CONF-890197--2

ANL-HEP-CP--89-25

DE89 009811

THE NONLINEAR CWFA

Paul Schoessow
Argonne National Laboratory, Argonne, IL 60439

ABSTRACT

The possible use of nonlinear media to enhance the performance of the Cherenkov Wakefield Accelerator (CWFA) is considered. Numerical experiments have been performed using a new wakefield code which demonstrate larger gradients and transformer ratios in the nonlinear CWFA than are obtained in the linear case.

INTRODUCTION

The CWFA has been the subject of recent theoretical[1] and experimental[2] investigations. The work to date has involved only linear media, and the question naturally arises as to whether the use of a nonlinear medium in the CWFA might enhance the gradient and transformer ratio analogous to what is observed in the nonlinear plasma wakefield accelerator.[3,4] The technique of using nonlinear media in transmission lines to compress electromagnetic pulses is well known,[5] and it was expected that similar effects should occur in dielectric wake field devices for an appropriate choice of the medium. The difficulty of solving Maxwell's equations with nonlinear constitutive relations argues for a numerical approach; however, none of the commonly available wakefield codes permit the inclusion of nonlinear media. Therefore we have developed a code (ARRAKIS) which calculates the fields in the CWFA for essentially arbitrary dielectric properties of the medium.

ARRAKIS is based on the two-step Lax-Wendroff technique, which is found to give good results for nonlinear problems in fluid dynamics.[6] In its present implementation the driving bunch is taken to be a rigid, relativistic gaussian charge distribution which passes on axis through a tube of dielectric material. Conducting boundary conditions ($E_{\parallel} = 0$) are imposed at the radius and endcaps of the tube.

NUMERICAL EXPERIMENTS

Some initial numerical experiments on nonlinear effects in the CWFA were performed using a medium which possesses the constitutive relation plotted in Fig. 1. The shape of this curve is similar to that observed in real media, exhibiting linearity for small electric field amplitudes ($\epsilon = 6$), with a gradual roll off at larger fields. Eventually the relationship again becomes linear, with a saturation dielectric constant $\epsilon_{sat} = 2$. No hysteresis effects were included in the simulation, and the parameter values chosen are illustrative rather than characteristic of any particular medium. The tube radius used was 1.3 cm, with beam parameters $\sigma_z = 0.3$ cm, $\sigma_r = 0.2$ cm, and $Q_{tot} = 16$ nC. For comparison, a linear case for $\epsilon = 6$ was also run, using the same geometry and bunch parameters.

Work supported by the U.S. Department of Energy, Division of High Energy Physics, Contract W-31-109-ENG-38.
Submitted to the Proceedings of the 1989 Lake Arrowhead Workshop on Advanced Accelerator Concepts, Lake Arrowhead, CA, Jan. 9-13, 1989.

The time evolution of the longitudinal electric field at r = 0 is shown for the linear and nonlinear cases in Fig. 2, and expanded plots for the last time step in Fig. 3. As the bunch traverses the nonlinear device, the amplitude of the decelerating field inside the bunch remains constant, while successive periods of the wake behind the bunch demonstrate increasing amplitudes and steepening, in contrast to the linear case.

DISCUSSION

Some general inferences may be drawn from these simulations. First, the nonlinear CWFA can in fact exhibit a compression of the wakefield, with a corresponding enhancement of the gradient and transformer ratio. While the strength of the nonlinearity used in these numerical experiments may be unrealistically large for any material at microwave frequencies, it may be argued that if any nonlinearity is present the onset of wave steepening will occur given enough cycles of the wake. Thus nonlinear wakefield effects may be observable even in a weakly nonlinear medium, provided that it is sufficiently nondispersive and lossless.

Work is currently in progress on extending the code to handle radial beam offsets and to include a central beam hole, with the eventual goal of investigating transverse wakefield effects in the nonlinear CWFA. Insofar as the suppression of transverse modes in the linear CWFA[7] is one of the major advantages of this acceleration scheme, the presence of strong transverse wakes in the nonlinear CWFA could offset the benefits of its enhanced gradient and transformer ratio. Of additional interest is the addition of an explicit numerical viscosity to the code in order to study electromagnetic shock wave formation and propagation, since it might be expected that extremely high accelerating gradients would exist along the shock.

