RE-FORMATION OF THE PF 2.5-GeV LINAC TO 8 GeV

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Abstract

The B-Physics project at KEK (KEKB) started this fiscal year. The KEKB construction will be completed in 5 years. The 2.5-GeV electron/positron linac will be reformed as an 8-GeV injector for an 8-GeV electron x 3.5-GeV positron asymmetric collider. The main subjects of the injector linac are a substantial increase in the acceleration energy as well as an increase in the positron intensity while maintaining the injector operation for the Photon Factory experiments.

Introduction

The B-physics project at KEK started this fiscal year (1994), and has been named "KEKB". This project was approved as a five-year program. The KEKB 8-GeV electron (e^-) x 3.5-GeV positron (e^+) collider rings will be constructed in the same tunnel after the TRISTAN main ring is removed. The KEKB rings are to accumulate 1.1 A e^- and 2.6 A e^+ respectively. In order to save their injection times, both electrons and positrons must be injected at full energies (8 and 3.5 GeV respectively) from the linac into the rings (no booster synchrotron will be used); furthermore, a positron beam intensity of more than ten times as much as that which the present linac produces will be used.

The present 2.5-GeV linac was commissioned in early 1982 as an electron injector for the Photon Factory (PF) storage ring [1][2]; the positron generator linac was added during 1982-1985 for the TRISTAN [3]. 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 the electron to the positron type in 1988 autumn, resulting in a stable long-life storage for SOR experiments.

The PF linac has come to be reformed after its 13 years of operation. The linac energy will be upgraded from 2.5 to 8 GeV by increasing both the rf peak power and the total accelerator length. For the former purpose, the modulator powers will be increased by twice, and rf pulse compressors will be used; for the latter, a short extension will be built at the upstream side of the present linac.

This paper describes the basic design of the linac re-formation and the related R&D. After the strategy for the linac energy upgrade was discussed last year, the design work has been progressed, and the KEKB injector parameter, the new linac layout, and the linac re-formation schedule have recently been fixed. The R&D has been carried out in parallel with the design work. Regarding this paper, many reports, such as the upgrade of the rf source and the details concerning each components, are also being presented elsewhere [4]-[17].

Beam specifications of the KEKB injector linac

The parameters of the KEKB injector linac beam, rf, and accelerator unit are shown in Table 1.

TABLE 1
Parameters of the KEKB e^-/e^+ injector linac.

[Beam]			
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^-)	8×10^9	(1.28 nC)
	(e^+)	4×10^9	(0.64 nC)
	(e^- for e^+ production)	6×10^{10}	(10.0 nC)
Pulse repetition		50	pps
Emittance (2σ)	(e^-)	6.4×10^{-8}	m.rad
	(e^+)	8.8×10^{-7}	m.rad
Energy (half) width (σ_E/E)	(e^-)	0.125%	
	(e^+)	0.25%	
[RF]			
klystron output peak-power	(maximum)	46	MW
	(average)	41	MW
flat-top width		4.0	μs
[Accelerator unit]			
Total number		57	(+1 Pre-inj.)
Number before e^+ radiator		26	
Number for stand-by and energy-tuning		4+2	
Length of accelerator unit		9.6	m
Length of an accelerator section		2	m
Energy multiplication by rf compressor		1.8	
Energy gain per accelerator unit		160	MeV/unit
(except for the pre-injector and after e^+ radiator)			

1) Energy

The number of accelerator units, which comprises four 2-meter accelerator sections fed by divided rfs from one klystron, will be increased from 40 to 57. The average energy gain of one unit is set to be 160 MeV using an rf compressor. In the pre-injector and the first unit after the positron radiator, an rf pulse compressor will not be used, because electric breakdowns often occur in the focusing situation using a solenoidal field.

When all of the units are used in such a way that the electrons are accelerated on the crest of the accelerating field, the linac energy is to reach about 9 GeV. The extra energy over 8 GeV is to be about 13%; this, however, is needed to compensate for any gain loss due to defective units or energy-tuning units. For example, the corresponding extra energy is about 20% in SLC; the reason for the slightly higher value in SLC is that it employs a BNS damping scheme, in which the accelerating phase is shifted by about 20 degrees from the crest. A BNS damping is known to be effective for suppressing the tail instability due to a short-range wake excited by an intense bunch. In the KEKB linac, BNS damping will be effective for accelerating the primary electron beam to produce positrons, because the intensity of this beam is more than 10 nC, which is comparable to that of SLC; those of injection beams, however, are less by about one order.

2) Intensity and and Emittance

Electron beam It has been shown that an intense single-bunch electron/positron beam produces a strong wake-field when the bunch passes off-axis of the accelerator structure; the transverse component of the wake deflects the tail part of the same bunch, leading to an emittance growth, or a beam breakup (BBU), in the worse case.

