NUMERICAL STUDY OF INTERFERENCE BETWEEN TRANSITION RADIATION AND CERENKOV WAKE FIELD RADIATION IN A PLANAR DIELECTRIC STRUCTURE*

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Abstract

The PIC code KARAT is used to study the interference between transition radiation and Cerenkov wake field radiation, set up by the passage of a bunch of charge through a dielectric structure of finite length. An example studied is a tall, dielectric-lined rectangular wake field microstructure, recently proposed as a stageable element of an advanced linear accelerator, which would use a train of femtosecond duration bunches. These bunches would be chopped out of a longer bunch using a powerful $\mathrm{CO_2}$ laser and formed into a rectangular-profile bunch by a quadrupole. The bunches set up a periodic wake field which can be built up to as much as 600 MV/m using ten 3-fs bunches each containing a charge of 1-pC. Of interest is the difference in relative propagation speeds of the transition radiation and the Cerenkov radiation (which advances almost at c), and the relative magnitudes of the fields.

INTRODUCTION

Acceleration of electrons in wake fields set up by a series of driving bunches in a dielectric structure has shown promise as a linear accelerator in which large gradient electric fields might be possible [1, 2]. Such wake fields are appealing because they do not require power injected into the structure from an external source, but rather use fields set up by bunches obtained from a conventional rf linac. Recently, we have studied the use of tall, planar dielectric wake field structures having micron-scale dimensions [3]. Such structures are capable of precision manufacture using microcircuit technologies, and have the capability of achieving very high field gradients: indeed, a series of ten, 3-fs, 1-pC charge bunches has recently been shown to set up a wake field of $\sim$ 600 MV/m in a structure 20 $\mu\mathrm{m}$ $\times$ 150 $\mu\mathrm{m}$ in cross section [4]. The bunches are 10 $\mu\mathrm{m}$ wide, and dielectric slabs a few $\mu\mathrm{m}$ thick line the structure (see Fig. 1). Planar dielectric structures offer the attraction of improving the stability of the bunch motion and the amount of charge carried compared with a cylindrical structure of comparable size, and the small transverse dimension permits a large wakefield to be developed.

The bunches could be obtained initially from a 500 MeV rf linac-type source, and are processed using a LACARA accelerator "chopper" [3], or possibly an IFEL [5] used as a "pre-buncher", so as to obtain a sequence of bunches a few fsec in duration. A TW $\mathrm{CO_2}$ laser is used as a "modulator" [3] of the original psec, nC bunch provided by the linac to form such a sequence of short bunches, periodically spaced, each having charge in the pC range. These *drive* bunches, the energy of which can be recycled, would be followed by an *accelerated* bunch which is situated in the accelerating component of E_z which follows the drive bunch train. In this way fields comparable with those achieved in laser plasma wake field accelerators can be set up, yet the energy is obtained largely from the rf linac source rather than a laser. We have found that it is possible to distort the original circular cross section of the input bunches into a near rectangular profile, using a quadrupole, and that the rectangular profile is maintained for a distance $>$ 10 cm of travel [3].

Transverse fields set up by the bunch have been calculated, and an estimate has been made of how far a drive bunch might travel without additional focusing [6] ($\sim$ 7.1 cm). Also, studies have been made of fields in 3D using the PIC code KARAT [7], and show that the E_z component of wake field is rather uniform across the structure. In the structure under study, the wake fields are dominated by two modes having nearly the same periodicity.

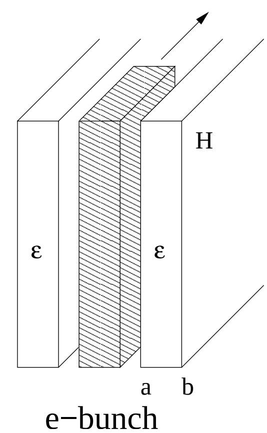

Figure 1: Schematic of slab bunch within a planar dielectric wake field structure.