The author acknowledges useful discussions with B. Cole, W. Gai, R. Konecny, J. Norem, J. Rosenzweig and J. Simpson. This work was supported by the U. S. Department of Energy, Division of High Energy Physics, Contract No. W-31-109-ENG-38.

REFERENCES

1. R.K. Keinigs, M.E. Jones, W. Gai, submitted to Particle Accelerators.
2. W. Gai, P. Schoessow, B. Cole, R. Konecny, J. Norem, J. Rosenzweig, J. Simpson, Phys. Rev. Lett **61** 2756 (1988).
3. J. Rosenzweig, Phys. Rev. Lett. **58** 555 (1987).
4. J. Rosenzweig, P. Schoessow, B. Cole, W. Gai, R. Konecny, J. Norem, J. Simpson, Phys. Rev. **39A**, 1586 (1989).
5. I.G. Kataev, Electromagnetic Shock Waves, (Iliffe Books, London, 1966).
6. R.D. Richtmeyer and K.W. Morton, Difference Methods for Initial Value Problems, pp. 360-365 (Wiley Interscience, N.Y., 1967).
7. W. Gai, these proceedings.

FIGURE CAPTIONS

Fig. 1. The constitutive relation used for the nonlinear CWFA experiments.

Fig. 2. Time evolution of the longitudinal electric field on-axis for the linear (a) and nonlinear (b) cases. The time separation between traces is 83 ps.

Fig. 3. Expanded plots at t = 996 ps of $E_z(r = 0,z)$.

