UPGRADE TO THE 8-GEV ELECTRON LINAC FOR KEKB

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Abstract

The KEK/PF 2.5-GeV linac is under reconstruction for KEKB (the B-Factory at KEK). The linac will be renewed in the autumn of 1998 as an 8-GeV electron linac, which can provide full-energy beams into the 8-GeV electron ring and 3.5-GeV positron ring of KEKB, while continuing the injection of 2.5-GeV beams for the synchrotron-radiation (SR) facilities. The main goal of the injector linac is to achieve an energy upgrade from 2.5 GeV to 8 GeV, as well as to increase the positron intensity. This report covers recent construction progress and the remarkable activities regarding the energy upgrade and positron beam improvements.

Introduction

KEKB includes an 8-GeV electron ring (HER: high-energy ring) and a 3.5-GeV positron ring (LER: low-energy ring), which is under construction in the same tunnel for TRISTAN (Fig.1). KEKB aims at a luminosity of 1x1034 cm-2s-1 by establishing a crossing angle (±11 mrad) collision between 1.1-A electrons and 2.6-A positrons. In order to save injection time, KEKB requires full-energy injection from the linac for both electrons and positrons; furthermore, a positron beam intensity ten times as much as the present linac produces is required.

The present 2.5-GeV linac [1] was commissioned in early 1982 as an electron injector for the Photon Factory (PF) storage ring; a positron generator linac [2] was added during 1982-1985 for the TRISTAN project. Electron/positron beam injection was started in the autumn of 1986 to the TRISTAN accumulation ring (AR); the storage beam in the PF ring was changed from electrons to positrons in 1988 autumn, resulting in a stable long-life storage for SR experiments.

For KEKB, the linac will be reconstructed and expanded as shown in Fig.2. The linac will be renewed so as to deliver 8-GeV electron / 3.5-GeV positron single-bunch beams as well as 2.5-GeV multi-bunch beams for the SR rings. The energy upgrade is to be achieved by using 57 accelerator units with an acceleration gain of 160 MeV each: the linac building is being extended at the upstream end of the present linac in order to increase the number of accelerator units from 40 to 57; for increasing the rf peak power, the klystron modulator powers will be increased twice, the 30-MW klystrons replaced

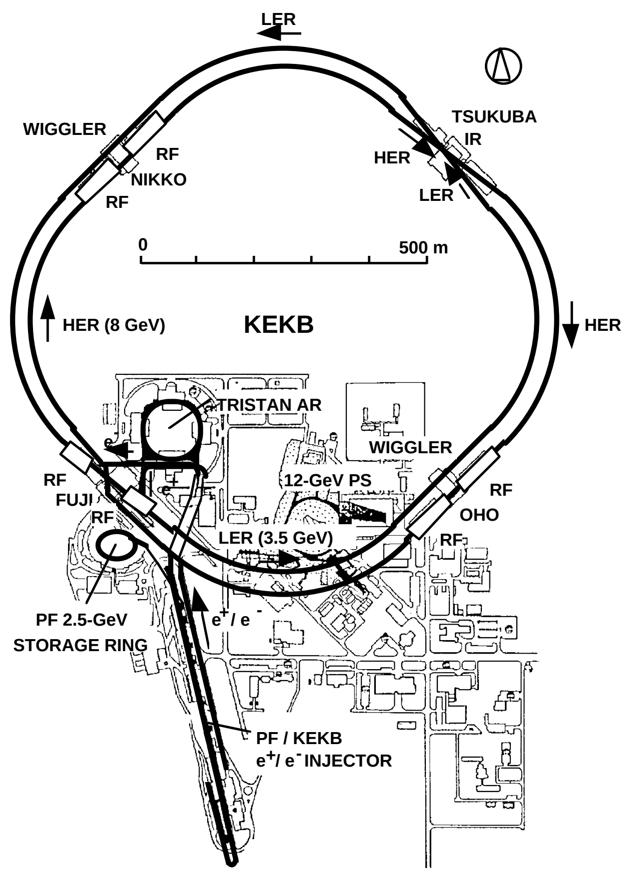

Fig.1 Schematic plan-view of KEKB.

