Performance of the Upgraded Positron Generator at KEK

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Abstract

To meet increasing requirements regarding positron beam use, the focusing system of the KEK positron generator was extensively reconstructed. The upgrade strategy, construction and performance of this system are described.

1. INTRODUCTION

As a part of the TRISTAN project, the KEK positron generator [1] was constructed on the south-west side of the Photon Factory (PF) 2.5-GeV electron linac during 1982-1985; it was then combined with the 2.5-GeV linac. In the autumn of 1986 it started routine-operation to inject 2.5-GeV positron beams into the TRISTAN ring; in the autumn of 1988, the PF ring storage beam was changed from electrons to positrons in order to realize more stable operation. Figure 1 shows the composition of the KEK positron generator: a 250-MeV primary electron linac; a positron radiator with a quarter-wave-transformer (QWT)-type focusing system; a 250-MeV post-linac; and a 30°-bending beamline to transfer positrons to the 2.5-GeV linac.

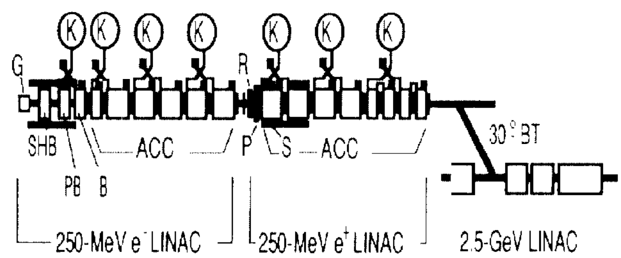

Figure 1. Block diagram of the KEK positron generator: G is the electron gun; SHB, a subharmonic buncher; PB, a prebuncher; B, a buncher; ACC, a regular accelerator section; R, a positron radiator; P, a pulsed solenoid; S, a uniform solenoid; K, a klystron.

A distinctive feature of the previous KEK positron generator was a compact focusing system used in conjunction with a high-current primary electron beam (10-A, 2-ns beam for the TRISTAN injection and 2-A, 40-ns for the PF). This choice enabled low-power operation (<100 kW) of the focusing system with sufficient positron intensities for injection (>10 mA for the TRISTAN and >2 mA for the PF). Details were described elsewhere [2].

Instead of undertaking TRISTAN energy-front studies, high-luminosity operation was started as PHASE-II experiments in 1990. Furthermore, within a few years, a B-physics plan is eagerly expected to be realized as our next project. In these experiments, additional positron intensities are required in order to save injection time; especially, the B-physics will require roughly ten times as many positrons as produced by the previous generator. To meet such requirements, an integrated upgrade will be necessary for the entire linac (e.g., to increase the primary electron energy, etc.); nevertheless, we started the upgrade from improvements of the positron focusing system.

2. UPGRADE STRATEGY

In principle, the positron yield is proportional to the product of the positron cross section, the primary electron number, the primary electron energy, and the spatial and momentum acceptance of the focusing system.

The first way to increase positron yield is to increase the primary electron beam power (beam energy × current). Investigations for this purpose were recently started [3][4], since acceleration of a high-current beam to high energy involves serious problems, such as beam breakup (BBU) phenomena, and arcing in the accelerator structures due to high-power rf operation.

To improve the focusing system the spatial and momentum acceptance for the positron beam, which emerges from the metal target hit by the primary electrons must be improved. It has a large emittance and a wide momentum distribution. The KEK positron generator adopts a QWT-type focusing system [5], comprising a strong, short-range axial field (strength of B_i and effective length of L) just behind the radiator, and a lower, long-range field (B_f) applied over the accelerator sections. The short-range strong field is produced by a pulsed solenoid, and the lower field by a DC solenoid.

Table 1 shows the designed parameter change to the upgraded one. The new features of the positron focusing system are as follows: (1) The shorter pulsed solenoid made the spatial acceptance larger. (2) Though the pulsed solenoid became shorter, the stronger field keeps the acceptable positron momentum ($P \propto B_i \times L$) higher, and suppressing

Table 1
Designed parameter change of the QWT system

	Previous		Present
Solenoidal field			
pulsed solenoid B_i(T)	1.2	----->	2.0
effective length L(mm)	76	----->	50
DC solenoid B_f(T)	0.2	----->	0.4
Acceptance			
U(πMeV/c cm)	0.15	----->	0.30
Matched beam on the radiator			
radius x(cm)	<0.12	----->	<0.14
momentum P(MeV/c)	8.7	----->	9.5
transverse momentum p(MeV/c)	1.25	----->	2.1
Positron yield (relative values)			
solid angle δΩ	1	----->	2.3
momentum acceptance δP	1	----->	1.3
specific yield n/E	1	----->	2.4

debunching effects due to their speed/orbit differences. (3) The stronger B_f keeps the positron momentum acceptance ($\delta P \propto P(B_f/B_i) \propto B_f L$) wide. Approximate improvement factors regarding the spatial acceptance, the momentum acceptance and the positron yield are also listed in Table 1. The factor for the positron yield is evaluated while taking account of the angular dependence of the positron production cross section.