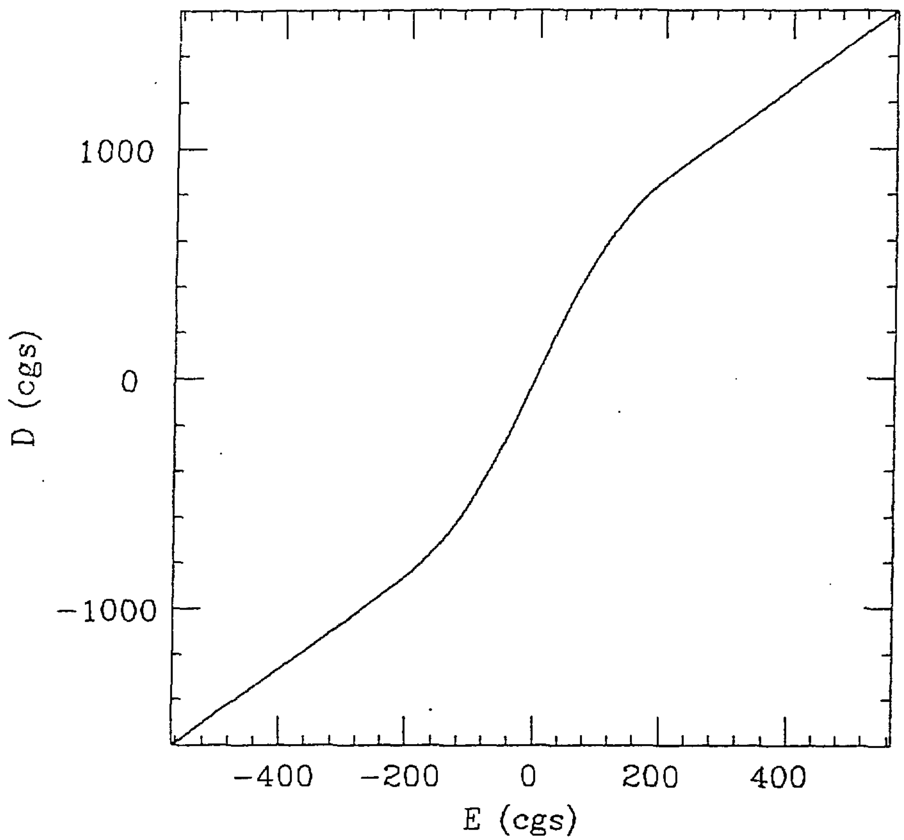


Fig. 1

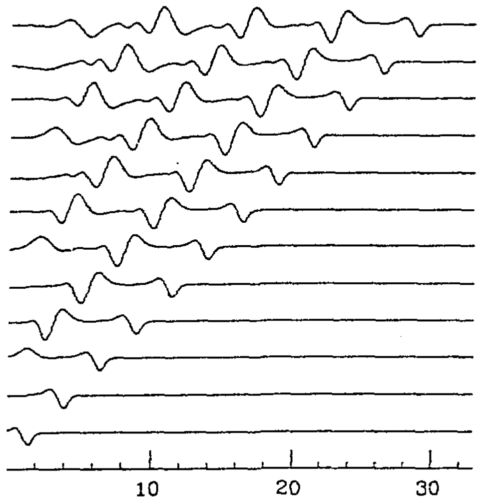


Fig. 2(a)

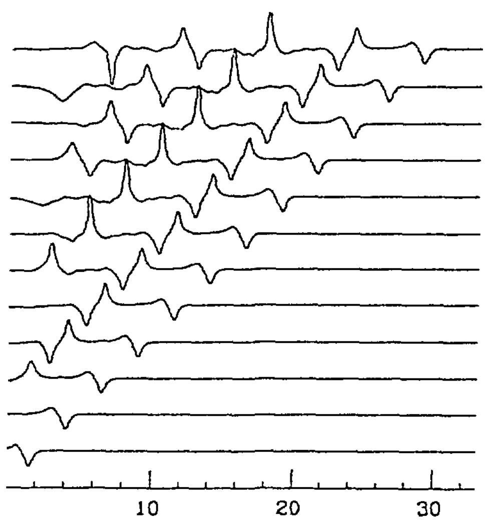
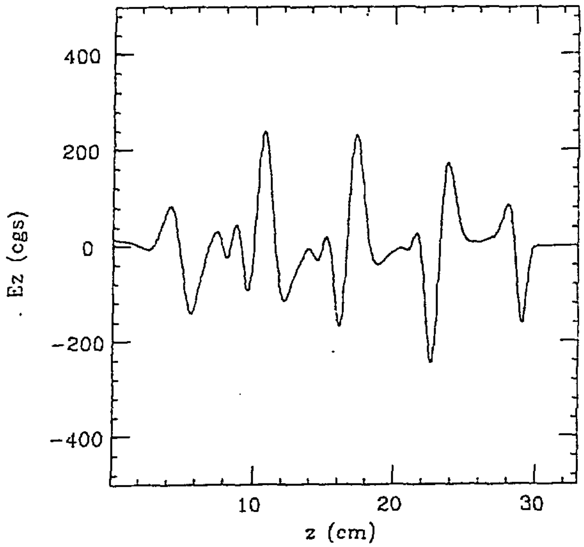
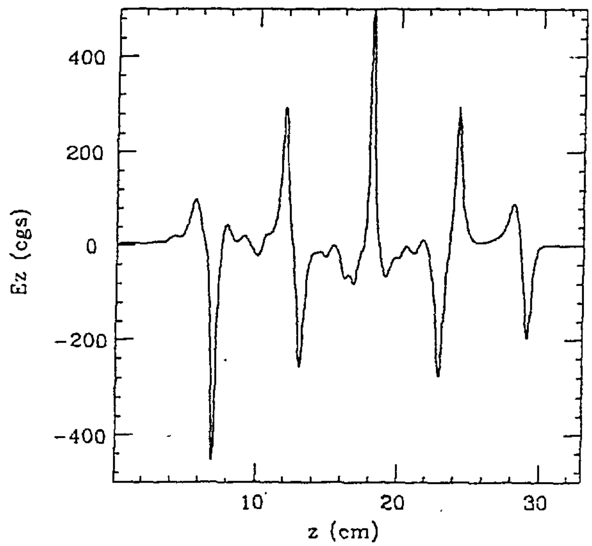


Fig. 2(b)



400
200
0
-200
-400
Ez (cgs)
10
20
30
z (cm)

Fig. 3(a)



400
200
0
-200
-400
Ez (cgs)
10
20
30
z (cm)

Fig. 3(b)