

Demi-Disk Travelling Wave Accelerating Structure *

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Abstract

The dark current in a normal disk-loaded accelerating structure is one of the main obstacles which limit the accelerating gradient going higher. In this paper a demi-disk accelerating structure is proposed in order to reduce the dark current. Its transverse rf focusing forces can reduce the effects of wakefields on the beam's emittance growth which is preferable in future linear colliders. 3D program PRIAM [1] has been used to calculate the field distributions and the dispersion curves of this structure. Estimations of the trajectories of the field emission electrons have been done.

I INTRODUCTION

The next generation TeV e^+e^- linear colliders require that the accelerating structures support high accelerating gradient in order to keep the machine within a reasonable scale. The fact that various beam property control methods, such as BNS damping [2], energy spread compensation [3] and fundamental mode detuning [4], lose acceleration efficiency emphasize also the importance of this requirement. It is found, however, that in a conventional axisymmetric disk-loaded accelerating structure, when the field level reaches certain value, appreciable electrons are emitted from the surface of the accelerating structure and some of them are captured by the travelling wave and accelerated continuously along the axis of the accelerating structure [5][6]. This captured electrons' flow is so-called dark current. The dark current has very wide energy spectrum and therefore produces lot of noises within detectors. On the other hand the dark current excites wakefields and takes precious rf power in the form of beam loading.

In this paper a demi-disk travelling wave accelerating structure is proposed aiming to reduce the dark current. In section 2 we will first look at the dark current in the case of conventional disk-loaded accelerating structures. In section 3 the demi-disk structure is investigated.

II CONVENTIONAL DISK-LOADED ACCELERATING STRUCTURE

In order to get some general ideas of the behaviour of the field emission electron in a conventional axisymmetric structure let's look at the longitudinal and the transverse motions of it.

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The longitudinal electric field inside an axisymmetric disk-loaded structure is expressed as:

$$E_z(r, z, t) = E_z(r, z)\sin(\omega t - k_g z + \phi_0) \quad (1)$$

where $\omega = 2\pi f$, $k_g = 2\pi/\lambda_g$ is the fundamental wave number of this travelling wave structure and ϕ_0 is the initial emission phase of the field emission electron when it is emitted at $z = 0$ and $t = 0$. If only linear term is kept, the electric field near the axis can be expressed as:

$$E_z(r, z, t) = E_z(0, z)\sin(\omega t - k_g z + \phi_0) \quad (2)$$

In the following analytical treatment, $E_z(0, z)$ has been chosen to be a constant E_{z0} . From eq. 2 we have

$$\frac{d\gamma}{dz} = \frac{qE_{z0}}{m_0c^2}\sin(\phi) \quad (3)$$

where

$$\phi = \omega t - k_g z + \phi_0 = k \int_0^z \left(\frac{\gamma}{(\gamma^2 - 1)^{1/2}} - 1 \right) dz + \phi_0 \quad (4)$$

where γ is the ratio between the electron's relativistic energy and the rest energy m_0c^2 , $k = 2\pi/\lambda$ and λ is the electromagnetic wavelength in free space. In eq. 4 k_g has been chosen equal to k (the phase velocity of this travelling wave $\beta_p = \omega/kc = 1$ through out this paper). When $\gamma \gg 1$, ϕ will be frozen at its asymptotic value [7]

$$\phi_f = \frac{1}{\alpha \sin(\phi_0 + \delta\phi)} + \phi_0 \quad (5)$$

$$\alpha = \frac{qE_{z0}}{m_0c^2k} \quad (6)$$

where $\delta\phi$ can be calculated from an empirical formula which is given as:

$$\delta\phi(\text{degree}) = 19E_{z0}^{-0.9} \quad (7)$$

where E_{z0} is in MV/cm. In fact it is found that $\delta\phi$ can be neglected if $\phi_0 > 60^\circ$. From eq. 3 and eq. 5 one can get the approximate expression of the final energy gain of longitudinally captured electrons with respect to the frozen phase and electron's longitudinal position z :

$$\Gamma_f = 1 + \alpha \sin(\phi_f)kz \quad (8)$$

In the following we will discuss the transverse motion of the field emission electron keeping the simplification of only using linear rf field terms. It is well known that the

