COMMISSIONING OF THE KEKB 8-GeV e$^-$ / 3.5-GeV e$^+$ INJECTOR LINAC

N.Akasaka, A.Enomoto, J. Flanagan, H.Fukuma, Y.Funakoshi, K.Furukawa, T. Ieiri, N.Iida, T.Kamitani, T.Kawamoto, M.Kikuchi, H.Koiso, T. Nakamura, Y.Ogawa, S.Ohsawa, K.Oide, K. Satoh, M. Suetake, and T. Suwada, KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

Abstract

The KEKB 8-GeV electron / 3.5-GeV positron injector linac is almost completed and is now under commissioning. Recently, both an 8-GeV electron beam and a 3.5-GeV positron beam were accelerated to the linac end. This report describes the current status of these beams with emphasis on the newly developed beam monitors being used for various stages of beam commissioning.

1 INTRODUCTION

KEKB includes an 8-GeV electron (e$^-$) ring and a 3.5-GeV positron (e$^+$) ring, which are under construction after having removed the TRISTAN accelerator. KEKB aims at a luminosity of 1 x 10^{34} cm^{-2}s^{-1} with collisions between 1.1-A e$^-$ and 2.6-A e$^+$. The first requirement of the linac is to deliver full-energy beams for both rings. The second is to increase the positron intensity to more than 0.64 nC/bunch. If the linac injects positrons with a charge of 0.64 nC/bunch at 50 Hz without any beam loss, it takes 13.5 minutes to accumulate from 0 to 2.6 A (the revolution time is 10 μs). The linac beam parameters are summarized in Table 1.

For an energy upgrade, the number of accelerator modules is to be increased from 40 to 57 and the acceleration gain of the module is improved from 70 to 160 MeV each by increasing the klystron modulator power, replacing the 30-MW klystrons by 50-MW klystrons, and using rf pulse compressors. For increasing the number of positrons, the old positron generator was moved to a higher energy point of about 3.7 GeV from 0.25 GeV.

The new layout of the linac is shown in Fig.1. Electron beams from the gun are bunched by 114.24-MHz and 571.2-MHz sub-harmonic bunchers (SHBs), as well as a 2856-MHz prebuncher and a buncher. The bunched electron beam is accelerated from north to south, up to 1.5 GeV by 11 accelerator modules, then deflected 180 degrees, and further accelerated in the inverse direction up to 8 GeV by 46 accelerator modules. When the positron beam is accelerated, a positron radiator is inserted at an energy point of about 3.7 GeV; then, intense primary electrons of about 10 nC/bunch hit the radiator and emerging positrons are focused and accelerated through the rest of the linac. The basic design details of the linac have been reported elsewhere [1, 2].

The linac has been in the process of being upgraded since 1994. Reconstruction of the old linac and construction of the extended 17 accelerator modules were independently performed, and two linacs were combined at the end of March, 1998.

TABLE 1

Beam parameters of the KEKB e$^-$/e$^+$ injector linac.

Injection energy	(e$^-$)	8.0	GeV
	(e$^+$)	3.5	GeV
	(e$^-$ for e$^+$ production)	3.7	GeV
Pulse length		single bunch	
Bunch (half) width (σ_Z)		5	ps
Particle number (Charge) / pulse	(e$^-$)	8 x 10^9	(1.28 nC)
	(e$^+$)	4 x 10^9	(0.64 nC)
	(e$^-$ for e$^+$ production)	6 x 10^{10}	(10 nC)
Pulse repetition		50	pps
Emittance (2σ)	(e$^-$)	6.4 x 10^{-8}	m.rad
	(e$^+$)	8.8 x 10^{-7}	m.rad
Energy (half) width (σ_E/E)	(e$^-$, e$^+$)	0.125%	

