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THE COST OF A 10 BEV PROTON LINEAR ACCELERATOR

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ABSTRACT

Questions of technical feasibility of a multi-Bev proton linear accelerator are discussed by comparing them with the Stanford experience with electron linear accelerators. Several difficulties whose origin is the non-constant velocity of protons in the energy range below 10 Bev are pointed out. The cost of a 10 Bev proton linear accelerator is estimated by comparison with the Stanford proposal to be at least $85 million.

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THE COST OF A 10 BEV PROTON LINEAR ACCELERATOR

Since there is still some discussion of the possibility of constructing a high energy linear proton accelerator and since it is possible to use the Stanford linear electron accelerator proposal as a starting point in estimating construction costs, it seems desirable to enumerate a few of the ways in which a linear proton accelerator differs from an electron machine.

All of these differences are primarily related of course to the fact that, except at extremely high (over 10 Bev) energies, the protons move at constantly increasing velocities while an electron, after the first foot of acceleration, can be considered as running at constant velocity. The proton accelerator can thereby be phase stable but requires focusing while the electron accelerator runs with no phase stability and no defocusing forces.

This leads to specific differences of the following nature:

1. Construction of sections

Until one reaches the region above 10 Bev, it would be inefficient to have uniform sections. Below 10 Bev, if there are many power feed points, these may be made in groups of two or three but certainly below 1 or 2 Bev the sections must be tailored to the exact energy unless power feed points occur more frequently than every 10 Mev energy gain. It would probably be advantageous to have the entire machine exactly tailored up to 10 Bev.

The tolerances in the accelerator structure of the proton accelerator can be relaxed somewhat from those of the electron machine due to phase stability. It is doubtful that these tolerances will be very much less stringent than those now used in electron accelerator construction. In this

construction the tolerances have recently been considerably relaxed (0.5 mil in diameter rather than 0.1 mil) since the accelerator cavities can be tuned after fabrication by pressing in on the soft copper sides of the cavities while measuring the cavity dimensions by rf techniques. Although the proton accelerator tolerances are even more relaxed, it is doubtful that any great cost savings will be experienced in going from tolerances of 0.5 mil for example to 2 mils. Because of the repetitive structure of the electron machine, use of automatic machines is possible in the construction and the cost of reasonable tolerances under these conditions should not be excessive.

Because of its repetitive structure, it is possible to use simple techniques in measuring the rf characteristics of an electron accelerator. In the low energy end of a proton machine these measurements will be much more expensive and less reliable.

It appears that the accelerator structure for a proton machine will be considerably more costly than that for an electron machine. In the low energy region where one might use a lower frequency and a resonant rather than traveling wave mode, the cost per Mev will be very much increased.

2. Phasing of the accelerator

Considerable attention must be given to the method of properly phasing the individual sections of the accelerator. This must be done frequently because of changes in the drive line, changing phase shifts in the klystrons as their voltage changes, possible uncontrolled frequency changes, and possible inadequate cooling of the accelerator structure. Although it is hoped that these changes can be very much reduced, they are present in

the Stanford 700 Mev accelerator and it would not be conservative to assume that they can be completely suppressed in a new design.

Methods which have been suggested for phasing the electron accelerator are as follows:

a. Measuring the energy change of the electron beam as it is phased.

The present 700 Mev accelerator is phased by adding tubes one at a time and adjusting the phase of the newly added klystron output to give the maximum beam energy at the end of the machine.

It will be difficult to see this change when more than 20 klystrons are being used since the contribution of an individual section and tube is very small. For this reason it was suggested that the machine be subdivided into groups of 20 klystrons or less, each group with its own gun and pulsed inflector and deflector. These 20-tube groups could be so arranged that a group can be run out of timing with the rest of the machine. The primary machine beam would coast through the group. After the beam had passed through, the group could be turned on and its own beam run. Thus it could be phased during the operation of the main machine. After phasing of a group is completed, it can be added to the machine as a group and phased into the machine as a sub unit. This method cannot be used with a proton accelerator since injection of a beam can only be done at the front of the machine.

b. Phasing by detection of the traveling wave set up by the electron beam.

The beam in traveling through the accelerator structure sets up a wave which is out of phase with the proper wave for accelerating the beam. This wave can be compared with the driving wave and thus used to adjust the phas-

ing of the accelerator. The sensitivity of this method increases with the square of the instantaneous current. Since it is likely that proton currents will be an order of magnitude lower than electron currents, this method will be more difficult to use.

Alternative methods of determining the phase absolutely can undoubtedly be formulated but they are not as pleasing as methods which actually use the beam as a reference.

3. Reliability

An advantage of the electron accelerator is that if an individual klystron or section is giving trouble it can be removed from operation and another substituted without interfering with the beam or phasing. With a proton accelerator considerable beam loss might be experienced if a section of the accelerator below about 2 Bev was not functioning. If a large number of klystrons were removed anywhere except at the end of the accelerator, beam loss and rephasing would be inevitable.

The reliability of the components must therefore be considerably greater than those for an electron machine. In the electron machine, because of the large number of components, it is this reliability which poses a major design problem.

4. Focusing

The linear electron machine requires no focusing except at the gun-while a proton machine will require continuous focusing. If this is done in the form of a series of lenses, all lens setting will have to be changed if a section of the accelerator is removed from operation. Again this requires a higher reliability.

Because of the focusing required, it is probable that the beam will have a larger size and angular divergence and will not be as easily handled in the beam switching and target areas.

5. Advantages of a proton linear accelerator

A positive point is that a lower beam energy spread would be expected from a proton machine because of the phase stability.

An additional advantage is that the bunching of the protons into a small portion of a 10 centimeter wave gives a fine structure which may be used to advantage in mass separation schemes. In the approximately 200 ft. long spectrometers which will be necessary if iron magnets are used for analysis, a series of 3000 megacycle cavities to put in transverse momentum components may allow accurate mass analysis.

The experimental utility of the external beam of protons must be weighed against the poor duty cycle of the linear accelerator.

Cost Analysis:

On the basis of the $105 million construction cost estimate of the Stanford Electron Linear Accelerator and a simple scaling from the Stanford 15 Bev proposal, a 10 Bev proton accelerator would cost $70 million. However, target facilities do not scale linearly. In particular, the shielding requirements change very slowly. In addition, the proton accelerator appears more complicated in several ways.

It would seem unconservative to estimate a cost below $85 million and it might easily be very much more.