FIELDS FROM A SINGLE BUNCH

The transition radiation which is emitted when the bunch enters or leaves the structure is typically omitted in analytic

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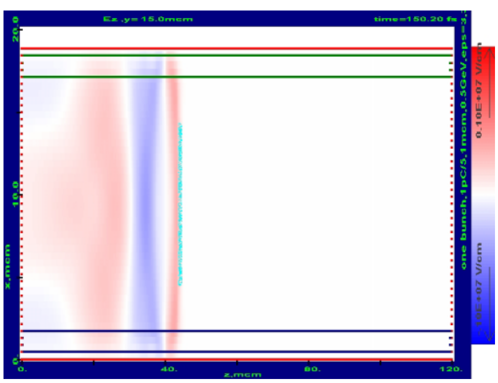
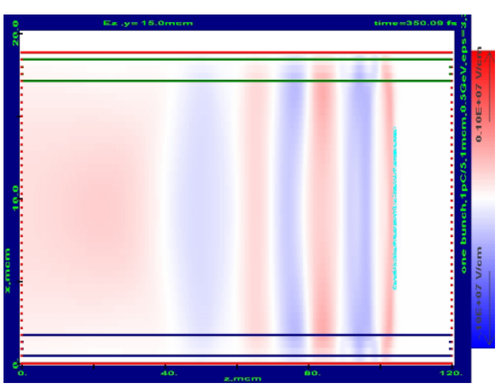
theoretical treatments of the wake fields. The transition radiation effect was remarked upon in [4, 8] and was recently treated analytically using a simplified model by Onishchenko, *et al* [9]. Qualitatively, the transition radiation emitted by the entry of the bunch into the structure interferes with the wake field radiation in a certain region. This region extends from the point where the bunch enters the structure to a front which expands with the group velocity of waves in the structure. As the bunch and its wake field move with nearly the speed of light, the expanding region between the transition zone and the bunch fills with wake field radiation which resembles that emitted by the bunch in an infinitely long structure. However, the group velocity depends on the mode frequency, so in cases of multimode operation (see e.g. [8]) the transition radiation zone would not be very clear. It shows up more clearly in the example of wake field structures in which mainly one mode is excited [9], which is the case studied here. The planar dielectric structure studied here is 18.8 μm $\times$ 30 μm $\times$ 120 μm long. The dielectric slab is 1.9 μm in thickness and has a dielectric constant ϵ of 3. The vacumn channel is 15 μm wide. The microbunch has a charge of 0.2-pC and its pulse duration is 3.3-fs long. The transverse profile of the bunch is 10 μm $\times$ 26 μm.



(a) at 150 femtosecond



(b) at 350 femtosecond

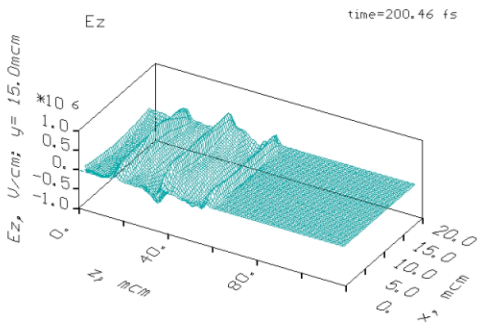
Figure 2: Transition radiation and wake field from a single bunch.

Figure 2 shows the axial field E_z pattern in the x-z plane at the midway y-plane, at 150-fs and 350-fs after the entry of the first bunch into the structure. [These are color figures. The color scale indicates the magnitude of the field and the color itself represents the field's polarity (red for positive polarity and blue for negative).] The excited wake field alternates its polarity, thus the color in the figures too, periodically. In Fig. 2(a), the electron bunch has just entered the structure for a short period of time (150-fs), such that the transition radiation dominates and only one wake field period is seen following the electron bunch. As the electron bunch traverses into the structure further (Fig. (2b)), the wake field radiation pulls away from the transition radiation, due to the difference in their propagation speeds, and several wake field periods are formed. The period of the wake field is close to 20 μm. We also see the region where the transition radiation intereferes with the wake field radiation gradually expands, as the electron bunch propagates further. The propagation speed of the head of the wake field radiation is that of the bunch, whereas the propagation speed of the transition radiation front is estimated at about 1.7×10^{10} cm/sec, close to $c/\sqrt{\epsilon}$ (further study is needed to determine the propagation speed of the transition radiation). The magnitude of the wake field (E_z) is $\sim$ 40 MV/m, whereas the magnitude of the transition radiation is weaker, at $\sim$ 10 MV/m, an decrease which is consistent with the simplified analytic model by Onishchenko, *et al* [9].