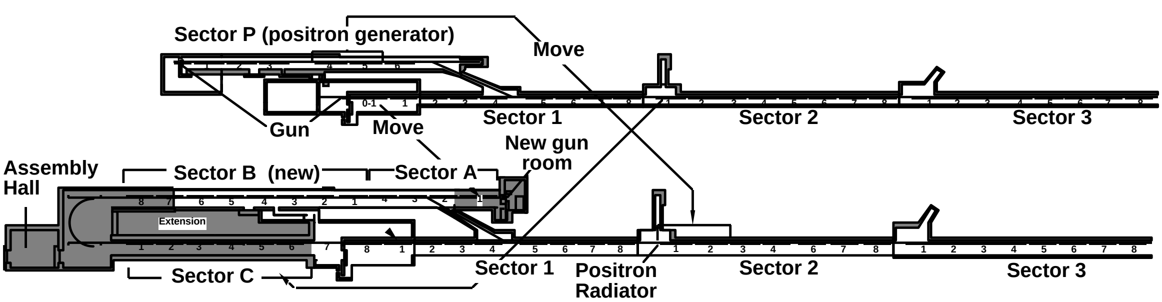

Fig. 2 Linac reconstruction from 2.5 GeV (upper) to 8 GeV (lower). The existing linac has 40 accelerator units which are divided into 5 sectors. The shadow areas are extension buildings to increase the number of accelerator units from 40 to 57.

by the 50-MW klystrons, and rf pulse compressors used. These parameter changes are summarized in Table 1. The basic design details have been reported elsewhere [3]. The following section considers recent construction progress and the research and developments regarding the KEKB injector linac.

Construction progress

The KEKB project was approved in FY 1994 as a five-year program; half of this time has already passed. All of the TRISTAN experiments were completed by the end of 1995, and the old TRISTAN accelerator and detectors were removed

Table 1 Change in the major parameters to the KEKB injector.

		PRESENT	KEKB
(1) INJECTION BEAM			
energy			
electron	(GeV)	2.5	8.0
positron	(GeV)	2.5	3.5
pulse length	(ns)	< 2	single bunch
bunch width (1σ)	(ps)	~ 5	~ 5
particle(charge)**/pulse**			
electron		2×10^{9}	8×10^{9}
	(nC)	(0.32)	(1.28)
positron		2×10^{8}	4×10^{9}
	(nC)	(0.032)	(0.64)
pulse repetition	(pps)	25	50
emittance (1σ)			
electron	(m)	4×10^{-8}	6.4×10^{-8}
positron	(m)	8×10^{-7}	8.8×10^{-7}
energy width (1σ)			
electron		0.2%	0.125%
positron		0.22%	0.125%
(2) MAIN LINAC			
frequency	(MHz)	2856	
filling time	(μs)	0.5	
accelerator structure		T.W., 2p/3-mode, semi-C.G.	
accelerator unit length	(m)	9.6	
accelerator unit number			
total		40	57
before positron radiator		3	26
standby, energy tuning		~ 3+1	4+2
energy gain per unit			
with SLED	(MeV)		160
without SLED	(MeV)	62.5	90
input rf power / unit	(MW)	20	40
energy multiplication			1.8
(3) PRE-INJECTOR			
Gun			
type (cathode)		triode (EIMAC Y796)	
normalized emittance	(m)	7×10^{-6}	
sub-harmonic buncher			
SHB-1 frequency	(MHz)	119.00	114.24
SHB-2 frequency	(MHz)		571.20
Prebuncher / Buncher			
frequency	(MHz)	2856	
phase velocity (Prebun.)		0.7 c	
phase velocity (Bun.)		0.7 ~ 1 c	
Output beam			
energy	(MeV)	40	60
energy spread (1σ)			1.2%
normalized emittance	(m)		~ 6×10^{-5}

