A SIMULATION STUDY ON KEK POSITRON GENERATOR

Takuya Kamitani, Atsushi Enomoto, Satoshi Ohsawa, Isamu Sato, Akira Asami,
Takao Oogoe, Kazuhisa Kakihara and Mitsuhiro Yokota
Injector Division, Photon Factory, KEK (National Laboratory for High Energy Physics)
Oho 1-1 Tsukuba-city Ibaragi-Pref JAPAN

Abstract

The KEK positron generator focusing system has been upgraded since FY 1990 and completed this spring. The strength of the solenoidal fields was doubled. We analyzed the improved performance of the positron yield by a detailed simulation of the particle motion in the focusing system. A preliminary result of a study on the change of the energy distribution of the positrons upon the rf accelerating phase is also described.

TABLE 1
Typical positron beam in operation

	2-ns beam	40-ns beam
Charge per pulse (number)	<x $10^8 e^+$>	<x $10^8 e^+$>
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)		
positron generator exit	4.2%	6%
2.5-GeV linac exit	1.8%	1.5%

Introduction

The KEK positron generator consists of a high current (~10A) electron linac, a positron radiator (8.2 mm thick tantalum), a focusing system with a solenoidal magnetic field, an e^-/e^+ separator to eliminate electrons for accurate beam current measurement, and a beam transport system with quadrupole. (See Fig.1).

The details of the positron generator and its recent improvements are described elsewhere [1][2][3]. The focusing system is a quarter-wave-transformer (QWT) type, comprising a strong magnetic field supplied by a short pulsed coil and a long solenoidal field extending over 8 meters of the accelerating sections. In the upgrade, (1) the strength and the length of the pulsed coil field were improved from 10 kG × 76 mm to 20 kG × 45 mm and (2) the solenoid field from 2 kG × 4 m to 4 kG × 8 m. Their field profiles are shown in Fig.2. A typical performance of the positron generator after the upgrade is tabulated in Table 1.

Though positrons are copiously produced in the radiator, only a small fraction of them can be accelerated because of the smaller transverse acceptance and the narrow band nature of the energy acceptance of the QWT system. The focusing system of the KEK positron generator was upgraded by doubling the magnetic field strength to make its acceptance larger. We have already estimated from a simple discussion of the acceptance [2][3], how much the positron yield would be improved by the upgrade. It was based on the assumptions that the form of the field distribution was idealistic; the actual distribution is not so uniform, however. Furthermore, the distribution in the transverse phase space and in the energy distribution of the positrons produced in the radiator was not considered and assumed uniform. A detailed simulation including these effects was necessary to obtain a more precise estimation. We performed simulations of the positron production in the radiator with the EGS4 [4] and of the particle motion in the magnetic field by tracing trajectories of the positrons.

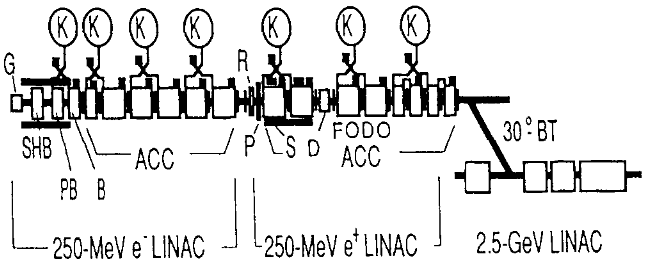

Fig.1 Lay out of the KEK positron generator: G is the electron gun; SHB, a subharmonic buncher; PB, a prebuncher; B, a buncher; ACC, a regular accelerator section; R, a positron radiator; P, a pulsed solenoid; S, a uniform solenoid; K, a klystron; D, e+/e– separator.

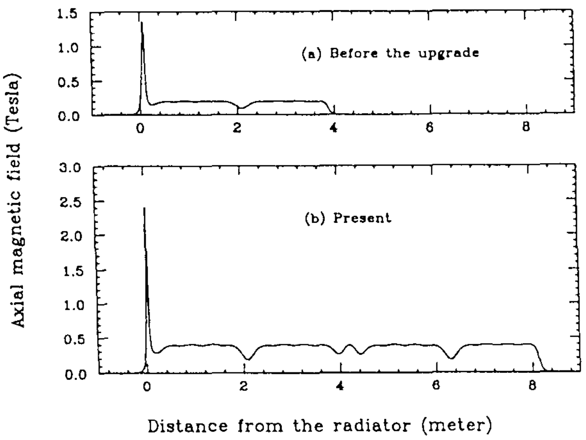

Fig.2 Field profiles of the QWT : (a) before the upgrade, (b) present

The positron yield has estimated with the simulation. The simulation is also useful to study the influence of the variation of the parameters of the focusing system on the beam quality of the positrons. The dependence of the energy spread upon the rf accelerating phase was studied with the simulation and compared with the measurement.

Particle simulation

We generated a sample of the kinematic information (the positions, angles and energies) of the positrons emerging from the radiator using the EGS4 (Electron Gamma Shower) code. In the calculation, we assumed that electrons impinge uniformly within a 1.0 mm radius on the radiator with energies of 250 MeV and that their transverse momenta are negligible. Positrons whose kinetic energies smaller than 1.0 MeV were neglected to save the calculation time. This was irrelevant to the result of the yield estimation since the energy acceptance of the focusing system is higher as shown below.

