Linac Upgrade Plan for the KEK B-Factory

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Abstract

In the KEK B-Factory plan, e^+/e^- collider rings with 3.5-GeV positrons and 8-GeV electrons are being considered, and full-energy injection from the existing linac is required. The acceleration energy of the linac must be upgraded from 2.5 to 8 GeV. The most effective way has been searched from several points of view, such as the beam quality, ease of beam handling, and construction. This article describes the basic plan of the energy upgrade and recent progress regarding this project.

I. INTRODUCTION

The KEK 2.5-GeV linac [1] was completed in early 1982 in order to inject electron beams for the Photon Factory (PF) storage ring. Three years later (1985), a 250-MeV positron generator [2] was constructed for TRISTAN, and then combined at the 250-MeV point of the linac (Fig.1). In 1986, routine-injection into TRISTAN was started with 2.5-GeV, 2-ns, 25-pps electron /positron (e^-/e^+) beams. In 1988, the storage beam in the PF ring was changed from electrons to positrons in order to realize more stable operation. Table 1 summarizes the major specifications.

A linac upgrade plan has been considered for the last two years concerning the KEK B-factory project. The ideas have been classified into two parts. One involves combining a moderate linac upgrade (roughly 4 GeV), which is essential for a positron increase, as well as a change in the TRISTAN accumulation ring (AR) to a rapid-cycle synchrotron. The other involves an 8-GeV upgrade of the linac for full-energy injection into the collider ring. Though the latter plan is harder regarding the linac, it came to be considered desirable from the viewpoint of efficient utilization of the existing facility; e.g., high-energy synchrotron-radiation experiments will still be conducted in the AR.

II. BEAM REQUIREMENTS FOR THE LINAC

The KEK B-factory will be normally operated at 8 GeV (e^-) x 3.5 GeV (e^+); however, a maximum energy slightly higher than 8 GeV will be required for experiments involving higher states. Although the linac will deliver single-bunch beams at a repetition rate of 50 pps, the possibility of multi-bunch injection still remains. When the linac beam has 2 x 10^9 particles per bunch, injection can be completed within 30 minutes for a storage beam of 2.6 A from vacancy (the ring circumstance is 3 km). The beam requirements for the linac are summarized in Table 2.

Table 1
General parameters of the KEK 2.5-GeV injector linac

Main linac beam		
Energy (50 mA loaded)		
(Total rf power : 840 MW)	2.5 GeV	
Beam pulse length	1.5 ns ~ 2.0 µs	
Repetition rate (max)	25(50) pps	
Accelerator (main linac)		
Type of structure	TW. 5 type Semi-C.G.	
Frequency	2856 MHz	
Length of section	2 m (with couplers)	
Total number of sections	160	
Length of acceleration unit	9.6 m	
Number of acceleration units	40	
Number of sectors	5	
RF source		
Peak power of klystron	30 MW	
Number of klystrons	40+1 (main linac)*	
	6+1 (e^+ generator)*	
RF pulse length	3.5 µs	
Pre-injector		
Type of gun	Triode	
Gun voltage	200 kV (max.)	
Output energy	50 MeV (max.)	
Positron generator		
Primary electron, energy	250 MeV	
Charge (per pulse)	20 nC,	80 nC
Pulse width	2 ns,	40 ns
Positron linac, energy	250 MeV	
Charge at e^+ gen. end	160 pC,	960 pC
(at 2.5-GeV end	70 pC,	250 pC)

* 1 for pre-injectors

Of these requirements, both an energy upgrade and a positron intensity increase are the most important. After the energy upgrade is achieved, the positron production target will be moved from the present (250-MeV) position to the ~4-GeV point. Primary electrons, which have a higher beam-power by more than an order of magnitude will hit the target and produce sufficient positrons, taking account of the fact that the present linac produces more than 4 x 10^8 positrons per pulse (5-bunch, 2-ns pulse). However, we need to make

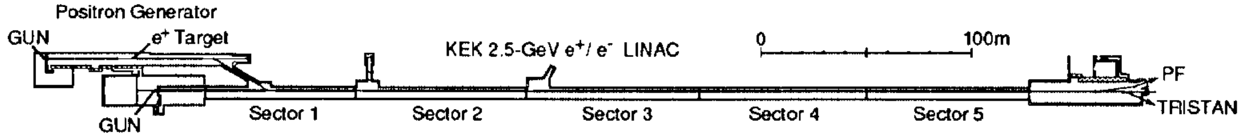

Figure 1. The KEK 2.5-GeV injector linac.