		PRESENT	KEKB
(4) POSITRON PRODUCTION			
Radiator			
material		tantalum(Ta)	tungsten(W)
thickness	(mm)	8	14
diameter	(mm)	8	4
Primary electron			
energy	(GeV)	0.25	3.7
particle / pulse		1×10^{11}	6×10^{10}
(charge / pulse)	(nC)	(16)	(10)
positron production rate			
after the DC solenoid	(e^+/e^-GeV)	6.5%	>6.5%
final	(e^+/e^-GeV)	1.8%	>1.8%
Focusing system			
type		quarter-wave transformer	
normalized acceptance	(m)	6×10^{-3}	
(5) RF SOURCE			
Modulator			
pfn charging voltage	(kV)	45	45
total capacitance	(μF)	0.29	0.60
stored energy	(J)	295	610
impedance	(Ω)	6.0	4.7
output width (FWHM)	(μs)	3.5	5.6
voltage	(kV)	22.5	22.5
power	(MW)	80	108
Pulse transformer			
step-up ratio		1:12	1:13.6
core bias		no	use
Klystron			
beam voltage	(kV)	270	305
current	(A)	295	354
output power max.	(MW)	33	46.5
power ave	(MW)	~ 27	~ 41
width	(μs)	1.8	3.8
efficiency		44%	46%
(6) SYNCHRONIZATION BETWEEN LINAC AND RING			
synchronization			
$\tau 0$:	(ns)		96.2886
f0:	(MHz)		10.3854
Linac			
f_{Linac} (2856MHz)			5x5x11f0
SHB-1	(MHz)		11f0(114)
SHB-2	(MHz)		5x11f0(571)
KEKB			
f_{Ring}	(MHz)		7x7f0(509)
$f_{revolution}$	(kHz)		7x7f0/n(99)
harmonic number n			5120 (29x10)

from the tunnel. From late 1996, the first magnet for LER is to be installed.

As for the linac, before the KEKB project was formally approved, the linac group had discussed ways to upgrade the energy, and conducted feasibility studies using the existing linac [4,5]; consequently, the way mentioned above was adopted as a reasonable one, because the linac must continue injection for the SR experiments and the upgrade should be performed only during annual shutdowns.

Since the project began, the upgrading of the existing 2.5-GeV linac has gradually been performed. By the end of FY1995, 32 high-power klystron pulse-modulators of 40 existing units had been upgraded; of 5 the sub-boosters, each of which will drive 8 klystrons, 2 were replaced by new ones for the SLED system [6]; 12 SLED’s and 50-MW klystrons were installed (Fig.3), and the rf conditioning was finished in 10 units. These units were tested in order to prove the acceleration gain and stability of the beam energy [7]. During the rf conditioning, electric discharge, which causes a strong

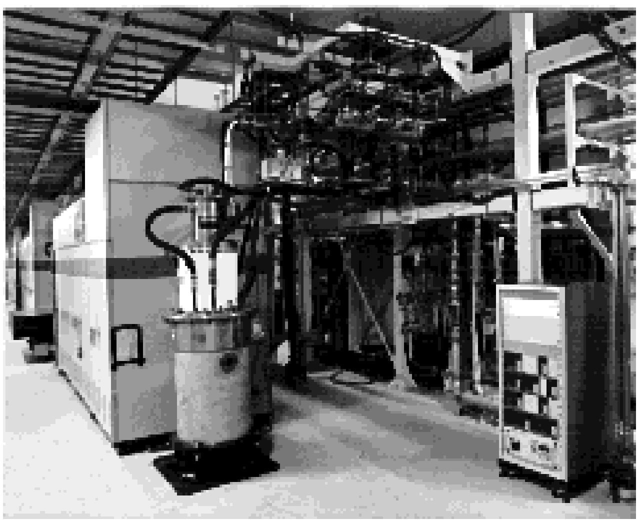

Fig.3 RF-source upgrade of the existing linac for KEKB: the modulator powers were doubled; the PFN cabinets became tall-boy in order to make a capacitance doubling; and the klystron outputs were upgraded from 30 MW to 50 MW while maintaining the height.

vacuum degradation, was frequently observed in one unit. The cause is now under investigation in connection with the rf rise time and phase-switching time. The upgrading of the existing linac will be almost completed by the end of FY1996.