In order to simulate particle motion in the magnetic field, the trajectories of the positrons were traced by a numerical integration of the relativistic equations of motion,

$$\frac{d}{d(ct)}\left(\frac{\gamma m_0 c^2}{e}\vec{\beta}\right) = \vec{E} + \vec{\beta} \times c\vec{B},$$

$$\frac{d}{d(ct)}\left(\frac{\gamma m_0 c^2}{e}\right) = \vec{\beta} \bullet \vec{E},$$

$$\vec{\beta} = \frac{\vec{v}}{c} = \frac{d\vec{r}}{d(ct)}.$$

The kinematic information generated with the EGS4 were used as initial conditions of the particles. The particles were started at the radiator and traced up to the exit of the solenoidal field. As for the magnetic field, the calculation includes the axial and radial magnetic field derived with the first order paraxial approximation from the measured field distribution on the central axis as

$$B_r(r,z) \approx -\frac{r}{2}\frac{dB_z(0,z)}{dz}, \qquad B_z(r,z) \approx B_z(0,z).$$

An axial symmetry of the magnetic field was assumed. The axial electric field was assumed a sine wave and the radial component was neglected. The strength of the accelerating field was assumed to be 10 MeV/m at the crest of the phase. Coulomb interaction between the particles was neglected. The particles were proceeded in a time step of $c\Delta t$ = 5 mm and checked in each step if they went outside of the aperture of the accelerating structure (20 mm in diameter).

Positron yield

The yield of the positrons depends on the transverse emittance and the energy distribution of the positrons produced in the radiator as well as on the transverse and energy acceptance of the focusing system. The transverse emittance of the positrons produced in the radiator was estimated with the EGS4. It was given by the area of the spread of the positions and the transverse momenta of them. The lateral dimensions of the positrons are dependent on the those of the impinging electrons on the radiator. Figure 3 shows the dependence for our radiator. The positron lateral dimension was a r.m.s. radius calculated from the distribution of the positrons emerged from the radiator. It should be noticed that the electron beam size was not an r.m.s. value but radius of the uniform distribution. To obtain the r.m.s value, a factor of $1/\sqrt{2}$ should be multiplied to the radius of the unform distribution.

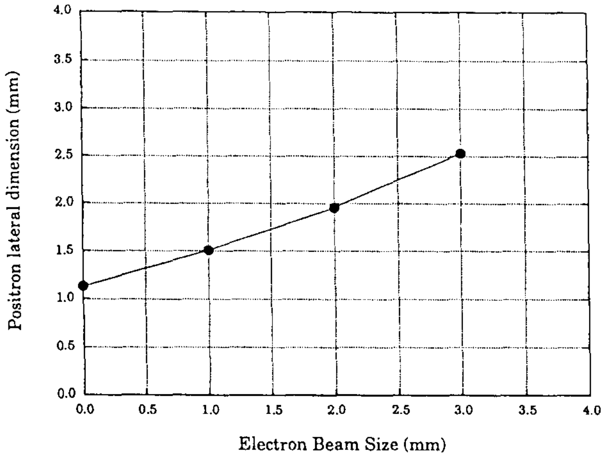

Fig.3 Positron lateral dimension vs Electron beam size

It showed that positrons have an intrinsic spread of about 1 mm even if electrons have no radial spread. It is due to the interaction in the radiator. The actual lateral spread is naturally larger than the intrinsic value, since the impinging electrons have finite spread. The radius of the electron beam on the radiator was assumed to be 1 mm for a sample used in the particle simulation. It produces the positron beam with a radius of 1.5 mm just behind the radiator. The transverse emittance of the positrons was estimated from the distribution in the transverse phase space shown in Fig. 4. The r.m.s. emittance was evaluated to be ε = 1.30 πMeV/c cm.

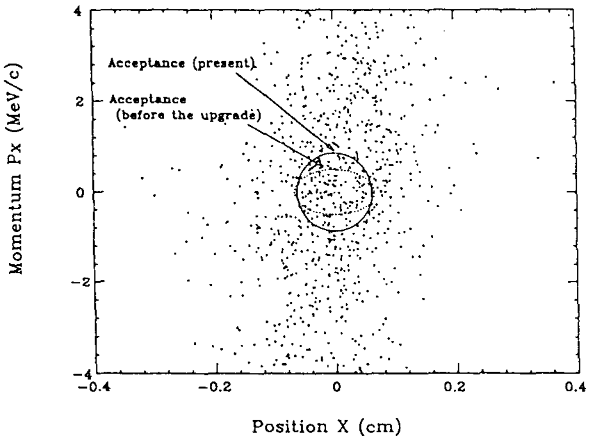

Fig.4 Emittance Plot of the positron just behind the radiator

The transverse acceptances of the focusing systems were estimated from the distribution of the positrons which passed through the system. They were evaluated from the r.m.s. emittance of them to be ε = 0.13 πMeV/c cm and 0.21 πMeV/c cm for the focusing systems before and after the upgrade. The dotted and solid ellipses in the Fig. 4 show the region of the acceptances of them at the radiator. The QWT system has narrow band of the energy acceptance restricted by the condition of the matching [5]. The curves in Fig. 5 show the energy acceptance of the positrons which can pass through the system. The acceptance has two peaks corresponding to the $\pi/2$ matching and $3\pi/2$ matching.

