IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

CALCULATIONS PERTAINING TO THE DESIGN OF A PREBUNCHER FOR A 150-MEV ELECTRON LINEAR ACCELERATOR: II RADIAL MOTION*

R. G. Alsmiller, Jr., F. S. Alsmiller and J. Barish[+]

Abstract

In a previous paper, calculated results based on a one-dimensional ballistic model were presented to indicate the extent to which a current pulse of 150-keV electrons containing 1 μC of charge and having a duration of 15 nsec (FWHM) could be bunched by a combination of accelerating and decelerating voltage gaps followed by a drift space. In the present paper a very approximate perturbation model is used to determine the extent to which the prebuncher performance determined previously is modified by radial electron motion. It is found that if a longitudinal magnetic field of 1 kG is applied in the region containing the voltage gaps and if a sufficiently strong longitudinal magnetic field (∿ 3 kG) is applied in the drift space the prebuncher performance determined here is essentially the same as that shown in the previous paper.

Introduction

The Oak Ridge Electron Linear Accelerator (ORELA) was designed to produce intense short neutron pulses for measurements of neutron cross sections by time-of-flight techniques. It is proposed to improve ORELA for time-of-flight measurements by "prebunching" the electron beam before it enters the accelerator, that is, it is proposed to substantially reduce the initial pulse length without appreciably changing the charge in the pulse by passing the beam through a combination of voltage gaps and drift spaces before it enters the accelerator.

In a previous paper[1], hereinafter referred to as 1, calculated results based on an essentially one-dimensional model, were presented of the degree of bunching that can be achieved with various combinations of voltage gaps and drift spaces. Because of the large charge densities considered in 1, space charge effects were very large and were taken into account in the calculations. In 1 it was pointed out that in the vicinity of the voltage gaps the magnitude of the longitudinal magnetic field that can be produced experimentally to prevent radial spreading of the beam is very limited, but it was assumed that by applying a sufficiently large longitudinal magnetic field in the drift space following the gaps excessive radial spreading of the beam could be prevented. Here calculated results similar to those given in 1, but with the radial motion of the electron treated very approximately, are presented to test this assumption. The treatment of the radial motion is based on the assumption that the longitudinal motion of the electrons is unaffected by the radial motion. Since the "bunched" electron beam is useful only insofar as it will be accelerated by the existing accelerator, the results presented here, as in 1, include calculated estimates of the fraction of the bunched electron beam that will be accelerated by ORELA.[2]

Calculational Procedure

Geometric Configuration and Physical Data

The cylindrically symmetric geometric configuration and the physical data considered here are the same as that considered in 1 in almost all details. The initial electron pulse shape, the voltage gap structure, and the time dependence of the voltages at both "accelerating" and "decelerating" gaps is the same as in 1. In particular, all of the results presented here are for the eight voltage gap configurations shown in Fig. 1 of 1. The gaps are assumed to be infinitesimally thin and the voltage in each is turned on when the first electron reaches it. The variation of the externally imposed longitudinal component of the magnetic field with space is the same as that considered in 1 (see Fig. 1 of 1). In all cases considered here, the longitudinal magnetic field has a constant value of 1 kG for distances less than 275 cm after which it rises linearly and reaches its maximum value H_{zm} in 25 cm. Beyond 300 cm the longitudinal component of the magnetic field is constant at the value H_{zm}. This magntidue, H_{zm}, is varied to determine its effect on the prebuncher performance.

Equations of Motion

Because of space limitations only a qualitative discussion of the equations will be given here. A detailed presentation and discussion of all of the equations used in the calculations is given in Ref. 3.

The equations used here to describe the longitudinal motion are slightly different from those used in 1. In 1 the electron beam radius was assumed to be constant throughout the motion even though the strength of the longitudinal magnetic field changed. Based on the radial motion considered here it is found that the beam radius changes substantially with the strength of the magnetic field and this change has been included very approximately in the equations of longitudinal motion used in obtaining the present results.

The radial motion considered here is based on three simplifying assumptions: 1) the electrons are emitted from the cathode of the electron gun with zero azimuthal velocity and the cathode is shielded from the magnetic field so that in the prebuncher electron orbits encircle the axis of the cylinder, 2) the longitudinal motions calculated with radial motion neglected remains valid when radial motion is present, 3) electron paths for the electrons of a given disk do not cross in the radial direction so that an electron that is on the periphery of a "disk" remains on the periphery of the disk throughout the motion. As a consequence of the third assumption, only a representation peripheral electron in each disk must be followed. Assumption 1 was also used in 1. Both of the other assumptions imply gross approximations and thus the results presented here must also be considered to be very approximate.