In order to conduct a study regarding the production and acceleration of a high-current, single-bunch primary electron beam for positron production, two sub-harmonic bunchers (SHBs) were inserted between the gun and the prebuncher. The results obtained by a streak-camera system using optical-transition radiation indicated that this system can produce a bunch of about 12 ps FWHM at 10 nC [8].

The positron production target and the positron focusing system have already been moved to a higher energy point (Fig.4). The target was newly fabricated in order to be used at higher beam powers; also, the layout was changed so as to replace two 4-m accelerator structures by two 1-m ones and two 2-m ones. A positron-production study was recently begun; a preliminary result concerning the electron-to-positron conversion rate is as follows : 5.4% e^+/e^-GeV after

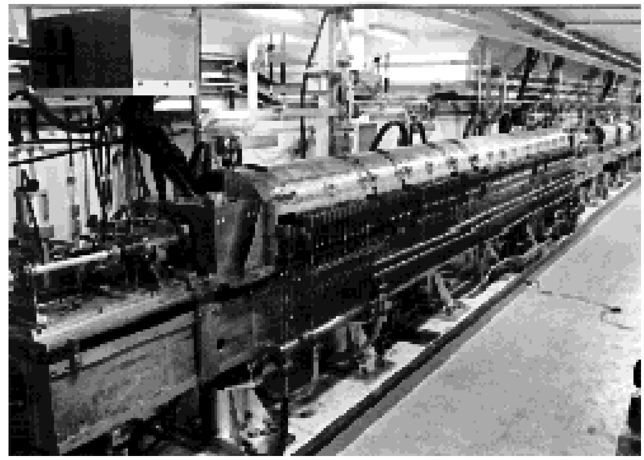

Fig.4 Positron generator replacement at a high-energy point of the upgraded linac. The accelerator structures behind the positron production target were improved in order to reduce the coupler field.

the DC solenoid with a 500 MeV and 3.2 nC single bunch.

The beam-transport system of the existing linac is being replaced so as to accommodate higher-energy beams, adding beam-position monitors accompanying the quadrupole magnets.

Expansion buildings are being added to two areas: one is the most upstream part; the other is the 180 degree-bend part (“arc”) of the new linac layout, which forms a J-shape (see Fig.2). These are under construction (Fig.5) and will be completed by October and December, 1996, respectively.

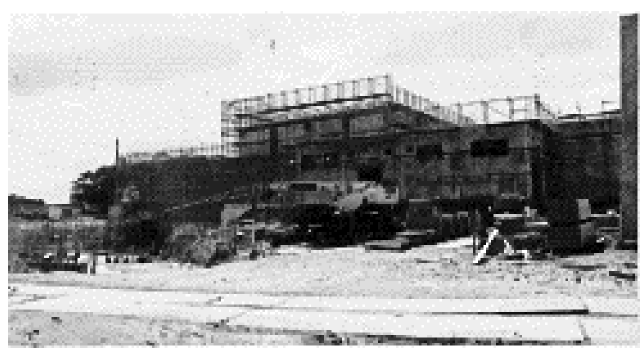

Fig.5 Extension buildings being constructed in order to increase the number of the accelerator units from 40 to 57.

Research and Developments

Compact high-power klystron

For KEKB, the 30-MW klystrons used for the PF 2.5-GeV linac will be replaced by the 50-MW klystrons, which should be operated at an average output of 41 MW, 4 μs, 50 pps. For this purpose, the 30-MW klystron has been improved at KEK. The design concept is to increase the output power while keeping its original size, so that such equipment as the focusing magnet and pulse-transformer tank can be utilized, and that the height of output port is not changed.