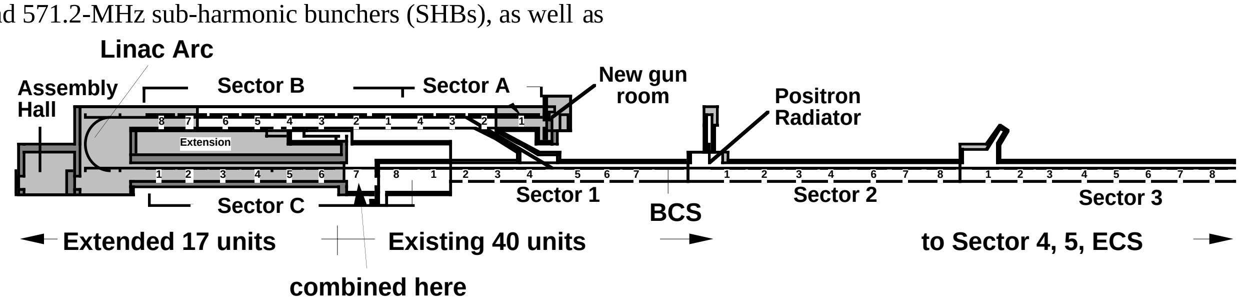

Fig.1 Layout of the 8-GeV e$^-$ / 3.5 GeV e$^+$ KEKB injector linac. Forty accelerator modules of the old 2.5-GeV linac were energy-upgraded from about 67.5 to 160 MeV/module on the average; also, 17 new modules were added at an upstream site. The old and new linacs were combined during March 23 to 30, 1998.

2 COMMISSIONING

Commissioning of the extended part was initiated in October, 1997. The pre-injector and the accelerator modules before the 180-degree arc were tuned. During January and February, 1998, the linac arc was constructed and an electron beam was accelerated through the extended linac. After the extended linac and existing linac were combined at the end of March, electron beams have been accelerated through the entire linac.

2.1 Tuning of the pre-injector

The first phase of pre-injector tuning was to transport a gun beam of 200 keV at the central trajectory from the gun to the exit of the buncher using a solenoid field of about 0.1 T. By improving the assembling error of the gun cathode, it was proved that the beam position at the buncher entrance did not move when the beam energy changed from 100 to 200 kV. Though the beam trajectory to the buncher was improved, it also found that this position might not be completely in accord with the buncher center axis, because it was necessary to apply a steering coil at the entrance of the buncher. This point has not yet been improved.

In order to smoothly tune the buncher system and to produce a single-bunch beam, it was very effective to use a streak-camera system. We have been improving it in order to use it for daily beam tuning in the linac, like when using an oscilloscope. Optical transition light (OTR) emitted by electrons from a metal plate, which is easily inserted into the beamline, is utilized as the light source to the streak-camera. The trigger-delay and synchronization systems were assembled in the streak camera proper, and became controllable by a personal computer. The developed streak-camera has an accuracy of 2 ps, and such necessary functions as an automatic peak search, integration of the peaks arranging each center of gravitation, and remote control of the optical lens system.

Thus, one is installed after the pre-injector. Empirically, a charge of more than 1 nC/pulse gives sufficient light for seeing a single-shot signal without focusing the electron beam on the metal plate.

Figure 2 shows the bunch width of the electron beam with a charge of about 10 nC. The gun beam has a full width of about 3 ns (an initial phase width of 120 degrees at the entrance of the 114.24-MHz SHB). By this SHB, it is bunched to 1 ns (an initial phase width of 200 degrees at the entrance of the 2856-MHz prebuncher). We measured the single-bunch purity and tuning tolerance of the buncher components. For a high-current gun beam of 10 nC /pulse, the phase tolerance for the 114-MHz SHB is quite severe (several degrees) at an input power of 10 kW, which is the maximum operating power. The full-width at half maximum (FWHM) of the bunch width was measured to be around 10 ps.

The electrons from the buncher were energy-analyzed using a steering magnet and a beam-position monitor (bpm); their emittance was measured and matched to the acceptance of the following beam transport. Thus, about eighty percent of the gun beam was bunched and could be accelerated.