In the KEKB injector, in order to hit the positron radiator, intense bunches (σ_z=1.5 mm, 10 nC each) are to be accelerated to 3.7 GeV under an acceleration condition of 20 MV/m and a betatron wavelength of 40 m. In this case, according to a report [7], energy broadening (σ_E/E) due to a longitudinal wake is 1.2% when the bunch is on crest, and 0.45% at 7 degrees off crest; the average energy loss is 4%. In order to suppress the transverse wake and to obtain a beam radius of less than 0.6 mm, the beam displacement from the accelerator axis must be less than 0.5 mm.

Based on the above points, exact accelerator alignment and beam positioning are very important for intense beam acceleration. A short bunch length is necessary so as to have a narrow energy spread, e.g. σ_z=1.65 mm for σ_E/E=0.25% (no beam-loading); however, an exceeding short bunch seems to be inappropriate because of wake.

Positron beam intensity The present production rate of positrons from electrons is 1.8% e^+/e^- GeV, which is a typical ratio of the number of accelerated positrons up to 2.5 GeV divided the number of primary electrons and their energy (0.25 GeV) [3]. From this value, it has been estimated that we can accelerate positron beams having 0.67 nC in each pulse using 3.7-GeV, 10-nC primary electron pulses. However, we have no experience in producing positrons at such a high energy of primary electrons. The main subject is considered how to keep intense positron beams stably without any problems or special treatments: e.g., electric breakdown of the accelerator section and waveguides inside solenoids after the radiator (this is a major problem concerning our present positron generator), vacuum trouble around a pulsed solenoid, reproduction of best-tuning the beam for each injection.

Emittance The observed emittance of the 2.5-GeV beam was 0.3 x 10^{-6} m.rad for a 2-ns electron beam and 1 x 10^{-6} m.rad for a 40-ns positron beam. Though the emittance of the 2.5-GeV electron beam is much larger than that estimated based on the measured normalized emittance of the pre-injector (70 x 10^{-6} m.rad), the emittance growth after the pre-injector has not yet been studied. The positron beam emittance is determined by the acceptance of the positron focusing system; the observed positron emittance is consistent with that obtained from this acceptance.

The observed half bunch length (σ_z) is less than 1.5 mm and the measured energy spread (σ_E/E) is less than 0.25%.

Re-formation of the linac

1) The new linac layout

The linac comprises a pre-injector and regular accelerator units. The pre-injector has double SHBs. Each of the acceleration units includes four 2-m accelerator sections fed by divided rfs from a klystron. The accelerator units are grouped as "sectors" for the convenience of computer control. The new linac is to comprise 8 sectors instead of the present 6 (the sectors are named A, B, C, 1, 2, 3, 4, 5 from the upstream, instead of the present P, 1, 2, 3, 4, 5).

Sector A has a pre-injector for producing intense single bunches, and three accelerator units. The new Sector 2 includes a positron generator, has seven units; each of the other sectors has eight regular units. In Sectors A, B and C the linac will newly be built in a housing which includes an extension and the old positron generator building. In Sector 2, the linac will be reconstructed to have a positron generator by moving Sector P to here. In Sectors 1, 3, 4 and 5, the linac layout will not be changed, or changed only slightly.

2) Klystron gallery

The pulse energy of the pulse modulators is to be increased by a factor of two; this will be achieved by increasing the PFN total capacitance while maintaining the same charging voltage [10]. All of the klystrons are to be replaced by 50-MW klystrons [11]. The rf pulse-compressors are to be installed after the klystron output by a slight modification of the waveguide system as well as a vacuum system improvements. The modulator position will be moved in the old Sector P and Sector 2.

