SPACE CHARGE EFFECTS ON LONGITUDINAL MOTION IN PROTON LINACS*

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The Machine Program

Several subroutines have been written for an existing BNL longitudinal motion program (LONMO) to include space charge effects. The basic program without space charge assumes all energy supplied to the particles by the rf field to be imparted at gap centers. The particles drift between centers at constant velocity and the phase changes are calculated without the Promé correction.

Space charge effects are calculated by Lapostolle's formulas.[1] The program calculates the center of gravity and second moment of the packet of charges and replaces it with a uniformly charged ellipsoid having the same center of gravity and second moment. The longitudinal axis of the ellipsoid is determined by the second moment; the axes in the transverse plane are specified as input to the program. Lapostolle supplies formulas for the energy change produced by space charge forces assuming the beam to be travelling in an infinitely long conducting cylinder while in a drift tube, and between two infinite parallel conducting plates while in a gap. These energies are added at the centers of the drift tubes and gaps respectively. In spaces between cavities, space charge contributions to energy are calculated by the same formulas as in drift tubes (merely changing the radius of the surrounding cylinder) and are added at intervals of $\beta\lambda$.

Machine Runs

One hundred and twenty particles were distributed in phase space to mock-up a uniform distribution in a Lapostolle ellipsoid. These particles were then run through the LONMO program (for currents of 0, 50, 75, 100, 150, and 200 milliamperes) for the proposed BNL 200 MeV linac. At 100 milliamperes, runs were made for four different values of the transverse axes of the ellipsoid.

Results

Results will not be reported at this time because they have not yet been completely analyzed and in several places appear to be incorrect, or at least inconsistent with our present expectations.

The contributions of Joe Vitale of Yale in programming several of the subroutines is gratefully acknowledged.

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Reference

1. P. M. Lapostolle, CERN Report AR/Int. SG/65-15, July 15, 1965.

DISCUSSION

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LAPOSTOLLE, CERN: About this point, I agree with most of what Bob Gluckstern said. Nevertheless, I don't understand why this μ doesn't vary more during acceleration. Because if one starts, as it is the case, with bunches which are almost spherical, and if one forgets space charge and uses the normal damping, the bunches remain almost spherical during acceleration. When there is a strong space charge which tends to make the longitudinal stability disappear, the first thing which happens is that the bunches tend to become longer and longer. But since the β, the wave length, increases during acceleration, assuming one uses the same phase stable angle, the space available for the bunches to extend over becomes longer. Then the μ correction goes down according to the ellipsoidal distribution function f as was explained. So I have the impression that the stability remains when the energy goes up. And so I am surprised by these results.

The next things I would like to say may look a little different from the subject. They are some ideas I had in CERN about the space-charge problems, in particular, following Colin Taylor's talk of the day before yesterday, where he mentioned the bunching problem. My feeling is that one of the places where some study should be made is the bunching of the beam, and this cannot be done with the previous computation which assumes that bunches exist, because in the bunching process there are no bunches. Even the second moment method doesn't mean anything when there is a continuous beam, which is the way the bunch starts. So it is a place where this method doesn't apply and where, according to experiments, there seems to be a difficulty, so I would encourage people to try to think about this part. My personal ideas on it are the following: Some results from Colin Taylor show that the bunching seems not to take place above a certain current. That is easily found by simple traveling wave theory from the old work of Hahn and Ramo, using a traveling wave representation of the space charge. According to it, one obtains a very simple formula in which, if one takes the voltage which is put on the buncher and the drift length of the bunching, this product must be constant in order to produce bunching. But, in addition, the product of the length by the square root of the current must remain below a certain other value in order to retain the linear approximation and avoid a saturation effect. Putting in figures, one finds that the limiting current in the CERN case is in the range of 300 mA when we inject or try to inject 500. I feel that, since the second condition is no longer valid, it is a reason why the bunching doesn't take place anymore.

So my proposal is to consider not using the normal bunching with buncher and drift space but to use a linac cavity, trying to produce an adiabatic bunching with an electric field varying, for instance, linearly with position. I would suggest studying such a system with the same type of space charge waves. A few days ago I found that one could derive expressions similar to the ones I just mentioned for the normal buncher. If one uses the maximum field and multiplies it by the square of the length of the system, this must equal a constant to produce full bunching. Another condition is that the fourth root of the current multiplied by the length must be less than another constant to avoid saturation. I have no figures yet, but I see no reason why it shouldn't work. Having achieved the bunching, the rest of the linac in my mind should start with a first cavity where I would propose to use a stable phase which decreases with energy, in contrast, maybe, with some of the previous conclusions of Bob Gluckstern. I would propose to start with 60 or 70°, going down to 20 or 30° and keeping the bucket area almost constant during acceleration. This way I would not like so much to keep the bucket filled but rather to keep the phase area, which is used almost always within the same distance of the boundary. That, in fact, is the same thing as to equate the nonlinear terms in the phase direction and in the energy-β direction. And equating the two nonlinear terms is the way to minimize their effect. But these are just ideas I'm putting to everybody, whoever would like to think about them.

Finally, I wonder whether G. Lee-Whiting could give the reference for work which has been done recently in Chalk River on a steady state particle distribution inside the buncher of a linac with a high space charge, which distribution might be better than the ellipsoidal uniform distribution.

LEE-WHITING, AECL: The work referred to is by T. D. Newton, and a report (AECL-2614) has just recently appeared. It is a sort of classical Hartree problem. The equilibrium distribution of a bunch of protons traveling through an imperfectly conducting pipe has been calculated. The transverse focusing forces have been smoothed out so that they are cylindrically symmetric; the longitudinal forces have been treated in the usual way. Dr. Newton was able to get the equilibrium distribution of charge in the bunch, and to calculate the decreases in longitudinal and transverse phase space areas resulting from the combination of space charge forces and image forces from the pipe.