In 50-MW klystrons, which were successfully developed at KEK [9], the overall size of the klystron assembly was not changed. However, the cathode insulator and the dimensions around the anode were improved so as to decrease the field strength at this part; the cathode diameter increased from 80 to 85 mm in order to decrease the current density; the distance between the anode and the input cavity was increased; the focusing field distribution was optimized so as to improve the efficiency on the basis of computer simulations.
The applied voltage has been increased from 270 to 305 kV. At this voltage, it can output more than 50 MW pulses with an efficiency of more than 46%.

RF compression system

The 50-MW klystron with an rf compression system is to be used for the rf source of the KEKB injector linac. Three types of SLED systems were considered: the original SLED fabricated at SLAC [6], a modified SLED developed by the Japan Linear Collider group [10], and a resonant-ring type compression system (RRCS) developed by the injector linac group [11]. The former two use double TM_{015}-cylindrical cavities with a 3-dB power divider; on the contrary, the RRCS has a simple structure comprising a single resonant ring.

However, we decided to adopt the JLC-type SLED, which is improved in a low-gradient electric field around the cavity-waveguide coupling irises by using a two-hole coupling system. The RRCS was not adopted for two reasons: (1) the energy multiplication factor is 8% lower (this corresponds 4 or 5 accelerator units against the total 57 units); (2) the radiation is higher (40 μSv/h at a 40-MW input), while not being detectable in JLC-type at more than 50 MW. These defects are due to the choice of the TE_{20}-like mode in a rectangular waveguide for the transverse cross section of resonant ring.

The detail structure of the JLC-type SLED was further modified in order to facilitate fabrication and handling in the existing linac: the processing precision and the welding structure/method were optimized so that they are sufficient for obtaining a Q-value of about 100,000 (theoretical value 107,000); the tuner function was improved so as to facilitate smooth adjustments with the necessary resolution (2 kHz in resonant frequency); the drive mechanism of the detuner needle was replaced by a solenoid type; the position of the needle was magnetically sensed while producing an electrical signal; and easily observable indicators were attached.

Accelerator structure

For the linac expansion, the number of regular accelerator section was increased from 160 to 228. The deficits are being newly fabricated. These are 2π/3-mode traveling-wave disk-loaded structures operated at 2856 MHz. In order to distribute the HEM-mode frequency, the structures have five sets of different disk-hole apertures, which have been decreased by 75 μm per cell from the input to the output, making an approximately flat field against wave attenuation through the structure. The input/output couplers are those of the cavity type, whose field asymmetry due to the coupling-iris is corrected by a dip on the opposite side of this iris.

The fabrication method used for the PF injector linac is unique compared to those widely used in other accelerators. The disk-loaded structure is made by an "electroplating method": disks and spacers, which were processed to a final dimension and inspected by measuring resonance frequency, are made one body by electroplating to a thickness of 5 mm. The motivation for developing this method was rather to facilitate mass production by eliminating any tuning after machining and welding. In a modern view of accelerator physics, it should be noticed that this method is only a "cool method" carried out at room temperature, thus eliminating any unexpected or uncontrollable HOM resulting from dimpling of the spacer surface.

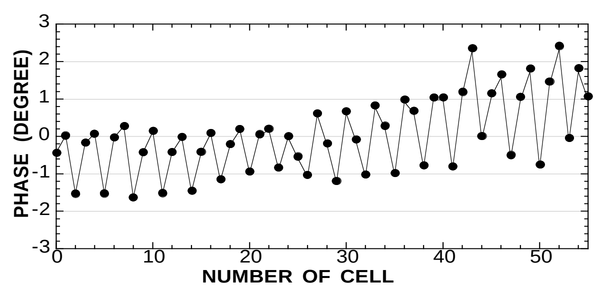

Fig. 6 Typical results of a nodal shift measurement: the standard deviation of phase error is about 0.9 degrees; the 2-m accelerator structures were fabricated by a "electroplating method" without any dimpling after machining.