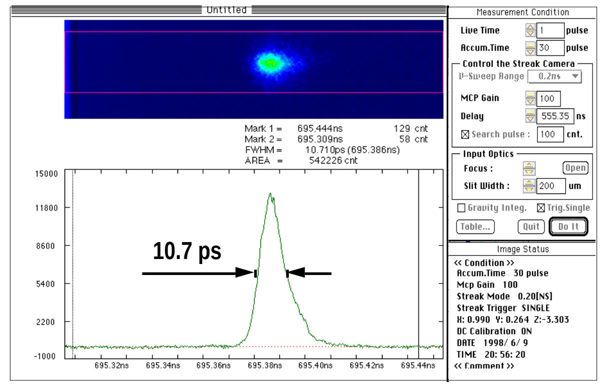

Fig. 2 Bunch width at a charge of about 10 nC.

2.2 Beam transport with a 180-degree arc

The linac arc is an achromatic and isochronous beam transport comprising 6 dipoles, 7 quadrupoles, and 6 sextupoles. The energy acceptance is 3% at full width.

The bpms were very important for tuning the beam-transport system. In the new linac, bpms were installed in front of each quadrupole. In order to solve the manpower problem to develop a data- acquisition system, 17 digital sampling oscilloscopes (5 GHz, 2 ch, and commercially available) were distributed every half (typically 40 m) of the linac sector. The signals from bpms are combined by combiners so that the signals from different bpms do not overlap each other, and are introduced to oscilloscopes controlled by a VME computer. The peak-heights are measured using the oscilloscope functions and analyzed by the VME. The position signals for one beam pulse are measured by a beam-trigger signal distributed to the monitor station. The position information from all bpms is presently renewed every 1.4 seconds.

The arc was tuned using a low-current beam of 2 nC/bunch, of which the energy width was 0.2%. The dispersion pattern in the arc and the dispersion error after the arc were measured by bpms while changing the beam energy. The isochronicity was measured by a streak-camera at the exit of the arc. In both measurements, the energy dependencies were measured up to the second order, and the errors were corrected using sextupoles.

2.3 Acceleration of an 8-GeV electron beam

The first acceleration of a 2-nC electron bunch to 8 GeV was achieved on April 27th, 1998, by employing 54 accelerator modules. The average gain of the module was more than 150 MeV. Due to three accelerator modules, which have not yet been installed, and several modules which have not been sufficiently conditioned or phased, a sufficient energy margin was not obtained.

2.4 Tuning of a high-current primary beam

The most difficult issue was to accelerate a high-current electron beam. The beam aspect changed when the charge exceeded 5 nC/bunch. We could accelerate more than 10 nC/bunch before the linac arc; however, so far, a maximum of 7.5 nC/bunch has been obtained to the positron radiator. The emittance was measured by the waist-scan method with a quadrupole and a beam screen. The typical normalized emittances were ~0.1 mm after the pre-injector (70 MeV), ~0.3 mm at the 500-MeV point, and 0.6~1 mm before the arc. Such emittance growth depended on the charge and the beam orbit. At high-current, the beam has two cores, which have different transverse/longitudinal positions, and energies. These two cores have already been observed after the buncher section. The growth of the transverse position difference of the cores has been observed in the vertical direction, and is dependent on the orbit. The energy difference has been observed in the arc. In order to suppress the emittance growth, bumps of about 2 mm are tested (Fig.3).

2.5 Tuning of the positron beam

As of June 17, a maximum positron current of 0.75 nC/bunch was transported to the end of the linac with a primary electron beam of about 3 GeV and 6 nC/bunch. This electron-to-positron conversion ratio slightly exceeded what we had expected for the design value (10-nC e^- to 0.64-nC e^+ at the linac end); at present, neither the primary nor positron beams are sufficiently stable, and the reproducibility is not very good. The one-sigma normalized positron emittances were 5.7 mm in the horizontal direction, and 3 mm in the vertical. The positron energy was more than 4 GeV, and the energy width 0.5% at full width.

