CONSTRUCTION OF THE 8-GEV e$^-$ / 3.5-GeV e$^+$ INJECTOR LINAC FOR KEKB

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Abstract

The KEK/PF 2.5-GeV linac has been upgraded since 1994 by upgrading the existing linac as well as extending it towards the upstream site. It has been almost completed and commissioned during May and June, 1998. This paper summarizes the construction status and the beam performance of the new injector.

1 INTRODUCTION

KEKB includes an 8-GeV electron (e$^-$) ring and a 3.5-GeV positron (e$^+$) ring, which has been under construction since the TRISTAN accelerator was removed. KEKB aims at a luminosity of 1 x 10^{34} cm^{-2}s^{-1} with collisions between 1.1-A electrons and 2.6-A positrons.

One of the requirements of the injector linac is to deliver full-energy beams for both rings. The other is to increase the positron beam intensity to 0.64 nC (4 x 10^9 particles) /bunch with a repetition rate of 50 Hz. This positron intensity is ten-times as much as what the old linac produced, and when the beam could be injected without any beam loss, it takes 13.5 minutes to accumulate from 0 to a maximum charge of 26 μC, since the KEKB ring has a circumstance of about 3 km.

In order to achieve these requirements, the linac has been reconstructed and expanded [1]-[3]. For the energy upgrade, the number of accelerator modules was increased from 40 to 57, as well as the acceleration gain of each module from 70 to 160 MeV. The old positron generator was moved to a higher energy point of about 3.7 GeV from 0.25 GeV in order to increase the positron intensity.

2 CONSTRUCTION

The KEKB injector has been constructed since FY 1994 as a five-year program. Reconstruction of the old linac was finished by the end of FY1996; the linac expansion was constructed during FY1997 and the combination with the old linac was completed by the end of FY1997 (March, 1998).

2.1 Energy Upgrade of the accelerator module

In order to increase acceleration gradient, the rf source of the old accelerator modules has been upgraded from the downstream to the upstream using summer and winter shutdown terms. For increasing the rf peak power, the klystron modulator power was increased by twice, the 30-MW klystrons replaced by 50-MW klystrons, and rf pulse compressors (SLED: SLAC energy doubler) used. Including newly fabricated ones, 58 upgraded accelerator modules were so far constructed and the number of the remaining modules to be installed is only one.

	summer	winter	annual
-FY1994			5
FY1995		7	7
FY1996	12	15	27
FY1997	12	6	17
FY1998	1		1
		total	58

Among 58 accelerator modules, the SLEDs are not used in the most upstream module (pre-injector) and the accelerator module just after the positron radiator, in order to avoid any troubles due to electric breakdown.

2.2 High-power klystrons and modulators

The newly developed 50-MW klystrons are compact, size-compatible with the old 30-MW klystrons. They have been satisfactorily fabricated and installed according to the schedule described above.

Forty-seven klystron modulators were improved to double the pulse energy and 11 modulators were newly produced. The high-voltages applied to the klystrons were tuned so that the pulse width is 3.7 μs with ripples less than 0.3%. The high voltage control and the interlock monitor are made using programmable logic controllers.

During the linac commissioning in May and June 1998, the klystrons were operated at 25 pps and the output power was 38.6 MW in average of 55 modules with SLEDs; and corresponding calculated no-load accelerator gain was 164 MeV /module.

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All the accelerator modules had been conditioned up to about ten-percent higher peak power, and the trip rate was low during the beam commissioning, ex., 0.31 times/klystron.hour during June 7 to 13. Since the operation started, two klystrons has been replaced owing to trouble in the output window and the gun cathode, respectively; and 4 more klystrons are to be removed during this summer shutdown in order to tune the focusing field again.

2.2 Low-power rf systems

The low-power rf systems have been extensively changed for the KEKB injector [4]. In order to synchronize the linac beam with the ring rf buckets within a requested precision of +-30 ps, the common factors between the linac and the ring rf frequencies were searched under the condition that the linac frequency was fixed and considering the ring rf bandwidth. The highest common factor was consequently chosen to be 10.38545 MHz, which is the 275 (11 x 5 x 5) -th subharmonic of the linac rf as well as the 49 (7 x 7) -th subharmonic of the ring rf (508.8872 MHz). This means the linac beam and the ring rf bucket are synchronized at 10.38545 MHz.

The subharmonic bunchers (SHBs), which produce single bunch beams from the gun beam pulses with a width of about 2ns, are to be operated at the fifth (571.2 MHz) and the 25-th subharmonic (114.24 MHz). For the former rf, a 10-kW solid-state amplifier was newly fabricated, however, for the latter, an old amplifier using vacuum tubes was still utilized with slight improvement.

The frequency of a master oscillator was chosen to be the fifth subharmonic (571.2 MHz). Using an optical fiber cable, the linac fundamental rf (2856 MHz) is transferred from a main-booster to sub-booster stations located at the upstream of every 8 accelerator modules.

For the SLED system, the sub-booster rf drive systems were improved so as to inverse phase at the latter part of the rf. The switching time is changeable. During the rf conditioning, it was set around 200 ns in order to avoid the rf breakdown.

Sub-booster klystrons were replaced by newly developed 60 kW klystrons in order to drive 8 klystrons instead of 4 klystrons in the old linac case. These klystrons are water-cooled. During the commissioning, the correlation between the rf phase shift and the cooling-water temperature was studied and measured 1 deg /0.1 deg.C. The temperature stability for the rf systems has been improved to be around 0.2 deg. by changing cooling-tour fan switching to continuous control of a 2-way valve.

