CHARACTERISTICS OF LONGITUDINAL WAKE FIELD AT THE KEK POSITRON GENERATOR LINAC

M. Takao, *Y. Ogawa, *T. Shidara and *A. Asami

Japan Atomic Energy Research Institute
Tokai, Ibaraki 319-11, Japan
*National Laboratory for High Energy Physics (KEK)
Tsukuba, Ibaraki 305, Japan

ABSTRACT

A detailed experimental study on the longitudinal wake field characteristics of a high intensity multi-bunched electron beam was carried out at the primary electron section of the KEK positron generator linac. The observed energy spectrum, which indicated the bunch-to-bunch energy variation, was explained by the longitudinal wake field effect. In the numerical estimation of the energy loss due to the longitudinal wake field, the importance of the individual bunch length was noted.

1. Introduction

Future e^+e^- linear colliders for high energy experiments in TeV region require high luminosity. For the purpose of achieving the required luminosity, it is intended to increase the number of particles in a bunch or to raise the repetition rate of the acceleration. But the increase of the luminosity by these methods is restricted by the available wall plug power. The multi-bunch acceleration, where a bunch train is accelerated in a RF pulse, can improve both the luminosity and the efficiency of the power transfer from RF to a beam. The drawback of the multi-bunch is the instabilities caused by the wake fields, which are the electromagnetic fields excited by the interaction between the beam and the envelopment. If the bunch train travels along the off-axis of the accelerating structure, it induces the transverse wake field as well as the longitudinal one. Transversally, the wake field kicks any trailing particles, and then brings about a cumulative beam breakup. On the other hand, a longitudinal wake field extracts energy from the accelerating field, leading to a variation in the beam energies. Although the problems related to the single-bunch phenomena have been studied by several people [1], there have so far been few investigations on the multi-bunch phenomena of highly intense bunched beams.

The positron generator linac at KEK [2] has a high intensity primary electron beam, which is bunched and accelerated to 250 MeV by an RF field. The beam is split into 5-6 bunches with the electric charge of a few nano Coulomb, respectively. A series of experimental studies on the wake field characteristics of the KEK positron generator linac has been carried out [3]. In this paper we discuss the longitudinal wake field characteristics of the high-intensity, multi-bunched beam. The energy spectrum of such a multi-bunched beam is measured at the energy analyzing station and compared with numerical analysis by using the computer code *TBCI.*

2. Results and Discussions

The measurement of a high-current multi-bunched beam at the above-mentioned energy analyzing station gave the energy spectrum shown in Fig.1. There are several peaks in the spectrum which correspond to bunches. The bunch-to-bunch energy difference, which should be attributed to the longitudinal wake field, was estimated by a numerical analysis according to the following. The energy gains and charges of bunches were determined from Fig.1 and are listed in Table 1.

Before starting a numerical analysis, we present the basis of energy extraction by a multi-bunched beam [4]. The assumptions of our numerical analysis are as follows.

1) An accelerating structure of length L is fully filled with RF power.

2) The attenuation of the field is negligible, or the structure has a constant gradient.

3) Since the group velocity of the fundamental mode is a few percent of the speed of light, we neglect the propagation of the fundamental wake field, compared to the structure length.

After all the total energy gain of the n-th bunch is given by

$$\Delta E_n/eL = \mathcal{E}_0 - kq_n - 2\sum_{m=1}^{n-1} kq_m \ , \qquad (1)$$

where q_m is the charge of the m-th bunch and k the loss factor, $\mathcal{E}_0$ the field gradient. Since the loss factor is a function of the bunch length, σ_z, it can assume different bunch-to-bunch values if each bunch possesses its own length, respectively.

We now compare the experimental result with a numerical analysis. We evaluate the longitudinal wake field by means of the *TBCI*-code. Although the structure of the KEK positron generator linac is a quasi-constant gradient, the evaluation was performed by assuming a constant impedance structure. Figure 2 shows the calculated longitudinal wake field excited by a bunch of length 7.5 mm, which is a probable bunch length of the KEK positron generator linac. In order to obtain a loss factor of constant gradient structure, we calculated the corresponding wake fields of a constant impedance structure using various apertures and then average them. Assuming that all of the bunches have the same bunch length (7.5 mm) and using the expression for the energy gain (1) with the calculated loss factor, we then obtained the energy spectrum shown in Fig.3(b).

