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ABSTRACT

Based on Lienard–Wiechert retarded potentials and the potential due charges image on the cathode, a rigorous relativistic description of beam transport inside an RF-photoinjector is presented. Velocity-dependent effects are explicitly taken into account. Simulations are presented for parameters of the ELSA photocathode where velocity-dependent effects are particularly important. These simulations show that at the center of the cathode ($r = 0, z = 0$) the self-field of the beam and the field driven by the image charges on the cathode are equal. The self-field of the beam is dominated by the field due to the charges image on the cathode as one moves from the tail to the head of the beam. Far from the cathode, the self-field becomes the dominant one.

1. Introduction

RF-photoinjectors facilitate the production of high-quality beams, with both low emittance and low-energy spread. Once charged particles are emitted from the cathode, they are rapidly accelerated. During this process, the bunches of charged particles excite parasitic higher-order modes within the cavity which have the ability to modify the acceleration of particles within the beam.

We contrast the beam dynamics interaction in a photoinjector with that which occurs when the particles have been accelerated to ultra-relativistic energies. At these ultra-relativistic energies the electromagnetic field (e.m.) excited by the charged-particle beam is conveniently represented as a wakefield [1] and the particles are assumed to be traveling at the velocity of light. This representation is valid for the acceleration of ultra-relativistic beams in the main linacs of linear colliders and light sources for example [2].The wakefield excited in this regime has been analyzed in some detail [3] and several codes are available to simulate both the wakefield effects and the associated beam dynamics of the interaction [4–6]. However, the initial stage of acceleration constitutes a different regime, and warrants a treatment in which both velocity-dependent and retardation effects must both be taken into account explicitly. This is clearly the case in photoinjectors where the energy is sufficiently low such that a rapid change in particle velocity occurs during acceleration. In this regime space-charge forces and self-field effects are important issues to consider in an analysis of the beam dynamics [1,7–9].

Wakefield effects in photoinjectors have been considered from the perspective of a normal-mode expansion [10–13]. In this paper the e.m field is analyzed in terms of Lienard–Wiechert potentials and the method of images. An important technique in the realization of high-brightness electron injectors is the velocity (or klystron bunching) in which the acceleration is off crest and there is significant rotation of the electron bunch in longitudinal phase space. Our model assumes that slices of the electron beam cannot overtake one another. Moreover, the restriction of a constant velocity beam is removed [1–3].

This technique is applied to parameters of the ELSA photoinjector facility [14]. A schematic representation of the essential parameters of this photoinjector cavity is illustrated in Fig. 1. We are able to simplify this analysis to that of the modes in a pill-box cavity by considering the time required for the radiation field to propagate to the walls of the cavity. The e.m field propagates at c (the speed of light), and after a time t, the field has propagated to a distance ct. Thus, by the principle of causality, at distances larger than ct the field excited by the beam is unable to influence subsequent parts of the beam. If we consider the ELSA parameters, for an RF-field on the cathode E_0 with amplitude of a few tens of

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