PERFORMANCE OF THE KEK 8-GeV ELECTRON LINAC

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Abstract

The KEK 8-GeV electron linac has been operated for the KEK B-Factory accelerator (KEKB) since December, 1998. After being upgraded from 2.5 GeV, it presently provides 8-GeV electrons and 3.5-GeV positrons for the KEKB colliders. It also injects 2.5-GeV electron beams for the synchrotron radiation (SR) experiments. To deliver different kinds of beams, many parameters are automatically switched; at the same time, many software programs are used to correctly reproduce these beams. This paper describes the current performance of the upgraded linac.

1 INTRODUCTION

The KEKB accelerator includes an 8-GeV electron ring (HER) and a 3.5-GeV positron ring (LER); its goal is a luminosity of 1 x 10^{34} $cm^{-2}s^{-1}$ with collisions between 1.1-A electrons (e^-) and 2.6-A positrons (e^+).

Two major goals are required of the linac: the first is to deliver full-energy beams for both rings; the second is to provide positrons of more than 0.64 nC/bunch at 50 Hz, which, assuming no beam loss, corresponds to an accumulation rate of 3.2 mA/s and an injection time of 13.5 minutes to accumulate from 0 to 2.6 A.

As shown in Figure 1, the linac contains two electron sources at Sectors A and C, a positron source at Sector 2, and 57 s-band accelerator modules with an average energy gain of 160 MeV each. During routine operation, it delivers different beams: 8-GeV e^- for the HER, 3.5-GeV e^+ for the LER, and 2.5-GeV e^- for the SR research.

Electron beams from the A-Gun are bunched by double sub-harmonic bunchers (SHBs) at 114.24 MHz and 571.2 MHz, as well as bunchers at 2856 MHz, in order to form a single-bunch beam with a 10-ps FWHM.

An electron bunch with 1 nC is accelerated to 8 GeV by the entire linac. When a positron beam is accelerated, a positron radiator is inserted at an energy point of 3.7 GeV; then, by increasing the gun-grid voltage, an intense electron of 10 nC hits the radiator and emerging positrons are accelerated through the remainder of the linac.

The reason to use the C-Gun is historical. This gun has been used since the old 2.5-GeV linac started, and also during the linac upgrade. It was, however, reset out of the beamline. When it is used, the gun beam is merged to the beamline by a 90-degree bending magnet. A multi-bunch short pulse beam with a 1 ns FW is formed by bunchers at 2856 MHz, and accelerated to 2.5 GeV in order to inject into the storage rings.

2 OPERATION HISTORY

The linac upgrade had been progressing since 1994, and was completed by March, 1998. On April 27th, 1998, the first acceleration of a 2-nC electron bunch to 8 GeV was achieved by employing 54 accelerator modules [1][2]; however, the necessary energy margin was later obtained by installing three more accelerator modules.

Though beam studies have continued since October, 1997, a positron goal of 0.64 nC at the end of the linac was achieved in April, 1999. Table 1 shows the best beam performance of the linac obtained so far.

In December, 1998, routine injection for the KEKB rings was initiated. At the beginning of the KEKB ring commissioning, the linac continued injection to the HER/LER and the PF storage ring. In June, injection to the AR storage ring was started.

During 7300 hours of the linac operation in FY 1999, to reproduce these beams correctly and as quickly as possible and to maintain the positron intensity for a long period became a major effort.

The different beam modes have been successfully switched using a software panel within about two minutes. Regarding the average intensity of positrons, two remarkable steps were made after the 1999-summer and the 2000-winter shutdown periods, as shown in

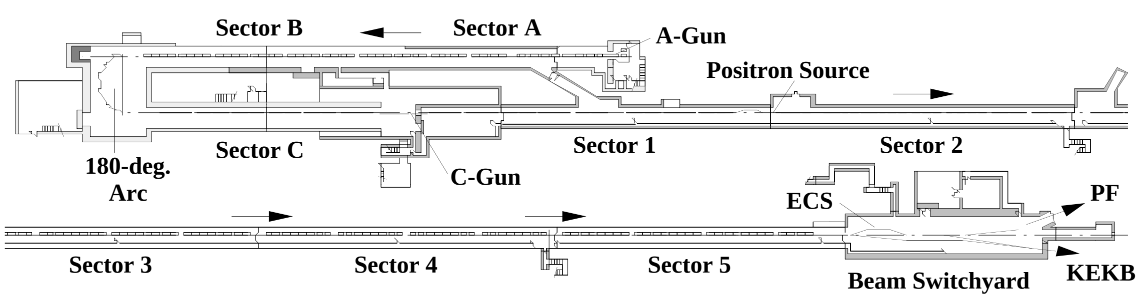

Figure 1: The KEKB 8-GeV electron/positron linac.