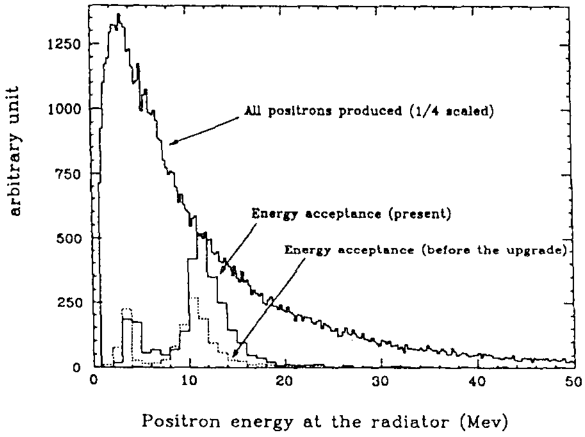

Fig.5 Energy distribution of the positron at the radiator

The yield of the positrons was estimated from the fraction of the positrons passed through the system. We had a sample of 64488 positrons generated from 100000 electrons with the EGS4. In the particle simulation for the focusing system, the numbers of particles survived were 1420 and 2829 for the old and the new focusing system, respectively. A factor of the improvement of the positron yield was estimated to be 2.0. In the previous report [2][3], the factor has estimated to be 2.4 with a simple discussion of the acceptances. According to a previous measurement of the positron charges, the normalized positron yield $n_{e+}/n_{e-}/E_{e-}$ was about 4.2 %/GeV [1]. It was measured at the end of the positron generator, since the electrons from the radiator were eliminated there. While, it was 1.7%/GeV in the recent measurement. A factor of the improvement was 2.5. The agreement of the result of the simulation with the measurement was not complete. The loss of the positrons in the transport system up to the end of the generator should be considered to make a more precise comparison.

Energy spectra

We obtained an interesting data in a beam study. A change of the energy distribution (the mean value and the width) of the positrons upon the rf accelerating phase in the solenoidal magnetic field region was studied. The phase was not changed in the region after the solenoid. In order to obtain the distribution, we carefully measured the positron beam current in analyzing its energy with a energy defining slit and a bending magnet at the end of the positron generator linac. The beam energy was around 250 MeV there and the energy resolution of the analyzing system was roughly $(\delta E/E) \sim 0.3\%$. The observed dependence of the energy spread upon the accelerating phase is shown in Fig.6. The energy spread was estimated by fitting the gaussian curve to the data. The width is minimum when the phase is slightly shifted beside the crest. It is supposed to cause a bunching due to phase slippage. A simulation study on the effect was performed using a sample used for the yield estimation. The particle motion in the transport system after the solenoid was not simulated, however the energy gain was taken into account. The result is shown in Fig.6. The longitudinal beam extent of the positron at the radiator was assumed to be 6 mm in full width. It corresponds to about 20 degree in the rf phase. The resolution of the analyzing system was taken into account in the simulation. The result of the simulation agreed well with the measurement

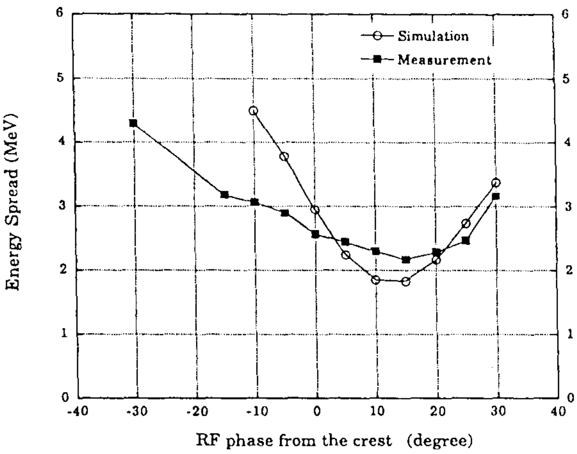

Fig.6 Dependence of a energy spread upon the rf accelerating phase

References

[1] A. Enomoto et al., "Focusing system of the KEK positron generator", NIM, A281, 1989, pp.1-9.

[2] A. Enomoto et al., "Present Status and Reinforcement Plan of the KEK Positron Generator", Proceedings of the 1990 Linear Accelerator Conference, Albuquerque, NM, U.S.A., September 10-14, 1990, pp.623-625.

[3] A. Enomoto et al., "Performance of the Upgraded Positron Generator at KEK", in Proceedings of the Third European Particle Accelerator Conference, 1992.

[4] W. R. Nelson, H. Hirayama, and D. W. O. Rogers ; The EGS4 Code System, SLAC-Report 265 (1985).

[5] The Stanford Two-Mile Accelerator: Benjamin, New York,1968, Chap. 16, "THE POSITRON SOURCE".