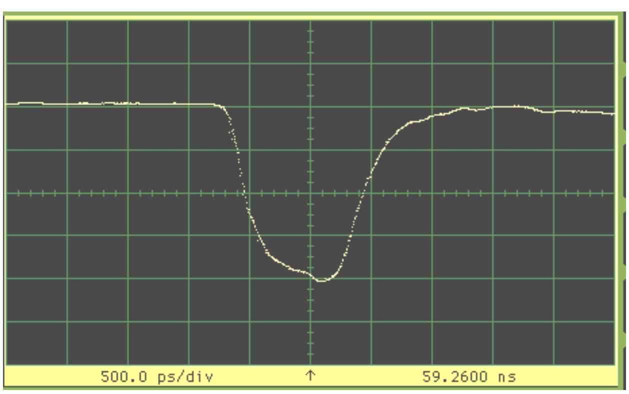

Figure 2: Pulse shape of the new grid pulser. A typical timing jitter (σ) is about 4 ps. The h-axis is 500ps/division.

2.2 Gun voltage control

The electron gun is operated at 200 kV with 50 pulses per second. When the gun modulator continuously operates without stops, the pulse amplitude remains stable. It actually stops, however, at an interval of two or four hours in regular operation, when the Photon Factory rings require injections from the other electron gun. This causes temperature change in load resistors of the gun modulator. This means that the gun voltage changes whenever the modulator starts operation again because the load resistance depends on its temperature. Under the present operation conditions, the temperature rise is about 10°C when it becomes stable, which causes a gun-voltage change of 1.5%. A software feedback system has been adopted to compensate the change by optimising the modulator reference voltage depending on the change.

The gun-pulse voltage is kept constant by the feedback system within a deviation of 0.05%. This satisfies the requirement of less than 0.1%, which corresponds to a 1.1-ps change of the gun-beam timing at a beam monitor located upstream the SHB1.

2.3 Gun beam timing control

If the pulse timing of the gun beam changes, the beam is bunched, in general, at a different rf phase with a different bunch shape. The requirement on the timing stability is as severe as 100 ps in the case of a 10-nC beam that is used to produce positrons. When a timing change exceeds this value, more than 10% of the beam is lost during acceleration to the target.

The beam intensity delivered from the gun is controlled by both grid-pulse and grid-cathode bias voltages. We are monitoring the timing and amplitude of the grid pulses after averaging 30 pulses to eliminate noises. The pulse timing is compared with a reference wave of 571MHz at a digital oscilloscope on the ground level. The time difference is kept at a constant value by a feedback loop.

Triggering signals for the grid pulses are synchronised with a reference rf wave of 571MHz by a time delay unit (TD4R) at the 200KV level. The synchronisation system is very effective for decreasing the time jitter (σ~2ps). There

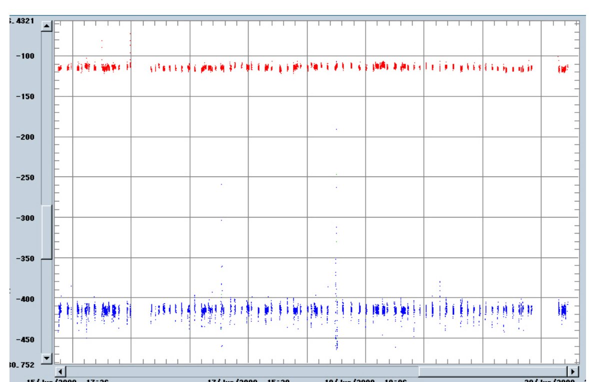

Figure 3: Timing history of grid pulses for 5 days: the vertical axis shows time at 50ps/division. The lower blue points represent grid-pulse timing, while the upper red points indicate the time difference between grid pulses and gun-beam pulses.

is, however, some element sensitive to ambient temperature somewhere. The feedback system is necessary to assure of the long-time stability.

Operational history of the grid-pulse timing is shown in Fig.3. The pulse timing is maintained usually within 20 ps.