Calculations of the Fraction of the Current Pulse That Will be Accelerated

The calculations of the fraction of the current pulse that will be accelerated are carried out in nearly the same manner as in 1. The only difference is that in 1 all of the particles in the beam were assumed to pass through the hole into the accelerator while here the radius of a "disk" at the entrance of the accelerator is often larger than the radius of the hole so only a fraction of the charge of the disk is allowed to enter the accelerator. The beam loading approximations used here are the same as those used in 1.

Results and Discussion

In this section calculated results for two cases

*Research sponsored by the Office of Basic Energy Sciences, Dept. of Energy, Washington, D.C.
+Oak Ridge National Laboratory, Oak Ridge, TN 37830

0018-9499/79/0600-3695$00.75 © 1979 IEEE

of interest are presented and discussed. The radius of the conducting cylinder, a, is 2.5 cm and the radius of the hole into the accelerator, r_0', is 0.4 cm. The total charge in the incident beam is 1 μC.

To carry out the calculations it is also necessary to specify the value of the initial radial velocity, β_{ro}, of the peripheral electron for each disk at the entrance to the prebuncher. It has been assumed that $\frac{\beta_{ro}}{\beta_{zo}}$ = .04 for all disks.* This is, however, relatively unimportant because the results are quite insensitive to this value.

In Figs. 1 and 2 the calculated results for the case H_{zm} equal 2 kG and 3 kG, respectively, are given. The results presented in each figure represent the current, $I_{\alpha\beta}(L,t)$, as a function of time (at the entrance to the accelerator) that will be accelerated for specific values of the length, L, of the prebuncher. In each figure the results shown by plotted points are for the case of no radial motion and the histograms give the results when radial motion is included. The plotted points, of course, also represent histograms. For each L value considered, the zero of time is taken to be the time when the first electron enters the accelerator. For each L value considered the current as a function of time is given "without beam loading" and "with beam loading." As explained in 1, the values "without beam loading" are an upper limit of the current that will be accelerated and the values "with beam loading" are a lower limit. In Table 1 the values of the total charge, $Q_{\alpha\beta}(L)$, that will be accelerated and the standard deviation, $\sigma_{\alpha\beta}(L)$, of the time distribution of the current that will be accelerated are given for each of the histograms in both Figs. 1 and 2. The values given in Table 1 are determined from the equations

$$Q_{\alpha\beta}(L) = \int_0^\infty I_{\alpha\beta}(L,t)dt \qquad (1)$$

$$\bar{t}_{\alpha\beta}(L) = \frac{1}{Q_{\alpha\beta}(L)} \int_0^\infty I_{\alpha\beta}(L,t)tdt \qquad (2)$$

$$\sigma_{\alpha\beta}(L) = \left[\frac{1}{Q_{\alpha\beta}(L)} \int_0^\infty I_{\alpha\beta}(L,t)[t-\bar{t}_{\alpha\beta}(L)]^2 dt\right]^{1/2} \qquad (3)$$

where α takes values U (meaning upper) for the case of no beam loading and L (meaning lower) for the case with beam loading and β takes values z for the case of no radial motion and r (meaning radial) for the case with radial motion.

The data at the top of Fig. 1 (H_{zm} = 2 kG) for L = 242 cm corresponds to the case when there is no drift space, i.e., when the electron beam enters the accelerator immediately after passing through the last voltage gap. The other L values considered in Fig. 1 correspond to increasingly longer drift spaces. For all of the L values considered in Fig. 1, the open circles differ noticeably from the dashed histograms and the closed circles differ noticeably from the solid histograms. This indicates that there is some degradation of the prebuncher performance, i.e., of the bunching and of the charge that will be accelerated, due to radial motion when H_{zm} = 2 kG. The amount of

