In this paper we expand on few important details of the Wakeatron concept. This is a device where electrons can be accelerated by the wake field of short intense proton bunches travelling along the axis of an rf structure. Specifically, we have examined the consequences of the longitudinal dynamics of both the electron and the proton bunches. Included were "mixing" in the proton bunches (crucial to the overall concept) and phase shifts (electron bunches relative to proton bunches) in the acceleration process. Because of the deterioration of the proton bunches, due to the "mixing" process, it is required that the Wakeatron is indeed staged in a number of consecutive sections.

The Wakeatron Concept

The Wakeatron has already been discussed in other papers /1,2,3/ to which we refer the reader. It consists of a sequence of cylindrical rf cavities or cells. Each cell has the shape of a pill-box with a length of 2 mm, an outer radius of 4 mm, and an inner diameter of 1 mm. The parameters of the geometry have been adjusted so that the lowest resonating frequency mode corresponds to a wavelength of 1 cm, or 30 GHz.

The Wakeatron is meant to accelerate electrons to very large energies, possibly in the TeV range, over a relative short distance. Two of these accelerators could be configured to provide an electron-positron linear collider with luminosity of 10^{33} cm^{-2} sec^{-1}.

The Wakeatron concept proposes to power the 30 GHz linac with relatively short intense proton bunches with an initial energy of 110 GeV. The proton bunch, which we shall call the "driver", is assumed to have a gaussian distribution with an rms bunch length of 3 mm. The driver, travelling along the axis of the rf structure, leaves a wake field. A test particle, moving in the same direction, would therefore be accelerated by an amount which depends on the distance from the driver. If we assume 3 x 10^{11} protons in a bunch, a maximum accelerating gradient of 80 MeV/m has been estimated, which is of reasonable interest. Moreover, the so called transformer ratio for the geometry described is 10, that is, with a 110 GeV proton bunch one should, in principle, be able to accelerate electrons to 1 TeV in one single stage. If near collider with luminosity of 10^{33} cm^{-2} set^{-1}.

Equations (1) and (2) describe a system consisting of charged particles moving due to applied fields of other particles and forces of their own. The physics comes from two parts; the wake field produced by the particles will cause a change in the particle momentum (Eq. (2)); this in turn will affect the speed of motion (Eq. (1)).

Equations (2) and (2) determine the motion of a particle with rest energy E0. Our model assumes that only one mode, the fundamental, is excited because of the length of the driver bunch. Wo and k, the wake field amplitude and number, are determined by the structure of the Wakeatron, as it has been explained above.

Electrons move practically at the speed of light, whereas protons have somewhat less velocity. This will cause the electrons to advance their motion with respect to protons and to slip out of the optimum phase of the accelerating field. To control the slippage, it is required to stop the acceleration at some point, to apply some mechanism to the two beams so that they are brought again at the right rf phase distance. We call "staging" the process of dividing the length of the accelerator in sections to minimize the slippage problem; and "phasing" the mechanism applied to both beams in between sections to compensate for the rf slippage. We have investigated the "staging" and came up with a criterion for the division of the accelerator length. This should be compared with the requirement due to "mixing". We have also investigated methods for "phasing" which would be useful for a one-stage design. One is forced to stage the accelerator because of the "mixing" problem. By using a fresh proton bunch for each stage, the requirement on "phasing" is softened.

Mixing

For a proton driven wake field accelerator, the energy gain or loss of a particle in the driver beam depends on the particles position within the bunch. Particles will acquire different momenta and, because of their heavy mass, will exchange position with respect to each other, a process called "mixing".

The physics can be described by the following equations that are derived from the Vlasov equation, which represents a sample of many real particles. We used the PIC (Particle In Cell) method /4/. The method divides the phase space (z,p) into Ng cells each of length Ax, with Ng x Ax. The motion of a macro-particle of charge q is approximated by the nearest grid node of coordinates Xj and Xj+1 with the weight...
accelerating and re-adjust the distance between the advanced 2 mm with respect to the protons, one stops dependent. Figure 4 shows the relation between proton bunches. The assumed 1 cm wavelength of the wake field could allow, for instance, perhaps 1 mm "phasing".

1. One serious problem for a proton driven wake field accelerator has to do with the difference in velocity of the proton and the trailing electron bunches. The assumed 1 cm wavelength of the wake field could allow, for instance, perhaps 1 mm slippage and maintain a high acceleration gradient. At the beginning the electrons could lag behind about 1 mm from the peak of the field. After electrons have advanced 2 mm with respect to the protons, one stops accelerating and re-adjust the distance between the two beams. We call this procedure "staging" and "phasing".

2. Another possible solution is to adjust the wavelength of the wake field. This depends on the geometry structure of the cavity. This can be done by simply varying the physical dimension of the structure in the different stages. For example, at the end of the stage, the distance d between the electrons and the protons is given by $d = \pi \lambda s/2$, here $s$ is an integer, $\lambda$ the wavelength and $s$ is the maximum allowed slippage in one stage. Thus by changing the wake field wavelength of the next stage such that $d = \pi \lambda l + \pi s/2$, the electron will be again in phase at the beginning of the next stage.

One can also consider the possibility of continuously adjusting the wavelength of the field so that the distance between the proton and electron bunches always be a multiple integer of the wake field wavelength. Since in this case there is no slippage, staging is necessary in order to recover the value of $\lambda(x)$ to its initial value $\lambda(0)$. Comparing this method with the mixing, one could use one stage for every new proton bunch. This method may be very impractical, nevertheless, because it requires precise mechanical tolerances in the construction of the cavities.

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References


Fig. 1. Average Momentum of a proton driver bunch in the Wakeatron.

Fig. 2. Energy gain of electrons in the Wakeatron.

Fig. 3. Schematic design of a multi-stage Wakeatron.

Fig. 4. Proton energy and stage length based on 2 mm slippage requirement.