Table 1: Design Beam Goal and Achieved Performance

			8-GeV electron		3.5-GeV positron	
			Goal	Achieved	Goal	Achieved
(1) Gun	Energy	keV	200	200	200	200
	Intensity	nC/pulse	1.5	2	13	14
	Pulse width	ns	2	1.8	2	2.8
(2) Buncher	Energy	MeV	16	16	15	15
	Energy spread (σ)	MeV			2	2
	Intensity	nC/pulse	1.4	1.9	>10	11
	Efficiency			95%		90%
	Emittance γβε (σ)	mm	0.06	0.04	0.06	0.08
	Bunch width	ps	5	6	16	10
(3) Arc	Energy	GeV	1.5	1.7	1.5	1.7
	Energy spread (σ)	MeV	0.6%	0.29%	0.6%	0.38%
	Jitters (p-p)					0.1%
	Drift (with feedback)				<0.2%/h	
	Emittance γβε (σ)	mm		0.17		1.7
	Transmission			100%	>95%	100%
(4) e+ target	Energy	GeV			3.7	3.7
	Intensity	nC/pulse			>10	10
	Transmission					96%
(5) e+ Solenoid exit	Intensity	nC/pulse				2.4
	Specific yield	e^+/e^-GeV				6.8%
(6) Linac end	Energy	GeV	8	>8	3.5	>3.5
	Energy spread (σ)	MeV	0.15%	0.05%	0.125%	0.15%
	Intensity	nC/pulse	1.28	>1.28	>0.64	0.82
	Specific yield	e^+/e^-GeV				2.3%
	Transmission			>80%		
	Emittance γβε (σ)	mm	0.25	0.31	1.5	1.4
	Pulse repetition	pps	50	50	50	50

Figure 2. It increased from 0.32 nC to 0.45 nC, and then again to 0.62 nC. The best injection rate of 1.7 mA/s was recorded in January, 2000.

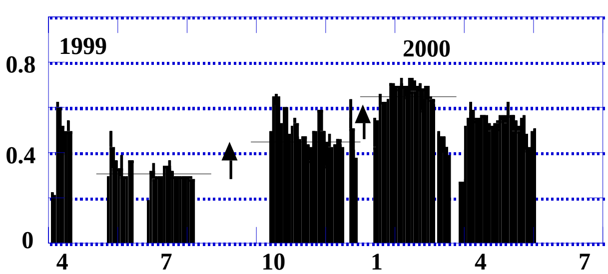

Figure 2: Positron intensity (nC/bunch) vs. Month.

To increase the positron intensity further is still necessary for decreasing the injection time. Instead of a single-bunch beam, a preliminary study for a two-bunch scheme was recently attempted.

Table 2: Injection Beam (June 2000)

Ring	HER	LER	PF	AR
Particle	electron	positron	electron	electron
Energy	8 GeV	3.5 GeV	2.5 GeV	2.5 GeV
Pulse	1 nC	0.6 nC	0.2 nC	0.2 nC
Width	single bunch		1 ns	
Store	500 mA	700 mA	400 mA	40 mA
Refill from	~350 mA		~250 mA	0 mA
Time	1 min	10min	3 min	2 min
Interval	1-2 h		24 h	2-4 h

Table 3: Switching parameters and devices

Ring	HER	LER	PF	AR
Gun	A	A	C	C
gun data	#1	#2	#3	#3
e+ target	off	on	off	off
pulse solenoid	off	on	off	off
chicane	off	on	off	off
rf timing	#1	#2	#3	#3
rf phase	#1	#2	#3	#4
magnet data	#1	#2	#3	#4
monitor range	#1	#2	#3	#3

3 BEAM SWITCH AND INJECTION

The linac must inject four kinds of beams (Table 2). To deliver these beams, some devices must be switched and the parameters must also be changed, as shown in Table 3. However, the number of changed items is suppressed as much as possible, in order to decrease the changing time and to reduce the error probability.