4 SUMMARY

(1) A linac electron energy of 8-GeV was achieved. In order to obtain a sufficient margin, two modules will be added this summer and incomplete rf conditioning and phasing will be improved.

(2) A positron intensity near to the design value has been achieved. However, the stability and reproducibility issues should be further investigated.

(3) Studies will still be conducted regarding the high-current primary electron beam.

REFERENCES

1) I. Sato, et al. edited, "Design Report of PF Injector Linac Upgrade for KEKB" (in Japanese), KEK Report 95-18.

2) A. Enomoto, "Upgrade to the 8-GeV Electron Linac for KEKB" , Proc. of LINAC96, Geneva, Switzerland, 26-30 August, 1996, pp.633-637.

3) T. Suwada, N. Kamikubota, K.Furukawa: "NEW DATA ACQUISITION SYSTEM OF A BEAM-POSITION MONITOR AND A WALL-CURRENT MONITOR FOR THE KEKB INJECTOR LINAC", Proc. of APAC98, Tsukuba, Japan, 23-27 March, 1998, to be published.

4) Y. Ogawa, et al.: "NEW STREAK-CAMERA SYSTEM FOR THE KEKB LINAC", Proc. of APAC98, Tsukuba, Japan, 23-27 March, 1998, to be published.

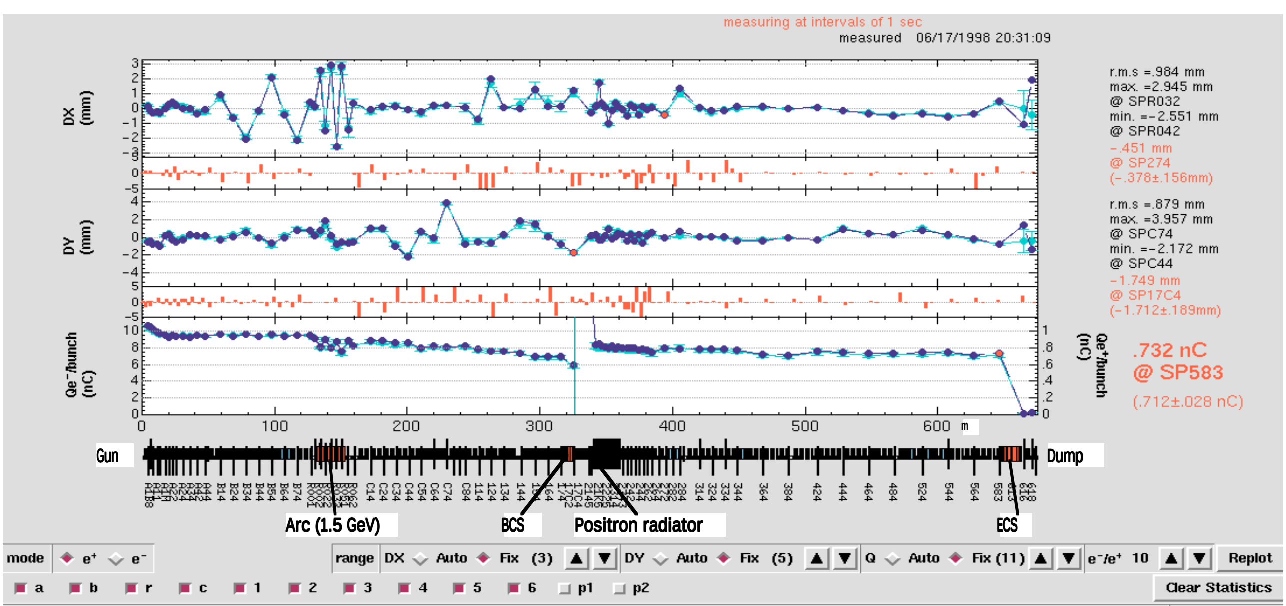

Fig. 3 Beam-position monitor display. The vertical axes indicate the horizontal displacement (mm) vertical displacement (mm) and charge/bunch (nC) from top to bottom. The horizontal axis indicates distance along the linac.