From $\nabla \times H = \epsilon_0 \frac{\partial E}{\partial t}$, we have

$$\frac{\partial H_x}{\partial y} = \left(\frac{\partial H_y}{\partial x} - \epsilon_0 \frac{\partial E_z}{\partial t} \right) \quad (16)$$

$$\begin{aligned} H_x &= \int_0^y \left(\frac{\partial H_y}{\partial x} - \epsilon_0 \frac{\partial E_z}{\partial t} \right) dy \\ &= -yK_h \sin(\omega t - kz + \phi_0) \\ &\quad - y\epsilon_0 \omega E_{z0} \cos(\omega t - kz + \phi_0) \end{aligned} \quad (17)$$

where the constants E_{y0} , H_{y0} , K_e and K_h can be determined from the numerical results of PRIAM. We know from eq. 15 and eq. 17 that the transverse rf force acting on a particle can be expressed as:

$$\begin{aligned} F_y &= qE_{y0} \cos(\omega t - 2kz + \phi_0) \\ &\quad + qyk(1 - \beta_p \beta_z) E_{z0} \cos(\omega t - kz + \phi_0) \\ &\quad - qyK_e \cos(\omega t - kz + \phi_0) - qy\mu_0 v_z K_h \sin(\omega t - kz + \phi_0) \end{aligned} \quad (18)$$

As for the expression of the rf force in the horizontal plane ($y = 0$), similarly, we have

$$F_x = qxK_e \cos(\omega t - kz + \phi_0) + qx\mu_0 v_z K_h \sin(\omega t - kz + \phi_0) \quad (19)$$

For the accelerated electrons ($\gamma \gg 1$ and $\beta_z \approx 1$), by ignoring the first term in eq. 18 which doesn't synchronize with the electrons and using eq. 5, the transverse rf forces can be rewritten as:

$$F_y = -qyK_e \cos(\phi_f) - qy\mu_0 v_z K_h \sin(\phi_f) \quad (20)$$

$$F_x = qxK_e \cos(\phi_f) + qx\mu_0 v_z K_h \sin(\phi_f) \quad (21)$$

It is obvious that if in one plane it is focusing in another plane it will be defocusing. In order to have focusing for accelerated beam in both transverse planes, rotating the polarization of the demi-disks along the structure is necessary as shown in Fig. 5. The philosophy of this design is to deflect the low energy field emission electrons in each short uniform section as shown in Fig. 1, while keep focusing the accelerated beam in the whole accelerating structure against the transverse wakefields. In this paper attentions will be put to the motions of the field emission electrons in the uniform section only. Based on the linear rf force expressions in eq. 18 and eq. 19, field emission electrons' trajectories have been calculated and shown in Fig. 6 and Fig. 7. From these two figures it can be seen clearly that few electrons can be captured as dark current since in one transverse plane field emission electron is focused in another plane it will be defocused.

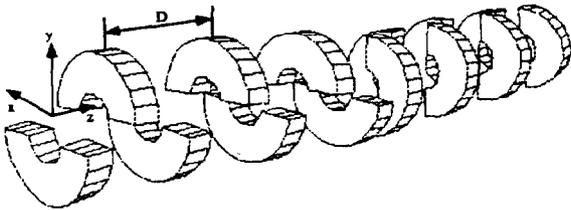


Figure 5: Demi-disk structure with rotating disks

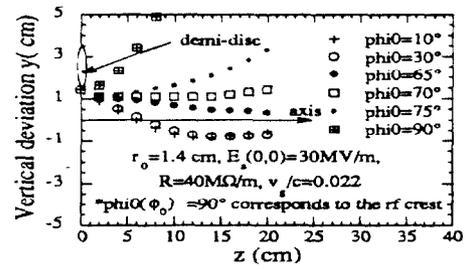


Figure 6: The trajectories of the field emission electrons in the vertical plane with different emission phase ϕ_0

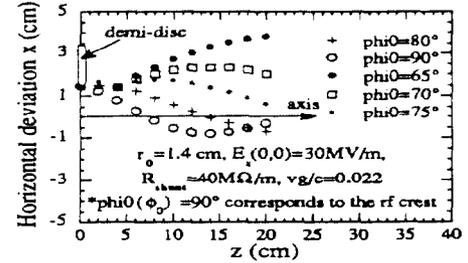


Figure 7: The trajectories of the field emission electrons in the horizontal plane with different emission phase ϕ_0

IV DISCUSSIONS

Even the demi-disk structure discussed above is proposed to reduce the dark current, it might have other applications such as rf wigglers and the positron generation linacs. What should be pointed out is that if it is used as a positron generation linac, the adjacent demi-disks should have 90° polarization difference in order to focus quickly the low energy positrons in both transverse planes.

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