3. CONSTRUCTION

Reconstruction was performed during the machine shut-down terms in the summers of 1990 and 1991 and the winters of 1991 and 1992, without disturbing either the PF or TRISTAN experiments. The changes in the layout are shown in Figure 2.

3.1. Pulsed Solenoid and the Power Supply

The KEK pulsed solenoid was first fabricated while referring to DESY's design; then, in 1987, it was replaced by an original one modified so as to be installed outside the accelerator vacuum. A coil made using a water-cooled copper tube was installed over an alumina-ceramic vacuum pipe. Because the diameter of the coil becomes larger than that installed inside a vacuum chamber, by at least an amount equivalent to the ceramic thickness, this is not a convenient way to make the field strong and short; nevertheless, we selected this way in order to avoid any trouble due to water leaking into the vacuum. The previous coil design used in 1987 was rather conservative regarding both the dimensions of the ceramic tube and the applied current. The inner diameter of the new ceramic tube has been decreased down to the limit of the accelerator aperture (23 mmφ) and the maximum applied current increased from 5 to 10 kA. The coil has 8 turns of winding and a return-yoke made of ferrite. The field is much improved, from 1.2 T × 76 mm to 2.3 T × 45 mm.

The pulsed power supply is capable of providing a half-sine shape pulse with a maximum peak-current of 20 kA and a pulse width of 100 μs for a load of 5 μH. The maximum repetition rate is 50 pulses per second (pps).

3.2. DC-Solenoids

The long solenoid following the pulsed solenoid was upgraded from 0.2 T × 4 m to 0.4 T × 8 m, which covers two 4-m accelerator sections. The main part consists of 224 "double pancakes" made of a hollow conductor of 14 × 14 mm^2 (t 4.5 mm); half of these pancakes is connected electrically in series; each pancake is connected through a alumina-ceramic insulator with water-cooling headers and directly cooled by passing pressurized water (4 kg/cm^2, 30 °C) in the hollow. However, a coil using such a thick wire has some disadvantage in producing a symmetrical field. Each pancake was therefore carefully fabricated in order to produce a field that is as uniform as possible; each one has a return-yoke of low-carbon steel; the intersecting points of the layers are made so as to be distributed at four points through-out the entire length (8 m) of the solenoid. Measurements show that the maximum transverse component is ~1%, and that the average is less than 0.05% against the longitudinal field. Bridge coils were installed in order to compensate for the field gaps between the pulsed coil and the end of the regular pancakes as well as between the 2-m accelerator sections.

3.3. Positron-Electron Separator

Both the electrons which pass through the target and those produced by "pair-creation" in the target, are initially out of phase in the first accelerator section behind the target, but become in phase after being decelerated and slipped by 180° in phase. Though these electrons are once decelerated down to a low-beta region, they can be transported in the solenoidal field as well as the positrons. The electrons which pass through the solenoidal region have a lower energy than do the positrons, and may continue to be accelerated if they match the transport acceptance. Since these electrons disturb measurements of the positron current, if we have no device to separate them beam tuning will be quite difficult in the long straight accelerator. We have thus developed a positron-electron separator which takes account of the possibility that the positron generator will be moved to a higher energy point in the PF 2.5-GeV linac.

This device comprises four small rectangular bending magnets, which have the same sizes and windings. They are equally excited by being connected in series, although the field directions are opposite between the first/fourth and second/third magnets. These magnets comprise a complete achromatic system as an entire system, but have dispersion at the center, where a copper-block absorber is inserted so as to stop the electrons.

