On the characteristics of the Cherenkov and Ohm forces

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Abstract

The wake field generated by a moving charge in the vicinity of a non-magnetic material is examined in terms of the decelerating reaction force. Two main cases are investigated – the Cherenkov and Ohm effects. In the first case we examine the force which results from the Cherenkov radiation emitted as the charge moves in the vicinity of a lossless dielectric medium; in the second – the decelerating force is a direct result of power dissipated by excited currents on the surrounding lossy wall. In both cases, for highly relativistic particles the force is independent of the particle's energy.

1. Introduction

When an electron moves along a vacuum channel bored in a dielectric material it causes emission of radiation, provided its velocity exceeds the phase velocity of an electromagnetic plane wave in the medium. This is the so-called Cherenkov radiation. What a remote observer measures as electromagnetic energy comes at the expense of the particle's kinetic energy; in other words, the particle is slowed down. For better understanding of this deceleration force, one has to examine the field distribution in the vicinity of the particle. Disregarding, for a moment, the presence of the dielectric, a point charge generates in its rest frame of reference an electrostatic field which is measured by an observer in the laboratory frame of reference as an infinite spectrum of (radially) evanescent waves. As these waves hit the discontinuity between the vacuum channel and the dielectric, a so called secondary field is generated. This is the reaction of the medium to the presence of the charged particle. It is this secondary field which slows down the electron. A similar force acts on an electron as it traverses a vacuum channel bored in a lossy medium. Currents excited by the moving charge in the metal where power is dissipated at the expense of the particle's kinetic energy. In this study we shall examine these processes in detail.

Abundant literature is available on the motion of charged particles in various structures, most of it is either related to particle accelerators [1] or to radiation sources [2]. In the first instance the finite conductivity of the surrounding structure is formulated in terms of so-called shunt impedance, which is a measure of the electromagnetic power dissipated on the walls relative to the accelerating electric field which acts on the bunch of electrons. The shunt impedance is defined at the frequency of this field and does not account directly for the decelerating effect experienced by the bunch due to the field it excites. Wake fields have been also investigated thoroughly (e.g. see Ref. [3]. Between two accelerating modules the electron bunches traverse long-drift regions and the effect of these regions on the motion of the electrons has also to be accounted for.

In the context of radiation sources, the input and the output section of a device are in many cases isolated by drift regions which, at the frequency of interest, are below cutoff. This is the case in klystrons, some traveling wave tubes [4] and some gyrotrons [5]. In some cases, such as severs in traveling wave tubes or low-Q cavities in gyrotrons, where lossy materials are introduced deliberately in order to minimize reflections or suppress high modes. Thus, lossy medium is important in many devices, and its effect on the single particle dynamics should be examined. As a comparison to the force which a lossy medium exerts on a moving particle we also examine the force in the vicinity of a dielectric medium.

2. General formulation

In examining the effect of the surrounding material on a moving particle, it is convenient to introduce first a cylindrical coordinate system $(r, \phi, z)$; its $z$-axis is aligned with the axis of the vacuum channel. In free space the