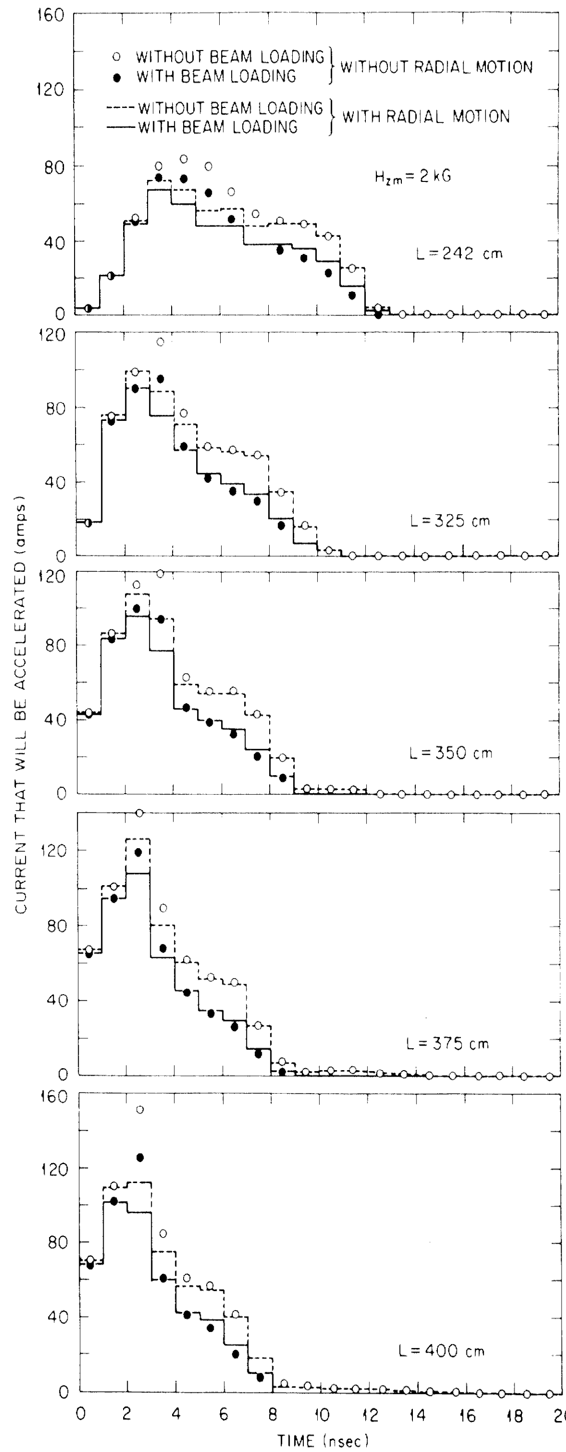

Fig. 1. Current that will be accelerated vs time.

degradation is, however, small and is hardly noticeable from the integral values given in Table 1. It should be noted that for all of the L values considered in Fig. 1, there is a "tail" on the current distribution calculated without beam loading (open circles and dashed histograms). This "tail" corresponds to particles that lag behind the main pulse and were shown in some cases in 1. In Fig. 1 the tails are shown only out to 20 nsec, but they do extend beyond this time. It is important to note that the tails occur only when there is no beam loading, i.e., on the upper bounds. Since the "tails" occur only on the upper bounds as calculated here and not on the

*This value was obtained from an analysis of the ORELA electron gun by J.R.M. Vaughan of the Electron Tube Division of the Litton Corporation.