The data of the A-gun have been changed in order to emit a 1 nC pulse or a 10 nC pulse. In addition to current control, a grid timing adjustment is essential because the pulse width increases with charge.

When a positron beam is accelerated, a water-cooled tungsten target of 14 mm thick, as a positron radiator, is inserted into the beamline by a pneumatic actuator, and a chicane (positron-electron separator) is also used. When an electron beam is accelerated, these devices are turned off and a 2-T pulsed solenoid just after the positron radiator is also switched off.

When some accelerator modules are not necessary to be used, the rf timing is delayed by 100 μs. The rf phase values of sub-booster klystrons, each of which drives 8 high-power klystrons, are changed when the positron beam is accelerated. To adjust the beam energies precisely, both at the 180-degree arc and the linac-end beam switchyard, the rf phase values of two pairs of high-power klystrons are changed.

The parameters of the transport magnets are changed according a simple standardize sequence. The up/down speeds of the magnet currents are controlled so as to avoid any problems due to abrupt switching that would damage the power supplies.

Regarding a parameter change, the feedback software for each beam detects the beam mode and runs automatically.

4 STABILITY OF THE LINAC

4.1 Tolerance of the linac parameters

Among four kinds of linac beams, it is most difficult to maintain a high-current primary electron beam to produce positrons [3]. Though many factors were considered possibly to be responsible for degradation in the positron intensity, when the positron beam intensity decreased, we found that the primary electron orbit had usually changed just below the buncher section, and that the primary electron intensity had particularly decreased downstream of the 180-degree arc.

Some studies were carried out to understand the beam physics concerning high-current single-bunch acceleration and to suppress beam blowup, both theoretically and experimentally [4][5]. The conclusion was that it is possible to transport a high-current beam if the intensity is 10 nC per bunch and the initial beam orbit and accelerator alignment distortion could be controlled to 0.1 mm. To control the beam orbit, the tolerances were measured by changing the parameters around the beam condition that gave a nearly maximum current (9.4 nC/bunch at the positron target). Table 4 gives the results needed to keep the current at more than 90% of the maximum.

Table 4: Tolerance for High-Current Beam

Beam timing	±45 ps
Gun high voltage	± 0.38%
SHB1 phase	±1.1 deg
SHB2 phase	±1.3 deg
Buncher phase	±1.7 deg

These parameters, except for the gun high voltage, is not so easy to maintain for a long time, and had not actually been stabilized before the monitors and the feedback system were installed [6].

4-2 Hardware improvements

The first initiative was to improve the monitors for the rf and beam timing. A 114-MHz, 10-kW main amplifier and a 2856-MHz 1-kW drive amplifier were replaced. The cooling performance of the SHB2 was improved. These were undertaken during the summer shutdown of 1999.

During the new-year shutdown, the gun-beam timing became monitored and stabilized. A gun modulator and a high-power klystron modulator for the fundamental bunchers were finely tuned and stabilized.

According to the rf and timing monitors and a beam study of the linac parameter tolerances, it seems that the linac beam instability was due to multiple factors regarding the pre-injector.

4-3 Feedback system

At fast, using a host computer, we had developed feedback software to stabilize the linac beam and equipment: 1) the beam energy at the linac arc and at the end of the linac; 2) the beam orbit along the linac; 3) the gun high-voltage; 4) the 114-MHz SHB power; and 5) the 571-MHz SHB power.

Subsequently we have added feedback loops to: 6) the gun grid pulse timing; 7) the 114-MHz SHB rf phase; 8) the 571-MHz SHB rf phase.

Although some of these feedback tasks should be run on local hardware or computers, this has not been done so far. One reason for not using hardware is noise problems in the klystron gallery. A fast host computer (CPUs: Alpha 21264, 500 MHz x 2) was added for this purpose before the summer shutdown.

6. SUMMARY

(1) The KEKB injector linac had been commissioned and went into routine operation in December, 1998. Two major goals of the energy (8 GeV) and the positron intensity (0.64 nC/bunch) were achieved.

(2) During 1999, the average intensity of the positron beam was remarkably increased, and the reproducibility of the different kinds of beam switchings has also been improved by the linac stabilizing project.

(3) To further increase the positron intensity, a preliminary study of two-bunch acceleration has just been initiated.

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