THE INFLUENCE OF DRIFT DISTANCE ON THE ATTAINABLE
ENERGY RESOLUTION OF A BUNCHED ELECTRON BEAM

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Summary

High intensity, low energy electron beams from linear accelerators are used extensively in photofission and (y, n) threshold reaction experiments. The degradation of the energy resolution of the beam due to the action of longitudinal space charge forces and the presence of a conducting cylinder surrounding the beam is considered. Results are presented for varying drift distances, beam currents, and phase spread of the bunch for an L-band accelerator.

Introduction

High intensity, high resolution electron beams in the energy range from 3 MeV to 15 MeV can be produced by a linear accelerator (Linac) and good energy resolution is obtained by careful tuning of the Linac and the use of a magnetic energy analyzing system. In many cases, however, the electrons must be transported some distance to the target inside a conducting evacuated beam pipe. This study is concerned with the degradation in the energy resolution of a bunched electron beam in a conducting cylinder due to the existence of longitudinal space charge forces.

Theory

If an electron bunch inside a conducting cylinder is considered to be divided into a number of discs, then it can be shown that the total force acting on the ith disc due to n other discs is given by:

\( F_T = \sum_{j=1}^{n} \sum_{r=1}^{a} Q_j \left( \frac{2Q_i}{4\pi r_0^2} \right) \sum_{j=1}^{n} \sum_{r=1}^{a} \frac{Q_j}{4\pi r_0^2} J_1^{(0)} \left( \frac{z_i - z_j}{2a} \right) \left( \frac{z_i^2 - z_j^2}{2a^2} \right) \)  \( \tag{1} \)

where \( Q_i, Q_j \) is the total charge in the ith and jth discs, \( a \) is the radius of the beam pipe, and \( J_1^{(0)} \) is a Bessel function of order 1.

As the electron bunch is allowed to drift through the transport system, this force is responsible for modifying the energy spectrum of the bunch.

From Eq. 1, the total force acting on the ith disc due to n other discs can be calculated. In the summation over \( n \) only five terms are necessary for the cases considered here as the contribution from higher orders becomes insignificant.

The velocity of the ith disc \( v_i \) can then be determined from the following expression:

\( v_i^t = v_i + \frac{F_T \Delta t}{M_i} \)  \( \tag{2} \)

where \( v_i \) is the initial velocity of the disc, \( \Delta t \) is the time interval over which the force \( F_T \) is considered to act, \( M_i \) is the mass of the ith disc.

The velocity of all electrons within the disc are assumed to be moving with this velocity. The z coordinate of the ith disc \( z_i \) is calculated next from:

\( z_i^t = z_i + \frac{v_{i1} + v_i}{2} \Delta t \)  \( \tag{3} \)

where \( z_i \) is the initial value of the z coordinate.

A computer program has been written to carry out the procedures outlined above.

Results

It can be seen from Eq. 1 that the deterioration of the beam energy resolution with drift distance depends on a number of parameters. The results shown here point out the range of values of beam current, phase spread of the bunch, and drift distance over which significant changes in the energy resolution occur.
The radius of the cylinder of charge, \( a \), is assumed to be 0.76 cm and the beam pipe radius \( R_0 \) to be 2.54 cm. A reference case with an electron kinetic energy \( E_e \) of 5 MeV, time averaged beam current of 1.0 amp, a phase spread of the bunch of 9° and a drift distance of 3.28 m was chosen as a basis for comparison. It is assumed that initially the cylinder of charge is monoenergetic. The effect of variations in the average beam current \( I \), phase spread \( \varphi \), and drift distance \( D \) are shown, respectively in Figs. 1, 2, and 3. It can be seen that in the case chosen as a reference, the energy degradation is of the order 1%; however, further increases in beam current and drift distance or decreases in phase spread result in a significant deterioration of the energy resolution.

The situation improves rapidly with increasing electron kinetic energy, as can be seen if the results at 10 MeV and 5 MeV are compared. A comparable deterioration of energy resolution with phase spread is obtained at \( E_e = 10 \text{ MeV} \) as was obtained with \( E_e = 5 \text{ MeV} \) after twice the drift distance \( D \) and with twice the peak current \( I \). The results are not changed significantly if the beam pipe radius is increased from 2.54 to 3.81 cm and the radius of the cylinder of charge is decreased from 0.76 to 0.51 cm. Both of these changes result in a slightly worse resolution for any given case. The effect of increasing the frequency from 1300 MHz (L-band) to 3000 MHz (S-band) for the reference case above is to approximately double the full width at half maximum of the electron energy versus current distribution.

Conclusions

The energy resolution of a particle beam is degraded with increasing drift distance due to longitudinal space charge forces. The effect is an important one for low energy, high intensity, high resolution electron beams such as those that can be obtained from a Linac. Improvements in accelerator design that are prompted by demands for higher beam intensities, must take this effect into consideration when high resolution is necessary.

References


Fig. 1. Histogram showing the effect of current on energy distribution.

Fig. 2. Histogram showing the effect of the phase spread of the bunch on energy resolution.

Fig. 3. Histogram showing the effect of drift distance on energy resolution.