Transverse wake field characteristics of the KEK positron generator linac

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Abstract

A multibunch transverse instability due to a wake field was investigated in detail by using a high-intensity, multi-bunched beam at the primary electron section of the KEK positron generator linac. The transverse motion of each bunch showed a peculiar behavior when a transverse instability occurred. The experimental results were compared with a numerical calculation based on a multibunch version of P. B. Wilson's two-particle model. The transverse wake field for our cavity was estimated using TBCI-code. The calculation explains fairly well the observed behavior of each bunch.

I. INTRODUCTION

The multibunch operation of an intense beam is considered to be indispensable in future linear colliders for an efficient rf power transfer to any beam limited by power requirements. A train of intense bunches on each rf fill, however, produces strong longitudinal and transverse wake fields in the cavities and causes a large energy spread as well as a multibunch transverse instability in the bunches. These effects lead to emittance growth, resulting in a reduction of luminosity. Although many theoretical ideas to cure these undesirable effects have been proposed and elaborated by several authors [1-4], the systematic experimental studies carried out have been very few [5-7], especially for an intense multibunch beam [8,9]. We have performed a series of experimental studies on the wake field characteristics of the KEK positron generator linac [8-10]. In this paper we present the experimental results concerning the transverse wake field characteristics of a multibunch intense beam as well as numerical simulations based on a rigid-macroparticle model.

II. EXPERIMENTAL SETUP

The primary electron section of the KEK positron generator [11] comprises a high-intensity electron gun with a peak current of 10 A and a pulse width of 4.2 ns, a pulse compression section employing a subharmonic buncher with a modulation frequency of 119 MHz, a bunching section operating at 2856 MHz, and a 22 m-long regular accelerating section with a quasi-constant gradient of about 11 MeV/m at the same frequency. Through this regular section, a high-intensity, multi-bunched electron beam with a peak current of about 10 A and a pulse width of 2 ns, corresponding to about 6 bunches, is accelerated; the average energy reaches about 250 MeV at the end of the section. Focusing quadrupoles are tuned so as to produce a betatron wavelength of about 30 m. A schematic layout of the primary electron section is shown in Fig. 1.

The measurement system for the transverse wake characteristics comprises a steering coil, an ST for providing an initial transverse offset of the beam at the entrance of the regular accelerating section and an energy analyzing station [12] for observing each bunch behavior at the end, which comprises an energy-analyzing magnet, beam-profile monitors, a current monitor, a slit, and a bunch monitor of the strip-line type. With this energy-analyzing station, the total energy spread was measured to be about 9 %, which comes from an energy difference of each bunch due to a longitudinal wake field [10].

The transverse motion of each bunch is observed at the beam-profile monitor after the energy-analyzing magnet, thanks to this bunch-to-bunch energy difference. The dependence of the transverse shift of the *last* bunch on the initial offset at the entrance of the regular accelerating section has already been measured with this system by changing the initial offset at ST (reported in a previous paper [9]). In the present experiment, we directed our attention to the transverse shifts of *all* bunches.

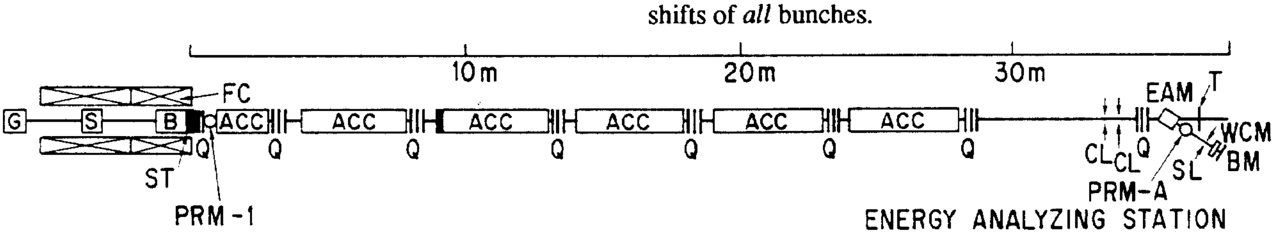

Fig. 1. Layout of the primary electron section of the KEK positron generator linac. G is an electron gun; S, SHB; B, a prebuncher and a buncher; ACC, accelerating cavities; FC, focusing solenoids; Q, quadrupole magnets; ST, steering coils; EAM, an energy-analyzing magnet; PRM, profile monitors; CL; collimators; SL, a slit; WCM, a wall current monitor; BM, a bunch monitor; and T, a positron production target.