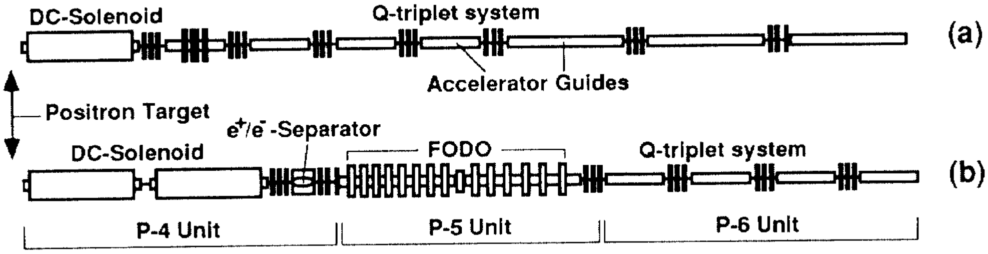

Figure 2. Change of the layout of the positron focusing system: (a) previous, (b) present.

3.4. *Quadrupole Magnet System*

The quadrupole system following the solenoid was also upgraded in order to match the enlarged acceptance of the solenoid system. The acceptance was increased to the end of the positron generator by a factor of two. A FODO system was employed in the region from 90 to 170 MeV, where quadrupole magnets were installed over the accelerator sections. In the energy region exceeding 170 MeV, an ordinary periodic quadrupole system is used. Quadrupole triplets are used in order to match the beam optics among different types of focusing systems, i.e., the solenoid, the positron-electron separator, the FODO, the periodic quadrupoles, and the 30°-bending achromatic beam transport.

4. PERFORMANCE

The parameters of the upgraded positron generator are summarized in Table 2. During reconstruction, the 4-m accelerator section just behind the positron production target was replaced because it had been used at a lower gradient, owing to frequent arching. We found many severe markings due to arcing around the input coupler (including the waveguide inside the solenoid). In commissioning, the new section was carefully aged for several days at various gradients and solenoidal fields. Consequently, it has been stably working at the operation gradient (10 MeV/m).

One of the important improvements was to introduce a positron-electron separator. Just after the solenoid, the number of electrons greatly exceed the positrons. When the separator is not switched on, the electrons remain even at the end of the positron generator exit (250 MeV) until they are bent to the opposite direction against the positrons by a 30°-bending magnet. The separator rejects the electrons without decreasing the positrons.

The positron current is monitored along the entire linac using wall-current monitors. Current signals were observed with a 400-MHz oscilloscope in the main control room. The absolute values of the accelerated charge were determined by calibration using reference pulses from a fast-pulse generator. The positron charge per pulse and the corresponding electron-to-positron conversion rate are listed in Table 3 at three typical locations. For the conversion rate at the exit of the solenoid (90 MeV), the same monitor and cables were used for measuring both the primary electrons and the positrons in order to check the calibration. The conversion rates shown in the table are normalized by primary electron energy. This measurement proves that the conversion rate has been improved as expected.

The positron characteristics (e.g., the spectrum and transmission) are under investigation regarding their dependence on the parameters of the focusing system. Preliminary results show that part of the beam loss is due to the wide energy spectrum captured upstream of the generator.

5. CONCLUSION

We have successfully completed upgrading from a compact positron focusing system with a reasonable electron-positron conversion rate to strong focusing with a high conversion rate to meet increasing requests of the positron beam. In addition to the positron intensity, we made effort to construct a system which will cause few problems, such as water leaking into the vacuum, and is capable of being easily tuned.

Table 2
Parameters of the KEK positron generator

General		
acceleration frequency	2856	MHz
pulse repetition (max.)	25(50)	pps
Primary electron linac		
energy	250	MeV
peak current	10<2>	A
pulse width	2<40>	ns
emittance (Pε)	0.05	πMeV/c cm
Electron-to-positron converter		
radiator(thickness)	tantalum	8.2 mm
pulsed solenoid	QWT	type
Positron linac		
energy	250	MeV
emittance (Pε)	0.3	πMeV/c cm
Pulsed solenoid		
field strength	2.3	T
effective length	45	mm
peak current	10	kA
peak voltage	2	kV
pulse width	100	μs
inductance	4	μH
repetition rate (max.)	25(50)	pps
DC solenoid		
field strength	0.4	T
length	8	m

< >: positrons for PF

Table 3
Typical positron beam in operation

	2-ns beam	40-ns beam
Charge per pulse (number)	<x 10^8e^+>	<x 10^8e^+>
DC solenoid exit	250 pC (16)	-
positron generator exit	160 pC (10)	960 pC (60)
2.5-GeV linac exit	70 pC (4.4)	250 pC (16)
Conversion rate (e^+/e^-GeV)		
DC solenoid exit	6.5%	-
positron generator exit	4.2%	6%
2.5-GeV linac exit	1.8%	1.5%

6. REFERENCES

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