2.3 SLEDs

So far 55 SLEDs has been operated. These SLEDs are of two-hole coupling type and are modified in order to facilitate handling in the existing linac: the tuner with smooth adjustments with the necessary resolution (2 kHz in resonant frequency); the drive mechanism of the detuner needle using solenoid. The radiation from the SLEDs is sufficiently low and the shielding is not necessary, though there are several SLEDs with relatively higher radiation. The tuners and the detuners are also well working.

2.4 Accelerator sections

About seventy 2-m sections, which are $2\pi/3$-mode traveling-wave structures, were fabricated using electro-plating method. One of them was tested up to 36 MV/m (21 MV/m is operational), where any limitation was not found. By the linac commissioning, all of the new sections were conditioned without any problem up to more than the operational gradient.

An accelerator section used just after the positron radiator is one meter long; the input coupler has two symmetric coupling holes in order to reduce electric field around the coupler and the input waveguides. This section is operated in the solenoidal magnetic field of 0.5 T and fed by an rf of about 30 MW, 1 μs without a SLED, producing an acceleration gradient of 17 MV/m. Rf conditioning for the accelerator sections used in the magnetic field was carefully performed. Consequently the klystron trip due to electric breakdown was hardly experienced during the commissioning for the positron beam in June. This was a drastic change from the four-meter sections which had been used in the old positron source.

2.5 Pre-injector

The KEKB injector requires the pre-injector to produce single bunches with a bunch length of about 10 ps (FWHM) and a charge of more than 10 nC. The gun is able to emit pulsed beams with a pulse width of about 2 ns (FW) and a peak current of about 10 A. In order to compress the gun beam to the single bunch beam, a 114.24-MHz SHB and a 571.2-MHz SHB were installed before the 2856-MHz bunchers. The gun beam energy was increased up to 200 kV (100 kV in the old electron linac) for suppressing space charge effect on the basis of a computer simulation. The pre-injector showed a good beam performance in the commissioning.

2.6 Positron production

The main improvement for the positron source was to replace 4-m accelerator section by shorter sections. In the KEKB injector, two 1-m sections and two 2-m sections were installed and rf pulses with shorter width are to be fed. This improvement was very effective for stable operation of the positron beam. The electron-to-positron conversion rate normalized by the incident electron energy was about 3.3%/GeV at the end of the linac.

2.7 Beam Instrumentation and control

One of the great progress of the KEKB injector from the old injector is to have developed a beam instrumentation system based on beam position monitors (BPMs) which were installed at every location of quadrupole magnets [5]. The BPMs were widely utilized to tune linac beam in such cases as orbit correction and dispersion correction of the linac beam transport system.

The BPMs comprises stripline-type beam position monitors and associated signal analyzing systems. For solving man-power problem to develop a data acquisition system, 17 digital sampling oscilloscopes, which are of 5 GHz, 2 ch, and communicated with a VME computer, were distributed every half of the linac sector (typically 38.4 m). The signals are combined by combiners so that each peak is not overlapped and their peaks are measured using the oscilloscope functions and analyzed by 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 renewed every 1.4 second at present.

The other important monitor is a streak-camera system to observe the bunch structure of the linac beam [6]. The streak-camera system was also used in the old linac. However, it was not so easy to handle, because it consisted of separate devices, such as an optical system, a trigger and its delay system, a synchronization circuit between the trigger and the rf to reduce trigger jitters, as well as a streak camera proper. Further, air-Cherenkov light emitted by a beam was used as a light source into a streak camera; therefore, it has for a long time been used only for experiments.

Newly developed streak-camera systems are more simply arranged, computer controlled, and they utilize optical transition light (OTR) emitted from a metal mirror which can be easily inserted to the beamline. Thus four streak-cameras were installed after the pre-injector, after the linac arc, after the positron radiator, and the linac end. So far they were frequently used at the pre-injector as a real time bunch tuner.

2.8 Linac Alignment

All the buncher system are operated in the Helmholtz coil of about 0.1 T. In this low energy region, the alignment of the equipment was carefully checked; by changing the gun beam energy, the position change on beam screens was investigated. However the alignment has been still checked in this summer shutdown, because it was essential to use steering coils before the buncher during the commissioning.

The linac alignment has not been sufficient at present. One of the reason is the girder slide rollers were superannuated. They have been replaced during this summer shutdown. And the linac alignment will be selectively improved upstream of the positron radiator in order to increase the primary electron beam intensity.

3 BEAM PERFORMANCE

The linac commissioning was carried out as scheduled in May and June and the results near to the design were obtained as follows:

	electron		positron	
	dsgn	achvd	dsgn	achvd
energy (GeV)	8	>8	3.5	>4
charge (nC/bunch)	1.2	1.5	0.64	0.6
energy width (% FW)	0.5	----	0.5	0.8
emittance (1σ, mm)	1.1	----	1.6	2.3

A remarkable feature of the linac commissioning was use of the beam instrumentation system and SAD (strategic accelerator design) computers in various stages of the beam tuning. Especially it was indispensable to tune high-current electron beams for positron production while suppressing emittance growth.

4 SUMMARY

(1) A linac upgrade was almost completed. A total energy of more than 8 GeV and average module gain of more than 160 MeV (20 MeV/m) were obtained.

(2) A positron beam near to the design quality has been achieved.

(3) To achieve a complete performance in the KEKB commissioning, the remaining issues, such as the linac alignment check, replacement of the old devices, and preparation for the 50-Hz operation, is to be still continued during this summer.

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