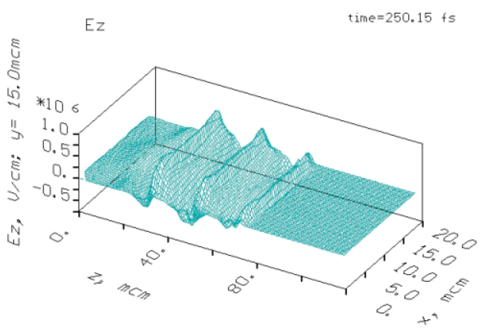
FIELDS FROM THREE BUNCHES

For the excitation of the wake field in a dielectric structure, a high gradient accelerating field can be obtained by using a train of bunches, carefully spaced at the wake field's period [1, 2].

For the dielectric structure in which mainly one mode is excited, transition radiation has an effect on the build-up of the wake field generated by a train of bunches. The dielectric structure we studied here is such a structure. For the PIC code Karat simulation, the bunches are placed 20 μm apart to match the wake field period of this planar structure and to permit the build-up of the wake field by coherent superposition. All other parameters are the same as the simulation for a single bunch. Figure 3 shows the axial field E_z in the x-z plane at mid y-plane at 200-fs and 250-fs. The build-up of the wake field is evidenced for the first 2 bunches of Fig. 3(a). The third bunch in Fig. 3(a), is still in the transition radiation zone and the wake fields of the three bunches don't add up linearly because of the interference between the transition radiation and the Cerenkov wake field radiation. As the bunches advance further away from the transition radiation region (Fig. (3b)), the build-up of the wake field is evidenced for all three bunches. Figure 4 is the E_z *vs* z plot along the center of the planar structure and gives a clear reading of the magnitude of the wake field. The intereference effect of the transition radiation is clearly seen in Fig. 4(a), as the magnitude for 2nd and 3rd wake field is nearly the same.

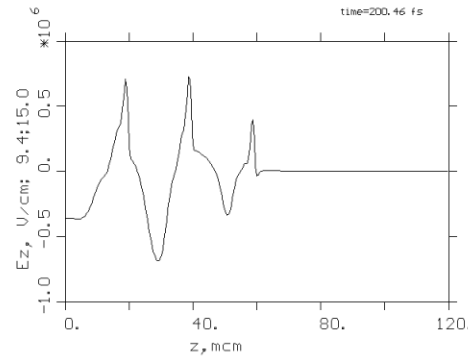


(a) 200 femtosecond

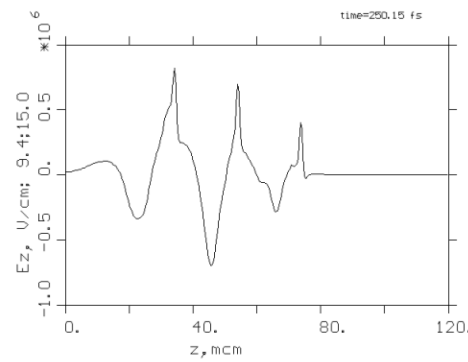


(b) 250 femtosecond

Figure 3: Transition radiation and wake field from three bunches.



(a) 200 femtosecond



(b) 250 femtosecond

Figure 4: E_z *vs* z along the center of the planar structure from three bunches.

CONCLUSIONS

We have studied the interference effect between the transition radiation and the Cerenkov wake field radiation in a planar dielectric structure using the PIC code Karat. We have chosen a structure where mainly one mode is excited. The transition radiation is important when the bunch has just entered the structure. Due to the difference in propagation speed between the transition radiation and the wake field radiation, a train of periodic wake fields is excited as the bunch advances further into the structure. The transition radiation also has an effect on the build-up of the wake field by a train of bunches. This is a problem for system that uses a very long train of drive bunches to build up the accelerating wake field in a short structure [10].

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