WAKE FIELD GENERATED BY A HIGH-CURRENT SINGLE BUNCH

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Abstract

The wake field generated by a bunch-cavity interaction increases in proportional to the bunch charge, and the shape of its potential depends on the bunch shape. The wake potential has been calculated by Maxwell equations, boundary conditions being considered. Experimental observation of the wake potential has been carried out with a single bunch accelerated by the Osaka University Single Bunch Electron Linear Accelerator. By measuring the phase dependence of the energy distribution of the single bunch, the wake potential can be observed. Besides, the time distribution of electrons with maximum energy shows the wake potential of the single bunch accelerated on the crest of the external accelerating field.

1. Introduction

When a high-current single bunch passes through a cavity, 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 successive electrons in the single bunch and increase the emittance of the single bunch itself. On the other hand, the longitudinal components of the wake field change energies of successive electrons in the single bunch and give rise to changes of both energy and current distributions of the single bunch itself.

When an electron passes through a cavity, 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 cavity and leaves it. When a high-current single bunch is accelerated in a cavity, 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. As the wake potential increases in proportional to the bunch charge, the average energy of electrons in the single bunch decreases in proportional to the bunch charge.

2. Energy Spectrum of the Single Bunch

The dependence of the energy spectrum of the single bunch has been observed on the bunch charge by the Osaka University Single Bunch Electron Linear Accelerator[1]. The experimental result shows that the average energy of the electrons in the single bunch decreases in linear with increasing bunch charge. The rate of decrease of the average energy is independent of both the external rf-power and rf-phase. The result also indicates that the minimum energy of electrons in the single bunch decreases in linear with increasing charge, while the maximum energy of electrons in the single bunch depends on the phase between the external rf and the single bunch. Whenever the head of the bunch is accelerated on the crest of the accelerating field, the maximum energy of electrons is kept constant, though the bunch charge being changed (fig.1). In other cases, the maximum energy decreases with increasing bunch charge (fig.2).

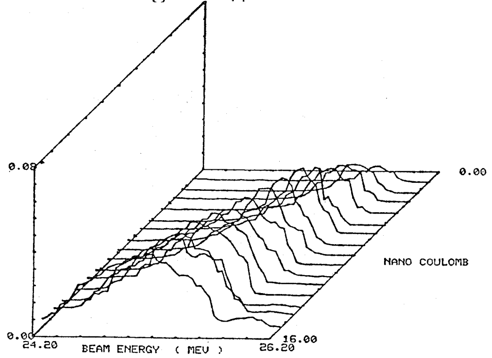

Figure 1. The dependence of the energy spectrum of the single bunch on single bunch charge.

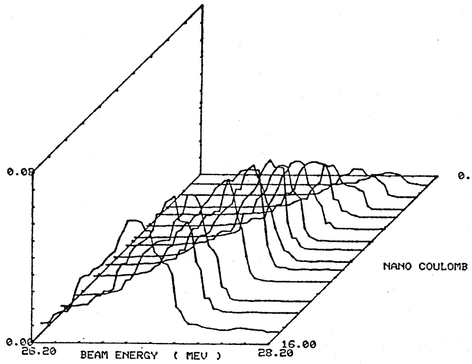

Figure 2. The dependence of the energy spectrum of the single bunch on single bunch charge.

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

When the linac 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 produced 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 3 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 until 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 (fig.4). It 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.

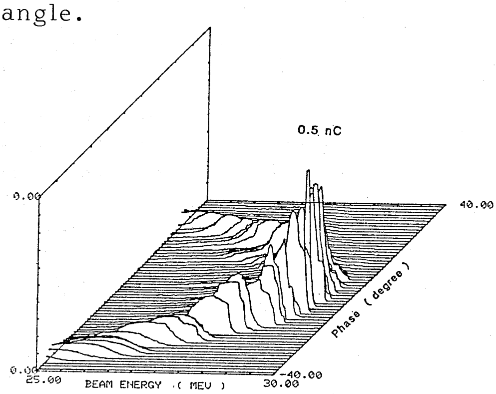

Figure 3. Dependence of the energy spectrum of the single bunch on the rf-phase.

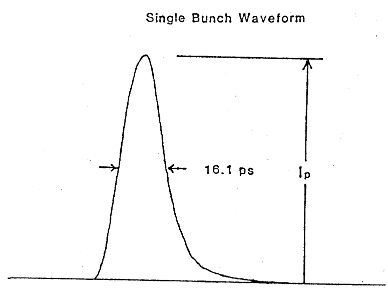

Figure 4. Single bunch waveform.

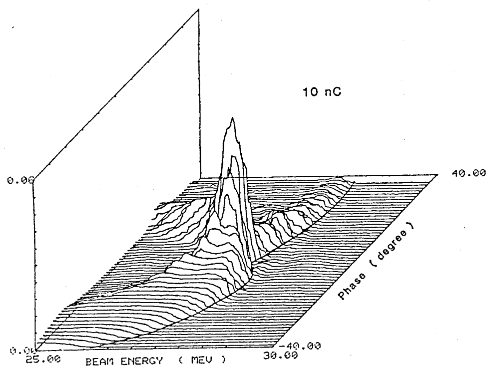

Figure 5. The dependence of the energy spectrum of the single bunch on the rf-phase.

When the high-current single bunch of 10 nC is accelerated, the wake potential is intense enough to change the energy spectrum of the single bunch. Figure 5 shows the dependence of the energy spectrum on the rf-phase for the single bunch of 10 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.

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 wave is made a dent in the crest by the wake field. 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.

From the experimental results, it is reasonable to consider that the wake field generated by the single bunch changes the energy distribution of the electrons in the single bunch itself. It seems that the electron in the head of the single bunch does not lose any energy, while the successive electrons decrease their energies with increasing bunch charge.

4. Energy Spectrum of Two Bunches

Two bunches can be accelerated only by varying the timing of beam injection to the subharmonic prebuncher. Each charge of these two bunches can also be controlled to be nearly equal by measuring the bunch waveforms with the streak camera. The total charges in two bunches can be controlled by adjusting the voltage of the grid bias. Each bunch of these two bunches can be selected by a 12th subharmonic single bunch chopper, and it is guided to the energy analyzer through the transport tube. Therefore, the energy spectrum of one of the two bunches can be separately observed.

The energy spectrum of the electrons in the first bunch can be minimized by adjusting the rf-phase angle in order to cancel the negative-going wake potential. When the second bunch is accelerated at the phase angle where the energy spread of the first bunch is minimized, the broad energy spectrum of the second bunch is observed. The energy spread of the first bunch is minimized only when the first bunch is accelerated at the phase angle of about 10 - 15 degrees. On the other hand, the energy spread of the second bunch is minimized when the second bunch is accelerated on the crest of the accelerating wave. It is reasonable to consider that the second bunch is affected by the wake field generated by the first bunch.

References

(1) S.Takeda, M.Kawanishi, K.Hayashi & H.Sakurai, Nucl. Instr. and Meth. 188 (1981) 1.