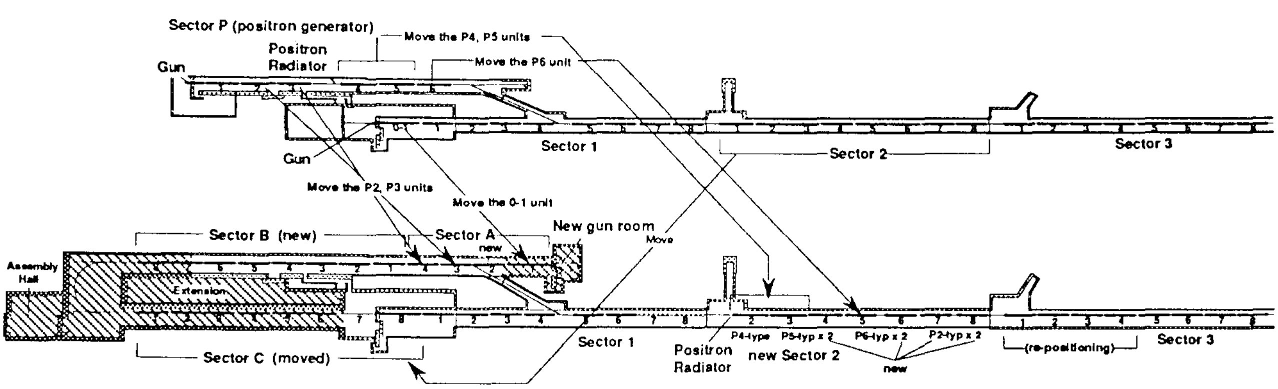

Fig.1 The linac re-formation from 2.5 GeV (upper) to 8 GeV (lower). The shadow area is an extension for expanding the linac length; accelerator units are to be increased from 40 to 57. The present positron generator is to be moved from Sector P to Sector 2; the primary electron energy is to be increased from 250 MeV to 3.7 GeV.

3) Accelerator tunnel

Sector A The pre-injector will be moved from the present 0-1 unit, which was recently re-designed and improved for high-intensity beam. An intense single-bunch acceleration study just started using a 476-MHz sub-harmonic buncher (SHB). Single-bunches with a charge of 6 nC, a length of 10 ps (FWHM), and a normalized emittance of 70 mm.mrad (1σ) has been obtained for the first result [4].

A distinctive issue of the SHB regarding KEKB is its operation frequency. Because the operable range of the ring frequency (508.58±0.3 MHz) is out of the sub harmonic of the linac frequency (2856 MHz), it is disadvantageous to have a common master frequency between the two. Thus, a feasibility study is underway, having a common frequency of 10.385...MHz, the 275th sub harmonic of the linac frequency, and 47th of the ring. The phase stability of the multipliers is the key for realizing the requirement for injection time jitters (±30 ps). In this case, the 5th and 25th sub harmonics will be employed for the SHBs.

Sector B, C , 1 To the positron radiator, focusing quadrupoles are to be placed regularly; that is, a quadrupole triplet or doublet is to be used every one acceleration unit; the betatron wavelength is about 40 meters.

Sector 2 A positron generator will be replaced here by some modifications; the positron target system will be optimized for 4-GeV incident electrons. The focusing system is to start from a pulsed solenoid to an 8-m long solenoids and a FODO system of 20 m long; finally, it will match a periodic quadrupole triplet (doublet) system.

Sector 3,4,5 The linac layout will be slightly changed in the first four units of Sector 3, so that quadrupole magnets can be installed at every accelerator unit. In the second half of Sector 3, no change will be made.

Switchyard In the beam switch yard at the end of the linac, an 8-GeV and a 3.5-GeV beamlines will separately constructed to the KEKB ring.

R&D regarding the linac components

1) Accelerator sections

The 2-m sections will be equivalent to those used in the PF 2.5-GeV linac. The 4-m sections used in the positron generator will be converted to 2-m sections.

In order to upgrade the linac energy, the accelerator sections will be operated at a new (inexperienced) peak field of nearly 30 MV/m instead of about 9 MV/m under the present operation. Therefore, high-gradient acceleration tests has been carried out for the past two years. Using a resonant ring fed by a 30-MW klystron, one of the used sections was tested; it turned out that this section can be stably operated at the maximum field (28.6 MV/m) [6].

Just behind the positron radiator, electric breakdown is a serious problem; it has been empirically seen that when a breakdown occurs here, the solenoidal field tends to maintain it, thus leading to serious damage to the surface of the accelerator section or the waveguide. Because high-field operation is essential to suppress debunching of the positron beam, this is one of the most important subjects to be solved.

2) Rf pulse compressor

An rf pulse-compressor (a SLED type improved by the JLC group at KEK) was installed at an accelerator unit of the PF linac in December , 1992. With a klystron output of 48 MW (3.5 μs) this unit gains 179 MeV using the SLED and 97 MeV under detuned condition [12]. On the basis of this test, four more SLEDs has been fabricated and installed by the summer of 1994. These SLEDs are of the PF-version, having a cavity coupling-constant of 6.4 for the PF 2-m accelerator section, a couple of solenoid-actuated detuners , a couple of precision tuners, and other assemblies suitable for installing in the PF linac system.

In parallel with the SLED application, a new type of rf pulse compressor, which use a TE620-mode traveling-wave resonant ring instead of standing-wave cavities in the SLED, has been developed. A cold test was completed and a high-power test will soon be started [13].

Future

The TRISTAN experiments will be completed by the summer of 1995. The linac duty will be limited for the SOR experiments with the injection of electron beams. The linac re-formation must be carried out during the shutdown time (usually 2 times, 3 months during the summer and 2 months during the winter). By the time that the linac extension is completed at the end of 1996, the major work will be reconstruction of the positron generator in Sector 2.

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