Table 2
Beam requirements for the B-Factory injector, along with parameters of the present linac.

	Present			8-GeV Upgrade	
	e^+(PF)	e^+(TR)	e^-(TR)	e^+(BF)	e^-(BF)
Energy (GeV)	2.5	2.5	2.5	3.5	8
Pulse width (ns)	40	2	2	Single bunch	
Particles/pulse	1.6×10^9	4.4×10^8	$>2.5\times10^9$		$\sim4\times10^9$
(Charge (pC))	(250)	(70)	(>400)		(~640)
Repetition (pps)	25	25	25		50
$\delta E/E$ (σ) (%)	0.35	0.22	0.20		0.25
ε (m.rad)	1.0×10^{-6}		0.3×10^{-6}		

intense single-bunch beams, each of which will contain nearly 10^{11} electrons; we must be very careful regarding beam breakup (BBU) in accelerating such intense beams used to produce positrons. The phase-space specifications seem to be reasonable compared with the measured values for the present 2.5-GeV beams [3], [4].

III. ENERGY UPGRADE OF THE LINAC

Several ideas concerning the linac energy upgrade have been discussed, such as a beam-recirculating system, an accelerator structure with a resonant ring, and an rf pulse compression system. The important criteria for choosing one of these are as follows: stability under high-gradient operation of the existing accelerator; accelerated beam quality and beam handling; construction cost and schedule. In high-gradient tests, though they have been limited to the six existing accelerator sections, after rf processing they could be operated at average fields of 17 to 25 MeV/m without any serious trouble. The time-schedule is also an important subject, since the linac must continue injection for the PF storage ring.

From the viewpoints mentioned above, the best way to carry out the linac energy upgrade is to make the rf peak power fed into the accelerator sections as high as possible. However, if we want to realize an energy upgrade by only increasing the rf power, it must be nearly one order of magnitude. We conclude that a cost-effective way is to combine increasing the rf power with a short extension of the entire linac length.

Because of the building capacity and construction costs, the pulse energy of the pulse modulators will be increased by at most a factor of two; this will be achieved by increasing the PFN total capacitance while maintaining the same charging voltage. This is a reasonable way to use commercially available 50- to 60-MW klystrons with an rf pulse-multiplication system, such as a SLED (SLAC energy doubler) [5], [6]. Table 3 shows the modulator upgrade required for two examples of the pulse modes.

Table 4 gives examples of the energy gain by upgraded klystrons and the SLED system, when they are applied to the existing acceleration units, each of which comprises four 2m-sections. The average field gradient of the accelerator will reach 24 MeV/m due to the SLED system. The last column of Table 4 shows the net number of acceleration units to obtain a total energy of 8 GeV. This number does not include any margins necessary for practical operation, such as standby units for klystron faults and off-crest operation units for energy adjustments. The margins should be at least several units; we are proposing a plan using 60 acceleration units. Fourteen units are the increments from the existing 46 acceleration units (see Table 1); these units can be installed by a small extension of the linac upstream building. We have started with the 4-μs mode , since we can use lower peak-power klystrons and the advantage of the 3-μs mode in the energy gain is not so large.

Table 3
An example of the pulse modulator upgrade. The pulse energy is increased by a factor of two.