2.4 Sub-harmonic Bunchers

In order to relax the requirements on the electron gun, two SHBs were introduced into the bunching system. The cavities are newly designed and fabricated to overcome difficulties of the old cavities [4]. Copper-plated stainless steel (SUS304) was used for the old SHB1 cavity. This time oxygen free copper was selected as the structural material for both cavities to improve cooling performance with a new cooling-pipe configuration. From computer simulations we had learned before fabrication that, owing to rf power dissipations, the resulting cavity thermal deformations changed the resonant frequencies, but they were estimated to be tolerable. Shunt impedances were improved as shown in Table 2 in order to relax power requirements for power amplifiers.

For stable acceleration, the phase stability of each cavity is important, especially for the 10-nC single-bunched beam. The phase tolerance on the beam, coming from the goal of keeping the beam transmission rate above 90% at the target, is only 1.5° for each cavity. We are monitoring the rf phases of these cavities relative to the 2856-MHz accelerating rf wave by means of a sampling oscilloscope. It is useful for measuring relative phase shifts between different frequencies. It shows all deviations from the master oscillator wherever they occur. Since the phases are usually stable at the present time on the timescale of a week, the SHBs operate without phase feedback systems.

Table 2: Results of low-power tests

Parameters	**SHB1**	**SHB2**
Shunt impedance (MΩ)	1 .14	3.04
Q_0 (Measurement)	6989	12580
R_0/Q_0 (Measurement)	163	241
Acceleration Gap (mm)	42.5	30.05
Shunt impedance (new/old)	1.7	2.03

2.5 Buncher and Accelerating Sections

The prebuncher and buncher were manufactured in 1992 for the purpose of studying the potential of the KEK PF linac for high current acceleration. After attaining that aim, they were moved and reconstructed in the new pre-injector of the KEKB Linac.

In March 2000, RF reflections owing to electric discharge began occurring often in the buncher. We opened a beam line downstream of the buncher and found discoloration in parts of the output coupler and some adjoining disks.

Since an rf source klystron fed power into the buncher and two accelerating sections, we decided immediately to change the rf feed connections of the two accelerating sections from serial to parallel in order to reduce the total rf-filling time. By this rearrangement it became possible to shorten the rf pulse length from 1.5 to 0.5 µs, which succeeded in avoiding electric discharges.

4 BEAM CHARACTERISTICS

The beam characteristics of the single bunches are measured at the buncher and the pre-injector exits. All of them satisfy the goals. As a result the beams are stably accelerated to the target or the end of the linac with transmission efficiencies of greater than 90%.

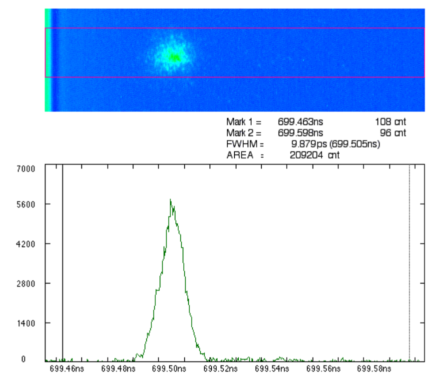

Figure 4: The 10-nC electron bunch of 10ps width.

Table 3: Typical beam characteristics

Parameters	**e-**	**e- for e+**
Beam charge#	1 nC	11 nC
Emittance $\gamma\varepsilon$#	35 µm	80 µm
Beam energy#	16.1 MeV	14.8 MeV
Bunch Width (FWHM)	8 ps	10 ps
Satellite bunches	0 %	< 1%
Beam charge	1 nC	10.5 nC
Beam energy	64 MeV	60 MeV

at the buncher exit. Others are at the pre-injector exit.

ACKNOWLEDGEMENTS

The authors wish to thank to all of the staff members of the linac and the commissioning group for their support.

REFERENCES

[1] Y. Ogawa, et al. “Commissioning of the KEKB Linac”, LINAC98, Chicago, U.S.A., August 1998.
[2] K. Furukawa, et al. “Energy Feedback Systems at the KEKB Injector Linac”, ICAREPCS 99, Trieste, Italy, October 1999. pp.248-251.
[3] S. Ohsawa, et al. “High-Intensity Single-Bunch Beam of the PF 2.5-GeV Linac”, LINAC94, Tsukuba, Japan, August 1994. pp.193-195.
[4] S. Yamagichi, et al. “Development of a 114.24MHz LINAC98, Chicago, U.S.A., August 1998. 558-561