To improve the numerical estimation, we include the higher modes of longitudinal wake field. To this end, we computed the loss factors at the positions of the trailing bunches, which are listed in Table 1. Note that the loss factors at the following bunches are almost double the single bunch loss factor, as expected. The difference is ascribed to the higher modes of the longitudinal wake field. Using the modified loss factors, the energy spectrum (c) in Fig.3 is computed.

The measured energy spectrum can be partly explained by a numerical analysis. To obtain a better agreement between the experimental and numerical investigations, we need to obtain the precise information concerning the bunch length. This implies that keeping the energy of bunches in high precision requires us to closely control the bunch lengths of the multi-bunched beam.

References

[1] K. Bane, C. Adolphsen, T.L. Lavine, M. Ross, J. Seeman and K. Thompson, Measurements of Longitudinal Phase Space in the SLC Linac.

[2] A. Asami and the Electron linac Group, in *Proceedings of the 1988 Linear Accelerator Conference*, Williamsburg, VA, U.S.A., 1988; A. Enomoto, I. Sato, A. Asami, G, Horikoshi and J. Tanaka, Nucl.Instrum.Methods. A281, 1 (1989).

[3] Y. Ogawa, T. Shidara, H. Kobayashi Y. Otake and G. Horikoshi, KEK Preprint 89-76 (1989); Y. Ogawa, T. Shidara, H. Kobayashi and A. Asami, in *Proceedings of the 1990 Linear Accelerator Conference*, Albuquerque, NM, U.S.A., 1990.

[4] R. Ruth, SLAC-PUB-4541 (1988).

Table 1. List of bunch characteristics

Bunch	Energy Gains (MeV)	Charges (nC)	Loss Factor ($\times 10^{13}$ V/C/m)
1	255.2	1	1.8
2	251.1	6	3.4
3	245.3	7	3.3
4	239.4	9	3.4
5	236.2	4	3.5
6	233.9	4	3.2

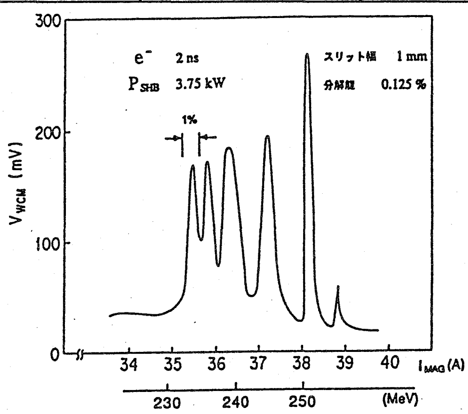

Figure 1. Energy spectrum measured at the energy analyzing station.

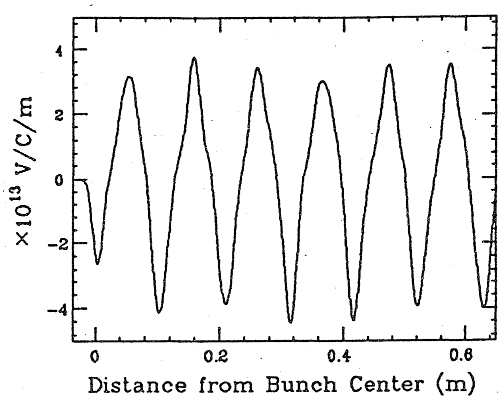

Figure 2. The longitudinal wake field of the KEK positron generator linac excited by a bunch 7.5 mm long.

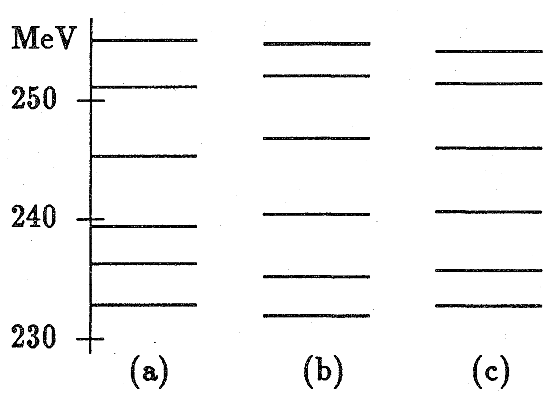

Figure 3. (a) Energy spectrum measured. (b) Energy spectrum computed not including higher modes. (c) Energy spectrum computed with higher modes.