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III. RESULTS AND DISCUSSIONS

The typical transverse behavior of the bunches photographed at the profile monitor of the energy-analyzing station is given in Fig. 2, where the initial transverse offset was set to 2 mm. This indicates that about 6 bunches are scattered peculiarly around a horizontal center line. While the energy difference of one bunch from another is attributed to the effect of a longitudinal wake field, the peculiar transverse behavior originates from a multibunch effect of the transverse wake field [9].

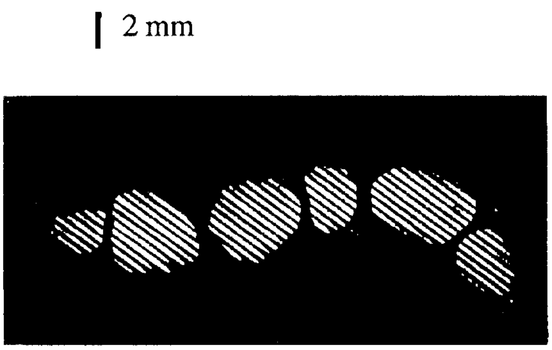

Fig. 2. Typical transverse behavior of the bunches photographed at the profile monitor of the energy analyzing station. In this figure, the vertical direction corresponds to a transverse displacement, while the horizontal direction corresponds to the beam energy (The left-side is high-energy side). The initial transverse offset was set at 2 mm.

In order to explain the observed transverse behavior of bunches, suppose that the rigid-macroparticle equations for transverse motion, a multibunch version of Wilson's two-particle model [13,14], is

$$\frac{d}{ds}\left(\gamma(s)\frac{dx_n}{ds}\right) + \gamma(s)k_n^2 x_n = r_0 \sum_{i=1}^{n-1} N_i W_{n-i+1} x_i \quad (n=1, N),$$

where s is the distance down the linac, x_n the transverse displacement of the n-th bunch, k_n the wave number of the betatron oscillation, $\gamma(s)$ the energy Lorentz factor, r_0 the classical electron radius, N_i the number of particles in the i-th bunch, N the number of the bunches, and W_i the transverse wake function at the position of the i-th bunch. We assume (1) a constant gradient of acceleration for $\gamma(s)$; $\gamma(s)=\gamma_0+g\,s$, where γ_0 is the initial energy and g the energy gain per meter, and that (2) the betatron wavelength is the same for all bunches; $k_n=k$. All related parameters required for integration of the equations of motion are tabulated in Table 1, among which the transverse wake function for our cavity was numerically estimated by the TBCI-code [15] for a Gaussian-shape bunch. Our cavity characteristics [16] are summarized in Table 2. Fig. 3 shows the calculated wave forms of the transverse wake function for two different cases of iris aperture diameters in a cavity of the constant-impedance type. They are almost consistent with a calculation performed by K. Bane [17]. Since our cavity is of the quasi constant-gradient type, we take a sort an "average value" in Fig. 3 for the transverse wake functions in Table 1. The convergence of calculations was also checked by varying the number of cavities.

Table 1. Parameters for equations of motion.

Initial Energy	γ_0	23 (12 MeV)
Energy Gain	g	22 /m (11 MeV/m)
Length of Acc.	L	22 m
Initial Position	$x_n(0)$	2 mm
Initial Angle	$dx_n(0)/ds$	0
Betatron Wave Number	k	$2\pi/27$ /m
No. of Particles in the n-th Bunch	N_1	6.2×10^9
	N_2	3.7×10^{10}
	N_3	4.4×10^{10}
	N_4	5.6×10^{10}
	N_5	2.5×10^{10}
	N_6	2.5×10^{10}
Total No. of Bunches	N	6
Transverse Wake Function	W_1	0 $1/m^3$
	W_2	8.9×10^4
	W_3	-4.5×10^4
	W_4	1.3×10^5
	W_5	-1.8×10^5
	W_6	1.3×10^5

Table 2. Related parameters of our cavity for calculating the transverse wake functions.

