WAKE FIELDS GENERATED BY A HIGH-CURRENT SINGLE BUNCH

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Abstract

Experimental observation of the wake potential has been carried out with a single bunch accelerated by the Osaka University Single Bunch Electron Linear Accelerator. The phase dependence of the energy distribution of the single bunch shows that the single bunch is accelerated by the superimposed field of the wake potential and the external accelerating wave. The energy distribution of a single bunch depends on the phase angle by which the bunch front leads the crest of the accelerating wave produced by the external rf source. In order to reduce the energy spread of the electrons in the single bunch, the bunch should be accelerated at the positive phase angle where the rising slope of the accelerating voltage waveform can be made to cancel. The decrease in energy spread gives rise to the reduction in the average energy gain per unit length of a accelerating waveguide.

1. Introduction

When a high-current single bunch passes through an rf-structure, a wake field is generated by a bunch-cavity interaction. The wake field generated by an electron in the single bunch gives rise to the forces acting on the successive electrons in the single bunch. The transverse components of the wake field deflect succesive electrons in the single bunch and gives rise to changes of both energy and current distributions of the single bunch itself.

When an electron passes throuth an rf-structure, the wake potential is defined as the potential experienced by a test particle following the electron for a distance. Therefore, the net change of energy of each electron is expressed as the wake potential obtained by the integration of the wake field while the bunch travels through the structure and leaves it. When a high-current single bunch is accelerated in an rf-structure, the wake potential is not negligible, compared with the external accelerating voltage. Therefore, the total energy gain of an electron in the single bunch is obtained by adding the external accelerating voltage to the wake potential.

2. Dependence of the Energy Spectrum on the RF-phase

When the Osaka University Single Bunch Electron Linear Accelerator is adjusted in detail to accelerate a single bunch, the phase angle between the bunch and the accelerating wave can be controlled by a phase shifter. The phase is the angle by which the bunch leads the crest of the accelerating wave supplied by the external rf-source. As the energy of the bunch injected to the accelerating waveguide is estimated to be about 2 MeV, it is reasonable to assume that the shape of the bunch is kept constant in spite of the changes of the phase.

Figure 1 shows the dependence of the energy spectrum on the rf-phase for the single bunch of 0.5 nC. With the increase of the phase, the head of the bunch approaches to the crest of the wave. Therefore, the maximum energy increases untill the bunch head reaches the crest. Whenever the bunch head leads the crest, and the electron in the bunch exists on the crest, the maximum energy is kept constant though the phase being increased. It is because the single bunch of 0.5 nC is not so intense that the wake potential gives rise to the distortion of the accelerating field generated by the external rf-source. When the bunch tail leads the crest, the maximum energy decreases with the phase. Therefore, the single bunch shape can be obtained by measuring the number of electrons with maximum energy against the phase. The result shows that the single bunch waveform is not Gaussian shape but Gamma function shape with a tail. The pulse width of the single bunch is evaluated to be 16.1 ps in f.w.h.m. from the phase angle.

When the high-current single bunch of 5 nC is accelerated, the wake potential is intense enough to change the energy spectrum of the single bunch. Figure 2 shows the dependence of the energy spectrum on the rf-phase for the single bunch of 5 nC. With increase of the phase, the head of the bunch approaches to the crest, and then the maximum energy increases. When the bunch head leads the crest, the maximum energy decreases by the wake potential. When the bunch tail approaches to the crest, the maximum energy increases. When a part of the bunch tail is accelerated on the crest, the maximum energy is kept constant. Figure 3 shows the dependence of the energy spectrum on the rf-phase for the single bunch of 10 nC. The decrease in the maximum energy for the single bunch of 10 nC is greater than that for the single bunch of 5 nC. It shows that the wake potential increases in proportional to the bunch charge.

When the center of the high-current single bunch is accelerated on the crest of the accelerating wave produced by the external rf source, the accelerating field is made a dent in the crest by the wake potential. Therefore, the electrons with the maximum energy exist not in the center of the single bunch but in either side of the center. When the Cerenkov radiation generated by the electrons with maximum energy is measured by a streak camera, the current waveform with two splitted peaks can be observed.