These basic design and fabrication method are also followed in the new structures. However, in the old positron generator, where two 4-m structures were used in a solenoidal magnetic field, the acceleration field in the accelerator structure installed immediately after the positron production target was not sufficient due to frequent electric breaking in the structure. Most marks due to arcing were found around the input coupler and the first disk. From this experience, in KEKB 1-m long structure was decided to be used after the positron production target; the coupler structure is being renewed in order to decrease the field strength when a higher input power is used. The coupler dimensions (2b:inner diameter, W:iris aperture), were determined by a computer simulation [12]. These structures will be tested under higher input power this autumn.

Positron beam increase

One of the major target is to increase the positron intensity. The required intensity of 4 x 109 positrons (0.64 nC) per bunch was determined so that the injection time from vacancy to 2.6 A would be ten-several minutes. In the case of a uniform fill into the 5120 ring rf buckets, the stored charge per bucket is 5 nC; about eight injections per bucket are therefore needed. This linac positron intensity is obtainable when a primary electron beam of 6 x 1010 electrons (10 nC) per bunch can be accelerated to the target, and the positron production rate still be kept at 1.8% e+/e- GeV, as in the old generator [13].

We have already experienced some difficulty concerning high-current beam acceleration at 2-ns, 16-nC beam up to 250 MeV. The investigation is still continuing using a combination of relevant fields: the first is how to produce an intense single-bunch beam by the pre-injector [14]; the second concerns theoretical studies regarding the wake-field [15]; the third involves beam monitoring [16]; the forth, an accelerator alignment [17]; and the fifth, a beam transport. Although beam studies regarding the pre-injector has been progressing, as mentioned before, the other studies are either under investigation on paper or are being qualitatively discussed.

Because of restrictions coming from the linac-ring beam transport line, the standard deviation of energy spread must be less than 0.125%. For the primary electron beam, the 180-degree bending "arc" in the expansion building was carefully designed so as to be achromatic and isochronous to the second-order optics [18]. The final design comprises 6 bends with quadrupoles and sextupoles, and satisfies less bunch and emittance growth for an energy spread of up to 1.2% σ_E/E. Further, a bunch-compression system (BCS) will be introduced before the radiator in order to suppress any debunching effect in the positron focusing system. For the produced positron beam, an energy compression system (ECS) will be used at the end of the linac.

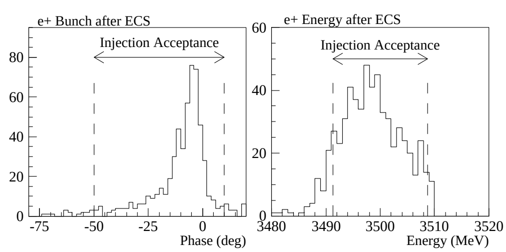

Fig. 7 Estimated bunch/energy width of the positrons after ECS.

For increasing the positron yield, the focusing system behind the positron production target will be improved. Recently, a feasibility study was initiated regarding the use of a super-conducting magnet. According to a preliminary study, a tapered shape solenoid field (6T) would improve the yield by more than two-times as much as the present system [19].

Summary and future

The construction of the KEKB injector linac is successfully progressing. Reconstruction for the energy upgrade in the existing linac will be finished by the end of FY1996. The expansion buildings will be completed by the end of 1996, and the construction of the expanded part will start at the beginning of 1997. The pre-injector, including sub-harmonic bunchers, will first be moved to the most upstream of the new building (before the construction is completed, injection for the PF ring will be made using a temporary pre-injection system). Then seventeen accelerator units will be installed sequentially. From the autumn of 1997, some of these units and "arc" will be tested by the local control system installed at the new sub-control station of the expansion building. Most of the construction will progress during FY1997, finished and connected to the existing linac by the summer 1998, and commissioned in the autumn of 1998.

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