	Present	SLED	
		4-μs mode	3-μs mode
Modulator			
Pulse: energy (J)	299	588	588
Width, FWHM. (μs)	3.5	5.5	4.5
Peak power (MW)	84	107	131
Peak voltage (kV)	22.5	22.5	22.5
PFN: number of caps.	20	40	40
Total capacitance (μF)	0.294	.588	.588
Charging voltage (kV)	45	45	45
Impedance (W)	6	4.7	3.9
Pulse transformer			
Step-up ratio	12	13.5	14.6
Voltage x width	0.95	1.7	1.5
Klystron			
Beam voltage (kV)	270	304	329
Beam current (kA)	295	352	397
Output power (MW)	36	46	56
Output average (MW)	26	41	51
Pulse flat-top (μs)	2.0	4.0	3.0

Table 4
Energy gain by upgraded klystrons with the SLED system, applied to the existing acceleration units.

	Present	SLED	
		4-μs mode	3-μs mode
Input RF pulse			
Flat-top (μs)	2.0	4.0	3.0
Ave. peak power (MW)	21	41	51
Power multiplication	1	4	3.5
Energy gain (MeV/m)	8.3	23	24
Total energy (GeV)	2.5	8	8
Net number of acc. units*	40	51	49

IV. PROGRESS

A. High-Gradient Acceleration

In order to realize the linac energy upgrade, the accelerator gain should be extensively increased. It should thus be first checked whether the accelerator works stably at this level of the accelerator field.

A high-gradient acceleration test was carried out at an acceleration unit of the linac by feeding the rf power from one 30-MW klystron into one 2-m accelerator guide; the power became four-times as much as that under normal operation. After rf-processing for several weeks, full power could be fed without any severe electric breakdown. The measured energy gain was roughly 20 MeV/m.

After the test described above, the 2-m section was moved to a new section with a traveling-wave resonant ring. Using the resonant ring the rf peak-power built up in the accelerator section was further increased by nearly a factor of two. This section was also stably operated after some rf processing; the measured gain was ~25 MeV/m.

B. RF System

A test upgrading of the klystrons from 30-MW to 60-MW class was carried out using a SLAC 5045 klystron during 1990-1991 at a test bench. An output power of 58 MW with a pulse width of 1μs was achieved at an applied beam voltage of 345 kV; the rf conversion efficiency was 44%.

The other task is to try to upgrade the presently used 30-MW klystron (MELCO-PV3030) by carrying out small modifications, which may provide the possibility of an efficient upgrade regarding cost. The first test was carried out by just increasing the beam voltage from 270 kV to 300 kV while limiting the pulse width and repetition rate from 3 μs, 50 pps to 1 μs, 10 pps, respectively. After adjusting the beam-focusing magnets, a maximum output of 47 MW was obtained. Recently, 51 MW was obtained at 3 μs, 50 pps by a new tube, the gun-insulator of which was improved [7].

In November, 1992, a SLED system was installed in the linac. This SLED is based on a system which was newly designed and tested by the Japan Linear Collider (JLC) group [8]; the design was slightly modified for our linac by changing the cavity coupling coefficient and adding RF monitors. Installing this system in an existing acceleration unit, an average energy gain of 19.4 MeV/m was measured at a klystron output of ~32 MW, 3.7 μs. By comparing energy gain between the tuned and detuned conditions of the SLED cavity, the energy-gain multiplication was measured to be 1.9. This result agreed with a prediction in our design work.

C. Others

Various works have been carried out regarding the B-Factory project, such as beam breakup of high-current beams [9], improvement of the 250-MeV positron generator [10] and the high-current pre-injector [11]. The development of beam monitors has been started recently; those are a wire-line type beam position monitor, a wire-scanner and a optical transition-radiation bunch monitor [12]. Investigations for the beam control and the triggering system for the B-Factory injector linac have also been started.

V. FUTURE

The feasibility study of high-gradient acceleration by the existing accelerator will further proceed with more units. In eight of forty units, the modulators and the klystron will be upgraded; in four of these, the SLED system will be installed by the end of March 1994. More studies regarding the B-Factory project, such as a single-bunch beam acceleration, will also be started this year.

VI. REFERENCES

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