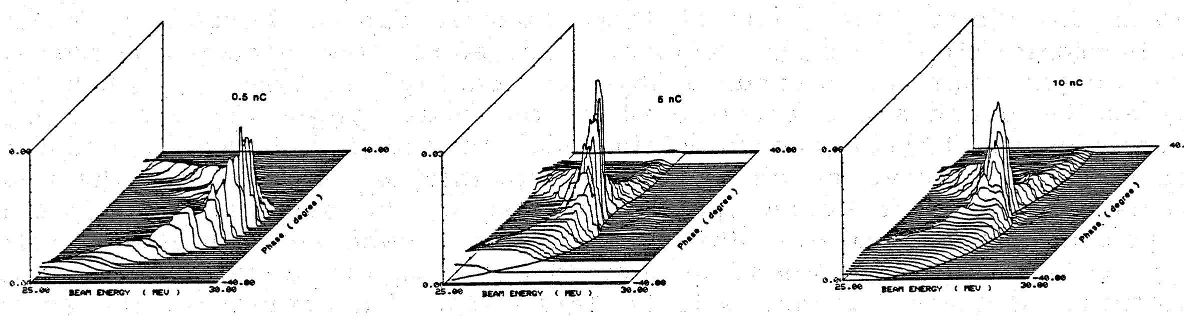
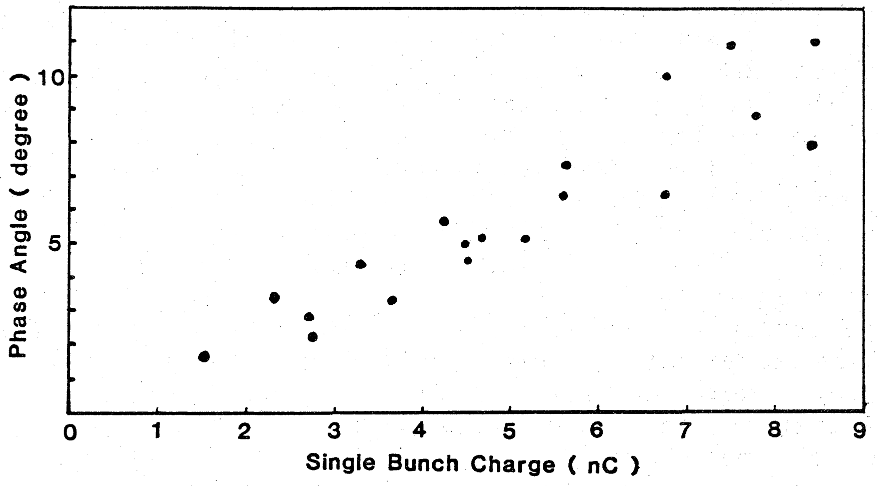


Figure 1-3. Dependence of the energy spectrum of the single bunch on the rf-phase

3. Energy Spread and Average Energy Gain

When a high-current single bunch is accelerated by the linear accelerator, the accelerating field has a deep dent produced by the wake potential. In order to reduce the energy spread of the electrons in the single bunch, the bunch should be accelerated at the positive phase angle where the rising slope of the accelerating voltage waveform can be made to cancel. The decrease in energy spread gives rise to the reduction in the average energy gain of the single bunch per unit length of the accelerating waveguide. As the wake potential increases with increasng single bunch charge, the rf-phase should be increased in order to accelerate a single bunch of higher current. Therefore, the average energy gain of the single bunch decreases with the single bunch charge. Figure 4 shows the dependence of the optimum rf-phase on the single bunch charge. As for the single bunch of 10 nC, the phase angle of 11.7 degrees is the optimum rf-phase to reduce the energy spread, but the average energy inebitably reduces about 2% in addition to the loss by the wake potential.



4. Effect of the Wake Fields between Bunches

When several bunches are accelerated in the transient mode by the Osaka University Linac, one of these bunches can be selected by a 12th subharmonic single bunch chopper. Therefore, the energy spectrum of one bunch can be measured by an energy analyser. When the successive bunches are accelerated at the phase angle where the energy spread of the first bunch is minimized, the broad spectrum is observed for every successive bunch. It is reasonable to consider that the wake fields excited by a bunch change energies of the successive bunches in a periodic rf-structure. When two or three bunches of higher current are accelerated by a linear accelerator, the energy spread of the total electrons in these bunches will be larger than the spread of the single bunch of the same charges.