Type of Structure	quasi-constant gradient travelling wave $2\pi/3$ mode
Operating Frequency	2856 MHz
Length of Acc. Cavity	2 m / 4 m
No. of Cavities	54 / 110
Cavity Inner Diameter, 2b	82 - 83 mm
Iris Aperture Diameter, 2a	20 - 26 mm
Disk Thickness	5 mm

A numerical integration of the equation of motion was performed by the method of Runge-Kutta using the parameters listed in Table 1. The trajectories of each bunch were calculated along the accelerator to the profile monitor, PRM at the energy-analyzing station. The results are in good agreement with the observed beam trajectories. The calculated transverse displacements for each bunch at the end (PRM) are shown in Fig. 4, which agree fairly well with the experimental result given in Fig. 2.

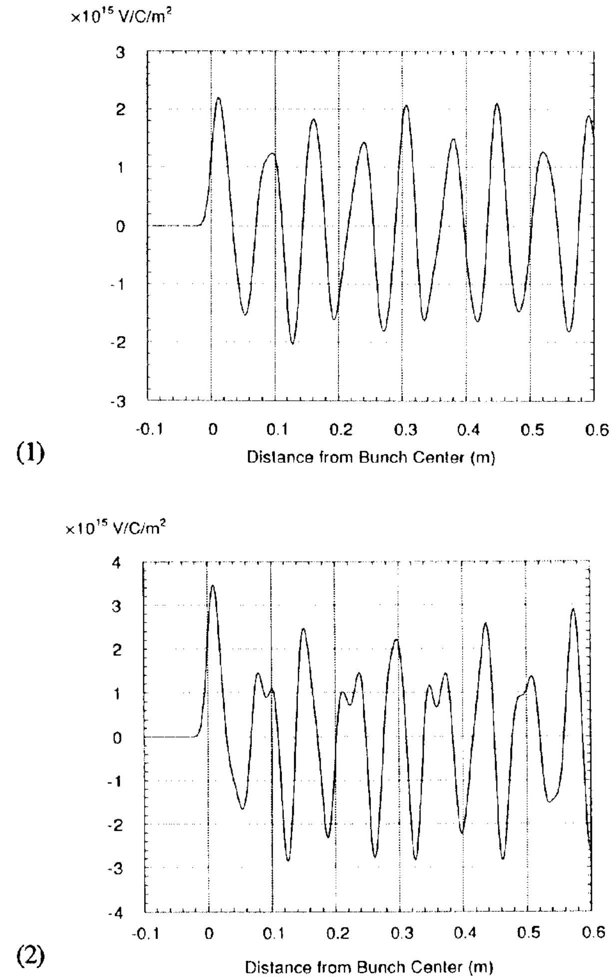

Fig. 3. The calculated wave forms of the transverse wake function for our cavities: (1) $2a$=26 mm, (2) $2a$=20 mm. A bunch length of about 7.5 mm was assumed.

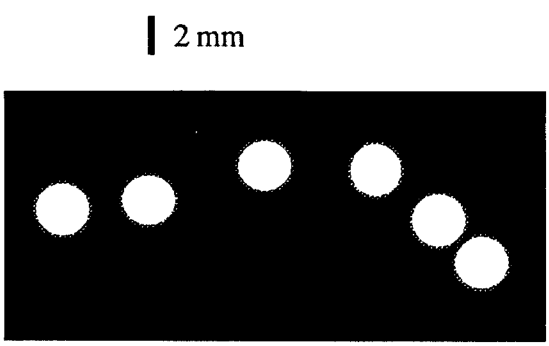

Fig. 4. Calculated transverse displacements of each bunch. The initial transverse offset was set at 2 mm. The coordinates in the figure are the same as those in Fig. 2. The white circles correspond to bunches. While the bunch intervals were reduced from the energy spectrum observed at the energy-analyzing station [8], the bunch spreads do not correspond to the size of the circles in this figure.

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