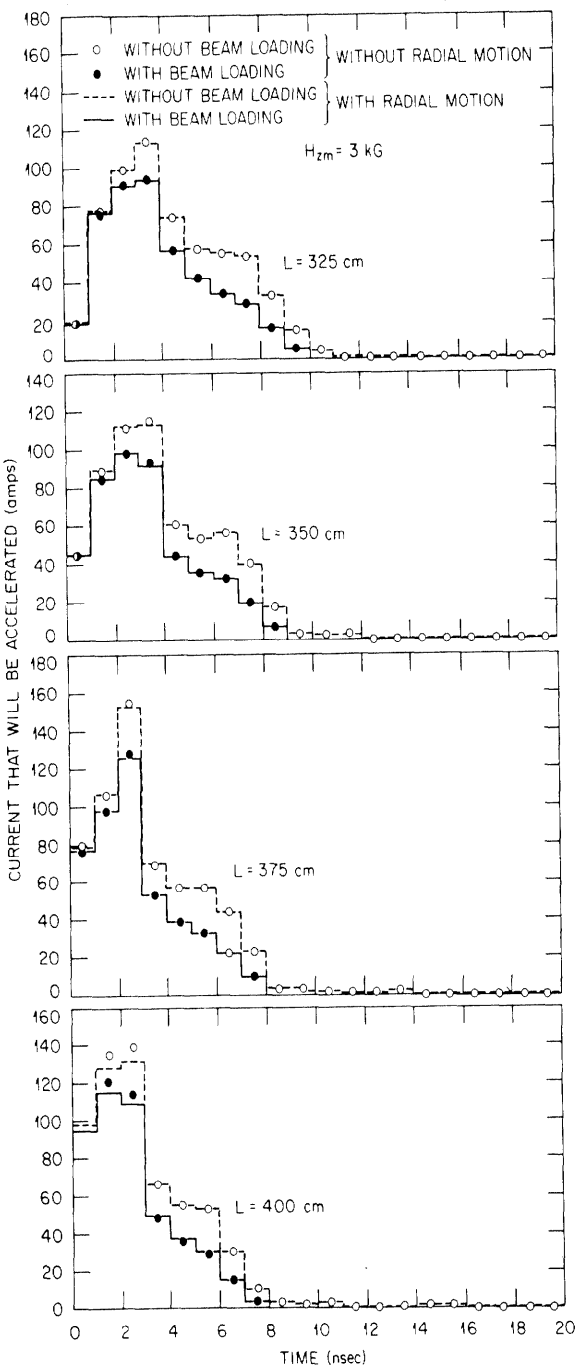

Fig. 2. Current that will be accelerated vs time.

lower bounds, the actual extent to which these tails will occur experimentally is not known from the present calculations.

Before leaving Fig. 1 it is interesting to note that at the later times the solid dots are often below the solid histograms, i.e., at the later times and when beam loading is considered more charge is accelerated when radial motion is considered than is accelerated when radial motion is neglected. This is due to the fact that in the approximation used here the magnitude of beam loading is dependent on the total amount of charge that has entered the accelerator before a given electron enters the accelerator, and since in the presence of radial motion less charge enters the accelerator at early time the effects of beam loading are reduced on those electrons that enter the accelerator at the later times.

TABLE 1

Total Charge That Will be Accelerated and the Standard Deviation of the Time Distribution of the Current That Will be Accelerated (Results are given for each of the histograms in Figs. 1 and 2)

L (cm)	Q_{uz} (μC)	Q_{Lz} (μC)	Q_{ur} (μC)	Q_{Lr} (μC)	σ_{uz} (nsec)	σ_{Lz} (nsec)	σ_{ur} (nsec)	σ_{Lr} (nsec)
				H_{zm} = 2 kG				
242	0.62	0.48	0.55	0.45	3.1	2.6	3.1	2.9
325	0.61	0.46	0.59	0.46	2.5	2.1	2.7	2.3
350	0.61	0.46	0.57	0.45	2.4	2.0	2.5	2.1
375	0.61	0.46	0.57	0.45	2.4	1.9	2.5	1.9
400	0.61	0.46	0.55	0.44	2.3	1.8	2.3	1.9
				H_{zm} = 3 kG				
325	0.61	0.46	0.61	0.46	2.5	2.1	2.5	2.1
350	0.61	0.46	0.61	0.46	2.4	2.0	2.4	2.0
375	0.61	0.46	0.60	0.46	2.4	1.8	2.3	1.8
400	0.61	0.46	0.59	0.45	2.3	1.7	2.3	1.7

In Fig. 2 results similar to those given in Fig. 1 are presented for the case of H_{zm} = 3 kG. Data for L = 242 cm are not given in Fig. 2 because it would be the same as that shown in Fig. 1. In Fig. 2 the difference between the plotted points and the histogram values are, for practical purposes, negligible at all L values. This is also apparent from the values in Table 1. Thus, based on the very approximate model considered here the performance of the prebuncher will not be substantially affected by radial motion provided a sufficiently strong longitudinal magnetic field (∿ 3 kG) is applied over the region of the drift space.

Acknowledgments

Thanks are due to T. A. Lewis, R. W. Peelle and F. C. Maienschein of the Oak Ridge National Laboratory for many helpful discussions during the course of this work.

References

1. R. G. Alsmiller, Jr. et al., "Calculations Pertaining to the Design of a Prebuncher for an Electron Linear Accelerator," ORNL/TM-5419 (1977) (to be published with appendices omitted in Particle Accelerators).

2. T. A. Lewis, "ORELA Performance," ORNL/TM-5112, Oak Ridge National Laboratory (1976).

3. R. G. Alsmiller, Jr., F. S. Alsmiller and J. Barish "Calculations Pertaining to the Design of a Prebuncher for a 150-MeV Electron Linear Accelerator: II Radial Motion," ORNL/TM-5419/V2, Oak Ridge National Laboratory (1979).